AUTOMATED ANALYSIS OF EEG PATTERNS IN SUBJECTS UNDER ABUSIVE LEVELS OF SEDATIVE-HYPNOTICS

A Dissertation

Presented to

the Faculty of the Department of Electrical Engineering

University of Houston

In Partial Fulfillment

of the Requirements for the Degree

Doctor of Philosophy

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by

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May 1976

ACKNOWLEDGMENTS

I wish to express my great appreciation to my advisor, Dr. Robert L. Everett, for his assistance and encouragement throughout the years of my graduate studies at this University. I would like to thank all the members of my dissertation committee for their time and consideration. I am greatful to Dr. Periklis Y. Ktonas for the many hours he spent with me discussing the various aspects of this research and for the valuable suggestions as well as criticism that he always offered.

My appreciation also goes to the people of the Sleep Laboratories at Baylor College of Medicine and at Veterans Administration Hospital, in particular to Dr. I. Karacan, for providing the data and for the time spent in discussing some of its aspects, to Ms. P. Sallis for helping me with the details of the experiment and to Mr. R. Weavers and Ray Ambuehl, for their assistance with the recording equipment.

I also want to thank Lew Folkerth of the Engineering Simulation Laboratory, for his valuable assistance in debugging and suggesting ways to improve my computer programs.

The financial support of the Conselho Nacional de Pesquisas (CNPq, Brazil) and of the Electrical Engineering Department of the University of Houston is greatfully acknowledged.

In addition, my deep appreciation is extended to my wife, Araci, for the feat of skillfully typing this work in time, while taking care of Tatiana, but above all, for the patience and understanding she exhibited throughout this entire endeavor.

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CHAPTER I

INTRODUCTION AND REVIEW OF THE LITERATURE

1.1 INTRODUCTION

The pionering work of Aserinsky and Kleitman (1953, 1955) has provided sleep researchers with better understanding of the fundamentals of nocturnal sleep. They observed that periodically throughout the night, rapid eye movements (REM) occured in association with low voltage mixed frequency EEG activity. The REM periods have been shown to occur about every 90 minutes in normal individuals and may last for 15-30 minutes. These periods of REM alternate with the other four stages (1,2,3 and 4) of sleep, that have been collectively called non-REM (NREM) sleep (Rechtschaffen and Kales, 1968).

Most of the studies on the effects of drugs on human sleep have been evaluated using the system of sleep staging (Rechtschaffen and Kales, 1968). One whole night's sleep in the sleep laboratory results on the average in eight hours of continuous EEG-EOG recording. This data is divided into hundreds of one minute epochs. An Electroencephalographer has to score each of these epochs in one of six possible stages (0,1,2,3,4 and REM) of sleep (Rechtschaffen and Kales, 1968). In the case of drug studies, if a drug decreases one sleep stage, it must unavoidably increase one or more other stages. The issue then revolves around whether a given drug effect on the sleep patterns is a direct drug effect on the

EEGs or whether it is an "artifact" due to this system of scoring.. It should be kept in mind that accepted definitions of sleep stages have been derived from drug-free sleep, and that the drugs can produce patterns of effects on the sleep EEG that do not fit the normal definitions (Kay et al, 1972).

Some researchers have suggested alternative solutions to this problem. They have proposed attempts at quantification of drug effects on the EEG signals themselves instead of looking for changes conventionally measured by sleep researchers (Kay et al, 1972; Karacan et al, 1973; Smith and Karacan, 1973; Saito, 1974; Karacan et al, 1975; Kay, 1976).

The data utilized in this work was originally obtained by the sleep research group of the Department of Psychiatry of the Baylor College of Medicine in Houston, Texas, for a project designed to study sleep-related growth hormone release patterns in: (a) patients being withdrawn from chronic and abusive use of secobarbital and methaqualone; (b) non-drug users that were given acute toxic dosages of these drugs. The main reason why these two drugs were chosen is because Houston is one of the top four areas in the nation where barbiturates and methaqualone are widely used. In the present study we try to quantify the effects of these two drugs on the sleep EEG of the above subjects by analyzing the sleep EEG waveforms with statistical and spectral analysis techniques. To date, we have not found any other studies that use these techniques to study the effects of

abusive or therapeutic levels of these two agents on sleep EEG patterns.

1.2 EFFECT OF SECOBARBITAL AND METHAQUALONE ON HUMAN SLEEP

Secobarbital and methaqualone can be classified as sedative-hypnotics. The common characteristic these sedative hypnotics have is their depressant effects on the CNS, with sedation at lower doses and hypnosis at higher doses (Kay, 1976).

Secobarbital belongs to that group of barbiturates which are derivatives of malonylurea or barbituric acid. The first hypnotic barbiturate, barbital, was introduced into medicine by Fisher and von Mering in 1903 (Kay, 1972). More than a billion hypnotic doses of barbiturates are produced each year in the United States alone, and numerous cases of addiction and death due to acute poisoning have been reported (Maynert, 1971).

The barbiturates are general depressants. They depress the activity of nerve, skeletal muscle, smooth muscle and cardiac muscle. These effects require large concentrations, generally higher than those necessary to produce CNS depression. However, it should be emphasized that the CNS is exquisitely sensitive to barbiturates, so that, when the drugs are given in sedative or hypnotic doses, direct action on peripheral structures is absent or negligible (Sharpless, 1970).

Secobarbital is marketed by Lilly Laboratories under the trade name of Seconal. The recommended hypnotic dosage for adults is 100 mg administered at bedtime (Sharpless, 1970). Secobarbital, as well as most of the barbiturates, is known to reduce REM sleep. (Lester, 1960; Lester et al, 1968; Allnutt and O'Conner, 1971; Feinberg et al, 1974; Kales and Bixler, 1975). Sleep spindles are increased by secobarbital (Allnutt and O'Conner, 1971; Feinberg et al, 1974), however, Lester et al (1968) found an opposite effect. Delta sleep is not significantly affected by barbiturates (Kay, 1972, 1973, 1976). Lester et al (1968) reported an increase in beta activity. All the above investigations were short-term studies, and the amount of drug given to the subjects was either 100 or 200 mg of secobarbital. The amount of barbiturates required to produce physical dependence in man has been carefully studied (Fraser et al, 1958). They reported that in adult males consumption of up to 400 mg of secobarbital daily does not usually create a significant degree of physical dependence. Thus, the minimal addictive dose of secobarbital would be more than 400 mg daily.

Methaqualone is a sedative and hypnotic agent, chemically unrelated to other sedative-hypnotics. Its hypnotic activity was demonstrated by Gujral and his coworkers in 1955; however, the exact mode of its sedative-hypnotic action is not known yet (Sharpless, 1970). The recommended hypnotic dosage is 150-300 mg. Methaqualone is marketed under the trade name of Quaalude by Rorer Laboratories.

Physical dependence in methaqualone has reached alarming proportions and some authorities on drug abuse believe that the potential for addiction and abuse for this drug are as serious as those for barbiturates in general, and for heroin (Swinyard, 1975).

The reported effects of methaqualone on the human sleep are comparable to those of the barbiturates (Kay et al, 1973). A decrease in REM sleep was found by Kales et al (1970), Rechtschaffen et al (1970) and Risberg et al (1975). However, Goldstein et al (1970) found that methaqualone did not affect REM sleep. An increase in spindle activity was reported by Goldstein et al(1970) and Risberg et al (1975). However, Kales et al (1970) did not find any significant change in the spindle activity. A decrease in stage 4 sleep was observed by Goldstein et al (1970). Itil et al (1974) found that 300 mg of methaqualone decreased spindle sleep and stage four sleep. All the above works were short-term studies and the amount of methaqualone administered to the subjects was either 150, 250 or 300 mg.

1.3 USE OF SPECTRAL ANALYSIS TO STUDY THE EEG SIGNALS DURING SLEEP

The spectrum of single EEG records has already become familiar in EEG work through the various types of analog frequency analyzers (Grass and Gibbs, 1938; Knott et al, 1942; Walter, 1943; and others).

In the last two decades, the methods of statistical

time series analysis have become of considerable importance in processing large amounts of random data (Blackman and Tukey, 1958; Parzen, 1964; Jones, 1965; Bendat and Piersol, 1966,1971; Jenkins and Watts, 1968; Otnes and Enochson, 1972). Of these methods, spectral analysis has found several applications in electroencephalography. The power spectrum is a representation of the mean square value, i.e. the variance of zero-mean EEG, as a function of frequency. Walter et al (1963) applied the methods suggested by Blackman and Tukey (1958) to compute the power spectrum of single EEG records. Other researchers applied similar methods (Walter and Adey, 1965; Hord et al, 1965; Dummermuth and Flühler, 1967; Dummermuth et al, 1970; Joy et al, 1971). The work of Hord et al (1965) was primarily concerned with the resolution and stability of the EEG power spectrum in the four stages of sleep. Johnson et al (1969) used spectral analysis to detect frequencies that are common to all stages as well as those unique to a specific stage of sleep. Dummermuth et al (1972) made a study of the different sleep stages in normal adults using spectral analysis techniques. Hagne et al (1973) used spectral analysis to study the waking EEG in normal infants. Bronzino et al (1973) investigated the possibility of using spectral "fingerprints" to distinguish between waking, slow wave sleep (SWS) and REM stages in the cat.

The use of the spectral components of the EEG to automatically classify the stages of sleep has been pursued by Lubin et al (1969), Larsen and Walter (1969, 1970),

Martin et al (1972) and Larsen (1975). Evaluation of these automatic techniques revealed the delta frequency band as the most useful discriminant with alpha and sigma bands next in importance. Lubin et al (1969) divided the EEG power spectra in five bands and a linear-discriminator for all sleep stages was computed using stepwise multiple regression techniques. The overall percentage of agreement with the human scorer was very poor. However, better results in classifying some stages were obtained by Larsen and Walter (1969) who divided the EEG power spectra in bands and then used a multiple discriminant analysis for the classification of the different sleep stages. Martin et al (1972) used, in addition to the spectral components, EEG amplitude information and REM presence in order to discriminate between the sleep stages. Lubin et al (1969) conclude that detectors for such phasic events as eye movement and k-complexes will have to be added to the frequency analysis to bring the performance of any system close to that of human scorers.

1.4 USE OF SPECTRAL ANALYSIS TO STUDY THE EFFECTS OF DRUGS ON THE EEG SIGNALS

Very few researchers have used spectral analysis techniques to evaluate the effects of drugs upon the EEG signals. Most of the studies have been done by using the classical sleep staging type of approach. An excellent review of the works applying this classical approach is

presented by Kay (1973, 1976).

Schalleck et al (1968) used power spectral analysis to study the effects of some drugs (chlorpromazine, diazepam, pentobarbital, and methyprylon) on the electrocorticogram (ECoG) of the cat. They made comparisons between the power spectra before and after the administration of a particular drug. Itil et al (1968) used a combination of period analysis and analog power spectral analysis to study the effects of three psychotropic compounds (chlorpromazine, imipramine and chlordiazepoxide) on human subjects.

Joy et al (1971a) applied spectral analysis to study the effects of diazepam and atropine on the ECoG of the monkey. They presented a three dimensional representation of the dynamic behavior of the EEG spetra during control and after the administration of one of the drugs. This type of representation of the EEG spectra was later on called Compressed Spectral Array (CSA) by Bickford et al (1972). Furthermore, this kind of plotting was used by Singleton and Poulter (1967) to plot the spectra of the sound of the male killer whale call. Joy et al (1971b), utilizing their previous type of approach, studied the effects of several types of benzodiazepines on the ECoG of primates. Schneider (1974) used the CSA to represent the dynamic behavior of the EEG spectra during halothane anesthesia in the dog. Killam and Killam (1975) used the same spectral analysis techniques of Joy et al (1971) to study opiate dependence in primates. Kay (1975) applied spectral and period analysis to study

human EEG through a cycle of methadone dependence. Analog frequency analysis has been used by Saito (1974) to study the effects of psychotropic drugs on the human EEG.

Caille (1974) studied the effects of psychotropic drugs on the human sleep, using power spectral analysis. A special purpose computer was developed in order to analyze the data in real time. The emphasis of this study was in the REM and NREM periodicity.

1.5 USE OF OTHER AUTOMATED TECHNIQUES TO STUDY THE EFFECTS OF DRUGS ON THE EEG SIGNALS

Another time series analysis method that has been used in electroencephalography is period analysis (Saltzberg and Burch, 1959; Burch and Childers, 1961; Burch et al, 1964).

Fink et al (1967) applied period analysis to study the changes in the human EEG due to the administration of pentothal at different rates. Itil et al (1974) classified psychotropic drugs based on digital computer sleep prints. This method uses parameters derived from period analysis for the classification of the EEG sleep stages.

An automatic hybrid system used for EEG sleep staging (Smith and Karacan, 1971) was applied to the quantification of the effects of a hypnotic-like drug on slow-wave sleep (Smith and Karacan, 1973). In this study the effects of the drug on the amplitude, frequency and amount of delta waves (stages 3 and 4) were quantified.

The various digital computer techniques that have been applied to the quantification of the EEG and to the automatic recognition of the sleep stages have been reviewed by Cox et al (1972) and by Gevins et al (1975).

1.6 SCOPE OF THIS STUDY

In the present work we use statistical techniques, including spectral analysis, which are more sensitive to the variations of the EEG waveforms, than the classical approach of sleep staging, in order to test their applicability to detect the possible effects of the two drugs (seconal and quaalude) on the human EEG during an entire night's sleep. The reasons we chose spectral analysis instead of other time series techniques are: (1) the noise nature of the signals in consideration which make this approach plausible; (2) its easy implementation with the facilities at hand; (3) the possibility of using the optics facilities in our Department to compute the EEG power spectra, in which case the process will be much faster and cheaper.

Our techniques were tested in two groups of six subjects each. The first group is formed of the drug addicts that were withdrawn from secobarbital and methaqualone (three subjects in each drug). The second group is composed of non-drug users that were given toxic doses of these drugs (again there are three subjects for each drug). As we mentioned in Section 1.1, these are the subjects that have participated in an early sleep-growth hormone release study

conducted by the sleep research group of the Department of Psychiatry of the Baylor College of Medicine. For each subject four nights of sleep EEG were processed.

Due to the large amount of data to be processed, several algorithms were developed in order to handle the problem efficiently. To reduce computational time, the power spectrum of a 30 sec epoch was computed at intervals of 2 1/2 minutes throughout the night. This approach showed to be more than satisfactory for the purpose of this study. In order to get meaningful power spectra, the epochs must be completely or nearly artifact free. To accomplish this, most of the researchers using spectral analysis usually select visually artifact free epochs (Hord et al, 1965; Johnson et al, 1969; Larsen and Walter, 1969; Lubin et al, 1969; Dummermuth et al, 1972, Bronzino et al, 1973; Hagne et al, 1973). We solved this problem by developing a special purpose artifact detection algorithm based on a chi-square goodness-of-fit test to a Gaussian distribution (see Chapter II).

The algorithm that computes the power spectrum of each of the epochs, was extensively evaluated using band limited white noise as a test signal to check the statistical stability of the resultant spectral estimates. After the power spectrum of each of the chosen epochs is computed, they are plotted in a form of a Compressed Spectral Array, which emphasizes the dynamic shift of the activity in the frequency bands during the night. The results of the spectral

analysis are further processed by dividing the power spectrum of each epoch in seven frequency bands. For each of these bands, it is possible to plot the percentage of power (expressed as the power in the band divided by the total power for the epoch), the spectral peaks, and its corresponding frequency as a function of the time of the night. Besides this, the mean frequency in each epoch and the results of the chi-square test can be plotted for the entire night. The above described data reduction techniques seem to be quite efficient in showing drug related patterns in the sleep EEG. These techniques form a statistical package that can be used efficiently on a dedicated general purpose digital computer for further studies on EEG patterns quantification.

With the implemented system, about 45 minutes are required to process an entire night of sleep EEG (based on an average of eight hours of EEG data), which is much faster than the two or three hours required by an experienced Electroencephalographer to score the same night.

This dissertation is divided in five chapters. The first serves as an introduction and gives a historical background on the techniques used to quantify the effects of drugs on the EEG. In Chapter II the subjects and the methods are discussed. Also an algorithm for data reduction and detection of EEG artifacts is developed. In Chapter III the basic theory of spectral analysis is reviewed, and the approach used to compute the power spectrum is presented. An

algorithm to extract the main features from the power spectrum is also presented. The results for each of the subjects and the comparisons between them are the objective of Chapter IV. In Chapter V some conclusions are drawn and some suggestions are made for further research on the subject.

CHAPTER II

DATA ACQUISITION AND PREPROCESSING

2.1 SUBJECTS

Two groups of subjects were utilized in this study. One consisted of hypnotic drug abusers and was called Group 1. The other group was composed of non-drug users (Group 2).

The subjects in Group 1 were five males, 16-35 year of age, and one 25-year-old female. They were patients in a local Poly Drug Treatment Unit at the Center Pavilion Hospital in Houston. Three of the patients were taking secobarbital and the other three were taking methaqualone.

The subjects in Group 2 were six males, 22-26 years of age. They were medical students and staff members of the Center Pavilion Hospital in Houston. All subjects were in good health.

2.2 METHODS

2.2.1 Group 1

On admission to the Poly Drug Treatment Unit, the patients gave a history of multiple drug abuse and were evaluated for signs of drug dependence. If such signs appeared, the patients underwent a titration procedure to establish their drug tolerance levels. Beginning in the morning, each patient was administered hourly therapeutic doses of the primary drug of abuse until neurological

and vital signs of toxicity appeared. The total amount of drug administered during this titration procedure was taken as the starting dosage for the withdrawal process. On the following days, the total drug intake was reduced by approximately one therapeutic dose per day until zero drug intake levels were reached. Two factors could modify this scheduled step-by-step reduction in the daily drug intake: (1) occasionally the patient's clinical status necessitated a slower or faster than scheduled reduction or even some backtracking on the schedule; (2) some patients declined to take one or more scheduled doses and thus accelerated the withdrawal process. The length of the withdrawal process differed from patient to patient due to these schedule changes and because the patients began the withdrawal process with different initial doses.

Tables 2.1 and 2.2 show the age and sex of each patient, their withdrawal drug, their daily drug intake throughout the treatment, and the nights for which the EEG was automatically processed for this study. The tables also show the nights when the EEG was recorded after the subject had left the hospital and the nights when either the EEG was not recorded on magnetic tape or the tapes were not suitable for playback. The night records used in this study were recorded on various occasions: (1) either on the titration night or on the night following it; (2) on one or two nights while the subject was taking the drug; (3) on the night following the first day of zero drug intake; (4) on a night

TABLE 2.1

GROUP 1 - SECOBARBITAL

Nights	Subject SD1 · Sex M Age 21		Subject SD2 Sex M Age 16		Subject SD3 Sex M Age 17	
	Record Number	Daily Dosage (mg)	Record Number	Daily Dosage (mg)	Record Number	Daily Dosage (mg)
1st	15305	100	15012[N]	500	15030*	350
2nd	15310	500	15017*	300	15036	150
3rd	15315	400	15021	250	15044*	200
4th	15320*	500	15025	200	15051	100
5th	15322*	1000	15029*	150	15058	50
6th	15326	400	15037	0	15066	0
7th	15329	500	15043*	0	15071[N]	0
8th	15332	400	15052	0	15079*	0
9th	15337	300	15060	0	15087	0
10th	15340*	200	15065	0	15092	0
11th	15344	100	15072	0	15097	0
12th	15352	0	15080	0	15101	0
13th	15358*	0	15086*	0	15105*	0
14th	15364	0	15091	0	-	-
15th	15370	0	-	-	-	-
16th	15375*	0	-	-	-	-
17th	15383	0	-	-	-	-
18th	15390	0	-	-	-	-

*Night records used in this study.

[N]Either the record was not on magnetic tape or the tape was bad.

TABLE 2.2

GROUP 1 - METHAQUALONE

Nights	SUBJECT SD4 · SEX F AGE 25		SUBJECT SD5 SEX M AGE 35		SUBJECT SD6 SEX M AGE 16	
	Record Number	Daily Dosage (mg)	Record Number	Daily Dosage (mg)	Record Number	Daily Dosage (mg)
1st	14497*	2100	14498*	3000	15336	0
2nd	15002[N]	2400	15003	2100	15341*	600
3rd	15006*	1500	15007*	1875	15351*	300
4th	15010	1500	15011	1800	15359*	0
5th	15015	1200	15016*	1650	15363[N]	0
6th	15019	900	15020	1350	15368	0
7th	15024*	600	15026	1350	15376*	0
8th	15032	300	15031	1200	15382[N]	0
9th	15038	150	15039	1050	15389[N]	0
10th	15045	0	15046	600	15391[N]	0
11th	15050*	0	15053	600	-	-
12th	15059[N]	0	15061	300	-	-
13th	15064[N]	0	15063*	0	-	-
14th	15073[N]	0	15074[N]	0	-	-
15th	15078[+]	0	15081[N]	0	-	-
16th	15085[+]	0	15142[+]	0	-	-
17th	-	-	15148[+]	0	-	-
18th	-	-	15155[+]	0	-	-

*Night records used in this study.

[+]Recorded after the patient left the hospital.

[N]Either the record was not on magnetic tape or the tape was bad.

close to the patient's discharge from the hospital.

The recordings of the sleep EEG were made with a GRASS Model 78 polygraph. Three pair of electrodes were placed in accordance with the 10-20 international system, F_1-F_7, P_1-T_5, O_3-O_Z P_Z (between O_Z and P_Z). In addition, two pairs of electrodes were used for recording EOG signals and one pair for monitoring the heart rate. Electrodes placement were as described by Williams et al (1964 and 1974). The amplifiers were set to cutoff frequencies (half amplitudes) at 1 and 100 Hz. All EEG channels plus a timer channel were recorded on paper at a speed of 15mm/sec and on magnetic tape using a SANGAMO Model 35100 14 track FM tape recorder, at a speed of 15/16 ips. Each night the polygraph was calibrated to make a 5mm pen deflection corresponding to 50 μV. In addition to this, a 10 Hz sine wave with an amplitude of 50 μV peak-to-peak was also applied to each channel as a calibration signal.

2.2.2 Group 2

In this group the study consisted of two periods: the first period was to investiagte the effects of acute toxic levels of the drugs on the sleep EEG; the second period was designed to get baseline data under normal circumstances.

In the first period, the subjects were admitted to the hospital and stayed there for at least three consecutive nights. All of them were given careful physical examina-

TABLE 2.3 GROUP 2 - SECOBARBITAL

Sleep Sessions	SUBJECT SC3 SEX M AGE 24		SUBJECT SC2 SEX M AGE 23		SUBJECT SC1 SEX M AGE 22	
	Record Number	Daily Dosage (mg)	Record Number	Daily Dosage (mg)	Record Number	Daily Dosage (mg)
1st	15968	none	15943	none	15978	none
Nap	15971*	1000[1]	15945*	600[1]	15983*	600[1]
2nd	15971*	-	15952*	-	15989*	-
3rd	15979*	none	15956*	none	15994*	none
Baseline Night	16326*	none	16328*	none	16093*	none

*Records that were automatically processed for this study.
[1]The drug was given before the nap.

TABLE 2.4 GROUP 2 - METHAQUALONE

Sleep Sessions	SUBJECT SC4 SEX M AGE 25		SUBJECT SC5 SEX M AGE 23		SUBJECT SC6 SEX M AGE 22	
	Record Number	Daily Dosage (mg)	Record Number	Daily Dosage (mg)	Record Number	Daily Dosage (mg)
1st	15908	none	15923	none	15982	none
Nap	15909*	4200[1]	15928*	3000[1]	15984*	1800[1]
2nd	15912*	-	15928*	-	15990*	-
3rd	15917*	none	15935[N]	none	15995*	none
Baseline Night	16070*	none	16090*	none	16339*	none

*Records that were automatically processed for this study.
[N]Records not available on magnetic tape.
[1]The drug was given before tha nap.

tions prior to the beginning of the experiment. In the first day they ate regular food, retired to bed at their usual bedtime, were awakened the next morning at their usual arising time. This first night was an adjustment night for the subjects. In the morning of the second day they were fed liquid food, and after the application of the EEG electrodes they were given an initial dosage of 600mg of either secobarbital or methaqualone. Each subject was then checked for neurological and vital signs of toxicity. If these signals were absent, and additional dosage of 200mg of the drug was administered hourly, until signs of toxicity appeared. After this titration procedure, if the subject desired they could take a nap. Following the nap, they retired to bed between 0:00 and 1:00 AM and were awakened, after sleeping for their normal length of time. Two of the subjects slept straight from the beginning of the nap until the next morning. On the third night the subjects retired to bed at their usual time and were awakened at their usual arising time.

Approximately one month after the first period, the subjects reported to the sleep laboratory on four consecutive nights for the recording of the baseline EEG data. Their retiring and arising time were adjusted to their usual schedule. The EEG from the third night of sleep was used in this study as the baseline for each subject.

Tables 2.3 and 2.4 show the age and sex of each subject, the drug and dosage they were given and the nights

for which the EEG's were automatically processed for this study. The tables also show the nights where the sleep EEG's were not recorded on magnetic tape.

The recording procedures for the sleep EEG's were the same as those used in the Group 1, described in Section 2.2.1.

2.3 DATA ACQUISITION

2.3.1 Data Preparation

The recorded raw EEG data were played off-line from a SANGAMO Model 35100, 14 track FM tape recorder into an SS-100 Analog Computer through a bandpass filter. The play-back speed was 30 ips which is 32 times faster than the speed used in the recording stage. This procedure results in a time-compression of the same order, which means that an eight hours record can be digitized in 15 minutes. For simplicity, filter bandwidths, sampling frequency and signal durations are given in terms of the equivalent real time signals.

In order to reduce the computational time needed, this study was based on data from the central derivation (P_1-T_5) only. In the central channel spindle activity is more predominant than in the frontal and occipital channels. The central channel also shows activity that is more predominant in the other two channels such as: delta in the frontal and alpha in the occipital. (Smith et al, 1976)

The reproduced raw EEG signal from (P_1-T_5) was passed through a KROHNHITE Bandpass Filter with an adjustable bandwidth of 0.2-40 Hz and 18 dB/octave roll-off. The upper cutoff frequency was chosen, so that we could investigate any activity above 30 Hz that could be present due to the effects of the durgs. The filtered signal was fed into a hybrid system comprised of a SS-100 Analog Computer (Hybrid Systems Inc.) and an IBM 360/44 Digital Computer. In the Analog Computer the signal was amplified by two operational amplifiers. The first amplifier had a fixed gain of 10 and the second one was of a variable gain. With this set-up the total gain was adjusted, for each record, so that a 50μV calibration signal was equivalent to a 30 volts deflection at the input of the A/D multiplexer. Since the SS-100 Analog Computer permits output swings of $\pm$100V we can have EEG signals up to 300μV peak-to-peak with no distortion through the system.

2.3.2 Analog-to-Digital Conversion

Conversion of a continuous analog signal into an equivalent digitized form involves sampling in the time domain and quantization in the amplitude domain.

The sampling rate was chosen to be 128 samples/sec which means that we can represent signals up to 64 Hz without any aliasing (Bergland, 1969). In this way 60 Hz from the power line, which is a common source of noise in EEG signals, will not be aliased into lower frequency bands.

In the quantization process the amplitude of each data sample must be expressed by some fixed number of

digits. In this way, no matter how many quantization levels are available, there will always be an error associated with this process, called quantization error. The quantization error is related to the value of a quantization level q and can be given as the ratio of the exact magnitude of the sampled value x, and its quantized approximation expressed as a power of 2,

$$\varepsilon_q = \pm(x/2).(1/2^N) = \pm q/2$$

where N is the number of bits that make up the digital number. For ideal conversion ε_q will have a uniform probability distribution with a standard deviation of 0.29q (Beauchamp, 1973). We can think of this quantization error as a white noise added to the signal. The SS-100 Analog Computer can quantize a signal with 8192 level units (i.e. 2^{13} or 13 bits), then the peak signal to noise ratio is given by,

$$(S/N) = 20\log(8192q)/(0.29q) = 89 \text{ dB}$$

which is more than satisfactory for the present application.

2.3.3 Data Conversion and Storage

A FORTRAN program called CONVERSION was written in order to perform the following functions:

(1) to signal the operator when the Hybrid System is ready to start the A/D conversion process;

(2) to permit the operator to start the A/D conversion at any desired segment of the

analog tape, by pressing a switch, which starts the clock of the analog computer. This clock controls the sampling rate, and thus starts the A/D conversion;

(3) to convert the analog sampled data into binary integer numbers, by the use of the A/D system subroutines;

(4) to write those integer numbers on a 9-track magnetic tape (SCRATCH) for temporary storage.

A detailed listing of CONVERSION appears in Appendix B.

The digitized data from SCRATCH is copied into a standard magnetic tape labeled Master Tape for permanent storage.

The integer data is written on the magnetic tape in blocks of 7680 bytes, corresponding to a 30 seconds epoch. Since the tape driver can write at a density of 800 bytes/in, the length ℓ_r of each record on the tape is,

$$\ell_r = 7680/800 = 9.6"$$

Since the interecord gap (IRG) is 0.6", the total length of each record ℓ_t is

$$\ell_t = 9.6"+0.6" = 10.2"$$

For a night of sleep of eight hours we will have 8h/30sec = 960 records which will occupy a total tape length of

$$960 \times 10.2"/12" = 816 \text{ ft}$$

On the average then we can expect to accomodate two nights of sampled sleep EEG in each 2400 ft digital tape.

2.4 DATA PREPROCESSING

2.4.1 Artifacts and Data Reduction

The first big problem that we faced when we tried to automatically process the all-night sleep EEG signals was that of artifacts in the EEG record. Artifacts can be caused by several sources such as: loose electrodes, body movement, contamination of scalp electrodes by eye movements, etc. Most of the reported work using spectral techniques to analyze EEG signals has been conducted using artifact free epochs selected visually. Since in the present study we processed about 50 nights of sleep EEGs, the task of selecting artifact free epochs by visual inspection would have been practically impossible. At the beginning of this study, we tried to detect artifacts using an amplitude level criterion, due to the fact that artifacts usually have high amplitudes. With this method we ended up rejecting epochs with high amplitude delta activity and accepting other epochs with low amplitude artifacts.

One approach that worked much better than the amplitude criterion was a chi-square goodness-of-fit test to a Gaussian distribution (CSQ) to check for artifacts. This test is very sensitive to nonstationarities in the epochs and it will produce a large chi-square coefficient, X^2, when an artifact is present. This artifact detection method will

be explained in more details in Section 2.4.3.

Another big problem we faced was the huge amount of data to be processed. In order to minimize this problem, we decided not to process the epochs continuously during the night, but instead to pick one 30 second epoch each 2 1/2 minutes. Since our main interest was not in the automatic scoring of the sleep stages, but in studying possible patterns caused by the effects of the hypnotic drugs on the sleep EEGs during the night, this approach was justified. Furthermore, the amount of data was reduced to 20% of the original total.

The above preprocessing was implemented by a computer program, to be described in the next section.

2.4.2 The Main Algorithm

A FORTRAN program called REDUCE was written to perform the following tasks: (1) to reduce the amount of data to be processed by selecting one epoch in each set of five epochs from the original Master Tape (this means that at each 2 1/2 minutes one 30 seconds epoch containing 3840 data points was selected); (2) to check the first epoch of each set for artifacts; (3) to start checking the next three epochs of the set for an artifact free or nearly free epoch, in case an artifact had been already detected in the first epoch; (4) to print a message each time an artifact is detected, stating the cause of rejection and the number of the epoch where it was detected; (5) to print another mes-

sage if all the epochs in a given set were rejected due to artifacts; (6) to compute statistical parameters such as maximum and minimum amplitude values, mean, variance, kurtosis, skewness, and chi-square coefficient for each chosen epoch; (7) to write on an Auxiliary Tape all epochs that were selected from the Master Tape and their respective statistical parameters.

Figure 2.1 shows a flowchart diagram of REDUCE. Detailed listings of REDUCE and its subroutines are given in Appendix B. We should mention two of the subroutines: RDTAPE and TWRITE, both coded in Assembler Language. They were used to handle input and output operations (I/O) between the computer and the tape units. Due to the length and large number of tape records (7680 bytes), the use of these subroutines reduced the amount of computer time spent in I/O operations by a factor of ten when compared to the same operations executed in FORTRAN.

Four input parameters are required by REDUCE: the starting record (epoch) on the Master Tape for each night; the maximum amplitude level for the amplitude artifact detection test; the upper (UB) and lower (LB) bound for the CSQ test.

The number of the starting epoch on the Master Tape was obtained after the completion of the A/D conversion procedure, when the sampled EEG data was still on the SCRATCH tape. The power spectra for the first ten epochs were computed and then plotted on the IBM 360 computer

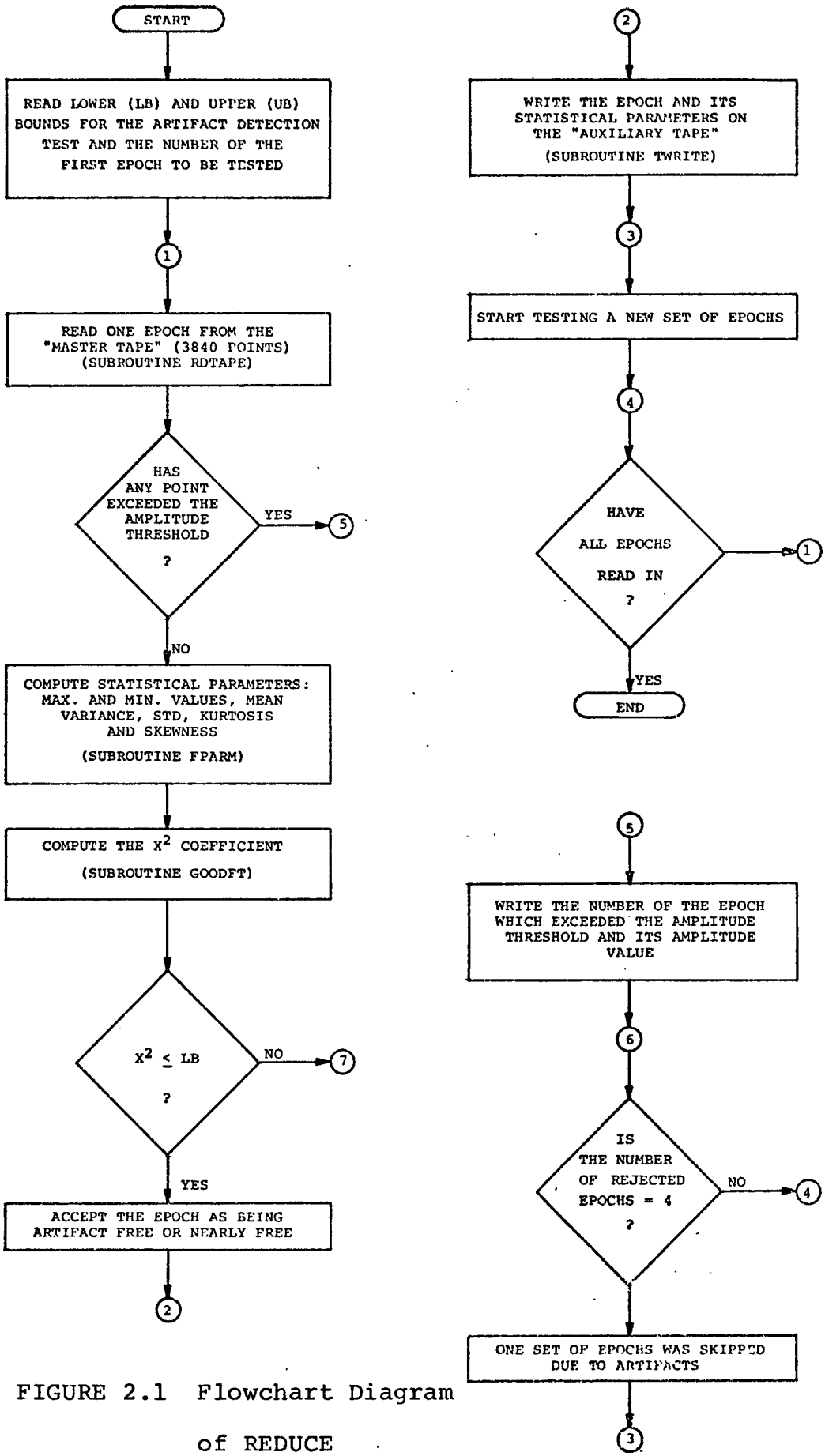


FIGURE 2.1 Flowchart Diagram of REDUCE

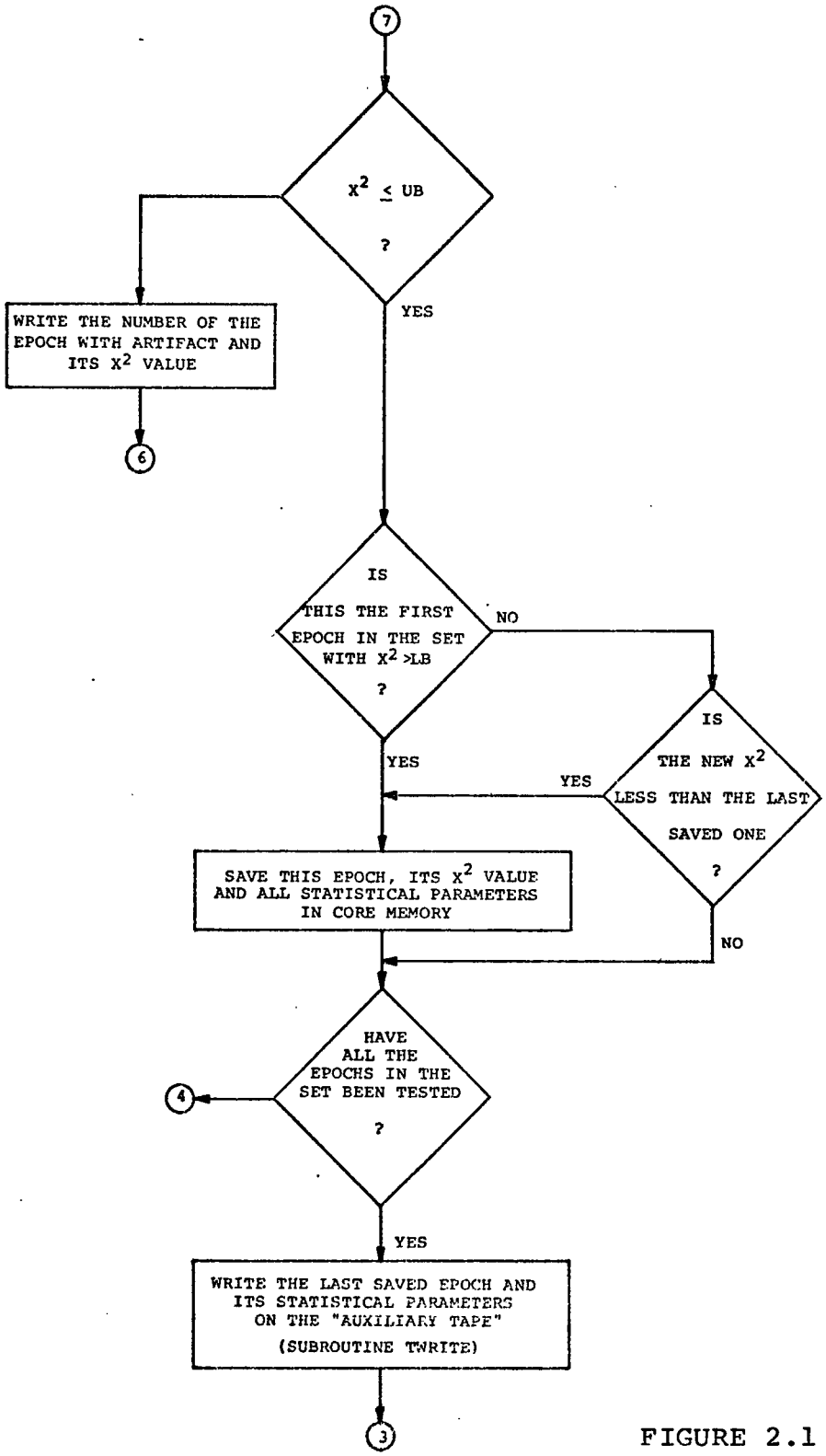


FIGURE 2.1 (continued)

printer. By visual inspection, the first plot that showed neither a power spectrum of the calibration signal (sine wave), nor one corresponding to obvious artifacts, was marked, and its number saved as being the number of the starting epoch on the Master Tape. The choice of the remaining input parameters of REDUCE is explained in the next section.

Figure 2.2 shows a typical output printout page generated by REDUCE.

2.4.3 Detection of Artifacts

During the preprocessing phase we used two tests for the detection of artifacts. One was based on amplitude criteria and the other used results of the chi-square test for goodness-of-fit to a Normal Distribution.

To check for very large amplitude artifacts each sampled data point was compared with maximum amplitude levels. In this study the maximum amplitude levels were set at 99 volts (±300μV), respectively. Since the Analog Computer allows a maximum swing of ±100 volts at the output of its amplifiers, any saturation of the amplifiers due to large signals at the input can thus be detected.

If no artifacts were detected by the amplitude test, then the epoch was submitted to a CSQ test. The implementation of this test is explained in detail in Appendix A. The acceptance region for the test was

$$X^2 \leq 66.2$$

```
 ARTIFACT   DETECTED  AT EPOCH NO.  15      XSQR=1918.97
 ARTIFACT   DETECTED  AT EPOCH NO.  20      XSQR=4612.00
 ARTIFACT   DETECTED  AT EPOCH NO.  25      XSQR= 301.01
 ARTIFACT   DETECTED  AT EPOCH NO.  30      XSQR=2548.85
 ARTIFACT   DETECTED  AT EPOCH NO.  31      XSQR=2995.70
 ARTIFACT   DETECTED  AT EPOCH NO.  32      XSQR=3855.78
 ARTIFACT   DETECTED  AT EPOCH NO.  33      XSQR= 407.23
* A SET OF EPOCHS WAS SKIPPED DUE TO ARTIFACTS
 ARTIFACT   DETECTED  AT EPOCH NO.  45      XSQR=3231.46
 ARTIFACT   DETECTED  AT EPOCH NO.  46      XSQR= 844.14
 ARTIFACT   DETECTED  AT EPOCH NO.  55      XSQR= 654.64
 ARTIFACT   DETECTED  AT EPOCH NO.  65      XSQR=1878.64
 ARTIFACT   DETECTED  AT EPOCH NO.  70      XSQR= 486.10
 AMPLITUDE  EXCEEDED  AT EPOCH NO.  71         X=-393.27
 ARTIFACT   DETECTED  AT EPOCH NO.  85      XSQR= 316.07
 ARTIFACT   DETECTED  AT EPOCH NO. 115      XSQR= 517.79
 ARTIFACT   DETECTED  AT EPOCH NO. 116      XSQR= 300.20
 ARTIFACT   DETECTED  AT EPOCH NO. 117      XSQR= 266.59
 ARTIFACT   DETECTED  AT EPOCH NO. 118      XSQR= 350.20
 ARTIFACT   DETECTED  AT EPOCH NO. 135      XSQR= 476.75
 ARTIFACT   DETECTED  AT EPOCH NO. 136      XSQR=2256.10
 ARTIFACT   DETECTED  AT EPOCH NO. 140      XSQR=1803.87
 ARTIFACT   DETECTED  AT EPOCH NO. 141      XSQR=1022.24
 ARTIFACT   DETECTED  AT EPOCH NO. 150      XSQR= 704.93
```

FIGURE 2.2 Partial Output Printout from REDUCE

(Subject SD4, 11th night, record #15050)

What this means is that, if the computed X^2 coefficient for a given epoch were within the acceptance region above, the hypothesis that the amplitude distribution function for the epoch follows a Gaussian Distribution could be accepted at the 5% level of significance. The test, by its own formulation, assumes that the set of samples to be tested represents a set of independent random observations. However, in practice, for a bandlimited EEG sequence this assumption does not hold due to the interdependence of successive samples, and the efficacy of the statistical hypothesis is consequently weakened. The problem of interdependence between samples will become even worse when the sampling rate is increased above the Nyquist rate (McEwen, 1975). Due to this fact, and because, furthermore, the EEG is not a purely random process, we would expect that the values of X^2 would not fall necessarily in the acceptance region of the test. For the purpose of detecting artifacts these limitations are not important with the data at hand. After examining ten nights of three subjects in which no artifact detection algorithm was used, we found the following results: artifacts were present in all the epochs in which $X^2 > 280$; artifacts were also present in about 75% of the epochs in which $160 < X^2 \leq 280$ and that 95% of the epochs with $X^2 \leq 160$ were artifact free or nearly free. Therefore, there is some uncertainty in the interval $160 < X^2 \leq 280$ as far as the presence of artifacts is concerned. Based on this, we designed the following detection test: (1) if $X^2 \leq 160$ the epoch is accepted as

artifact free or nearly free; (2) if $X^2 > 280$ the epoch is rejected; (3) if $160 < X^2 \leq 280$ the epoch is saved by storing its sampled data points in the computer core memory and the algorithm (REDUCE) proceeds to test the next epoch in the set of 5; (4) if none of the remaining epochs in the set has a $X^2 \leq 160$, then the epoch with the smallest X^2 in the interval $160 < X^2 \leq 280$ will be selected. The above detection algorithm was designed having in mind that no more than four epochs were to be rejected, by any combination of the two tests in any given set of five 30 seconds epochs. The values 160 and 280 correspond to what we called the upper and lower bounds for the CSQ test in Section 2.4.2, and they are input parameters to REDUCE. Later in this study, we found that a lower bound of 180 could be used instead of 160 as was first suggested. The reason we kept using the former value was that several night records had been already processed with the lower bound set at 160. By looking at the printed outputs of REDUCE, we concluded that the change of this parameter to 180 would affect less than 5% of the total number of epochs for each night. Furthermore, an extra amount of computer time would be required to reprocess all the data.

Allowing the selections of epochs with X^2 value in the range $160 < X^2 \leq 280$ could lead to only two possibilities: (1) the epoch does not have any artifacts; (2) the epoch contains artifacts indeed. In this case, the algorithm will misclassify it as artifact free. In the later

case most of the time, we detected the artifact by visual inspection of the Compressed Spectral Array (Section 3.4), and, therefore, we could minimize the changes of misclassification.

In order to better understand the operation of the CSQ artifact detection test we will present below six examples derived from the actual data. The epochs in the examples were chosen from the printed results of REDUCE, as being representatives of the test performance under various conditions. The plots were obtained by Digital-to-Analog (D/A) conversion of the sampled EEG, previously stored on the Master Tape, using the same Hybrid System as described in Section 2.3.1 plus a six channel BECKMAN RD DYNOGRAPH.

A FORTRAN program called DTOA was written to perform the D/A conversion and to plot three epochs simultaneously on the polygraph. A listing of this program appears on Appendix B. The polygraph speed was set to 15 mm/sec and calibrated so that 50 μV would correspond to 5 mm deflection.

Example 1:

Figures 2.4 a, b, c, and d show four successive 30 seconds epochs starting at minute 14 of the 10th night of subject SD1 (record #15340). In the first three epochs, Figures 2.4a, b, and c, there exist high amplitude very low frequency artifacts against a low amplitude and higher frequancy background. These three epochs were rejected by the algorithm, because their X^2 values were 507.9, 724.3, and

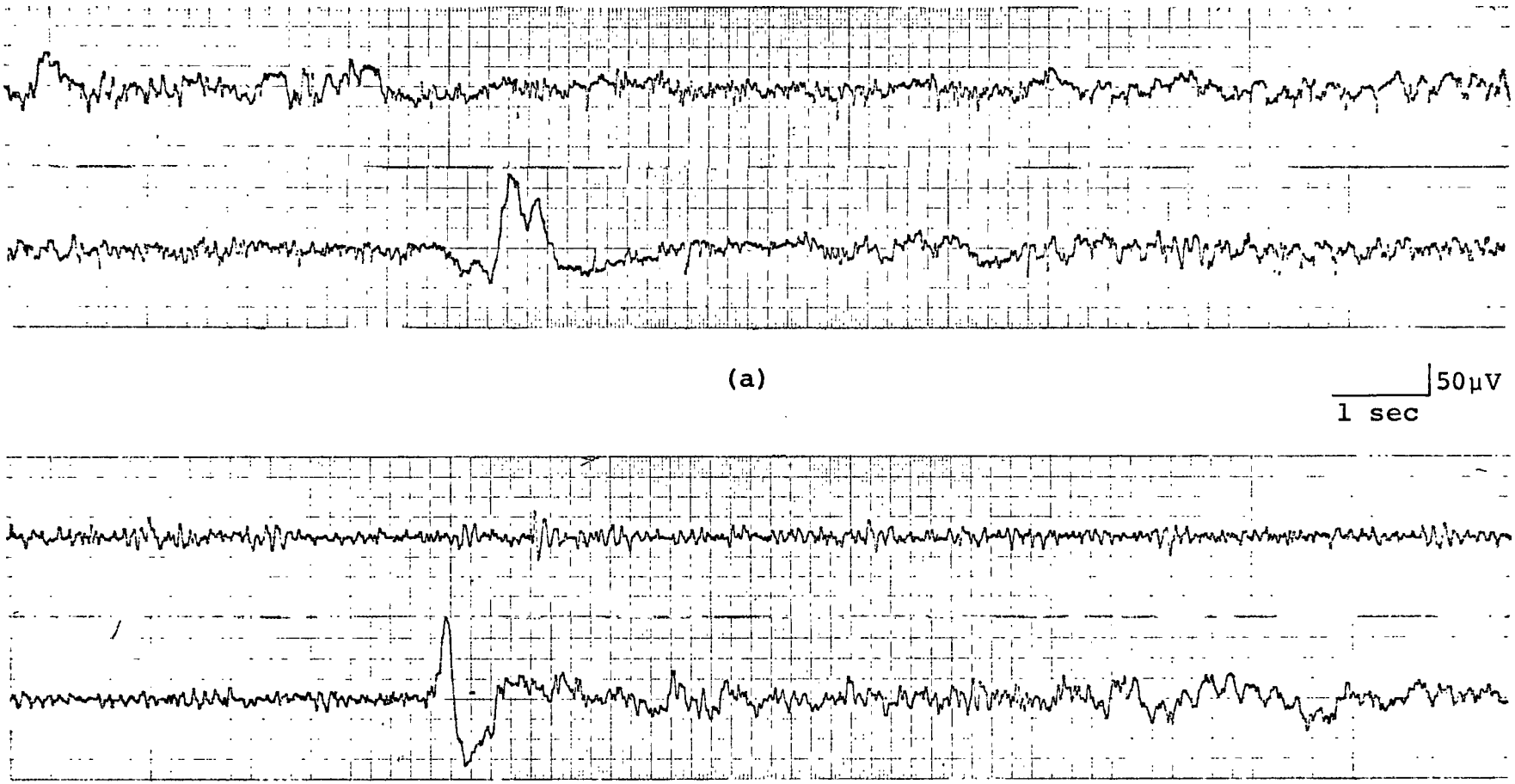
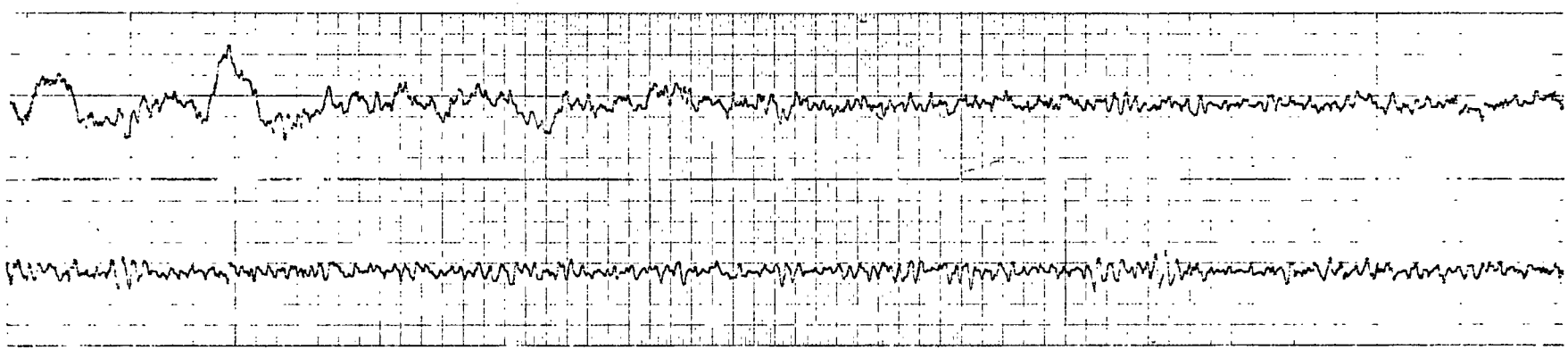


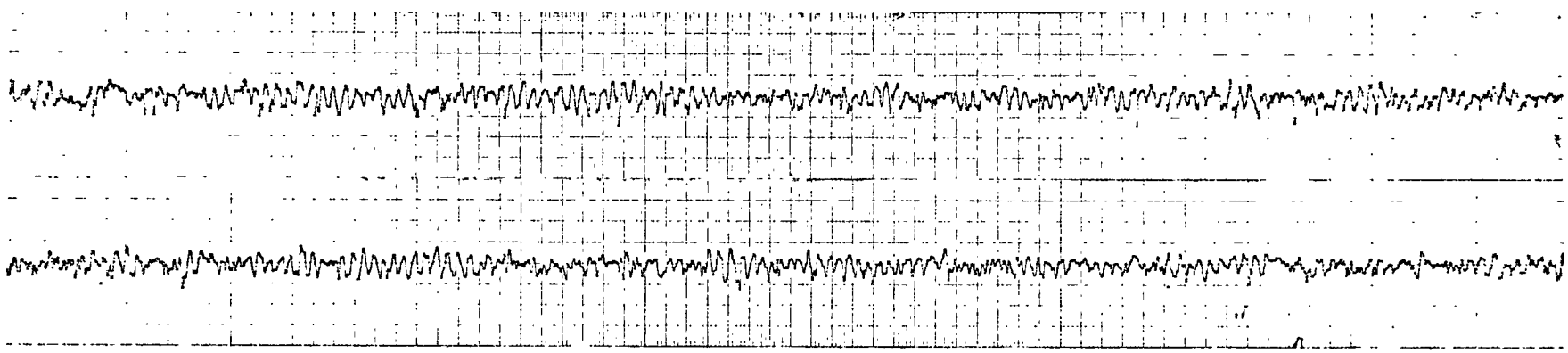
FIGURE 2.4 EEGs from Subject SD1 - record #15340

(a) Epoch #28, $X^2 = 507.9$
(b) Epoch #29, $X^2 = 724.3$



(c)

50μV
1 sec



(d)

FIGURE 2.4 (continued)

(c) Epoch #30, X^2 = 377.8
(d) Epoch #31, X^2 = 65.7

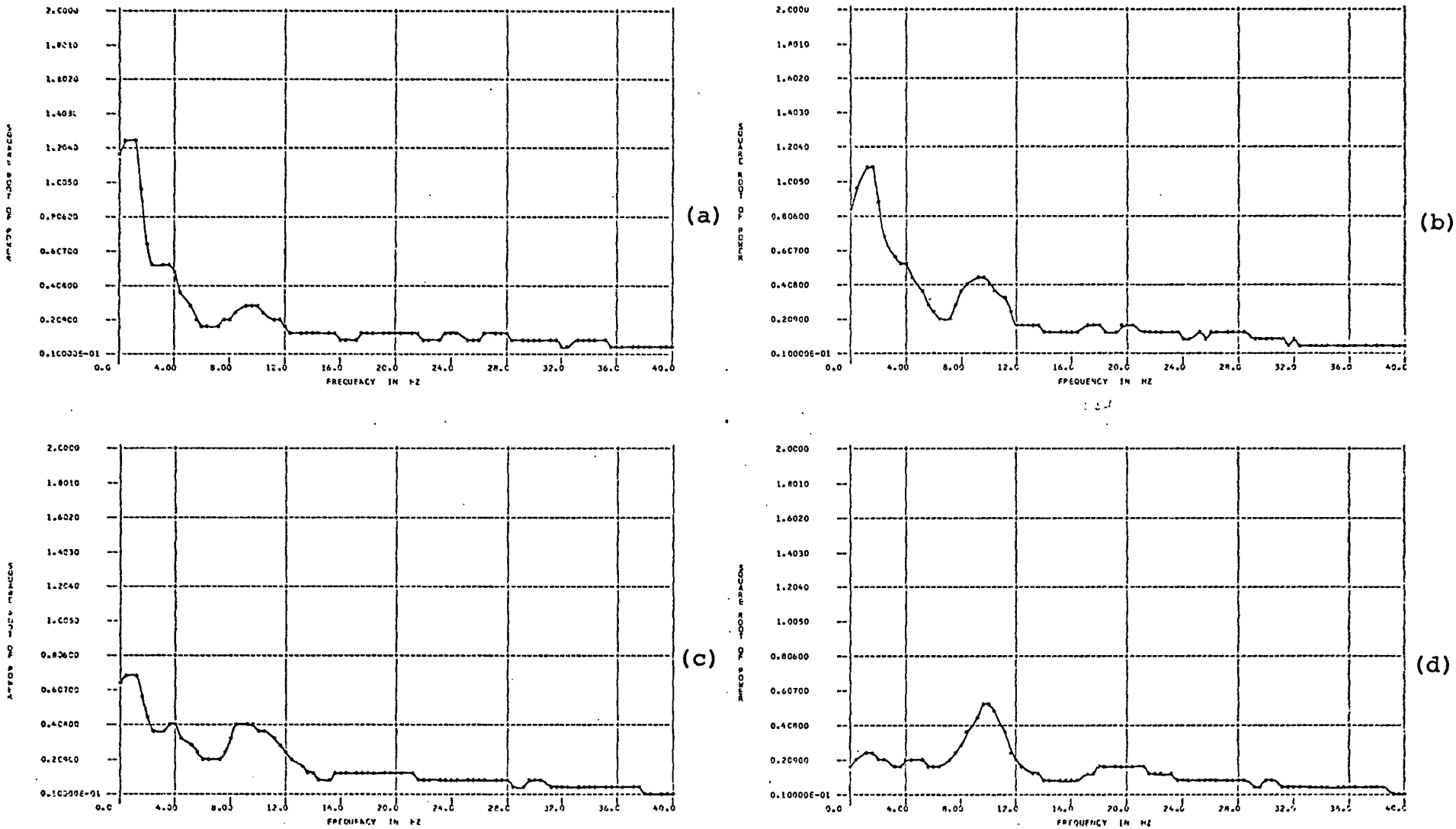


FIGURE 2.5 Power Spectrum (Subject SD1, 10th night, record #15340)

(a) Epoch #28 (b) Epoch #29
(c) Epoch #30 (d) Epoch #31

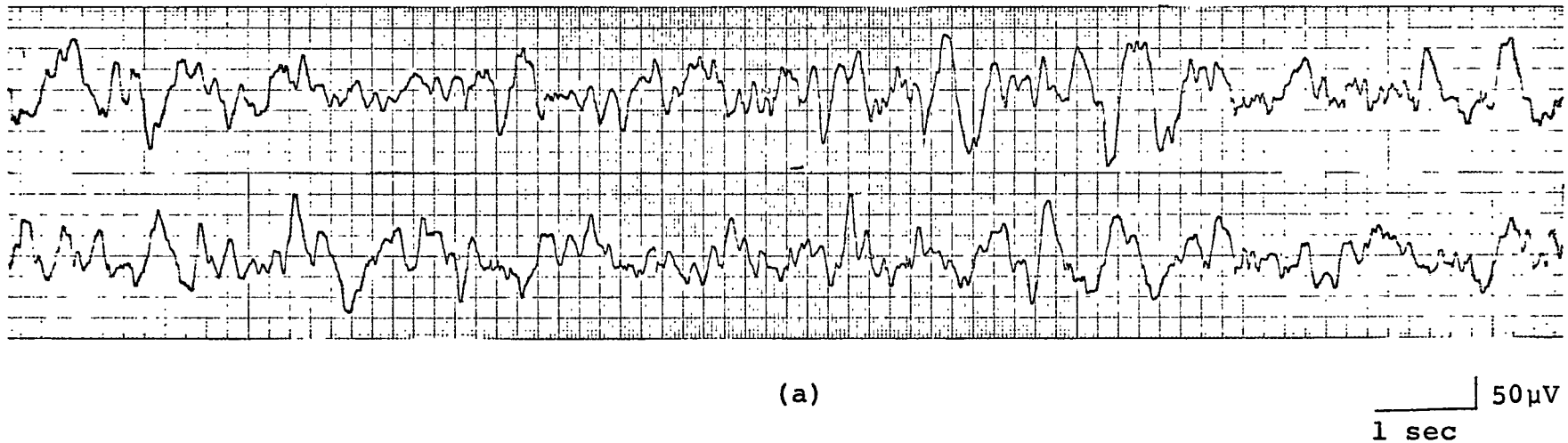
377.8, respectively. The fourth epoch, Figure 2.4d, was chosen to represent the set since its X^2 value was 65.7. In Figures 2.5a, b, c, and d the corresponding power spectrum plots for each of the four epochs are shown. From these it can be seen that the presence of the artifact and of the slow wave activity that followed it resulted in a much larger peak in the Delta Band than the one produced by the entire alpha activity at 9.5 Hz. So by looking at the power spectrum plot the presence of the artifact plus the slow wave activity gave the false impression of a predominant delta activity. In order to see how much of this activity is due to the artifact itself, we recomputed the power spectrum of the epoch shown in Figure 2.4b, with the artifact removed. This operation can be easily performed in the digital computer, by removing only the sampled data points that are comprised of the artifact. Since the time of occurence of the artifact in the epoch, and its duration can be estimated from Figure 2.4b, to locate the sampled data points to be removed becomes an easy task. After the removal of these data points, an equal number of zeros are inserted at the end of the modified epoch in order to keep its duration at 30 seconds. Figure 2.12a, shows the power spectrum corresponding to the epoch in Figure 2.4b with the artifact removed. Comparing the plots in Figures 2.5b and 2.12a, we can see that the artifact alone is responsible for about 70% of the total peak intensity in the Delta Band.

Example 2:

Figures 2.6a and b illustrate two epochs that were correctly selected by the algorithm and their respective X^2's. Figure 2.6a shows an epoch with slow wave sleep from the 13th night of subject SD2. Spindle activity is clearly seen in the epoch of Figure 2.6b which belongs to the 10th night of subject SD1.

Example 3:

In Figures 2.7a, b, c and d we plotted four successive 30 seconds epochs belonging to the 13th night of subject SD1. The computed X^2 value for the first epoch was 246.3 which fell in the interval $160 < X^2 \leq 280$. According to the rules of the artifact detection algorithm, this epoch was saved in the computer core memory and the algorithm proceeded to test the next epoch. The X^2 value for the second epoch was 175.7, still inside the above interval. This X^2 value was smaller than the one for the first epoch ($175.7 < 246.3$) and, therefore, the algorithm substituted the second epoch for the first and saved it in core memory. The third epoch that was tested showed a X^2 value of 207.3 that was in the interval $160 < X^2 \leq 280$. Since the X^2 value for the third epoch was greater than the X^2 value of the second epoch ($207.3 > 175.7$), the algorithm kept the second epoch previously stored. The fourth and last epoch of the set had a X^2 value of 96.5, and, therefore, this epoch was chosen by the system to represent the set, since its X^2 value was



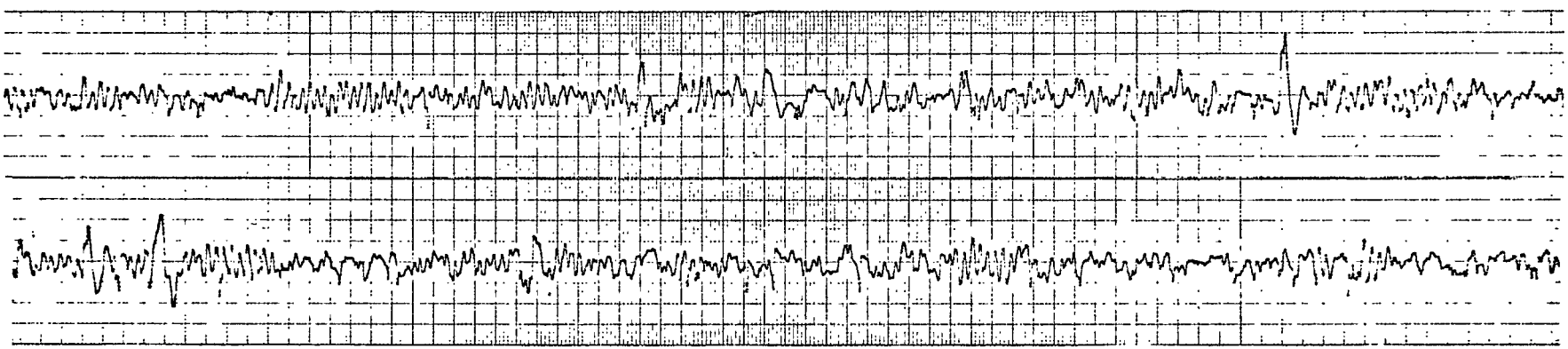


FIGURE 2.6 (a) EEG from Subject SD2 - record #15086
Epoch #63, $X^2 = 92.4$

(b) EEG from Subject SD1 - record #15340
Epoch #69, $X^2 = 106.3$

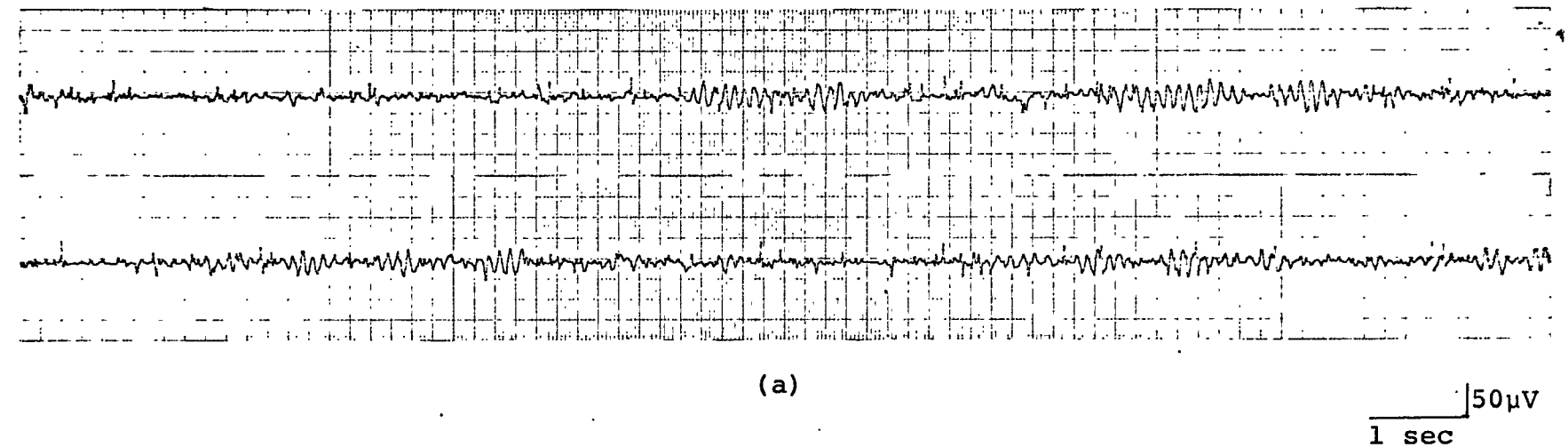
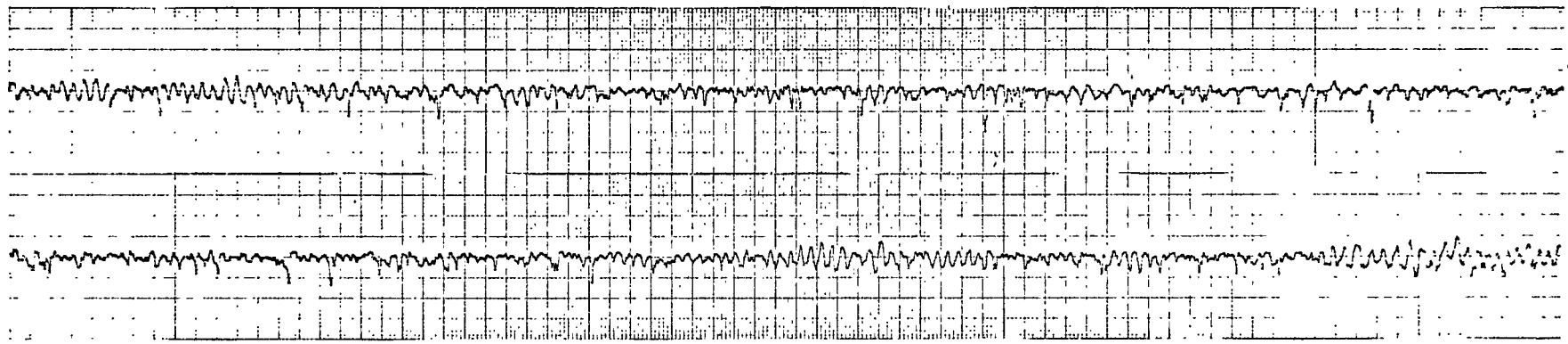


FIGURE 2.7 EEGs from Subject SD1 - record #15358

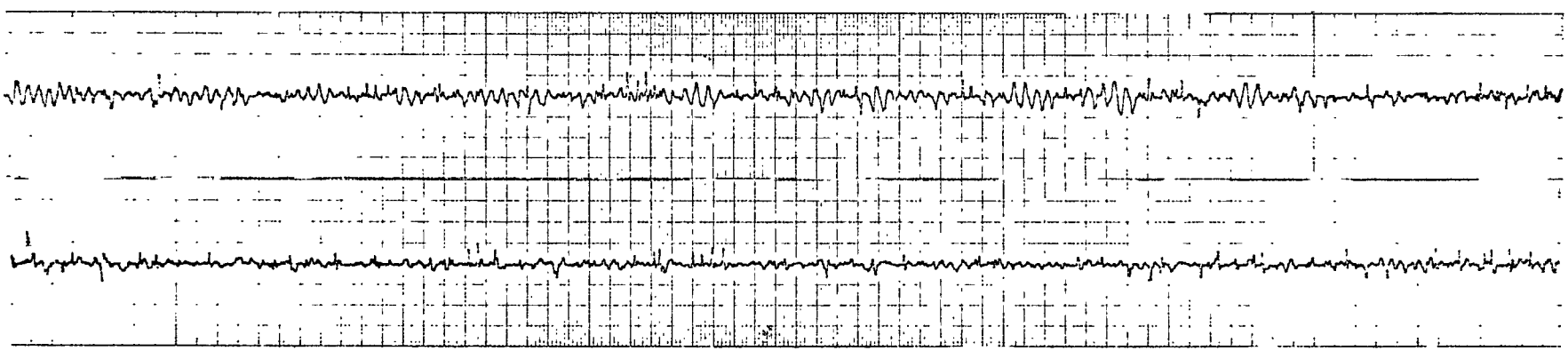
(a) Epoch #50, $X^2 = 246.3$
(b) Epoch #51, $X^2 = 175.7$



(c)

50μV

1 sec



(d)

FIGURE 2.7 (continued)

(c) Epoch #52, X^2 = 207.3
(d) Epoch #53, X^2 = 96.5

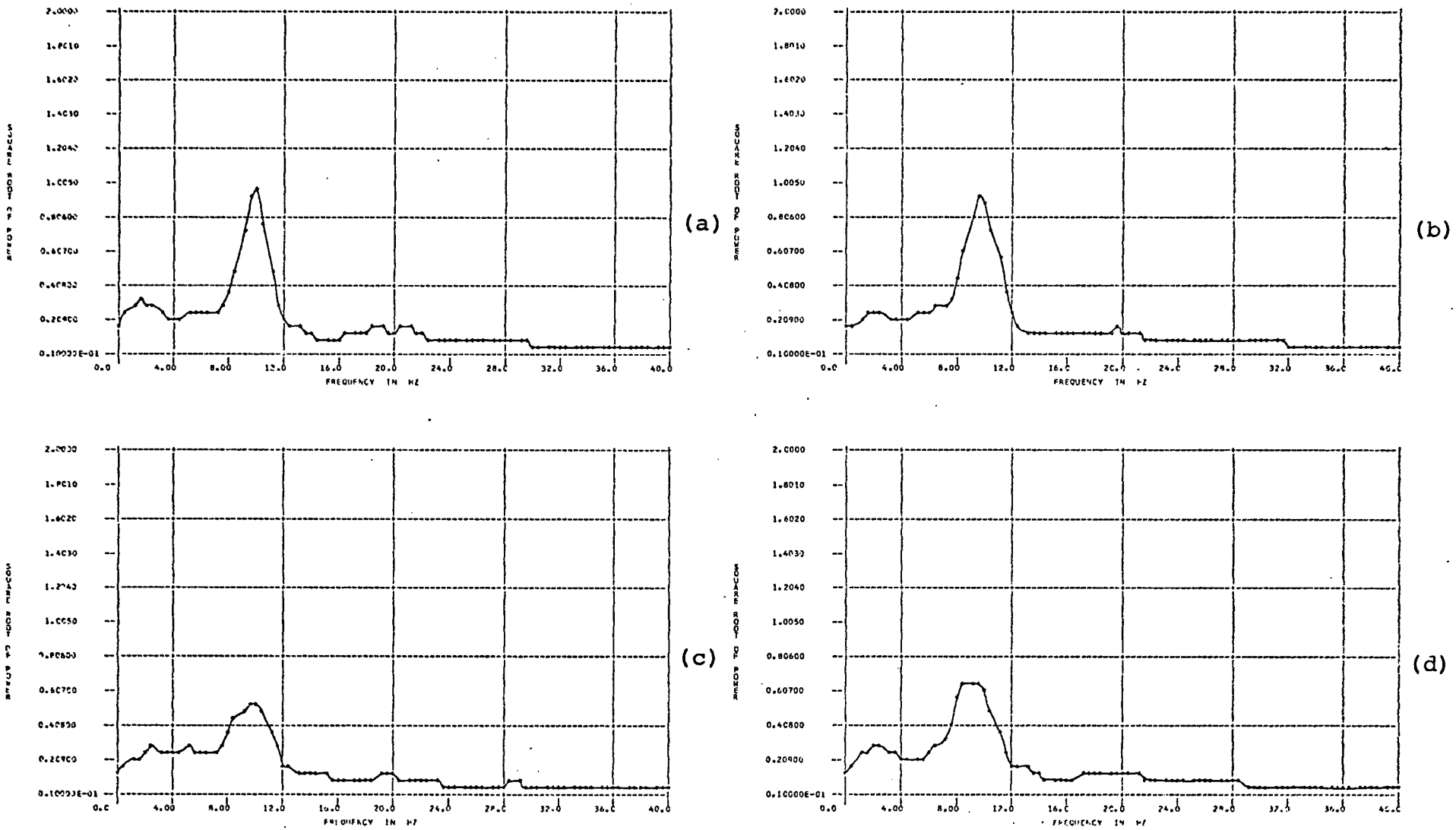


FIGURE 2.8 Power Spectrum (Subject SD1, 13th night, record #15358)

(a) Epoch #50 (b) Epoch #51
(c) Epoch #52 (d) Epoch #53

below the 160 threshold. This example illustrates the case where no visible artifacts can be seen, but three of the X^2 values fall into the region of uncertainty for artifact detection. The decision by the algorithm to reject the first three epochs was correct, according to the rules set before, even though they showed no visible artifacts. The large values of X^2 in the first three epochs are probable due to the high amplitude alpha bursts that appeared against a background of low amplitude activity. Figure 2.8a, b, c and d show the power spectrum plots of the four epochs studied in this example. These plots show that the power spectra for the epochs are essentially the same, except for differences in peak intensities in the alpha band.

Example 4:

Figures 2.9a and b show two consecutive 30 seconds epochs from the 13th night of subject SD1. For the first epoch the computed X^2 value was 204.7 which was in the uncertainty region of the test. Therefore, the algorithm saved this epoch and proceeded to test the second one. Since the X^2 value for this epoch was 96.0, the algorithm selected it as being artifact free, and, therefore, rejected the first epoch. The decision of rejecting the first epoch was a correct one, since a low frequency artifact can be seen in Figure 2.9a. The power spectrum plots corresponding to these two epochs are shown in Figure 2.10a and b. The presence of the low frequency artifacts in epoch #45,

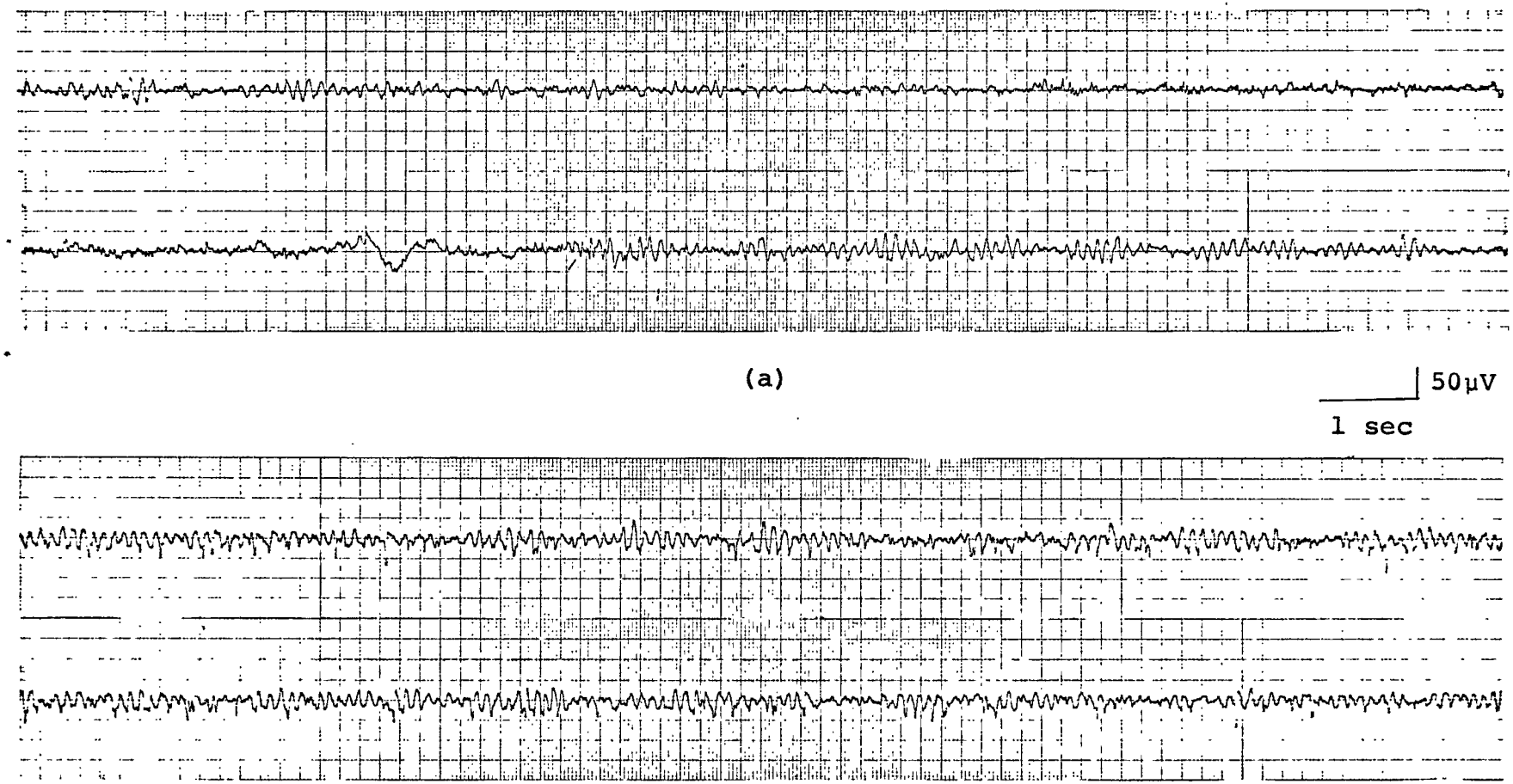
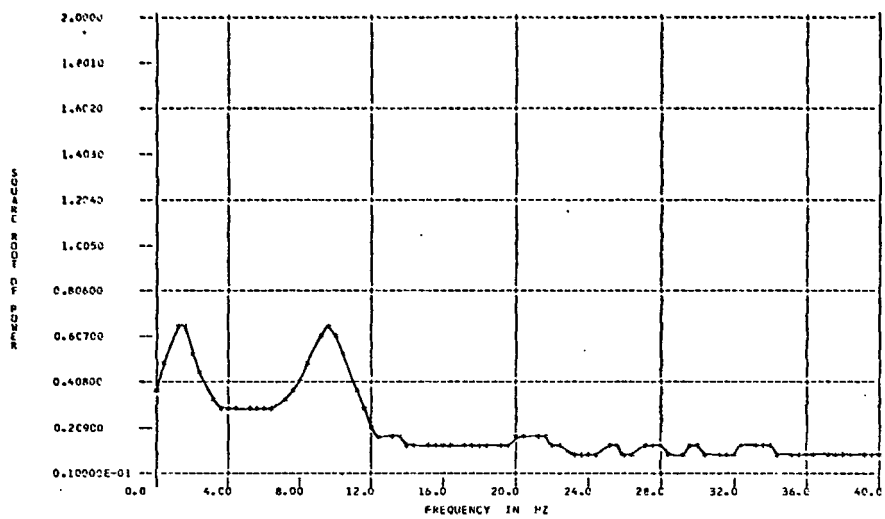
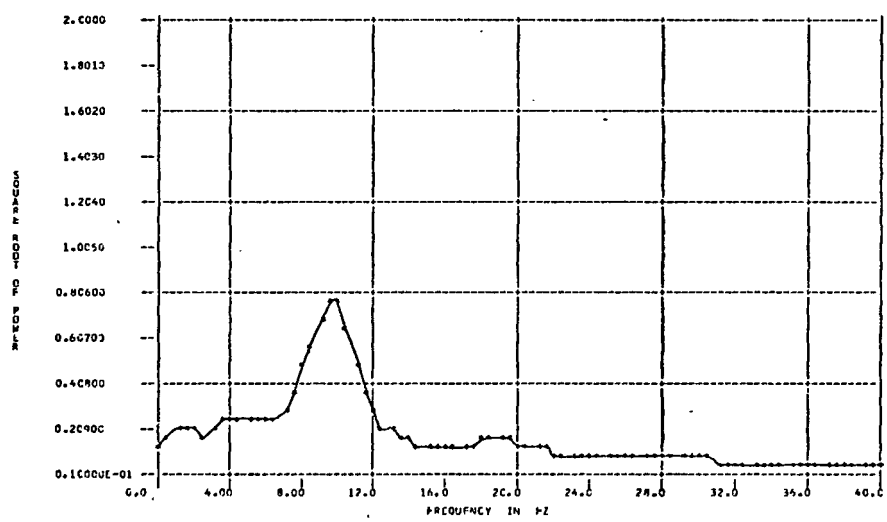


FIGURE 2.9 EEGs from Subject SD1 - record #15358

(a) Epoch #45, X^2 = 204.7
(b) Epoch #46, X^2 = 96.0



(a)



(b)

FIGURE 2.10 Power Spectrum (Subject SD1, 13th night, record #15358)

(a) Epoch #45

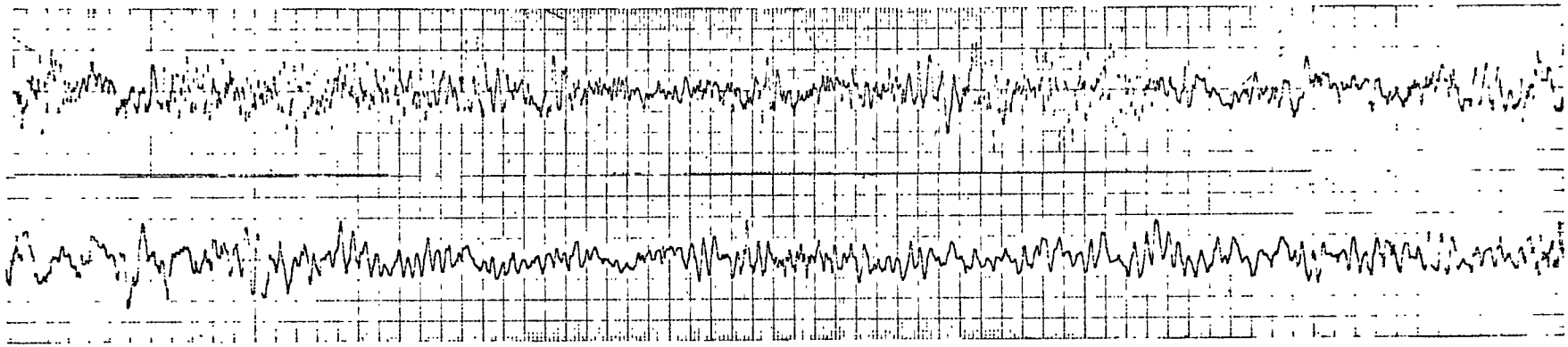
(b) Epoch #46

Figure 2.9a, resulted in a low frequency spectral peak of intensity comparable to the one corresponding to the alpha activity in the epoch and located at 9.5 Hz. Using the same procedure described in Example 1, we removed the artifact from the epoch and recomputed its power spectrum which is shown in Figure 2.12b. Comparing this plot with the one already shown in Figure 2.10a, we can see the change introduced in the power spectrum as a result of the artifact.

By comparing the results of Examples 3 and 1, we can see the need of having an uncertainty region ($160 < X^2 \leq 280$) in the artifact detection algorithm.

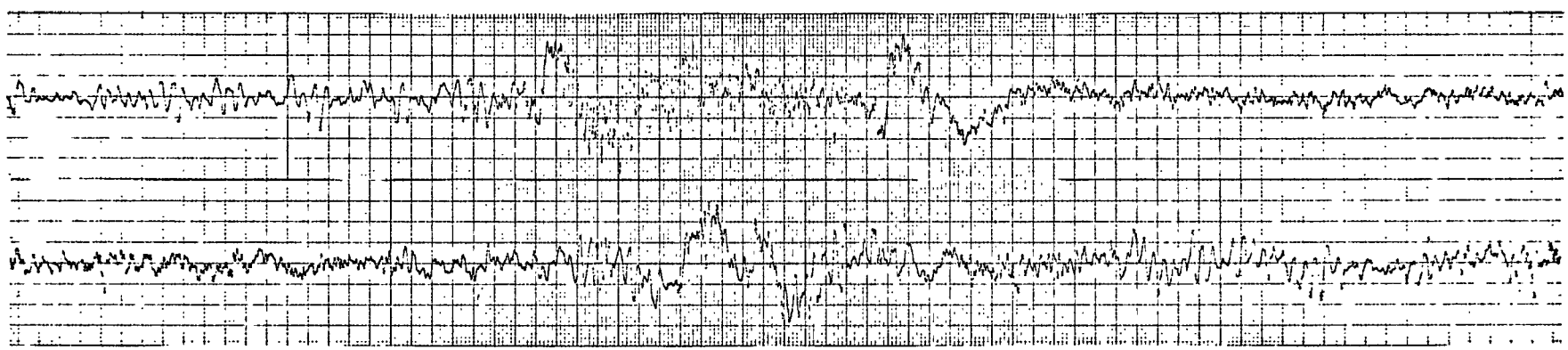
Example 5:

In this example we illustrate a case where the CSQ test failed to detect an artifact. Figure 2.11a shows epoch #83 from the 13th night of subject SD2. The computed X^2 value for this epoch was 70.1 and, therefore, it was selected by the algorithm as being artifact free. As we can see from Figure 2.11a an artifact with high frequency activity, probably caused by muscle twitch, is present at the beginning of the epoch. The presence of this artifact resulted in a broadband power spectrum as illustrated in Figure 2.13a.It is this particular characteristic of the resultant power spectrum that enables us to detect this kind of misclassification by the CSQ test, when we examine visually the CSA plots.



(a)

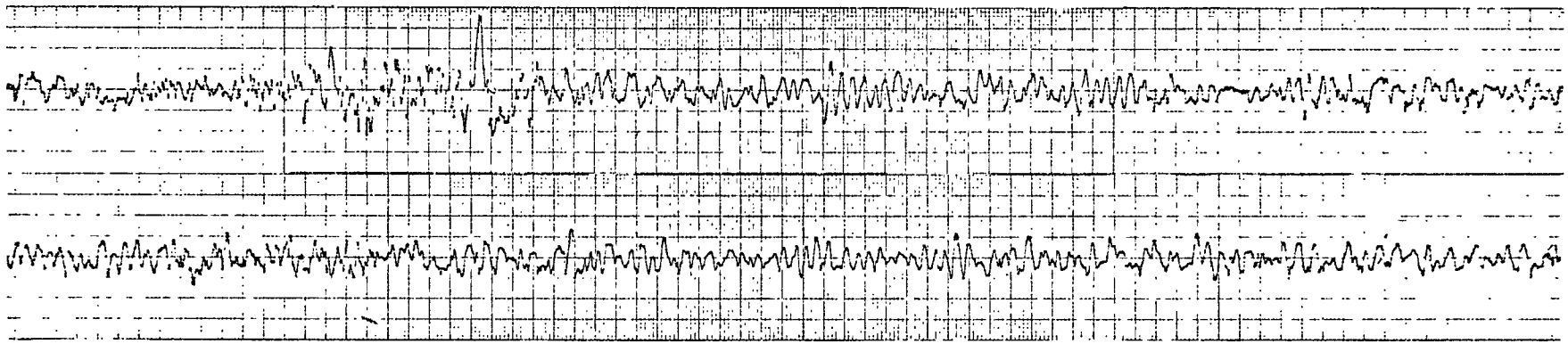
50μV
1sec



(b)

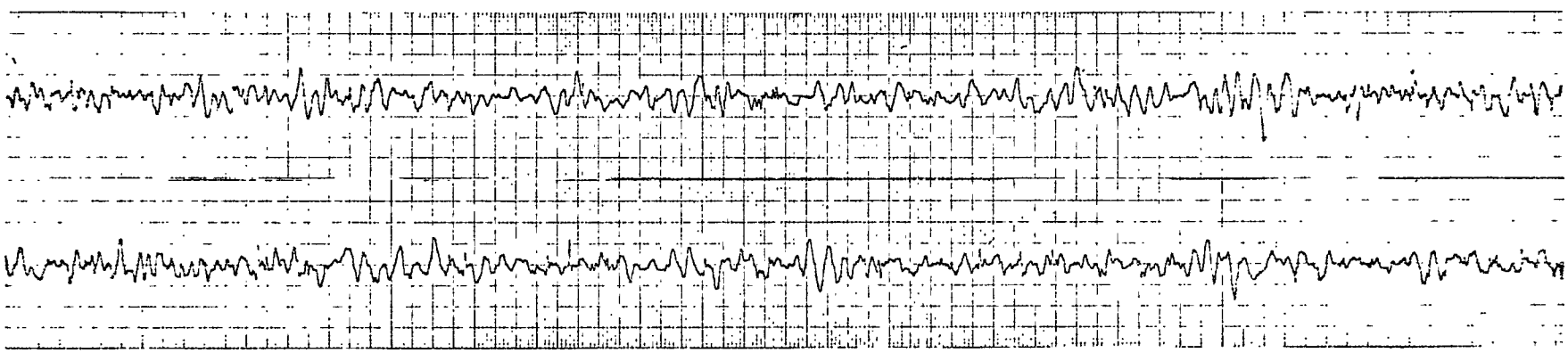
FIGURE 2.11 EEGs from Subject SD2 - record #15086

(a) Epoch #83, X^2 = 70.1
(b) Epoch #88, X^2 = 562.3



(c)

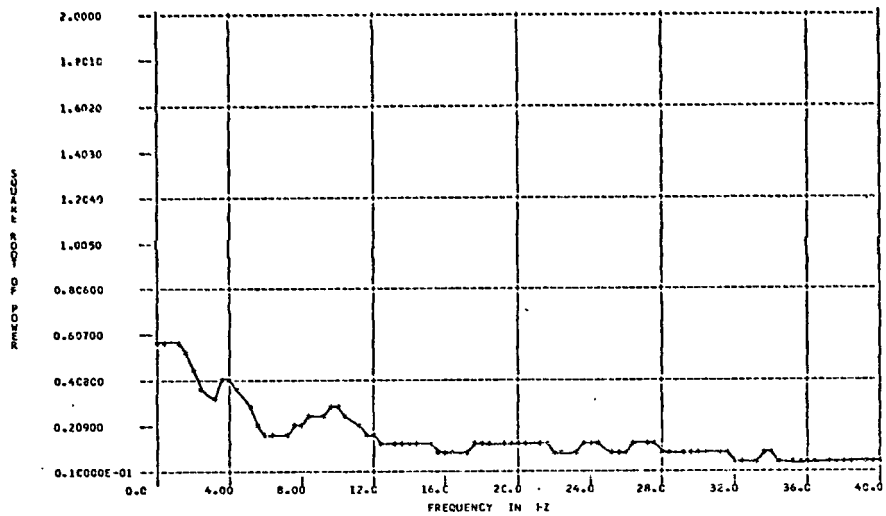
50μV
1 sec



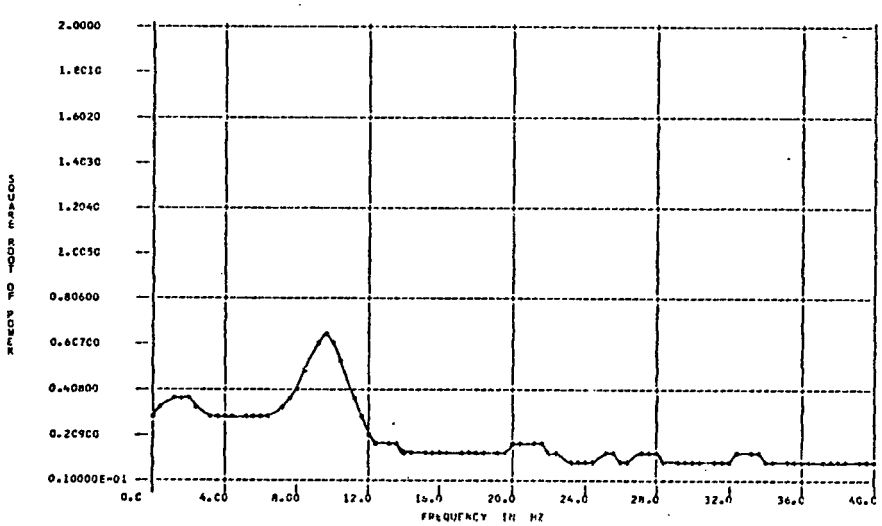
(d)

FIGURE 2.11 (continued)

(c) Epoch #89, X^2 = 171.2
(d) Epoch #90, X^2 = 76.5



(a)



(b)

FIGURE 2.12 Power Spectrum

(a) Epoch #29, Figure 2.46 , with artifact removed
(b) Epoch #45, Figure 2.9a , with artifact removed

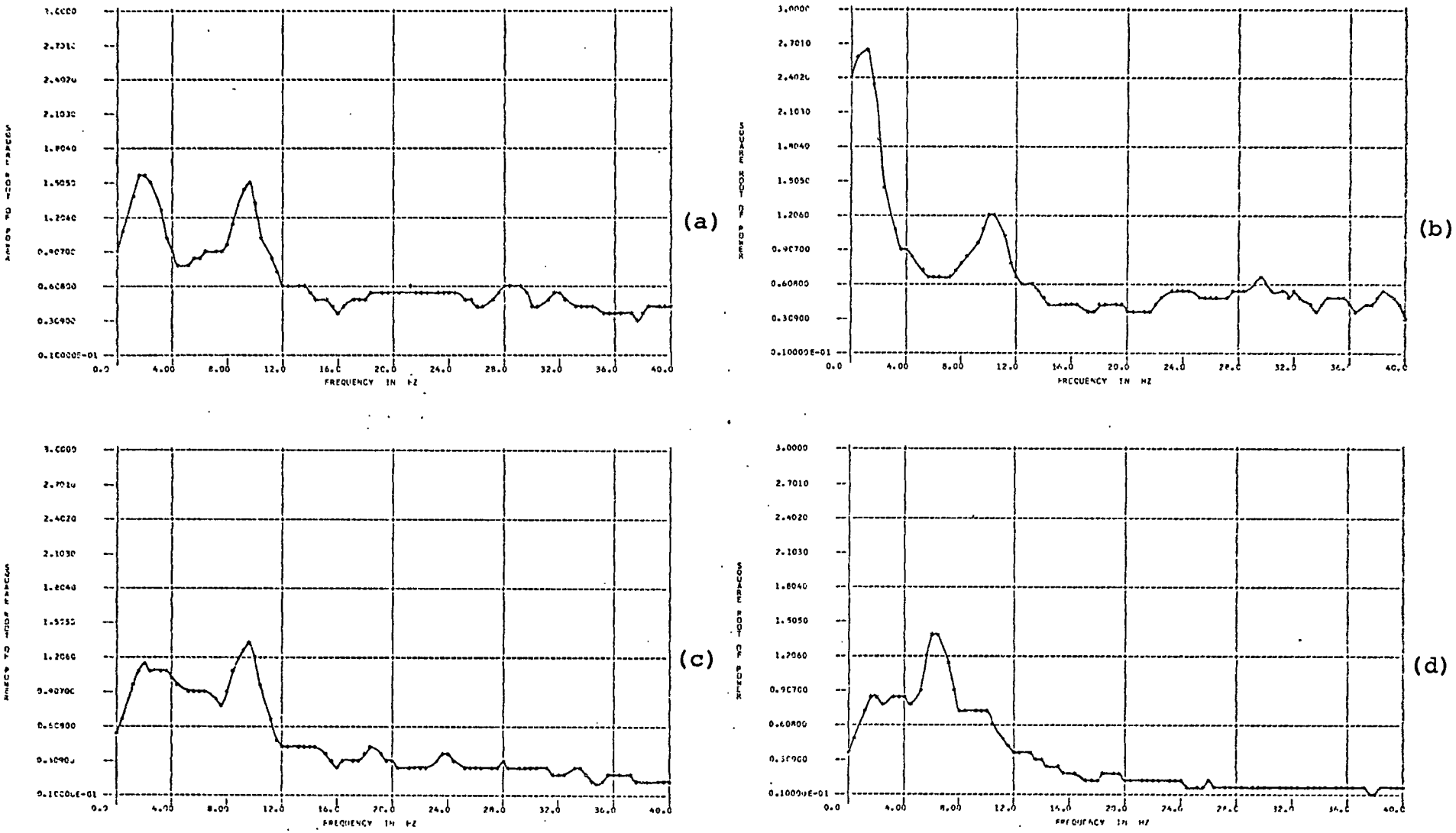


FIGURE 2.13 Power Spectrum (Subject SD2, 13th night, record #15086)

(a) Epoch #83 (b) Epoch #88
(c) Epoch #89 (d) Epoch #90

Example 6:

In Figures 2.11b, c and d three consecutive epochs from the 13th night of subject SD2 are shown. Starting at the first epoch and continuing up to the beginning of the second epoch, there are high amplitude artifacts mixed with high frequency activity, probably due to body movements with muscle twitches. (Figures 2.11b and c). The computed X^2 coefficients for the three epochs in this example were 562.3, 171.2 and 76.5 respectively. According to the algorithm rules the last epoch was chosen to represent the set.

Figures 2.13b, c and d show the power spectrum plots corresponding to the three epochs discussed in this example. The first plot, Figure 2.13b, shows a very high intensity peak at 1 Hz. The second one, Figure 2.13c, shows a peak at 2 Hz of much lower intensity than the one before. In both plots there is a relatively high power content in the upper parts of the spectrum, probably due to muscle activity, as we had already mentioned. The main difference between the plot shown in Figure 2.13d and the other two is the reduction in the power contents in the upper parts of the spectrum.

2.4.4 Performance of the Artifact Detection Algorithm

In order to evaluate the performance of the present artifact detection algorithm, we compared the percentage of epochs rejected due to artifacts, by visual inspection of

the CSA plots, with the same quantity obtained before when no artifact detection test was used. Table 2.5 presents the results of this comparison for nine different nights of three subjects. The record number corresponding to each night appears in the first column; the second and third columns show the percentages of epochs that have to be removed from the CSA plots under the two conditions specified above. The last column shows the percentage of change in the results from the second and third columns. From these results we may conclude that with the use of the present artifact detection algorithm, the number of epochs with artifacts that were present in the CSA plots has been reduced from 58.9% to 94.8% when compared to the results when no detection algorithm was used.

TABLE 2.5

Performance of the Artifact Detection Algorithm

Record #	Percentage of Rejected Epochs by Visual Inspection of the CSA's: With No Artifact Detection	With Artifact Detection	Improvement
15320	7.3%	3.0%	58.9%
15340	10.0%	2.6%	74.0%
15358	14.5%	1.6	90.0%
15375	6.9%	2.7%	61.0%
15006	7.2%	2.6%	63.8%
15024	16.7%	1.5%	91.0%
15050	20.7%	3.1%	85.0%
15043	13.3%	2.0%	84.9%
15086	9.7%	0.5%	94.8%

CHAPTER III

DATA ANALYSIS

3.1 SPECTRAL ANALYSIS

3.1.1 The Fast Fourier Transform

An infinite-range Fourier transform of a real-valued or a complex-valued record x(t) is defined by the complex-valued quantity

$$X(f) = \int_{-\infty}^{\infty} x(t)\exp[-j2\pi ft]dt \qquad (3.1)$$

For a finite time interval of x(t), say in the range (0,T), the finite-range Fourier transform is defined by

$$X(f,T) = \int_{0}^{T} x(t)\exp[-j2\pi ft]dt$$

If x(t) is sampled at N equally spaced points a distance Δt apart, where Δt has been selected such that $\Delta t = 1/(2f_c) = 1/f_s$, where f_c is the highest frequency to be represented and f_s is the sampling frequency of interest (Nyquist rate), then, for an arbitrary frequency f, the discrete version of (3.1) (Discrete Fourier Transform, DFT) is given by: (Bendat and Piersol, 1971)

$$X(f,T) = \Delta t \sum_{n=0}^{N-1} x_n \exp[-j2\pi fn\Delta t]$$

where $x_n = x(n\Delta t)$ $\qquad n = 0,1,2,\ldots,N-1$

The usual selection of discrete frequency values for the computation of X(f,T) is

$$f_k = k\Delta f = k/T = k/N\Delta t$$

At these discrete frequencies the Fourier coefficients are given by

$$X_k = \frac{X(f_k,T)}{\Delta t} = \sum_{n=0}^{N-1} x_n \exp[-j2\pi kn/N] \qquad k = 0,1,2,..N-1$$

The above results are unique only out to k = N/2-1 since the Nyquist cutoff frequency occurs at this point. Fast Fourier transform (FFT) methods are utilized to compute these quantities.

The FFT is simply an efficient method for computing the DFT. The FFT can be used in place of the continuous Fourier transform only to the same extent as the DFT, but with a substantial reduction in computer time. The Cooley-Tukey FFT algorithm (Cooley and Tukey, 1965) results in a procedure requiring a number of operations proportional to $N\log_2 N$ rather than N^2 which is required in the DFT algorithms (Brigham and Morrow, 1967; Bergland, 1969; Brigham, 1974).

3.1.2 Leakage Reduction

The problem of leakage is inherent in the Fourier analysis of any finite record of data. The finite record is formed by observing the infinite duration signal for a finite period of time, disregarding what happened to the signal before and after this period of time. This is equivalent to multiplying the actual signal by a rectangular data window. Now, multiplication in the time domain is equivalent

to convolution in the frequency domain (Simpson and Houts,1971). The Fourier transform of a rectangular data window is a function with amplitude of the form (sinx)/x. Thus, the Fourier transform of a finite record of data will have additional spectral estimates due to the sidelobes of the sinx/x shape of the Fourier Transformed data window. These sidelobes will "leak" power into adjacent spectral estimates (Bergland, 1969).

The usual approach to reduce leakage is to apply to the actual signal a data window which has lower sidelobes in the frequency domain. A cosine tapered data window was suggested by Tukey (1967) and Bingham et al (1967) to replace the rectangular window in order to reduce the leakage. In this window, a cosine taper is applied to the first and last ten percent of the data, and a unit weight is applied to the data in between. Since only 20 percent of the data points are given weight other than the unit, the computation required to apply this window in the time domain is relatively small. The cosine tapering window W(t) has the form:

$$W(t) = \begin{cases} 0.5(1-\cos\pi t/0.1T), & 0 \leq t \leq 0.1T \\ 1, & .1T \leq t < 0.9T \\ 0.5(1-\cos\pi(T-t)/0.1T) & .9T \leq t \leq T \end{cases}$$

where T is the data epoch length.

3.1.3 Spectral Resolution and Stability

The need to balance the bandwidth (frequency resolution) of a power spectral estimate against its statistical stability, when dealing with Gaussian data, has been expressed in the form of an uncertainty relation (Bendat and Piersol, 1971).

The frequency resolution of a power spectral estimate is directly related to the time length of the epoch ($B_e = 1/T$). In other words, the greater the time epoch the better the resolution will be.

The power spectral density function of a stationary random process x(t), when the sample record is of unlimited length T, is given by (Bendat and Piersol, 1971)

$$G_x(f) = \lim_{T\to\infty}(1/T)E[|X(f,T)|^2] \qquad (3.2)$$

where X(f,T) is the finite Fourier transform of x(t), and E denotes expectation. Now an estimate of $G_x(f)$ can be obtained by simply omitting the limiting and expectation operations in (3.2). This will yield the estimate

$$\tilde{G}_x(f) = (2/T)|X(f,T)|^2 \qquad (3.3)$$

with the narrowest possible resolution $B_e = 1/T$. Since X(f,T) is a complex number ($X(f,T) = X_R(f,T)+jX_I(f,T)$), it can be shown, assuming Gaussian data, that the real and imaginary parts are uncorrelated random variables with zero mean and equal variances. Furthermore, it can be shown that by squaring them and summing they produce a χ^2 variable

(Bendat and Piersol, 1971; Otnes and Enochson, 1972). The mean and variance of the chi-square variable are n and 2n, respectively, and the normalized standard error, which defines the random portion of the estimator error, is (Bendat and Piersol, 1971)

$$\varepsilon_r = \sigma[\tilde{G}_x(f)]/G_x(f) = (\sqrt{2n})/n = \sqrt{2/n} \qquad (3.4)$$

where n=2 (number of degrees of freedom). Therefore, ε_r=1, which means that the standard deviation of the estimate is as great as the quantity being estimated. This random error would be unnacceptable for most applications.

The estimates given by (3.3) are now estimates of the power spectral density function where B_e= 1/T so that each estimate is governed by a chi-square distribution with two degrees of freedom. In order to get useful estimates we must reduce the standard error ε_r, which is equivalent to increasing the spectral stability. Essentially there are two ways of achieving this. The first way is by averaging over an ensemble of q estimates. The second way is to average together the results for ℓ contiguous spectral components of a single sample record. These two methods are also known as smoothing techniques, since, in order to decrease the statistical variability of the spectral estimates, they introduce a smoothing in $G_x(f)$, a reduction of spectral resolution. We can also think of these two operations as approximating the expectation operation in Eq. (3.2), and, therefore, making the estimates consistent.

A variation to the first method above was proposed by Welch (1967). This variation involves sectioning a record in segments with variable overlapping intervals, computing the modified periodiograms of these segments and averaging. Principal advantages of this method are:(a) reduction in the required core storage; (b) convenient application in test for nonstationarity.

Another way of expressing the normalized standard error ε_r of Eq. (3.4) is in terms of the resolution bandwidth B_e and the time length of the record T:

$$\varepsilon_r = \sqrt{2/n} = \sqrt{1/B_e T} \tag{3.5}$$

where $n = 2B_e T$ is the number of degrees of freedom (Blackman and Tukey, 1958). Of course these results depend on the signal (noise) being exactly Gaussian. Real noises and especially real signals need not be exactly Gaussian. Thus exact results in Gaussian theory would be approximations in practice (Blackman and Tukey, 1958; Richards, 1967).

3.1.4 Spectral Averaging

As we have seen before, one way of gaining statistical stability in G(f) is by averaging together the raw estimates of ℓ contiguous spectral components. This operation is achieved by using what is called "spectral windows". Several types of spectral windows have been suggested in the literature.

Two classical spectral windows that have enjoyed a great deal of popularity are the Hann and Hamming Windows,

respectively. (Blackman and Tukey, 1958; Otnes and Enochson, 1972).

The Hann Window is the most widely used mainly due to its easy implementation. It is a triangular window with span of three and has the following weights:

$$\hat{G}_k = 0.25\tilde{G}_{k-1}+0.5\tilde{G}_k+0.25\tilde{G}_{k+1}$$

where $\tilde{G}_k$ is the raw estimate at harmonic k and $\hat{G}_k$ is the corresponding smoothed estimate. An alternative weighting, due to Hamming, achieves a lower amplitude for the immediately adjacent side-lobes, but a slower falling off for subsequent lobes. The weighting is:

$$\hat{G}_k = 0.23\tilde{G}_{k-1}+0.54\tilde{G}_k+0.23\tilde{G}_{k+1}$$

Another convenient method of smoothing the power spectrum is to use symmetric triangular weighting (Singleton and Poulter, 1967) of the form:

$$\hat{G}_k = (1/m^2)\sum_{j=m+1}^{m-1}(m-|j|)\tilde{G}_{k+j}$$

of span 2m-1, with index of the center value used as the index of the smoothed value. A triangular smoothing of the power spectral density function estimate with span 2m-1 is equivalent to multiplying the autocorrelation function estimate by

$$\left[\frac{\sin(m\pi j/N)}{m\sin(\pi j/N)}\right]^2 \qquad \text{for } j = 0,1,2,\ldots N/2$$

3.1.5 The Present Approach

The 30 seconds epoch selected by REDUCE (Section 2.4.2) were processed as a unit. Each of these epochs contained 3840 sampled data points. Before the data was passed through a cosine tapering window, as described in Section 3.1.2, the estimated mean was subtracted from each data point. Since the FFT algorithm used required a number of data points porportional to a power of two, and the data set had only 3840 points, 296 zeros were added to the original data after the tapering resulting in a new set with 4096 points (2^{12}). Due to the nature of the FFT computational formulas, the effect of adding zeros to the actual data is that of decreasing the space between the spectral estimates, thereby increasing their resolution.

The raw power spectrum for each epoch was calculated with a resolution of 0.03125 Hz ($B_e = 1/T = 1/32$ sec). The raw power spectrum was then smoothed, first by a triangular window with a span of 15, and then by a Hanning window, resulting in a modified power spectrum with a final resolution of $B_e' = 0.5$ Hz. Assuming that the data under consideration is from a Gaussian random process, the standard error ε_r computed from Eq. (3.5), by substituting in $B_e = 0.5$ Hz and $T = 32$ sec, will be $\varepsilon_r = 0.25$. The equivalent number of degrees of freedom is from Eq. (3.4),

$$n = 2/(\varepsilon_r^2) = 2/(0.25)^2 = 32$$

The (1-α) confidence interval for a spectral density function G(f) based upon an estimate $\hat{G}(f)$ with n degrees of freedom is given by: (Bendat and Piersol, 1971)

$$n\hat{G}(f)/\chi^2_{n;\alpha/2} \leq G(f) < n\hat{G}(f)/\chi^2_{n;1-\alpha/2}$$

In the present work, for a 95% confidence interval for G(f) we have,

$$32\hat{G}(f)/\chi^2_{32;0.025} \leq G(f) < 32\hat{G}(f)/\chi^2_{32;0.975}$$

From a table of percentage of points of a chi-square distribution (Meyer, 1975) it is found, for $\alpha = 0.05$, that $\chi^2_{32;0.025} = 46.98$ and $\chi^2_{32;0.975} = 16.79$, so the interval reduces to

$$0.63\hat{G}(f) \leq G(f) < 1.79\hat{G}(f)$$

Expressing the above equation in decibels (dB),

$$\hat{H}(f)-2.0\text{dB} \leq H(f) < \hat{H}(f)+2.52\text{dB} \qquad (3.6)$$

where $H(f) = 10\log G(f)$ and $\hat{H}(f) = 10\log\hat{G}(f)$.

In order to check the performance of the present approach, a bandlimited Gaussian signal with an upper cutoff frequency of B=15 Hz, from a noise generator (Hewlett Packard 3722A) was digitized at 128 samples/sec in epochs of 30 sec duration. The noise generator had an internal digital filter with a roll-off of more than 25 dB/octave above the

cutoff frequency B. At the cutoff frequency B the specified attenuation was -3dB. A 30 seconds epoch was frequency analyzed, and the resulting power spectrum is shown in Figure 3.1. The dots are the actual spectral estimates values and they fell within the confidence interval given by Equation (3.6).

3.1.6 Computing the Power Spectral Estimates for the All Night Sleep Data

A FORTRAN program called PSPEC has been written in order to compute the power spectral density function of each epoch for the entire night. A flowchart diagram of PSPEC is shown in Figure 3.2. A detailed list of PSPEC and its subroutines is given in Appendix B.

The input data to PSPEC was the preprocessed data previously selected by REDUCE and stored on the Auxiliary Tapes (Section 2.4.2). Besides the 3840 sampled data points of each epoch, seven additional statistical parameters (maximum and minimum amplitude values, mean, variance, kurtosis, skewness and X^2 coefficient) computed by REDUCE, were stored for each 30 sec record of the tape. After each of these records had been read in, the mean was subtracted from each data point, and the data was tapered by a cosine tapering window (subroutine TAPER1). After zeros had been added to the tapered data, as described in Section 3.1.5, the data was ready to be Fourier transformed.

In the beginning of this work we used a FFT computer subroutined called FOUR1 to compute the Fourier coef-

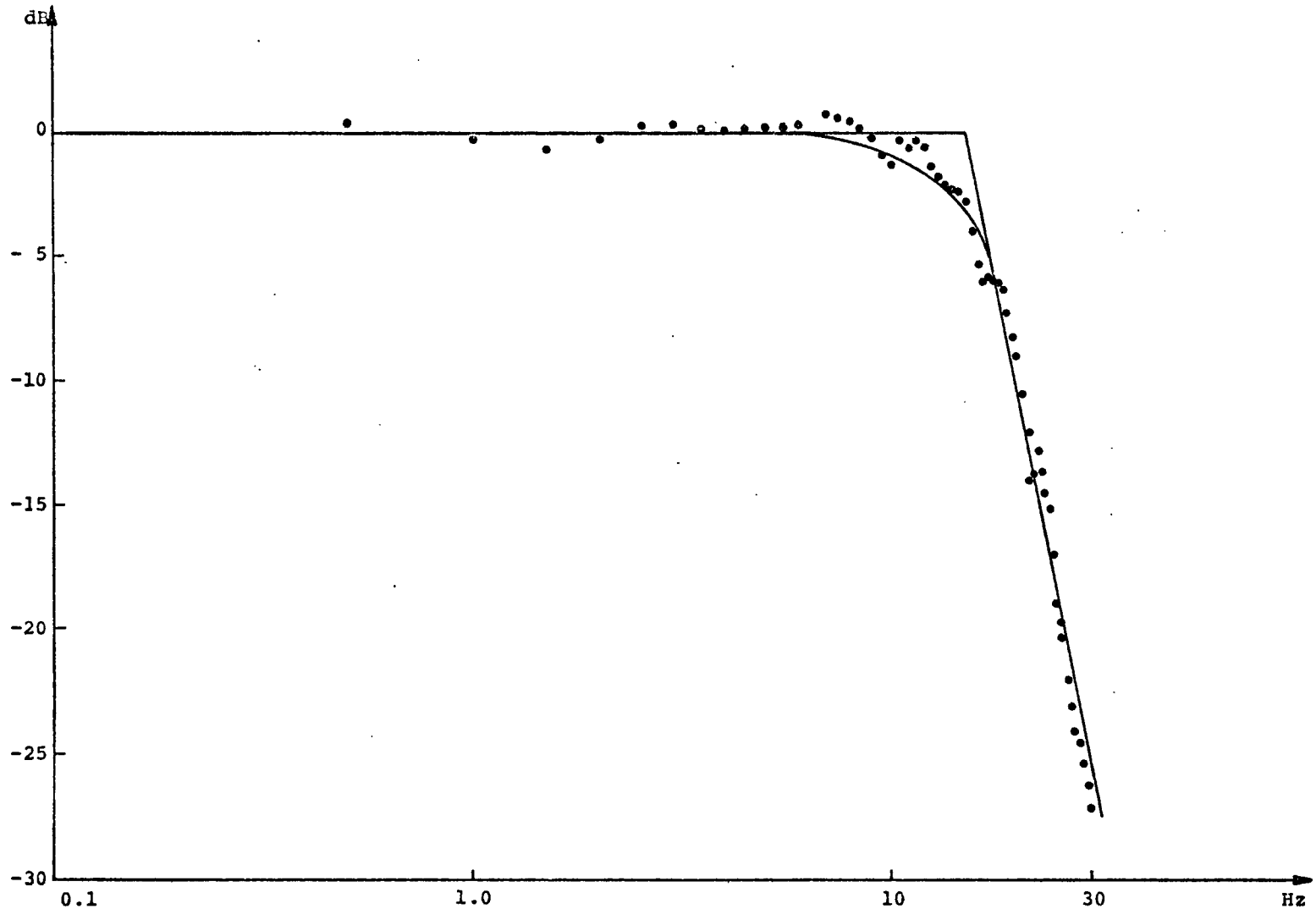


FIGURE 3.1 Power Spectrum of a Bandlimited Gaussian Signal (BW=15Hz)

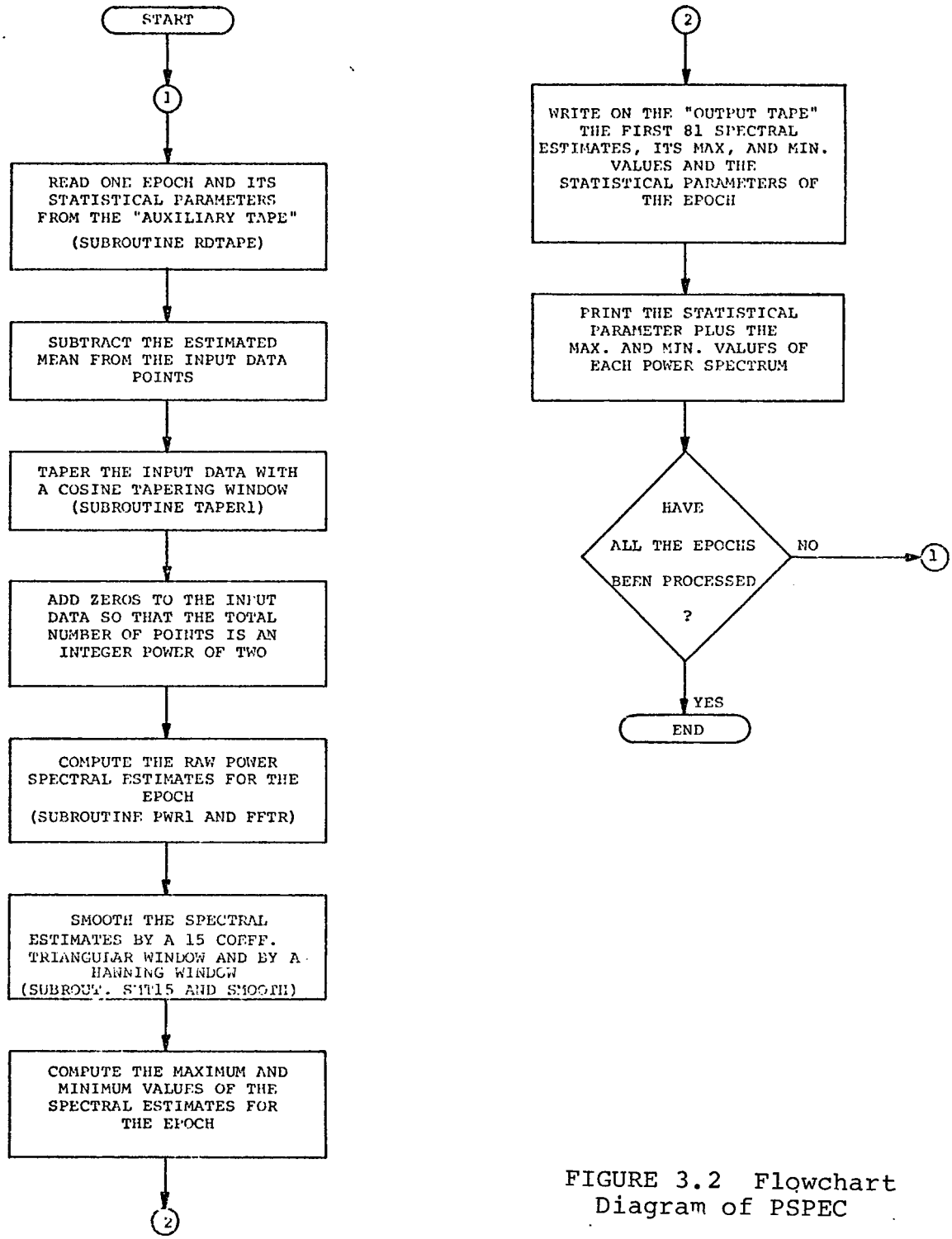


FIGURE 3.2 Flowchart Diagram of PSPEC

ficients. This subroutine is a FORTRAN version of the Cooley-Tukey FFT algorithm for use upon one-dimensional arrays of complex data whose length is a power of two, and it was written by Brenner (1969). Since our data was real we had to fill with zeros all the imaginary entries of the complex array. The resulting complex Fourier coefficients were symmetrical about N/2. In this way, besides using twice as much core space as we needed, we were also computing twice as many complex Fourier coefficients. The execution time of this subroutine for 4096 real data points was 5.3 seconds. In order to minimize the execution time of PSPEC, we replaced the above FFT algorithm by another one suggested by Singleton (1967) and coded by Aird and Kamer (1975) for the IMSL Library that is available at the Engineering Systems Simulation Laboratory of the Cullen College of Engineering. This New FFT algorithm is called FFTR and it computes the FFT of a real vector of length N, where N is any positive even integer, and the resulting complex Fourier coefficients are computed up to N/2. The execution time of this subroutine for 4096 real data points was 2.74 seconds. As we can see, this algorithm, besides using half of the core space required by the first one, is almost twice as fast.

After the complex Fourier coefficients were obtained, the raw power spectrum was computed. This raw power spectrum was smoothed, as described in Section 3.2.5, using two subroutines: SMT15 and SMOOTH. The maximum and minimum values

of the smoothed power spectrum were then computed. Finally, 81 spectral estimates, corresponding to frequencies from 0 to 40 Hz, the seven statistical parameters previously read in, and the maximum and minimum values of the power spectrum were written on a tape (Output Tape). The statistical parameters, plus maximum and minimum values of the power spectrum were also printed in paper as shown in Figure 3.3. The maximum and minimum values of the spectral estimates are used in the scaling of the CSA plots.

3.2 COMPRESSED SPECTRAL ARRAY (CSA)

Once all the power spectral estimates for the entire night were on a digital tape, as described in Section 3.1.6, we then proceeded to obtain the Compressed Spectral Array (CSA). The CSA's were generated at the Image Processing Laboratory of the Electrical Engineering Department, whose facilities include a HP-2100A minicomputer, a HP-7900A Disc Drive, a HP-7970B Digital Tape Unit, a BEEHIVE CRT Display with console, a Teletype Unit and a BENSON-LEHNER incremental plotter.

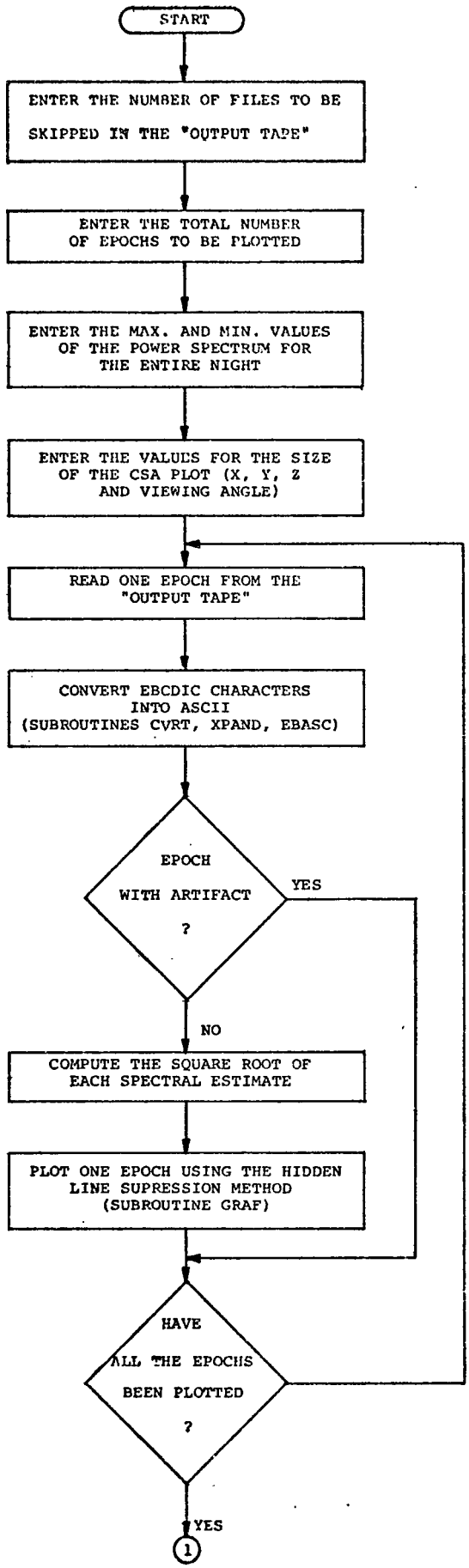
A FORTRAN program called ARA has been written in order to generate the CSA. A detailed list of ARA and its subroutines is given in Appendix B. A flowchart diagram of ARA is given in Figure 3.4. The teletype or the CRT display with the console were used for input-output communication with the minicomputer.

The CSA is generated by the hidden-line suppression method, and it consists simply of point by point comparison

EPOCH	XMAX	XMIN	VARIANCE	SKEWNESS	KURTOSIS	XSQR	MEAN	PSPECMX	PSPECMN
1	15.62	-16.75	71.34	-0.042	2.84	48.65	-0.467	3.284	0.00706
2	16.55	-16.15	61.20	-0.002	3.16	51.55	-0.422	2.770	0.00582
3	17.72	-17.26	70.47	0.053	3.14	58.97	-0.546	2.192	0.00518
4	14.90	-16.49	63.82	-0.038	2.82	79.85	-0.261	2.363	0.00397
5	15.78	-15.29	52.33	0.042	3.16	46.57	-0.245	1.519	0.00265
6	16.38	-15.71	59.61	0.081	3.23	43.67	-0.290	1.730	0.00288
7	14.98	-15.62	53.52	0.039	3.03	33.19	-0.271	2.264	0.00350
8	18.61	-15.31	58.83	0.091	2.96	76.79	-0.265	2.111	0.00624
9	14.51	-15.10	54.68	-0.133	3.06	53.74	-0.334	1.746	0.00492
10	19.57	-15.59	66.05	0.121	3.21	39.39	-0.314	2.549	0.00755
11	16.98	-14.63	54.59	0.034	3.10	46.43	-0.245	2.361	0.00377
12	16.33	-16.72	59.61	0.045	2.97	39.77	-0.294	2.882	0.00446
13	19.17	-13.65	55.71	0.064	3.04	48.98	-0.289	2.199	0.00271
14	13.97	-17.92	48.83	0.092	3.17	62.00	-0.254	2.335	0.00394
15	15.23	-17.24	55.43	0.041	3.07	45.02	-0.289	2.259	0.00438
16	16.04	-17.42	60.71	0.031	3.12	51.68	-0.246	3.367	0.00345
17	15.55	-19.34	59.34	0.019	3.09	54.47	-0.189	3.389	0.00262
18	14.93	-17.70	56.03	0.022	2.97	58.08	-0.176	2.074	0.00255
19	18.38	-20.59	63.08	-0.107	3.35	52.85	-0.209	3.457	0.00238
20	16.34	-18.74	65.84	-0.004	3.26	49.38	-0.262	3.721	0.00289
21	17.25	-21.17	73.46	-0.070	3.36	55.23	-0.266	3.882	0.00288
22	21.83	-17.37	74.21	0.112	3.46	42.42	-0.232	3.588	0.00202
23	16.16	-16.34	73.50	0.044	2.81	49.79	-0.243	3.366	0.00158
24	26.78	-20.08	84.96	0.050	3.34	42.77	-0.270	4.730	0.00139
25	20.27	-21.58	101.17	-0.062	3.02	69.72	-0.200	7.908	0.00108
26	17.09	-18.67	93.36	-0.033	2.91	60.38	-0.177	7.000	0.00092
27	20.29	-20.82	89.30	-0.032	3.00	41.10	-0.251	7.274	0.00180
28	19.09	-21.70	83.84	-0.056	3.17	61.90	-0.242	7.541	0.00124
29	21.01	-18.60	92.96	0.047	3.02	49.60	-0.367	6.118	0.00196
30	18.76	-22.54	103.63	-0.068	2.89	41.83	-0.375	8.617	0.00147
31	26.92	-23.96	103.92	0.018	3.24	52.25	-0.246	8.483	0.00140
32	17.00	-21.34	88.99	-0.173	3.18	74.41	-0.301	9.524	0.00151
33	18.74	-19.83	91.30	-0.030	2.80	50.76	-0.352	8.541	0.00166
34	23.68	-20.12	100.00	0.024	3.22	63.74	-0.231	8.188	0.00104
35	21.12	-20.10	101.74	0.073	3.04	29.26	-0.317	10.536	0.00159
36	21.26	-23.39	97.02	-0.018	3.09	50.68	-0.278	6.443	0.00166
37	17.48	-20.66	87.16	0.049	3.07	57.72	-0.328	7.116	0.00132
38	18.50	-19.30	95.27	0.084	3.00	90.71	-0.298	8.130	0.00114
39	24.50	-16.07	81.37	0.172	3.28	48.95	-0.284	8.676	0.00161
40	37.04	-25.95	103.41	0.067	4.46	95.51	-0.274	5.872	0.00178
41	22.76	-18.51	91.41	0.163	3.15	52.01	-0.345	7.480	0.00135
42	20.46	-21.80	89.26	-0.141	3.17	53.91	-0.286	8.529	0.00125
43	14.93	-18.01	69.07	-0.123	2.96	69.99	-0.293	5.910	0.00142
44	23.50	-19.81	81.38	0.096	3.45	63.06	-0.317	7.436	0.00123
45	14.32	-13.72	48.03	0.017	3.13	48.52	-0.269	2.893	0.00165
46	14.64	-13.16	45.99	0.112	3.04	53.77	-0.204	2.170	0.00109
47	19.84	-18.32	51.67	0.115	4.21	94.23	-0.288	2.625	0.00098
48	15.29	-13.39	46.30	0.052	3.05	40.55	-0.275	2.844	0.00101
49	17.09	-17.53	52.12	-0.004	3.26	49.79	-0.246	3.165	0.00132
50	13.19	-15.01	42.67	0.016	3.04	59.32	-0.331	1.640	0.00126
51	16.78	-14.77	48.20	-0.046	3.27	52.28	-0.277	2.519	0.00080
52	18.92	-19.16	62.59	-0.058	3.16	52.71	-0.291	2.871	0.00160
53	17.41	-15.57	68.25	0.126	3.09	46.48	-0.314	3.859	0.00141
54	15.86	-15.75	57.86	-0.010	3.14	65.88	-0.328	1.946	0.00138
55	20.87	-18.73	70.58	0.194	3.45	82.72	-0.250	2.723	0.00184
56	19.53	-19.20	52.19	-0.031	3.16	40.69	-0.255	1.687	0.00174
57	18.17	-17.96	62.95	0.062	3.28	33.86	-0.204	1.995	0.00159
58	28.19	-15.49	64.64	0.293	3.79	58.92	-0.221	2.782	0.00227
59	15.55	-14.98	53.71	0.129	3.14	40.42	-0.372	2.163	0.00230
60	14.27	-12.06	41.45	0.098	3.09	43.42	-0.269	1.488	0.00159

FIGURE 3.3 Partial Output Printout of PSPEC

(subject SD1, 5th night, record #15322)



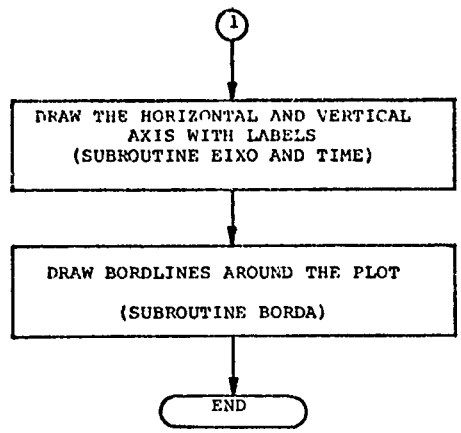


FIGURE 3.4 Flowchart Diagram of ARA

of spectral magnitudes. Plotting of a spectral point was suppressed if its magnitude plus a vertical scale increment was smaller than the magnitude of the corresponding point in the previously plotted spectrum. This algorithm was executed by subroutine GRAF. The size of the CSA plots is determined by the values assigned to the width in the horizontal direction (X), to the depth (Y), to the height (Z) and the viewing angle, which is the angle that an observer would be looking at the plots in a three dimensional space. In the present study we chose: the viewing angle = 45°, X = 3", Z = 2", and Y = 10". These plots were reduced by approximately 35% in order to fit four of them in a 8 1/2 by 11" page. This value of Y is for a CSA plot with 200 epochs, which means that the depth dimension of the plot is also a function of the number of epochs, the net effect of this is to cause an uniform separation between the epochs in the Y direction. The height of the peaks in the Z direction is a function of the largest spectral estimate for a given night, the value of Z and the viewing angle.

Once the CSA was obtained for a given night, it was examined very carefully for epochs with visible artifacts, that have been falsely selected by the artifact detection algorithm. Usually, we can expect their number to range from 1 to 3% of the total number of epochs for the night (see Table 2.5). After the epochs with artifacts were visually detected, their tag numbers were recorded. These numbers were entered into the computer before we proceeded to

generate a new CSA with artifact-free epochs.

3.3 FEATURE EXTRACTION

3.3.1 Main Algorithm

In order to get more useful information from the all night power spectra, a computer program called FEATURE has been written. A flowchart diagram of FEATURE is given in Figure 3.5 and a detailed list of it appears in Appendix B. This program was run in the IBM-360 Computer and the input data was fed in by cards and by magnetic tape.

The first thing FEATURE did was to read in the total number of epochs with artifacts and their individual numbers. These numbers were the ones obtained from the CSA as described in Section 3.2. After that a value for the variable NSKIP is read in from a card. NSKIP can take the values of 0, 1, or 2 depending whether we wanted to process all epochs, only the odd or the even numbered ones, respectively

It was found very convenient to process only half of the epochs (either the odd or the even numbered ones), which means that the points in the output plots are spaced at five minute intervals in the horizontal axis. There are some advantages to this procedure. First the plots are not so crowded with points as in the case of considering all the epochs. Nevertheless, the patterns are essentially the same as in the case when all epochs were processed. Second, since some of the epochs are to be skipped due to artifacts,

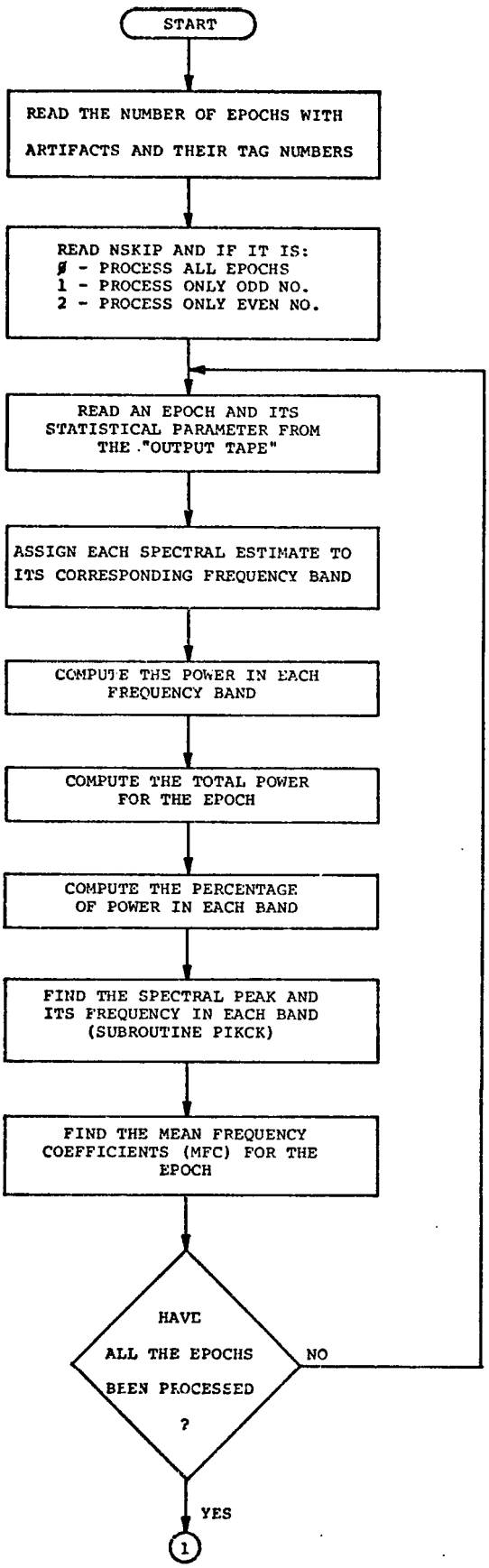


FIGURE 3.5 Flowchart Diagram of FEATURE

we can reduce this number by only processing half of the epochs instead of all of them. An additional feature provided by the program allows for the reduction of this number even further. If an epoch is to be skipped, say epoch number 15, the program will then process the next one, epoch number 16, provided that its number is not included in the set of epochs with artifacts. In this way, we can keep track of the timming during the night, which will make it easier to compare our plots with the score sheet results obtained by manual scoring.

The input data to be processed by FEATURE was previously stored on a magnetic tape, as described in Section 3.1.6. Each time an epoch was to be processed, 90 data values are read in. The first 81 of these correspond to power spectral estimates from 0 to 40 Hz, and the remaining nine data values contained additional information about the epoch such as: maximum and minimum amplitude values, mean, variance, skewness, kurtosis, and chi-square coefficient from the sampled EEG, plus maximum and minimum values of the magnitude of the power spectrum estimates.

3.3.2 Plot of the Statistical Parameters

Three statistical parameters were processed by FEATURE: chi-square coefficient, kurtosis (plotted as excess of kurtosis), and skewness. The parameters for the entire night are stored in three different arrays for further processing. In order to get rid of the fast frequency

variations between the points in each array, a simple moving average lowpass digital filter (Y(k) = 0.25X(k-1)+0.5X(k)+ 0.25X(k+1) , where the X and Y are the input and output to the filter respectively) was used (Steiglitz, 1974). This operation is equivalent to a smoothing of the data. After this was performed, the arrays were put in the appropriate form to be plotted with respect to the time of the night by the subroutine PLOTR2. The subroutine SPARM was then called to compute maximum, minimum, mean and standard deviation values for each array, and these results were printed under each plot.

3.3.3 Separation of the Spectral Estimates in Frequency Bands

The power spectrum of each 30 seconds epoch was divided into seven bands, as follows:

Band	Frequency Range
Delta	0.0 - 3.5 Hz
Theta	4.0 - 7.5 Hz
Alpha	8.0 - 11.5 Hz
Sigma	12.0 - 15.5 Hz
Betal	16.0 - 20.5 Hz
Beta2	21.0 - 29.5 Hz
Fastf	30.0 - 40.0 Hz

After the 81 spectral estimates are read in from the magnetic tape, they are assigned to their respective bands. The power P_j in Band $j(B_j)$ was computed by adding

the magnitude of the power spectrum estimates $\hat{G}_i$ contained in B_j

$$P_j = \sum_{i=k}^{\ell} \hat{G}_i \qquad j = 1, 2, \ldots, 7$$

where k and ℓ are indices computed from the lower and upper frequencies specified for B_j. The total power for the epoch, TPOWR is given by:

$$TPOWR = \sum_{i=1}^{81} \hat{G}_i$$

The percentage of power for each B_j is then evaluated by:

$$\bar{P}_j = ((P_j)/TPOWR)100\% \qquad j = 1,2,\ldots,7$$

For each B_j the maximum value of $\hat{G}_i$ was found and its corresponding frequency (F_j) stored. We then tested whether or not this value of $\hat{G}_i$ corresponded to a frequency peak for the band. This test was performed by subroutine PIKCK. For a frequency peak to be classified as such, the intensity in the five adjacent spectral estimates, at least two in each side of the peak, had to be a monotonic decreasing function. In order for $\hat{G}_i$ to be identified as a peak of B_j it was required that: $\hat{G}_{i-2}<\hat{G}_{i-1}<\hat{G}_i>\hat{G}_{i+1}>\hat{G}_{i+2}>\hat{G}_{i+3}$ or that $\hat{G}_{i-3}<\hat{G}_{i-2}<\hat{G}_i>\hat{G}_{i+1}>\hat{G}_{i+2}$. If $\hat{G}_i$ was accepted as being a frequency peak, then its value and the corresponding frequency were saved into a two-dimensional array for further processing. If $\hat{G}_i$ did not satisfy the above criterion, then PIKCK would search for a value of $\hat{G}_i$ that was a new maximum in B_j and the same criterion would be applied again. The

entire procedure would be repeated until all the spectral estimates $\hat{G}_i$ of B_j have been tested. If a frequency peak could not be encountered for B_j then a zero value is assigned to it. A flowchart diagram of PIKCK is given in Figure 3.6 and a detailed list of it is presented in Appendix B.

After all the P_j were computed, they were smoothed, as described in Section 3.3.2, and then plotted by subroutine PLOTR2. Subroutine VOST was then called in order to compute maximum, minimum, mean and standard deviation values for the percentage of power in each B_j. These results were printed under each plot.

The frequency peaks and its spectral intensities for each B_j were plotted separately. The spectral intensity plots for all bands B_j were in the same scale. The spectral estimates were scaled by a square root function. The maximum and minimum values for the spectral intensities for all bands and for the entire night were computed by subroutine NERKA. Subroutine PLOTR2 used these values in all the spectral intensity plots for scaling purpose.

3.3.4 Mean Frequency Variation

In Section 3.3.3 it was described how the spectral estimates were separated in frequency bands and how the percentage of power in each of the bands B_j was computed. With this we can picture how the power was shifted among the bands during the night and from night to night. In

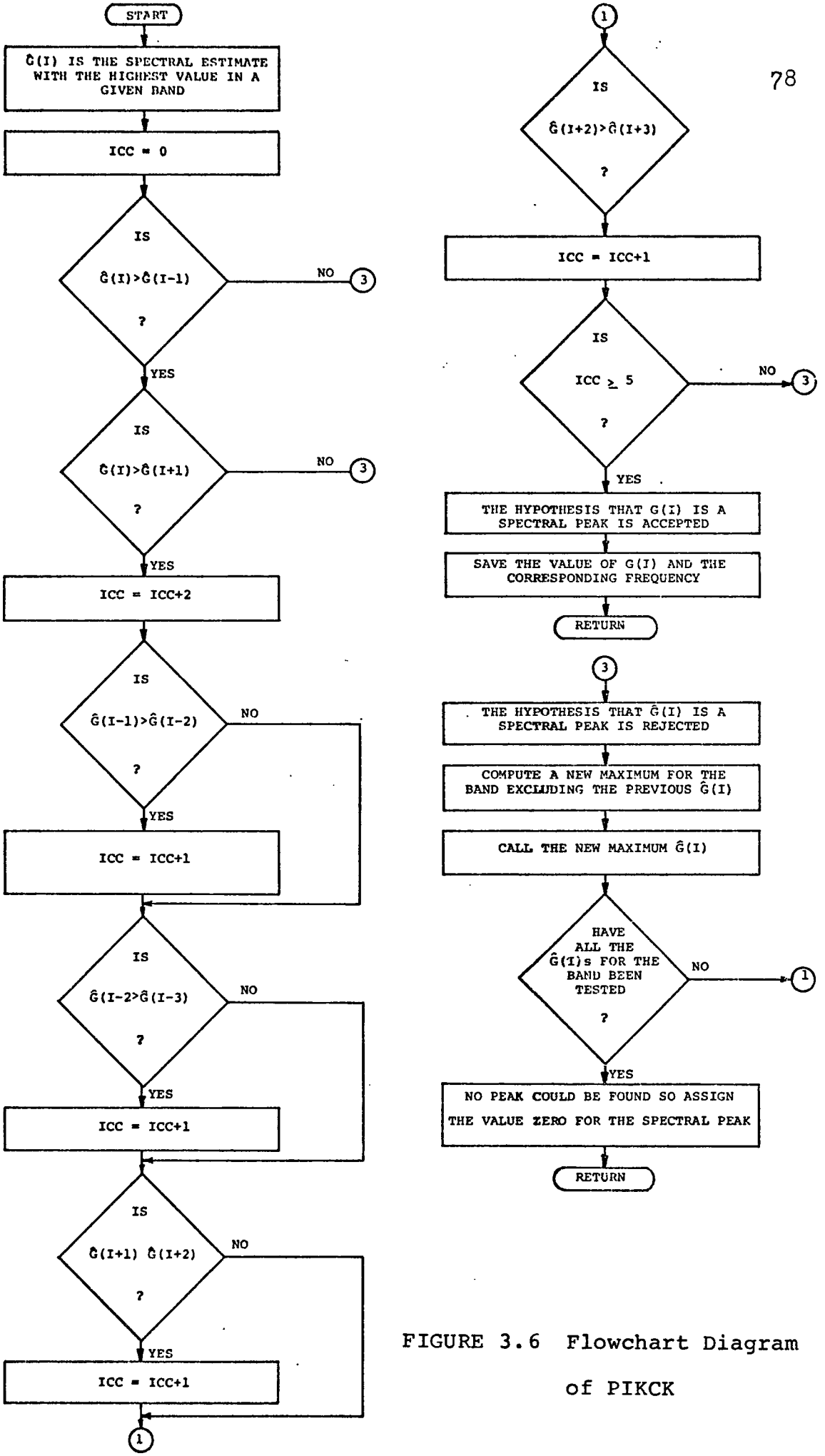


FIGURE 3.6 Flowchart Diagram of PIKCK

order to obtain the same kind of picture, for the mean frequency activity during the night, an algorithm was developed that would compute a mean frequency value for each epoch by plotting these values as a function of the time of the night, we can visualize how the mean frequency varies during a given night and from night to night.

The algorithm simply computes an average of the frequencies of the peak, weighted by their corresponding spectral intensity. Calling this average for each epoch Mean Frequency Coefficient (MFC_n), we have,

$$MFC_n = \left(\sum_{j=1}^{7} F_j \hat{G}_j\right) / \left(\sum_{j=1}^{7} \hat{G}_j\right) \qquad \text{for } n = 1,2,\ldots,N$$

where F_j is the frequency peak at band B_j, $\hat{G}_j$ is its corresponding spectral intensity and N is the total number of epochs being processed. A FORTRAN subroutine called FMED has been written to carry out this algorithm.

CHAPTER IV

RESULTS

4.1 INTRODUCTION

In this chapter we present the results of the application of our data processing techniques to analyze the effect of toxic levels of secobarbital and methaqualone in the sleep EEG of two groups of six subjects each, Group 1 (drug addicts) and Group 2 (nondrug users), as described in Section 2.1. Each of these groups was divided into two subgroups of three subjects each. The subjects in each subgroup were given either secobarbital or methaqualone.

For each subject's night a compressed spectral array (CSA) was plotted (Section 3.2). This kind of plot emphasizes the dynamic shift in power between the frequency bands during a given night and from night to night throughout the withdrawal process. Since the EEG amplitudes for each subject were different, a calibration scale is presented with the CSA plots of each subject.

The algorithm FEATURE (Section 3.3) can generate three plots for each frequency band plus a plot for the MFC coefficients, and three for the statistical parameters (X^2 coefficient, excess of kurtosis and skewness), resulting in a total of 25 plots per night. In order to reduce the amount of output data we chose only four plots (percentage of power in the Delta and Sigma Bands, Mean Frequency Coefficients

(MFC) and X^2 coefficient), which, in our opinion, best describe the effects of the drugs on the sleep EEG.

Due to the small size of our samples (three subjects), we could not make any statistical inference about the results. Therefore, we decided to treat each subject as its own control. After we describe the results for all subjects in a given subgroup, we proceed to compare these results among themselves and, if possible, with other subgroups.

4.2 GROUP 1 - SECOBARBITAL

4.2.1 Subject SD1

4.2.1.1 Subject's Protocol

Subject SD1, a 21 year-old male, was in treatment for 18 days. Of these, four nights were selected for automatic analysis. Table 4.1 shows the nights that were processed in a chronological order, the daily amount of drug administered, and the corresponding record number for each night. See Table 2.1 for the subject's complete withdrawal schedule.

TABLE 4.1

Analyzed Data for Subject SD1

Night	Record Number	Daily Dosage (mg)
5th	15322	1000
10th	15340	200
13th	15358	0
16th*	15375	0

*Subject complained of intense pain in his arm during the night.

4.2.1.2 Compressed Spectral Array (CSA) Results

Figures 4.1a, b, c and d show the CSA plots for the nights listed in Table 4.1. The plot for the 5th night, Figure 4.1a, shows that the activity in the Delta Band was present most of the time as low intensity spectral peaks except at the beginning of the night, when there is a train of high intensity peaks. Appearing simultaneously with this train, there is a series of spectral peaks centered around 10-11 Hz, which probably correspond to slow spindle activity "riding" on the low frequency waves. At the very beginning of the night there are some peaks located at 7-7.5 Hz, which correspond to an alpha-like activity according to the raw EEG recorded on paper and to the subject's sleep stage score sheet for this night. The peaks in the Sigma Band are not well defined and their central frequencies are shifting between 12 and 14 Hz. Some low intensity activity in the Beta1 and Beta2 bands can also be seen in the plot.

In the 10th night, Figure 4.1b, when the subject was still taking the drug (200 mg daily), several changes have taken place mainly in the Alpha, Sigma, Beta1 and Beta2 Bands. At the onset of the night there are well-defined peaks in the Alpha Band. The Sigma Band shows peaks with lower intensity, centered around 13-13.5 Hz, which are now more well defined. No visible activity can be seen in the Beta1 and Beta2 Bands.

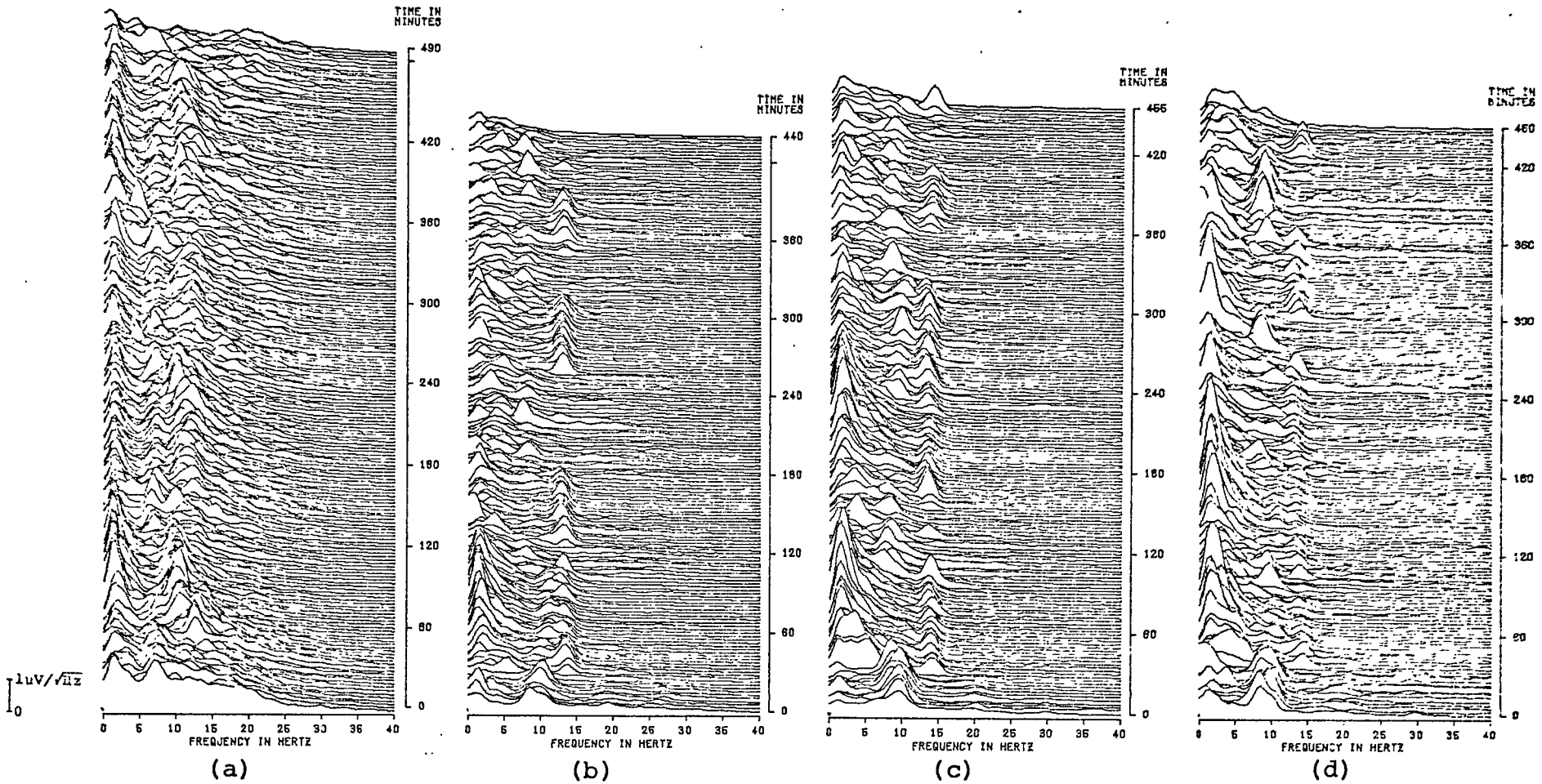


FIGURE 4.1 Subject SD1 - Compressed Spectral Array (CSA)
(a) 5th night, record #15322 (b) 10th night, record #15240
(c) 13th night, record #15358 (d) 16th night, record #15375

During the 13th and 16th nights, Figures 4.1c and 4.1d, when the subject was not taking the drug anymore, the main noticeable change is the appearance of a new train of high intensity peaks in the Delta Band before the first half of the night.

4.2.1.3 Summary of the Output Results from the FEATURE Algorithm

In Table 4.2, the results of the data reduction analysis performed by FEATURE are given. From this table it can be seen that there is a tendency for the mean percentage of power in the Delta and Theta Bands, the mean value and the percentage of rejections of the X^2 coefficient to increase as the drug was being withdrawn. On the other hand, the mean percentage of power in the remaining frequency bands and the mean value of the Mean Frequency Coefficients (MFC) have a tendency to decrease. Table 4.3 shows the percentage of change in the results of Table 4.2, between the last and the first nights.

It should be noticed that in Table 4.2, the values for the mean percentage of power and for the mean frequency peaks in the Theta and Alpha Bands are higher than what it would be expected. This was caused by the alpha-like activity (7.0-7.5 Hz) that was detected by the algorithm as being in the Theta Band and by the slow spindle activity (10.0-11.0 Hz), as described in Section 4.2.1.2, that was detected as being in the Alpha Band.

TABLE 4.2

Summary of the Output Results from FEATURE for Subject SD1

NIGHT			5th	10th	13th	16th
RECORD NUMBER			15322	15340	15358	15375
DOSAGE (mg)			1000	200	0	0
DELTA BAND (0.0-3.5Hz)	PERC. OF POWER	MEAN	27.3	38.0	44.3	46.3
		STD	8.2	9.9	12.9	12.4
	FREQ. PEAK (Hz)	MEAN	1.5	2.0	1.7	1.8
		STD	0.5	0.8	0.5	0.5
THETA BAND (4.0-7.5Hz)	PERC. OF POWER	MEAN	16.2	24.9	25.1	22.5
		STD	4.2	6.9	5.6	4.9
	FREQ. PEAK (Hz)	MEAN	6.9	5.3	5.5	5.5
		STD	0.8	1.4	1.1	1.3
ALPHA BAND (8.0-11.5Hz)	PERC. OF POWER	MEAN	23.3	15.2	16.7	14.5
		STD	5.0	5.2	11.1	10.6
	FREQ. PEAK (Hz)	MEAN	10.3	9.3	9.3	9.4
		STD	1.0	1.3	0.8	0.9
SIGMA BAND (12.0-15.5Hz)	PERC. OF POWER	MEAN	17.4	10.3	6.4	5.6
		STD	5.0	6.9	2.9	2.5
	FREQ. PEAK (Hz)	MEAN	13.1	13.4	13.7	13.6
		STD	1.0	1.0	0.6	0.8

TABLE 4.2

(continued)

NIGHT			5ht	10th	13th	16th
RECORD NUMBER			15322	15340	15358	15375
DOSAGE (mg)			1000	200	0	0
BETA1 BAND (16.0-20.5Hz)	PERC. OF POWER	MEAN	8.7	3.5	1.9	2.5
		STD	3.1	1.7	1.1	1.2
	FREQ. PEAK (Hz)	MEAN	18.0	18.5	18.5	18.4
		STD	1.2	1.2	1.2	1.3
BETA2 BAND (21.0-29.5Hz)	PERC. OF POWER	MEAN	3.9	3.8	1.8	2.3
		STD	1.7	2.1	1.0	1.1
	FREQ. PEAK (Hz)	MEAN	24.5	24.4	24.6	25.1
		STD	2.5	1.9	2.4	2.5
FASTF BAND (30.0-40.0Hz)	PERC. OF POWER	MEAN	1.5	1.2	1.1	0.45
		STD	0.4	0.5	0.6	0.3
	FREQ. PEAK (Hz)	MEAN	33.6	33.4	33.0	33.1
		STD	2.7	2.5	2.2	2.3
x^2	MEAN		59.1	81.1	93.9	96.6
	STD		8.0	13.2	17.2	15.6
	PERCENTAGE OF REJECTIONS		27.0	73.0	86.0	86.8
MFC	MEAN		7.9	6.2	5.0	5.0
	STD		1.7	1.6	1.6	1.4

	DELTA BAND	THETA BAND	ALPHA BAND	SIGMA BAND	BETA1 BAND	BETA2 BAND	FASTF BAND	X^2 COEF.	MFC
MEAN PERC. OF POWER	+ 70%	+ 40%[1]	- 38%[1]	- 68%	- 71%	- 41%	- 82%	-	-
MEAN FREQ. PEAK	+ 20%	- 20%[1]	- 9%[1]	+ 5%	+ 2%	+ 3%	- 1%	-	-
MEAN	-	-	-	-	-	-	-	+ 63%	- 37%
PERC. OF REJECTIONS	-	-	-	-	-	-	-	+210%	-

[1]See text for comments

TABLE 4.3 Subject SD1 - Percentage Change in the Results of Table 4.2 Between the Last and the First Nights

In Figures 4.2a, b, c and d the plots of the percentage of power in the Delta Band vs time are shown. For the 5th night, Figure 4.2a shows a well-defined peak in the beginning of the night and the mean percentage of power in the band is 27.3%. In the 10th night, Figure 4.2b, the mean percentage of power has increased to 38% and the well-defined peak is still present at the beginning of the plot. Figure 4.2c, for the 13th night, illustrates the appearance of a second well-defined peak 110 minutes after the first one. The same pattern is repeated in the 16th night, Figure 4.2d, except that the two peaks are now separated by a 90 minutes interval. The mean percentage of power in the band during these two nights has increased to 44.3 and 46.3% respectively. From Table 4.3, we can see that the mean percentage of power in the Delta Band has increased 70% between the 5th and the 16th nights. In the same period the mean frequency in this band has increased 20%.

The plots for the percentage of power in the Sigma Band are shown in Figure 4.3a, b, c and d. In the 5th night, Figure 4.3a, the plot stays almost flat for the entire night, which reflects the "constancy" of the activity in the Sigma Band. From the 10th night on, well-defined peaks can be seen with a decreasing amplitude. The mean percentage of power has decreased 68% from the 5th to the 16th night, and the mean frequency peak has changed from 13.1 to 13.6 Hz in the same period.

The Mean Frequency Coefficients (MFC) for four nights are plotted in Figures 4.4a, b, c and d. In the 5th night, Figure 4.4a, most of the MFC points are above 7 Hz, except for a low frequency dip which is close to the 4 Hz frequency line, when the EEG was dominated by slow wave activity. The mean frequency for this night is 7.9 Hz. The plot for the 10th night, Figure 4.4b, shows a similar pattern to the one in the 5th night, except that the frequency dip in the beginning of the night is under the 3 Hz frequency line, which shows a slight increase in the slow wave activity. For the rest of the night the MFC are of lower frequency than in the preceeding nights. The mean frequency for the entire night decreased to 6.2 Hz. By the 13th night, Figure 4.4c, when the subject was out of the drug, the mean frequency for the night continued its downward trend reaching a value of 5 Hz. Now there are two low frequency dips that are under the 3Hz frequency line, and the rest of the MFC points are below the 6 Hz frequency line, except at the very beginning of the night when the activity in the Alpha Band was dominant as shown in Figure 4.1c. The plot for the 16th night, Figure 4.4d, shows a pattern similar to the one in the 13th night, except that the low frequency dips are of shorter duration and there is a high frequency peak around minute 400. According to the CSA plot, Figure 4.1a, this peak corresponds to activity in the Alpha Band (the subject was probably awaken). The mean frequency during the night has decreased 37% between the 5th and the 16th nights.

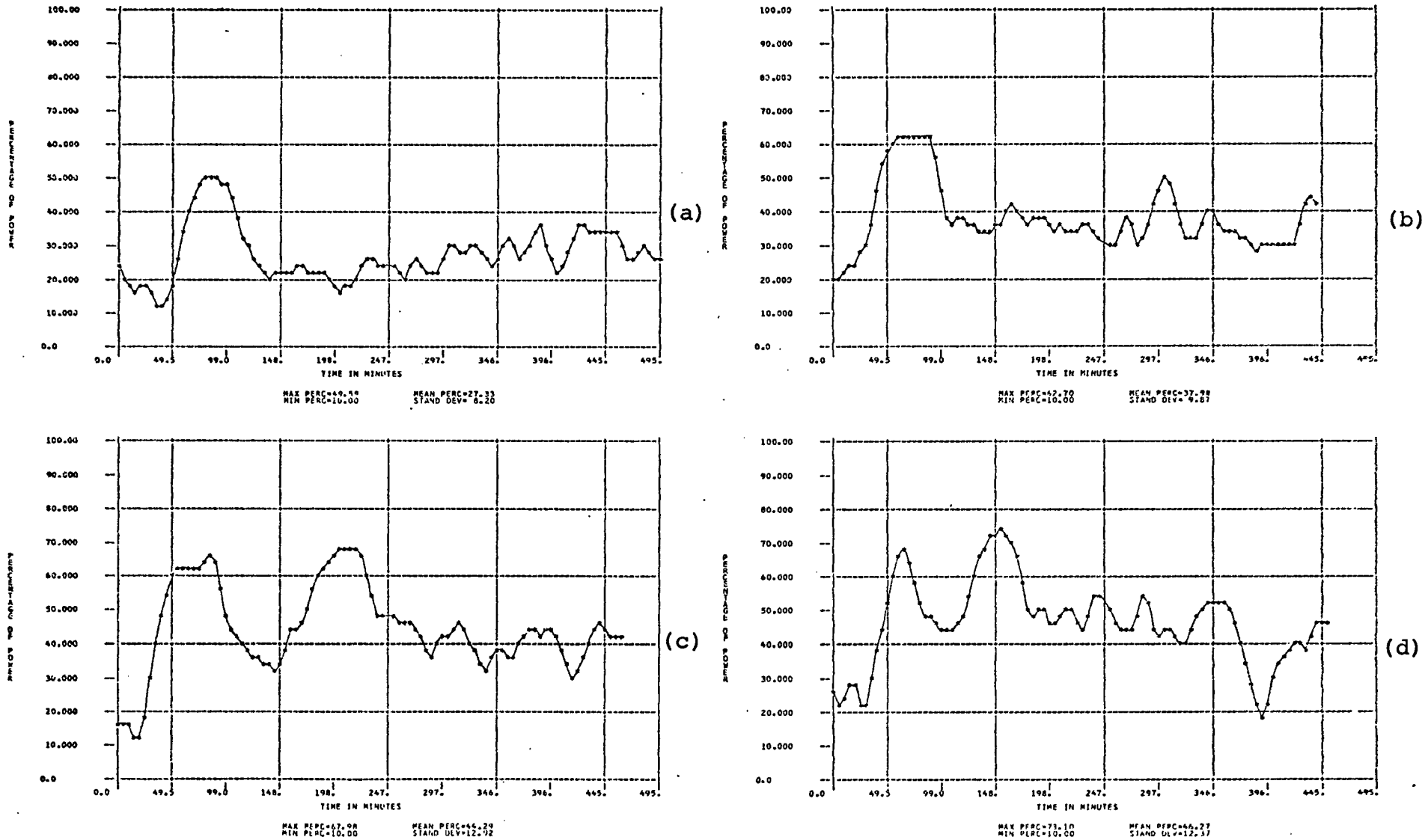


FIGURE 4.2 Subject SD1 - Percentage of Power in the Delta Band
(a) 5th night, record #15322 (b) 10th night, record #15240
(c) 13th night, record #15358 (d) 16th night, record #15375

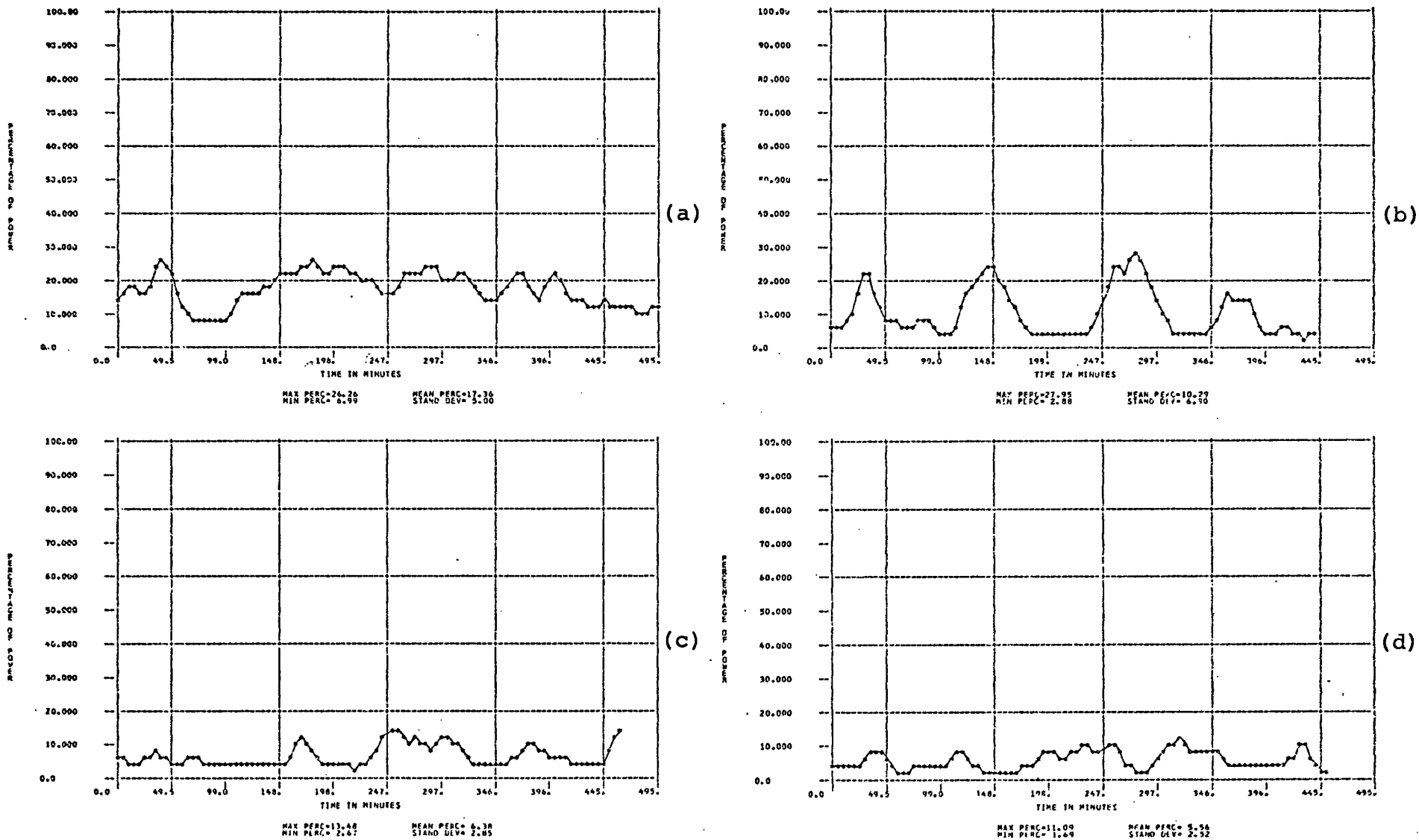


FIGURE 4.3 Subject SD1 - Percentage of Power in the Sigma Band
(a) 5th night, record #15322 (b) 10th night, record #15340
(c) 13th night, record #15358 (d) 16th night, record #15375

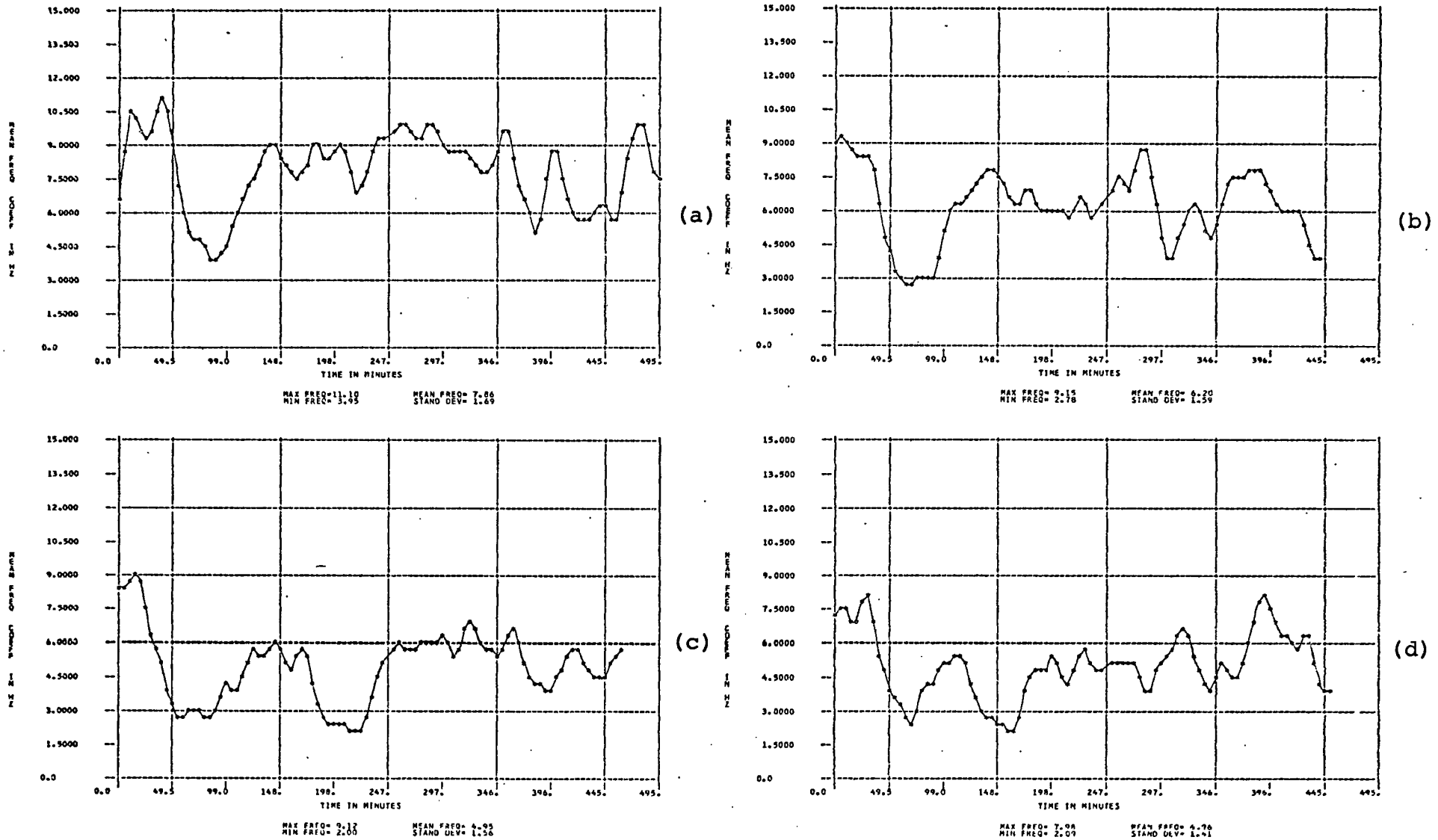


FIGURE 4.4 Subject SD1 - Mean Frequency Coefficient (MFC)
(a) 5th night, record #15322 (b) 10th night, record #15340
(c) 13th night, record #15358 (d) 16th night, record #15375

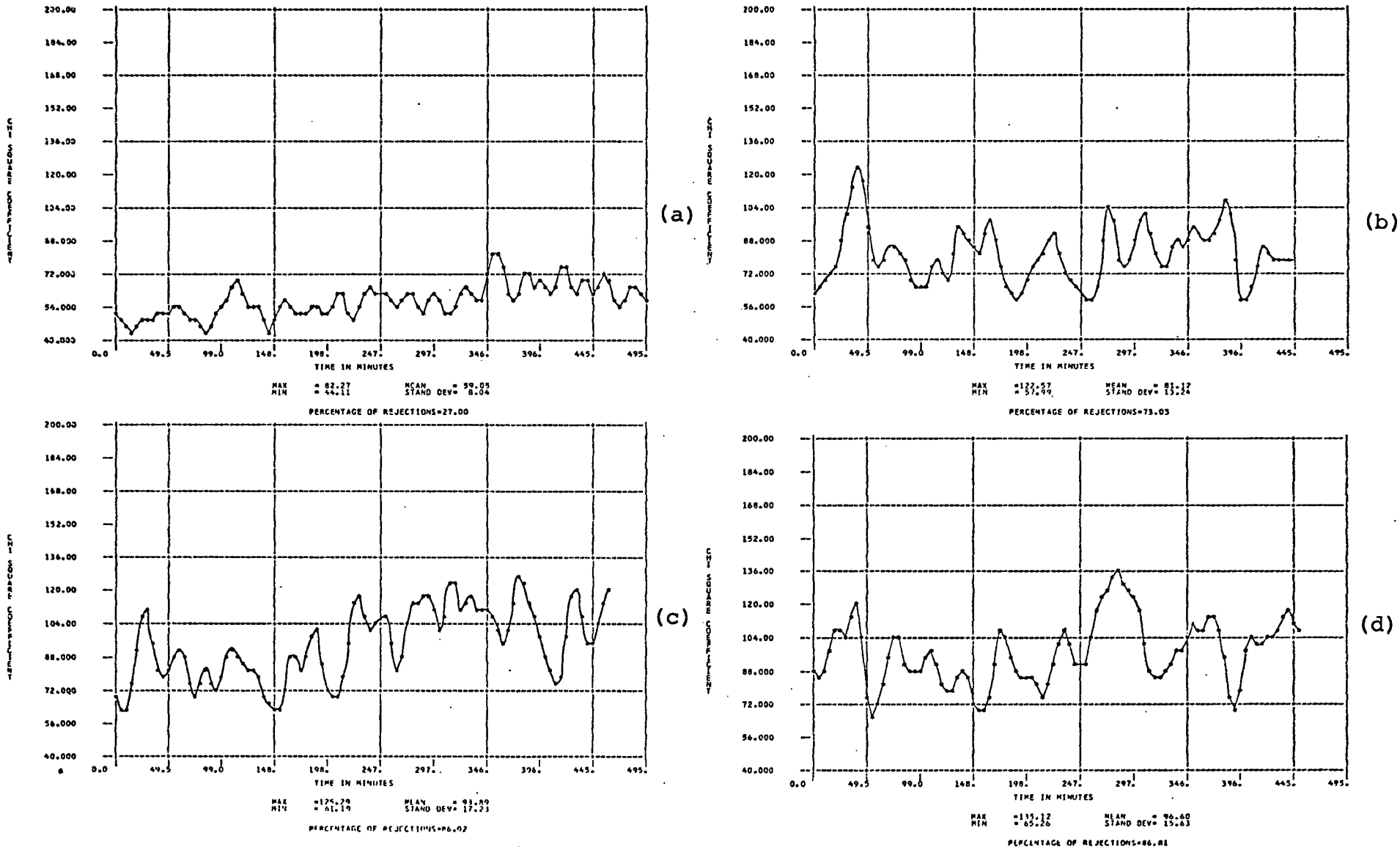


FIGURE 4.5 Subject SD1 - Chi-Square Coefficient
(a) 5th night, record #15322 (b) 10th night, record #15340
(c) 13th night, record #15358 (d) 16th night, record #15375

Figures 4.5a, b, c and d show the plots for the X^2 coefficients. In the 5th night, Figure 4.5a, the great majority of the points are below 72 and only 27% of the epochs were rejected, by the chi-square test of goodness-of-fit to a Gaussian distribution (CSQ). This means that the EEG amplitude in 73% of the epochs follows a Gaussian probability density function. As the drug is being withdrawn, the X^2 values start increasing and consequently more and more epochs are being rejected by the CSQ test as we can see in the remaining plots (Figures 4.5b, c and d). There is an increase of 210% in the percentage of rejections between the 5th and the 15th nights.

4.2.2 Subject SD2

4.2.2.1 Subject's Protocol

Subject SD2 is a 16 year-old male, who was in treatment for a period of 14 days. Four nights of sleep EEG, as shown in Table 4.4 were automatically processed. This table was compiled from Table 2.1. The titration night (daily dosage of 500 mg) was not processed because its record was not available on magnetic tape.

TABLE 4.4

Analyzed Data for Subject SD2

Night	Record Number	Daily Dosage (mg)
2nd	15017	300
5th	15029	150
7th	15043	0
13th	15086	0

4.2.2.2 Compressed Spectral Array

The CSA plots for the nights listed in Table 4.4 are shown in Figures 4.6a, b, c and d. In the 2nd night, Figure 4.6a, the activity in the Delta Band is dominated by low intensity peaks throughout the night, with the exception of two clusters of high intensity peaks that appear in the first third of the night. The Sigma Band shows well-defined peaks around 12-12.5 Hz and in some parts of the night it is the dominant frequency band. No peaks can be seen in the Beta frequency bands and very few peaks are present in the Theta Band. Several changes can be seen in the CSA plot for the 5th night, Figure 4.6b. The peaks in the Delta Band are of much higher intensity than before, and two new clusters of high peaks have appeared. The first one around the middle of the night and the other in the last third of it. The peaks in the Sigma Band are also of higher intensity. Several peaks can now be seen in the Theta Band. In the 7th night, Figure 4.6c, when the subject was not taking the

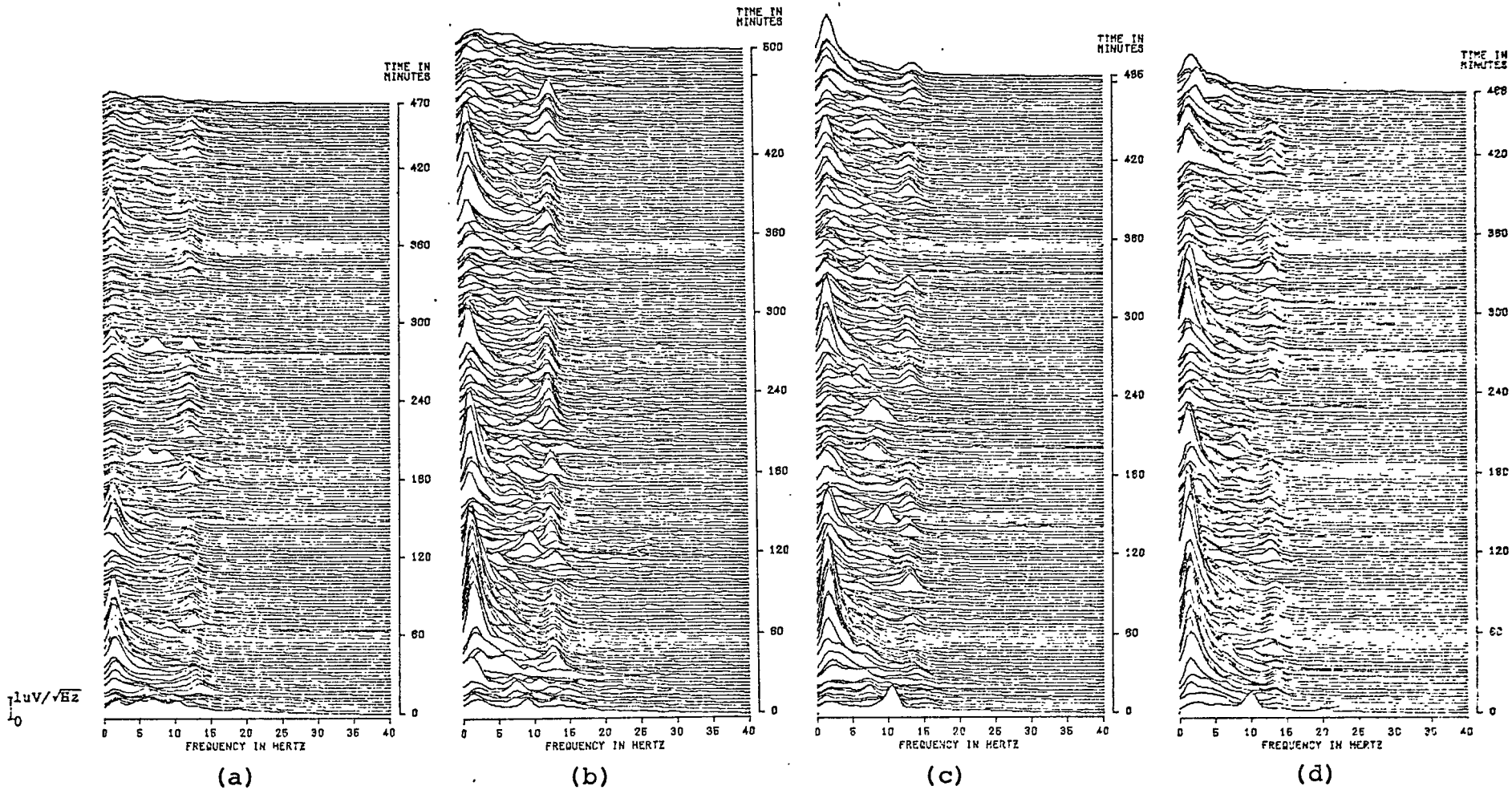


FIGURE 4.6 Subject SD2 - Compressed Spectral Array (CSA)
(a) 2nd night, record #15017 (b) 5th night, record #15029
(c) 7th night, record #15043 (d) 13th night, record #15086

drug, the Delta Band continued to show large intensity peaks and the peaks in the Sigma Band are of smaller amplitude than before. No significant changes can be seen in the patterns of the 13th night as shown in Figure 4.6d.

4.2.2.3 Summary of the Output Results from the FEATURE Algorithm

Table 4.5 shows the output results from the data reduction analysis. From these results we can see that the drug affected the amount of SWS, which resulted in a reduction in the mean percentage of power in the Delta and Theta Bands. On the other hand, the drug also affected the high frequency activity, which resulted in an increase in the amount of power in the Alpha, Sigma, Betal, and Beta2 frequency bands. The above changes can be further summarized by the results from the mean value of the Mean Frequency Coefficient for each night.

Figures 4.7a, b, c and d show the plots vs time of the percentage of power in the Delta Band for the 2nd, 5th, 7th and 13th nights respectively. The 2nd and 5th nights, Figures 4.7a and b, show a similar pattern, with two large peaks in the first half of the night and another one at the last third of it. This last peak is of much higher amplitude in the 5th night. The mean percentage of power in the two nights was 40.4 and 45.3% respectively. In the 7th night, Figure 4.7c, there are three well-defined large peaks: two in the first third of the night and the other in the beginning of

TABLE 4.5

Summary of the Output Results from FEATURE for Subject SD2

NIGHT			2nd	5th	7th	13th
RECORD NUMBER			15017	15029	15043	15086
DOSAGE (mg)			300	150	0	0
DELTA BAND (0.0-3.5Hz)	PERC. OF POWER	MEAN	40.0	45.3	51.8	57.7
		STD	13.5	13.8	12.2	10.3
	FREQ. PEAK (Hz)	MEAN	1.5	1.7	1.6	1.6
		STD	0.5	0.5	0.4	0.5
THETA BAND (4.0-7.5Hz)	PERC. OF POWER	MEAN	18.3	19.9	23.2	21.7
		STD	7.8	6.0	5.4	6.7
	FREQ. PEAK (Hz)	MEAN	5.9	6.2	6.3	6.5
		STD	0.9	1.0	1.0	0.9
ALPHA BAND (8.0-11.5Hz)	PERC. OF POWER	MEAN	14.2	13.1	11.9	9.0
		STD	4.9	5.1	6.5	4.3
	FREQ. PEAK (Hz)	MEAN	9.7	9.1	9.2	9.4
		STD	1.2	1.1	1.0	1.0
SIGMA BAND (12.0-15.5Hz)	PERC. OF POWER	MEAN	14.8	11.8	6.6	4.9
		STD	7.4	6.8	3.5	2.7
	FREQ. PEAK (Hz)	MEAN	12.6	13.1	13.4	13.2
		STD	0.9	0.9	0.8	0.7

TABLE 4.5

(continued)

NIGHT			2nd	5th	7th	13th
RECORD NUMBER			15017	15029	15043	15086
DOSAGE (mg)			300	150	0	0
BETA1 BAND (16.0-20.5Hz)	PERC. OF POWER	MEAN	4.7	3.2	1.7	1.2
		STD	2.1	1.8	1.0	0.6
	FREQ. PEAK (Hz)	MEAN	18.2	18.3	18.3	18.3
		STD	1.3	1.4	1.4	1.3
BETA2 BAND (21.0-29.5Hz)	PERC. OF POWER	MEAN	3.0	2.5	1.0	0.8
		STD	1.3	1.4	0.7	0.4
	FREQ. PEAK (Hz)	MEAN	24.0	24.2	24.2	24.4
		STD	2.3	2.0	2.4	2.3
FASTF BAND (30.0-40.0Hz)	PERC. OF POWER	MEAN	1.1	1.1	0.3	0.3
		STD	0.5	0.6	0.2	0.2
	FREQ. PEAK (Hz)	MEAN	33.4	32.8	33.2	32.5
		STD	2.4	2.0	2.5	2.3
X^2	MEAN		75.0	76.3	85.6	86.6
	STD		8.9	12.5	17.5	19.8
	PERCENTAGE OF REJECTIONS		63.2	62.4	68.4	71.3
MFC	MEAN		5.8	5.4	4.2	3.4
	STD		1.8	1.8	1.6	1.0

	DELTA BAND	THETA BAND	ALPHA BAND	SIGMA BAND	BETA1 BAND	BETA2 BAND	FASTF BAND	X^2 COEF.	MFC
MEAN PERC. OF POWER	+ 43%	+ 19%	- 37%	- 67%	- 75%	- 73%	- 73%	-	-
MEAN FREQ. PEAK	+ 7%	+ 10%	- 3%	+ 5%	+0.5%	+ 2%	- 3%	-	-
MEAN	-	-	-	-	-	-	-	+ 16%	- 41%
PERC. OF REJECTIONS	-	-	-	-	-	-	-	+ 13%	-

TABLE 4.6 Subject SD2 - Percentage Change in the Results of Table 4.5 Between the Last and the First Nights

the second half of the night. It seems that a fourth one was appearing at the very end of the night. The mean percentage of power for the night has increased to 51.8%. In the 13th night there are four large peaks, two in the first third and two in the second third of the night. From these plots it seems that the drug has suppressed one of the peaks and somehow altered the timming of their occurance. Table 4.6 shows that the mean percentage of power in the Delta Band has increased 43% between the 2nd and the 13th nights. The mean frequency in the Delta Band has also increased 7% in the same period.

Figures 4.8a, b, c and d show the plots of the percentage of power in the Sigma Band. In the 2nd night, Figure 4.8a, there are peaks with large amplitude and long duration. From the 5th night on, Figures 4.8b, c and d, the amplitude and the latency of the peaks start decreasing. From Table 4.6 it can be seen that the mean percentage of power in the Sigma Band has decreased 67% between the 2nd and the 13th nights. In the same period, the mean frequency in the band increased from 12.6 to 13.2 Hz, (as shown in Table 4.5).

Figures 4.9a, b, c and d show the plots of the MFC's for the four nights of subject SD2. In the 2nd night, Figure 4.9a, the mean frequency was 5.8 Hz and for most of the night the MFC points were above 5 Hz, except for three low frequency dips that went below 3 Hz. Almost the same picture is still valid for the 5th night, Figure 4.9b, with

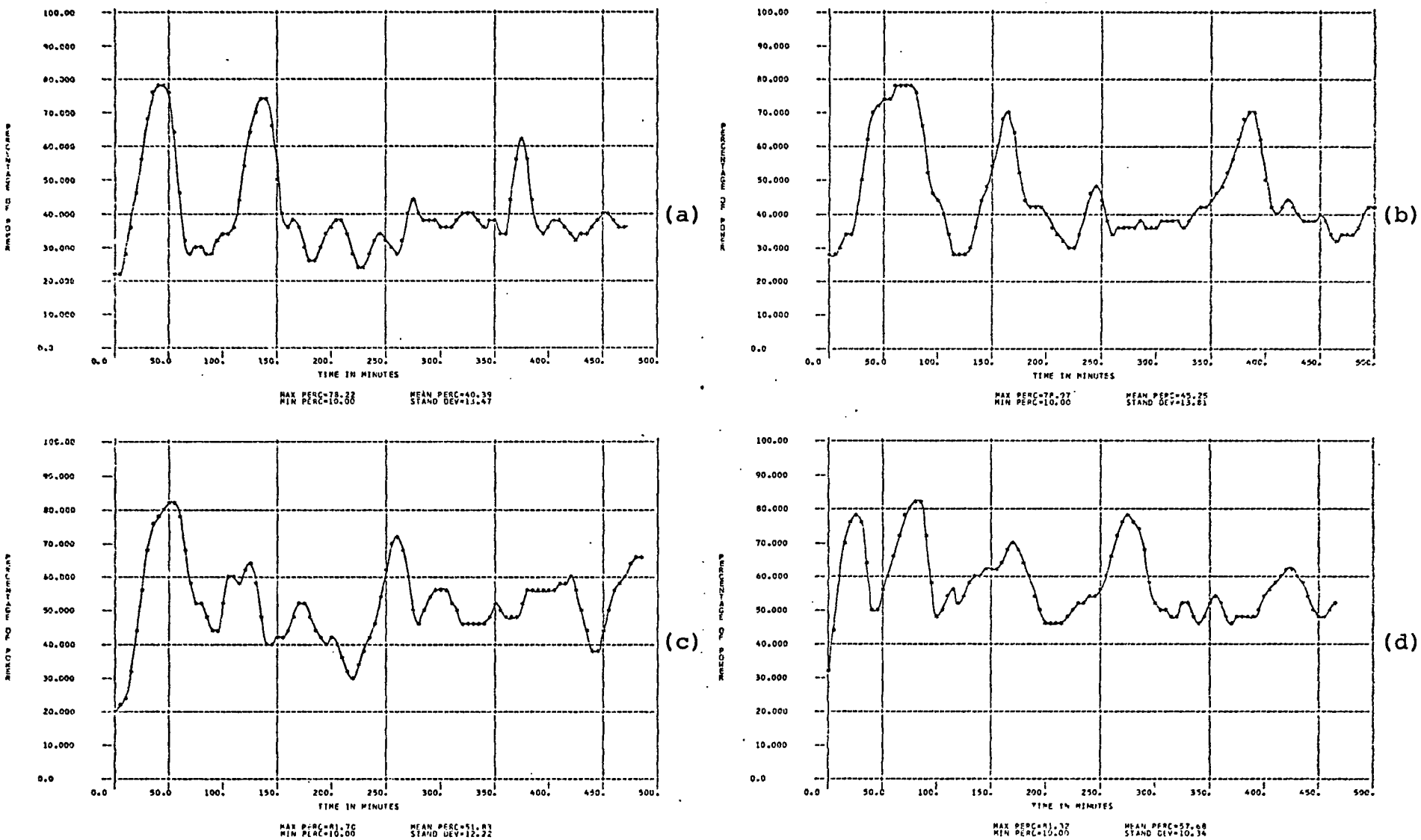


FIGURE 4.7 Subject SD2 - Percentage of Power in the Delta Band
(a) 2nd night, record #15017 (b) 5th night, record #15029
(c) 7th night, record #15043 (d) 13th night, record #15086

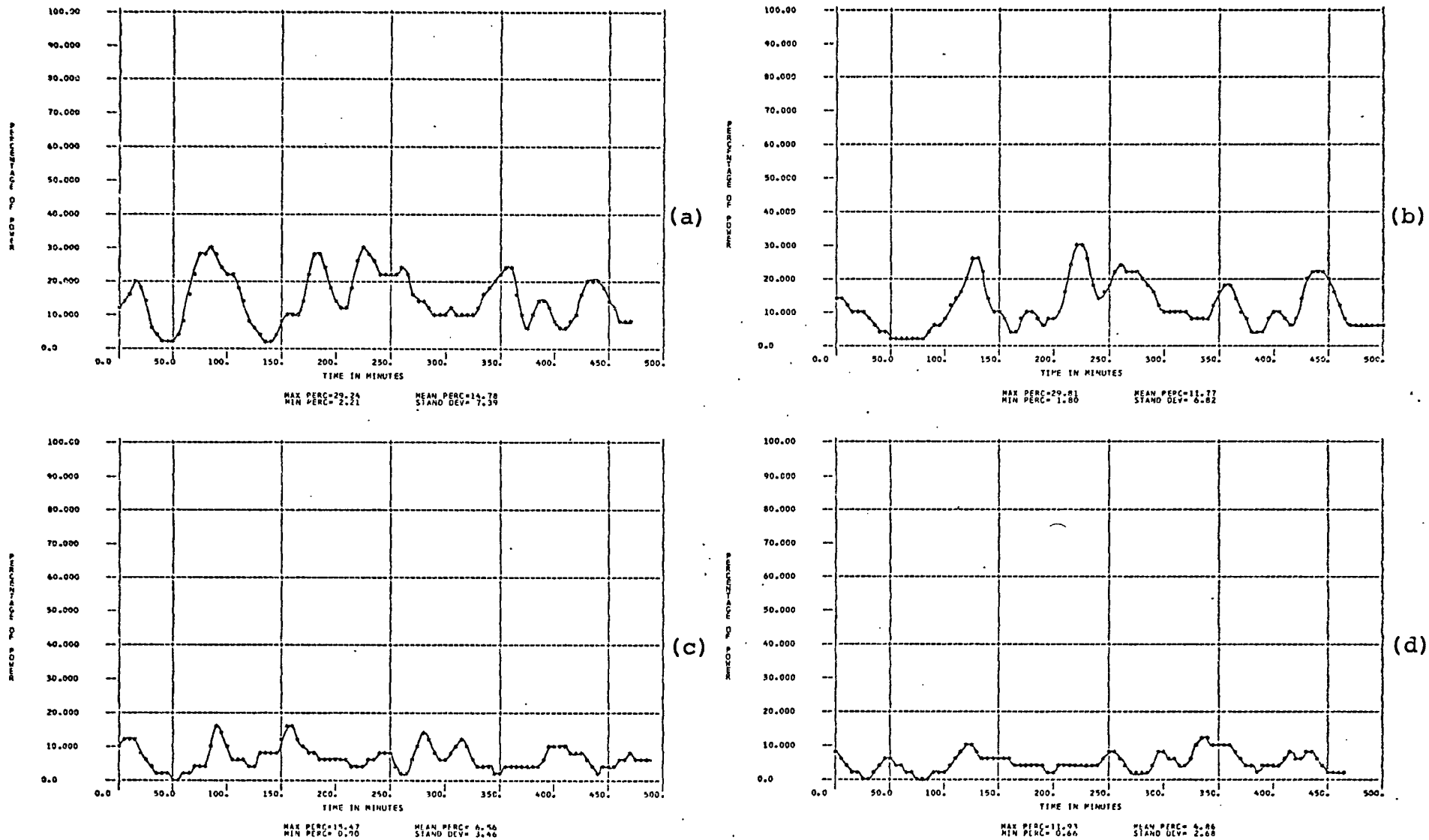


FIGURE 4.8 Subject SD2 - Percentage of Power in the Sigma Band
(a) 2nd night, record #15017 (b) 5th night, record #15029
(c) 7th night, record #15043 (d) 15th night, record #15086

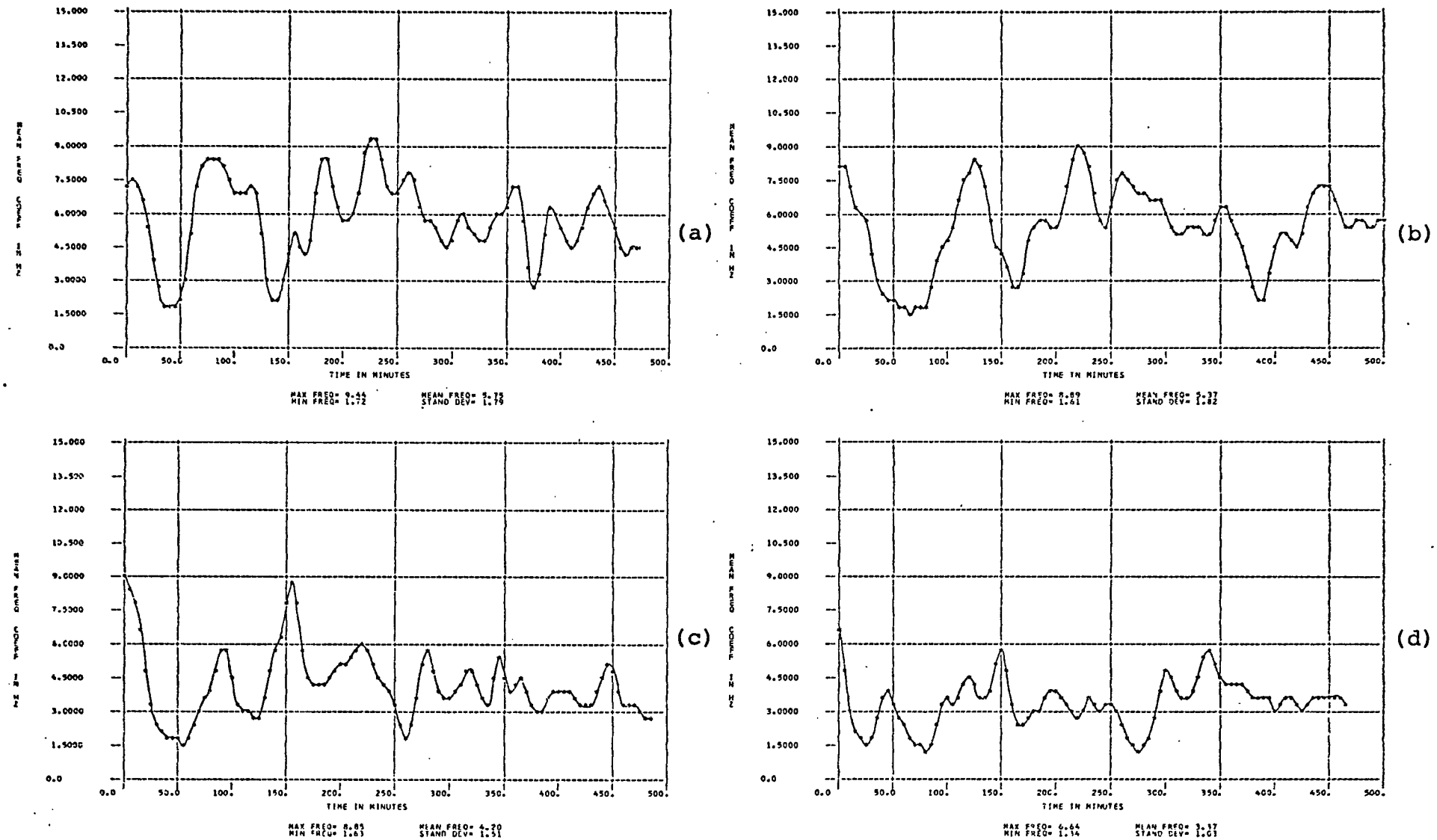


FIGURE 4.9 Subject SD2 - Mean Frequency Coefficient (MFC)
(a) 2nd night, record #15017 (b) 5th night, record #15029
(c) 7th night, record #15043 (d) 13th night, record #15086

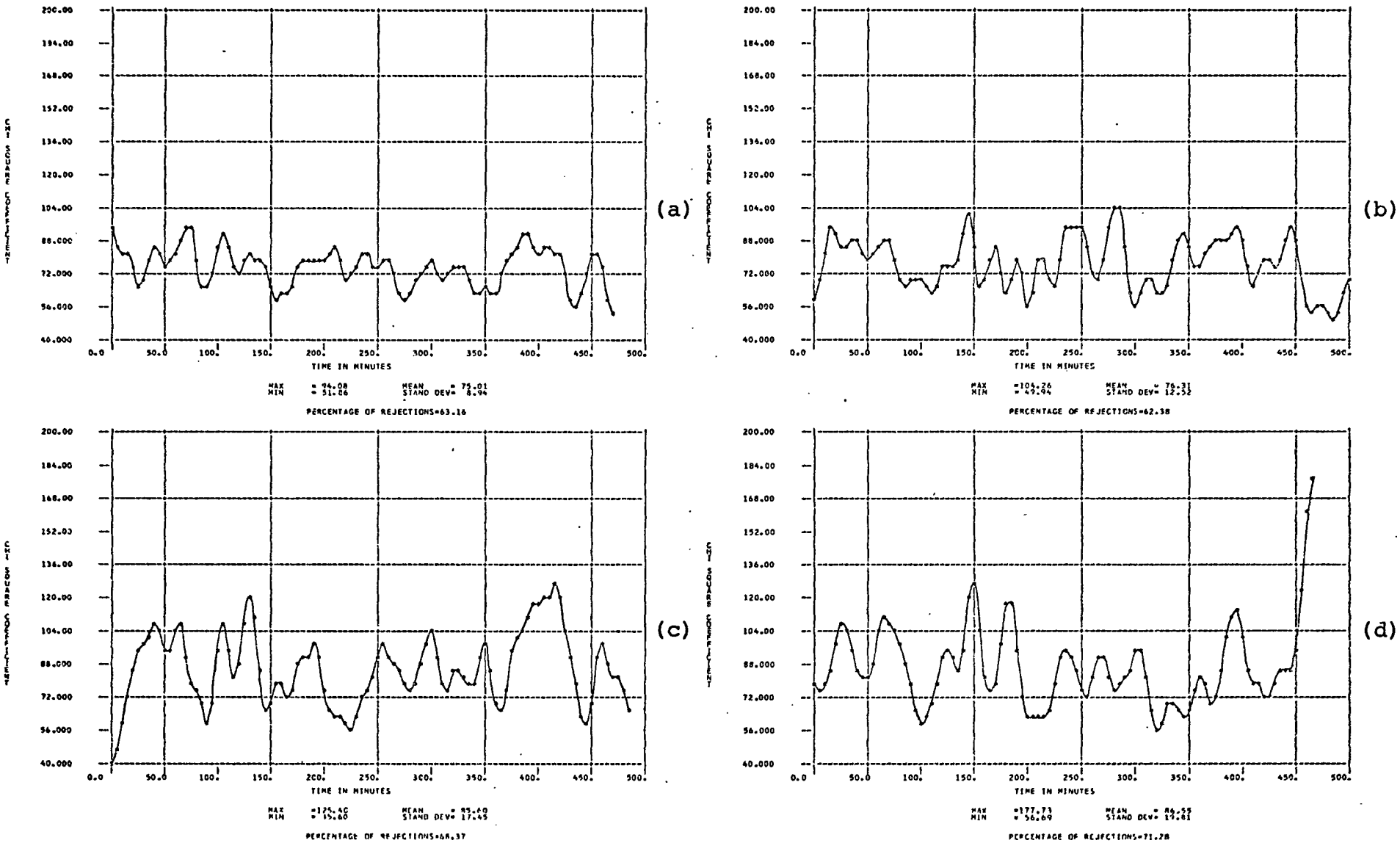


FIGURE 4.10 Subject SD2 - Chi-Square Coefficient
(a) 2nd night, record #15017 (b) 5th night, record #15029
(c) 7th night, record #15043 (d) 13th night, record #15086

the exception of the latency of the low frequency dips, which is now longer. The mean frequency for this night was 5.4 Hz. Most of the MFC points in the 10th night, Figure 4.9c, were below 5 Hz and the mean frequency went further down to 3.4 Hz, with most of the MFC points staying below 4.5 Hz. For this subject the mean frequency in the MFC plots, has decreased 41% between the 2nd and the 13th nights.

The plots for the X^2 coefficient are shown in Figures 4.10a, b, c and d. As we can see from these plots, the mean and the percentage of rejections of the X^2 coefficients had their lowest values close to the subject's titration night. As the drug was being withdrawn, these values started increasing. From Table 4.6 it can be seen that the mean and the percentage of rejections increased 16 and 13%, respectively, between the 2nd and the 13th nights.

4.2.3 Subject SD3

4.2.3.1 Subject's Protocol

Subject SD3, a male 16 years of age, was a patient at the hospital for 13 days. A total of four nights were automatically processed. Table 4.7 shows these nights, their corresponding record number and the subject's daily intake of the drug. The data in Table 4.7 was derived from Table 2.1, where the complete subject's withdrawal schedule is shown.

TABLE 4.7

Analyzed Data for Subject SD3

Night	Record Number	Daily Dosage (mg)
1st	15030	350
3rd	15044	200
8th	15079	0
13th	15105	0

4.2.3.2 Compressed Spectral Array Results

Figures 4.11a, b, c and d show the CSA plots corresponding to the four nights in Table 4.7. For the 1st and 3rd nights, Figures 4.11a and b, the activity in the Delta Band is characterized by low intensity peaks, except for two separate occurrence of sharp high intensity spectral peaks in the first half of the night. The delta peaks for the 3rd night have a higher intensity than the ones for the 1st night in the beginning of the night. The activity in the Sigma Band is about the same magnitude in both nights, however, it is better defined in the 3rd night. Furthermore, its peak frequency has shifted from 12.5 Hz in the beginning of the 1st night to 13.0 Hz in the beginning of the 3rd night. Little activity is also seen in the Beta1 and Beta2 frequency bands during the 1st night, but it is not visible anymore in the 3rd one.

In the 8th and 10th nights, Figures 4.11c and d, when the subject was out of the drug, the large peaks in the

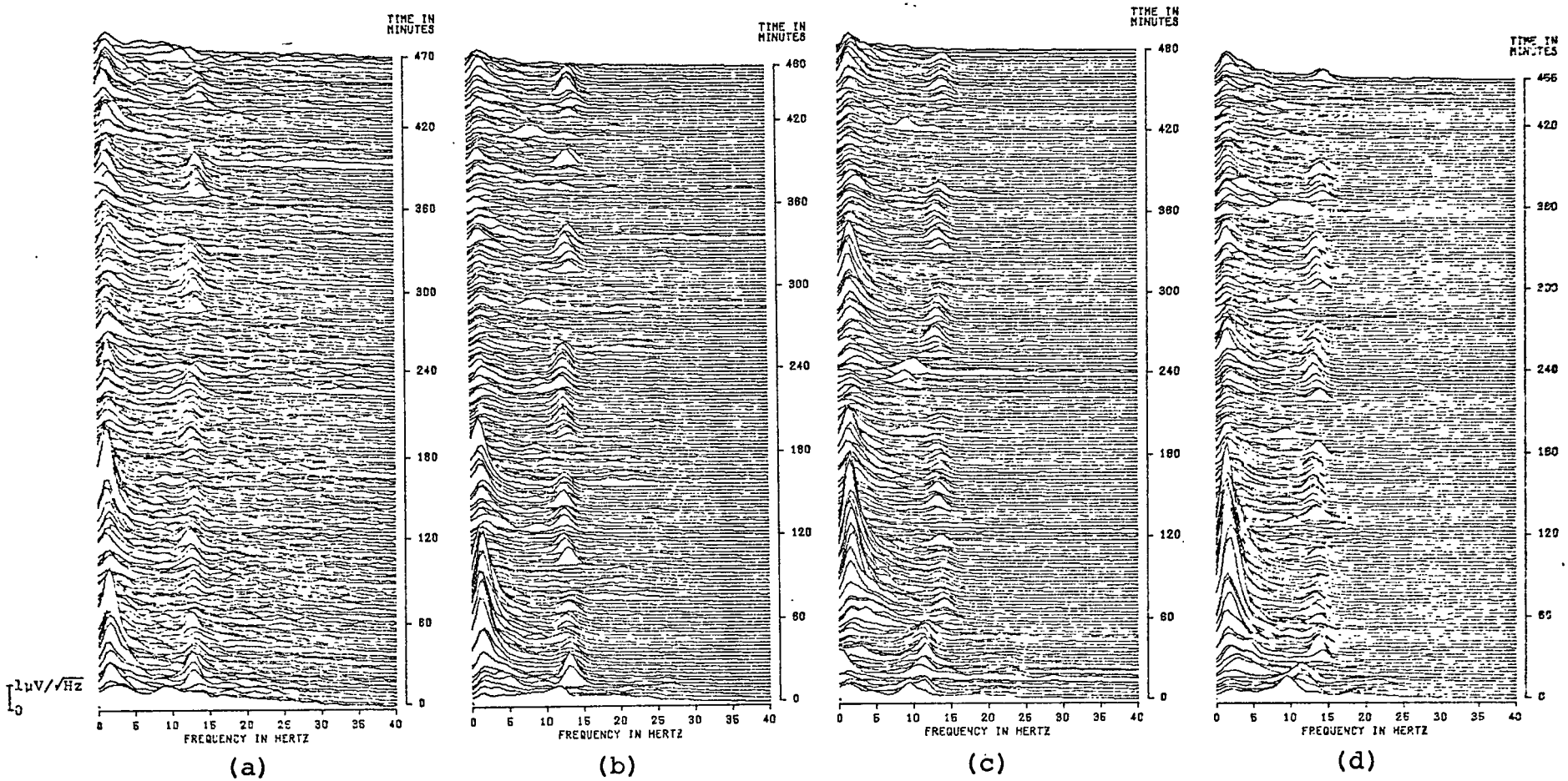


FIGURE 4.11 Subject SD3 - Compressed Spectral Array (CSA)
(a) 1st night, record #15030 (b) 3rd night, record #15044
(c) 8th night, record #15079 (d) 13th night, record #15105

Delta Band at the beginning of each night are of higher intensity than the corresponding ones in the 1st and 3rd nights. In the 8th night, Figure 4.11c, there are also some large peaks after the first half of the night. Activity in the Alpha Band is clearly seen during the first 50 minutes of the 8th night. The frequency peaks in this band are first at 9 Hz and then shifted to 11.5 Hz during this period.

4.2.3.3 Summary of the Output Results from the FEATURE Algorithm

Table 4.8 shows the output results of the data reduction algorithm. As we can see from this table, there is an upward trend in the mean percentage of power in the Delta and Theta Bands, as well as in the mean value and in the percentage of rejection of the X^2 coefficient as the treatment progresses. However, a downward trend is shown in the mean percentage of power in the remaining frequency bands and by the MFC. Table 4.9 shows, in terms of percentages, the variations in the results of Table 4.8 between the last and the first nights of treatment.

Figures 4.12a, b, c and d show the plots vs time of the percentage of power in the Delta Band for the nights listed in Table 4.7. For the 1st night, Figure 4.12a, there are two large peaks 100 minutes apart at the beginning of the night. The mean percentage of power in the band is 37%. These two peaks are still present in the 3rd night, except that now the first peak is of much higher amplitude, its

TABLE 4.8

Summary of the Output Results from FEATURE for Subject SD3

NIGHT			1st	3rd	8th	13th
RECORD NUMBER			15030	15044	15079	15105
DOSAGE (mg)			300	200	0	0
DELTA BAND (0.0-3.5Hz)	PERC. OF POWER	MEAN	37.0	44.1	54.8	54.2
		STD	9.2	12.8	13.5	13.5
	FREQ. PEAK (Hz)	MEAN	1.5	1.6	1.6	1.7
		STD	0.3	0.5	0.4	0.3
THETA BAND (4.0-7.5Hz)	PERC. OF POWER	MEAN	13.4	18.7	18.1	19.9
		STD	2.7	6.0	4.3	5.6
	FREQ. PEAK (Hz)	MEAN	6.1	5.1	5.9	5.7
		STD	0.8	0.9	1.0	1.30
ALPHA BAND (8.0-11.5Hz)	PERC. OF POWER	MEAN	10.4	10.2	9.8	9.6
		STD	2.2	3.3	7.5	7.4
	FREQ. PEAK (Hz)	MEAN	9.6	9.8	10.2	9.7
		STD	1.1	1.1	1.0	1.0
SIGMA BAND (12.0-15.5Hz)	PERC. OF POWER	MEAN	13.5	13.4	7.4	8.3
		STD	4.7	7.7	4.0	4.4
	FREQ. PEAK (Hz)	MEAN	13.2	13.3	13.7	13.7
		STD	0.8	0.9	0.7	0.7

TABLE 4.8

(continued)

NIGHT			1st	3rd	8th	13th
RECORD NUMBER			15030	15044	15079	15105
DOSAGE (mg)			300	200	0	0
BETA1 BAND (16.0-20.5Hz)	PERC. OF POWER	MEAN	8.2	5.2	2.5	2.3
		STD	2.6	2.8	1.8	1.3
	FREQ. PEAK (Hz)	MEAN	18.0	18.5	18.6	18.5
		STD	1.3	1.3	1.4	1.2
BETA2 BAND (21.0-29.5Hz)	PERC. OF POWER	MEAN	9.6	4.5	2.4	1.8
		STD	2.7	2.5	1.9	1.2
	FREQ. PEAK (Hz)	MEAN	23.7	23.9	24.4	24.6
		STD	2.7	2.3	2.4	2.3
FASTF BAND (30.0-40.0Hz)	PERC. OF POWER	MEAN	4.5	1.0	1.3	0.7
		STD	1.7	0.5	0.8	0.4
	FREQ. PEAK (Hz)	MEAN	33.1	33.4	33.0	33.2
		STD	2.3	2.3	2.2	2.5
X^2	MEAN		75.7	76.2	83.0	84.7
	STD		10.2	14.8	11.7	16.5
	PERCENTAGE OF REJECTIONS		61.1	60.2	78.4	70.7
MFC	MEAN		7.3	5.9	4.4	4.4
	STD		1.9	1.8	2.0	1.7

	DELTA BAND	THETA BAND	ALPHA BAND	SIGMA BAND	BETA1 BAND	BETA2 BAND	FASTF BAND	X^2 COEF.	MFC
MEAN PERC. OF POWER	+ 47%	+50%	- 4%	- 39%	- 72%	- 81%	- 87%	-	-
MEAN FREQ. PEAK	+ 13%	- 7%	+ 1%	+ 4%	+ 3%	+ 4%	0.3%	-	-
MEAN	-	-	-	-	-	-	-	+ 12%	- 40%
PERC. OF REJECTIONS	-	-	-	-	-	-	-	+ 16%	-

TABLE 4.9 Subject SD3 - Percentage Change in the Results of Table 4.8 Between the Last and the First Nights

duration is twice as longer and they are separated by 110 minutes interval (Figure 4.12b). The mean percentage of power in the 3rd night has increased to 44%. In the 8th night, Figure 4.12c, when the subject was not taking the drug anymore, there are three large peaks present in the plot. Two of these peaks are in the first half of the night and the other at the beginning of the second half of it. The first two peaks are separated by about 100 minutes and the third peak is 120 minutes apart from the second one. The mean percentage of power has now increased to 54.8%. In the last night the mean percentage of power in the Delta Band stayed at 54.2% and only two large peaks are shown at the beginning of the night (Figure 4.12d). These peaks are 50 minutes apart. The mean percentage of power in the Delta Band has increased 47% according to Table4.9. The mean frequency peak in this band has also increased from 1.4 to 1.7 Hz, between the 1st and the 13th nights.

Figures 4.13a, b, c and d show the plots of the percentage of power in the Sigma Band for the four nights. In the 1st night, Figure 4.13a, the percentage of power stays relatively high for long periods of time with a mean of 13.5%, and no well-defined peaks can be seen. The plot for the 3rd night, Figure 4.13b, shows some high amplitude peaks. The mean percentage of power for the night remained at 13.4%. In the 8th and 13th nights the mean percentage of power has decreased to 7.4 and 8.3% respectively. Their plots, Figure 4.13c and d, show that the amplitude of the

peaks has also decreased. From Table 4.9 we can see that the mean percentage of power in the Sigma Band has decreased 39% between the 1st and the 13th nights. In the same period the mean frequency peak in the band has increased from 13.2 to 13.7 Hz.

In Figures 4.14a, b, c and d we can see the plots for the MFCs. In the 1st night, Figure 4.14a, the mean frequency is high for most of the night, except for two well-defined, short duration low frequency dips in the first third of the night. The mean frequency for the entire night is 7.3 Hz. The plot for the 3rd night, Figure 4.14b, shows a large low frequency dip of long duration in the beginning of the night. A second low frequency dip is present at the beginning of the second third of the night, however, its duration is much shorter than that of the first one. The mean frequency for the night was 5.9 Hz, which is lower than the previous value for the 1st night. By the 8th night, Figure 4.14c, when the subject's daily drug intake was reduced to zero, the two low frequency dips are still present and a third one appeared towards the end of the second third of the night. The mean frequency during the night went down even further to reach a value of 4.4 Hz. In the last night, Figure 4.14d, the low frequency activity dominates most of the first third of the night, which results in two low frequency dips in this interval. The mean frequency for the night stayed at 4.4 Hz. There is a 40% reduction in the mean frequency from the 1st to the 13th night as shown by Table 4.9.

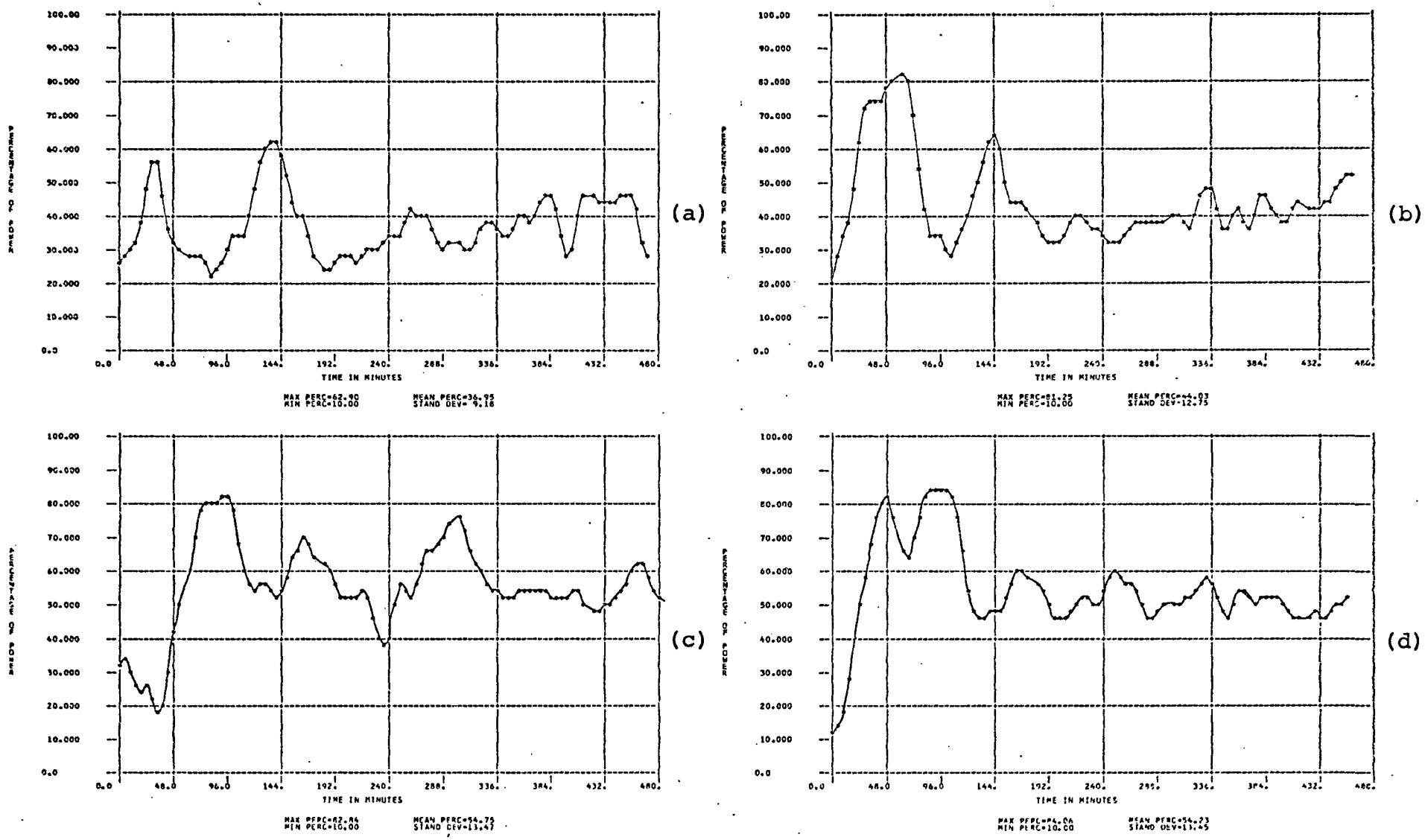


FIGURE 4.12 Subject SD3 - Percentage of Power in the Delta Band
(a) 1st night, record #15030 (b) 3rd night, record #15044
(c) 8th night, record #15079 (d) 13th night, record #15105

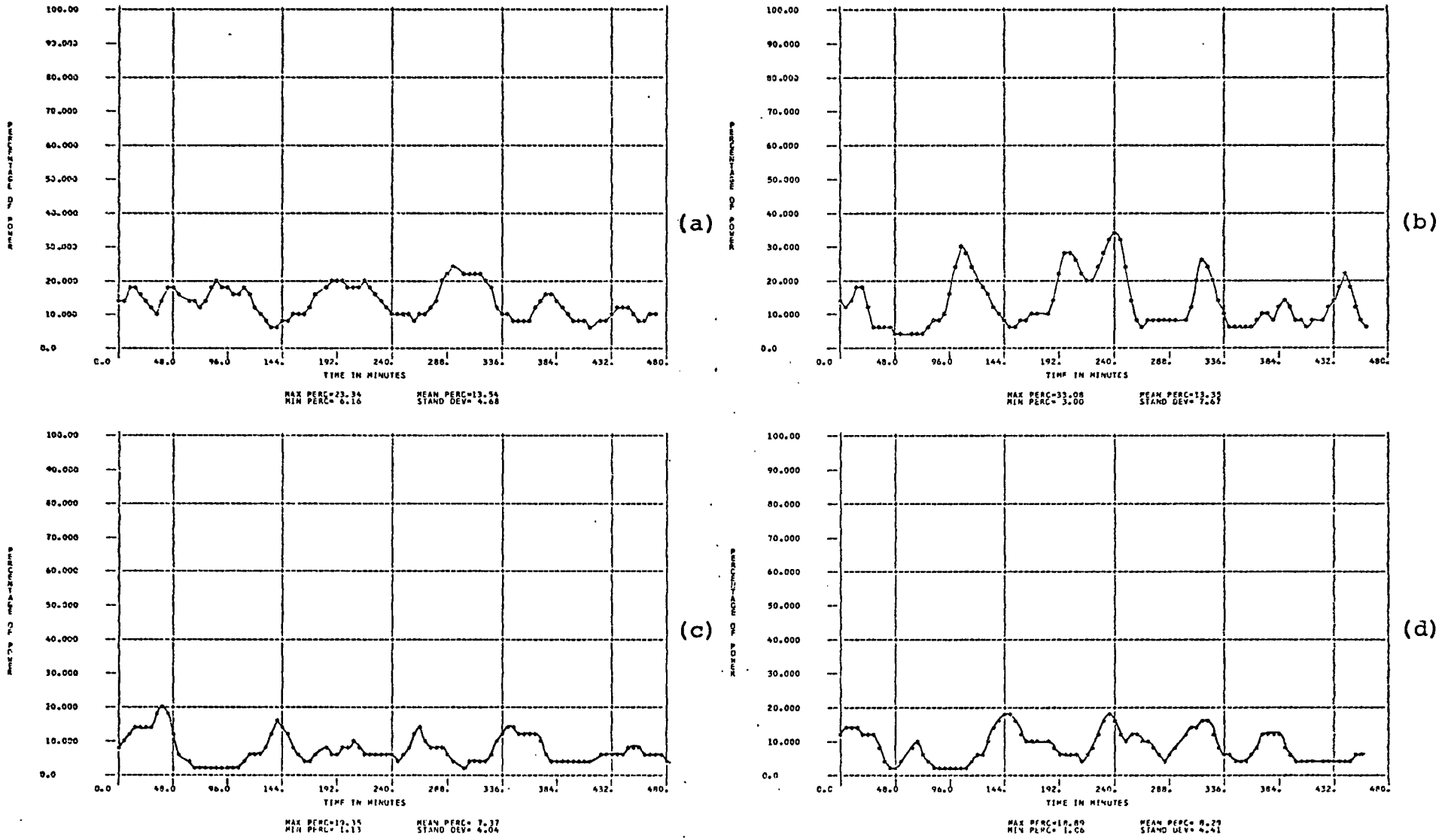


FIGURE 4.13 Subject SD3 - Percentage of Power in the Sigma Band
(a) 1st night, record #15030 (b) 3rd night, record #15044
(c) 8th night, record #15079 (d) 13th night, record #15105

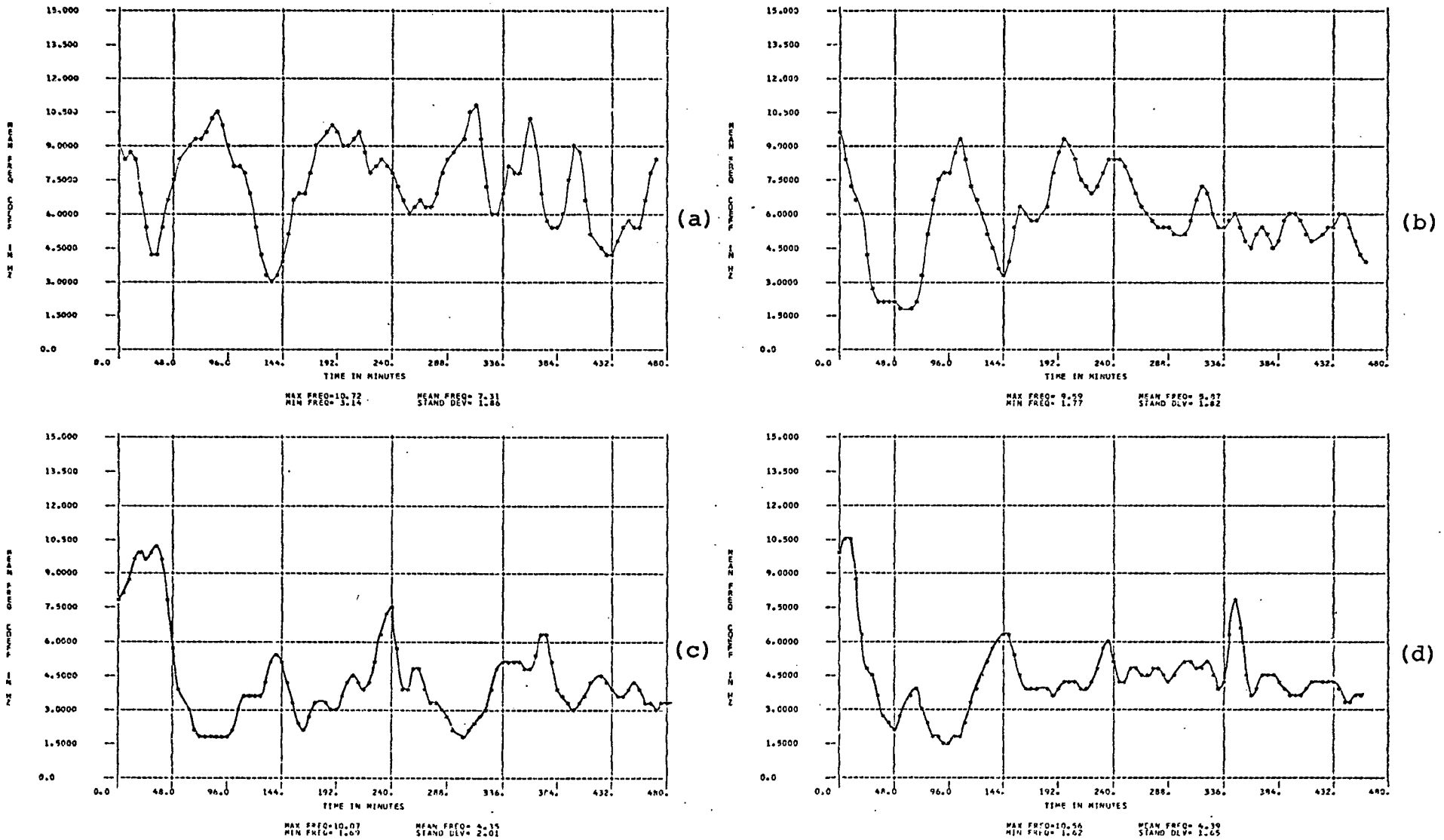


FIGURE 4.13 Subject SD3 - Mean Frequency Coefficient (MFC)
(a) 1st night, record #15030 (b) 3rd night, record #15044
(c) 8th night, record #15079 (d) 13th night, record #15105

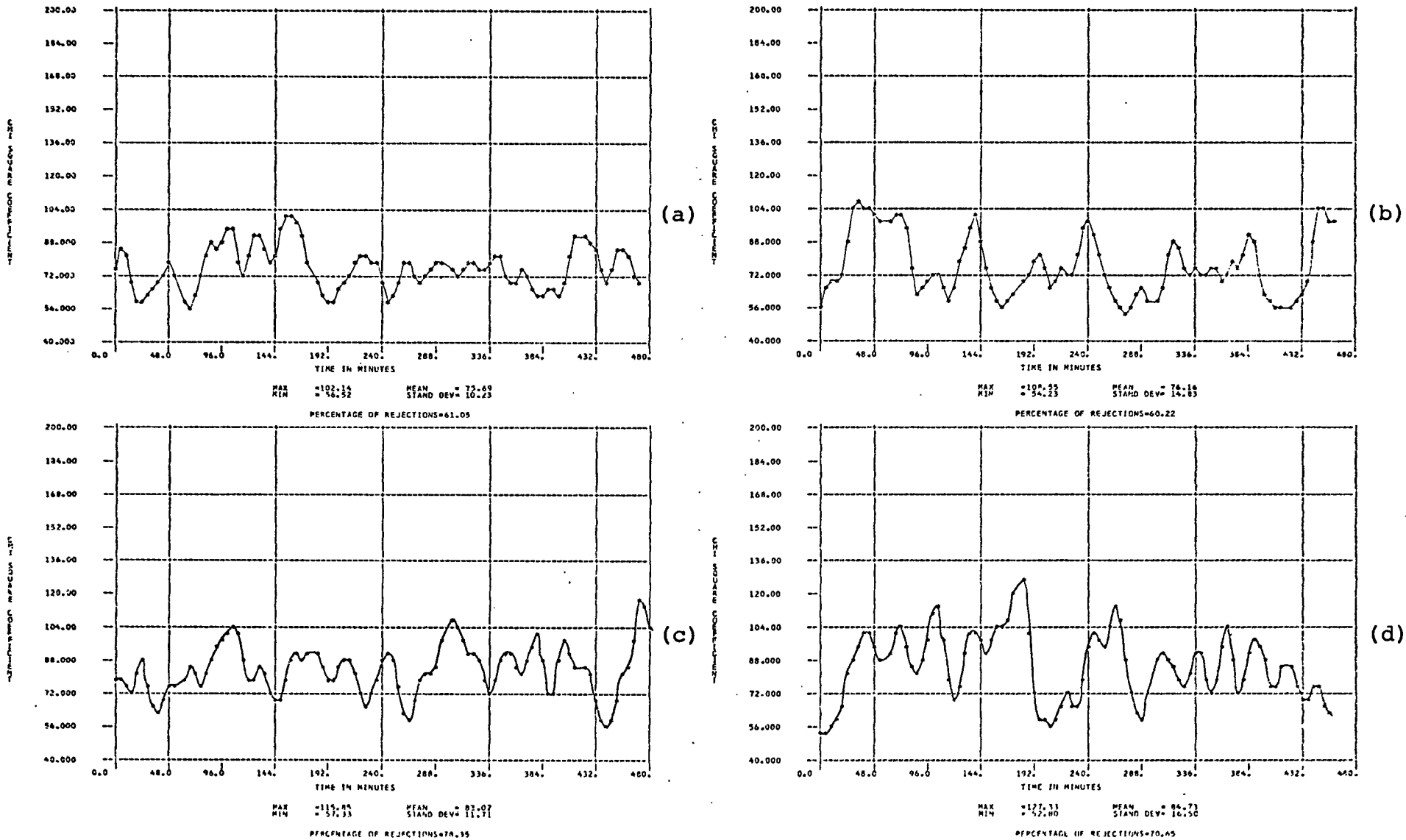


FIGURE 4.15 Subject SD3 - Chi-Square Coefficient
(a) 1st night, record #15030 (b) 3rd night, record #15044
(c) 8th night, record #15079 (d) 13th night, record #15105

The plots for the X^2 coefficients are shown in Figures 4.15a, b, c and d. The mean and the percentage of rejection for the X^2 coefficient followed the same upward trend observed in the previous subjects. The mean and the percentage of rejections increased 12 and 16%, respectively, between the 1st and the 13th nights.

4.2.4 Discussion of Results of the Subjects in Group 1 Withdrawn from Secobarbital

Table 4.10 contains comparisons of the changes in the output results of FEATURE between the last and the first nights that were processed for each of the subjects in the Group 1, that were withdrawn from secobarbital. This table summarizes the results already presented in Tables 4.3, 4.6, and 4.9.

From Table 4.10 we can see that the mean percentage of power in the Delta Band increased with the withdrawal of the drug in all subjects. Subject SD1, who started with the highest titration dosage (1000mg of secobarbital) in the Group, had the largest increase (70%) and the other two subjects showed increases above 40%. In addition, two of the subjects, SD1 and SD3, showed a marked increase in the mean frequency peak in this band as the drug was withdrawn. This is equivalent to saying that the drug caused not only a reduction in the percentage of power in the Delta Band, but that it also slowed down the "frequency" of the "delta waves." This reduction in the percentage of power is accompanied by

TABLE 4.10

Summary of the Results of Tables 4.3, 4.6 and 4.9 for in Subjects in Group 1 - Secobarbital

SUBJECTS			SD1	SD2	SD3
TITRATION DOSAGE (mg)			1000	500	350
DELTA BAND (0.0-3.5Hz)	PERC. OF POWER	MEAN	+70%	+43%	+47%
	FREQ. PEAK (Hz)	MEAN	+20%	+ 7%	+13%
THETA BAND (4.0-7.5Hz)	PERC. OF POWER	MEAN	+40%	+19%	+50%
	FREQ. PEAK (Hz)	MEAN	-20%	+10%	- 7%
ALPHA BAND (8.0-11.5Hz)	PERC. OF POWER	MEAN	-38%	-37%	- 4%
	FREQ. PEAK (Hz)	MEAN	- 9%	- 3%	+ 1%
SIGMA BAND (12.0-15.5Hz)	PERC. OF POWER	MEAN	-68%	-67%	-39%
	FREQ. PEAK (Hz)	MEAN	+ 5%	+ 5%	+ 4%

TABLE 4.10

(continued)

SUBJECTS			SD1	SD2	SD3
TITRATION DOSAGE (mg)			1000	500	350
BETA1 BAND (16.0-20.5Hz)	PERC. OF POWER	MEAN	_71%	-75%	-72%
	FREQ. PEAK (Hz)	MEAN	+ 2%	+0.5%	+ 3%
BETA2 BAND (21.0-29.5Hz)	PERC. OF POWER	MEAN	-41%	-73%	-81%
	FREQ. PEAK (Hz)	MEAN	+ 3%	+ 2%	+ 4%
FASTF BAND (30.0-40.0Hz)	PERC. OF POWER	MEAN	-70%	-73%	-87%
	FREQ. PEAK (Hz)	MEAN	- 1%	- 3%	0.3%
x^2	MEAN		+63%	+16%	+12%
	PERCENTAGE OF REJECTIONS		+210%	+13%	+16%
MFC	MEAN		-37%	-41%	-40%

an increase in the power in the higher frequency bands, as we can clearly see from the CSA plots. The amount of power in a frequency band is a function of the amplitude as well as the amount of activity present in that particular frequency. In this way, using only spectral analysis results, we cannot say for sure that the reduction of power in the Delta Band is caused only by a reduction in the amplitude of the delta waves, because it can also be caused by a decrease in the number of these waves, or by both. Spectral analysis is, by its own nature, a good descriptor of the "background" EEG activity in the different sleep stages, especially regarding the "frequency content" in the different bands. A good example of this occurs in the 5th night of subject SD1, in which the results of the manual scoring show no sleep stages 3 or 4 present during the night. However, the CSA plot for this night, Figure 4.1a, shows the presence of relatively high intensity peaks in the Delta Band at the beginning of the night. This could suggest that the patient even under the effects of a large dosage of the drug, may generate sufficient activity in the delta frequency band to qualify as stage 3, or, perhaps, stage 4 sleep, although the EEG voltage did not reach the 75 μV threshold, required by the visual scorer, for acceptance as delta activity. (Williams et al, 1964).

There is disagreement among investigators on to the effects of barbiturates on sleep. Most studies report no significant change in delta sleep after barbiturates

(Kay, 1973). Lester et al (1968) reported changes in the distribution of the delta sleep throughout the night, after the administration of 200 mg of secobarbital to a group of 14 college students. However, the drug did not cause a significant change in the total amount of delta sleep, computed by using period analysis techniques. In the present study we do observe changes in the 90-100 minutes delta rhythm that is present in normal subjects (Lubin et al, 1973) as shown in the plots vs time of the percentage of power in the delta band (Figures 4.2, 4.7, and 4.12). The drug also caused the suppression of some of the delta peaks in these plots. This can be further illustrated by the plots for subject SD1., Figures 4.2a, b, c and d, in which the second delta peak was completely suppressed in the first two nights

The average percentage of power in the Sigma Band decreased with the withdrawal of the drug in all three subjects. Two of them showed changes above 60%. The mean frequency peak in this band increased 4-5% for all the subjects, which is equivalent to a slowdown of 0.5-0.6 Hz in the frequency of the spindle activity due to the effects of the drug. These results agree with several studies in the literature (Kay et al, 1972 and Kay, 1973).

From Table 4.10 we can also see that there is a reduction in the average percentage of power in the Alpha, Betal and Beta2, and FASTF frequency bands with the withdrawal of the drug. An opposite trend is observed in the mean percentage of power in the Theta Band.

The average frequencies computed for each night showed a downward trend with the withdrawal of the drug. Table 4.10 shows that the subjects in this group had a reduction in the mean frequency between 37 and 41% during the treatment. For two of the subjects, SD1 and SD2, we can see from Tables 4.2 and 4.8 that although the mean frequency for each night was decreasing as the drug was being withdrawn, the standard deviation for each subject stayed practically constant from night to night. This could suggest that the basic mechanism responsible for the EEG's frequency shifts during the night was not seriously affected by the drug and that the changes in the mean frequency from night to night were probably due to the changes in the amount of slow and fast wave activities.

The mean value and the percentage of rejections (percentage of epochs in which the computed X^2 fell outside the region of acceptance for the chi-square test for goodness-of-fit to a Gaussian distribution) of the X^2 coefficients increased in all subjects with the withdrawal of the drug. The highest changes were shown by subject SD1. From Table 4.2 we can see that during the night following the subject's titration procedure (5th night, record #15322) the EEG amplitude followed a Gaussian probability density function in 73% of the epochs during the night. By the 16th night this number was reduced to 13.2%. The other two subjects followed the same trend, but with much less variability. This suggest that the EEG's amplitude distribution had become

more Gaussian due to the effects of the drug. Furthermore, it seems that the degree of Gaussianity is related to the initial amount of drug given to the subjects. It has been suggested that, on the basis of the Central Limit theorem, increased Gaussianity in observed EEG activity may reflect an increased degree of independence among individual cortical neural generators (Elul, 1969). A similar increase was also observed by McEwen et al (1975) in subjects under halothane anesthesia.

4.3 GROUP 1 - METHAQUALONE

4.3.1 Subject SD4

4.3.1.1 Subject's Protocol

Subject SD4, a 25 year-old female, was intreatment at the Poly Drug Treatment Unit for 14 days. After the discharge the subject reported to the hospital for two additional nights. The subject's complete withdrawal schedule is shown in Table 2.2. Table 4.11 shows the four nights that were selected for analysis, the daily amount of drug administered and the corresponding record number for each night. It was not possible to process any of the nights close to the subject's discharge from the hospital, due to the lack of good analog tape recordings for these nights.

TABLE 4.11

Analyzed Data for Subject SD4

Night	Record Number	Daily Dosage (mg)
1st	14497	2100
3rd	15006	1500
7th	15024	600
11th[1]	15050	0

[1]Night following the first day of zero drug intake.

4.3.1.2 Compressed Spectral Array Results

Figures 4.16a, b, c and d show the CSA plots for the nights listed in Table 4.11. For the 1st and 3rd nights. Figures 4.16a and b, the activity in the Delta Band was present most of the time as low intensity peaks, except at the beginning of the nights when there are large peaks. These delta peaks are, however, of less intensity in the 3rd night. For both nights the subject's alpha activity produced spectral peaks centered around 7.0-7.5 Hz. For the 3rd night this is only true at the beginning of the night, since some spectral peaks are seen in the Alpha Band at 10.0-10.5 Hz in the second half of the night. The Sigma Band shows well-defined high intensity peaks around 13.0-13.5 Hz. These peaks, however, are of lower intensity in the 3rd night. Some low intensity activity can also be seen in the Betal and Beta2 Bands during the 1st night.

In the 7th night, Figure 4.16c, when the subject's daily intake of drug has been reduced to 600 mg, several

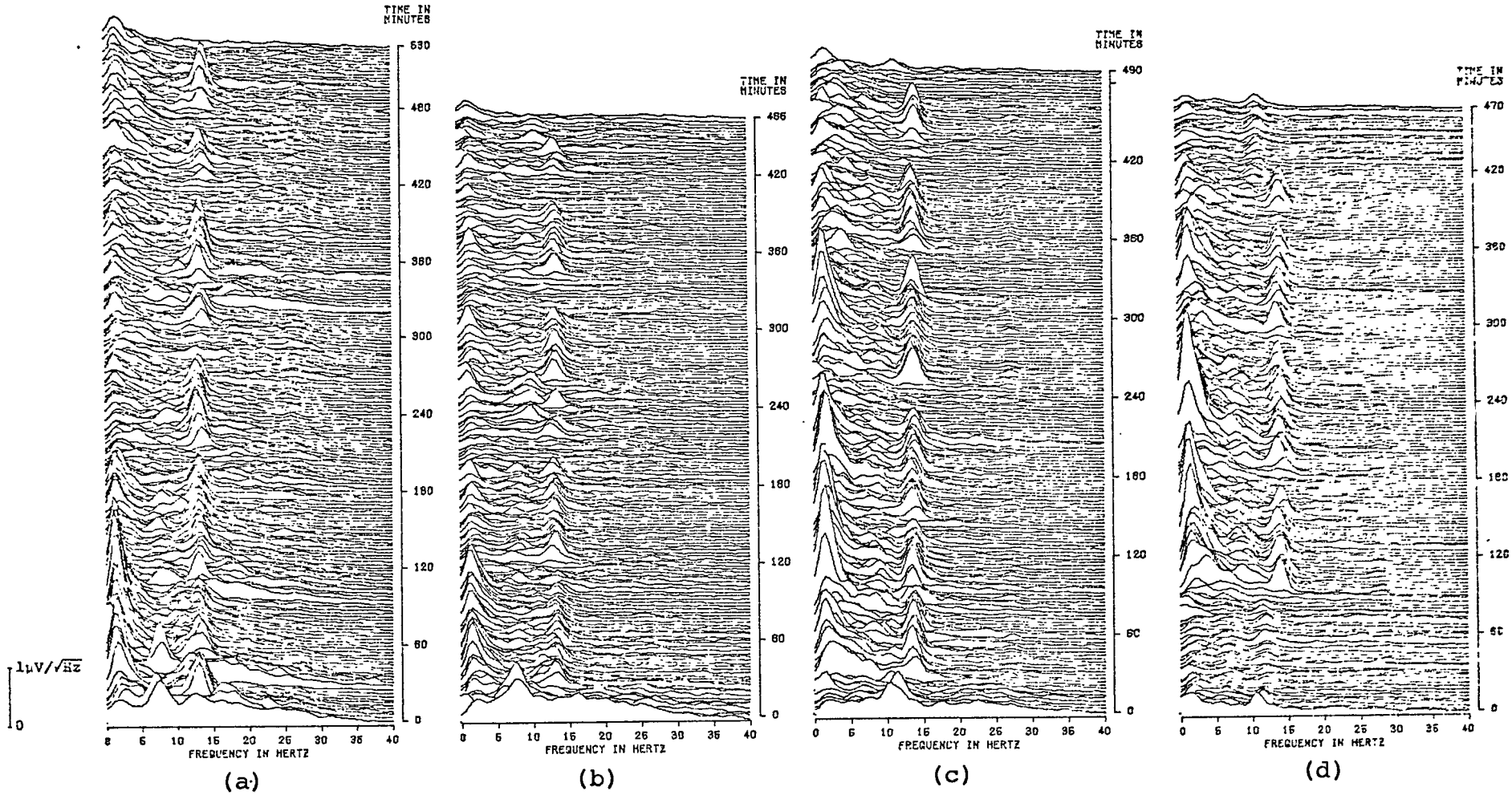


FIGURE 4.16 Subject SD4 - Compressed Spectral Array (CSA)
(a) 1st night, record #14497 (b) 3rd night, record #15006
(c) 7th night, record #15024 (d) 11th night, record #15050

changes have taken place mainly in the Delta and Alpha Bands. The frequency peaks corresponding to the subject's alpha activity has moved from 7.0-7.5 Hz to 10.0-11.0 Hz and its intensity is much lower. In the Delta Band a new cluster of high intensity peaks are present in the beginning of the second half of the night. The high intensity peaks in the Sigma Band are still present and its center frequency is now shifted between 13.5 and 14 Hz.

The first 90 minutes of the 11th night, Figure 4.16d, are dominated by alpha activity which resulted in spectral peaks centered around 10.5-11.5 Hz. In the Delta Band there are two clusters of high intensity spectral peaks The central frequency of the spectral peaks in the Sigma Band is now between 14 and 14.5 Hz.

4.3.1.3 Summary of the Output Results from the FEATURE Algorithm

In Table 4.12 the results of the data reduction analysis performed by FEATURE are given. From these results we can see that due to the effects of the drug there is a tendency for the mean percentage of power in the low fre- bands (Delta and Theta) to decrease in the first night when compared to the results in the 11th night. The mean value and the percentage of rejection of the X^2 coefficient also follow the same trend. An upward trend is, however, shown by the mean percentage of power in the Sigma, Betal, Beta2 and FASTF frequency bands and by the mean of the MFCs.

TABLE 4.12

Summary of the Output Results from FEATURE for Subject SD4

NIGHT			1st	3rd	7th	11th
RECORD NUMBER			14497	15006	15024	15050
DOSAGE (mg)			2100	1500	600	0
DELTA BAND (0.0-3.5Hz)	PERC. OF POWER	MEAN	31.8	28.7	36.3	38.8
		STD	11.8	10.4	8.6	10.5
	FREQ. PEAK (Hz)	MEAN	1.7	1.8	1.9	2.0
		STD	0.5	0.6	0.7	0.6
THETA BAND (4.0-7.5Hz)	PERC. OF POWER	MEAN	15.5	16.9	23.2	24.4
		STD	3.9	3.0	5.0	3.5
	FREQ. PEAK (Hz)	MEAN	6.4	5.9	6.0	6.0
		STD	1.1	1.2	1.1	0.8
ALPHA BAND (8.0-11.5Hz)	PERC. OF POWER	MEAN	12.1	15.5	13.5	15.9
		STD	3.4	4.4	3.3	3.7
	FREQ. PEAK (Hz)	MEAN	9.6	9.3	9.5	10.2
		STD	1.1	1.1	1.2	1.3
SIGMA BAND (12.0-15.5Hz)	PERC. OF POWER	MEAN	18.5	15.7	14.2	10.6
		STD	9.4	6.7	6.6	2.4
	FREQ. PEAK (Hz)	MEAN	13.2	13.4	13.6	14.1
		STD	0.7	0.7	0.5	0.6

TABLE 4.12

(continued)

NIGHT			1st	3rd	7th	11th
RECORD NUMBER			14497	15006	15024	15050
DOSAGE (mg)			2100	1500	600	0
BETA1 BAND (16.0-20.5Hz)	PERC. OF POWER	MEAN	8.1	7.2	4.0	3.8
		STD	4.0	2.8	1.9	1.9
	FREQ. PEAK (Hz)	MEAN	18.4	18.4	18.7	18.4
		STD	1.2	1.3	1.3	1.3
BETA2 BAND (21.0-29.5Hz)	PERC. OF POWER	MEAN	8.6	8.9	4.5	4.3
		STD	4.6	3.9	3.4	3.5
	FREQ. PEAK (Hz)	MEAN	24.7	24.5	24.9	24.5
		STD	2.2	2.4	2.6	2.5
FASTF BAND (30.0-40.0Hz)	PERC. OF POWER	MEAN	2.8	4.8	1.7	1.9
		STD	1.5	2.0	1.0	2.0
	FREQ. PEAK (Hz)	MEAN	33.6	33.4	33.3	33.6
		STD	2.3	2.3	2.4	2.3
x^2	MEAN		72.9	76.2	83.6	87.6
	STD		13.4	14.9	12.4	19.2
	PERCENTAGE OF REJECTIONS		57.0	59.6	77.8	75.8
MFC	MEAN		8.2	8.9	6.9	6.5
	STD		2.1	2.1	1.7	1.7

	DELTA BAND	THETA BAND	ALPHA BAND	SIGMA BAND	BETA1 BAND	BETA2 BAND	FASTF BAND	X^2 COEF.	MFC
MEAN PERC. OF POWER	+ 22%	+ 56%	+ 31%	- 43%	- 53%	- 49%	- 32%	-	-
MEAN FREQ. PEAK	+ 18%	- 6%	+ 7%	+ 7%	0%	- 1%	0%	-	-
MEAN	-	-	-	-	-	-	-	+ 20%	- 21%
PERC. OF REJECTIONS	-	-	-	-	-	-	-	+ 33%	-

TABLE 4.13 Subject SD4 - Percentage Change in the Results of Table 4.12 Between the Last and the First Nights

Table 4.13 shows, in terms of percentage, the changes in the results of Table 4.12 between the last and the first nights in consideration. However, these results should be compared with caution with the previous ones, mainly due to the shorter interval of time between the 11th night and the last day the subject took the drug.

Figures 4.17a, b, c and d show the plots of the percentage of power in the Delta Band for the 1st, 3rd, 7th and 11th nights respectively. The 1st and 3rd nights, Figures 4.17a and b, show a similar kind of pattern, with two large peaks in the first third of the night. The mean percentage of power for the two nights was 31.8 and 28.7%, respectively. In the 7th night, Figure 4.17c, two large peaks can be seen, located around minutes 115 and 280 respectively. In between them there are two other peaks with smaller amplitudes. The mean percentage of power for the night has increased to 36.3%. The plot for the 11th night, Figure 4.17d, shows two high amplitude peaks in the first half of the night, and the mean percentage of power for the night was 38.4%. Table 4.13 shows that the mean percentage of power in the Delta Band has increased 21% between the 1st and the 11th nights. The mean frequency in this band has also increased 18% in the same period.

In Figures 4.18a, b, c and d the plots of the percentage of power in the Sigma Band for the four nights are presented. The first three nights show well-defined high amplitude peaks. The means of the percentage of power for

these three nights were 18.5, 15.7 and 14.2% respectively. By the 11th night, Figure 4.18d, the high amplitude peaks have disappeared and the mean percentage of power is reduced to 10.6%. From Table 4.13 we can see that the average percentage of power in the Sigma Band has decreased 43% between the 1st and the 11th nights. In the same period the mean frequency peak in the band has changed from 13.2 to 14.1 Hz (Table 4.12).

The Mean Frequency Coefficients (MFC) for the nights listed in Table 4.12, are plotted in Figures 4.19a, b, c and d. For the 1st night the mean frequency in most of the epochs was above 7.5 Hz, except for a low frequency dip in the beginning of the night which reached the frequency of 3Hz. The mean frequency for the entire night was 8.2 Hz. In the 3rd night the low frequency dip was still present at the beginning of the night as shown in Figure 4.19b, and the activity for the rest of the night was dominated by fast frequency waves which resulted in the MFC points being above 8 Hz. The mean frequency during this night was 8.9 Hz. By the 7th night, Figure 4.19c, the mean frequency has decreased to 6.9 Hz and there is only one frequency dip of short duration in the first third of the night. In the first 90 minutes of the 11th night, Figure 4.19d, the MFC's in the epochs stayed above 7.5 Hz, reflecting the activity in the Alpha Band, as shown by the CSA plot in Figure 4.16d. There are two low frequency dips before the first half of the night. In the last 60 minutes the alpha activity was again dominant.

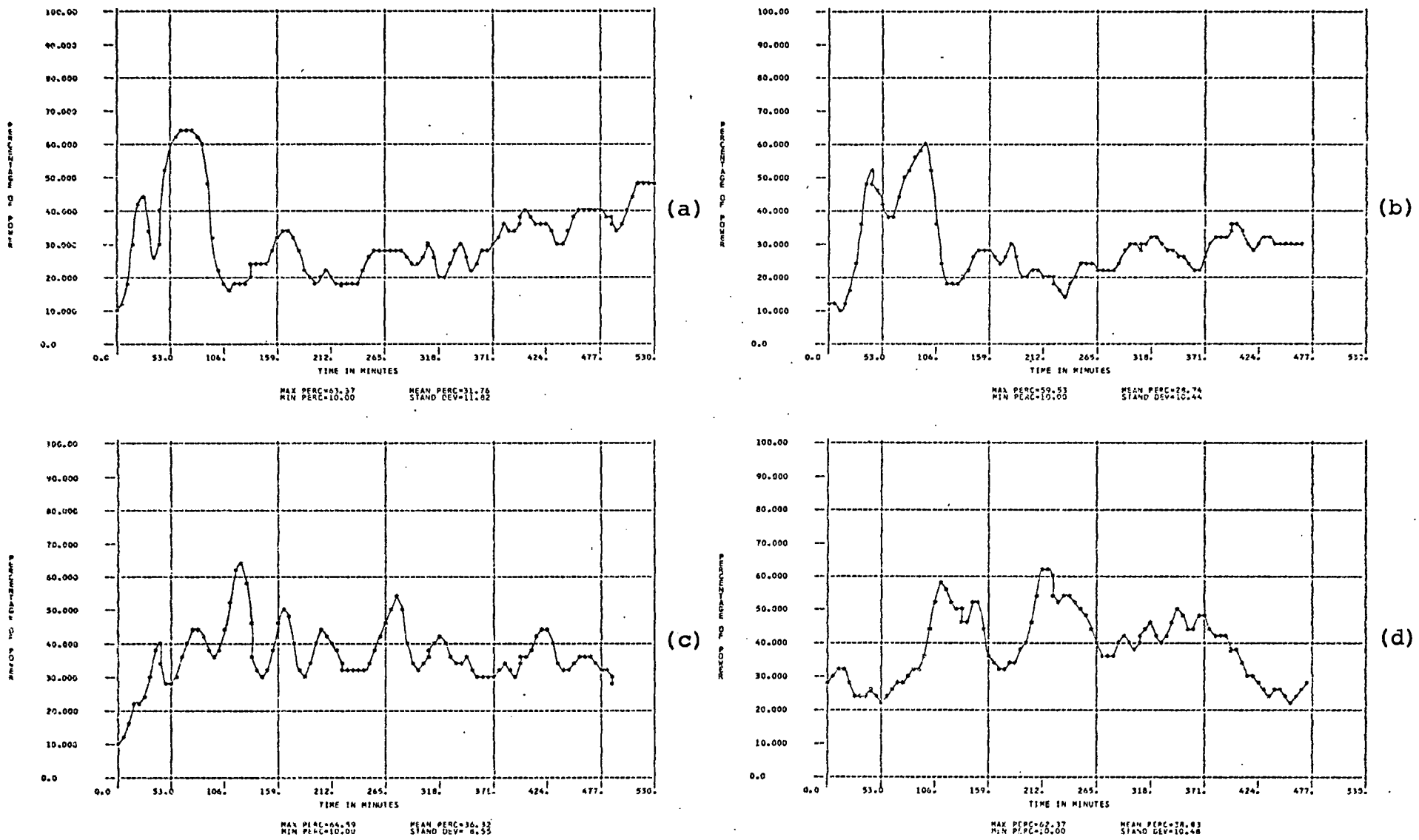


FIGURE 4.17 Subject SD4 - Percentage of Power in the Delta Band
(a) 1st night, record #14497 (b) 3rd night, record #15006
(c) 7th night, record #15024 (d) 11th night, record #15050

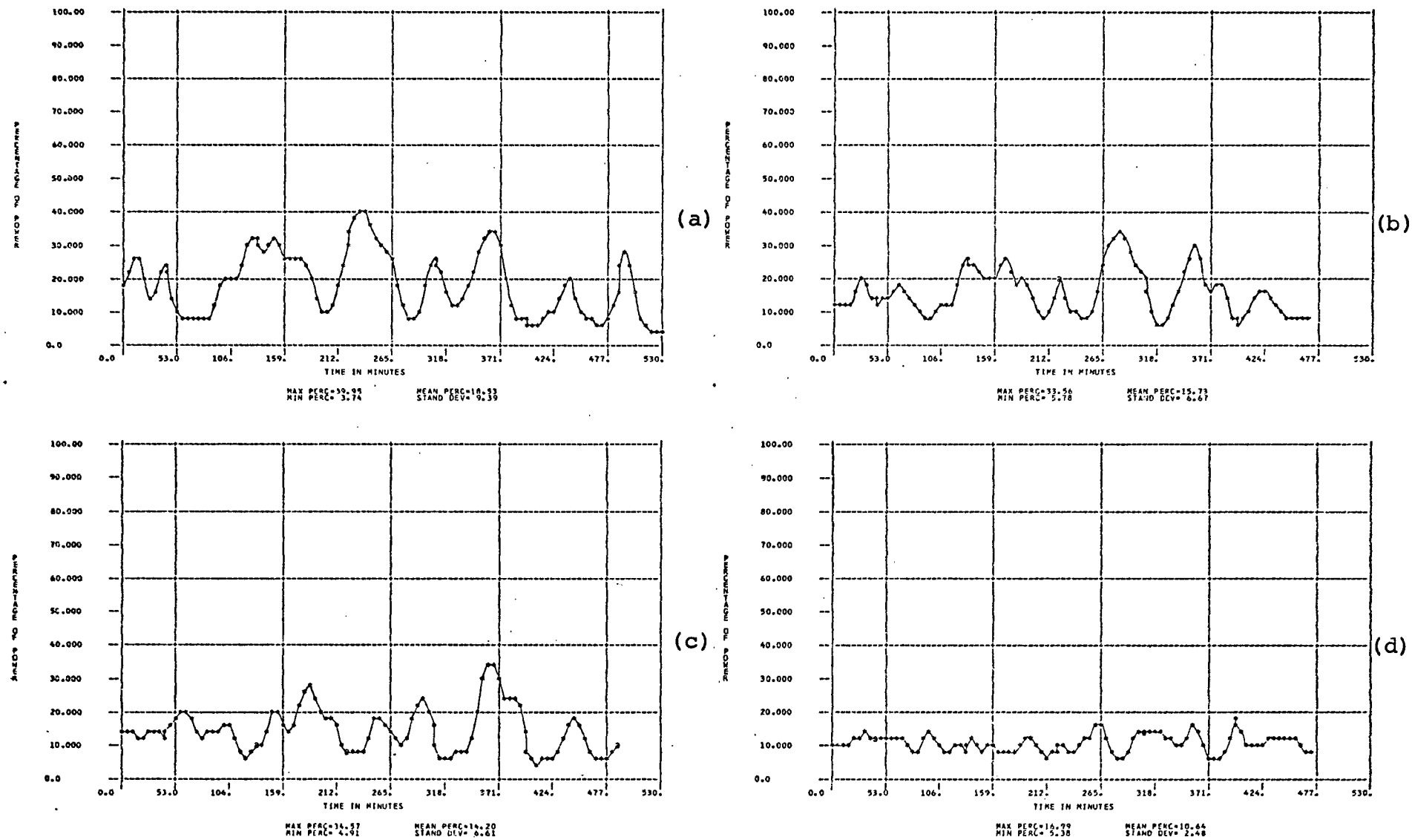


FIGURE 4.18 Subject SD4 - Percentage of Power in the Sigma Band
(a) 1st night, record #14497 (b) 3rd night, record #15006
(c) 7th night, record #15024 (d) 11th night, record #15050

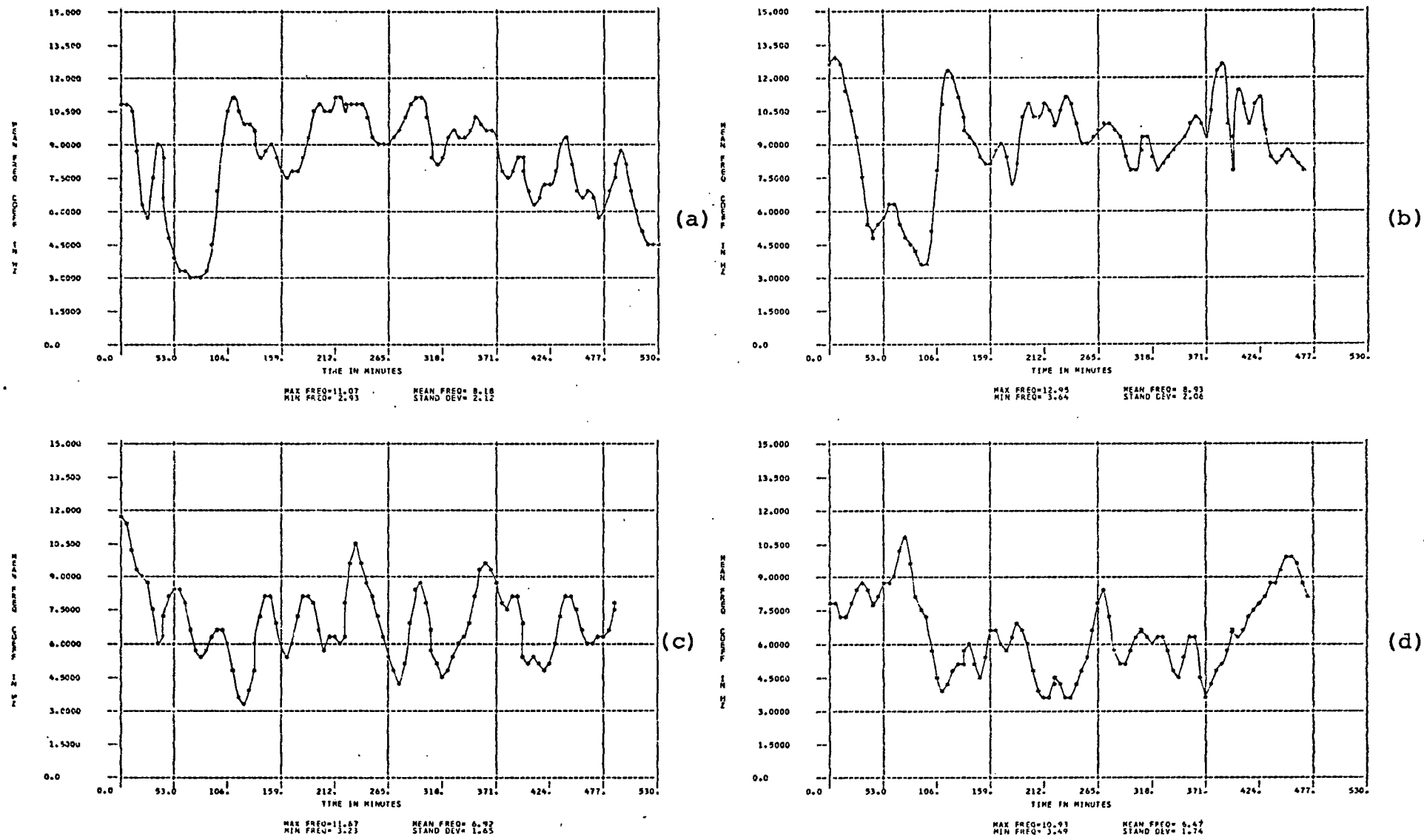


FIGURE 4.19 Subject SD4 - Mean Frequency Coefficient (MFC)
(a) 1st night, record #14497 (b) 3rd night, record #15006
(c) 7th night, record #15024 (d) 11th night, record #15050

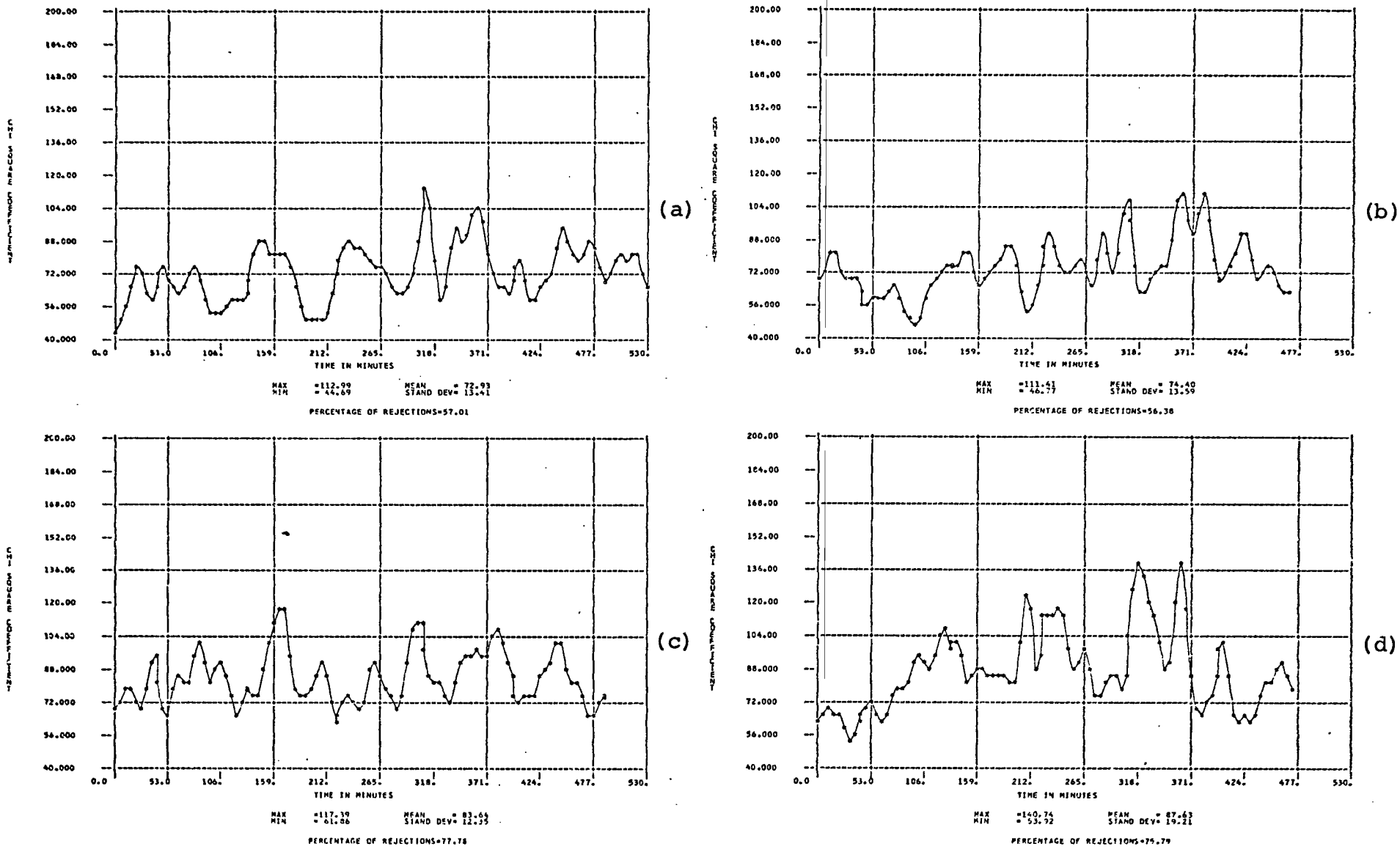


FIGURE 4.20 Subject SD4 - Chi-Square Coefficient
(a) 1st night, record #14497 (b) 3rd night, record #15006
(c) 7th night, record #15024 (d) 11th night, record #15050

The mean frequency for this night was 6.5 Hz. According to the results of Table 4.13, the mean frequency decreased 21% between the 11th and the 1st nights.

In Figures 4.20a, b, c and d the plots of the X^2 coefficient for the four nights are shown. In the first two nights, Figures 4.20a and b, more than 40% of the epoch had an EEG with a Gaussian amplitude distribution and the mean value of the X^2 coefficients were 72.9 and 74.4 respectively. These values were up to 83.6 and 83.5 in the last two nights (Figures 4.20c and d), and the percentage of epochs with a Gaussian distribution has decreased to 22.2 and 34.7 respectively. The average value and the percentage of rejections for the X^2 coefficient have increased 20 and 33% between the 1st and the 11th nights respectively (Table 4.13).

4.3.2 Subject SD5

4.3.2.1 Subject's Protocol

Subject SD5, a 35 year-old male, was patient at the Poly Drug Unit for 15 days. After the discharge, the subject slept at the hospital on three consecutive nights (16th, 17th and 18th). It was reported that he had been drinking heavily since after leaving the hospital. Table 4.14 shows the nights that were automatically processed, the daily amount of drug given to the subject and the corresponding record number for each night. This table was derived from Table 2.2, in which the subject's withdrawal schedule is

shown. Due to technical problem with the tape recorder, the first 40 minutes of the 13th night (record #15063) were not recorded on magnetic tape. According to the score sheet for this night, the subject spent the first 61 minutes of the night in stage 0 sleep. The only reason to process this record is that no other record was available before the subject's discharge from the hospital, and due to his drinking problem the data collected after this time would be questionable.

TABLE 4.14

Analyzed Data for Subject SD5

Night	Record Number	Daily Dosage (mg)
1st	14498	3000
3rd	15007	2100
5th	15016	1875
13th[1]	15063	0

[1]This night correspond to the first day the subject was out of the drug.

4.3.2.2 Compressed Spectral Array

The CSA plots for the nights listed in Table 4.14 are shown in Figures 4.21a, b, c and d. In the last night, Figure 4.21a, the activity in the Delta Band is characterized by low intensity spectral peaks throughout the night, except for some high intensity peaks towards the end of the night. Most of the energy, however, is concentrated in the

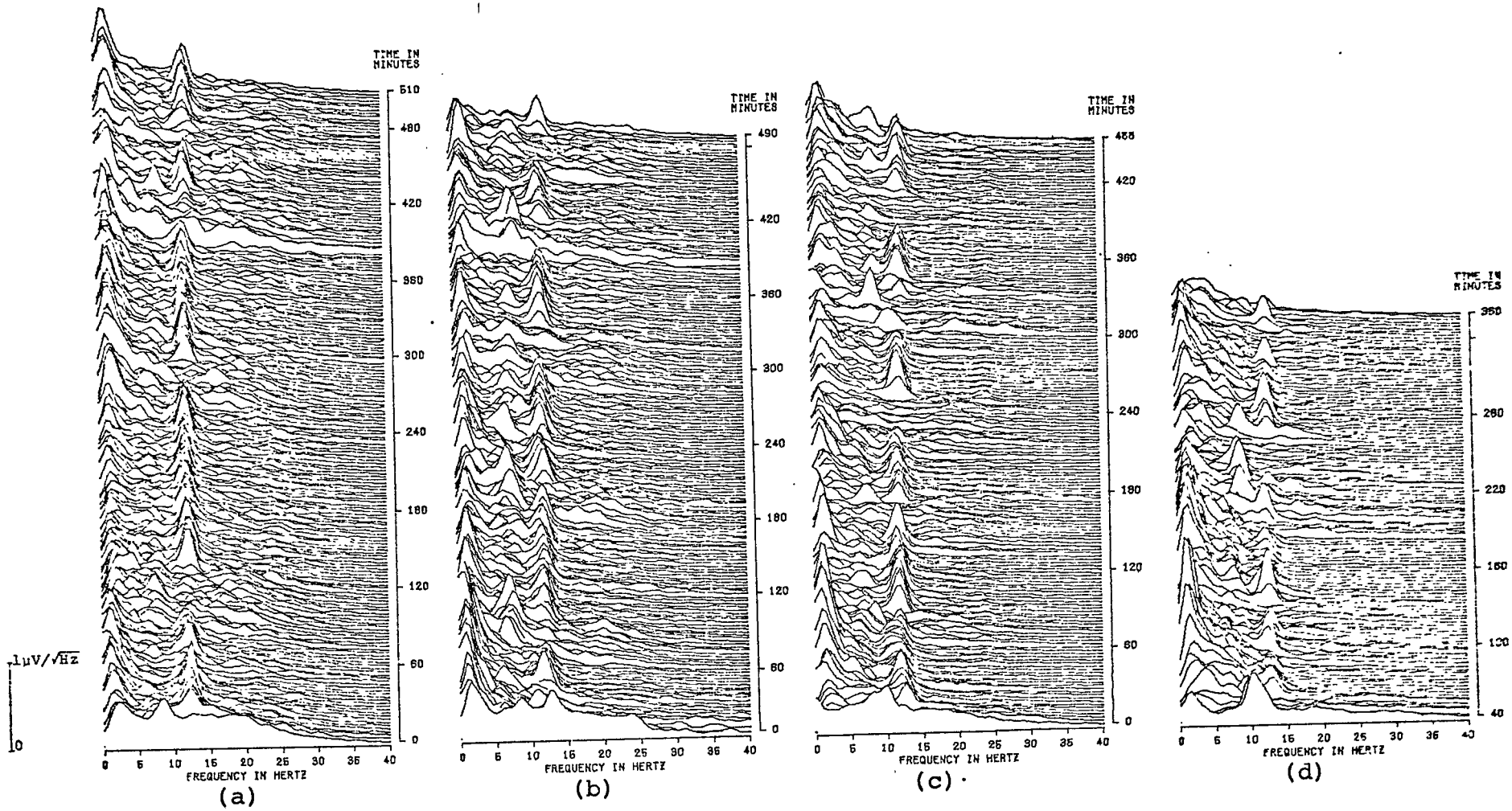


FIGURE 4.21 Subject SD5 - Compressed Spectral Array (CSA)
(a) 1st night, record #14498 (b) 3rd night, record #15007
(c) 5th night, record #15016 (d) 13th night, record #15063

Sigma Band, where high intensity peaks are present around 12.0-12.5 Hz. The peaks in the Alpha Band are centered at 8.5 Hz. Activity in the Betal and Beta2 frequency bands can also be seen. In the 3rd night, Figure 4.21b, the CSA plot shows that there is a little increase in the intensity of the peaks in the Delta Band at the beginning of the night. However, the main observable change in this plot is the decrease in the intensity of the peaks in the Sigma Band. Activity in the Beta Bands can still be seen. The decrease in activity in the Sigma Band continued in the 5th night, Figure 4.21c, and a cluster of high intensity peaks in the Delta Band started forming at the beginning of the night. As we had already explained in Section 4.3.2.1, 40 minutes of EEG are missing in the beginning of the 13th night. This was indicated in the CSA plot, Figure 4.21d, by starting the time axis at minute 40. As we can see from this plot, after the first hour of sleep some high intensity peaks are present in the Delta Band. The activity in the Sigma Band is much lower than in the previous nights. The peaks in the Alpha Band are now centered around 10 Hz.

4.3.2.3 Summary of the Output Results from the FEATURE Algorithm

The results of the data reduction analysis, performed by FEATURE are shown in Table 4.15. These results show the same kind of trends already described for subject SD4. In Table 4.16, the changes in the results of Table 4.15, between the first and last nights that were processed are

TABLE 4.15

Summary of the Output Results from FEATURE for Subject SD5

NIGHT			1st	3rd	5th	13th
RECORD NUMBER			14498	15007	15016	15063
DOSAGE (mg)			3000	1875	1650	0
DELTA BAND (0.0-3.5Hz)	PERC. OF POWER	MEAN	34.0	34.0	40.1	45.1
		STD	8.5	10.0	10.0	9.8
	FREQ. PEAK (Hz)	MEAN	1.6	1.7	1.6	1.8
		STD	0.4	0.7	0.6	0.5
THETA BAND (4.0-7.5Hz)	PERC. OF POWER	MEAN	17.6	22.4	22.0	25.1
		STD	2.5	4.6	2.4	3.2
	FREQ. PEAK (Hz)	MEAN	6.2	6.5	6.2	6.2
		STD	0.9	0.8	1.0	1.1
ALPHA BAND (8.0-11.5Hz)	PERC. OF POWER	MEAN	15.5	18.1	14.9	13.4
		STD	3.4	4.3	4.3	5.6
	FREQ. PEAK (Hz)	MEAN	9.0	9.6	9.5	9.3
		STD	1.2	1.3	1.3	1.1
SIGMA BAND (12.0-15.5Hz)	PERC. OF POWER	MEAN	15.8	11.6	10.5	6.6
		STD	4.8	3.6	4.2	2.6
	FREQ. PEAK (Hz)	MEAN	12.5	12.7	12.7	13.0
		STD	0.7	1.1	1.0	0.9

TABLE 4.15

(continued)

NIGHT			1st	3rd	5th	13th
RECORD NUMBER			14498	15007	15016	15063
DOSAGE (mg)			3000	1875	1650	0
BETA1 BAND (16.0-20.5Hz)	PERC. OF POWER	MEAN	7.5	5.9	4.9	3.4
		STD	2.9	3.0	3.1	2.3
	FREQ. PEAK (Hz)	MEAN	18.3	18.2	18.0	18.3
		STD	1.21	1.2	1.4	1.2
BETA2 BAND (21.0-29.5Hz)	PERC. OF POWER	MEAN	5.7	4.4	3.5	2.6
		STD	1.7	2.4	2.3	1.8
	FREQ. PEAK (Hz)	MEAN	23.7	23.8	23.9	23.8
		STD	2.0	2.4	1.9	2.1
FASTF BAND (30.0-40.0Hz)	PERC. OF POWER	MEAN	0.9	0.9	0.7	0.6
		STD	0.4	0.8	0.4	0.4
	FREQ. PEAK (Hz)	MEAN	33.3	33.5	33.1	32.6
		STD	2.3	2.4	2.3	2.2
x^2	MEAN		68.5	66.0	85.6	88.6
	STD		12.1	7.7	16.4	17.2
	PERCENTAGE OF REJECTIONS		46.6	47.5	80.4	81.5
MFC	MEAN		7.3	6.5	6.0	4.9
	STD		1.2	1.7	1.9	1.7

	DELTA BAND	THETA BAND	ALPHA BAND	SIGMA BAND	BETA1 BAND	BETA2 BAND	FASTF BAND	X^2 COEF.	MFC
MEAN PERC. OF POWER	+ 33%	+ 43%	- 14%	- 58%	- 55%	- 54%	- 30%	-	-
MEAN FREQ. PEAK	+ 13%	0%	+ 3%	+ 4%	0%	+0.4%	- 2%	-	-
MEAN	-	-	-	-	-	-	-	+ 29%	-33%
PERC. OF REJECTIONS	-	-	-	-	-	-	-	+ 75%	-

TABLE 4.16 Subject SD5 - Percentage Change in the Results of Table 4.15 Between the Last and First Nights

shown. The results in this table should be looked with caution due to the following: (1) technical problems with the analog magnetic tape in the 13th night (record #15063), as we have already mentioned in Section 4.3.2.1 and (2) the date of this night is not far enough from the date of the last ingestion of the drug, as it was in the other patients (with the exception of SD4). In fact, as we can see from Table 2.3, this was the first night the subject was not taking the drug.

The plots for the percentage of power in the Delta Band are shown in Figures 4.22a, b, c and d. In the 1st night, Figure 4.22a, only two peaks can be seen, one at the beginning of the night and the other around minute 380. The plot for the 3rd night, Figure 4.22b, shows three well-defined peaks. Of those the first one is of higher amplitude than the peaks in the 1st night. The average percentage of power stayed at 34% for both nights. By the 5th night, the mean percentage of power in the band was up to 40%, four peaks are present in the plot (Figure 4.22c) and the amplitude of the first peak has risen even further. In the 13th night, Figure 4.22d, three peaks are present and of those the second one has the largest amplitude. The average percentage of power for the night has increased to 45%. Table 4.16 shows that the average percentage of power and the mean frequency in the Delta Band have increased 33 and 13% respectively between the first and the last nights.

Figures 4.23a, b, c and d show the plots for the percentage of power in the Sigma Band. In the first three nights the amplitude of the peaks stayed relatively high, declining sharply in the last night. From Table 4.16 we can see that the average percentage of power in the band has decreased 58% between the 1st and 13th nights. In the same period the mean frequency in the band has increased 4%.

The plots for the Mean Frequency Coefficients (MFC) are shown in Figures 4.24a, b, c and d. In the 1st night, Figure 4.24a, most of the MFC points are above the 6.5 Hz frequency line, with a mean frequency for the night of 7.3 Hz. In the 2nd night, Figure 4.24b, a low frequency dip can be clearly seen in the beginning of the plot. This dip went below the 2.5 Hz line. The mean frequency for the night is down to 6.5 Hz, reflecting mainly a decrease in the activity in the Sigma Band as shown by the CSA plot in Figure 4.21b. Figure 4.24c shows the plot for the 5th night, in which the low frequency dip is still present in the beginning of the night, except that now it went close to 2 Hz. The mean frequency for the night continued its downward trend reaching now 6 Hz. In the 13th night, Figure 4.24d, there are two low frequency dips that went below 3 Hz, and the mean frequency for the night is 4.9 Hz. This last result would probably be higher if the first 40 minutes of the night were not deleted, since, according to the manual scoring, the subject was in stage 0 sleep during that time. From Table 4.16, we can see that the mean frequency during the night

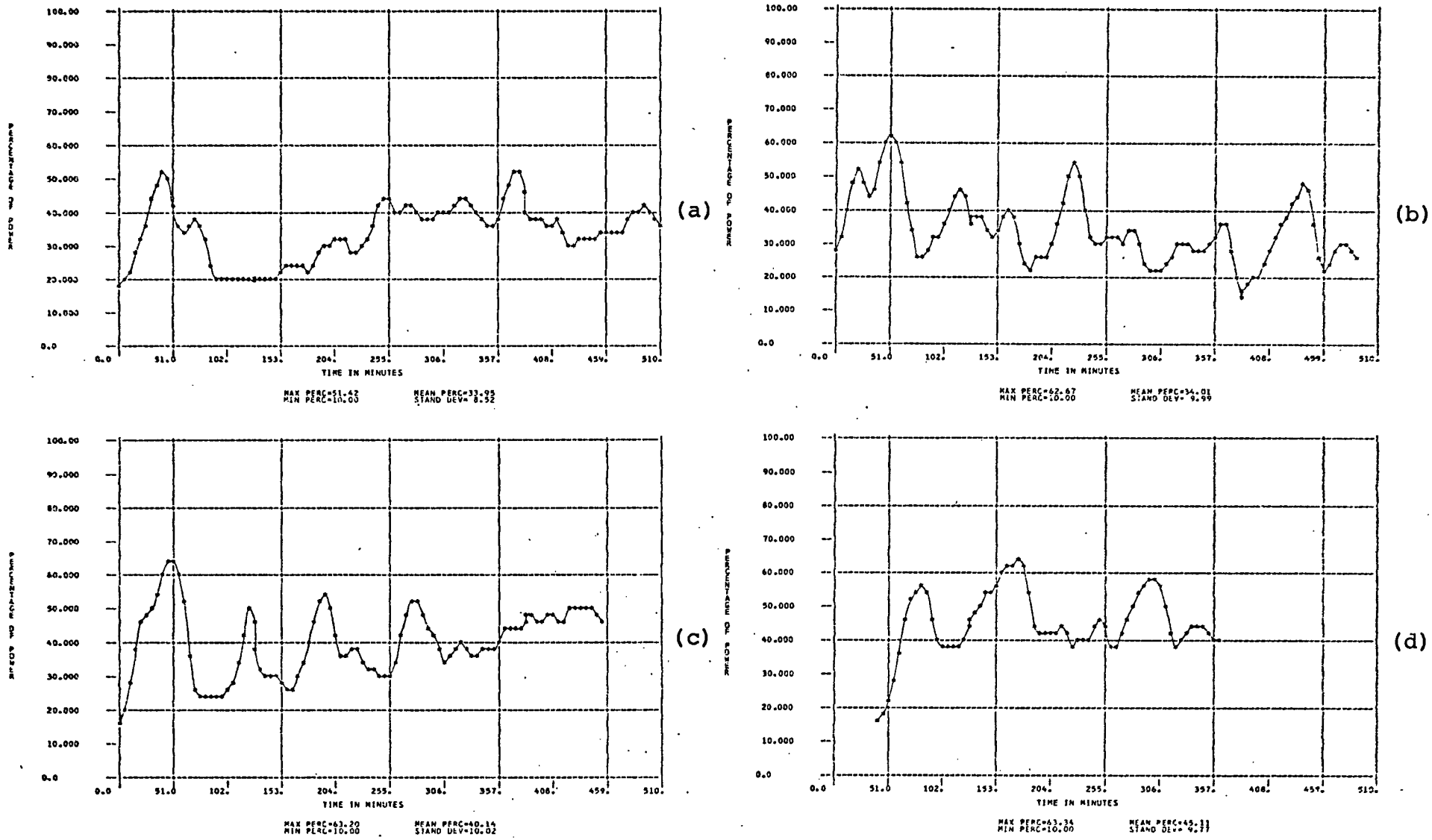


FIGURE 4.22 Subject SD5 - Percentage of Power in the Delta Band
(a) 1st night, record #14498 (b) 3rd night, record #15007
(c) 5th night, record #15016 (d) 13th night, record #15063

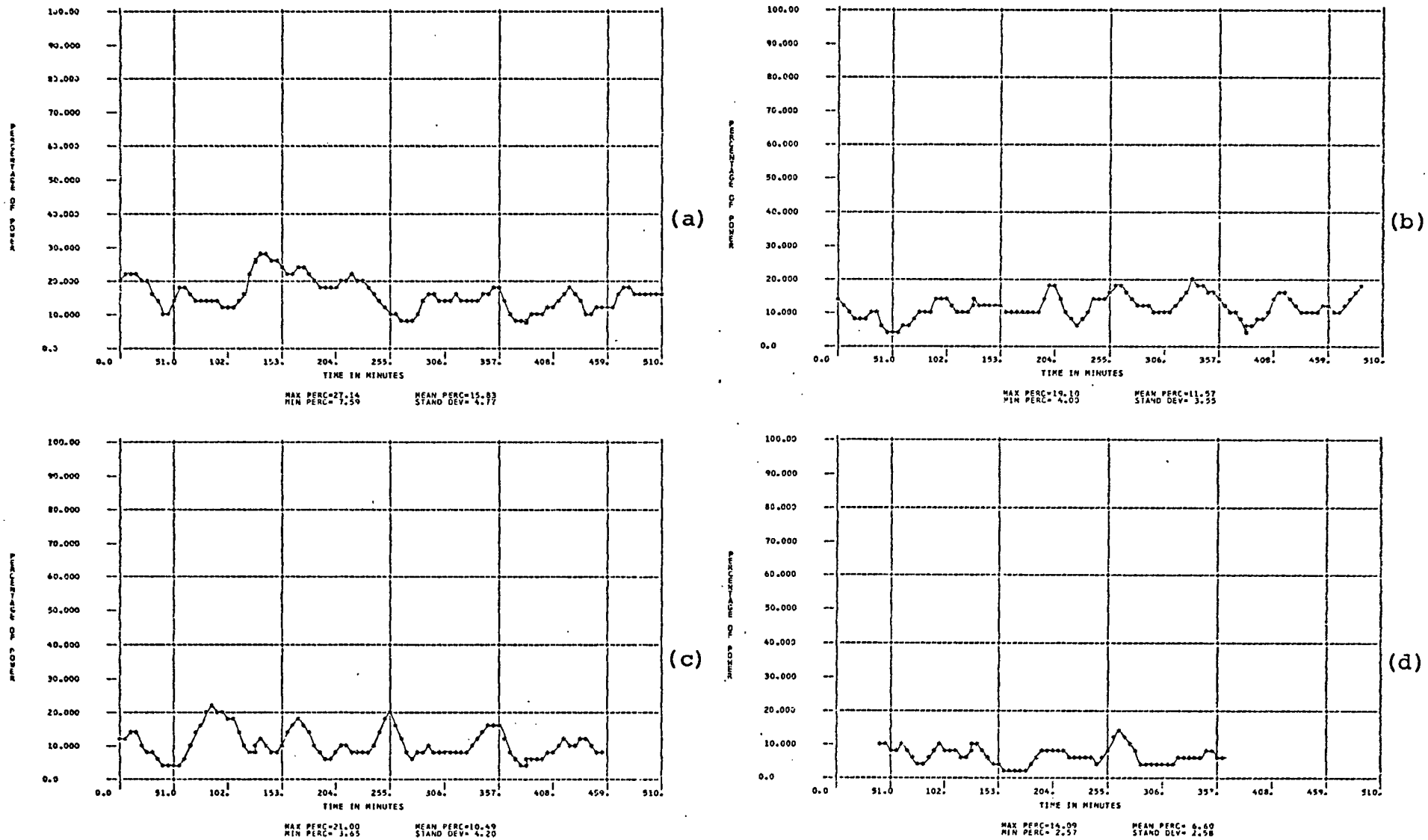


FIGURE 4.23 Subject SD5 - Percentage of Power in the Sigma Band
(a) 1st night, record #14498 (b) 3rd night, record #15007
(c) 5th night, record #15016 (d) 13th night, record #15063

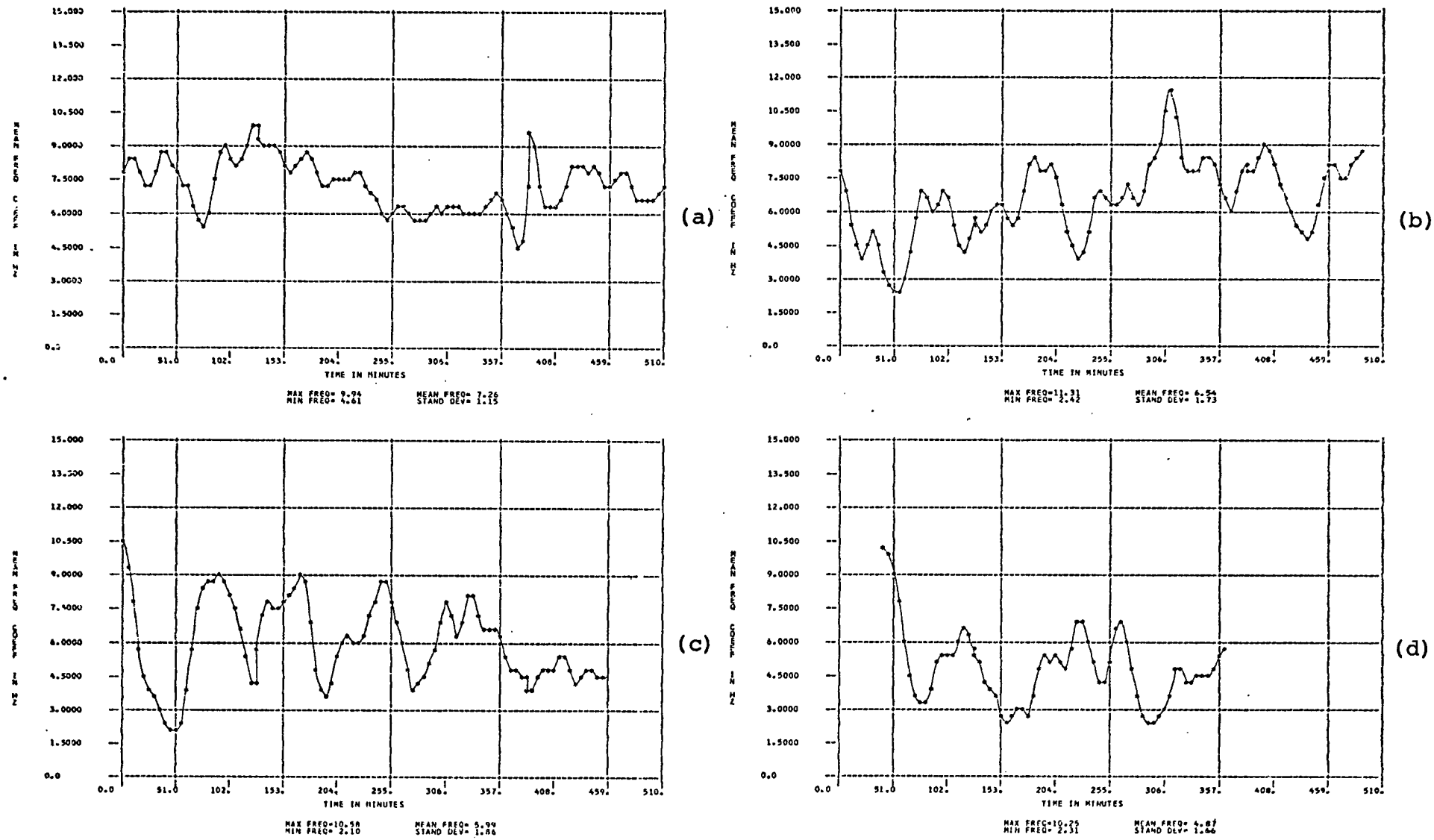


FIGURE 4.24 Subject SD5 - Mean Frequency Coefficient (MFC)
(a) 1st night, record #14498 (b) 3rd night, record #15007
(c) 5th night, record #15016 (d) 13th night, record #15063

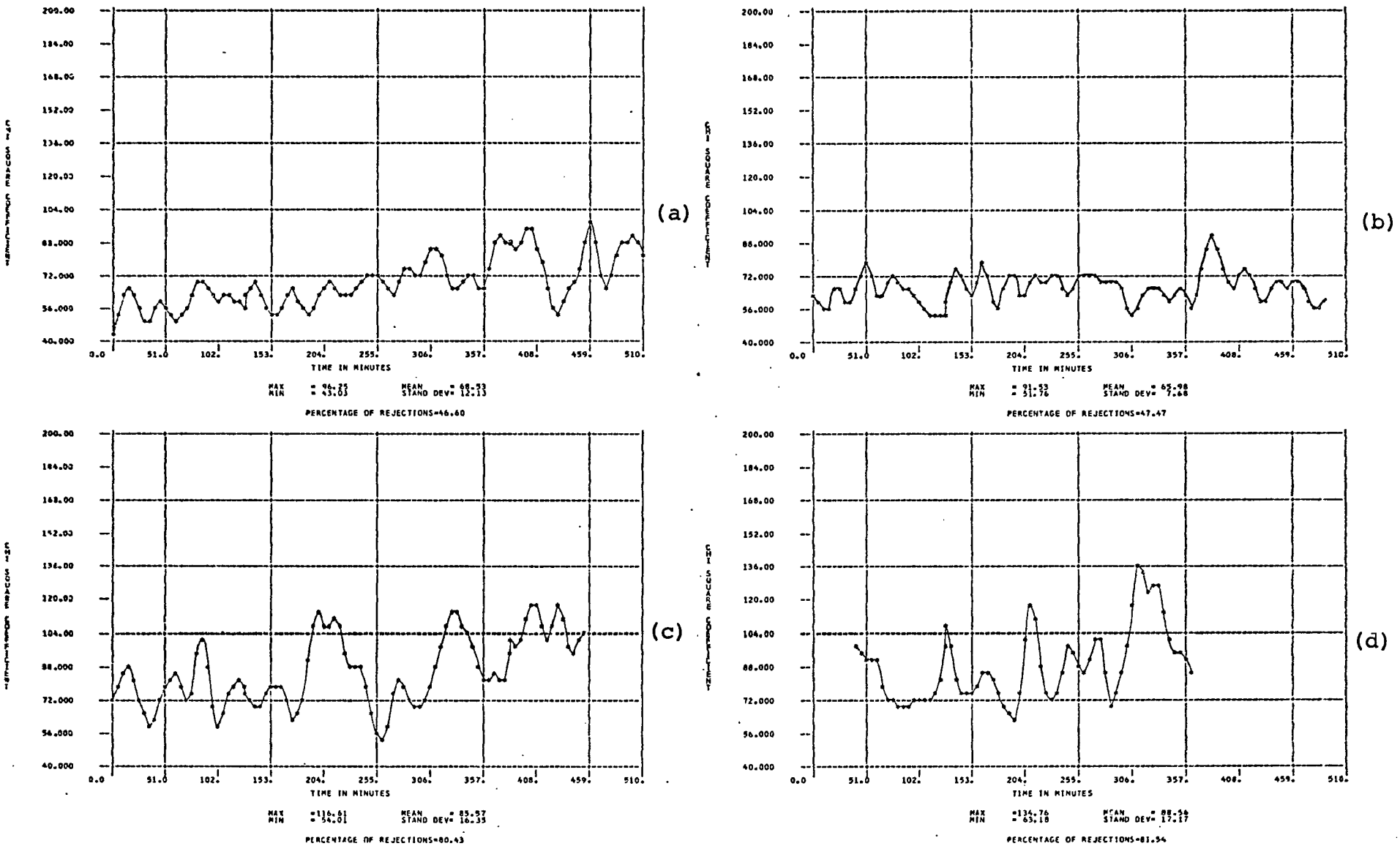


FIGURE 4.25 Subject SD5 - Chi-Square Coefficient
(a) 1st night, record #14498 (b) 3rd night, record #15007
(c) 5th night, record #15016 (d) 13th night, record #15063

has decreased 33% between the 1st and the 13th nights.

In Figures 4.25a, b, c and d the plots for the X^2 coefficients are shown. In the first two nights, Figures 4.25a and b, the EEG's amplitude follows a Gaussian probability function in more than 50% of the epochs. In the last two nights this number has decreased to less than 20%. Table 4.16 shows that the mean and the percentage of rejections for the X^2 coefficient has increased 29 and 75% respectively between the 1st and the 13th nights.

4.3.3 Subject SD6

4.3.3.1 Subject's Protocol

Subject SD6, a 16 year-old male, was a patient at the hospital during a period of 10 days. A total of four nights were automatically perocessed. Table 4.17 shows these nights, their corresponding record number and the subject's daily intake of the drug. The data in Table 4.17 was derived from Table 2.2, in which the subject's complete withdrawal schedule is shown.

TABLE 4.17

Analyzed Data for Subject SD6

Night	Record Number	Daily Dosage (mg)
2nd	15341	600
3rd	15351	300
4th	15359	0
7th	15376	0

4.3.3.2 Compressed Spectral Array

Figures 4.26a, b, c and d show the CSA plots corresponding to the four nights listed in Table 4.17. For the 2nd and the 3rd nights, Figures 4.26a and b, the activity in the Delta Band is characterized by low intensity spectral peaks for most of the night, except for some peaks with high intensities at the beginning of each night. The peak activity in the Sigma Band is about the same magnitude in both nights and its center frequency is around 12.0-12.5 Hz. In the 4th and 7th nights, Figures 4.26 c and d, two clusters of high intensity peaks can be clearly seen in the Delta Band. The intensity of the spectral peaks in the Sigma Band is now lower than in the previous two nights.

4.3.3.3 Summary of the Output Results from the FEATURE Algorithm

Table 4.18 shows the output results from the data reduction algorithm. From these results we can see that the drug affected the amount of SWS, which resulted in a reduction in the mean percentage of power in the Delta Frequency Band. On the other hand the drug also affected the high frequency activity which resulted in an increase in the percentage of power in the Sigma, Betal and Beta2 frequency bands. The above changes can be further summarized by the results from the mean value of the MFC's for each of the nights.

Figures 4.27a, b, c and d show the plots of the percentage of power in the Delta Band, for the 2nd, 3rd, 4th

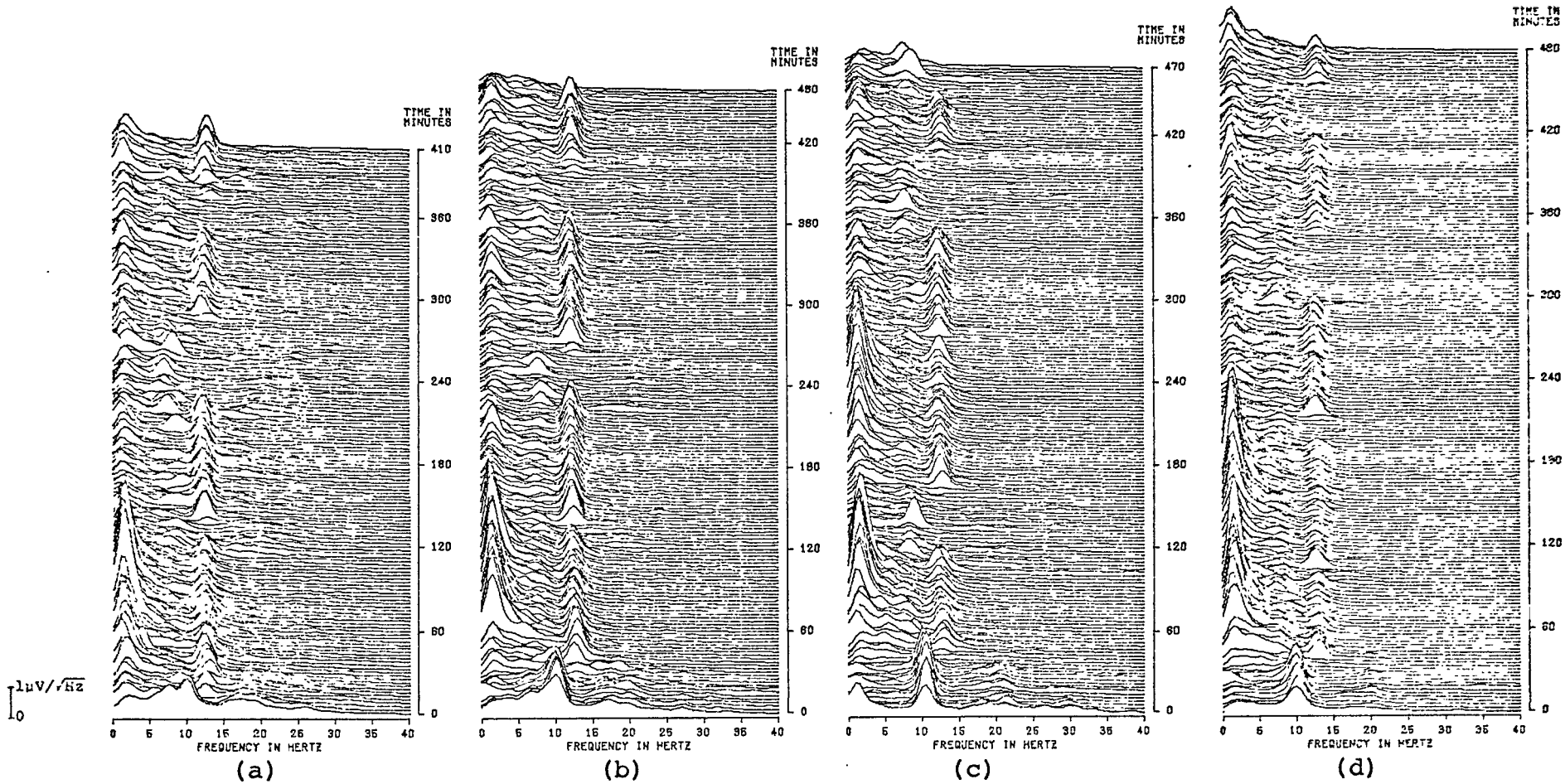


FIGURE 4.26 Subject SD6 - Compressed Spectral Array (CSA)
(a) 2nd night, record #15341 (b) 3rd night, record #15351
(b) 4th night, record #15359 (d) 7th night, record #15376

TABLE 4.18

Summary of the Output Results from FEATURE for Subject SD6

NIGHT			2nd	3rd	4th	7th
RECORD NUMBER			15341	15351	15359	15376
DOSAGE (mg)			600	300	0	0
DELTA BAND (0.0-3.5Hz)	PERC. OF POWER	MEAN	42.7	39.3	43.8	52.4
		STD	14.4	14.4	16.5	15.4
	FREQ. PEAK (Hz)	MEAN	1.5	1.6	1.6	1.6
		STD	0.4	0.5	0.4	0.3
THETA BAND (4.0-7.5Hz)	PERC. OF POWER	MEAN	18.5	19.9	21.8	21.7
		STD	6.5	5.6	7.2	6.5
	FREQ. PEAK (Hz)	MEAN	6.7	6.3	6.3	6.8
		STD	0.8	1.1	1.2	0.8
ALPHA BAND (8.0-11.5Hz)	PERC. OF POWER	MEAN	12.0	15.9	17.1	12.6
		STD	4.9	9.0	13.5	13.7
	FREQ. PEAK (Hz)	MEAN	8.9	8.7	9.0	8.9
		STD	1.0	0.9	1.2	0.9
SIGMA BAND (12.0-15.5Hz)	PERC. OF POWER	MEAN	12.9	15.4	9.0	7.5
		STD	8.3	9.3	5.9	5.6
	FREQ. PEAK (Hz)	MEAN	12.6	12.6	13.0	13.0
		STD	0.6	0.8	1.1	0.8

TABLE 4.18

(continued)

NIGHT			2nd	3rd	4th	7th
RECORD NUMBER			15341	15351	15359	15376
DOSAGE (mg)			600	300	0	0
BETA1 BAND (16.0-20.5Hz)	PERC. OF POWER	MEAN	5.0	3.5	2.8	1.4
		STD	2.8	2.5	2.0	1.0
	FREQ. PEAK (Hz)	MEAN	18.2	18.6	18.8	18.5
		STD	1.3	1.4	1.4	1.2
BETA2 BAND (21.0-29.5Hz)	PERC. OF POWER	MEAN	4.0	2.5	2.3	0.8
		STD	2.3	1.7	1.9	0.5
	FREQ. PEAK (Hz)	MEAN	24.0	24.2	24.4	24.4
		STD	2.1	1.9	2.5	2.0
FASTF BAND (30.0-40.0Hz)	PERC. OF POWER	MEAN	1.2	0.8	0.6	0.2
		STD	0.7	0.5	0.6	0.1
	FREQ. PEAK (Hz)	MEAN	32.7	32.9	32.9	33.0
		STD	2.1	2.1	2.0	2.3
X^2	MEAN		74.4	73.9	78.7	85.8
	STD		10.8	10.4	16.8	16.3
	PERCENTAGE OF REJECTIONS		60.2	61.2	62.8	78.4
MFC	MEAN		5.9	6.4	5.4	4.3
	STD		2.0	2.0	2.1	1.8

	DELTA BAND	THETA BAND	ALPHA BAND	SIGMA BAND	BETA1 BAND	BETA2 BAND	FASTF BAND	X^2 COEF.	MFC
MEAN PERC. OF POWER	+ 23%	+ 17%	+ 5%	- 42%	- 72%	- 80%	- 83%	-	-
MEAN FREQ. PEAK	+ 7%	+1.4%	0%	+ 3%	+ 2%	+ 2%	+ 1%	-	-
MEAN	-	-	-	-	-	-	-	+ 15%	- 27%
PERC. OF REJECTIONS	-	-	-	-	-	-	-	+ 30%	-

TABLE 4.19 Subject SD6 - Percentage Change in the Results of Table 4.18 Between the Last and the First Nights

and 7th nights respectively. The 2nd and 3rd nights, Figures 4.27a and b, show a similar kind of pattern, with a high amplitude and long duration peak in the beginning of both nights. The mean values of the percentage of power in the two nights are 42.7 and 39.3% respectively. In the 4th and 7th nights, Figures 4.27c and d, there are two high amplitude peaks in the first half of the night. However, the peaks in the 7th night are of higher amplitude and the time interval between them is shorter when compared to the peaks in the 3rd night. The mean percentage of power in the 7th night is 52.4% for the 4th night. Table 4.19 shows that the mean percentage of power in the Delta Band has increased 23% from the 1st to the 7th night.

Figures 4.28a, b, c and d show the plots of the percentage of power in the Sigma Band, for the four nights. In the 1st and 2nd nights, Figures 4.28a and b, there are peaks with large amplitude and long duration. The values of the mean percentage of power for these two nights are 12.9 and 15.4% respectively. The peaks in the 4th and 7th nights, Figures 4.28c and d, are of lower amplitude and short latency than the ones in the previous nights. The values of the mean percentage of power in these two nights have decreased to 9.0 and 7.5% respectively. Table 4.19 shows that the mean percentage of power in the Sigma Band has decreased 42% between the 2nd and the 7th nights.

The plots of the Mean Frequency Coefficients for the four nights of subject SD6 are shown in Figures 4.29a, b, c

and d. In the 2nd night, Figure 4.29a, the mean frequency is 5.9 Hz and there is a low frequency dip in the first third of the night, which reached the frequency of 1.5 Hz. The MFC points stayed above 5 Hz for the remaining of the night. In the 3rd night, Figure 4.29b, the pattern is almost the same, except that the MFC points were above the 6.5 Hz line for the rest of the night. The mean frequency for the entire night has increased to 6.4 Hz. In the 4th and 7th nights, Figures 4.29c and d, there is the appearance of a new low frequency dip in the first third of the night, in addition to the one already present in the previous plots. The mean frequency for the nights has now decreased to 5.4 Hz and 4.3 Hz respectively. From Table 4.18, we can see that the mean frequency has declined from 5.8 Hz in the 2nd night to 4.3 Hz in the 7th night which represents a 27% change (Table 4.19).

Figures 4.30a, b, c and d show the plots of the X^2 coefficients for the four nights listed on Table 4.17. In the first three nights the EEG's amplitude followed a normal distribution in almost 40% of the epochs. In the last night, however, this value has decreased to 21.6%. From Table 4.19, we can see that the mean and the percentage of rejections of the X^2 coefficient had increased 15 and 30% respectively from the 2nd to the 7th night.

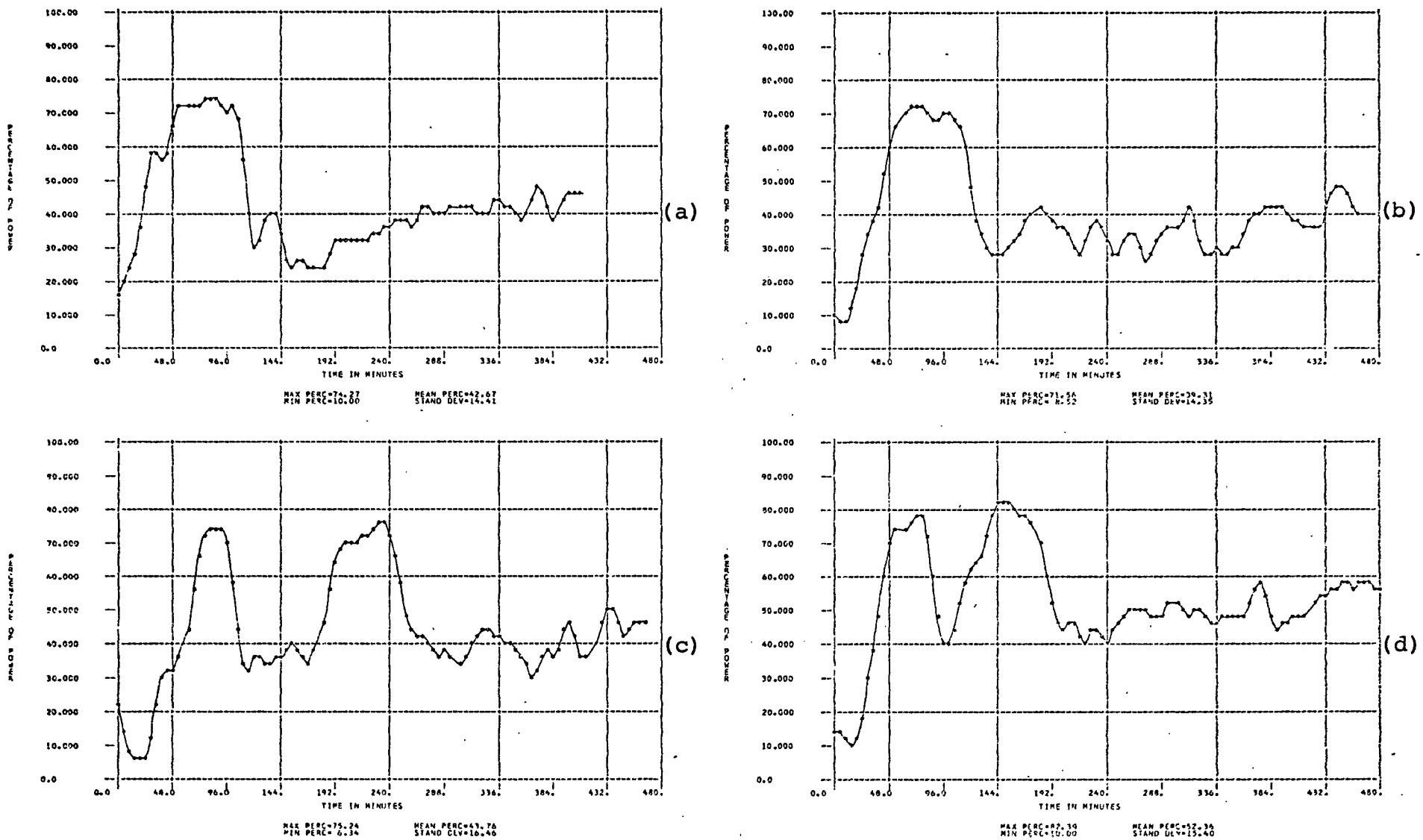


FIGURE 4.27 Subject SD6 - Percentage of Power in the Delta Band
(a) 2nd night, record #15341 (b) 3rd night, record #15351
(c) 4th night, record #15359 (d) 7th night, record #15376

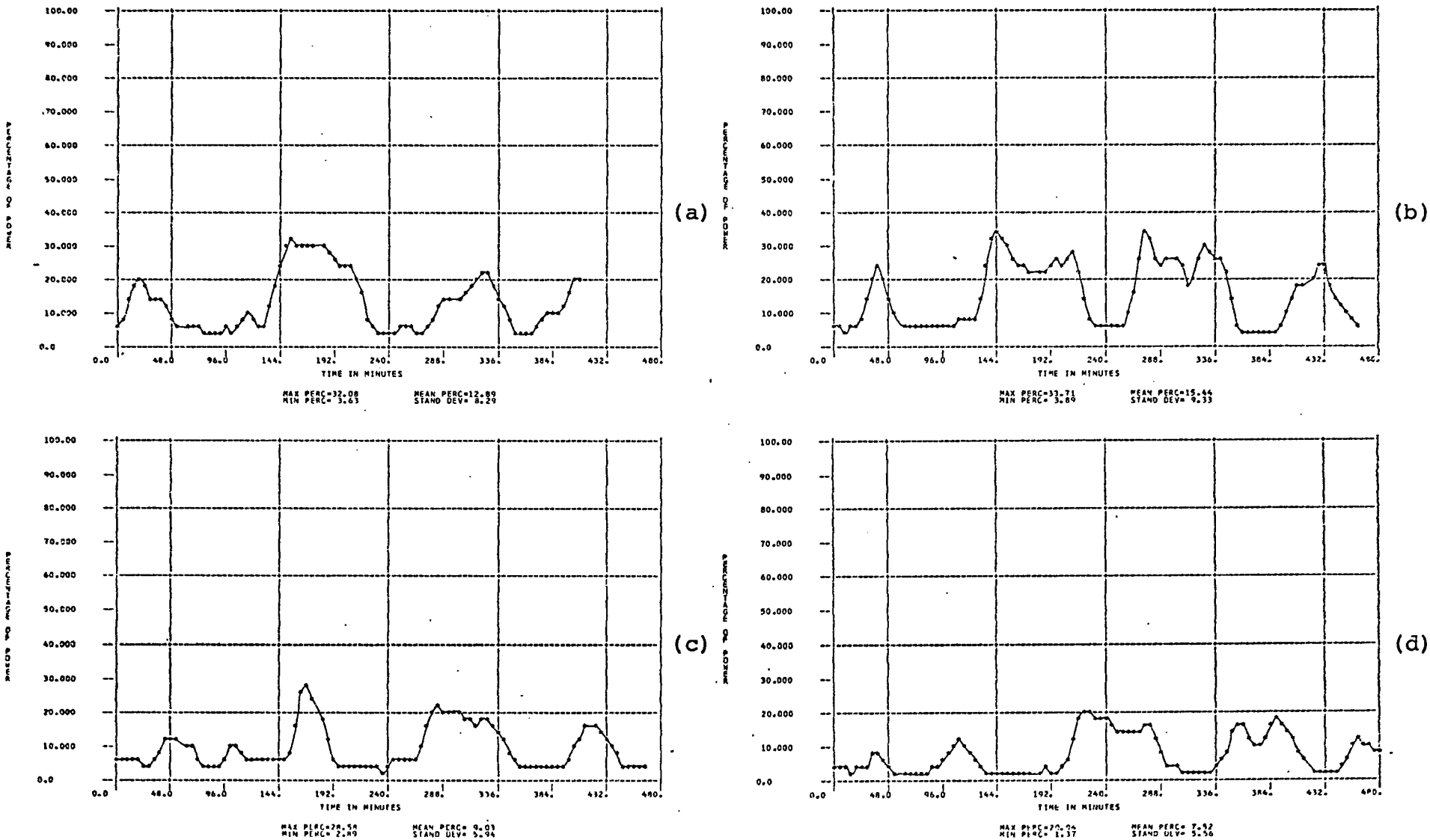


FIGURE 4.28 Subject SD6 - Percentage of Power in the Sigma Band
(a) 2nd night, record #15341 (b) 3rd night, record #15351
(c) 4th night, record #15359 (d) 7th night, record #15376

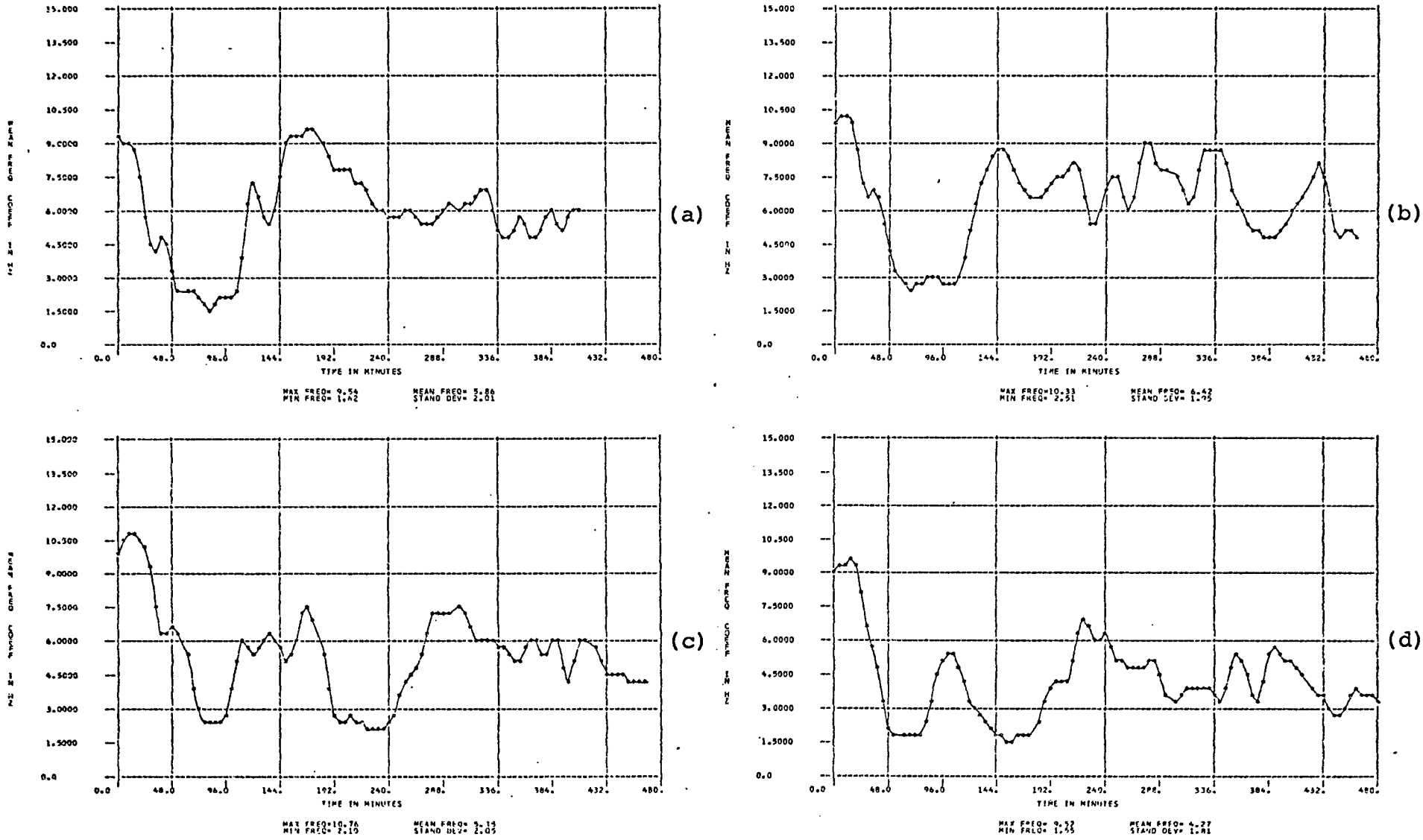


FIGURE 4.29 Subject SD6 - Mean Frequency Coefficient (MFC)
(a) 2nd night, record #15341 (b) 3rd night, record #15351
(c) 4th night, record #15359 (d) 7th night, record #15376

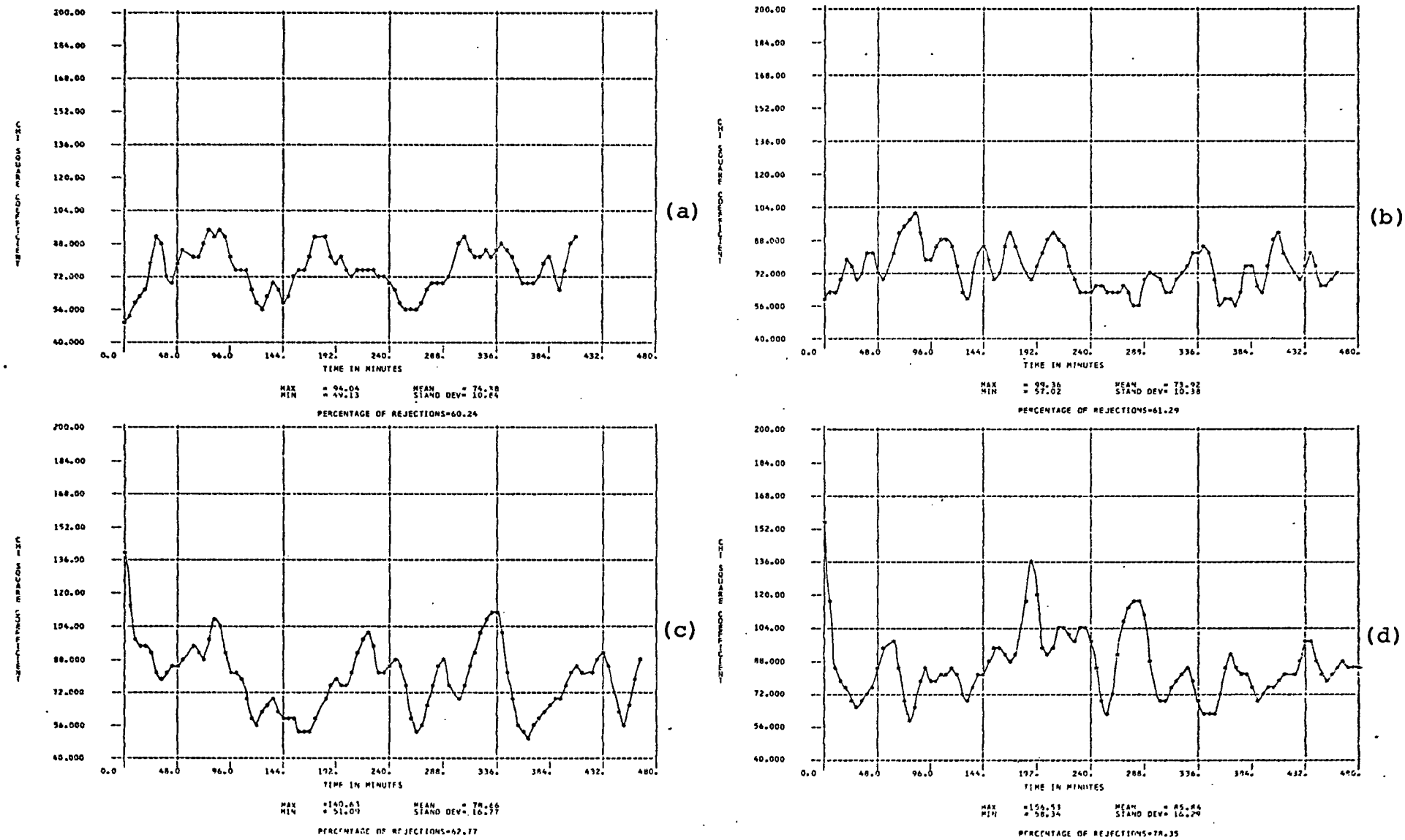


FIGURE 4.30 Subject SD6 - Chi_square Coefficient
(a) 2nd night, record #15341 (b) 3rd night, record #15351
(c) 3rd night, record #15359 (d) 7th night, record #15376

4.3.4 Discussion of the Results for the Subjects in Group 1 Withdrawn from Methaqualone

In order to compare the results between the subjects in Group 1 that were titrated and withdrawn from methaqualone, we grouped the results presented in Tables 4.13, 4.16 and 4.19 in Table 4.20. As we pointed out before, the results in this table for subjects SD4 and SD5 should be looked with caution due to the fact that the data used as baseline was obtained from nights in which the subject were still under the effects of the drug.

From Table 4.20 we can see that the mean percentage of power in the Delta Band increased in all subjects with the withdrawal of the drug. The largest change (+33%) is shown by subject SD5, who was titrated with the highest dosage (3000 mg of methaqualone). In two of the subjects, SD4 and SD5, a marked increased in the mean frequency in the Delta Band accompanied the withdrawal of the drug (18 and 13% respectively). The delta rhythm was altered by the drug in a manner similar to the one described in Section 4.2.4, for the subjects under secobarbital. The three subjects in this group showed changes in the mean percentage of power in the Delta Band that were smaller when compared to the ones presented by the subjects that were withdrawn from secobarbital. On the other hand, the changes in the mean frequency in the band were essentially the same in both groups. The above results must be looked at with caution due to the differences not only in the amount of drug given to the subjects, but also in the withdrawal schedule for the two groups.

Most of the studies in the literature report either no significant change (Williams and Agnew, 1969; Kales et al, 1970; Risberg et al, 1975), or a little decrease in delta sleep (Goldstein et al, 1970; Itil et al, 1974) after the administration of methaqualone. In all these studies the subjects received no more than 300 mg of methaqualone.

In all three subjects, the average percentage of power in the Sigma Band decreased with the withdrawal of the drug. Subject SD5 showed the largest change (58%) and the others had changes around 40%. These changes, however, are smaller than the ones observed in two of the subjects under secobarbital (Section 4.2.4). The mean frequency in this band also increased between 3 and 7%, which is equivalent to a slowdown of 0.4-0.9 Hz in the frequency of the spindle activity due to the chronic administration of the drug.

From Table 4.20 we can also see that there is an increase in the average percentage of power in Theta Band with the withdrawal of the drug. However, an opposite trend is observed in the mean percentage of power in the Beta1, Beta2 and FASTF Bands. Two of the subjects, SD4 and SD5, showed smaller changes in these last results when compared to the ones in the subjects withdrawn from secobarbital. This is probably due to the different time interval between the last and first nights that were compared in these two groups. As we can see from the last columns in Tables 4.12 and 4.15, the values for the mean percentage of power in the Beta1, Beta2 and FASTF Bands are the highest among all the subjects in the present study, with the exception of subject SC5.

This probably reflects the fact that although the subjects were not taking the drug anymore, their organisms did not have enough time to wash out the drug (Kay et al, 1976).

The mean frequency in each night decreases with the withdrawal of the drug. From Table 4.20 it can be seen that the subjects in this group showed reduction in this parameter between 21 and 33%. Again the highest change is observed in subject SD5. On the other hand, subject SD6, had a larger change than subject SD4, despite the fact that this subject was titrated with an amount of drug at least three times as large as that of subject SD6. A partial explanation for this discrepancy could be in the choice of the baseline night for subject SD4, as we already mentioned. We should also keep in mind that these subjects had a long history of polydrug abuse and that these discrepancies could also be the results of intersubject sensitivity to the drug.

The mean and the percentage of rejections of the X^2 coefficient decreased in all subjects with the administration of the drug. Table 4.20 shows these results as a percentage increase in the mean and in the percentage of rejections of the X^2 coefficient between the titration night and the night used as baseline (the last night that was processed for each subject). Subject SD5 had increases of 29 and 75% for the mean and for the percentage of rejection respectively. The other subjects had changes of 30% in the percentage of rejections and 15-20% in the mean value of X^2 coefficient with the withdrawal of the drug. As we can see

TABLE 4.20

Summary of the Results of Tables 4.13, 4.16 and 4.19 for Subjects in Group 1 - Secobarbital

SUBJECTS			SD4[1]	SD5[2]	SD6
TITRATION DOSAGE (mg)			2100	3000	600
DELTA BAND (0.0-3.5Hz)	PERC. OF POWER	MEAN	+22%	+33%	+23%
	FREQ. PEAK (Hz)	MEAN	+18%	+13%	+ 7%
THETA BAND (4.0-7.5Hz)	PERC. OF POWER	MEAN	+56%	+43%	+17%
	FREQ. PEAK (Hz)	MEAN	- 6%	0%	+1.4%
ALPHA BAND (8.0-11.5Hz)	PERC. OF POWER	MEAN	+31%	-14%	+ 5%
	FREQ. PEAK (Hz)	MEAN	+ 7%	+ 3%	0%
SIGMA BAND (12.0-15.5Hz)	PERC. OF POWER	MEAN	-43%	-58%	-42%
	FREQ. PEAK (Hz)	MEAN	+ 7%	+ 4%	+ 3%

[1]The results of the titration night were compared with the ones in the night following the first day of zero drug intake.

[2]The results of the titration night were compared with the ones in the night of the first day of zero drug intake.

TABLE 4.20

(continued)

SUBJECTS			SD4	SD5	SD6
TITRATION DOSAGE (mg)			2100	3000	600
BETA1 BAND (16.0-20.5Hz)	PERC. OF POWER	MEAN	-53%	-55%	-72%
	FREQ. PEAK (Hz)	MEAN	0%	0%	+ 2%
BETA2 BAND (21.0-29.5Hz)	PERC. OF POWER	MEAN	-49%	-54%	-80%
	FREQ. PEAK (Hz)	MEAN	- 1%	+0.4%	+ 2%
FASTF BAND (30.0-40.0Hz)	PERC. OF POWER	MEAN	-32%	-30%	-83%
	FREQ. PEAK (Hz)	MEAN	0%	- 2%	+ 1%
X^2	MEAN		+20%	+29%	+15%
	PERCENTAGE OF REJECTIONS		+33%	+75%	+30%
MFC	MEAN		-21%	-33%	-27%

from Table 4.15, during the nights close to the titration night of subject SD5, the EEG amplitude followed a Gaussian probability density function in more than 50% of the epochs. However, this was reduced to less than 20% when the subject stopped taking the drug. The other subjects in this group show the same trend but with less variability. As we suggested in Section 4.2.2, it seems that the EEG's amplitude distribution become more Gaussian with the administration of the drug and that this is also dosage dependent.

4.4 GROUP 2 - SECOBARBITAL

4.4.1 Subject SC1

4.4.1.1 Subject's Protocol

Subject SC1 is a 22 year-old male. A total of four sleep sessions were automatically processed. Table 4.21 shows these sessions in a chronological order, their corresponding record number and the amount of drug given to the subject. This table was derived from Table 2.3, in which the complete procedure for the subject is shown. The baseline night was recorded one month after the first period.

TABLE 4.21

Analyzed Data for Subject SC1

Sleep Sessions	Record Number	Titration Dosage (mg)
Nap[1]	15983	600
1st Night[1]	15989	-

[1]Both sessions were run in the same day.

TABLE 4.21

(continued)

Sleep Sessions	Record Number	Titration Dosage (mg)
2nd Night	15994	none
Baseline[2] Night	16093	none

[2]Recorded one month after the administration of the drug.

4.4.1.2 Compressed Spectral Array

Figures 4.31a, b, c, and d show the CSA plots corresponding to the four sleep records listed in Table 4.21. For the nap, Figure 4.31a, the activity in the Delta Band is characterized by some high intensity spectral peaks at the beginning of the record. The spectral peaks in the Sigma Band are not well-defined in the beginning of the nap. In the 1st night, Figure 4.31b, the activity in the Delta Band is characterized by low intensity spectral peaks throughout the night. Well-defined peaks in the Sigma Band are the dominant activity for most of the night. The CSA plot for the 2nd night, Figure 4.31c, shows the return of the high intensity peaks in the Delta Band and that the magnitudes of the peaks in the Sigma Band have declined from their previous values. A similar pattern is also shown by the baseline night (Figure 4.31d).

4.4.1.3 Summary of the Output Results from the FEATURE Algorithm

Table 4.22 shows the output results from the data

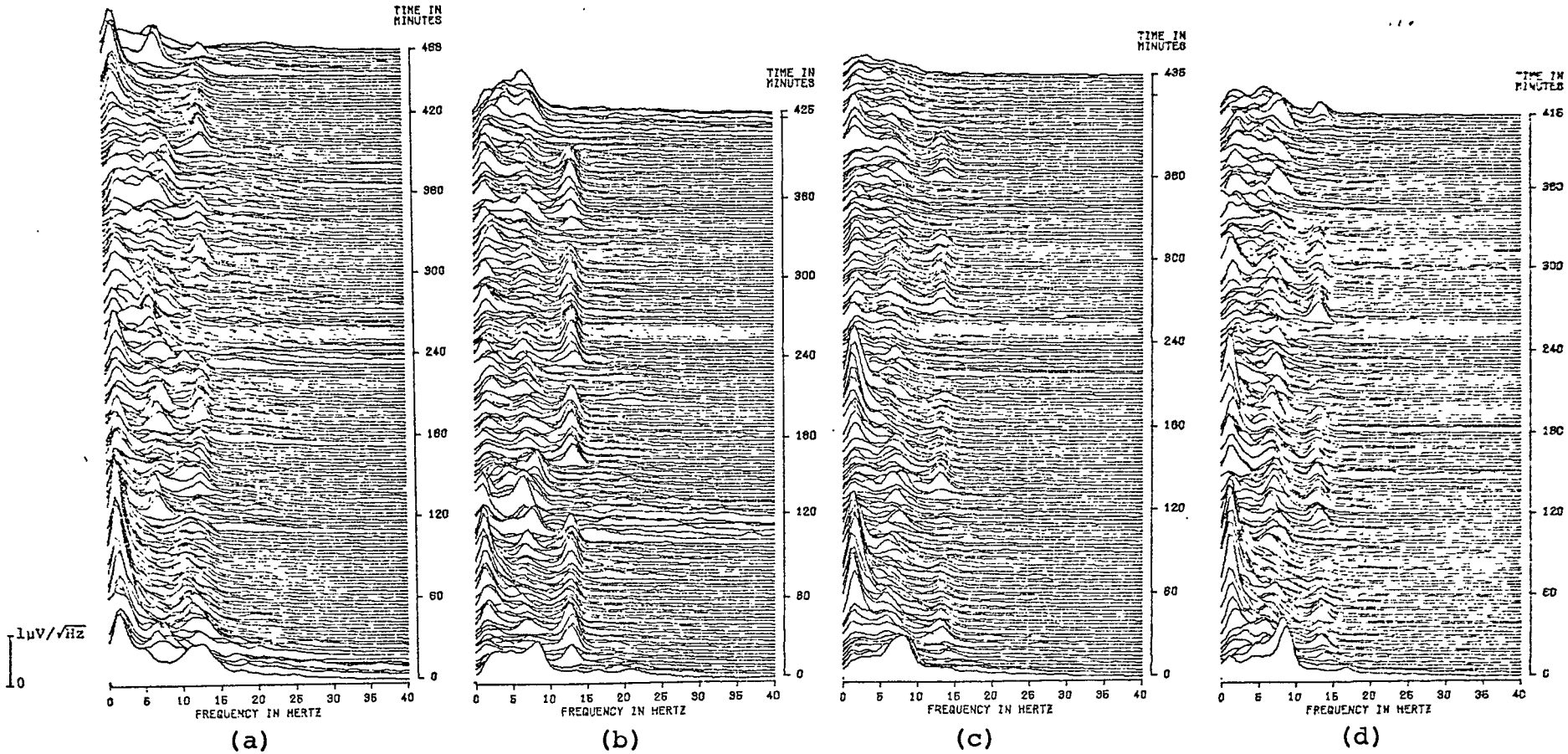


FIGURE 4.31 Subject SC1 - Compressed Spectral Array (CSA)
(a) nap, record #15983 (b) 1st night, record #15989
(c) 2nd night, record #15994 (d) baseline night, record #16093

TABLE 4.22

Summary of the Output Results from FEATURE for Subject SC1

SLEEP SESSION			Nap	1st	2nd	Baseline
RECORD NUMBER			15983	15989	15994	16093
DOSAGE (mg)			600	-	0	0
DELTA BAND (0.0-3.5Hz)	PERC. OF POWER	MEAN	42.4	32.6	43.4	43.5
		STD	16.9	10.8	13.7	10.8
	FREQ. PEAK (Hz)	MEAN	1.6	1.8	1.7	1.7
		STD	0.5	0.5	0.5	0.6
THETA BAND (4.0-7.5Hz)	PERC. OF POWER	MEAN	22.9	27.1	33.4	34.7
		STD	9.2	7.6	8.2	7.4
	FREQ. PEAK (Hz)	MEAN	6.3	6.4	6.2	6.2
		STD	1.0	0.9	0.8	1.0
ALPHA BAND (8.0-11.5Hz)	PERC. OF POWER	MEAN	13.7	13.2	11.4	11.0
		STD	5.0	3.9	4.5	4.4
	FREQ. PEAK (Hz)	MEAN	10.2	9.1	9.5	8.9
		STD	1.2	1.3	1.2	0.7
SIGMA BAND (12.0-15.5Hz)	PERC. OF POWER	MEAN	9.9	17.1	5.9	4.9
		STD	6.1	10.3	3.8	2.8
	FREQ. PEAK (Hz)	MEAN	13.1	13.3	13.6	13.4
		STD	1.0	0.8	0.8	0.7

TABLE 4.22

(continued)

SLEEP SESSION			Nap	1st	2nd	Baseline
RECORD NUMBER			15983	15989	15994	16093
DOSAGE (mg)			600	-	0	0
BETA1 BAND (16.0-20.5Hz)	PERC. OF POWER	MEAN	4.3	4.1	1.6	1.1
		STD	2.4	1.9	0.7	0.4
	FREQ. PEAK (Hz)	MEAN	18.2	18.5	18.7	18.4
		STD	1.3	1.3	1.2	1.2
BETA2 BAND (21.0-29.5Hz)	PERC. OF POWER	MEAN	2.7	3.1	1.2	0.8
		STD	1.7	1.8	0.6	0.3
	FREQ. PEAK (Hz)	MEAN	23.7	23.7	23.8	24.1
		STD	1.9	2.0	2.2	2.3
FASTF BAND (30.0-40.0Hz)	PERC. OF POWER	MEAN	0.5	0.8	0.4	0.3
		STD	0.4	0.6	0.2	0.1
	FREQ. PEAK (Hz)	MEAN	33.3	34.0	33.0	33.9
		STD	2.3	2.6	2.3	2.3
X^2	MEAN		79.5	79.4	86.8	87.0
	STD		10.9	12.7	11.4	14.4
	PERCENTAGE OF REJECTIONS		68.4	66.3	75.9	82.1
MFC	MEAN		5.2	6.9	4.5	4.4
	STD		2.1	1.7	1.5	1.4

	DELTA BAND	THETA BAND	ALPHA BAND	SIGMA BAND	BETA1 BAND	BETA2 BAND	FASTF BAND	X^2 COEF.	MFC
MEAN PERC. OF POWER	+ 33%	+ 28%	- 17%	- 71%	- 73%	- 74%	- 63%	-	-
MEAN FREQ. PEAK	- 5%	- 3%	- 2%	+ 1%	-0.5%	- 2%	-0.3%	-	-
MEAN	-	-	-	-	-	-	-	+ 10%	- 36%
PERC. OF REJECTIONS	-	-	-	-	-	-	-	+ 24%	-

TABLE 4.23 Subject SC1 - Percentage Change in the Results of Table 4.22 Between the Baseline and the First Nights

reduction algorithm. As we can see from this table, there is a tendency for the mean percentage of power in the Delta Band to decrease in the first night from their previous values during the nap. This tendency is however reversed in the 2nd and in the baseline nights. An upward trend is shown by the mean percentage of power in the Sigma, Beta1 and Beta2 Bands, and by the mean of MFC's between the nap and the 1st night. This trend is also reversed in the 2nd and in the baseline nights. The mean percentage of power in the Theta Band has it lowest value during the nap, increasing afterwards.

Figures 4.32a, b, c and d show the plots of the percentage of power in the Delta Band, for the sleep records shown in Table 4.21. For the nap, Figure 4.32a, there are two large peaks: one with a long duration at the beginning of the plot and the other towards the end of the nap. The mean percentage of power in the band is 42.4%. In the 1st night, Figure 4.32b, there is only one high amplitude peak with a short duration at the beginning of the night, and the mean percentage of power in the band has declined to 32.6%. By the 2nd night, this value has increased to 43% which is close to the previous value computed for the nap. Figure 4.32c shows the corresponding plot for the 2nd night, in which two large peaks can be clearly seen in the first half of the night. In the baseline night, Figure 4.32d, there are three high amplitude peaks in the first half of the night and the mean percentage of power for the band

stayed at 43.5%. There is an increase of 33% in the mean percentage of power in the Delta Band, between the 1st and the baseline nights, as shown by Table 4.23. In the same period the mean frequency in the band has decreased 5%.

The plots for the percentage of power in the Sigma Band are shown in Figures 4.33a, b, c and d. The plot corresponding to the nap, Figure 4.33a, shows that the amplitude of the peaks is increasing as the nap progresses. The mean percentage of power in the band during the nap is 9.9%. In the 1st night the mean percentage of power has increased to 17.1% and its percentage of power plot, Figure 4.33b, shows high amplitude peaks most of the time. By the 2nd night, the mean percentage of power was reduced to 5.9%, and the number of peaks and their amplitudes have also diminished as illustrated in Figure 4.36c. In the baseline night the mean percentage of power in the band was 4.9%, and Figure 4.36d shows only few low amplitude peaks. From Table 4.23 we can see that there is a reduction of 71% in the percentage of power in the Sigma Band between the 1st and the baseline nights. In the same period the mean frequency has increased 1%.

Figures 4.34a, b, c and d show the plots for the Mean Frequency Coefficients. During the nap, Figure 4.34a, the mean value of the MFCs stayed above the 5 Hz line for most of the time, except for two low frequency dips that reached the 2.0 Hz frequency line, one of long duration at the beginning of the nap and the other towards its end. Figure 4.34b

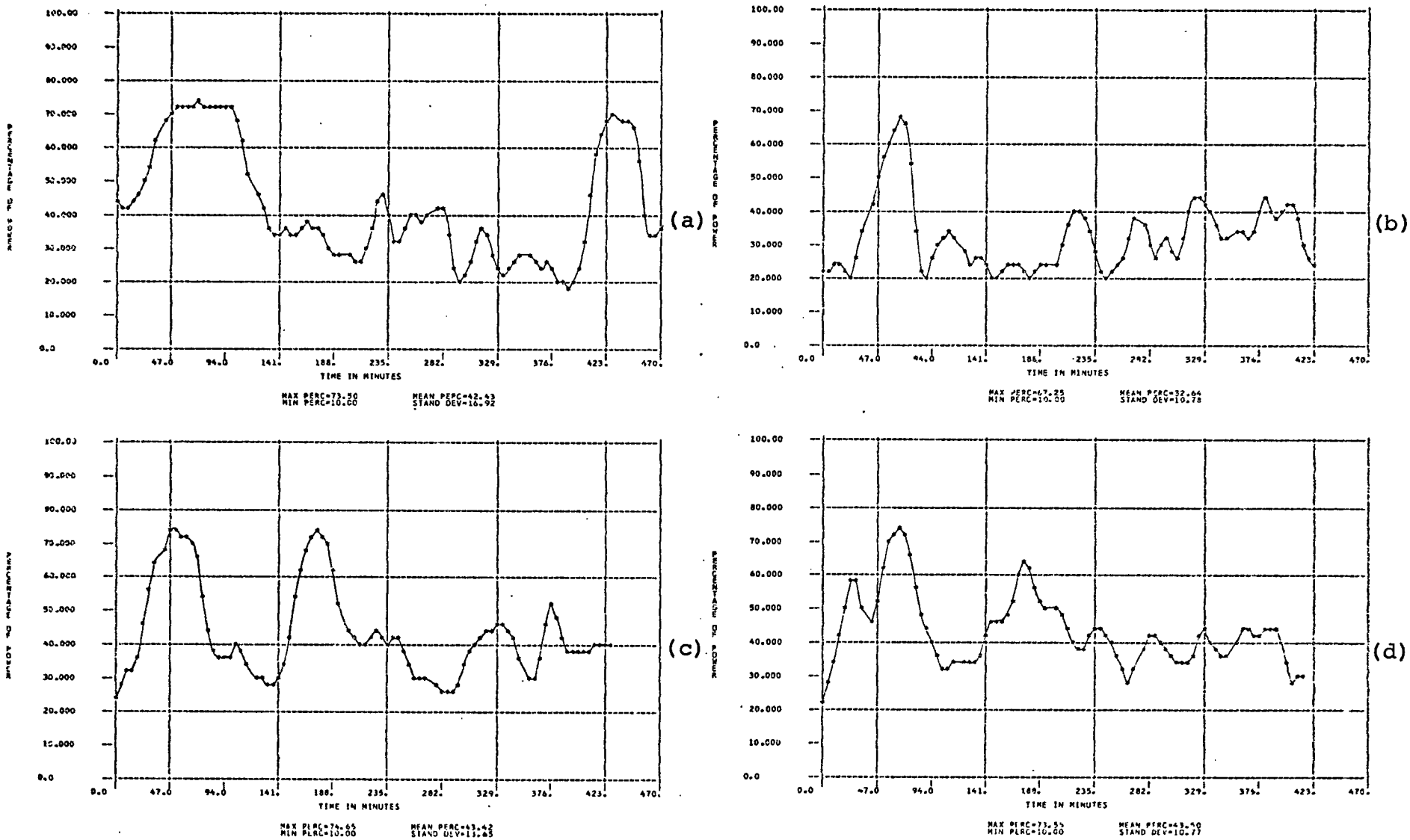


FIGURE 4.32 Subject SC1 - Percentage of Power in the Delta Band
(a) nap, record #15983 (b) 1st night, record #15989
(c) 2nd night, record #15994 (d) baseline night, record #16093

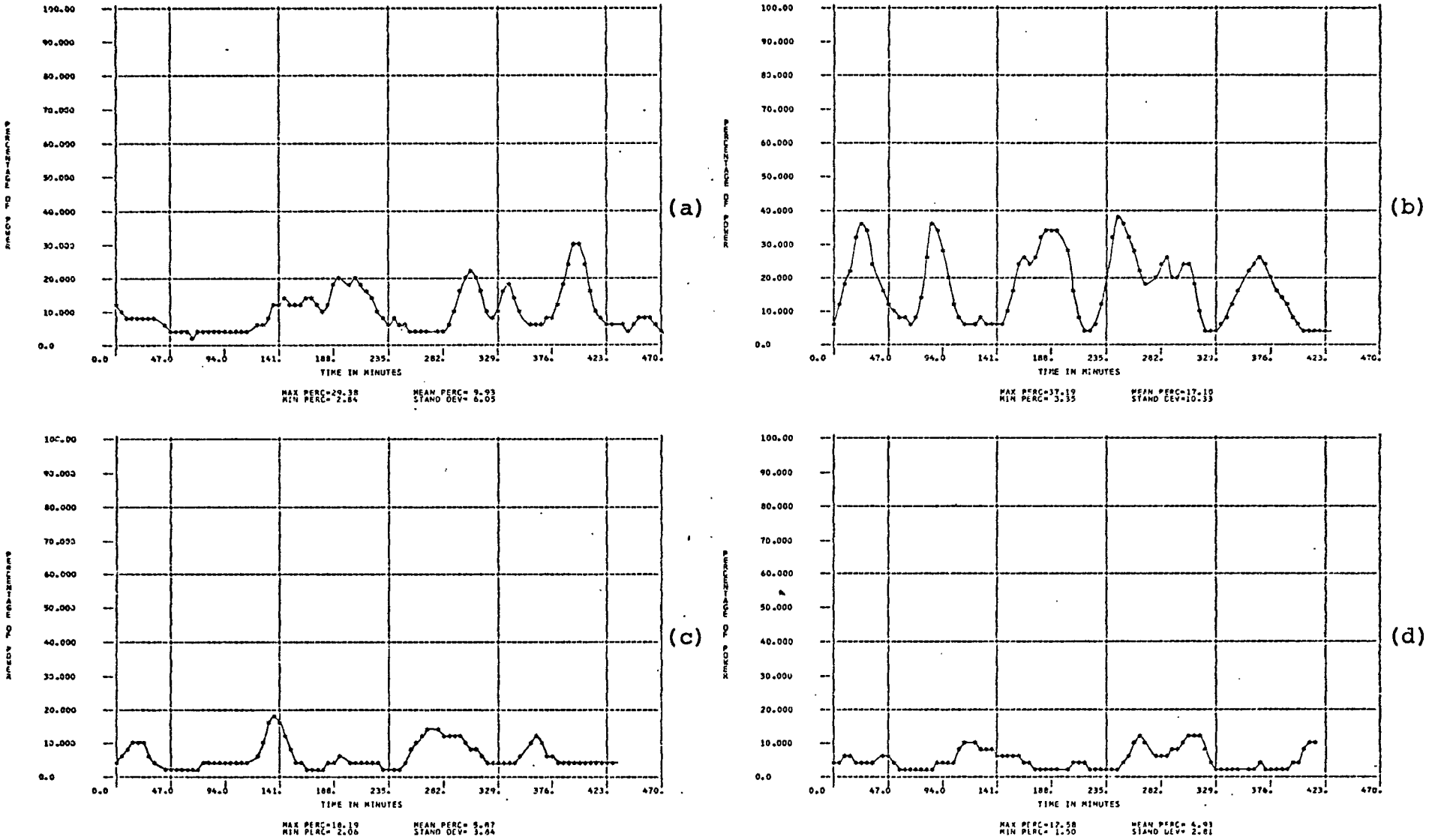


FIGURE 4.33 Subject SC1 - Percentage of Power in the Sigma Band
(a) nap, record #15983 (b) 1st night, record #15989
(c) 2nd night, record #15994 (d) baseline night, record #16093

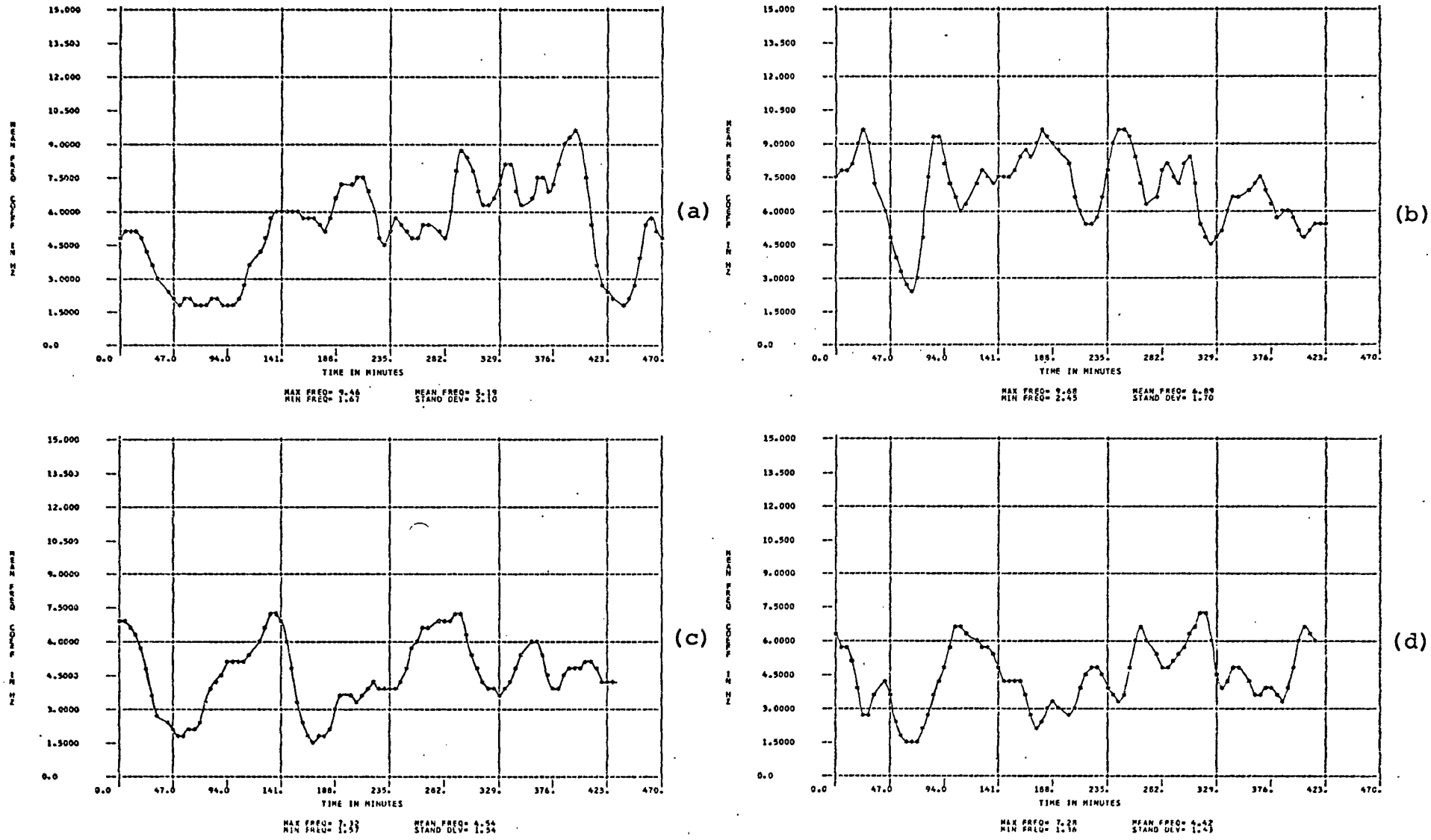


FIGURE 4.34 Subject SC1 - Mean Frequency Coefficient (MFC)
(a) nap, record #15983 (b) 1st night, record #15989
(c) 2nd night, record #15994 (d) baseline night, record #16093

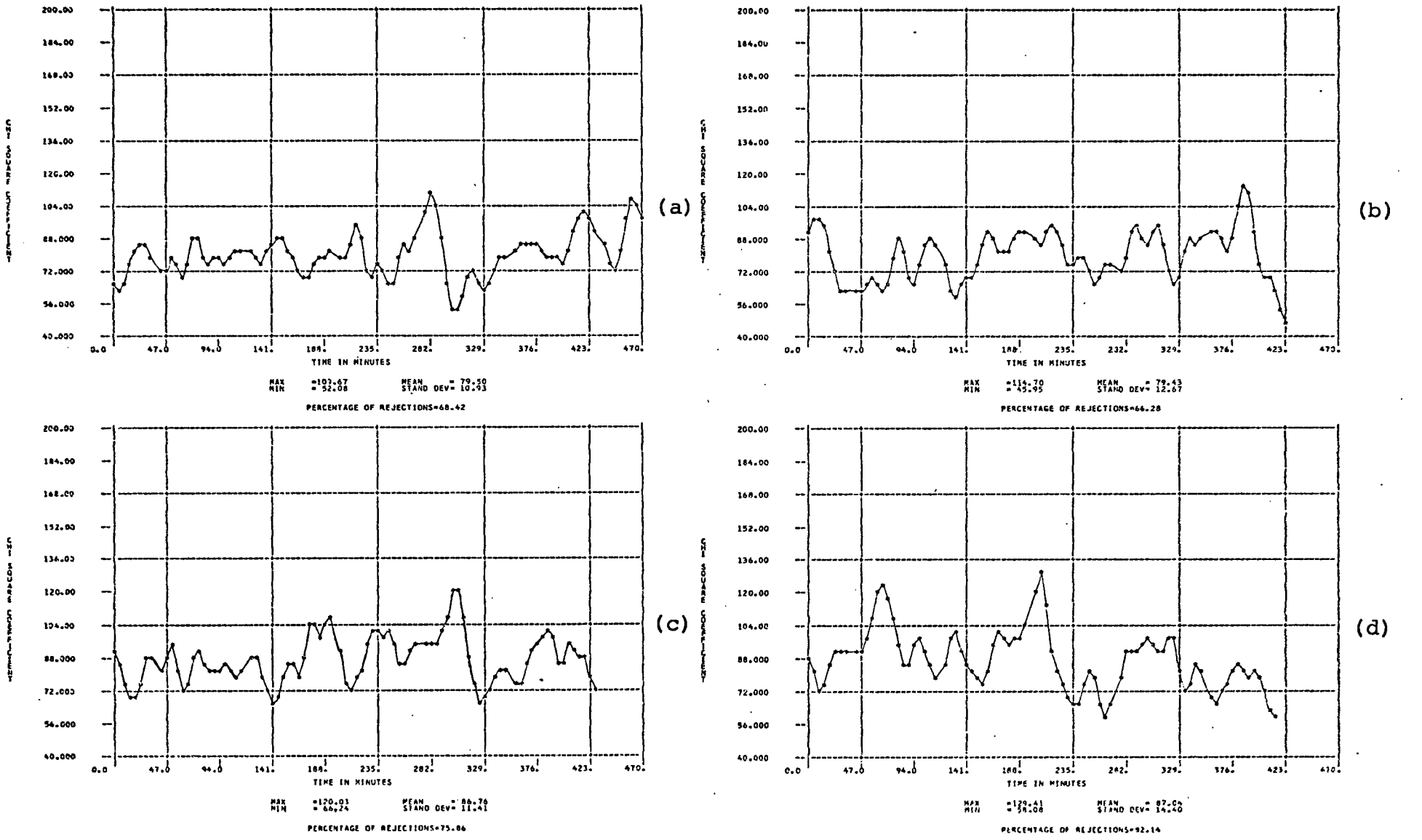


FIGURE 4.35 Subject SC1 - Chi-Square Coefficient
(a) nap, record #15983 (b) 1st night, record #15989
(c) 2nd night, record #15994 (d) baseline night, record #16093

shows that for the 1st night there is one low frequency dip reaching the 3 Hz frequency line and that the MFC's points stayed above 6 Hz for the remaining of the night. The mean frequency for the entire night was up to 6.9 Hz in contrast to the one from the previous night of 5.2 Hz. In the 2nd and in the baseline nights the mean frequency values were 4.5 Hz and 4.4 Hz respectively. Figures 4.34c and d show low frequency dips in the first half of the night. The mean frequency has decreased 36% between the 1st and the baseline nights, as shown in Table 4.23.

The plots for the X^2 coefficient are shown in Figures 4.35a, b, c and d. During the nap, Figure 4.35a, we can see that the hypothesis that the EEG's amplitude follows a Gaussian distribution was rejected in 68.4% of the epochs. This value has decreased to 66.3% in the 1st night, Figure 4.35b. In the 2nd and in the baseline nights the percentages of rejections have increased to 75.9 and 82% respectively. From Table 4.23 we can see that the percentage of rejections for the X^2 coefficient, in the baseline night, has increased 24% over the computed value for the 1st night.

4.4.2 Subject SC2

4.4.2.1 Subject's Protocol

Subject SC2 is a 23 year-old male. The sleep sessions that were automatically processed are listed in Table 4.24, which also shows their corresponding record number and the amount of drug taken by the subject. This table was derived from Table 2.3.

TABLE 4.24

Analyzed Data for Subject SC2

Sleep Sessions	Record Number	Titration Dosage (mg)
Nap[1]	15945	600
1st Night[1]	15952	-
2nd Night	15956	none
Baseline[2] Night	16328	none

[1]Both sessions were run in the same same day.

[2]Recorded one month after the administration of the drug.

4.4.2.2 Compressed Spectral Array

The CSA plots for subject SC2 are shown in Figures 4.36a, b, c and d. The CSA for the nap, Figure 4.36a, shows high intensity spectral peaks in the Delta and Sigma Bands. The later ones persisted throughout the 1st night, Figure 4.36b, however the peaks in the Delta Band are of less intensity than the ones in the nap plot. In the 2nd night, Figure 4.36c, there exist two trains of high intensity spectral peaks in the Delta Band, and the intensity of the peaks in the Sigma Band has been reduced a little. The CSA of the baseline night, Figure 4.36d, shows that the two trains of high intensity peaks in the Delta Band are still present and that the peaks in the Sigma Band have reached their lowest level for the four plots. The activity in the Alpha Band is located at 8.5 Hz in the 1st night, Figure 4.36b,

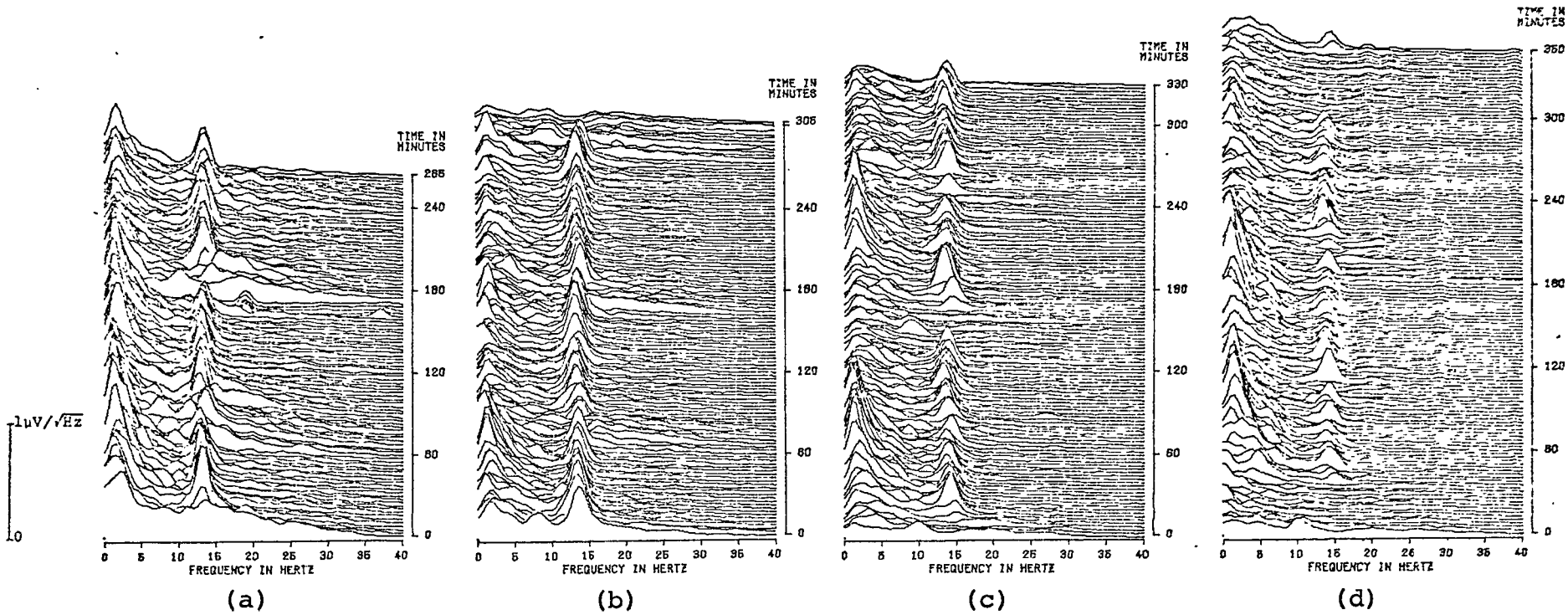


FIGURE 4.36 Subject SC2 - Compressed Spectral Array (CSA)
(a) nap, record #15945 (b) 1st night, record #15952
(c) 2nd night, record #15956 (d) baseline night, record #16328

but it is shifted to 10 Hz in the 2nd and in the baseline nights (Figures 4.36c and d).

4.4.2.3 Summary of the Output Results from the FEATURE Algorithm

The output results from the data reduction algorithm are listed in Table 4.25. From there we can see that in the 1st night there is a decrease in the average percentage of power in the Delta Band and in the percentage of rejection of the X^2 coefficient in relation to the values computed during the nap. This trend is, however, reversed in the 2nd and in the baseline nights. The mean percentage of power in the Sigma, Betal, Beta2 and FASTF Bands and the average value of the MFCs increased from the nap to the 1st night and then started decreasing to their baseline values. The mean percentage of power in the Theta Band has its lowest value during the nap but it starts increasing after the 1st night.

The plots for the percentage of power in the Delta Band are shown in Figures 4.37a, b, c and d. From Figure 4.37a, we can see the presence of two high amplitude peaks in the first two thirds of the nap. The average percentage of power for this record is 43.5%. Only one large peak is present in the plot for the 1st night, Figure 4.37b, and the mean percentage of power has decreased to 33.5%. In the 2nd night, Figure 4.37c, there are two high amplitude peaks in the beginning of the first and second halves of the

TABLE 4.25

Summary of the Output Results from FEATURE for Subject SC2

SLEEP SESSION			Nap	1st	2nd	Baseline
RECORD NUMBER			15945	15952	15956	16328
DOSAGE (mg)			600	-	0	0
DELTA BAND (0.0-3.5Hz)	PERC. OF POWER	MEAN	43.5	33.5	40.3	50.7
		STD	8.4	8.5	11.0	9.4
	FREQ. PEAK (Hz)	MEAN	1.5	1.8	1.8	1.7
		STD	0.5	0.6	0.7	0.7
THETA BAND (4.0-7.5Hz)	PERC. OF POWER	MEAN	15.6	16.3	21.4	22.4
		STD	1.4	1.7	3.3	4.3
	FREQ. PEAK (Hz)	MEAN	6.4	6.2	5.4	5.1
		STD	1.0	1.2	1.2	1.1
ALPHA BAND (8.0-11.5Hz)	PERC. OF POWER	MEAN	9.5	10.0	10.0	7.5
		STD	1.4	2.5	2.7	2.8
	FREQ. PEAK (Hz)	MEAN	9.8	9.5	9.7	9.8
		STD	1.2	1.1	1.2	1.1
SIGMA BAND (12.0-15.5Hz)	PERC. OF POWER	MEAN	16.0	24.5	18.6	6.8
		STD	6.5	9.4	10.0	3.4
	FREQ. PEAK (Hz)	MEAN	13.3	13.7	13.6	13.9
		STD	0.6	0.7	0.6	0.7

TABLE 4.25

(continued)

SLEEP SESSION			Nap	1st	2nd	Baseline
RECORD NUMBER			15945	15952	15956	16328
DOSAGE (mg)			600	-	0	0
BETA1 BAND (16.0-20.5Hz)	PERC. OF POWER	MEAN	5.7	6.3	3.5	2.5
		STD	4.0	4.1	2.3	1.6
	FREQ. PEAK (Hz)	MEAN	18.6	18.9	18.9	19.2
		STD	1.1	1.1	1.3	0.9
BETA2 BAND (21.0-29.5Hz)	PERC. OF POWER	MEAN	3.8	5.0	2.7	2.0
		STD	2.0	3.5	2.0	1.8
	FREQ. PEAK (Hz)	MEAN	23.9	25.1	24.9	24.9
		STD	2.0	2.3	2.5	3.1
FASTF BAND (30.0-40.0Hz)	PERC. OF POWER	MEAN	1.4	1.6	0.9	0.6
		STD	0.9	1.3	0.6	0.5
	FREQ. PEAK (Hz)	MEAN	33.3	33.2	33.5	34.6
		STD	2.4	2.1	2.2	2.9
X^2	MEAN		93.9	85.4	93.5	91.7
	STD		12.6	10.8	14.3	10.1
	PERCENTAGE OF REJECTIONS		87.0	80.7	88.2	88.7
MFC	MEAN		6.3	8.5	6.7	4.9
	STD		1.9	2.0	2.2	2.0

	DELTA BAND	THETA BAND	ALPHA BAND	SIGMA BAND	BETA1 BAND	BETA2 BAND	FASTF BAND	X^2 COEF.	MFC
MEAN PERC. OF POWER	+ 51%	+ 37%	- 25%	- 72%	- 60%	- 60%	- 56%	-	-
MEAN FREQ. PEAK	- 5%	- 18%	+ 3%	+1.5%	+1.6%	- 1%	+ 4%	-	-
MEAN	-	-	-	-	-	-	-	+ 8%	- 42%
PERC. OF REJECTIONS	-	-	-	-	-	-	-	+ 10%	-

TABLE 4.26 Subject SC2 - Percentage Change in the Results of Table 4.25 Between the Baseline and the 1st Nights

night respectively. The average percentage of power in this night has returned to the value of 40.3%. During the baseline night, Figure 4.37d, the two high amplitude peaks are still present with the difference being that they now have moved close to each other. The mean percentage of power in the baseline night is 50.7%, which is the highest value for all nights. From Table 4.26 we can see that the mean percentage of power in the Delta Band for the baseline night is 51% above the same quantity computed during the 1st night. The mean frequency in this band has decreased 5% between the first and the baseline nights.

The percentage of power in the Sigma Band is plotted, as a function of time, in Figures 4.38a, b, c and d. During the nap, Figure 4.38a, we can see that the amplitude of the peaks is becoming larger as the nap evolved. In the 1st night, Figure 4.38b, the amplitude and the number of peaks have increased in relation to the nap. The average percentage of power has also augmented from 16.0% during the nap, to 24.5%. Some high amplitude peaks still remain during the 2nd night, Figure 4.38c, but the mean percentage of power for this night has decreased to 18.6%. During the baseline night, Figure 4.38d, the high activity that was predominant in the first two nights has disappeared, which in turn resulted in a decrease in the average percentage of power to 6.8%. The total change in the mean percentage of power between the 1st and the baseline nights was -72%, as shown in Table 4.26. The mean frequency in this band has

increased by 1.5% in the same period.

Figures 4.39a, b, c and d show the Mean Frequency Coefficient (MFC) plotted as a function of time for the records listed in Table 4.24. During the nap, Figure 4.39a, there are two low frequency dips that are close to the 3 Hz frequency line in the first two third of the plot. The plot for the 1st night, Figure 4.39b, shows one low frequency dip above 3 Hz in the beginning of the night. The mean frequency for this night is up to 8.5 Hz from the value of 6.3 Hz during the nap. In the 2nd night, Figure 4.39c, there are two low frequency dips in the beginning of the first and second halves of the night respectively. Of these, the first one went below the 3 Hz frequency line. The mean frequency for this night is 6.7 Hz which is below the computed value for the previous night. The plot for the baseline night, Figure 4.39d, shows two low frequency dips in the first half of the night which are below the 3 Hz frequency line. The mean frequency for the night is down to 4.9 Hz. From table 4.26 it can be seen that the mean frequency in the baseline night has decreased 42% from its corresponding value during the 1st night. As we pointed out before the low frequency dips in these plots coincide with the delta peaks in the corresponding plots for the percentage of power in the Delta Band.

The plots for the X^2 coefficients are shown in Figures 4.40a, b, c and d. During the nap, Figure 4.40a, the EEG's amplitude did not follow a Gaussian probability dis-

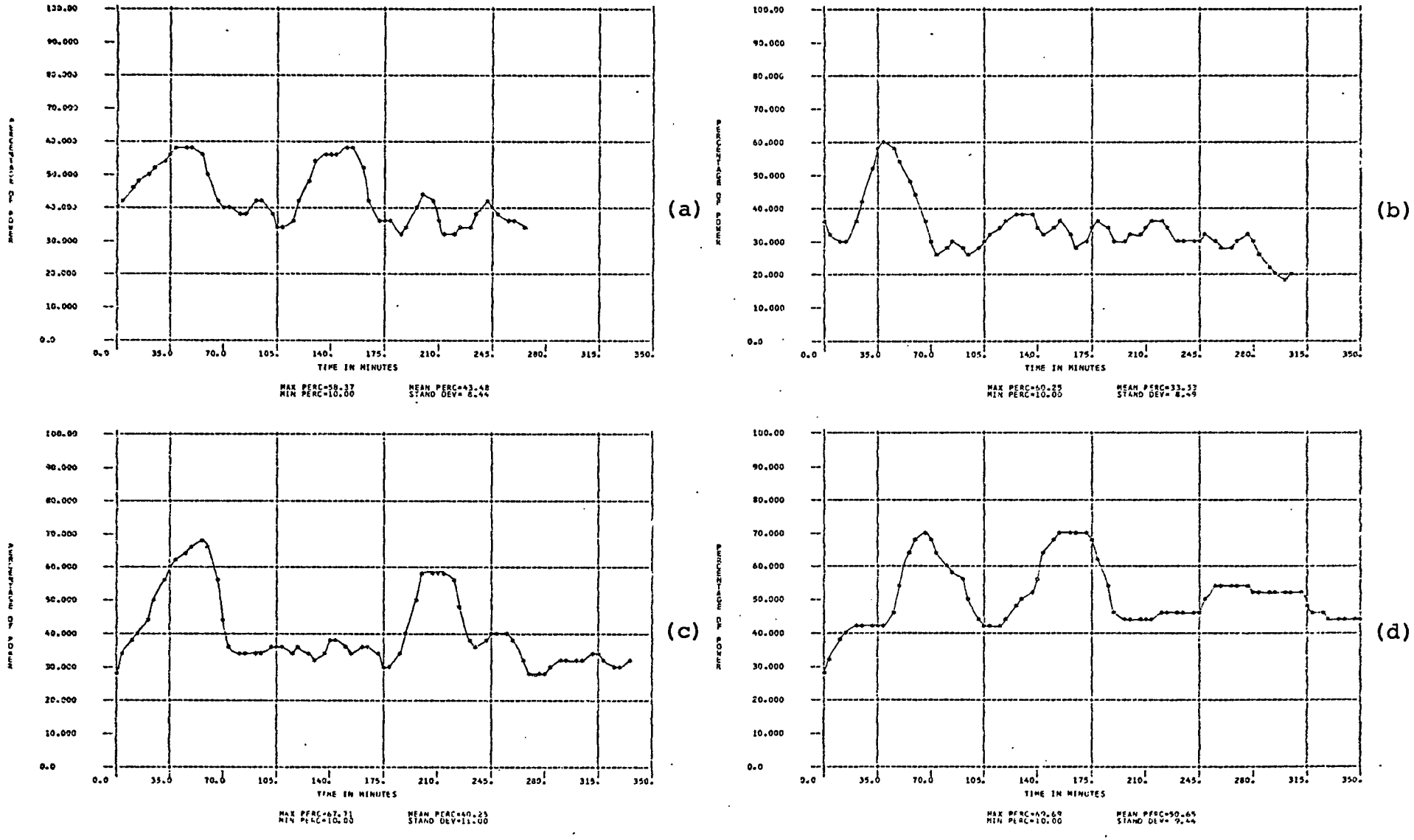


FIGURE 4.37 Subject SC2 - Percentage of Power in the Delta Band
(a) nap, record #15945 (b) 1st night, record #15952
(c) 2nd night, record #15956 (d) baseline night, record #16328

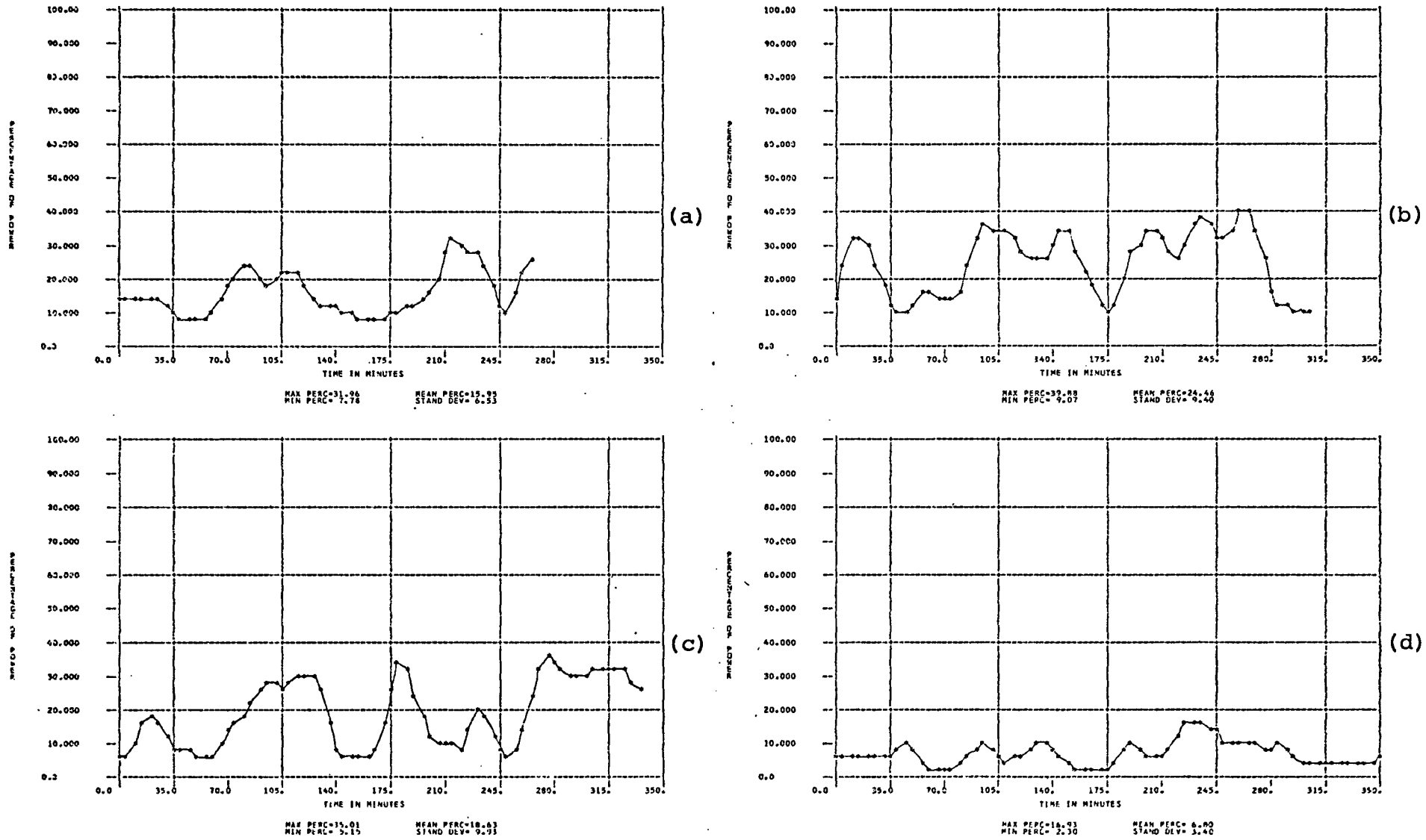


FIGURE 4.38 Subject SC2 - Percentage of Power in the Sigma Band
(a) nap, record #15945 (b) 1st night, record #15952
(c) 2nd night, record #15956 (d) baseline night, record #16328

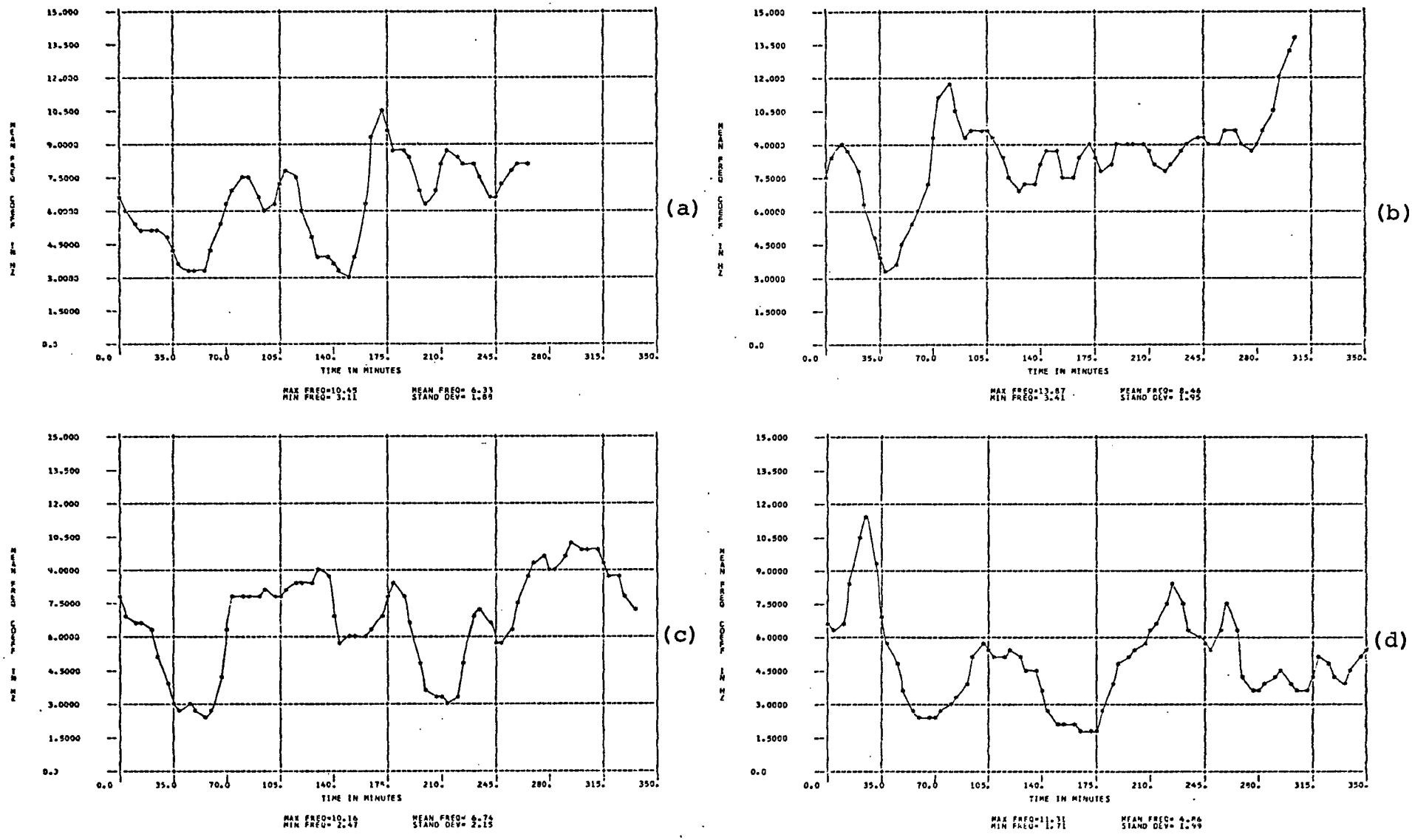


FIGURE 4.39 Subject SC2 - Mean Frequency Coefficient (MFC)
(a) nap, record #15945 (b) 1st night, record #15952
(c) 2nd night, record #15956 (d) baseline night, record #16328

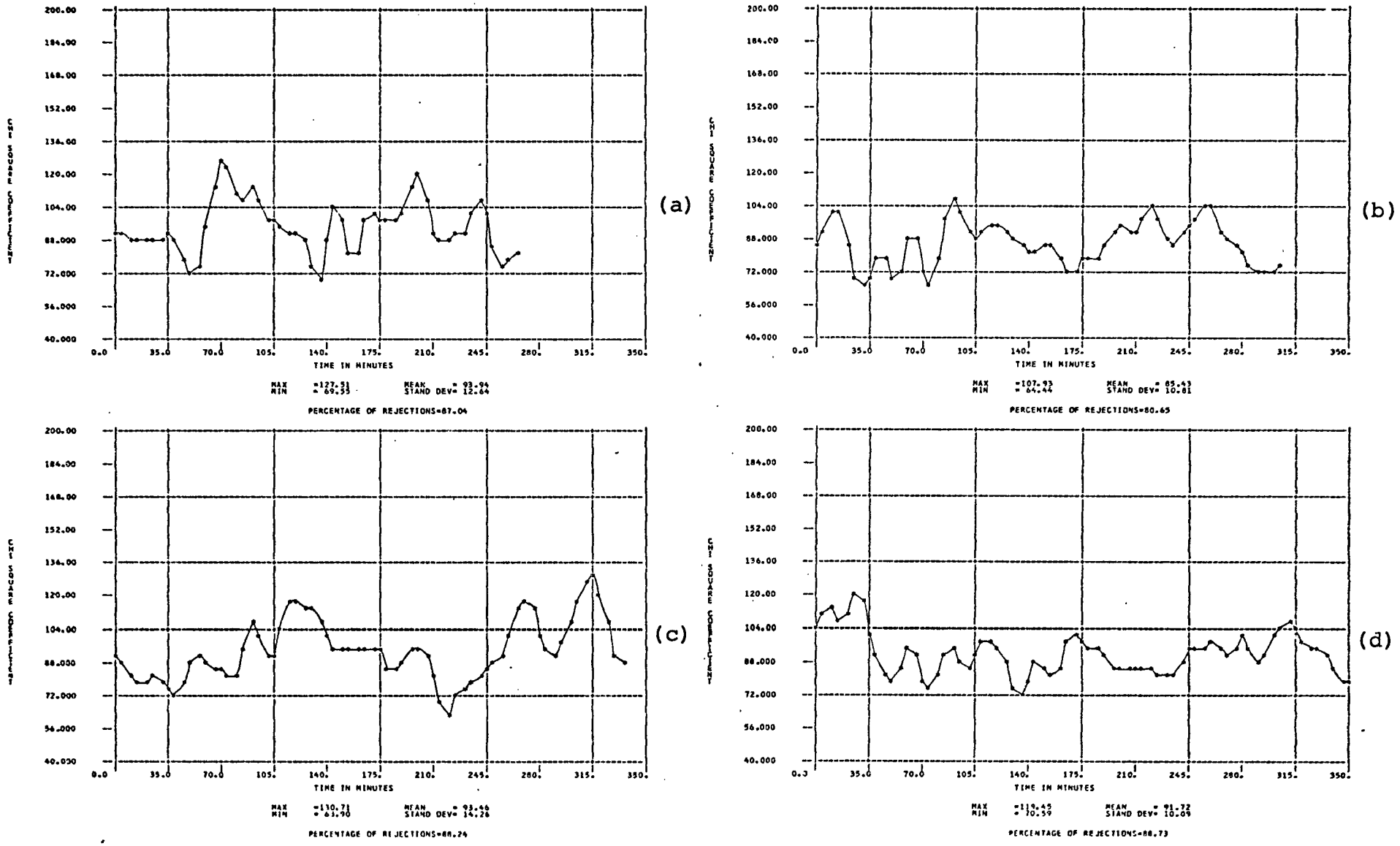


FIGURE 4.40 Subject SC2 - Chi-Square Coefficient
(a) nap, record #15945 (b) 1st night, record #15952
(c) 2nd night, record #15956 (d) baseline night, record #16328

tribution function in 87% of the epochs. This value decreased to 80.7% in the 1st night and returned to its previous level in the 2nd and in the baseline nights (88.2 and 88.7 respectively). Table 4.26 shows that the mean value and the percentage of rejections for the X^2 coefficients have increased in the baseline night by 8 and 10% over their previous values in the 1st night.

4.4.3 Subject SC3

4.4.3.1 Subject's Protocol

Subject SC3 is a 24 year-old male. A total of three sleep sessions were automatically processed. Since this subject slept straight from the beginning of the nap until the next morning, the nap and the 1st night records are merged into a single long record. In order to facilitate the comparison of the results between the subjects, we divided the entire record into two parts of equal time duration and called them "nap" and "1st" night, respectively. Table 4.27 shows the sleep sessions, their corresponding record number and the amount of drug given to the subject.

TABLE 4.27

Analyzed Data for Subject SC3

Sleep Session	Record Number	Titration Dosage (mg)
"Nap"[1]	15971	1000
"1st" Night[1]	15971	-

[1]Both sessions are in a single long record.

TABLE 4.27

(continued)

Sleep Sessions	Record Number	Titration Dosage (mg)
2nd Night	15979	none
Baseline[2] Night	16326	none

[2]Recorded one month after the administration of the drug.

4.4.3.2 Compressed Spectral Array

Figures 4.41a, b, c and d show the CSA plots of the four sleep sessions listed in Table 4.27. The CSA plot for the "nap", Figure 4.41a, shows some high intensity spectral peaks in the delta range at the beginning and towards the end of the nap. The spectral peaks in the Sigma Band are not well-defined in this plot and their central frequency is shifting between 13 and 14 Hz. Appearing with the first train of peaks in the Delta Band, there is a series of spectral peaks centered around 11.0 to 11.5 Hz which probably correspond to slow spindle activity "riding" on the delta waves. Activity in the Theta and Betas Bands can be also seen. Figure 4.41b shows that in the "1st" Night, the high intensity peaks in the Delta Band have disappeared. The peaks in the Sigma Band are better defined and most of them are centered around 13.5 Hz. Activity in the Theta and Betas Bands can still be seen.

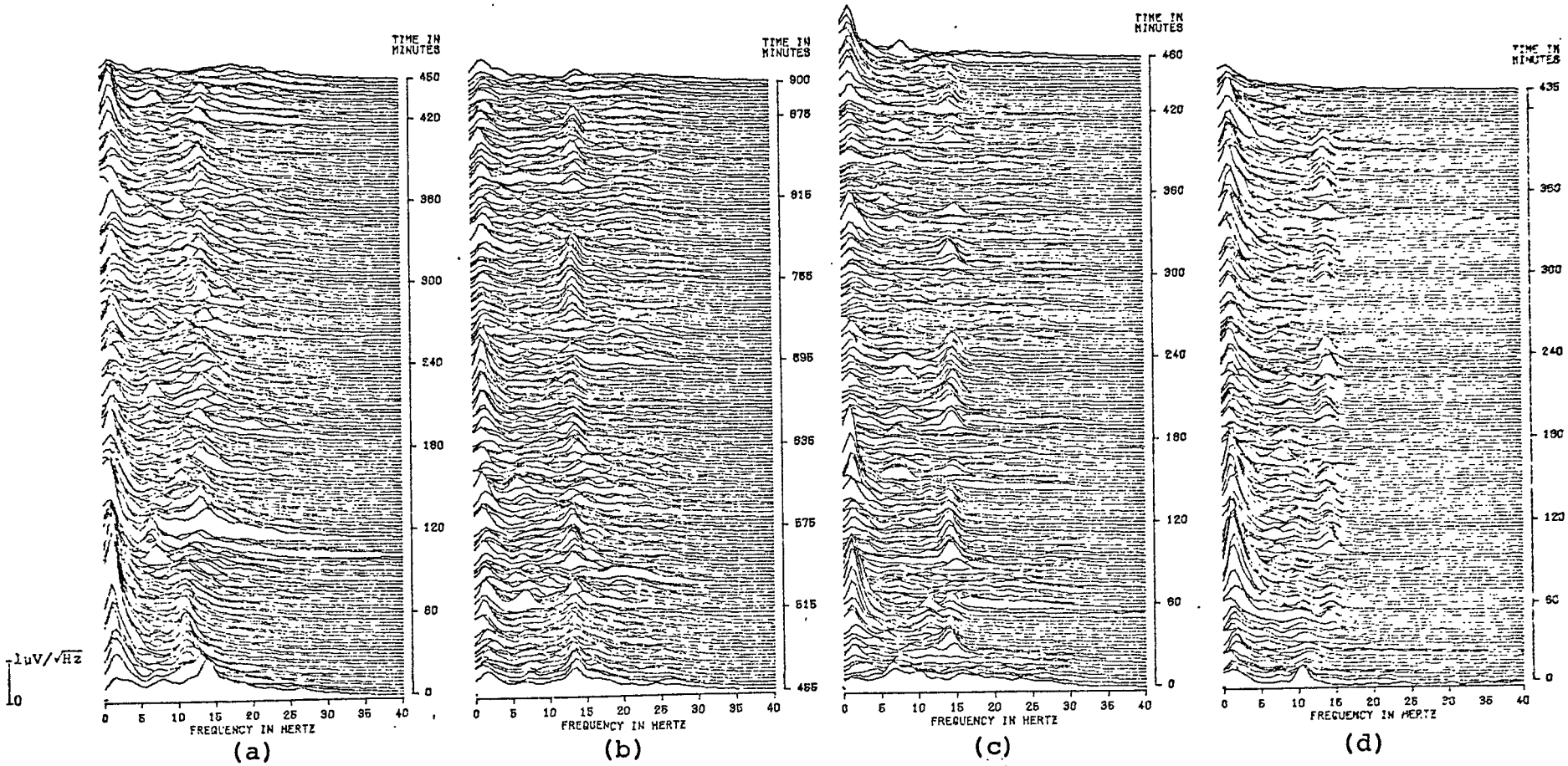


FIGURE 4.41 Subject SC3 - Compressed Spectral Array (CSA)
(a) "nap", record #15971 (b) "1st" night, record #15971
(c) 2nd night, record #15979 (d) baseline night, record #16326

The CSA plot for the 2nd night, Figure 4.41c, shows trains of high intensity delta-activity spectral peaks in the first half of the night and at the very end of it. The number of peaks in the Sigma Band has lessened in comparison to the ones in the first two plots and their peak frequencies are now between 14.0 and 14.5 Hz. Very little activity can be seen in the Beta's frequency range. For the baseline night, Figure 4.41d, the CSA plot shows that the peaks in the Delta Band are of higher intensity than the corresponding ones in the 2nd night, and the magnitude of the peaks in the Sigma Band remained essentially unchanged.

4.4.3.3 Summary of the Output Results from the FEATURE Algorithm

Table 4.28 shows the output results computed by the data reduction algorithm (FEATURE). As we can see from these results, the mean percentage of power in the Delta and Theta Bands decreased between the "nap" and the "1st" nights. On the other hand the average percentage of power in the Sigma, Beta1, Beta2 and the mean value and the percentage of rejection of the X^2 coefficient increased in the same period. However an opposite trend is followed by all of the above results in the 2nd and in the baseline nights. Table 4.29 shows the percentage changes in all the results of Table 4.28 between the "1st" and the baseline nights.

Figures 4.42a, b, c and d show the plots of the percentage of power in the Delta Band for the sleep records

TABLE 4.28

Summary of the Output Results from FEATURE for Subject SC3

SLEEP SESSION			Nap	1st	2nd	Baseline
RECORD NUMBER			15971	15971	15979	16326
DOSAGE (mg)			1000			
DELTA BAND (0.0-3.5Hz)	PERC. OF POWER	MEAN	36.1	25.0	37.5	58.3
		STD	15.1	9.8	12.2	8.4
	FREQ. PEAK (Hz)	MEAN	1.4	1.5	1.5	1.3
		STD	0.4	0.4	0.4	0.3
THETA BAND (4.0-7.5Hz)	PERC. OF POWER	MEAN	13.2	13.0	17.5	16.3
		STD	3.5	3.3	4.2	2.8
	FREQ. PEAK (Hz)	MEAN	6.7	6.6	6.6	7.0
		STD	0.6	0.8	0.9	0.8
ALPHA BAND (8.0-11.5Hz)	PERC. OF POWER	MEAN	14.4	14.4	12.5	9.6
		STD	3.0	2.0	3.3	4.1
	FREQ. PEAK (Hz)	MEAN	10.6	9.9	10.0	9.7
		STD	1.1	1.1	1.3	1.0
SIGMA BAND (12.0-15.5Hz)	PERC. OF POWER	MEAN	18.9	21.8	13.5	5.7
		STD	9.0	8.4	6.2	2.7
	FREQ. PEAK (Hz)	MEAN	13.5	13.7	14.2	14.2
		STD	0.8	0.7	0.8	0.6

TABLE 4.28

(continued)

SLEEP SESSION			Nap	1st	2nd	Baseline
RECORD NUMBER			15971	15971	15979	16326
DOSAGE (mg)			1000			
BETA1 BAND (16.0-20.5Hz)	PERC. OF POWER	MEAN	8.8	12.8	6.9	1.83
		STD	5.8	3.9	3.5	0.9
	FREQ. PEAK (Hz)	MEAN	18.6	18.4	18.8	18.8
		STD	1.4	1.5	1.3	1.0
BETA2 BAND (21.0-29.5Hz)	PERC. OF POWER	MEAN	9.2	10.1	6.5	1.5
		STD	0.6	3.5	4.1	1.1
	FREQ. PEAK (Hz)	MEAN	23.4	23.6	24.5	24.7
		STD	2.1	2.0	2.7	2.5
FASTF BAND (30.0-40.0Hz)	PERC. OF POWER	MEAN	0.4	0.9	0.7	0.4
		STD	0.2	0.4	0.5	0.3
	FREQ. PEAK (Hz)	MEAN	34.4	33.9	34.6	34.7
		STD	2.3	2.2	2.5	2.8
x^2	MEAN		65.9	61.2	83.9	105.5
	STD		9.4	7.1	15.7	23.0
	PERCENTAGE OF REJECTIONS		38.5	35.6	71.0	94.3
MFC	MEAN		6.5	9.0	6.7	3.5
	STD		2.5	2.0	2.1	1.2

	DELTA BAND	THETA BAND	ALPHA BAND	SIGMA BAND	BETA1 BAND	BETA2 BAND	FASTF BAND	X^2 COEF.	MFC
MEAN PERC. OF POWER	+133%	+ 18%	- 33%	- 73%	- 85%	- 84%	- 56%	-	-
MEAN FREQ. PEAK	- 13%	+ 6%	- 2%	- 4%	+ 2%	+ 5%	+ 2%	-	-
MEAN	-	-	-	-	-	-	-	+ 72%	- 61%
PERC. OF REJECTIONS	-	-	-	-	-	-	-	+165%	-

TABLE 4.29 Subject SC3 - Percentage Change in the Results of Table 4.28 Between the Baseline and the 1st Nights

listed on Table 4.27. During the "nap", Figure 4.42a, there are three large peaks, of which two are located at the first half of the plot and the other towards its end. The first peak is of higher amplitude and longer duration compared to the other two. The mean percentage of power in the band for the "nap" is 36.1%. The plot for the "1st" night, Figure 4.42b, shows only one high amplitude peak located close to the center of the plot, and the mean percentage of power in the band is down to 25%. By the 2nd night this value is up to 37.5%, which is close to the computed value during the "nap". The plot for the 2nd night, Figure 4.42c, shows four high amplitude and short duration peaks, two in the first third and two in the last third of the night. In the baseline night, Figure 4.42d, the mean percentage of power is up to 58.3% and only two large amplitude peaks can be clearly distinguished agains the high activity background. From Table 4.28 it can be seen that the mean percentage of power in the Delta Band during the baseline night has increased 133% over the corresponding value computed for the "1st" night. The mean frequency in this band has decreased 13% between these two nights.

The plots for the percentage of power in the Sigma Band are shown in Figure 4.43a, b, c and d. Figure 4.43a, shows that during the "nap" the amplitude of the peaks in the band is increasing as the "nap" progresses. The mean percentage of power in the band is 18.9%. This value has increased to 21.8% during the 1st night, Figure 4.43b.

However the peaks in the 2nd night, Figure 4.43c, are of less amplitude than the ones in the previous plots, and the mean percentage of power for the night is down to 13.5%. In the baseline night, Figure 4.43d, the average percentage of power is reduced to 5.7% and the peaks are of low amplitude. There is a reduction of 73% between the mean percentage of power in the "1st" night and the one in the baseline night. The mean frequency in this band has also increased 4% between the two nights.

Figures 4.44a, b, c and d show the plots for the Mean Frequency Coefficients (MFC) for the records as listed in Table 4.27. The plot for the"nap," Figure 4.44a, shows two low frequency dips. The first which is located at the beginning of the "nap" is of longer duration and it is closer to the 2 Hz frequency line. The second one is in the last third of the "nap", and its frequency is above the 3 Hz frequency line. After the first dip the MFC points are of increasing frequencies as the nap progresses. During the "1st" night, Figure 4.44b, most of the MFCs are located at the higher frequency part of the plot, except for a low frequency dip around the middle of the night that is below the 3 Hz line. The mean frequency now has increased to 9 Hz. In the 2nd night this is down to 6.7Hz, which is close to the previous value for the "nap". The plot for this night, Figure 4.44c, shows three low frequency dips that are either close or below the 3 Hz frequency line. Two of them are located in the first third of the night and the other at the

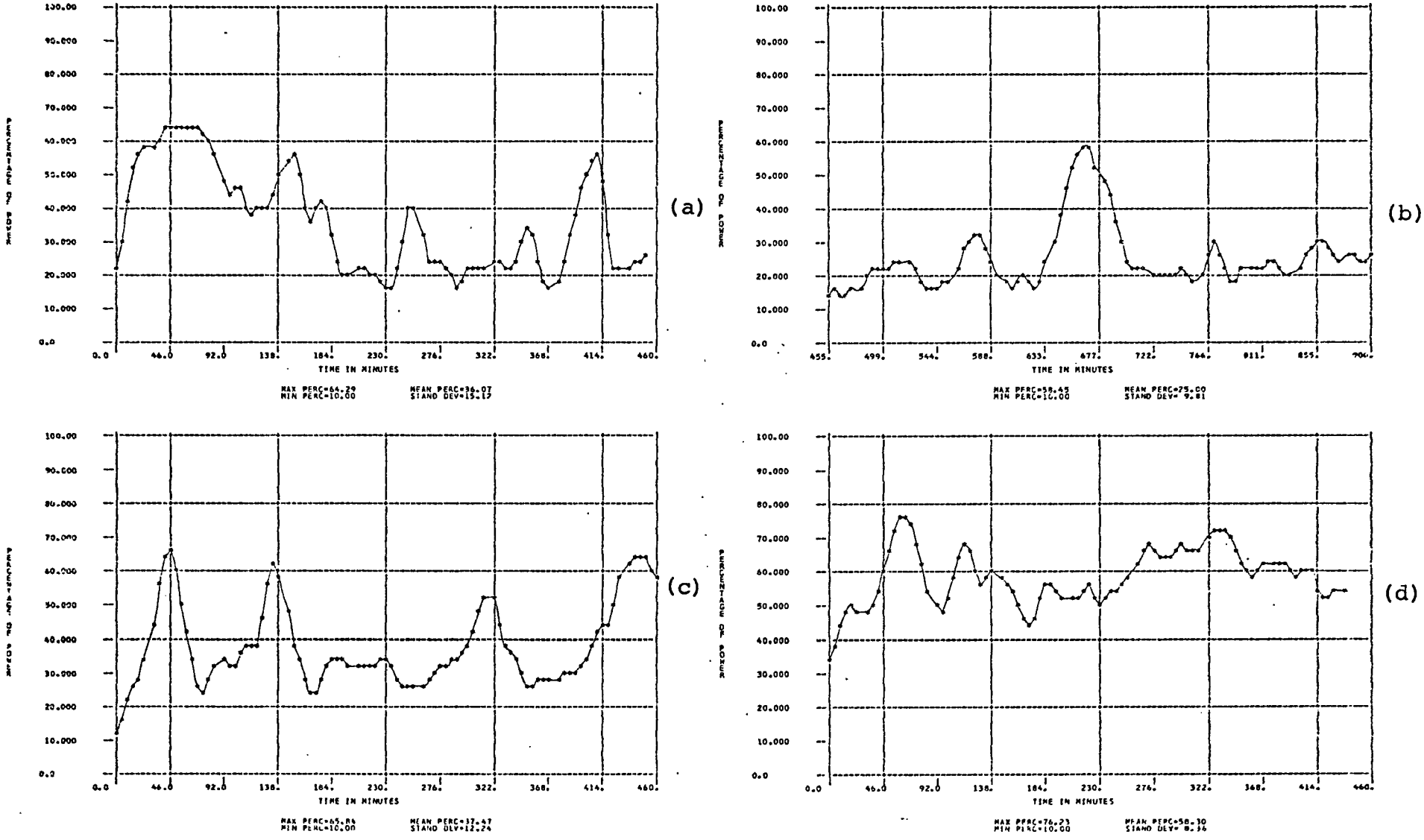


FIGURE 4.42 Subject SC3 - Percentage of Power in the Delta Band
(a) "nap", record #15971 (b) "1st" night, record #15971
(c) 2nd night, record #15979 (d) baseline night, record #16326

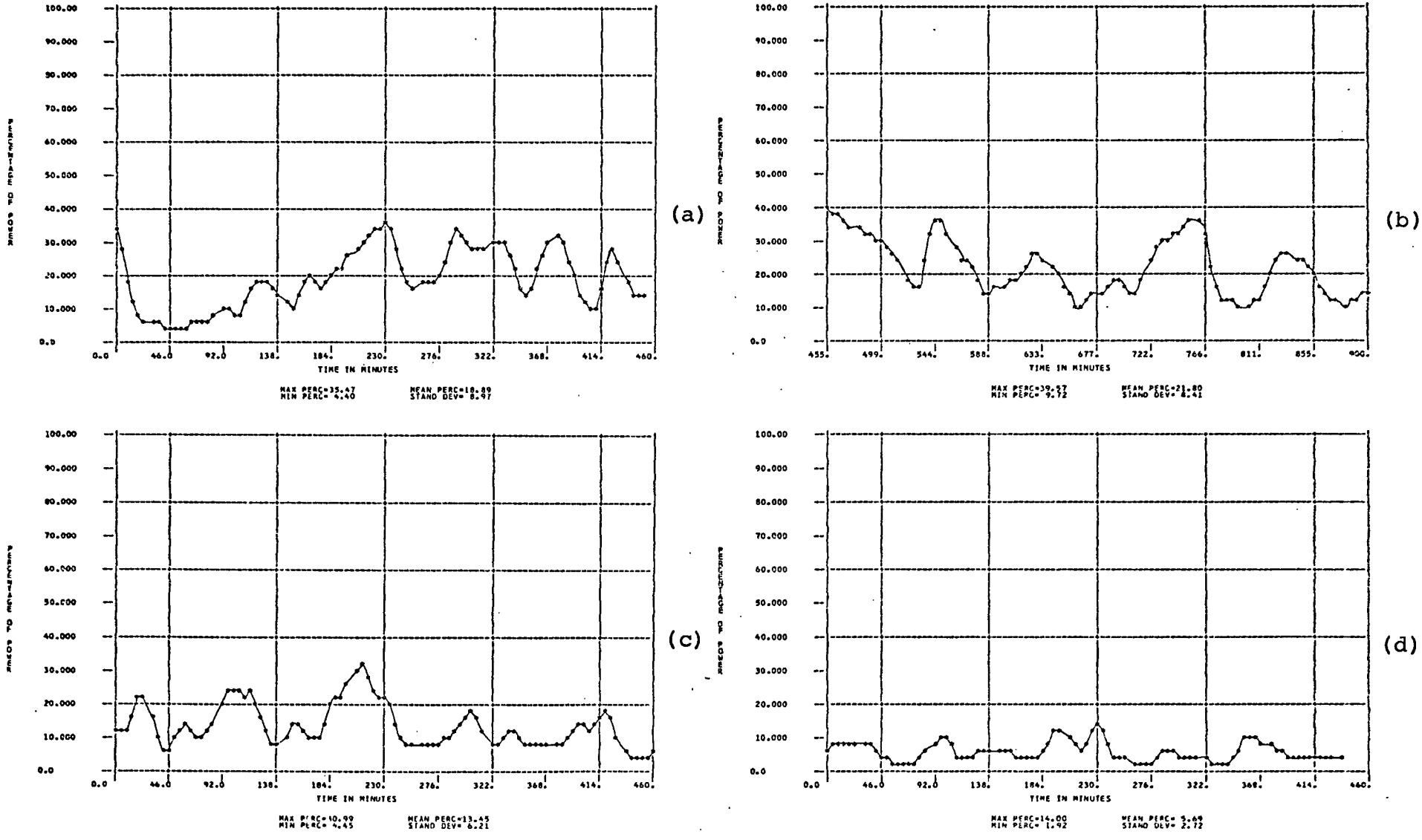


FIGURE 4.43 Subject SC3 - Percentage of Power in the Sigma Band
(a) "nap", record #15971 (b) "1st" night, record #15971
(c) 2nd night, record #15979 (d) baseline night, record #16326

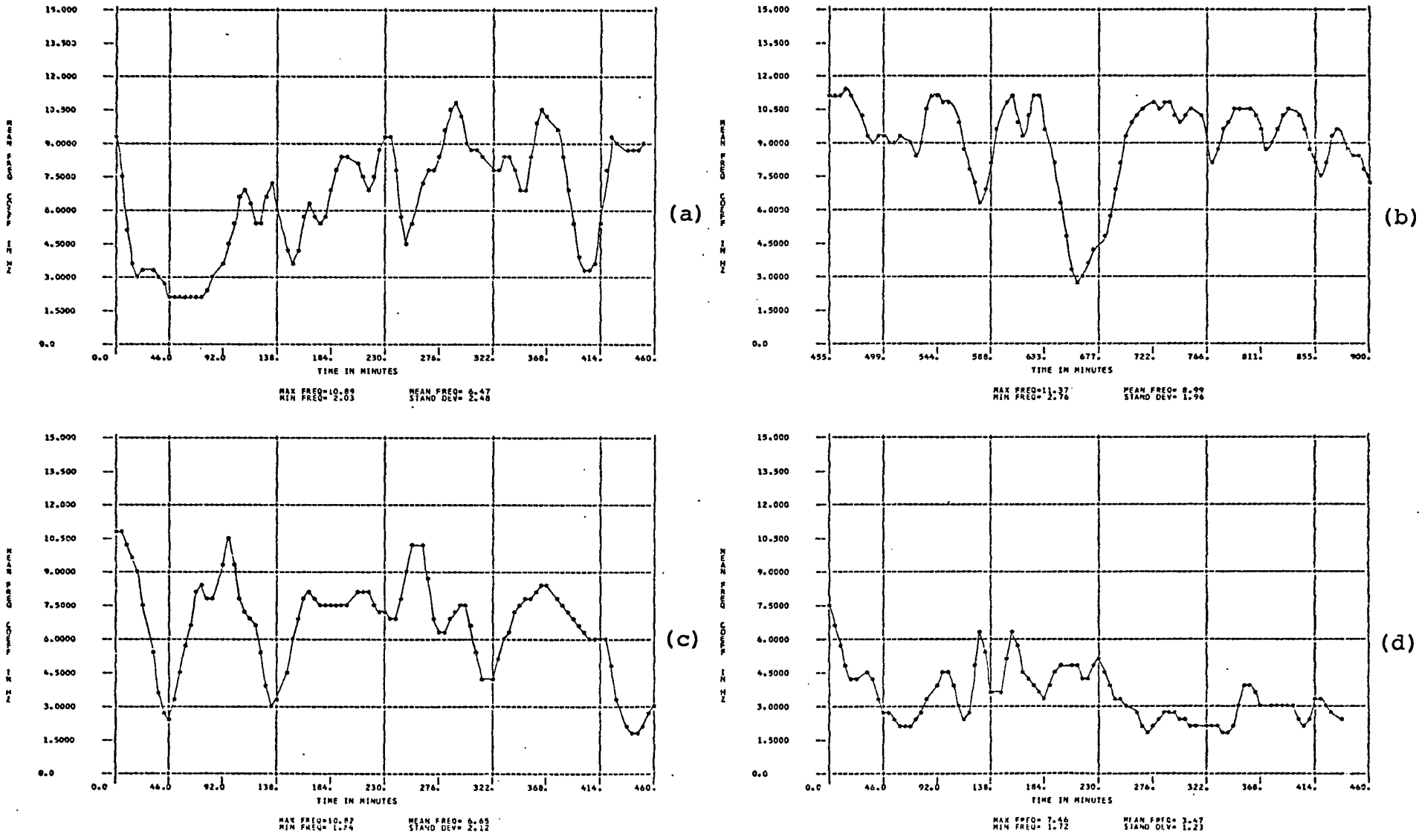


FIGURE 4.44 Subject SC3 - Mean Frequency Coefficient (MFC)
(a) "nap", record #15971 (b) "1st" night, record #15971
(c) 2nd night, record #15979 (d) baseline night, record #16326

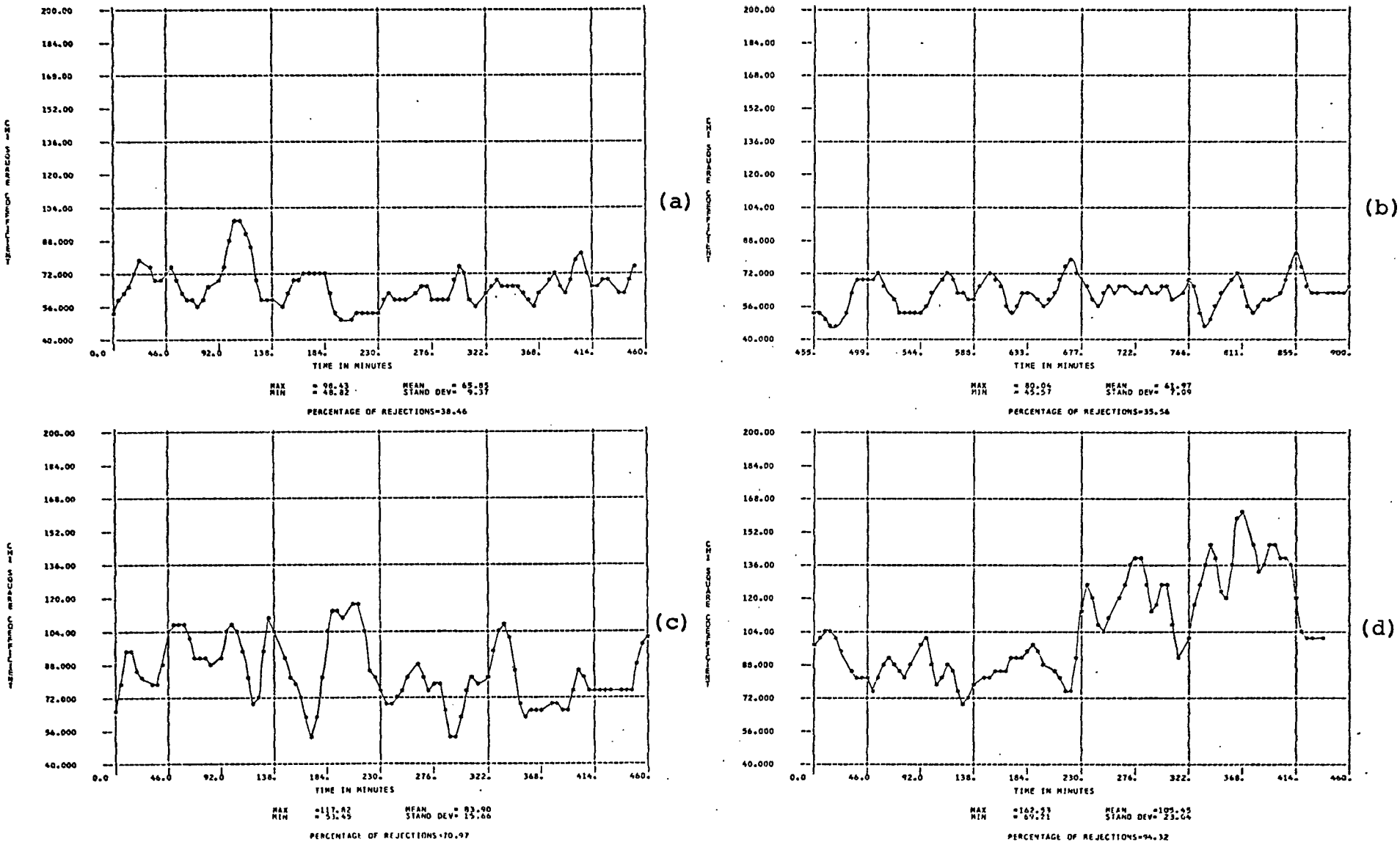


FIGURE 4.45 Subject SC3 - Chi-Square Coefficient
(a) "nap", record #15971 (b) "1st" night, record #15971
(c) 2nd night, record #15979 (d) baseline night, record #16326

very end of it. The baseline night, Figure 4.44d, is dominated by low frequency activity and the low frequency dips are not well-defined. The mean frequency for this night is down to 3.5 Hz. According to Table 4.29, this result is 61% below the value computed for the "1st" night.

Figures 4.45a, b, c and d show the plots for the X^2 coefficients. In the first two plots, Figures 4.45a and b, most of the points are below the 72 line and the EEG's amplitude distribution follows a Gaussian probability density function in more than 60% of the epochs. However, this percentage is reduced to less than 30% in the 2nd night and to 5% in the baseline night. The last two plots, Figure 4.45c and d, show that the X^2 points are more scattered than in the previous plots (Figures 4.45a and b). This can also be seen by an increase in the standard deviation in these last two records. From Table 4.29 we can see that the mean value and the percentage of rejections for the X^2 coefficient have increased 72 and 165% between the "1st" and the baseline nights.

4.4.4 Discussion of the Results of Subjects in Group 2 Receiving Secobarbital

Table 4.30 shows the comparisons of the percentage changes in the output results of the data reduction algorithm between the baseline night and the first night for each of the subjects in Group 2, that were given secobarbital.

The mean percentage of power in the Delta Band decreased in all subjects during the first night when they were under the effects of the drug. Table 4.30 shows this as an increase in the mean percentage of power in the baseline night compared to the corresponding value during the first night. Karacan et al (1970) has found that afternoon naps, during which there was significantly more stage 4 sleep, were followed by nights during which stage 4 was reduced below normal levels. Since we cannot correlate especifically stage 4 with the percentage of power in the Delta Band, we can only speculate that probably part of the reduction in the percentage of power in the Delta Band during the first night could be caused by the fact that the subjects took a nap following the administration of the drug. Subject SC3, to whom was given the highest dosage (1000 mg of secobarbital) had the largest increase (133%). The other two subjects who were given 600 mg of secobarbital showed increases in the mean of 33 and 15%. In addition, one of the subjects, SC3, showed a marked decrease in the mean frequency peak in this band. This later results is in contradiction with the previous results obtained for the subjects in Group 1 that were withdrawn from the same drug (Section 4.2.4).

The average percentage of power in the Sigma Band decreased below 70% in all the subjects during the baseline night, when compared to the results obtained in the first night. Two of the subjects, SC1 and SC2, showed a decrease

in the mean frequency peak in this band during the first night. However, only subject SC3 had a frequency change (4%) compared to the ones observed in the drug abusers (Table 4.10).

From Table 4.30 we also can see that there is a reduction in the average percentage of power in the Alpha, Beta1, Beta2 and FASTF frequency bands in the baseline night when compared to the same results during the first night. However an opposite trend is observed in the mean percentage of power in the Theta Band.

The mean frequency during the baseline night decreased in all subjects from the previous high values computed for the first night. The highest reduction (61%) was shown by subject SC3. The other two subjects showed changes between -36 and -42%.

The mean value and the percentage of reduction of the X^2 coefficient decreased in all subjects with the administration of the drug. Table 4.30 shows these results as a percentage increase in the mean value and in the percentage of rejections in the X^2 coefficient between the first and the baseline nights. Again subject SC3, showed the highest increases of 72% for the mean and 165% for the percentage of rejections. Furthermore, as we can see from Table 4.28, during the first night in almost 65% of the epochs the EEG's amplitude was distributed according to a Gaussian probability density function. This value was reduced

TABLE 4.30

Summary of the Results of Tables 4.23, 4.26 and 4.29 for Subjects in Group 1 - Secobarbital

SUBJECTS			SC1	SC2	SC3
TITRATION DOSAGE (mg)			600	600	1000
DELTA BAND (0.0-3.5Hz)	PERC. OF POWER	MEAN	33%	+51%	+133%
	FREQ. PEAK (Hz)	MEAN	- 5%	- 5%	- 13%
THETA BAND (4.0-7.5Hz)	PERC. OF POWER	MEAN	+25%	+37%	+ 18%
	FREQ. PEAK (Hz)	MEAN	- 3%	+ 3%	+ 6%
ALPHA BAND (8.0-11.5Hz)	PERC. OF POWER	MEAN	-17%	-25%	- 33%
	FREQ. PEAK (Hz)	MEAN	- 2%	+ 3%	- 2%
SIGMA BAND (12.0-15.5Hz)	PERC. OF POWER	MEAN	-71%	-72%	- 73%
	FREQ. PEAK (Hz)	MEAN	+ 1%	-1.5%	+ 4%

TABLE 4.30

(continued)

SUBJECTS			SC1	SC2	SC3
TITRATION DOSAGE (mg)			600	600	1000
BETA1 BAND (16.0-20.5Hz)	PERC. OF POWER	MEAN	-73%	-60%	-85%
	FREQ. PEAK (Hz)	MEAN	-0.5%	+1.6%	+ 2%
BETA2 BAND (21.0-29.5Hz)	PERC. OF POWER	MEAN	-74%	-60%	-84%
	FREQ. PEAK (Hz)	MEAN	- 2%	- 1%	+ 5%
FASTF BAND (30.0-40.0Hz)	PERC. OF POWER	MEAN	-63%	-56%	-56%
	FREQ. PEAK (Hz)	MEAN	-0.3%	+ 4%	+ 2%
X^2	MEAN		+10%	+ 8%	+72%
	PERCENTAGE OF REJECTIONS		+24%	+10%	+165%
MFC	MEAN		- 36%	-42%	-61%

to less than 5% in the baseline night. The other subjects followed the same trend but with much less variability.

4.5 GROUP 2 - METHAQUALONE

4.5.1 Subject SC4

4.5.1.1 Subject's Protocol

Subject SC4 is a 25 year-old male. Table 4.31 lists the sleep sections that were automatically processed. This table was derived from Table 2.4. Record #15912, for the 1st night, showed a very low frequency artifact that was present for most of the night. It was possibly caused by the subject's sweating or by the fact that blood samples were drawn during the night. This artifact resulted in large spectral peaks around 0 Hz in the CSA plot. In order to minimize its effects, the raw EEG data was passed through a 9th order high-pass Chebyshev digital filter (Papp, 1975) with a cutoff frequency at 1 Hz, before the algorithm REDUCE was applied to it (See Section 2.4.2).

TABLE 4.31

Analyzed Data for Subject SC4

Sleep Sessions	Record Number	Titration Dosage (mg)
Nap[1]	15909	4200
1st Night[1]	15912	-

[1] Both sessions were run in the same day.

TABLE 4.31

(continued)

Sleep Sessions	Record Number	Titration Dosage (mg)
2nd Night	15917	none
Baseline[2] Night	16070	none

[2]Recorded one month after the administration of the drug.

4.5.1.2 Compressed Spectral Array

Figures 4.46a, b, c and d show the CSA plots for the sleep sessions listed on Table 4.31. The CSA plot for the nap, Figure 4.46a, shows some high intensity spectral peaks in the Delta, Alpha and Sigma Bands. The peaks in the Alpha Band are centered around 8.5-9.0 Hz and the ones in the Sigma Band are between 12.5 and 13.0 Hz. In the 1st night, Figure 4.46b, the peaks in the Delta Band are of lower intensities than the ones during the nap and the activity in the Sigma Band is present most of the night, centered at 13.0 Hz. The peaks in the Alpha Band are still located at 8.5-9.0 Hz. Figure 4.46c, shows the CSA plots corresponding to the 2nd night. From there we can see that the main change from the previous plots is an increase in the amplitude of the peaks in the Delta, Sigma, and Theta Bands. Furthermore, this increase is much larger in the Delta Band. During the baseline night, Figure 4.46d, there exist very high amplitude peaks in the Delta Band and the number of peaks in the Sigma

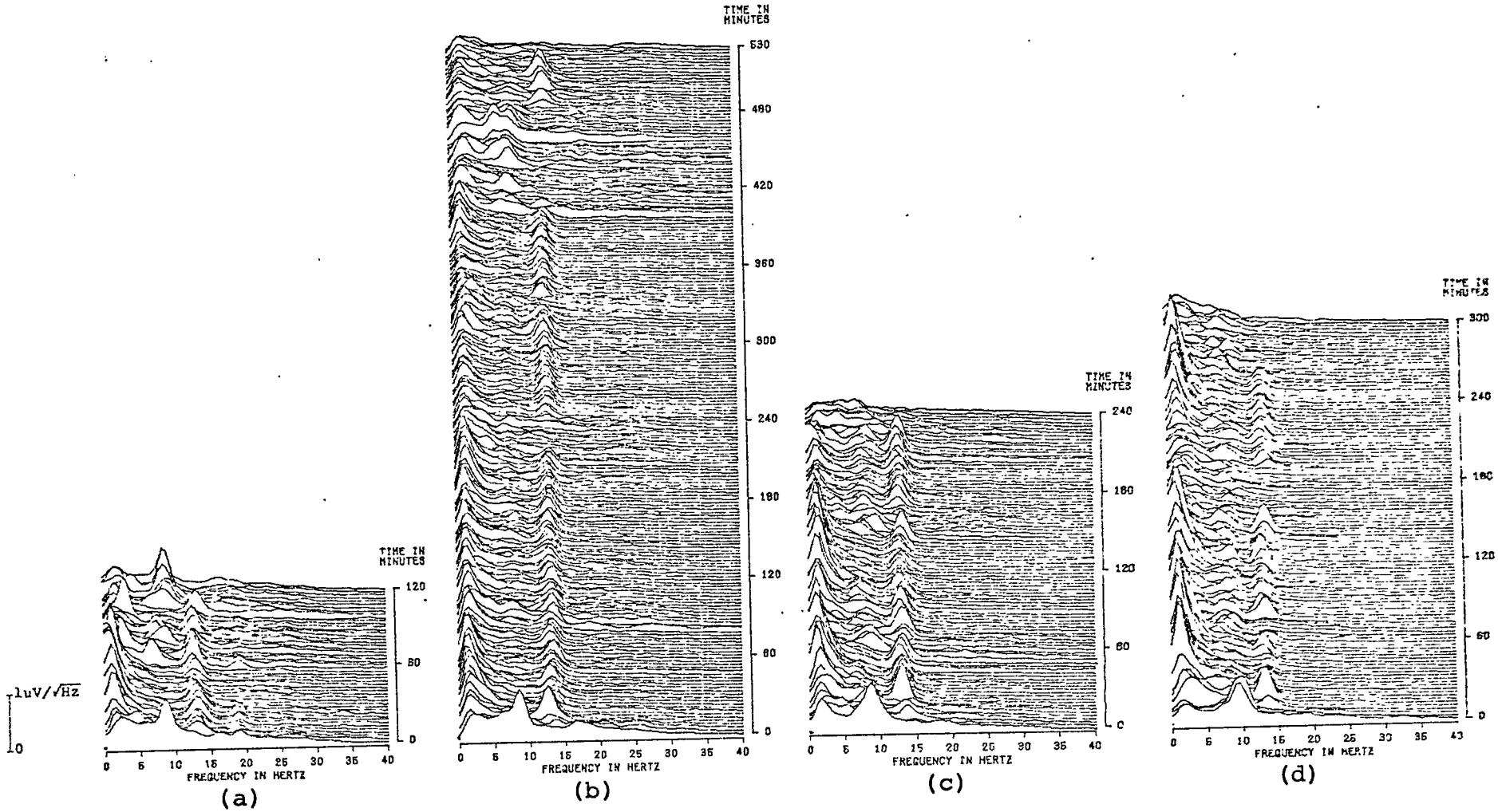


FIGURE 4.46 Subject SC4 - Compressed Spectral Array (CSA)
(a) nap, record #15909 (b) 1st night, record #15912
(c) 2nd night, record #15917 (d) baseline night, record #16070

Band has diminished in comparison to the 2nd night. The peaks in the Alpha Band are now located at 10 Hz, and some activity can also be seen in the Theta Band.

4.5.1.3 Summary of the Output Results from the FEATURE Algorithm

In Table 4.32, the results of the data reduction analysis performed by FEATURE are given. From this table it can be seen that there is a decrease in the percentage of rejections for the X^2 coefficient in the 1st night in relation to the values previously computed for the nap. This trend is, however, reversed in the 2nd and in the baseline nights. The mean percentage of power in the Sigma, Betal, Beta2 and Fastf Bands, and the mean value of the MFCs increase from the nap to the 1st night, and then start decreasing to their baseline values. The mean percentage of power in the Theta Band reached its lowest value during the nap, but it starts increasing in the subsequent nights. The mean percentage of power in the Delta Band stays almost the same during the nap, and in the 1st night, but it increases in tne baseline night. Table 4.33 shows the percentage change in the results of Table 4.32 between the 1st and the baseline nights.

In Figures 4.47a, b, c and d the plots of the percentage of power in the Delta Band vs time are shown. Only one peak is present at the beginning of the nap, Figure 4.47a. The plot for the 1st night, Figure 4.47b, shows three high

TABLE 4.32

Summary of the Output Results from FEATURE for Subject SC4

SLEEP SESSION			Nap	1st	2nd	Baseline
RECORD NUMBER			15909	15912	15917	16090
DOSAGE (mg)			4200	-	0	0
DELTA BAND (0.0-3.5Hz)	PERC. OF POWER	MEAN	42.0	41.5	43.7	51.9
		STD	15.1	9.6	15.2	11.4
	FREQ. PEAK (Hz)	MEAN	1.5	1.7	1.4	1.5
		STD	0.6	0.4	0.5	0.5
THETA BAND (4.0-7.5Hz)	PERC. OF POWER	MEAN	15.5	18.3	19.1	20.9
		STD	3.7	5.0	6.3	5.8
	FREQ. PEAK (Hz)	MEAN	6.5	6.7	6.3	6.6
		STD	1.0	0.8	1.2	1.0
ALPHA BAND (8.0-11.5Hz)	PERC. OF POWER	MEAN	14.9	12.9	14.0	12.4
		STD	9.8	4.5	6.9	7.3
	FREQ. PEAK (Hz)	MEAN	9.1	9.0	8.6	8.4
		STD	0.7	1.0	0.6	0.6
SIGMA BAND (12.0-15.5Hz)	PERC. OF POWER	MEAN	12.0	15.6	12.4	5.7
		STD	4.6	5.6	5.9	2.4
	FREQ. PEAK (Hz)	MEAN	12.9	13.1	13.1	13.6
		STD	0.6	0.6	0.6	0.6

TABLE 4.32

(continued)

SLEEP SESSION			Nap	1st	2nd	Baseline
RECORD NUMBER			15909	15912	15917	16090
DOSAGE (mg)			4200	-	0	0
BETA1 BAND (16.0-20.5Hz)	PERC. OF POWER	MEAN	4.5	4.6	2.8	2.1
		STD	2.5	1.8	1.8	1.1
	FREQ. PEAK (Hz)	MEAN	18.4	18.7	18.7	18.5
		STD	0.8	1.2	1.3	1.3
BETA2 BAND (21.0-29.5Hz)	PERC. OF POWER	MEAN	4.4	4.8	2.6	1.5
		STD	2.4	2.0	1.9	0.9
	FREQ. PEAK (Hz)	MEAN	24.3	22.9	24.2	24.7
		STD	1.9	2.1	1.9	2.4
FASTF BAND (30.0-40.0Hz)	PERC. OF POWER	MEAN	1.0	1.1	0.7	0.5
		STD	0.4	0.4	0.5	0.3
	FREQ. PEAK (Hz)	MEAN	34.2	34.0	33.3	34.1
		STD	2.4	2.4	2.4	2.4
X^2	MEAN		71.0	67.1	88.6	88.5
	STD		10.8	9.8	15.5	12.8
	PERCENTAGE OF REJECTIONS		52.0	46.7	79.6	83.9
MFC	MEAN		5.9	6.2	5.3	3.8
	STD		2.2	1.2	1.9	1.4

	DELTA BAND	THETA BAND	ALPHA BAND	SIGMA BAND	BETA1 BAND	BETA2 BAND	FASTF BAND	X^2 COEF.	MFC
MEAN PERC. OF POWER	+ 26%	+ 14%	- 4%	- 63%	- 54%	- 69%	- 55%	-	-
MEAN FREQ. PEAK	- 12%	-1.5%	- 7%	+ 4%	+ 1%	+ 3%	+0.3%	-	-
MEAN	-	-	-	-	-	-	-	+ 32%	- 39%
PERC. OF REJECTIONS	-	-	-	-	-	-	-	+ 80%	-

TABLE 4.33 Subject SC4 - Percentage Change in the Results of Table 4.32 Between the Baseline and the 1st Nights

amplitude peaks, two in the first half and the other in the last third of the night. The average percentage of power in this night has remained essentially the same computed for the nap (41.5 and 42% respectively). In the 2nd night, Figure 4.47c, there are two high amplitude peaks in the first and in the 2nd half of the night and the average percentage of power in the band has slightly increased to 43.7%. In the plot for the baseline night, Figure 4.47d, three high amplitude peaks can be seen, two in the first half and the other in the last third of the night. The mean percentage of power is now 51.9%, which represents an increase of 26% over the value computed in the 1st night, as shown in Table 4.33. The mean frequency in the band has decreased 12% in the same interval. The change in the mean percentage of power in the band, for the amount of drug administered, is small compared to the other subjects in the group. This could be a result of the high background activity in the Delta Band caused by the artifact mentioned in Section 4.5.1.1 which was not totally eliminated by the filter.

The plots for the percentage of power in the Sigma Band are shown in Figures 4.48a, b, c and d. During the nap, Figure 4.48a, it can be seen that the amplitude of the peaks is becoming larger as the nap evolved. In the 1st night, Figure 4.48b, the plot stays almost flat, for a long period of time in the first half of the night, reflecting the "constancy" of the activity in the Sigma Band. After the second half of the night, some well-defined peaks can be seen. The average percentage of power has increased to

15.5% from the previous value of 12% obtained during the nap. By the 2nd night this value has been reduced to 12.4% and only two high amplitude peaks can be seen in the plot (Figure 4.48c). In the baseline night, Figure 4.48d, the amplitude of the peaks has reached its lowest value and the average percentage of power in the band is down to 5.7%. From Table 4.33 we can see that the mean percentage of power in the Sigma Band has decreased 63% from the 1st to the baseline night. In the same period the mean frequency in the band has increased from 13.1 to 13.6 Hz (Table 4.32).

Figures 4.49a, b, c and d show the plots for the Mean Frequency Coefficients as a function of time. During the nap, Figure 4.49a, there is only one low frequency dip that went close to the 1.5 Hz frequency line. In the 1st night, Figure 4.49b, there are three low frequency dips located between the 4.5 and the 3.0 Hz frequency lines, coinciding in time with the delta peaks in Figure 4.47b. As we can see from this night's CSA plot (Figure 4.46b), there is a high background activity in the Delta Band and relatively low amplitude peaks in the Sigma Band. These two facts together result in a relatively small mean frequency for this night (6.2 Hz), when compared to the same quantity computed for other subjects, who took smaller dosages of the drug. Figure 4.49c, shows the plot for the 2nd night, in which two low frequency dips can be seen. The first is below the 3 Hz and the second reached the 1.5 Hz frequency line, which is mainly the result of an increase in the activity in the Delta Band. The mean frequency for this

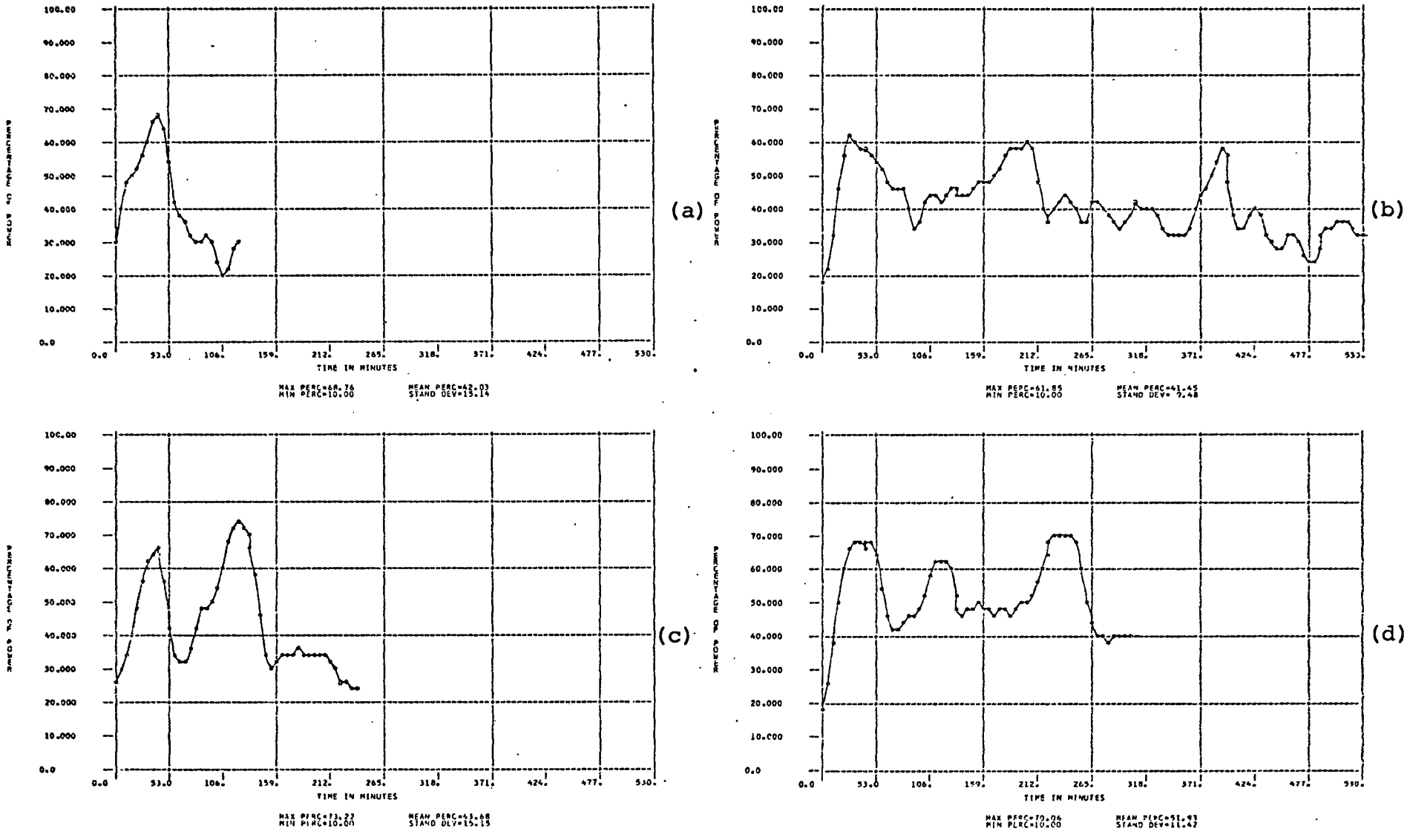


FIGURE 4.47 Subject SC4 - Percentage of Power in the Delta Band
(a) nap, record #15909 (b) 1st night, record #15912
(c) 2nd night, record #15917 (d) baseline night, record #16070

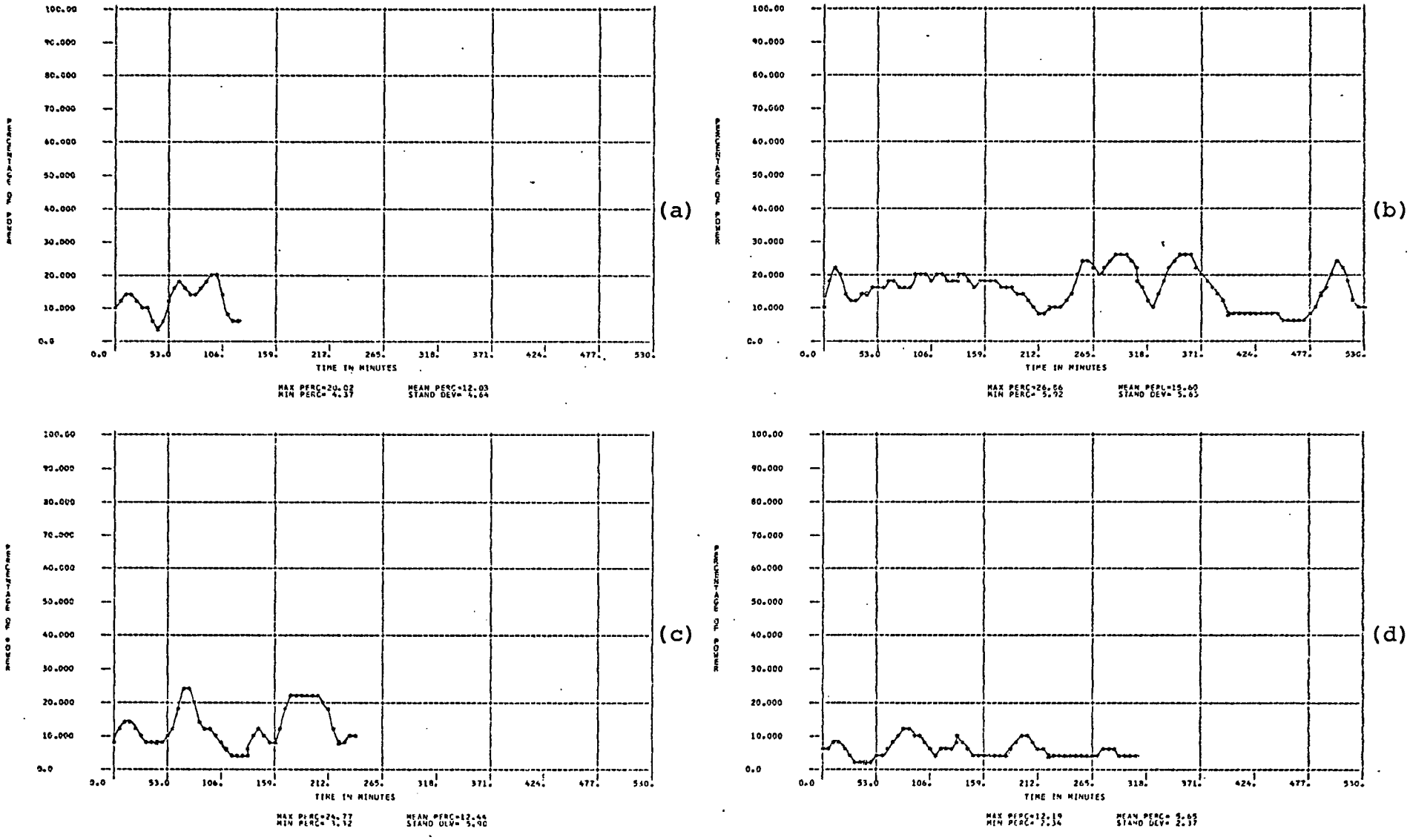


FIGURE 4.48 Subject SC4 - Percentage of Power in the Sigma Band
(a) nap, record #15909 (b) 1st night, record #15912
(c) 2nd night, record #15917 (d) baseline night, record #16070

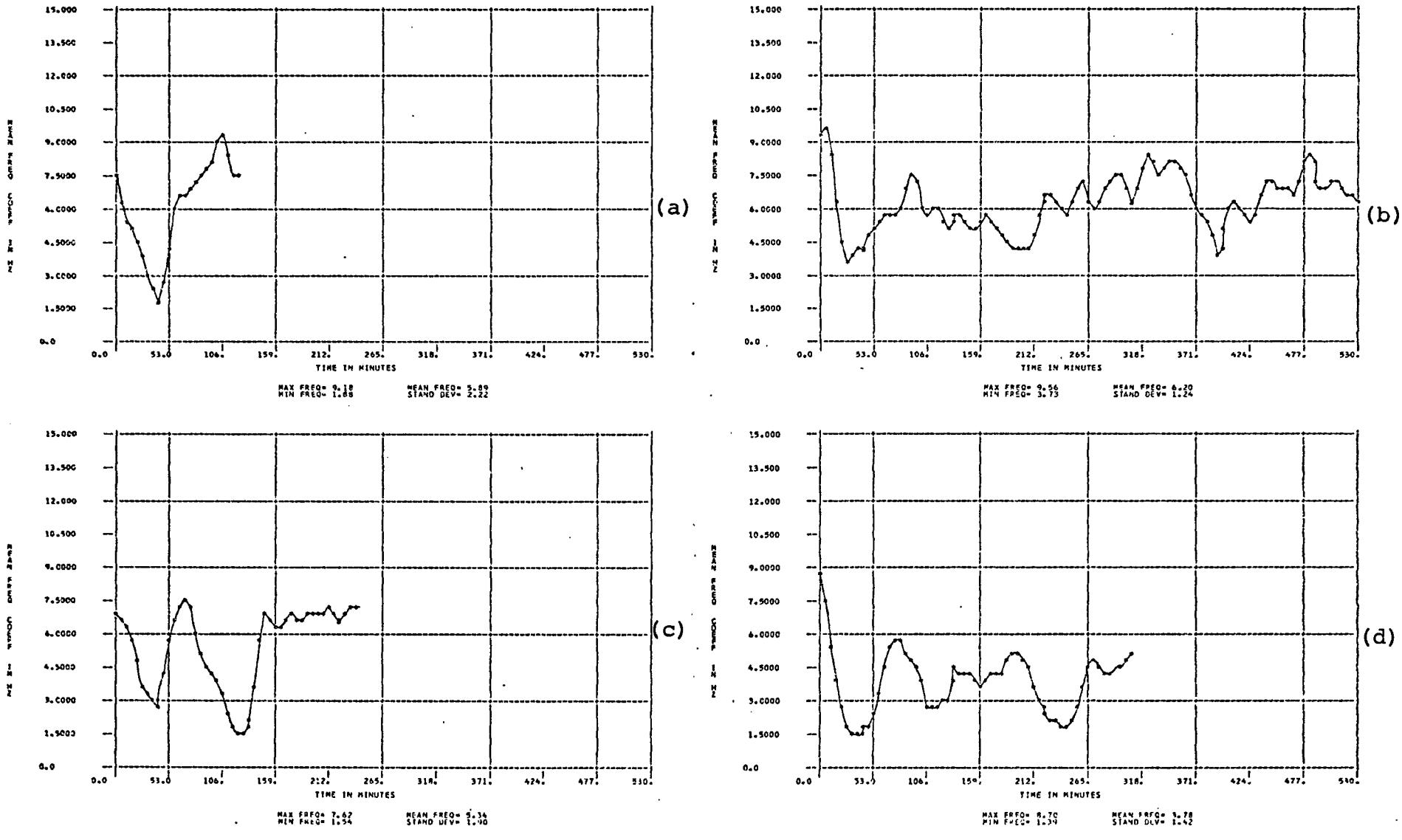


FIGURE 4.49 Subject SC4 - Mean Frequency Coefficient (MFC)
(a) nap, record #15909 (b) 1st night, record #15912
(c) 2nd night, record #15917 (d) baseline night, record #16070

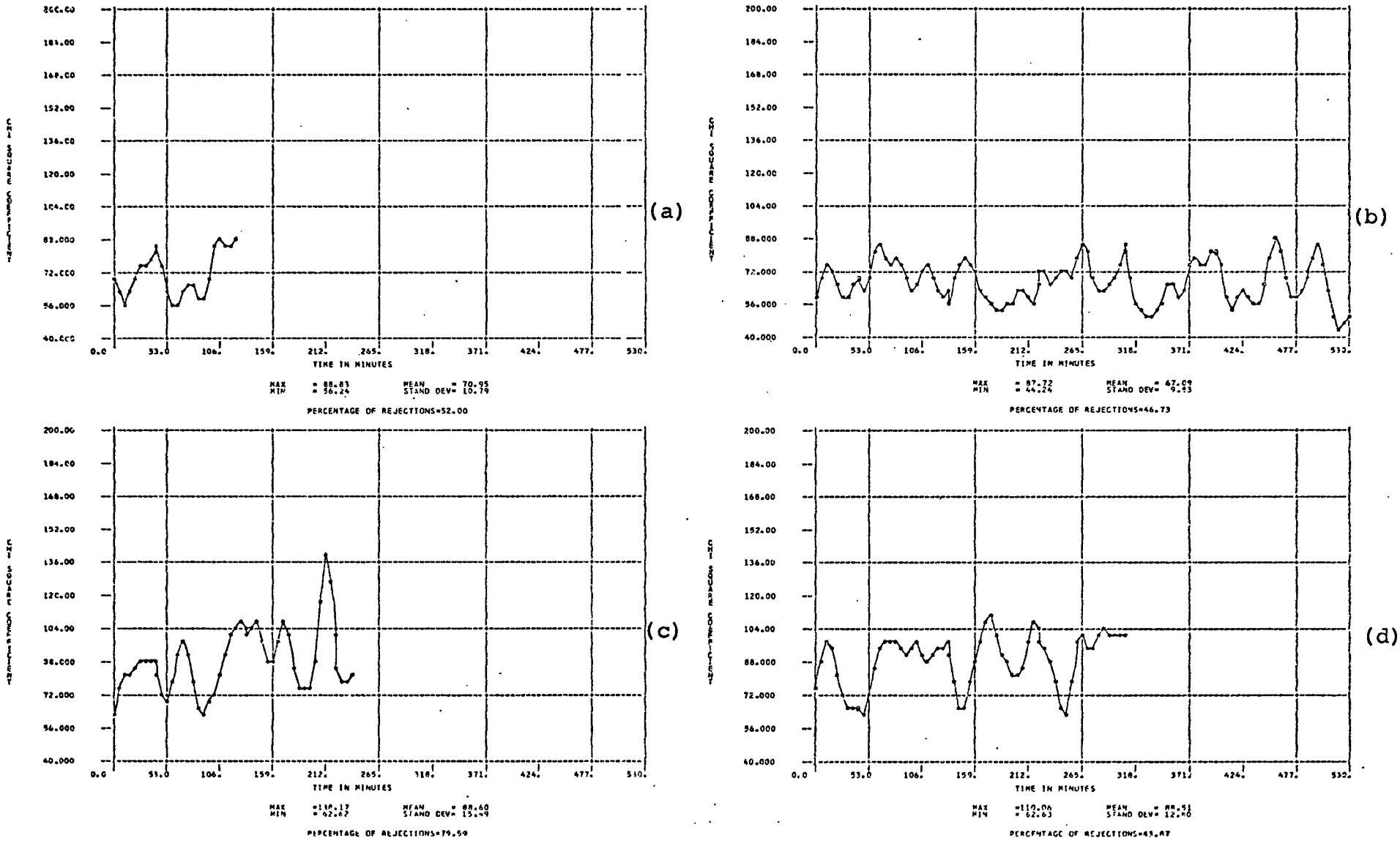


FIGURE 4.50 Subject SC5 - Chi-Square Coefficient
(a) nap, record #15909 (b) 1st night, record #15912
(c) 2nd night, record #15917 (d) baseline night, record #16070

night decreased to 5.3 Hz. In the baseline night, Figure 4.49d, there exist three low frequency dips. Two of them are close to the 1.5 Hz frequency line. The mean frequency for the night is down to 3.8 Hz, reflecting the dominance of the low frequency activity. The mean frequency was reduced 39% between the 1st and the baseline nights as we can see from Table 4.33.

The plots for the X^2 coefficient are shown in Figures 4.50a, b, c and d. During the nap, Figure 4.50a, 52% of the epochs were rejected by the CSQ test. In the 1st night, Figure 4.50b, the great majority of the points are below 72 and only 46.7% of the epochs were rejected by the CSQ test. This means that the EEG amplitude in 53% of the epochs follows a Gaussian probability density function. As the subject is recovering from the drug, the X^2 values start increasing as we can see in Fgiures 4.50c and d. There is an increase of 80% in the percentage of rejections for the X^2 coefficients between the 1st and the baseline nights.

4.5.2 Subject SC5

4.5.2.1 Subject's Protocol

Subject SC5 is a 23 year-old male. This subject was titrated with 3000 mg of methaqualone according to the procedure described in Section 2.2.2. The subject slept straight from the afternoon of the titration day until the next morning and, therefore, the EEG data was stored in a

single long record. In order to facilitate the comparisons of this subject's results with the others, we divided that record into two equal duration records, which we called "nap" and "1st" night respectively. The subject's 2nd night was not processed because its analog record was not available on magnetic tape. Table 4.34 shows the sleep sessions and their corresponding record numbers that were automatically processed.

TABLE 4.34

Analyzed Data for Subject SC5

Sleep Sessions	Record Number	Titration Dosage (mg)
"Nap"[1]	15928	3000
"1st" Night[1]	15928	-
Baseline[2] Night	16070	none

[1] Both sessions are in a single long record.

[2] Recorded one month after the administration of the drug.

4.5.2.2 Compressed Spectral Array Results

Figures 4.51a, b, and c show the CSA plots for the sleep sessions listed in Table 4.34. During the "nap", Figure 4.51a, the activity in the Delta Band is characterized by low amplitude spectral peaks for most of the time, except at the beginning and towards the end of the nap, when some high amplitude peaks are present. The peaks in Alpha Band are centered around 8.5-9.0 Hz. The Sigma Band

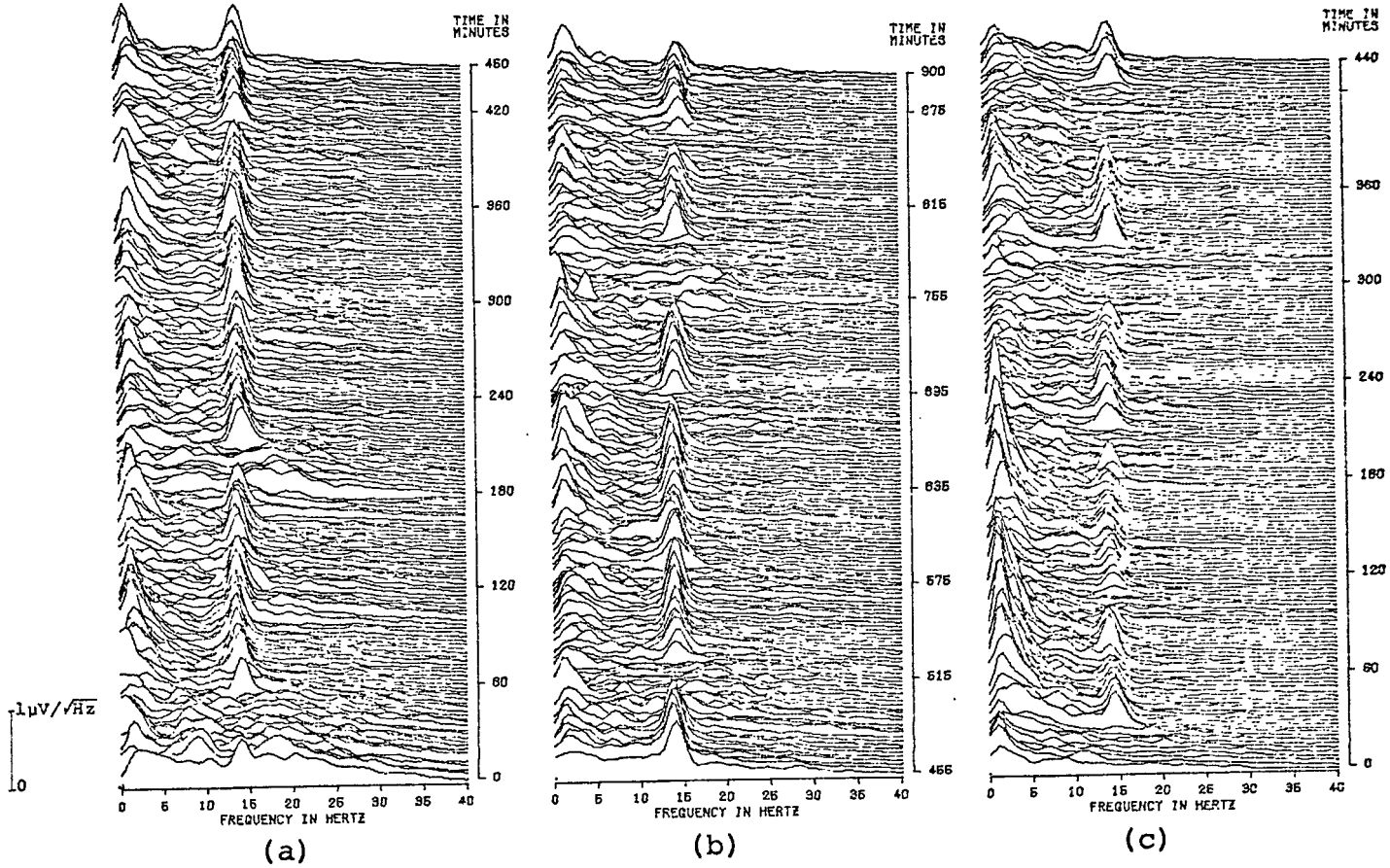


FIGURE 4.51 Subject SC5 - Compressed Spectral Array (CSA)
(a) "nap", record #15928 (b) "1st" night, record #15928
(c) baseline night, record #16090

shows well-defined high amplitude peaks located at 13.5-14.0 Hz and for most parts of the "nap" it is the dominant frequency band. Some activity can also be observed in the Beta Bands. The main difference in the CSA plot for the "1st" night, Figure 4.51b, compared to the one for the "nap", is the absence of high amplitude peaks in the Delta Band. In the baseline night, Figure 4.51c, we can see two trains of high amplitude peaks in the Delta Band in the first half of the night. The activity in the Sigma Band is greatly reduced in comparison to the previous plots and no visible activity can be seen in the Beta Bands.

4.5.2.3 Summary of the Output Results from the FEATURE Algorithm

Table 4.35 shows the output results from the data reduction analysis. From these results we can see that the drug affected the amount of the SWS, which resulted in a reduction in the mean percentage of power in the Delta Band. On the other hand, the drug also affected the high frequency activity by increasing the percentage of power in the Sigma, Beta1, Beta2 and Fastf frequency bands. The above changes can be further summarized by the results of the average value of the MFCs for each sleep record.

Figures 4.52a, b and c show the plots of the percentage of power in the Delta Band vs time, for the sleep sessions listed on Table 4.34. During the "nap", Figure 4.52a, two high amplitude peaks can be seen, one in the first

TABLE 4.35

Summary of the Output Results from FEATURE for Subject SC5

SLEEP SESSION			Nap	1st	2nd	Baseline
RECORD NUMBER			15928	15928		16090
DOSAGE (mg)			3000	-		0
DELTA BAND (0.0-3.5Hz)	PERC. OF POWER	MEAN	30.0	27.7		42.3
		STD	9.3	6.8		11.7
	FREQ. PEAK (Hz)	MEAN	1.6	1.9		1.7
		STD	0.5	0.6		0.6
THETA BAND (4.0-7.5Hz)	PERC. OF POWER	MEAN	14.4	19.0		22.8
		STD	1.6	4.5		6.3
	FREQ. PEAK (Hz)	MEAN	6.6	6.0		5.9
		STD	1.0	1.2		1.3
ALPHA BAND (8.0-11.5Hz)	PERC. OF POWER	MEAN	11.5	11.7		12.0
		STD	2.4	1.4		3.4
	FREQ. PEAK (Hz)	MEAN	9.5	9.3		9.2
		STD	1.0	1.0		0.9
SIGMA BAND (12.0-15.5Hz)	PERC. OF POWER	MEAN	24.0	21.8		11.7
		STD	7.6	9.8		7.2
	FREQ. PEAK (Hz)	MEAN	14.0	14.2		14.2
		STD	0.6	0.7		0.7

TABLE 4.35

(continued)

SLEEP SESSION			Nap	1st	2nd	Baseline
RECORD NUMBER			15928	15928		16090
DOSAGE (mg)			3000	-		0
BETA1 BAND (16.0-20.5Hz)	PERC. OF POWER	MEAN	8.4	8.7		3.9
		STD	5.0	4.7		1.9
	FREQ. PEAK (Hz)	MEAN	18.9	18.6		18.6
		STD	1.1	1.4		1.3
BETA2 BAND (21.0-29.5Hz)	PERC. OF POWER	MEAN	6.8	7.0		2.8
		STD	3.3	4.2		1.7
	FREQ. PEAK (Hz)	MEAN	24.3	24.5		24.6
		STD	2.4	2.7		2.7
FASTF BAND (30.0-40.0Hz)	PERC. OF POWER	MEAN	1.9	2.1		0.9
		STD	1.1	1.1		0.6
	FREQ. PEAK (Hz)	MEAN	33.3	33.7		34.7
		STD	2.0	2.4		2.8
X^2	MEAN		92.2	88.8		91.1
	STD		17.0	13.7		12.5
	PERCENTAGE OF REJECTIONS		75.0	73.9		87.6
MFC	MEAN		9.1	8.9		5.9
	STD		2.0	1.5		1.8

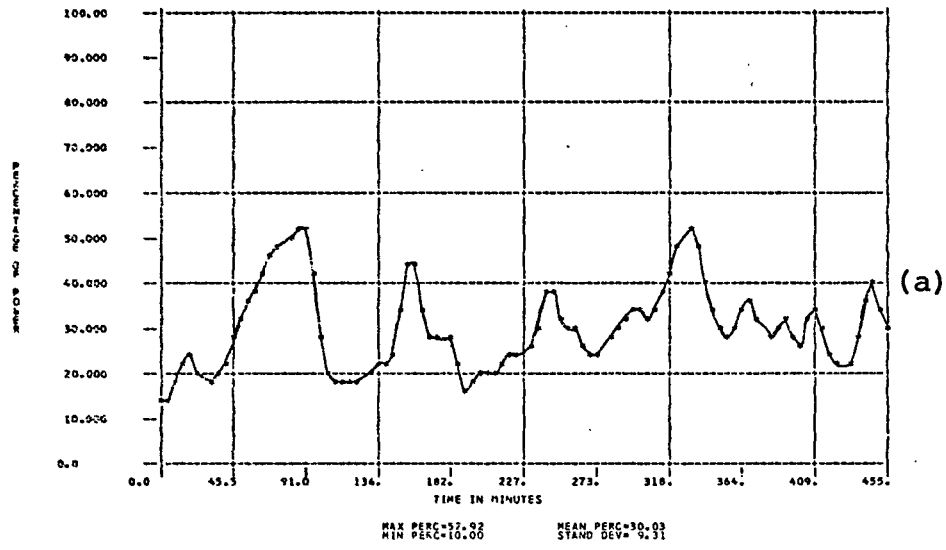
	DELTA BAND	THETA BAND	ALPHA BAND	SIGMA BAND	BETA1 BAND	BETA2 BAND	FASTF BAND	X^2 COEF.	MFC
MEAN PERC. OF POWER	+ 53%	+ 20%	+ 3%	- 46%	- 55%	- 59%	- 57%	-	-
MEAN FREQ. PEAK	- 11%	-1.7%	+ 3%	0%	0%	+0.4%	+ 3%	-	-
MEAN	-	-	-	-	-	-	-	+ 3%	- 34%
PERC. OF REJECTIONS	-	-	-	-	-	-	-	+ 19%	-

TABLE 4.36 Subject SC5 - Percentage Change in the Results of Table 4.35 Between the "1st" and the Baseline Nights

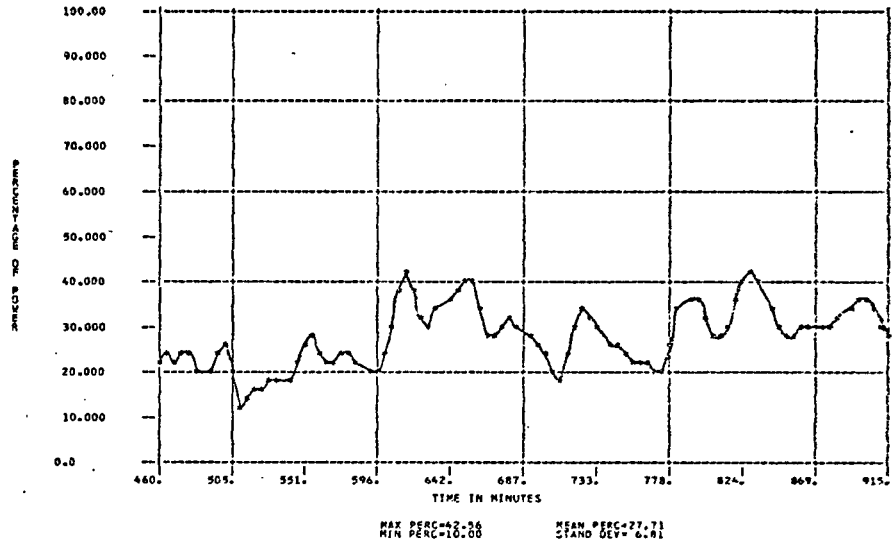
third and the other in the last third of the plots, and the average percentage of power is 30%. These peaks are no more present during the "1st" night, Figure 4.52b, and the mean percentage of power decreases slightly to 27.7%. The plot for the baseline night, Figure 4.52c, shows three high amplitude peaks in the first half of the night. The mean percentage of power is now 42.3% which represents an increase of 53% over the previous value computed for the "1st' night (Table 4.36). From Table 4.35 we can see that the mean frequency in the band decreased from 1.9 Hz during the "1st" night to 1.7 Hz in the baseline night.

The plots for the percentage of power in the Sigma Band vs time are shown in Figures 4.53a, b and c. The first two plots, Figures 4.53a and b, are dominated by high amplitude peaks most of the time, and the mean percentage of power in the band is above 21% in both sleep sessions. In the baseline night, Figure 4.53c, this value is reduced to 11.7% and the majority of the peaks are of smaller amplitudes. From Table 4.36 we can see that the mean percentage of power in the Sigma Band has decreased 46% between the 1st and the baseline nights. However, the mean frequency in the band has not changed in the same period.

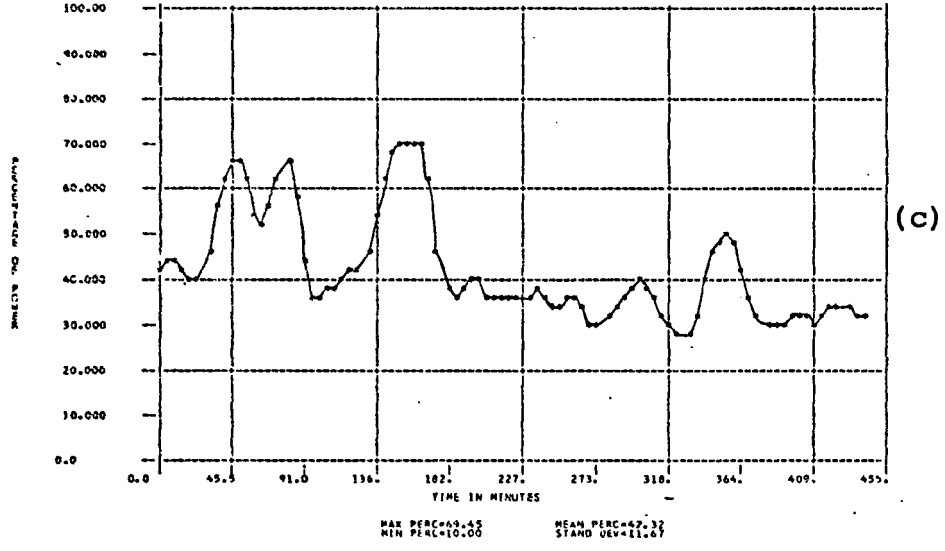
Figures 4.54a, b and c show the plots for the MFCs. The plot for the "nap", Figure 4.54a, shows two low frequency dips above the 4.5 Hz frequency line. However, most of the points in the plot are above 8 Hz. The computed mean frequency for the "nap" was 9.1 Hz. In the "1st" night the



(a)



(b)



(c)

FIGURE 4.52 Subject SC5 - Percentage of Power in the Delta Band
(a) "nap", record #15928 (b) "1st" night, record #15928
(c) baseline night, record #16090

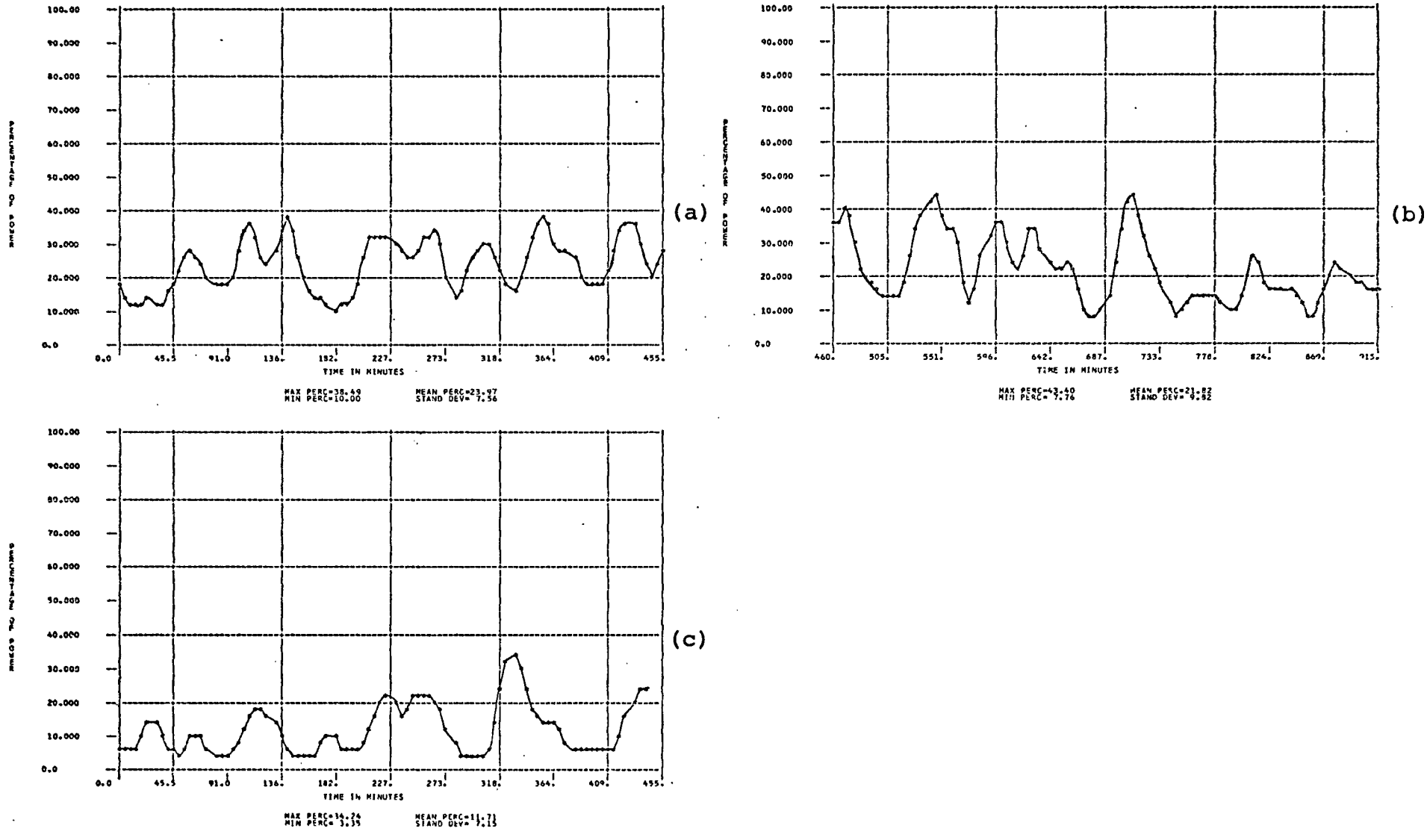
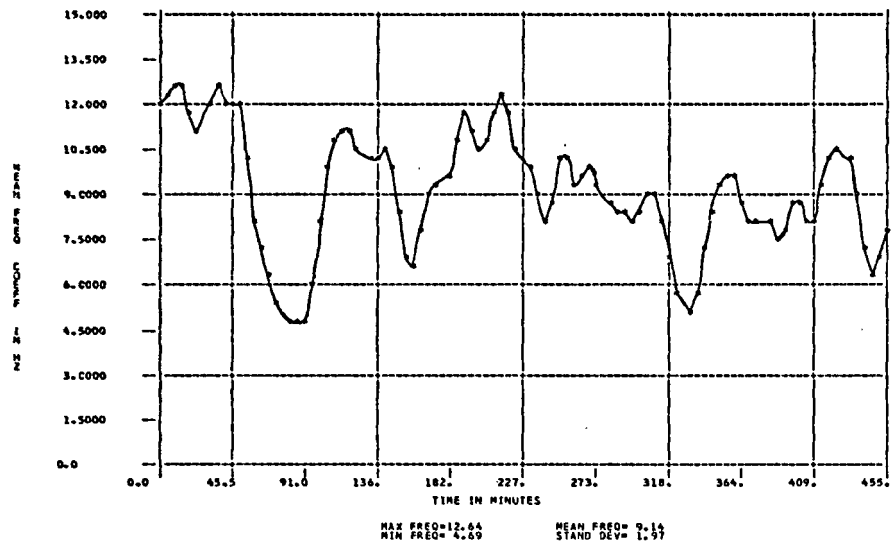
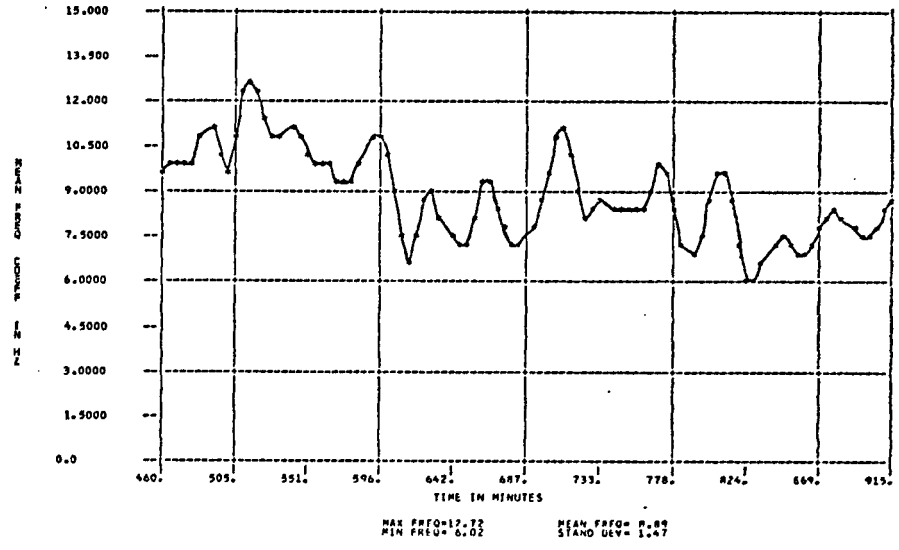


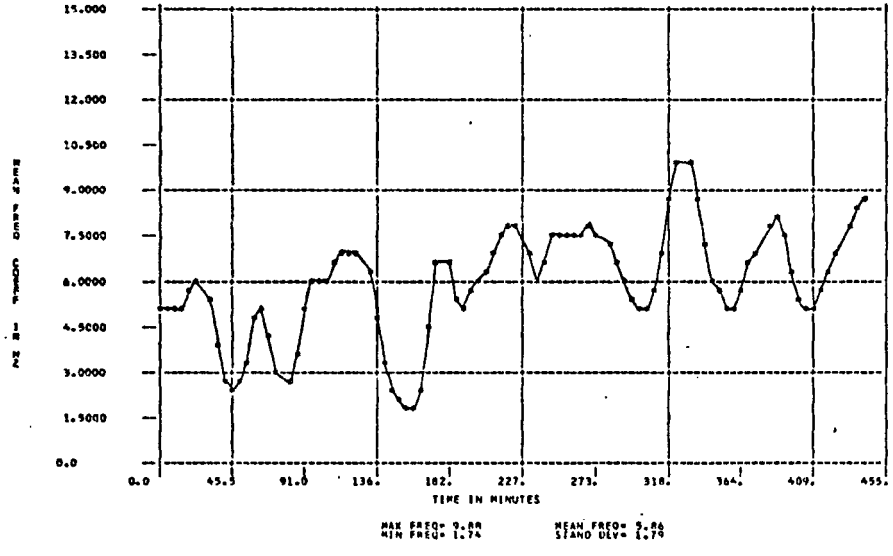
FIGURE 4.53 Subject SC5 - Percentage of Power in the Sigma Band
(a) "nap", record #15928 (b) "1st" night, record #15928
(c) baseline night, record #16090



(a)



(b)



(c)

FIGURE 4.54 Subject SC5 - Mean Frequency Coefficient (MFC)
(a) "nap", record #15928 (b) "1st" night, record #15928
(c) baseline night, record #16090

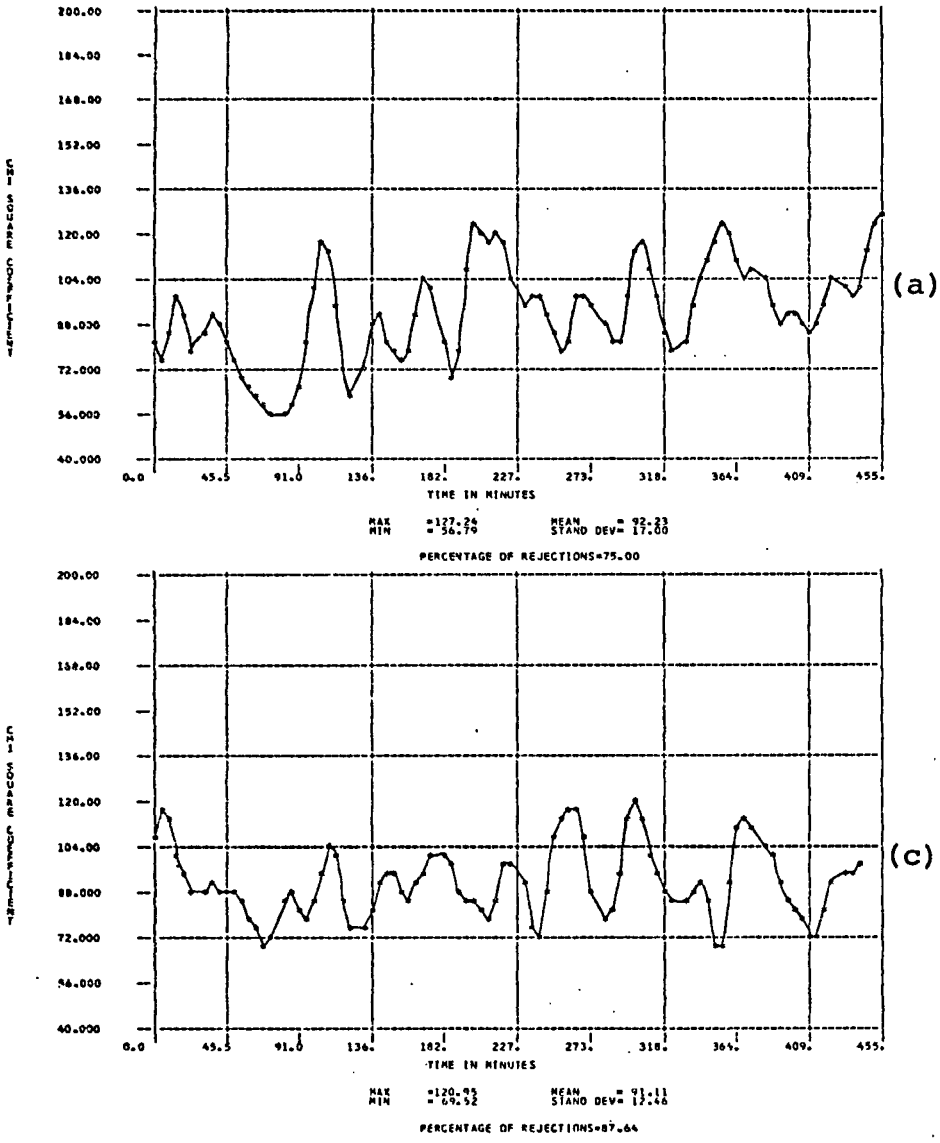


FIGURE 4.55 Subject SC5 - Chi-Square Coefficient
(a) "nap", record #15928 (b) "1st" night, record #15928
(c) baseline night, record #16090

mean frequency remained high at 8.9 Hz and no low frequency dips can be seen in this plot. During the baseline night, the mean frequency went down to 5.9 Hz and three low frequency dips are present in the plot (Figure 4.54c). For this subject, the mean frequency in the baseline night has decreased 34% from its previous value during the "1st" night (Table 4.36).

The plots for the X^2 coefficients are shown in Figures 4.55a, b and c. As we can see from these plots, the percentage of rejections for the X^2 coefficients has its lowest values on the subject's titration day. This value increases on the baseline night. From Table 4.36 it can be seen that the percentage of rejections increased 19% between the "1st" and the baseline nights.

4.5.3 Subject SC6

4.5.3.1 Subject's Protocol

Subject SC6 is a 22 year-old male. The sleep sessions that were automatically processed and their record numbers are shown in Table 4.37. This table was derived from Table 2.4.

TABLE 4.37

Analyzed Data for Subject SC6

Sleep Sessions	Record Number	Titration Dosage (mg)
Nap[1]	15984	1800
1st Night[1]	15990	-

[1]The two sessions were run in the same day.

TABLE 4.37

(continued)

Sleep Sessions	Record Number	Titration Dosage (mg)
2nd Night	15995	none
Baseline[2] Night	16339	none

[2]Recorded one month after the administration of the drug.

4.5.3.2 Compressed Spectral Array

Figures 4.56a, b, c and d show the CSA plots corresponding to the sleep sessions listed on Table 4.37. During the nap, Figure 4.56a, the activity in the Delta Band is characterized by the presence of high amplitude peaks most of the time. The peaks in the Sigma Band have also high amplitude and are centered around 13.5-14.0 Hz. The high activity in the Sigma Band persisted throughout the 1st night, Figure 4.56b, but the activity in the Delta Band is greatly reduced. In the 2nd night, Figure 4.56c, there are two trains of high intensity peaks in the Delta Band and the peaks in the Sigma Band are of reduced amplitudes. In the baseline, Figure 4.56d, the peaks in the Delta Band are of even higher amplitudes and the activity in the Sigma Band remained low.

4.5.3.3 Summary of the Output Results from the FEATURE Algorithm

Table 4.38 shows the output results of the data re-

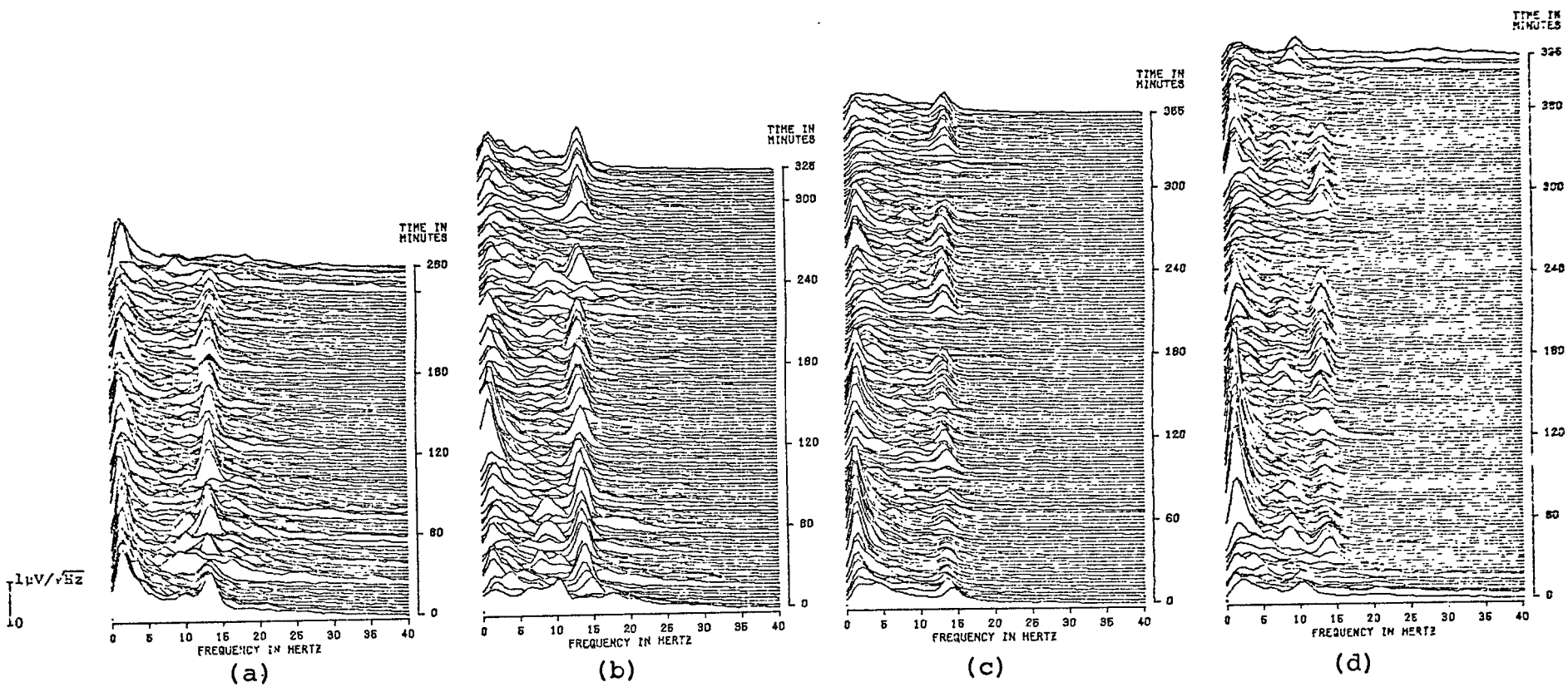


FIGURE 4.56 Subject SC6 - Compressed Spectral Array (CSA)
(a) nap, record #15984 (b) 1st night, record #15990
(c) 2nd night, record #15995 (d) baseline night, record #16339

TABLE 4.38

Summary of the Output Results from FEATURE for Subject SC6

SLEEP SESSION			Nap	1st	2nd	Baseline
RECORD NUMBER			15984	15990	15995	16339
DOSAGE (mg)			1800	-	0	0
DELTA BAND (0.0-3.5Hz)	PERC. OF POWER	MEAN	41.6	36.5	46.3	47.7
		STD	8.4	8.0	13.9	13.8
	FREQ. PEAK (Hz)	MEAN	1.6	1.8	1.8	1.9
		STD	0.3	0.6	0.6	
THETA BAND (4.0-7.5Hz)	PERC. OF POWER	MEAN	15.2	19.5	21.0	22.3
		STD	2.2	4.5	5.8	5.8
	FREQ. PEAK (Hz)	MEAN	6.7	5.9	5.9	6.2
		STD	0.9	1.1	1.3	1.0
ALPHA BAND (8.0-11.5Hz)	PERC. OF POWER	MEAN	11.0	13.3	12.4	13.4
		STD	1.7	3.6	3.9	4.5
	FREQ. PEAK (Hz)	MEAN	10.0	9.4	9.0	9.0
		STD	1.1	0.9	0.9	0.9
SIGMA BAND (12.0-15.5Hz)	PERC. OF POWER	MEAN	18.7	19.0	13.7	9.3
		STD	6.0	6.9	7.3	5.4
	FREQ. PEAK (Hz)	MEAN	13.6	13.6	13.5	13.6
		STD	0.7	0.7	0.5	0.7

TABLE 4.38

(continued)

SLEEP SESSION			Nap	1st	2nd	Baseline
RECORD NUMBER			15984	15990	15995	16339
DOSAGE (mg)			1800	-	0	0
BETA1 BAND (16.0-20.5Hz)	PERC. OF POWER	MEAN	7.2	4.9	2.8	2.7
		STD	3.6	2.5	1.6	2.0
	FREQ. PEAK (Hz)	MEAN	18.2	18.4	18.3	18.4
		STD	1.5	1.2	1.5	1.2
BETA2 BAND (21.0-29.5Hz)	PERC. OF POWER	MEAN	3.9	2.5	1.7	1.7
		STD	1.6	1.3	1.0	1.5
	FREQ. PEAK (Hz)	MEAN	24.4	24.5	24.5	24.1
		STD	2.3	2.4	2.3	2.2
FASTF BAND (30.0-40.0Hz)	PERC. OF POWER	MEAN	1.0	0.6	0.5	0.4
		STD	0.4	0.3	0.3	0.3
	FREQ. PEAK (Hz)	MEAN	32.9	33.3	33.3	33.2
		STD	2.2	2.3	2.6	3.4
x^2	MEAN		80.1	79.9	82.6	88.2
	STD		9.7	12.7	17.8	23.6
	PERCENTAGE OF REJECTIONS		73.6	70.2	77.8	85.0
MFC	MEAN		6.7	6.8	5.2	5.0
	STD		1.6	1.3	1.9	1.9

	DELTA BAND	THETA BAND	ALPHA BAND	SIGMA BAND	BETA1 BAND	BETA2 BAND	FASTF BAND	X^2 COEF.	MFC
MEAN PERC. OF POWER	+ 27%	+ 14%	+ 1%	- 51%	- 45%	- 48%	- 33%	-	-
MEAN FREQ. PEAK	+ 6%	+ 5%	- 5%	0%	0%	- 2%	-0.3%	-	-
MEAN	-	-	-	-	-	-	-	+ 10%	- 27%
PERC. OF REJECTIONS	-	-	-	-	-	-	-	+ 21%	-

TABLE 4.39 Subject SC6 - Percentage Change in the Results of Table 4.38 Between the 1st and the Baseline Nights

duction algorithm. As we can see from this table, the results show essentially the same trends that were observed in the two previous subjects.

Figures 4.57a, b, c and d show the plots of the percentage of power in the Delta Band vs time. The plot for the nap, Figure 4.57a, shows three high amplitude peaks, two located in the first half and the other in the last half of the nap. The mean percentage of power during the nap is 41.6%. This quantity is down to 36.5% in the 1st night. The plot for this night, Figure 4.57b, shows two high amplitude peaks in the first half of the night. Of these, the first one is of longer duration. The mean percentage of power has now increased to 46.3%. During the baseline night, Figure 4.57d, we can see a very high amplitude long duration peak at the beginning of the night and the mean percentage of power stayed at 47.7%. Table 4.39 shows that the mean percentage of power in the baseline night is 27% above the same quantity during the 1st night.

The plots for the percentage of power in the Sigma Band are shown in Figures 4.58a, b, c and d. As we can see from these plots, the mean percentage of power is high during the nap and in the 1st night and then it starts decreasing in the 2nd night to reach its lowest value in the baseline night. From Table 4.39 we can see that the mean percentage of power in the Sigma Band has decreased 51% in the baseline night in comparison to the value computed in the 1st night.

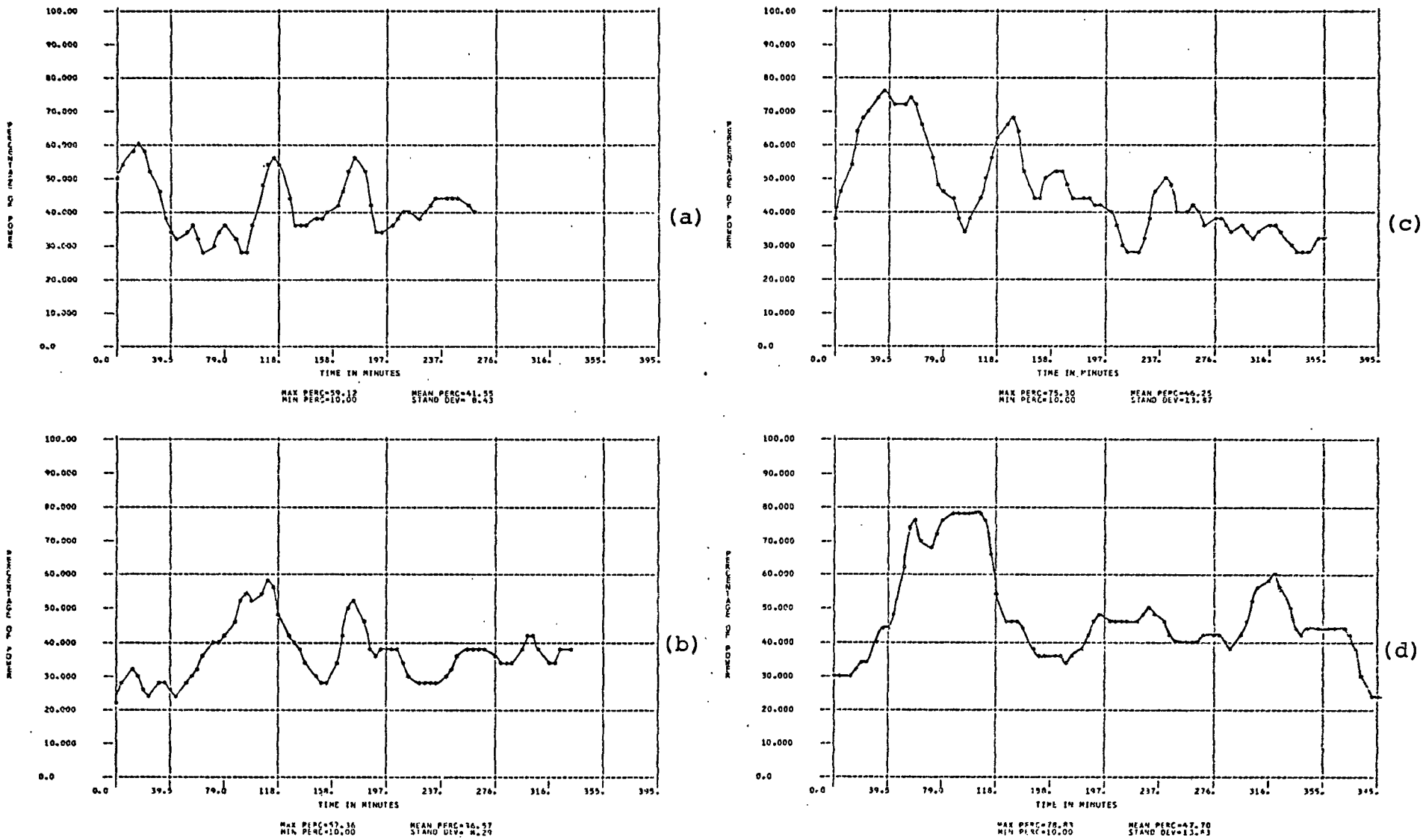


FIGURE 4.57 - Subject SC6 - Percentage of Power in the Delta Band
(a) nap, record #15984 (b) 1st night, record #15990
(c) 2nd night, record #15995 (d) baseline night, record #16339

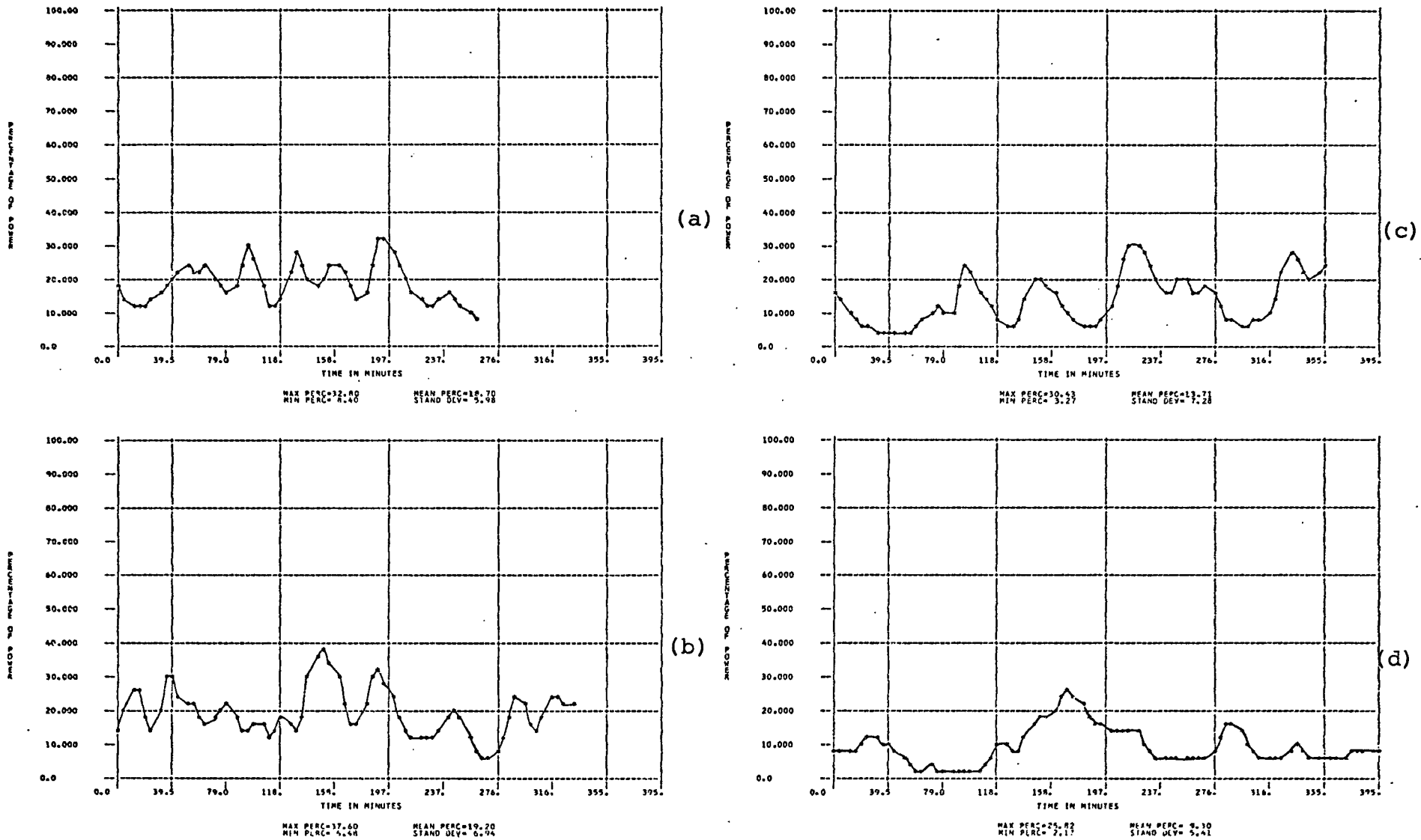


FIGURE 4.58 - Subject SC6 - Percentage of Power in the Sigma Band
(a) nap, record #15984 (b) 1st night, record #15990
(c) 2nd night, record #15995 (d) baseline night, record #16339

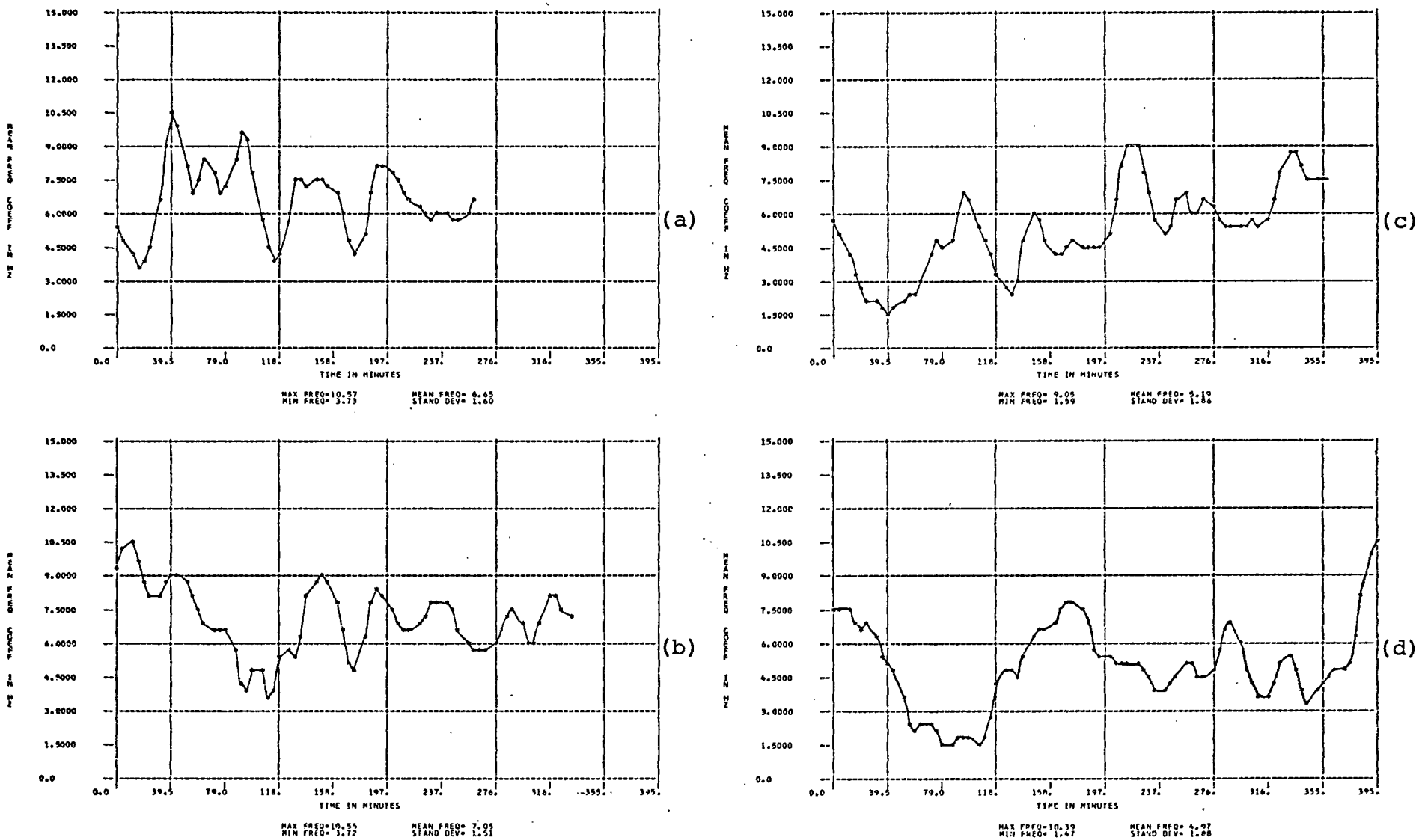


FIGURE 4.59 Subject SC6 - Mean Frequency Coefficient (MFC)
(a) nap, record #15984 (b) 1st night, record #15990
(c) 2nd night, record #15995 (d) baseline night, record #16339

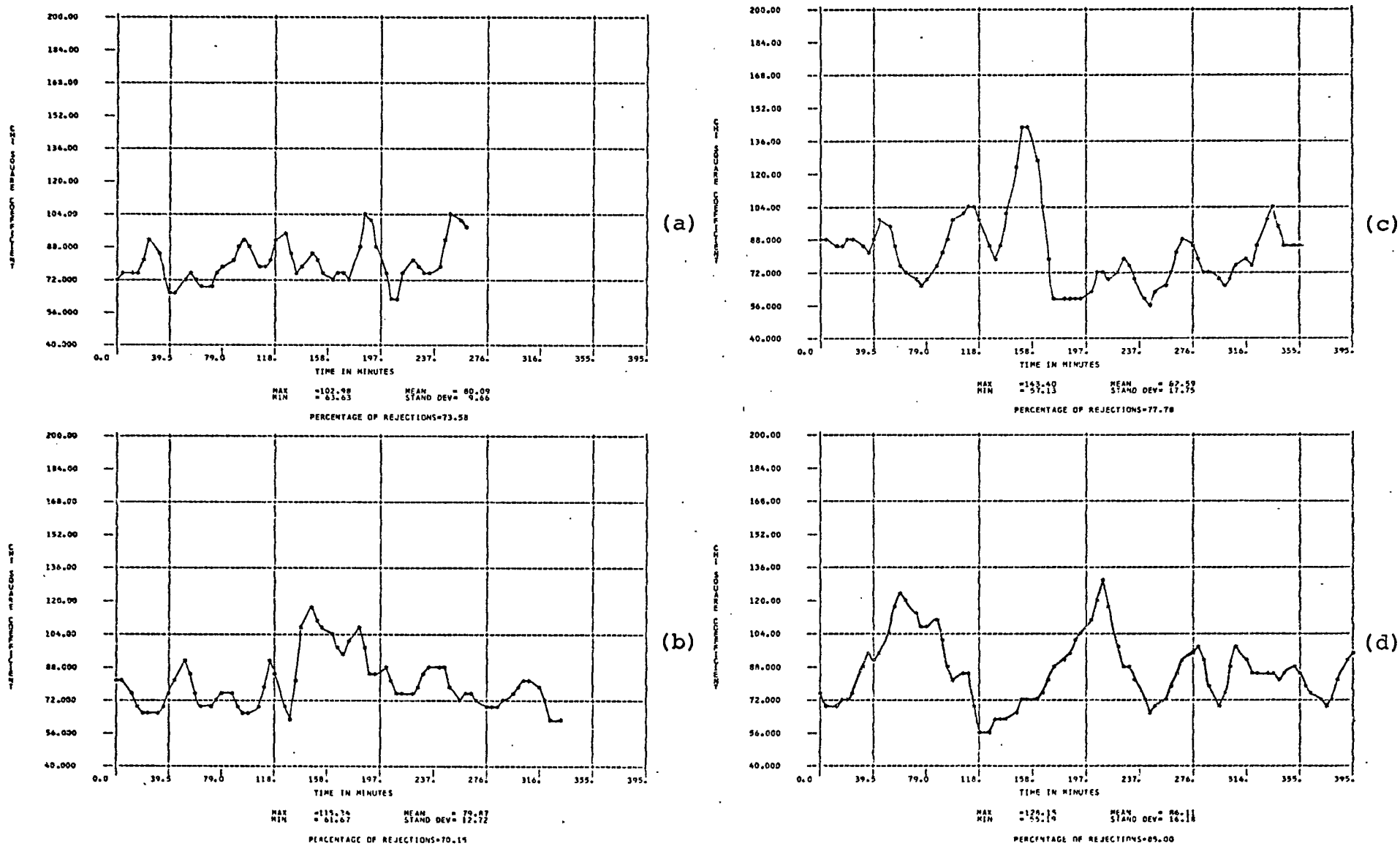


FIGURE 4.60 Subject SC6 - Chi-Square Coefficient
(a) nap, record #15984 (b) 1st night, record #15990
(c) 2nd night, record #15995 (d) baseline night, record #16339

The plots for the Mean Frequency Coefficient vs time are shown in Figures 4.59a, b, c and d. The plot for the nap, Figure 4.59a, shows three low frequency dips between 4.5 and 3 Hz, and that the mean frequency for the night is 6.7 Hz. This quantity is at 6.8 Hz in the 1st night, and the plot for this night, Figure 4.59b shows a low frequency dip between4.5 and 3 Hz. In the 2nd night, Figure 4.59c, there are two low frequency dips between 3 and 1.5 Hz. The mean frequency for this night is now 5.2 Hz. This value is down to 5 Hz during the baseline night, Figure 4.59d, in which there is a low frequency dip that went down to the 1.5 Hz frequency line. There is a decrease of 27% in the mean frequency between the 1st and the baseline nights (Table 4.39).

Figures 4.60a, b, c and d show the plots for the X^2 coefficient. During the nap, Figure 4.60a, we can see that the hypothesis that the EEG's amplitude follows a Gaussian distribution was rejected in 73.6% of the epochs. This value has decreased to 70.2% in the 1st night, Figure 4.60b. In the 2nd and in the baseline nights the percentage of rejections have increased to 77.8 and 85% respectively. From Table 4.39 we can see that the percentage of rejections for the X^2 coefficient, in the baseline night, has increased 21% over the same quantity in the 1st night.

4.5.4 Discussion of the Results of the Subjects in Group 2 Receiving Methaqualone

Table 4.40 shows the comparison of the percentage

changes in the output results of the data reduction algorithm between the baseline night and the first night for each of the subjects in Group 2, that were given methaqualone.

The mean percentage of power in the Delta Band increases between the first and the baseline night, in all three subjects. This is equivalent to saying that the mean percentage of power decreases in the first night when the subjects were under the effects of the drug. As we pointed out in section 4.4.4 this could be partially caused by the fact that the subjects had an afternoon nap preceeding the first night. Subject SC3 who received 3000 mg of methaqualone had the largest increase (53%). However, subject SC4 who was given the highest dosage (4200 mg) showed an increase of 26%. This could be the result of the low frequency artifact that was present during the first night (see Section 4.5.1). In addition, two of the subjects, SC4 and SC5, showed a marked increase in the mean frequency peak in this band during the first night. This is shown in Table 4.40 as a percentage decrease in the mean frequency peak in the baseline night when compared to the same quantity during the first night. These results are in contradiction with the previous ones obtained for the subjects in Group 1 that were withdrawn from the same drug (section 4.3.4).

In all three subjects the average percentage of power in the Sigma Band decrease in the baseline night from the values computed during the 1st night. The highest change is shown by subject SC4 (-63%) and the other subjects have changes

of 46 and 51%. These results are close enough to the ones obtained from the abuser group that were withdrawn from the same drug. Only subject SC4 showed a decrease in the mean frequency peak during the first night. This result is in agreement with the ones observed in the abusers group.

From Table 4.40 we also can see that there is a reduction in the average percentage of power in the Betal, Beta2 and Fastf frequency bands in the baseline night in comparison to the first night. However, an opposite trend is observed in the mean percentage of power in the Theta Band.

The mean frequency during the baseline night (computed as the mean of the MFCs) decreased in all subjects from the previous high values calculated in the first night. The highest reduction (39%) was shown by subject SC4, the other two subjects had changes between -27 and -34%. These results compare well with the ones computed for the abusers group (Section 4.3.4), but in absolute values these changes are smaller than the ones for the subjects in Group 2, that were given secobarbital.

The mean value and the percentage of rejection of the X^2 coefficient decreased in all subjects with the administration of the drug. Table 4.40 shows these results as a percentage increase in the mean value and in the percentage of reduction in the X^2 coefficient between the first and the baseline nights. Subject SC4 shows the highest increase in both the mean and in the percentage of rejection (32 and 80%

respectively). The other two subjects show the same trend but with much smaller changes.

TABLE 4.40

Summary of the Results of Tables 4.33, 4.36 and 4.39 for Subjects in Group 1 - Secobarbital

SUBJECTS			SC4	SC5	SC6
TITRATION DOSAGE (mg)			4200	3000	1800
DELTA BAND (0.0-3.5Hz)	PERC. OF POWER	MEAN	+26%	+53%	+27%
	FREQ. PEAK (Hz)	MEAN	-12%	-11%	+ 6%
THETA BAND (4.0-7.5Hz)	PERC. OF POWER	MEAN	+14%	+20%	+14%
	FREQ. PEAK (Hz)	MEAN	-1.5%	-1.7%	+ 5%
ALPHA BAND (8.0-11.5Hz)	PERC. OF POWER	MEAN	- 4%	+ 3%	+ 1%
	FREQ. PEAK (Hz)	MEAN	- 7%	+ 3%	- 5%
SIGMA BAND (12.0-15.5Hz)	PERC. OF POWER	MEAN	-63%	-46%	-51%
	FREQ. PEAK (Hz)	MEAN	+ 4%	0%	0%

TABLE 4.40

(continued)

SUBJECTS			SC4	SC5	SC6
TITRATION DOSAGE (mg)			4200	3000	1800
BETA1 BAND (16.0-20.5Hz)	PERC. OF POWER	MEAN	-54%	-55%	-45%
	FREQ. PEAK (Hz)	MEAN	+ 1%	0%	0%
BETA2 BAND (21.0-29.5Hz)	PERC. OF POWER	MEAN	-69%	-59%	-48%
	FREQ. PEAK (Hz)	MEAN	+ 3%	+0.4%	- 2%
FASTF BAND (30.0-40.0Hz)	PERC. OF POWER	MEAN	-55%	-57%	-33%
	FREQ. PEAK (Hz)	MEAN	+0.3%	+ 3%	-0.3%
X^2	MEAN		+32%	+ 3%	+10%
	PERCENTAGE OF REJECTIONS		+80%	+19%	+21%
MFC	MEAN		-39%	-34%	-27%

CHAPTER V

CONCLUSIONS AND RECOMMENDATIONS

5.1 CONCLUSIONS

Before we start this section we want to make it clear that whenever we refer to the activity or to the frequency in one of chosen frequency bands (Delta, Theta, Alpha, Sigma, Betal, Beta2 and Fastf) we are talking from the point of view of spectral analysis. These parameters are not necessarily the same ones for Electroencephalographers, since they look at the EEG waves in terms of periods and amplitudes. For example, a spectral peak in the Delta Band for us can be the result of: (1) delta activity as the visual scorer sees it; (2) activity with the same period as the delta, but whose amplitude does not reach the 75μV peak-to-peak threshold required to be called delta (Rechtschaffen and Kales, 1968); (3) some low frequency artifact; (4) amplitude modulation in the EEG waveform; (5) any combination of the above.

From the results of Chapter IV we can see that the administration of either drug reduced the mean percentage of power in the Delta Band in all subjects. This value, however, increased with the withdrawal of the drug as in the case of the subjects in Group 1, or returned to its normal value during the baseline night for subjects in Group 2. The highest reductions in this parameter were observed in subjects SD1 and SC3, who received the largest dosages of secobarbital (1000 mg). The subjects with the highest titration dosages

of methaqualone did not show this kind of dosage related changes, except for subject SC5. Since with the other subjects that were also titrated with large doses of methaqualone, we had problem with either choosing their baseline nights (SD4 and SD5), or with a low frequency artifact present in the first night (SC4), we cannot say, based on the available data, that the mean percentage of power in the Delta Band is less affected by methaqualone than it is by secobarbital.

All the subjects in Group 1 showed a decrease in the mean frequency in the Delta Band with the administration of the drug. Furthermore, four of the subjects (SD1, SD3, SD4, and SD5) had a marked decrease in this parameter. This is equivalent to saying that the drugs caused not only a reduction in the percentage of power in the Delta Band, but that they also slowed down the "frequency" of the "delta waves". On the other hand, the subjects in Group 2, with the exception of subject SC6, had an increase in the mean frequency of the Delta Band with the acute administration of the drugs. This discrepancy could be explained by the fact that the subjects in Group 1 were all chronic drug abusers who have been using these drugs for quite some time. To date we have not found any references in the literature related to these frequency shifts.

As we already pointed out in section 4.2.4, the energy in a given frequency band is a function of the EEG amplitude, as well as of the amount of activity present in that particular frequency. In this manner, spectral analysis

is a blunt tool in the sense that it cannot tell us if the reduction of power in a given band is due to the reduction in the amplitude of the EEG waves in that frequency, or to the decrease in their total number or both. A good illustration of this was shown in section 2.4.3, example 1, when a low frequency high amplitude artifact was present in an epoch of relatively low voltage background EEG. The power spectrum of the epoch resulted in a high intensity peak in the Delta Band. However, this peak was larger than the one corresponding to the dominant alpha activity, despite the fact that the time duration of the artifact was much shorter than the total time occupied by the alpha activity.

Furthermore, it must be clear by now that the peaks we see in the Delta Band (either in the CSA plots or in the plots of the percentage of power in this band vs time) are not necessarily due to the presence of delta activity as the visual scorer sees it.

The above comments on the "weakness" of spectral analysis as compared to human EEG scoring should not imply that spectral analysis as an EEG quantification tool should be abandoned. On the contrary, we believe it provides a sensitive and reliable tool for a gross examination of noise-like nocturnal EEG activity in artifact-free data. A good example of this are the plots for the percentage of power in the Delta Band vs time, which shows a time profile of the low frequency EEG activity during a night's sleep. These profiles illustrate clearly the cyclic nature of the "delta activity"

which occurs throughout the night. Due to the effects of the drugs this "delta rhythm" usually was not detected by visual scoring, since some of the delta activity did not reach the required 75μV amplitude threshold to be scored as EEG activity belonging to stages 3 or 4, and the Electroencephalographer scored the EEG as stage 2. An illustration of this was already presented in section 2.2.4. It referred to the 5th night of subject SD1, in which the results of the manual scoring showed no sleep stages 3 or 4 present. However, the plot for the percentage of power in the Delta Band vs time showed a large peak at the beginning of the night. A further illustration of the usefullness of these low frequency profiles can be seen in the four nights of subject SD5 (1st, 3rd, 5th and 13th nights). In none of these nights sleep stages 3 or 4 were ever scored. However, the plots for the percentage of power in the Delta Band, Figures 4.22a, b, c and d show cyclic variations in the Delta Band throughout the night. Two subjects in Group 2, SC4 and SC5, have also no sleep stages 3 or 4 scored during their first nights, but the plots for the percentage of power in the Delta Band show peaks in this band. The above examples suggest that even under the effects of large doses of the drugs, the subjects may generate sufficient activity in the delta range to qualify for sleep stages 3 or 4. We observed in some of the corresponding EEG records that this activity indeed had the same period of the delta waves, but its amplitude did not reach the 75μV threshold required by the visual scoring system for acceptance as

delta activity. Similar observations were also found in some of the score sheets that we looked at, in which the scorer stated that, although there was "delta activity" present, its amplitude was not high enough to be called delta, and so the EEG epochs were scored as stage 2 sleep. The times of the night when these observations were made correspond, in our case, to the times of occurrence of the peaks in the plots of the percentage of power in the Delta Band vs time.

By looking at the plots of the percentage of power in the Delta Band, it can be seen that there is a tendency for a shortening of the period of the "delta rhythm" during the nights as the drug was being withdrawn, for most subjects in Group 1 (SD1, SD2, SD3, SD5 and SD6), or in the 2nd and in the baseline nights, when compared to the first night, for subjects in Group 2 (SC1, SC2, SC3 and SC4). Furthermore, it seems that these peaks tend to move towards the early parts of the night as the drug was withdrawn. Lubin et al (1973) have tried to model this "delta rhythm" (also obtained by spectral analysis) as a damped sinusoid function. However, we did not find any references in the literature with respect to changes in this "rhythm" caused by barbiturates or methaqualone.

The mean percentage of power in the Sigma Band increased in all subjects with the administration of the drugs. It seems that the amount of changes in this parameter is not much related to the dosage the subjects received, and that the two drugs produced similar effects. It has been reported

that barbiturates cause an increase in sleep spindle activity (Allnutt and O'Connor, 1971; Kay et al (1972);Feinberg et al 1974). The drugs also caused a decrease in the mean frequency in the Sigma Band for all subjects in Group 1. Only two subjects in Group 2, SC3 and SC4, had changes in this parameter that were comparable to the ones exibited by the subjects in Group 1. This slowing of the sigma frequency may be related to the observation by Kay et al (1972),in which they reported that the incidence of sleep spindle bursts increased after pentobarbital and that the frequency within the bursts tended to decrease. However, no reference was made as to the amount of this reduction. The lack of information with respect to changes in frequency of the various EEG waveforms can be explained by the fact that the Electroencephalographers do not look for these kind of changes when they score sleep EEGs into various stages.

The mean percentage of power in the Betal, Beta2 and Fastf Bands increased in all subjects with the administration of either drug, and it seems that there is no apparent drug-related type of changes. No appreciable changes can be observed in the mean frequencies in these bands. Lester et al (1968) also observed an increase in beta activity after the administration of 200 mg of secobarbital, however no quantification of this increase was presented.

The mean percentage of power in the Theta Band decreased with the administration of the drugs in all subjects. However,these results, in some subjects, could have been

artifactual due to the slowing down of the frequency of their alpha activity. This system artifact could be also responsible for the high variability among the subjects in the results for the mean percentage of power in the Alpha Band.

An efficient summary of the effects of the drugs on the activity in the various frequency bands was shown in the plots for the mean frequency coefficients (MFC) for each night. These plots illustrate in a quantitative fashion how the dominant EEG frequencies were shifted during the nights. In all subjects the mean frequency during the night (computed as the mean of the MFCs for an entire night) increases with the administration of the drugs, and then it starts decreasing to its baseline values as the drug is withdrawn. Furthermore, in most of the subjects, this value also seems to be related to the amount of drug administered. In six of the subjects, SD1, SD3, SD4, SD5, SC1 and SC2 we observed that although the mean frequency for each night was decreasing with withdrawal from the drug,, the standard deviation stayed pratically constant from night to night. This suggests that the basic mechanism responsible for the EEG frequency shifts during the night was not seriously affected by the drugs, and that the changes in the mean frequency from night to night were probably due to changes in the amount of slow (Delta, Theta) and fast (Sigma, Betas) wave activities.

The mean value and the percentage of rejections for the X^2 coefficient decreased in all subjects with the administration of either drug. What this suggests is that the EEG amplitude distribution had become more Gaussian due to the effects of the drugs. Furthermore, it seems that the degree of Gaussianity is related to the titration dosage given to the subjects. However, this relation is more clearly seen in the chronic users (Group 1). Furthermore, this drug-related effect is more pronounced in the subjects of both groups that were titrated with the highest doses of either drug. Elul (1969) suggested that, on the basis of the central limit theorem, increased Gaussianity in observed EEG activity may reflect an incresed degree of independence among individual cortical neural generators. A similar increase was also observed by McEwen et al (1975) in subjects under halothane anesthesia. To date, we have not found any other studies that report the effects of abusive or therapeutic dosage of sedative-hypnotic agents on the Gaussianity of the EEG amplitude distribution.

From the above discussion it can be seen that the proposed system seems to be quite efficient in showing drug related patterns in the sleep EEG that otherwise cannot be seen by using the classical approach of sleep staging. Karacan et al (1975) reported that conventional sleep staging parameters obtained from the manual scoring of the sleep EEG of subjects in Group 1, did not exhibit clearly dose-related effects. However, these effects could be better seen in the

EEG waveform characteristics, mainly with respect to spindle activity, which was virtually continuous throughout stage 2 in the titration night and in some nights following it.

The development of an automatic artifact detection algorithm made possible, not only the computation of more reliable power spectra, but also the processing of an entire night of EEG sleep automatically. With the implemented system, about 45 minutes are required to process an entire night of EEG sleep (based on an average of eight hours of EEG data), which is much faster than the two or three hours required by an experienced Electroencephalographer to score the same night. This time can be further reduced if in future applications the sampling rate is reduced to 64 samples/sec instead of the 128 samples/sec used in this study. This reduction in the sampling rate will result in a 50% reduction in the number of data points to be processed. The upper frequency in the analog bandpass filter (Section 2.3.1) can also be reduced to 30 Hz, since no appreciable activity was observed between 30 and 40 Hz.

5.2 RECOMMENDATIONS FOR FURTHER STUDY

In order to better understand the application of the Mean Frequency Coefficients and that of the X^2 coefficients for drug action evaluation, results from normative data are necessary. We suggest the application of the present system to process the sleep EEGs of normal individuals to obtain values for these coefficients that will permit further comparisons with the ones computed in the present work.

Further work is also necessary in order to correlate the values of the X^2 coefficients with the different EEG frequencies, and to investigate how the Gaussianity of the sleep EEGs is associated with slow wave sleep (SWS) and/or non-SWS. Weiss (1973) found in a normal subject that low frequency activity was correlated in time with non-Gaussian properties of the EEG amplitude distribution.

The quantification of the changes in the "delta rhythm" as a result of drug withdrawal with respect to changes in the amplitude and in the periodicity of the peaks is necessary.

Application of other automated techniques, such as the one proposed by Smith and Karacan (1973), are important to investigate the low frequency activity in order to see if the decrease we observed in the intensity of the spectral peaks, due to the effects of the drug, were the result of a reduction in the amplitude or in the amount of delta waves, or both.

More subjects and more nights per subject are needed if any statistical inference is to be made from the results.

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APPENDIX A

CHI-SQUARE GOODNESS-OF-FIT TEST

A Chi-square goodness-of-fit test is commonly employed to test whether or not a sample was drawn from a population having a specified distribution. In order to carry out this test, we first set up a null hypothesis stating that the sample was drawn from a set with a known distribution, in our case the normal distribution. Next we compute the chi-square coefficient according to:

$$X^2 = \sum_{i=1}^{k} (f_i - Np_i)/Np_i = \sum_{i=1}^{k} (f_i - F_i)^2/F_i \qquad (A.1)$$

where f_i is the actual or observed number of frequencies in the ith class, p_i the probability under the null hypothesis that an observation will fall into the ith class, $F_i = Np_i$ is the expected frequency in the ith class, N the number of observation in the sample, and k is the number of classes. It can be shown that as the size of the sample approaches infinity the distribution of this statistic approaches the chi-square distribution with n=k-1-s degrees of freedom where s is the number of parameters estimated from the sample. In our case s=2 since two parameters (mean and variance) must be estimated to fit a normal distribution function. Hence the number of degrees of freedom for X^2 in Equation (A.1) is n=k-3.

In practice the chi-square distribution is assumed to hold for finite values of N, and the region of acceptance

for the test is

$$X^2 \leq \chi^2_{n;\alpha}$$

where the value of χ^2 is available from a table of the chi-square distribution and α is the level of significance. If the sample value X^2 is greater than $\chi^2_{n;\alpha}$, the hypothesis that the sample distribution is Gaussian is rejected at the α level of significance, otherwise the null hypothesis is accepted at the α level of significance.

The number of classes was computed according to the formula:

$$K = 4\sqrt[5]{2(N-1)^2/C^2} \qquad (A.2)$$

where K is the number of classes, N the number of observations in the sample, and c is obtained from a table of areas under the normal (Gaussian) curve such that (Mann and Wald, 1942)

$$(1/\sqrt{2\pi}) \int_c^\infty e^{-y^2/2} dy = \alpha \qquad (A.3)$$

For $\alpha = 0.05$ (5% level of significance) it follows from Eq. (A.3) that $c = 1.64$.

In our case $N = 3840$ and the test is to be conducted at a 5% level of significance. The value of k calculated from Eq. (A.2) is 102.3. Williams (1950) has shown that for large values of N ($N \geq 1000$) the number of classes can be cut in half with a relatively small effect on the power of the test. In the present study we use $k = 52$ and it follows

that the number of degrees of freedom will be n=49. The acceptance region will be given by:

$$X^2 \leq \chi^2_{49;0.05} = 66.2$$

A FORTRAN subroutine called GOODFT was written to perform the chi-square goodness-to-fit test.

This subroutine was extensively tested both with normally distributed random numbers generated by the digital computer and with digitized Gaussian white noise with a bandwidth of 15 Hz from a noise generator (Hewlett Packard 3722A with infinite sequence length). To generate the normal distributed random numbers we use two IBM Library subroutines: GAUSS and RANDU. Subroutine GAUSS uses 12 uniform distributed random numbers to compute normal random numbers by the central limit theorem. The subroutine RANDU produces the uniform distributed random numbers to be used by GAUSS.

Table A.1 below shows the result of the X^2 test for 10 sets of 3840 normally distributed random number generated by GAUSS. As we can see the null hypothesis was accepted for all sets.

Set	X^2	Null Hypothesis
1	38.4	A
2	42.6	A
3	56.6	A
4	65.1	A
5	40.8	A

TABLE A.1

Set	X^2	Null Hypothesis
6	48.5	A
7	47.5	A
8	31.7	A
9	37.9	A
10	54.2	A

TABLE A.1 (continued)

Table A.2 shows the results of the application of the χ^2 test to digitized bandlimited white noise generated by a Hewlett Packard Model 3722A noise generator. The A/D conversion procedure is the same described in Chapter II. The Gaussian noise was lowpass filtered with cutoff frequency of 15 Hz and digitized at a rate of 128 samples per second. Each 30 seconds of data was stored as an epoch. In only one epoch was the null hypothesis rejected.

Epoch	X^2	Null Hypothesis
1	53.4	A
2	48.5	A
3	42.5	A
4	53.7	A
5	45.2	A
6	74.7	R
7	55.5	A
8	35.9	A
9	54.4	A
10	40.2	A

TABLE A.2

In both examples the test's acceptance region is

$$X^2 \leq 66.2$$

The execution time for subroutine GOODFT was minimized by using optimization techniques suggested by Dean (1971) and by compiling the subroutine under FORTRAN IV H-Level. For 3840 data points the total execution time was 1.4 seconds. A detailed listing of GOODFT appears in Appendix B.

APPENDIX B

COMPUTER PROGRAMS

```
C                                                                       MAIN  10
C     ***************************************************************** MAIN  20
C     *                                                               * MAIN  30
C     *                        PROGRAM  CONVERSION                    * MAIN  40
C     *                                                               * MAIN  50
C     ***************************************************************** MAIN  60
C                                                                       MAIN  70
      DATA POT1,POT2,POT3/'P001','P002','P003'/                         MAIN  80
      REAL*8 CCWAD1(2),TPCCW1(2),CCWAD2(2),TPCCW2(2)                    MAIN  90
      INTEGER*2 LOCAD1(3841),LOCAD2(3841),DUMMY                         MAIN 100
      REAL*8 WTMCCW                                                     MAIN 110
      INTEGER*2 IVAL/1000/                                              MAIN 120
      DATA POT1,POT2,POT3/'P001','P002','P003'/                         MAIN 130
      INTEGER*2 IHOLD,CB/1/,OP/4/          ,WTM/31/                     MAIN 140
      LOGICAL XRDSNS                                                    MAIN 150
      IT=30                                                             MAIN 160
      N=128*IT                                                          MAIN 170
      WRITE(15,105)                                                     MAIN 180
  105 FORMAT('READY TAPE ON DRIVE 281 - RING IN, ')                     MAIN 190
      CALL TYPE(0)                                                      MAIN 200
      WRITE(15,108)                                                     MAIN 210
  108 FORMAT('TURN LOGIC PUSHBUTTON # 1 - ON --- ALL OTHERS OFF')       MAIN 220
      CALL TYPE(0)                                                      MAIN 230
      WRITE(15,106)                                                     MAIN 240
  106 FORMAT(' SET ANALOG IN RMT MODE AND DEPRESS EOB')                 MAIN 250
      CALL XPOTSS(POT1,IVAL)                                            MAIN 260
      CALL XPOTSS(POT2,IVAL)                                            MAIN 270
      CALL XPOTSS(POT3,IVAL)                                            MAIN 280
      CALL XIC                                                          MAIN 290
   10 IHOLD = 0                                                         MAIN 300
      IFILE = 0                                                         MAIN 310
      IDR = 4                                                           MAIN 320
      N2N = N * 2                                                       MAIN 330
      CALL CCWCB (TPCCW1,CB,OP,LOCAD1(2),N2N)                           MAIN 340
      CALL CCWCB (TPCCW2,CB,OP,LOCAD2(2),N2N)                           MAIN 350
      CALL READAD (CCWAD1,N,2,LOCAD1)                                   MAIN 360
      CALL READAD (CCWAD2,N,2,LOCAD2)                                   MAIN 370
      CALL CCWCB (WTMCCW,WTM,OP,DUMMY,N)                                MAIN 380
      NCH=1                                                             MAIN 390
      LOCAD1(1) = 0*256 +NCH-1                                          MAIN 400
      LOCAD2(1) = 0*256 +NCH-1                                          MAIN 410
 2000 CONTINUE                                                          MAIN 420
      IB = 0                                                            MAIN 430
      IFILE = IFILE + 1                                                 MAIN 440
      CALL XRSCTL (IHOLD,0)                                             MAIN 450
      CALL XRSCTL(IHOLD,3)                                              MAIN 460
  203 CONTINUE                                                          MAIN 470
      IF(.NOT.XRDSNS(1)) GO TO 111                                      MAIN 480
      CALL XSTCTL(IHOLD,1)                                              MAIN 490
C     DELAY TO HOLD LIGHT ON                                            MAIN 500
      DO 20 J=1,10000                                                   MAIN 510
   20 CONTINUE                                                          MAIN 520
      CALL XRSCTL(IHOLD,1)                                              MAIN 530
      DO 30 I=1,10000                                                   MAIN 540
   30 CONTINUE                                                          MAIN 550
      GO TO 203                                                         MAIN 560
  111 CALL XIC                                                          MAIN 570
      CALL XSTCTL(IHOLD,3)                                              MAIN 580
      CALL FSTIO(0,CCWAD1,0)                                            MAIN 590
 1000 IB=IB+2                                                           MAIN 600
      CALL FSTCHK(0)                                                    MAIN 610
      CALL FSTIO(0,CCWAD2,0)                                            MAIN 620
      CALL FSTIO(IDR,TPCCW1,1)                                          MAIN 630
      CALL FSTCHK(0)                                                    MAIN 640
      CALL FSTIO(0,CCWAD1,0)                                            MAIN 650
      CALL FSTIO(IDR,TPCCW2,1)                                          MAIN 660
      IF (.NOT.XRDSNS(1))  GO TO 1000                                   MAIN 670

      CALL FSTCHK(0)                                                    MAIN 680
      CALL FSTIO (IDR,WTMCCW,1)                                         MAIN 690
      CALL XRSCTL(IHOLD,3)                                              MAIN 700
      WRITE (6,159) IFILE,IB                                            MAIN 710
  159 FORMAT ('                    FILE NUM. =',I3,'  NO. OF BLOCKS =',I5)MAIN 720
      IF(XRDSNS(4)) GO TO 2000                                          MAIN 730
  777 CONTINUE                                                          MAIN 740
      CALL TYPE(0)                                                      MAIN 750
      WRITE(15,110)                                                     MAIN 760
  110 FORMAT('DEPRESS LOAD/REWIND ON TAPE DRIVE 281 - THEN EOB')        MAIN 770
      STOP 777                                                          MAIN 780
      END                                                               MAIN 790
```

```
C
C     ***************************************************************** MAIN  10
C     *                                                               * MAIN  20
C     *                                                               * MAIN  30
C     *                          PROGRAM  DTOA                        * MAIN  40
C     *                                                               * MAIN  50
C     ***************************************************************** MAIN  60
C                                                                       MAIN  70
      INTEGER*2 LOCAD(3860),LOCA(11581)                                 MAIN  80
      DIMENSION IE(30)                                                  MAIN  90
      DATA POT4,POT5/'P004','P005'/                                     MAIN 100
      INTEGER*2 IVAL/500/                                               MAIN 110
      INTEGER EA,SA                                                     MAIN 120
      LOGICAL XRDSNS                                                    MAIN 130
      INTEGER*2 IHOLD/0/                                                MAIN 140
C     IT IS THE TIME DURATION OF THE EPOCH IN SECONDS                   MAIN 150
      CAL=18.0/11.0                                                     MAIN 160
      IBLOCK=61                                                         MAIN 170
      READ(5,100) KE,(IE(J),J=1,KE)                                    MAIN 180
  100 FORMAT(2013)                                                      MAIN 190
      NN=11580                                                          MAIN 200
      IT=30                                                             MAIN 210
      N=128*IT                                                          MAIN 220
      N1=N+1                                                            MAIN 230
      N3=3*N                                                            MAIN 240
      N31=N3+1                                                          MAIN 250
      EA=2                                                              MAIN 260
      SA=0                                                              MAIN 270
      ICON=10                                                           MAIN 280
      IS=1                                                              MAIN 290
      CALL XPOTSS(POT4,IVAL)                                            MAIN 300
      CALL XPOTSS(POT5,IVAL)                                            MAIN 310
      CALL XIC                                                          MAIN 320
      CALL XRSCTL(IHOLD,3)                                              MAIN 330
      IREC=0                                                            MAIN 340
      ITEST=3                                                           MAIN 350
      IC=ISTART                                                         MAIN 360
      CALL TOPEN                                                        MAIN 370
      DO 777 IB=1,IBLOCK                                                MAIN 380
      CALL RDTAPE(LOCAD,&9999)                                          MAIN 390
      DO 35 J=1,KE                                                      MAIN 400
      IF(IB.EQ.IE(J)) GO TO 36                                          MAIN 410
   35 CONTINUE                                                          MAIN 420
      GO TO 777                                                         MAIN 430
   36 CONTINUE                                                          MAIN 440
      WRITE(6,200) IB                                                   MAIN 450
  200 FORMAT(20X,I3//)                                                  MAIN 460
   11 IS=IS+1                                                           MAIN 470
      I=0                                                               MAIN 480
      DO 72 J=IS,N31,3                                                  MAIN 490
      I=I+1                                                             MAIN 500
      LOCA(J)=LOCAD(I)/3                                                MAIN 510
   72 CONTINUE                                                          MAIN 520
      IREC=IREC+1                                                       MAIN 530
C     TO TEST IF LOCA IS FILLED WITH THE THREE EPOCHS                   MAIN 540
      IF(IREC.NE.ITEST) GO TO 777                                       MAIN 550
      IS=1                                                              MAIN 560
      IREC=0                                                            MAIN 570
      L=11521                                                           MAIN 580
      DO 74 J=1,43,3                                                    MAIN 590
      LOCA(L+J)=819                                                     MAIN 600
      LOCA(L+J+1)=1638                                                  MAIN 610
      LOCA(L+J+2)=2457                                                  MAIN 620
   74 CONTINUE                                                          MAIN 630
      L=L+45                                                            MAIN 640
      DO 75 J=1,15                                                      MAIN 650
      LOCA(L+J)=0                                                       MAIN 660
   75 CONTINUE                                                          MAIN 670
      DO 85 J=2,NN                                                      MAIN 680
      X=LOCA(J)*CAL                                                     MAIN 690
      LOCA(J)=X                                                         MAIN 700
   85 CONTINUE                                                          MAIN 710
C     PRESS PSB # 5 TO START THE PLOTTING                               MAIN 720
   29 IF(XRDSNS(5)) GO TO 31                                            MAIN 730
      CALL XSTCTL(IHOLD,5)                                              MAIN 740
      DO 50 J=1,10000                                                   MAIN 750
   50 CONTINUE                                                          MAIN 760
      CALL XRSCTL(IHOLD,5)                                              MAIN 770
      DO 39 K=1,10000                                                   MAIN 780
   39 CONTINUE                                                          MAIN 790
      GO TO 29                                                          MAIN 800
C     STARTS THE CLOCK WITH 5 MS OF DELAY                               MAIN 810
   31 CALL XSTCTL(IHOLD,3)                                              MAIN 820
      CALL XWRTDA(NN,ICON,SA,EA,LOCA)                                   MAIN 830
C     RESETS THE CLOCK AT THE END OF THE PLOTTING                       MAIN 840
      CALL XRSCTL(IHOLD,3)                                              MAIN 850
C     TO REPEAT THE PLOTTING PRESS PSHB #2                              MAIN 860
      IF(XRDSNS(2)) GO TO 29                                            MAIN 870
C     TO STOP THE ENTIRE RUN PRESS PSHB # 0                             MAIN 880
      IF(XRDSNS(0)) GO TO 9999                                          MAIN 890
  777 CONTINUE                                                          MAIN 900
 9999 STOP                                                              MAIN 910
      END                                                               MAIN 920
```

```
1:  C                                                                          MAIN  10
2:  C     ***************************************************************************MAIN  20
3:  C     *                                                                       *MAIN  30
4:  C     *                          PROGRAM    REDUCE                          *MAIN  40
5:  C     *                                                                       *MAIN  50
6:  C     ***************************************************************************MAIN  60
7:  C                                                                          MAIN  70
8:        INTEGER*2 LOCA(3860),LOCAD(3860)                                     MAIN  80
9:        DIMENSION X(3840),XCHIS(500),XX(10),YY(10)                           MAIN  90
10:       EQUIVALENCE (LOCA(3841),XX(1))                                       MAIN 100
11:       EQUIVALENCE (LOCAD(3841),YY(1))                                      MAIN 110
12:       ITR=30                                                               MAIN 120
13:       N3=128*ITR                                                           MAIN 130
14:       FN3=N3                                                               MAIN 140
15:       KINTER=52                                                            MAIN 150
16:       CHISQ=66.3                                                           MAIN 160
17:  C                                                                         MAIN 170
18:  C    XMAX=XX(1)                                                           MAIN 180
19:  C    XMIN=XX(2)                                                           MAIN 190
20:  C    XVARX=XX(3)                                                          MAIN 200
21:  C    SKEW=XX(4)                                                           MAIN 210
22:  C    XKURT=XX(5)                                                          MAIN 220
23:  C    XSQR=XX(6)                                                           MAIN 230
24:  C    XBARX=XX(7)                                                          MAIN 240
25:  C    CSTDX=XX(8)                                                          MAIN 250
26:  C                                                                         MAIN 260
27:       XX(9)=0.0                                                            MAIN 270
28:       XX(10)=0.0                                                           MAIN 280
29:       READ(5,100) IBLOCK,ISTART,ISKIP,IARTF,XSQRL1,XSQRL2                  MAIN 290
30:  100  FORMAT(I4/,I4/,I4/,I4/,F10.0/,F10.0)                                 MAIN 300
31:       ARTF=IARTF/81.92                                                     MAIN 310
32:       WRITE(6,199)                                                         MAIN 320
33:  199  FORMAT(1H1/////)                                                     MAIN 330
34:       ICOUNT=0                                                             MAIN 340
35:       IC=ISTART                                                            MAIN 350
36:       LT=0                                                                 MAIN 360
37:       MT=0                                                                 MAIN 370
38:       IFL=0                                                                MAIN 380
39:       SUM=0.0                                                              MAIN 390
40:       CALL TOPEN                                                           MAIN 400
41:       CALL TWOPEN                                                          MAIN 410
42:       DO 71 IB=1,IBLOCK                                                    MAIN 420
43:       CALL RDTAPE(LOCA,&9999)                                              MAIN 430
44:       IF(MT) 10,1000,10                                                    MAIN 440
45:  1000 IF(LT) 10,2000,10                                                    MAIN 450
46:  2000 IF(IB-IC) 71,10,71                                                   MAIN 460
47:  10   CONTINUE                                                            MAIN 470
48:       DO 11 I=1,N3                                                         MAIN 480
49:       LH=LOCA(I)                                                           MAIN 490
50:       X(I)=LOCA(I)/81.92                                                   MAIN 500
51:       IF(IABS(LH)-IARTF) 11,20,20                                          MAIN 510
52:  20   II=I                                                                 MAIN 520
53:       GO TO 22                                                             MAIN 530
54:  11   CONTINUE                                                            MAIN 540
55:       CALL PARMR(X,N3,XX)                                                  MAIN 550
56:       CALL GOODFT(X,N3,KINTER,XX(7),XX(8),CHISQ,NHYPT,XX(6))               MAIN 560
57:       XSQR=XX(6)                                                           MAIN 570
58:       IF(XSQR-XSQRL1) 30,31,31                                             MAIN 580
59:  30   IC=IC+ISKIP                                                          MAIN 590
60:       ICOUNT=ICOUNT+1                                                      MAIN 600
61:       LT=0                                                                 MAIN 610
62:       MT=0                                                                 MAIN 620
63:       IFL=0                                                                MAIN 630
64:       XCHIS(ICOUNT)=XSQR                                                   MAIN 640
65:       SUM=SUM+NHYPT                                                        MAIN 650
66:       CALL TWRITE(LOCA)                                                    MAIN 660
67:       GO TO 71                                                             MAIN 670
```

```
 68:     22  IC1=IC+LT+MT                                                                  MAIN 680
 69:         WRITE(6,210) IC1,X(II)                                                       MAIN 690
 70:   210   FORMAT(40X,' AMPLITUDE  EXCEEDED  AT EPOCH NO.',I4,5X,'   X=',F7.2MAIN 700
 71:        2/)                                                                           MAIN 710
 72:         LT=LT+1                                                                      MAIN 720
 73:         ISL=LT+MT                                                                    MAIN 730
 74:         IF(ISL-3) 71,71,21                                                           MAIN 740
 75:   21    IF(IFL) 40,41,40                                                             MAIN 750
 76:   41    LTT=LT-1                                                                     MAIN 760
 77:         WRITE(6,250)                                                                 MAIN 770
 78:   250   FORMAT(40X,'* A SET OF EPOCHS WAS SKIPPED DUE TO ARTIFACTS'/)               MAIN 780
 79:         MT=0                                                                         MAIN 790
 80:         LT=0                                                                         MAIN 800
 81:         IC=IC+ISKIP                                                                  MAIN 810
 82:         GO TO 71                                                                     MAIN 820
 83:     31  IC2=IC+MT+LT                                                                 MAIN 830
 84:         WRITE(6,240) IC2,XSQR                                                        MAIN 840
 85:   240   FORMAT(40X,' ARTIFACT   DETECTED  AT EPOCH NO.',I4,5X,'XSQR=',F7.2MAIN 850
 86:        2/)                                                                           MAIN 860
 87:         MT=MT+1                                                                      MAIN 870
 88:         ISM=MT+LT                                                                    MAIN 880
 89:         IF(XSQR-XSQRL2) 42,42,43                                                     MAIN 890
 90:   42    IF(IFL) 44,45,44                                                             MAIN 900
 91:   45    DO 47 K=1,N3                                                                 MAIN 910
 92:         LOCAD(K)=LOCA(K)                                                             MAIN 920
 93:   47    CONTINUE                                                                     MAIN 930
 94:         DO 60 J=1,8                                                                  MAIN 940
 95:         YY(J)=XX(J)                                                                  MAIN 950
 96:   60    CONTINUE                                                                     MAIN 960
 97:         XSQRF=XSQR                                                                   MAIN 970
 98:         IFL=1                                                                        MAIN 980
 99:         IF(ISM-3) 71,71,40                                                           MAIN 990
100:   44    IF(XSQR-XSQRF)45,43,43                                                       MAIN1000
101:   43    IF(ISM-3) 71,71,50                                                           MAIN1010
102:   50    IF(IFL) 40,32,40                                                             MAIN1020
103:   40    IC=IC+ISKIP                                                                  MAIN1030
104:         ICOUNT=ICOUNT+1                                                              MAIN1040
105:         LT=0                                                                         MAIN1050
106:         MT=0                                                                         MAIN1060
107:         IFL=0                                                                        MAIN1070
108:         XCHIS(ICOUNT)=XSQRF                                                          MAIN1080
109:         DO 61 J=1,8                                                                  MAIN1090
110:         XX(J)=YY(J)                                                                  MAIN1100
111:   61    CONTINUE                                                                     MAIN1110
112:         SUM=SUM+NHYPT                                                                MAIN1120
113:         CALL TWRITE(LOCAD)                                                           MAIN1130
114:         GO TO 71                                                                     MAIN1140
115:   32    MTT=MT-1                                                                     MAIN1150
116:         WRITE(6,250)                                                                 MAIN1160
117:         MT=0                                                                         MAIN1170
118:         LT=0                                                                         MAIN1180
119:         IFL=0                                                                        MAIN1190
120:         IC=IC+ISKIP                                                                  MAIN1200
121:   71    CONTINUE                                                                     MAIN1210
122:   9999  CONTINUE                                                                     MAIN1220
123:         IF(IFL) 51,52,51                                                             MAIN1230
124:   51    ICOUNT=ICOUNT+1                                                              MAIN1240
125:         XCHIS(ICOUNT)=XSQRF                                                          MAIN1250
126:         SUM=SUM+NHYPT                                                                MAIN1260
127:         CALL TWRITE(LOCAD)                                                           MAIN1270
128:   52    CONTINUE                                                                     MAIN1280
129:         STOP                                                                         MAIN1290
130:         END                                                                          MAIN1300
```

```
RDTP     TITLE  'HYBRID  TAPE READ   ROUTINE'                                MAIN  10
RDTAPE   CSECT                                                               MAIN  20
*                                                                            MAIN  30
*        CALL RDTAPE(IBUF,&9999)                                             MAIN  40
*        IBUF = INPUT BUFFER AREA (MAY BE OF ANY MODE)                       MAIN  50
*                  THE SIZE OF THE INCOMING RECORD DETERMINES THE            MAIN  60
*                  DIMENSIONS OF IBUF.                                       MAIN  70
*             I.E. IF YOU HAD AN A/D TAPE WITH 1024 SAMPLES PER TAPE         MAIN  80
*                  RECORD YOU WOULD DIMENSION IBUF AS FOLLOWS:               MAIN  90
*                  INTEGER*2 IBUF(2048)                                      MAIN 100
*        &9999 = END OF FILE ADDRESS                                         MAIN 110
*                                                                            MAIN 120
*        THE USER MUST CALL TOPEN ONLY ONCE BEFORE MAKING CALLS ON           MAIN 130
*                         ----------                                         MAIN 140
*             RDTAPE.                                                        MAIN 150
*                                                                            MAIN 160
*        IN ORDER TO SKIP A FILE MARK ON THE TAPE YOU MAY USE THE            MAIN 170
*             FOLLOWING:                                                     MAIN 180
*             CALL SKFILE.                                                   MAIN 190
*                                                                            MAIN 200
*        THE ONLY CONTROL CARD NECESSARY IS THE FOLLOWING:                   MAIN 210
* //GO.TAPE08 DD UNIT=2400,VOL=SER=ADDATA,DISP=(OLD,PASS),                   MAIN 220
* //   LABEL=(1,NL),DCB=(RECFM=U,BLKSIZE=8192)                               MAIN 230
         SPACE 2                                                             MAIN 240
         ENTRY  TOPEN,SKFILE                                                 MAIN 250
         SPACE 4                                                             MAIN 260
* --- --- --- --- --- --- --- --- --- --- --- --- --- --- --- --- --- ---     MAIN 270
*        RDTAPE ENTRY                                                        MAIN 280
         SAVE  (14,12),T,RDTAPE                                              MAIN 290
         BALR  10,0                                                          MAIN 300
         USING *,10                                                          MAIN 310
         ST    13,SAVE+4                                                     MAIN 320
         LA    5,SAVE                                                        MAIN 330
         ST    5,8(13)                                                       MAIN 340
         LR    13,5                                                          MAIN 350
         LA    8,EOFADDR1                                                    MAIN 360
         LA    9,TAPEDCB                                                     MAIN 370
         MVC   X'21'(3,9),1(8)                                               MAIN 380
         LM    2,3,0(1)              GET ADDR OF PARMS                       MAIN 390
         MVI   DECBT,X'00'                                                   MAIN 400
         READ  DECBT,SF,TAPEDCB,(2),'S',MF=E                                 MAIN 410
         CHECK DECBT                                                         MAIN 420
         L     13,SAVE+4                                                     MAIN 430
         RETURN (14,12),T                                                    MAIN 440
         SPACE 2                                                             MAIN 450
LOCEOF   EQU   *                                                             MAIN 460
         L     13,SAVE+4                                                     MAIN 470
         LM    14,12,12(13)                                                  MAIN 480
         MVI   12(13),X'FF'                                                  MAIN 490
         LA    15,4                                                          MAIN 500
         BCR   15,14                                                         MAIN 510
*                                                                            MAIN 520
         EJECT                                                               MAIN 530
* --- --- --- --- --- --- --- --- --- --- --- --- --- --- --- --- --- ---     MAIN 540
*                                                                            MAIN 550
*        CALL TOPEN                                                          MAIN 560
*                                                                            MAIN 570
TOPEN    EQU   *                                                             MAIN 580
         SAVE  (14,12),T,TOPEN                                               MAIN 590
         BALR  10,0                                                          MAIN 600
         USING *,10                                                          MAIN 610
         ST    13,SAVE+4                                                     MAIN 620
         LA    5,SAVE                                                        MAIN 630
         ST    5,8(13)                                                       MAIN 640
         LR    13,5                                                          MAIN 650
         OPEN  (TAPEDCB,INPUT)                                               MAIN 660
         L     13,SAVE+4                                                     MAIN 670
```

```
                RETURN (14,12),T                                                MAIN 680
*                                                                               MAIN 690
                EJECT                                                           MAIN 700
* --- --- --- --- --- --- --- --- --- --- --- --- --- --- --- --- --- --- ---   MAIN 710
*                                                                               MAIN 720
*               CALL SKFILE                                                     MAIN 730
*                                                                               MAIN 740
SKFILE          EQU   *                                                         MAIN 750
                SAVE  (14,12),T,SKFILE                                          MAIN 760
                BALR  10,0                                                      MAIN 770
                USING *,10                                                      MAIN 780
                ST    13,SAVE+4                                                 MAIN 790
                LA    5,SAVE                                                    MAIN 800
                ST    5,8(13)                                                   MAIN 810
                LR    13,5                                                      MAIN 820
                LA    8,EOFADDR2                                                MAIN 830
                LA    9,TAPEDCB                                                 MAIN 840
                MVC   X'21'(3,9),1(8)                                           MAIN 850
*               CNTRL  TAPEDCB,FSM                                              MAIN 860
*               CNTRL MACRO NOT WORKING THEREFORE CODE HAND GENERATED           MAIN 870
                LA    1,TAPEDCB                                                 MAIN 880
                L     15,84(1,0)                                                MAIN 890
                BALR  14,15                                                     MAIN 900
                DC    AL2(63)                                                   MAIN 910
                MVI   DECBT,X'00'                                               MAIN 920
                READ  DECBT,SF,TAPEDCB,OUMARA,'S',MF=E                          MAIN 930
                CHECK DECBT                                                     MAIN 940
CTRLEOF         EQU   *                                                         MAIN 950
                L     13,SAVE+4                                                 MAIN 960
                RETURN (14,12),T                                                MAIN 970
* --- --- --- --- --- --- --- --- --- --- --- --- --- --- --- --- --- --- ---   MAIN 980
*                                                                               MAIN 990
*                                                                               MAIN1000
                EJECT                                                           MAIN1010
*               D A T A    C O N T R O L    A R E A                             MAIN1020
                SPACE 2                                                         MAIN1030
SAVE            DC    18F'0'          SAVE AREA                                 MAIN1040
*                                                                               MAIN1050
                READ  DECBT,SF,MF=L                                             MAIN1060
                SPACE 4                                                         MAIN1070
EOFADDR1        DC    AL4(LOCEOF)                                               MAIN1080
EOFADDR2        DC    AL4(CTRLEOF)                                              MAIN1090
OUMARA          DS    CL20                                                      MAIN1100
                SPACE 4                                                         MAIN1110
TAPEDCB         DCB   DDNAME=TAPE08,DEVD=TA,MACRF=(RC),DSORG=PS,EODAD=(LOCEOF)  MAIN1120
                END                                                             MAIN1130
```



```
TWRITE          CSECT                                                           MAIN  10
                ENTRY TWRITE                                                    MAIN  20
                ENTRY TWOPEN                                                    MAIN  30
                USING TWRITE,15                                                 MAIN  40
                SAVE  (14,12),T,*                                               MAIN  50
                LR    14,13                                                     MAIN  60
                CNOP  0,4                                                       MAIN  70
                BAL   13,*+76                                                   MAIN  80
                USING *,13                                                      MAIN  90
                DS    18F                                                       MAIN 100
                ST    13,8(14)                                                  MAIN 110
                ST    14,4(13)                                                  MAIN 120
                DROP  15                                                        MAIN 130
                L     2,0(1)                                                    MAIN 140
                WRITE TODECB,SF,,(2),MF=E                                       MAIN 150
                CHECK TODECB                                                    MAIN 160
                L     13,4(13)                                                  MAIN 170
                RETURN (14,12),T,RC=0                                           MAIN 180
TWOPEN          SAVE  (14,12),T,*                                               MAIN 190
                USING TWOPEN,15                                                 MAIN 200
                LR    14,13                                                     MAIN 210
                CNOP  0,4                                                       MAIN 220
                BAL   13,*+76                                                   MAIN 230
                USING *,13                                                      MAIN 240
                DS    18F                                                       MAIN 250
                ST    13,8(14)                                                  MAIN 260
                ST    14,4(13)                                                  MAIN 270
                DROP  15                                                        MAIN 280
                OPEN  (TAPEO,OUTPUT)                                            MAIN 290
                L     13,4(13)                                                  MAIN 300
                RETURN (14,12),T,RC=0                                           MAIN 310
TAPEO           DCB   DDNAME=TAPEOUT,DEVD=DA,DSORG=PS,MACRF=(W)                 MAIN 320
                WRITE TODECB,SF,TAPEO,MF=L                                      MAIN 330
                END                                                             MAIN 340
```

```
      SUBROUTINE GOODFT(XDATA,NSIZE,KINTR,XBARX,CSTDX,CHISQ,            GOOD  10
     1NHYPT,XSQRT)                                                      GOOD  20
C                                                                       GOOD  30
C     ***************************************************************GOOD  40
C                                                                       GOOD  50
C        THIS SUBROUTINE TESTS THE NORMALITY OF THE ARRAY XDATA  BY     GOOD  60
C        PERFORMING A CHI-SQUARE GOODNESS OF FIT TEST USING CLASS       GOOD  70
C        INTERVALS WITH EQUAL EXPECTED FREQUENCIES                      GOOD  80
C                                                                       GOOD  90
C     ***************************************************************GOOD 100
C                                                                       GOOD 110
C     XDATA -- REAL ARRAY CONTAINING THE DATA POINTS                    GOOD 120
C     NSIZE -- INTEGER VALUE FOR THE SIZE OF THE ARRAY XDATA            GOOD 130
C     KINTR -- INTEGER VALUE FOR THE NUMBER OF CLASS INTERVALS          GOOD 140
C     XBARX -- REAL VALUE OF THE SAMPLE MEAN OF THE DATA                GOOD 150
C     CSTDX -- REAL VALUE OF THE SAMPLE STANDARD DEVIATION OF THE DATA  GOOD 160
C     ZGAUS -- ARRAY OF THE ABCISSA VALUES FROM THE NORMAL DENS. FUNCTIOGOOD 170
C     CHISQ -- REAL VALUE OBTAINED FROM A CHI-SQUARE TABLE              GOOD 180
C    *XSQRT -- REAL VALUE OF THE SAMPLE STATISTICS  CALCULATED BY GOODFTGOOD 190
C    *NHYPT -- IF IT IS 1 THE NORMALITY HYPOTHESIS IS ACCEPTED AT THE   GOOD 200
C              ALPHA LEVEL OF SIGNIFICANCE                             GOOD 210
C              IF IT IS 0 THE NORMALITY HIPOTHESIS IS REJECTED AT ALPHA GOOD 220
C              LEVEL OF SIGNIFICANCE                                   GOOD 230
C                                                                       GOOD 240
C     ***************************************************************GOOD 250
C                                                                       GOOD 260
C        THIS SUBROUTINE CALLS NDTRI TO GENERATE THE ZGAUS ARRAY        GOOD 270
C                                                                       GOOD 280
C     ***************************************************************GOOD 290
      DIMENSION XDATA(1),ZGAUS(100),OFREQ(100),X(100)                   GOOD 300
      DATA IFLAG/0/                                                     GOOD 310
      FSIZE=NSIZE                                                       GOOD 320
      FINTR=KINTR                                                       GOOD 330
      KK=KINTR-1                                                        GOOD 340
C     COMPUTES THE ZGAUS ARRAY                                          GOOD 350
      IF(IFLAG) 20,30,20                                                GOOD 360
30    PROBI=1.0/FINTR                                                   GOOD 370
      DO 19 J=1,KK                                                      GOOD 380
      P=PROBI*J                                                         GOOD 390
      CALL NDTRI(P,Z,D,IER)                                             GOOD 400
      ZGAUS(J)=Z                                                        GOOD 410
19    CONTINUE                                                          GOOD 420
      IFLAG=1                                                           GOOD 430
20    CONTINUE                                                          GOOD 440
C     CALCULATE THE EXPECTED FREQUENCY IN EACH INTERVAL                 GOOD 450
      EFREQ=FSIZE/FINTR                                                 GOOD 460
      CONST=1.0/EFREQ                                                   GOOD 470
C     CALCULATES THE END POINTS OF EACH INTERVAL                        GOOD 480
      DO 1 I=1,KK                                                       GOOD 490
      X(I)=CSTDX*ZGAUS(I)+XBARX                                         GOOD 500
1     CONTINUE                                                          GOOD 510
C     TO FIND THE OBSERVED FREQUENCY AT EACH INTERVAL                   GOOD 520
      DO 2 I=1,KINTR                                                    GOOD 530
2     OFREQ(I)=0.0                                                      GOOD 540
      DO 7 J=1,NSIZE                                                    GOOD 550
      IF(XDATA(J)-X(1)) 3,3,4                                           GOOD 560
3     OFREQ(1)=OFREQ(1)+1.0                                             GOOD 570
      GO TO 7                                                           GOOD 580
4     IF(XDATA(J)-X(KK)) 6,6,5                                          GOOD 590
5     OFREQ(KINTR) =OFREQ(KINTR) +1.0                                   GOOD 600
      GO TO 7                                                           GOOD 610
6     DO 9 I=2,KK                                                       GOOD 620
      IF(XDATA(J)-X(I)) 8,8,9                                           GOOD 630
8     OFREQ(I)=OFREQ(I)+1.0                                             GOOD 640
      GO TO 7                                                           GOOD 650
9     CONTINUE                                                          GOOD 660
7     CONTINUE                                                          GOOD 670
```

```
      C     CALCULATE THE TOTAL DISCREPANCY FOR ALL CLASS INTERVALS          GOOD 680
            XSQRT=0.0                                                       GOOD 690
            DO 10 K=1,KINTR                                                 GOOD 700
            FDIF=EFREQ-OFREQ(K)                                             GOOD 710
            XSQRT=XSQRT+OFREQ(K)**2                                         GOOD 720
     10     CONTINUE                                                        GOOD 730
            XSQRT=XSQRT*CONST-FSIZE                                         GOOD 740
      C     NUMBER OF DEGREES OF FREEDOM IS GIVEN BY                        GOOD 750
            N=KINTR-3                                                       GOOD 760
      C     TO TEST THE HYPOTHESIS OF NORMALITY                             GOOD 770
            NHYPT=1                                                         GOOD 780
            IF(XSQRT.LE.CHISQ) NHYPT=0                                      GOOD 790
     69     RETURN                                                          GOOD 800
            END                                                             GOOD 810
```



```
            SUBROUTINE PARMR(X,N3,XX)                                       PARM  10
      C                                                                     PARM  20
      C     ************************************************************* PARM  30
      C                                                                     PARM  40
      C        THIS SUBROUTINE COMPUTES THE FOLLOWING PARAMETERS FOR THE  X PARM  50
      C        ARRAY: MIN AND MAX VALUES,MEAN,VARIANCE,STD,KURTOSIS AND   PARM  60
      C        SKEWNESS                                                   PARM  70
      C                                                                   PARM  80
      C     ************************************************************* PARM  90
      C                                                                   PARM 100
            DIMENSION X(1),XX(1)                                          PARM 110
            XX(1)=X(1)                                                    PARM 120
            XX(2)=X(1)                                                    PARM 130
            FN3=N3                                                        PARM 140
            SUMX1=0.0                                                     PARM 150
            SUMX2=0.0                                                     PARM 160
            SUMX3=0.00                                                    PARM 170
            SUMX4=0.0                                                     PARM 180
            DO 11 I=1,N3                                                  PARM 190
            TERM=X(I)                                                     PARM 200
            SUMX1=SUMX1+TERM                                              PARM 210
            TERM=TERM*X(I)                                                PARM 220
            SUMX2=SUMX2+TERM                                              PARM 230
            TERM=TERM*X(I)                                                PARM 240
            SUMX3=SUMX3+TERM                                              PARM 250
            TERM=TERM*X(I)                                                PARM 260
            SUMX4=SUMX4+TERM                                              PARM 270
            XX(1)=AMAX1(XX(1),X(I))                                       PARM 280
            XX(2)=AMIN1(XX(2),X(I))                                       PARM 290
     11     CONTINUE                                                      PARM 300
            XX(7)=SUMX1/FN3                                               PARM 310
            XX(3)=SUMX2/FN3                                               PARM 320
            XX(8)=SQRT(XX(3)-XX(7)**2)                                    PARM 330
            XMT3=SUMX3/FN3-3.0*XX(7)*XX(3)+2.0*XX(7)                      PARM 340
            XMT4=SUMX4/FN3+4.0*XMT3+6.0*XX(3)*XX(7)**2+5.0*XX(7)**4       PARM 350
            XX(4)=XMT3/(XX(3)**1.5)                                       PARM 360
            XX(5)=XMT4/(XX(3)**2)                                         PARM 370
            RETURN                                                        PARM 380
            END                                                           PARM 390
```

PAGE 1

```
C                                                                               NDTR  10
C*******************************************************************************NDTR  20
C                                                                               NDTR  30
C       SUBROUTINE NDTRI                                                        NDTR  40
C                                                                               NDTR  50
C       PURPOSE                                                                 NDTR  60
C         COMPUTES X = P**(-1)(Y), THE ARGUMENT X SUCH THAT Y= P(X) =           NDTR  70
C         THE PROBABILITY THAT THE RANDOM VARIABLE U, DISTRIBUTED               NDTR  80
C         NORMALLY(0,1), IS LESS THAN OR EQUAL TO X.  F(X), THE                 NDTR  90
C         ORDINATE OF THE NORMAL DENSITY, AT X, IS ALSO COMPUTED.               NDTR 100
C                                                                               NDTR 110
C       USAGE                                                                   NDTR 120
C         CALL NDTRI(P,X,D,IER)                                                 NDTR 130
C                                                                               NDTR 140
C       DESCRIPTION OF PARAMETERS                                               NDTR 150
C         P   - INPUT PROBABILITY.                                              NDTR 160
C         X   - OUTPUT ARGUMENT SUCH THAT P = Y = THE PROBABILITY THAT          NDTR 170
C                 U, THE RANDOM VARIABLE, IS LESS THAN OR EQUAL TO X.           NDTR 180
C         D   - OUTPUT DENSITY, F(X).                                           NDTR 190
C         IER - OUTPUT ERROR CODE                                               NDTR 200
C               = -1 IF P IS NOT IN THE INTERVAL (0,1), INCLUSIVE.              NDTR 210
C                 X=D=.99999E+74 IN THIS CASE                                   NDTR 220
C               = 0 IF THERE IS NO ERROR.  SEE REMARKS, BELOW.                  NDTR 230
C                                                                               NDTR 240
C       REMARKS                                                                 NDTR 250
C         MAXIMUM ERROR IS 0.00045.                                             NDTR 260
C         IF P = 0, X IS SET TO -(10)**74.  D IS SET TO 0.                      NDTR 270
C         IF P = 1, X IS SET TO  (10)**74.  D IS SET TO 0.                      NDTR 280
C                                                                               NDTR 290
C       SUBROUTINES AND SUBPROGRAMS REQUIRED                                    NDTR 300
C         NONE                                                                  NDTR 310
C                                                                               NDTR 320
C       METHOD                                                                  NDTR 330
C         BASED ON APPROXIMATIONS IN C. HASTINGS, APPROXIMATIONS FOR            NDTR 340
C         DIGITAL COMPUTERS, PRINCETON UNIV. PRESS, PRINCETON, N.J.,            NDTR 350
C         1955.  SEE EQUATION 26.2.23, HANDBOOK OF MATHEMATICAL                 NDTR 360
C         FUNCTIONS, ABRAMOWITZ AND STEGUN, DOVER PUBLICATIONS, INC.,           NDTR 370
C         NEW YORK.                                                             NDTR 380
C                                                                               NDTR 390
C*******************************************************************************NDTR 400
C                                                                               NDTR 410
      SUBROUTINE NDTRI(P,X,D,IE)                                                NDTR 420
C                                                                               NDTR 430
      IE=0                                                                      NDTR 440
      X=.99999E+74                                                              NDTR 450
      D=X                                                                       NDTR 460
      IF(P)1,4,2                                                                NDTR 470
    1 IE=-1                                                                     NDTR 480
      GO TO 12                                                                  NDTR 490
    2 IF (P-1.0)7,5,1                                                           NDTR 500
    4 X=-.999999E+74                                                            NDTR 510
    5 D=0.0                                                                     NDTR 520
      GO TO 12                                                                  NDTR 530
C                                                                               NDTR 540
C                                                                               NDTR 550
    7 D=P                                                                       NDTR 560
      IF(D-0.5)9,9,8                                                            NDTR 570
    8 D=1.0-D                                                                   NDTR 580
    9 T2=ALOG(1.0/(D*D))                                                        NDTR 590
      T=SQRT(T2)                                                                NDTR 600
      X=T-(2.515517+0.802853*T+0.010328*T2)/(1.0+1.432788*T+0.189269*T2        NDTR 610
     1  +0.001308*T*T2)                                                        NDTR 620
      IF(P-0.5)10,10,11                                                         NDTR 630
   10 X=-X                                                                      NDTR 640
   11 D=0.3989423*EXP(-X*X/2.0)                                                 NDTR 650
   12 RETURN                                                                    NDTR 660
      END                                                                       NDTR 670
```

```
C                                                                               MAIN  10
C     ***************************************************************************MAIN  20
C     *                                                                         *MAIN  30
C     *                          PROGRAM     PSPEC                              *MAIN  40
C     *                                                                         *MAIN  50
C     ***************************************************************************MAIN  60
C                                                                               MAIN  70
      INTEGER*2 LOCA(3860)                                                      MAIN  80
      DIMENSION X(4096),PSPEC(2058),PNORM(2048),XX(10),TNORM(90),PARM(9)        MAIN  90
      EQUIVALENCE(TNORM(1),PNORM(1)),(XX(1),PARM(1))                            MAIN 100
      EQUIVALENCE(PSPEC(1),LOCA(1))                                             MAIN 110
      ITR=30                                                                    MAIN 120
      ITZ=32                                                                    MAIN 130
      N=128*ITZ                                                                 MAIN 140
      NHALF=N/2                                                                 MAIN 150
      NDEL=NHALF/128                                                            MAIN 160
      DFREQ=128.0                                                               MAIN 170
      N3=128*ITR                                                                MAIN 180
      N1=N3                                                                     MAIN 190
      N2=2*N                                                                    MAIN 200
      FN=N                                                                      MAIN 210
      DELTT=1.0/DFREQ                                                           MAIN 220
      TTIME=FN *DELTT                                                           MAIN 230
      DELTF=1.0/TTIME                                                           MAIN 240
      READ(5,100) ISMTH                                                         MAIN 250
100   FORMAT(I3)                                                                MAIN 260
      ICOUNT=0                                                                  MAIN 270
      KCOMP=82                                                                  MAIN 280
      JP=81                                                                     MAIN 290
      LL=2048                                                                   MAIN 300
      IK=NDEL                                                                   MAIN 310
      NLAP=0                                                                    MAIN 320
      L=1920                                                                    MAIN 330
      WRITE(6,200)                                                              MAIN 340
200   FORMAT(3X,'EPOCH',3X,'XMAX',6X,'XMIN',3X,'VARIANCE',3X,'SKEWNESS',MAIN 350
     13X,'KURTOSIS',3X,'XSQR',5X,'MEAN',4X,'PSPECMX',3X,'PSPECMN'//)            MAIN 360
      CALL TOPEN                                                                MAIN 370
      DO 71 IB=1,400                                                            MAIN 380
      CALL RDTAPE(LOCA,&9999)                                                   MAIN 390
      DO 20 K=1,10                                                              MAIN 400
      XX(K)=PSPEC(L+K)                                                          MAIN 410
20    CONTINUE                                                                  MAIN 420
      DO 70 K=N3,N                                                              MAIN 430
      X(K)=0.00                                                                 MAIN 440
70    CONTINUE                                                                  MAIN 450
      DO 72 J=1,N3                                                              MAIN 460
      X(J)=LOCA(J)/81.92-XX(7)                                                  MAIN 470
72    CONTINUE                                                                  MAIN 480
      CALL TAPER1(X,N1,DFREQ)                                                   MAIN 490
      CALL PWRP(X,PSPEC,N,DELTT)                                                MAIN 500
      ICOUNT=ICOUNT+1                                                           MAIN 510
      CALL SMTH15(PSPEC,N,PNORM,NLAP)                                           MAIN 520
      J=0                                                                       MAIN 530
      DO 10 I=1,NHALF,IK                                                        MAIN 540
      J=J+1                                                                     MAIN 550
      PNORM(J)=PSPEC(I)                                                         MAIN 560
10    CONTINUE                                                                  MAIN 570
      DO 29 I=1,ISMTH                                                           MAIN 580
      CALL SMOOTH(PNORM,KCOMP)                                                  MAIN 590
29    CONTINUE                                                                  MAIN 600
C     COMPUTES THE MAX AND MIN VALUES OF PNORM                                  MAIN 610
      XX(8)=0.0                                                                 MAIN 620
      XX(9)=1.0                                                                 MAIN 630
      DO 187 KF=1,81                                                            MAIN 640
      XX(8)=AMAX1(XX(8),PNORM(KF))                                              MAIN 650
      XX(9)=AMIN1(XX(9),PNORM(KF))                                              MAIN 660
187   CONTINUE                                                                  MAIN 670
      DO 35 I=1,9                                                               MAIN 680
      PNORM(JP+I)=XX(I)                                                         MAIN 690
35    CONTINUE                                                                  MAIN 700
      WRITE(2,69) TNORM                                                         MAIN 710
69    FORMAT(9F10.6)                                                            MAIN 720
      WRITE(6,310) IB,PARM                                                      MAIN 730
310   FORMAT(3X,I3,3X,F7.2,3X,F7.2,3X,F7.2,4X,F6.3,5X,F7.2,2X,F6.2,3X,          MAIN 740
     1F6.3,3X,F7.3,3X,F7.5)                                                     MAIN 750
71    CONTINUE                                                                  MAIN 760
9999  CONTINUE                                                                  MAIN 770
      WRITE(6,747) ICOUNT                                                       MAIN 780
747   FORMAT(20X,'NO. OF BLOCKS WRITTEN= ',I3//)                                MAIN 790
      STOP                                                                      MAIN 800
      END                                                                       MAIN 810
```

```
      SUBROUTINE SMTH15(PSPEC,N,PSPED,NLAP)                                  SMTH  10
C                                                                            SMTH  20
C     ***************************************************************      SMTH  30
C                                                                            SMTH  40
C        THIS SUBROUTINE SMOOTS THE SPECTRAL ESTIMATES BY MEANS OF  A        SMTH  50
C        TRIANGULAR WINDOW WITH A SPAN OF 15                                 SMTH  60
C                                                                            SMTH  70
C     ***************************************************************      SMTH  80
C                                                                            SMTH  90
      DIMENSION PSPEC(1),PSPED(1)                                            SMTH 100
      NHALF=N/2                                                              SMTH 110
      PSPED(1)=(8.0*PSPEC(1)+14.0*PSPEC(2)+12.0*PSPEC(3)+10.0*PSPEC(4)+      SMTH 120
     18.0*PSPEC(5)+6.0*PSPEC(6)+4.0*PSPEC(7)+2.0*PSPEC(8))/64.0              SMTH 130
      IF(NLAP.EQ.0) GO TO 5                                                  SMTH 140
      NM=NHALF-1                                                             SMTH 150
      NI=2                                                                   SMTH 160
      NS=1                                                                   SMTH 170
      LJ=-2                                                                  SMTH 180
      GO TO 6                                                                SMTH 190
    5 NM=NHALF-8                                                             SMTH 200
      LJ=0                                                                   SMTH 210
      NI=8                                                                   SMTH 220
      NS=8                                                                   SMTH 230
    6 K=1                                                                    SMTH 240
      DO 1 II=NI,NM,NS                                                       SMTH 250
      J=LJ-8                                                                 SMTH 260
      K=K+1                                                                  SMTH 270
      PSPED(K)=0.00                                                          SMTH 280
      DO 1 I=1,15                                                            SMTH 290
      J=J+1                                                                  SMTH 300
      P=J                                                                    SMTH 310
      INDX=II+J                                                              SMTH 320
      IF(INDX.LT.0) INDX=-INDX                                               SMTH 330
      IF(INDX.EQ.0) INDX=1                                                   SMTH 340
      IF(INDX.GT.NHALF) INDX=INDX-NHALF                                      SMTH 350
      PSPED(K)=PSPED(K)+(8.0-ABS(P))*PSPEC(INDX)/64.0                        SMTH 360
    1 CONTINUE                                                               SMTH 370
      PSPED(K+1)=(8.0*PSPEC(NHALF)+14.0*PSPEC(NHALF-1)+12.0*PSPEC(NHALF-     SMTH 380
     12)+10.0*PSPEC(NHALF-3)+8.0*PSPEC(NHALF-4)+6.0*PSPEC(NHALF-5)+4.0*      SMTH 390
     2PSPEC(NHALF-6)+2.0*PSPEC(NHALF-7))/64.0                                SMTH 400
      I=0                                                                    SMTH 410
      DO 10 J=1,NHALF,NS                                                     SMTH 420
      I=I+1                                                                  SMTH 430
      PSPEC(J)=PSPED(I)                                                      SMTH 440
   10 CONTINUE                                                               SMTH 450
      RETURN                                                                 SMTH 460
      END                                                                    SMTH 470
```



```
      SUBROUTINE PWRP(XDATA,PSPEC,NSIZE,DELTT)                               PWRP  10
C                                                                            PWRP  20
C     ***************************************************************      PWRP  30
C                                                                            PWRP  40
C        THIS SUBROUTINE COMPUTES THE POWER SPECTRUM OF THE INPUT DATA       PWRP  50
C        CONTAINED IN THE ARRAY XDATA                                        PWRP  60
C                                                                            PWRP  70
C     ***************************************************************      PWRP  80
C                                                                            PWRP  90
      DIMENSION XDATA(1),PSPEC(1),IWK(12)                                    PWRP 100
      INTEGER IWK                                                            PWRP 110
      COMPLEX  GAMN                                                          PWRP 120
      FSIZE = NSIZE                                                          PWRP 130
      CALL FOURI(XDATA,NSIZE,-1)                                             PWRP 140
C     COMPUTE VALUE OF CORRECTION FACTOR FOR A FINITE FFT.                   PWRP 150
      CORTX = DELTT / FSIZE                                                  PWRP 160
      J = 0                                                                  PWRP 170
      DO 3 I=1,NSIZE,2                                                       PWRP 180
      J = J + 1                                                              PWRP 190
      PSPEC(J)=(XDATA(I)**2+XDATA(I+1)**2)*CORTX                             PWRP 200
    3 CONTINUE                                                               PWRP 210
      RETURN                                                                 PWRP 220
      END                                                                    PWRP 230
```

```
      SUBROUTINE TAPER1(XDATA,NREC,DFREQ)                                    TAPE  10
C                                                                            TAPE  20
C*****************************************************************************TAPE  30
C                                                                            TAPE  40
C     THIS SUBROUTINE USES A COSINE TAPER WINDOW TO TAPER XDATA              TAPE  50
C                                                                            TAPE  60
C*****************************************************************************TAPE  70
C                                                                            TAPE  80
C     XDATA -- REAL ARRAY CONTAINING THE INPUT DATA                          TAPE  90
C     NREC  -- NUMBER OF POINTS IN XDATA                                     TAPE 100
C     DFREQ -- SAMPLING FREQUENCY                                            TAPE 110
C                                                                            TAPE 120
C*****************************************************************************TAPE 130
C                                                                            TAPE 140
      DIMENSION XDATA(1),TCOS(400)                                           TAPE 150
      DATA IFLAG/0/                                                          TAPE 160
      IF(IFLAG) 10,1,10                                                      TAPE 170
    1 DELTT=1.0/DFREQ                                                        TAPE 180
      TREC=DELTT*(NREC-1)                                                    TAPE 190
      PI=3.141592654                                                         TAPE 200
      NTAPR=NREC/10                                                          TAPE 210
      CONST=PI/(0.1*TREC)                                                    TAPE 220
      J=0                                                                    TAPE 230
      DO 10 I=1,NTAPR                                                        TAPE 240
      XJ=J*DELTT                                                             TAPE 250
      J=J+1                                                                  TAPE 260
      ARG=CONST*XJ                                                           TAPE 270
      TCOS(I)=(1.0-COS(ARG))/2.0                                             TAPE 280
   10 CONTINUE                                                               TAPE 290
      IFLAG=IFLAG+1                                                          TAPE 300
      JC=NREC+1                                                              TAPE 310
      DO 20 I=1,NTAPR                                                        TAPE 320
      JC=JC-1                                                                TAPE 330
      XDATA(I)=XDATA(I)*TCOS(I)                                              TAPE 340
      XDATA(JC)=XDATA(JC)*TCOS(I)                                            TAPE 350
   20 CONTINUE                                                               TAPE 360
      RETURN                                                                 TAPE 370
      END                                                                    TAPE 380
```

```
0001   FTN,L
0002         SUBROUTINE GRAF(A,XMAX,XMIN,NUMX,NUMY,XSIZE,YSIZE,ZSIZE,
0003        1KEY,ANGLE,YPEAK,YYT,KC)
0004         DIMENSION A(1),YYT(1),DC(500)
0005         DATA IFLAG/0/
0006         IF(KEY.GT.1) GO TO 100
0007         KC=1
0008         DX=2.0*XSIZE/FLOAT(NUMX-1)
0009         XPL=2.0*XSIZE
0010         T=ANGLE*3.14159/180.0
0011         RANGE=2.0*COS(T)*ZSIZE/(XMAX-XMIN)
0012         DY=2.0*SIN(T)*YSIZE/FLOAT(NUMY-1)
0013         YPK=YPEAK*RANGE
0014         CALL PLOT(0.0,0.0,-3)
0015         XM=A(1)
0016         DO 10 I=2,NUMX
0017    10   XM=AMIN1(XM,A(I))
0018         RY=(XMIN-XM)*RANGE
0019         XP=0.0
0020         YP=(A(1)-XMIN)*RANGE + RY
0021         IF((YP-RY).GT.YPK) YP=YPK+RY
0022         DC(1)=YP
0023         CALL PLOT(XP,YP,3)
0024         DO 20 I=2,NUMX
0025         XP= XP + DX
0026         YP=(A(I)-XMIN)*RANGE + RY
0027         IF((YP-RY).GT.YPK) YP=YPK+RY
0028         DC(I)= YP
0029    20   CALL PLOT (XP,YP,2)
0030         IR=1
0031         YYT(KC)=DC(NUMX)
0032         RETURN
0033   100   IFLAG=IFLAG+1
0034         IF(IR.EQ.0) GO TO 200
0035         RY=RY+DY
0036         I=NUMX
0037         XP= 2.0*XSIZE
0038         YP=(A(NUMX)-XMIN)*RANGE + RY
0039         IF((YP-RY).GT.YPK) YP=YPK+RY
0040         IF(YP.LT.DC(NUMX)) GO TO 150
0041         CALL PLOT(XP,YP,3)
0042         DC(NUMX)=YP
0043   110   I=I-1
0044         IF(I.EQ.0) GO TO 160
0045         YO=YP
0046         YP=(A(I)-XMIN)*RANGE + RY
0047         IF((YP-RY).GT.YPK) YP=YPK+RY
0048         XP=XP-DX
0049         IF(YP.LE.DC(I)) GO TO 120
0050         DC(I)=YP
0051         CALL PLOT(XP,YP,2)
0052         GO TO 110
0053   120   B1=DC(I)
0054         B2=DC(I+1)
0055         XT=(B1-YP)*DX/(YO-YP+B1-B2)
0056         YT=(YO-YP)*XT/DX
0057         XM=XP+XT
0058         YM=YP+YT
0059         CALL PLOT(XM,YM,2)
```

```
0060   150    I=I-1
0061          IF(I.EQ.0) GO TO 160
0062          YO=YP
0063          YP=(A(I)-XMIN)*RANGE + RY
0064          IF((YP-RY).GT.YPK) YP=YPK+RY
0065          XP=XP-DX
0066          IF(YP.LE.DC(I)) GO TO 150
0067          B1=DC(I+1)
0068          B2=DC(I)
0069          XT=(B1-YO)*DX/(YP-YO+B1-B2)
0070          YT=(YP-YO)*XT/DX
0071          XM=XP+(DX-XT)
0072          YM=YO+YT
0073          DC(I)=YP
0074          CALL PLOT(XM,YM,3)
0075          CALL PLOT(XP,YP,2)
0076          GO TO 110
0077   160    IR=0
0078          KC=KC+1
0079          YYT(KC)=DC(NUMX)
0080          RETURN
0081   200    IR=1
0082          XP=0.0
0083          RY=RY+DY
0084          I=1
0085          YP=(A(1)-XMIN)*RANGE+RY
0086          IF((YP-RY).GT.YPK) YP=YPK+RY
0087          IF (YP.LT.DC(1)) GO TO 250
0088          DC(1)=YP
0089          CALL PLOT (0.0,YP,3)
0090   210    I=I+1
0091          IF (I.GT.NUMX) GO TO 260
0092          YO=YP
0093          YP=(A(I)-XMIN)*RANGE+RY
0094          IF((YP-RY).GT.YPK) YP=YPK+RY
0095          XP=XP+DX
0096          IF (YP.LT.DC(I)) GO TO 220
0097          DC(I)=YP
0098          CALL PLOT(XP,YP,2)
0099          GO TO 210
0100   220    B1=DC(I)
0101          B2=DC(I-1)
0102          XT=(B1-YP)*DX/(YO-YP+B1-B2)
0103          YT=(YO-YP)*XT/DX
0104          XM=XP-XT
0105          YM=YP+YT
0106          CALL PLOT (XM,YM,2)
0107   250    I=I+1
0108          IF (I.GT.NUMX) GO TO 260
0109          YO=YP
0110          YP=(A(I)-XMIN)*RANGE+RY
0111          IF((YP-RY).GT.YPK) YP=YPK+RY
0112          XP=XP+DX
0113          IF (YP.LT.DC(I)) GO TO 250
0114          B1=DC(I-1)
0115          B2=DC(I)
0116          XT=(B1-YO)*DX/(YP-YO+B1-B2)
0117          YT=(YP-YO)*XT/DX
0118          XM=XP-DX+XT
0119          YM=YO+YT

0120          CALL PLOT (XM,YM,3)
0121          CALL PLOT (XP,YP,2)
0122          GO TO 210
0123   260    IR=1
0124          KC=KC+1
0125          YYT(KC)=DC(NUMX)
0126          RETURN
0127          END
0128          END$
**** LIST END ****
```

```
0001  FTN,L
0002        PROGRAM ARA
0003        DIMENSION Y(90),YY(250),IARTF(20)
C004        IFLAG=0
0005        WRITE(6,220)
0006  220   FORMAT("ENTER # OF FILES TO BE SKIPPED IN I2 FORMAT")
C007        READ(1,120) ISKIP
0008  120   FORMAT(I2)
0009        IF (ISKIP.EQ.0) GO TO 7
0010        DO 7 L=1,ISKIP
0011        CALL EXEC(3,001310B)
0012  7     CONTINUE
0013        CALL PLTLU(10)
0014        WRITE(6,210)
0015  210   FORMAT("ENTER NUMY,NUMX,NSKIP IN 2I3 AND I1 FORMAT")
0016        READ(1,110) NUMY,NUMX,NSKIP
0017  110   FORMAT(2I3,I1)
0018        WRITE(6,400)
0019  400    FORMAT("ENTER YMAX,YMIN,YPEAK,CAL IN F6.0 FORMAT")
0020        READ(1,180) YMAX,YMIN,YPEAK,CAL
0021  180   FORMAT(4F6.0)
0022        WRITE(6,240)
0023  240   FORMAT("ENTER # OF EPOCHS W/ARTIFACTS AND THEIR NUMBER IN 21I3")
0024        READ(1,140)  IT,(IARTF(I),I=1,IT)
0025  140   FORMAT(21I3)
0026        WRITE(6,140) IT,(IARTF(I),I=1,IT)
0027        WRITE(6,201)
0028  201   FORMAT("ENTER TS & DT FOR LABELING THE TIME AXIS IN F4.0")
0029        READ(1,101) TS,DT
0030  101   FORMAT(2F4.0)
0031        WRITE(6,200)
0032  200   FORMAT("ENTER XSIZE,YSIZE,ZSIZE,ANG IN F4.0 FORMAT")
0033        READ(1,100) XSIZE,YSIZE,ZSIZE,ANG
0034  100   FORMAT(4F4.0)
0035        WRITE(6,230) NUMY,NUMX,CAL,YMAX,YMIN,XSIZE,YSIZE,
0036       1ZSIZE,ANG
C037  230   FORMAT(2I3,F6.2,2F10.6,3F6.2)
0038        GO TO (30,31,32),NSKIP+1
0039  30    WRITE(6,300)
C040  300   FORMAT("PLOT ALL EPOCHS")
0041        NUMYT=NUMY
0042        GO TO 40
0043  31    WRITE(6,310)
0044  310   FORMAT("PLOT ONLY ODD # EPOCHS")
0045        GO TO 39
0046  32    WRITE(6,320)
0047  320   FORMAT("PLOT ONLY EVEN # EPOCHS")
0048  39    NUMYT=2*NUMY
0049  40    PSPCMX=YMAX
0050        YMAX=SQRT(YMAX)
0051        YMIN=SQRT(YMIN)
0052        YPK=SQRT(YPEAK)
0053        FNUMY=NUMY-IT
0054        YSIZE=YSIZE*FNUMY/200.0
0055        KP=0
0056        DO 11 K=1,NUMYT
0057        CALL CVRT(Y)
0058        GO TO (18,19,20),NSKIP+1
0059  20    IF(IFLAG.NE.0) GO TO 12
```

```
0060          KT=(K/2)*2
0061          KP=K-1
0062          IF(KT-K) 11,12,11
0063    19    IF(IFLAG.NE.0) GO TO 12
0064          KT=(K/2)*2+1
0065          KP=K
0066          IF(KT-K)11,12,11
0067    18    KP=KP+1
0068    12    DO 24 M=1,IT
0069          IF(K-IARTF(M)) 24,25,24
0070    25    IFLAG=IFLAG+1
0071          IF(K.EQ.1) KP=0
0072          WRITE(6,561) K
0073    561   FORMAT(10X,I3)
0074          IF(IFLAG-2) 11,26,11
0075    26    IFLAG=0
0076          GO TO 11
0077    24    CONTINUE
0078          IFLAG=0
0079    13    DO 10 JK=1,NUMX
0080          Y(JK)=SQRT(Y(JK)*CAL)
0081    10    CONTINUE
0082          CALL GRAF(Y,YMAX,YMIN,NUMX,NUMY,XSIZE,YSIZE,ZSIZE,KP,ANG,
0083         1YPEAK,YY,KC)
0084    11    CONTINUE
0085          CALL EIXO(XSIZE)
0086          CALL TIME(YY,KC,XSIZE,TS,DT)
0087          CALL BORDA(XSIZE,YSIZE,ANG)
0088          STOP
0089          END
0090          END$
**** LIST END ****
```

```
0001    FTN,L
0002          SUBROUTINE EIXO(XSIZE)
0003          DIMENSION ITX(10)
0004          DATA ITX/2HFR,2HEQ,2HUE,2HNC,2HY ,2HIN,2H H,2HER,2HTZ/
0005          DATA IHZ/2HHZ/
0006          X=2.*XSIZE
0007          DX=X/8.0
0008          YX=0.1
0009          XP=0.0
0010          CALL PLOT(0.0,-0.1,-3)
0011          CALL PLOT(XP,-YX,3)
0012          CALL PLOT(XP,0.0,2)
0013          DO 10 I=1,8
0014          XP=XP+DX
0015          CALL PLOT(XP,0.0,2)
0016          CALL PLOT(XP,-YX,3)
0017          CALL PLOT(XP,0.0,2)
0018    10    CONTINUE
0019          CALL PLOT(0.0,0.0,3)
0020          HGT=0.14
0021          YP=0.3+HGT/2.0
0022          XP=.02-HGT/2.0
0023          FN=0.0
0024          CALL NUMB(XP,-YP,HGT,FPN,0.0,-1)
0025          XP=XP+DX
0026          FPN=5.0
0027          CALL NUMB(XP,-YP,HGT,FPN,0.0,-1)
0028          XP=DX-HGT
0029          DO 20 I=2,8
0030          XP=XP+DX
0031          FPN=FLOAT(I*5)
0032          CALL NUMB(XP,-YP,HGT,FPN,0.0,-1)
0033    20    CONTINUE
0034          XS=X/2.0 -9.0*HGT
0035          YS=0.3 + 2.5*HGT
0036          CALL SYMB(XS,-YS,HGT,ITX,0.0,18)
0037          RETURN
0038          END
0039          END$
**** LIST END ****
```

```
0001   FTN,L
0002         SUBROUTINE TIME(YY,KC,XSIZE,TS,DT)
0003         DIMENSION YY(1),ITM(4),ITN(4)
0004         DATA ITM/2HTI,2HME,2H I,2HN /
0005         DATA ITN/2HMI,2HNU,2HTE,2HS /
0006         X=2.0 * XSIZE + 0.2
0007         TT=DT/2.5
0008         XY=0.1
0009         IT=TT
0010         KI=KC/IT
0011         CALL PLOT(X,0.1,-3)
0012         CALL PLOT(XY,YY(1),3)
0013         CALL PLOT(0.0,YY(1),2)
0014         DO 10 J=1,KI
0015         I=IT*J + 1
0016         CALL PLOT(0.0,YY(I),2)
0017         CALL PLOT(XY,YY(I),3)
0018         CALL PLOT(0.0,YY(I),2)
0019   10    CONTINUE
0020         CALL PLOT(0.0,YY(KC),2)
0021         CALL PLOT(XY,YY(KC),3)
0022         CALL PLOT(0.0,YY(KC),2)
0023         CALL PLOT(0.0,0.0,3)
0024         HGT=0.14
0025         XP=0.2 + HGT/2.0
0026         YP=0.02 - HGT/2.0
0027         FN=TS
0028         YR=YY(1) + YP
0029         CALL NUMB(XP,YR,HGT,FN,0.0,-1)
0030         KI1=KI - 1
0031         DO 20 J=1,KI1
0032         I=IT*J + 1
0033         YR=YY(I) + YP
0034         FN=FN + DT
0035         CALL NUMB(XP,YR,HGT,FN,0.0,-1)
0036   20    CONTINUE
0037         I=IT*KI+1
0038         FN=FN + DT
0039         IF((KC-I).LT.10) GO TO 21
0040         YR=YY(I) + YP
0041         CALL NUMB(XP,YR,HGT,FN,0.0,-1)
0042   21    FN=(KC-1-IT*KI)*2.5 + FN
0043         YR=YY(KC) + YP
0044         CALL NUMB(XP,YR,HGT,FN,0.0,-1)
0045         XS=2.0*HGT
0046         YS=YY(KC) + 1.5*HGT + 0.5
0047         CALL SYMB(-XS,YS,HGT,ITM,0.0,7)
0048         YS=YS - 1.5*HGT
0049         CALL SYMB(-XS,YS,HGT,ITN,0.0,7)
0050         CALL PLOT(-X,0.0,-3)
0051         RETURN
0052         END
0053         END$
**** LIST END ****
```

```
0001   FTN,L
0002         SUBROUTINE BORDA(XSIZE,YSIZE,ANG)
0003         ANG=ANG*3.1415/180.0
0004         YT=YSIZE*COS(ANG)
0005         XR=2.0*(XSIZE+0.7)
0006         XL=-2.0*0.3
0007         YUP=2.0*(YT+1.0)
0008         YDW=-2.0*0.5
0009         CALL PLOT(XR,YDW,3)
0010         CALL PLOT(XR,YUP,2)
0011         CALL PLOT(XL,YUP,2)
0012         CALL PLOT(XL,YDW,2)
0013         CALL PLOT(XR,YDW,2)
0014         YNXT=YUP+2.0
0015         CALL PLOT(0.0,YNXT,3)
0016         CALL PLOT(0.0,YNXT,2)
0017         RETURN
0018         END
0019         END$
**** LIST END ****
```

```
0001   ASMB
0002           NAM    XPAND,7       FORTRAN SUBROUTINE
0003           ENT    XPAND         CALLING SEQUENCE -
0004   *                                 CALL XPAND(I,I1,I2)
0005   *                            EXPANDS INTEGER WORD I INTO
0006   *                            TWO INTEGER WORDS I1 AND I2,
0007   *                            BITS 15-8 OF I TO 7-0 OF I1,
0008   *                                 7-0 OF I TO 7-0 OF I2,
0009   *                            ALL OTHER BITS CLEARED.
0010   XPAND NOP
0011           LDA    XPAND,I       STORE RETURN ADDRESS
0012           STA    RTN                        IN RTN.
0013           ISZ    XPAND         GET I
0014           LDA    XPAND          GET WORD TO BE EXPANDED
0015           LDA    A,I
0016           RAL,CLE,SLA,ERA         CHASE THOSE LITTLE BITS
0017           JMP    *-2
0018           LDA    0,I
0019           STA    I
0020           ALF,ALF               BITS 15-8 MOVE TO 7-0
0021           AND    =B000377          CLEAR BITS 15-8
0022           ISZ    XPAND             GET ADDRESS OF
0023           LDB    XPAND                  THE SECOND ARGUMENT
0024           LDB    B,I
0025           RBL,CLE,SLB,ERB                CHASE THOSE LITTLE BITS
0026           JMP    *-2
0027           STA    1,I               STORE I2
0028           LDA    I             BITS 7-0 MOVE TO 7-0
0029           AND    =B000377          CLEAR BITS 15-8
0030           ISZ    XPAND             GET ADDRESS OF
0031           LDB    XPAND                  THE SECOND ARGUMENT
0032           LDB    B,I
0033           RBL,CLE,SLB,ERB                CHASE THOSE LITTLE BITS
0034           JMP    *-2
0035           STA    1,I               STORE I1
0036           JMP    RTN,I         RETURN
0037   *
0038   RTN    BSS    1
0039   I      BSS    1
0040   A      EQU    0
0041   B      EQU    1
0042   *                          END OF XPAND
0043           END
**** LIST END ****
```

```
0001   FTN,L
0002           SUBROUTINE CVRT(Y)
0003           INTEGER EBASC
0004           DIMENSION INPUT(45),Y(90)
0005           DO 20 JJ=1,10
0006           READ(8) INPUT
0007           DO 10 I=1,45
0008           CALL XPAND(INPUT(I),K,J)
0009           K=EBASC(K)
0010           J= EBASC(J)
0011           INPUT(I)=256*K
0012           INPUT(I)=IOR(INPUT(I),J)
0013   10      CONTINUE
0014           KL=(JJ-1)*9
0015           CALL CODE
0016           READ(INPUT,100) (Y(KL+I),I=1,9)
0017   100      FORMAT(9F10.3)
0018   20      CONTINUE
0019           RETURN
0020           END
0021           END$
**** LIST END ****
```

```
C     ********************************************************************* MAIN  10
C     *                                                                   * MAIN  20
C     *                          PROGRAM  FEATURE                         * MAIN  30
C     *                                                                   * MAIN  40
C     ********************************************************************* MAIN  50
C                                                                           MAIN  60
C     THIS PROGRAM DIVIDES THE EEG POWER SPECTRUM IN SEVEN FREQUENCY        MAIN  70
C                                                                           MAIN  80
C     THE FREQUENCY BANDS ARE DEFINED AS FOLLOWS,                           MAIN  90
C                                                                           MAIN 100
C        DELTA --  0.0 -  3.5  HZ                                           MAIN 110
C        THETA --  4.0 -  7.5  HZ                                           MAIN 120
C        ALPHA --  8.0 - 11.5  HZ                                           MAIN 130
C        SIGMA -- 11.5 - 15.5  HZ                                           MAIN 140
C        BETA1 -- 16.0 - 20.5  HZ                                           MAIN 150
C        BETA2 -- 21.0 - 29.5  HZ                                           MAIN 160
C        FASTF -- 30.0 - 40.0  HZ                                           MAIN 170
C                                                                           MAIN 180
      DIMENSION XSQR(400),EXKURT(400),SKEW(400),YSQR(400,1),                MAIN 190
     1YSKEW(400,1),YEXKUR(400,1)                                            MAIN 200
      EQUIVALENCE (YSQR(1,1),XSQR(1)),(YSKEW(1,1),SKEW(1)),(YEXKUR(1,1),MAIN 210
     1EXKURT(1))                                                            MAIN 220
      DIMENSION YQ(6),YV(6),YK(6)                                           MAIN 230
      DIMENSION DELTAP(6),THETAP(6),ALPHAP(6),ALPHOP(6),SIGMAP(6),          MAIN 240
     1BETA1P(6),BETA2P(6),FASTFP(6)                                         MAIN 250
      DIMENSION YDELTA(6),YTHETA(6),YALPHA(6),YSIGMA(6),YBETA1(6),          MAIN 260
     1 YBETA2(6),YFASTF(6),YALPHO(6),YMF(6)                                 MAIN 270
      DIMENSION DELTAF(800),THETAF(800),ALPHAF(800),SIGMAF(800),            MAIN 280
     1BETA1F(800),BETA2F(800),FASTFF(800),ALPHOF(800)                       MAIN 290
      DIMENSION Y(400,1),YW(400,1),X(400),DD(400,1),TT(400,1),AL(400,1),MAIN 300
     1SI(400,1),B1(400,1),B2(400,1),FF(400,1),AO(400,1),FM(400,1)           MAIN 310
      DIMENSION DELTA(400),THETA(400),ALPHA(400),SIGMA(400),BETA1(400),     MAIN 320
     1 BETA2(400),FASTF(400),PNORM(90) ,IARTF(60),ALPHO(400),FMEAN(400)     MAIN 330
      EQUIVALENCE (DD(1,1),DELTA(1)),(TT(1,1),THETA(1)),(AL(1,1),           MAIN 340
     1ALPHA(1)),(SI(1,1),SIGMA(1)),(B1(1,1),BETA1(1)),(B2(1,1),             MAIN 350
     28ETA2(1)),(FF(1,1),FASTF(1)),(AO(1,1),ALPHO (1)),                     MAIN 360
     3(FM(1,1),FMEAN(1))                                                    MAIN 370
      COMPLEX FRT(8)                                                        MAIN 380
      DIMENSION LTA(6),LB1A(6),LTS(6),LSD(6),LB2A(6)                        MAIN 390
      DIMENSION LIST1(8),LIST2(8)                                           MAIN 400
      INTEGER XUNIT1(6),YUNIT1(6),XUNIT2(6),YUNIT2(6),YUNIT3(6)             MAIN 410
      DATA YMF/'MEAN',' FRE','Q  C','OEFF','   IN',' HZ '/                 MAIN 420
      DATA YQ /'CHI ','SQUA','RE C','OEFF','ICIE','NT  '/                   MAIN 430
      DATA YV/2*'    ','SKEW','NESS',2*'    '/                             MAIN 440
      DATA YK /'    ','EXCE','SS O','F KU','RTOS','IS  '/                   MAIN 450
      DATA YUNIT3/'FREQ','UENC','Y VA','RIAT','ION ',' '/                   MAIN 460
      DATA YSIGMA /'PERC','ENTA','GE O','F PO','WER ',' '/                  MAIN 470
      DATA DELTAP/'DELT','A   ','PEAK','S   ',2*'    '/                    MAIN 480
      DATA YTHETA/'PERC','ENTA','GE O','F TH','ETA ',' '/                   MAIN 490
      DATA THETAP/'THET','A   ','PEAK','S   ',2*'    '/                    MAIN 500
      DATA YALPHA/'PERC','ENTA','GE O','F AL','PHA ',' '/                   MAIN 510
      DATA ALPHAP/'ALPH','A   ','PEAK','S   ',2*'    '/                    MAIN 520
      DATA YALPHO/'PERC','ENTA','GE O','F AL','PHOI','D  '/                 MAIN 530
      DATA ALPHOP/'ALPH','OID ','PEAK','S   ',2*'    '/                    MAIN 540
      DATA YDELTA /'PERC','ENTA','GE O','F PO','WER ',' '/                  MAIN 550
      DATA SIGMAP/'SIGM','A   ','PEAK','S   ',2*'    '/                    MAIN 560
      DATA YBETA1/'PERC','ENTA','GE O','F BE','TA1 ',' '/                   MAIN 570
      DATA BETA1P/'BETA','1   ','PEAK','S   ',2*'    '/                    MAIN 580
      DATA YBETA2/'PERC','ENTA','GE O','F BE','TA2 ',' '/                   MAIN 590
      DATA BETA2P/'BETA','2   ','PEAK','S   ',2*'    '/                    MAIN 600
      DATA YFASTF/'PERC','ENTA','GE O','F FA','ST  ',' '/                   MAIN 610
      DATA FASTFP/'FAST','FREQ',' PEA','KS  ',2*'    '/                    MAIN 620
      DATA XUNIT2/'    ','TIME',' IN ','MINU','TES ',' '/                   MAIN 630
      DATA YUNIT2/'PERC','ENTA','GE O','F PO','WER ',' '/                   MAIN 640
      DATA ICHAR/'*'/                                                       MAIN 650
C                                                                           MAIN 660
C     ENTER NSKIP. IF NSKIP=0 ALL EPOCHS ARE PROCESSED,NSKIP=1 ONLY THE     MAIN 670
```

```
 68:  C      ODDS ARE PROCESSED AND NSKIP=2 THE EVEN ONES ARE PROCESSED          MAIN 680
 69:  C                                                                         MAIN 690
 70:         DELFF=0.5                                                          MAIN 700
 71:         NC=40./DELFF+1                                                     MAIN 710
 72:         CHISQT=66.3                                                        MAIN 720
 73:         CMX=200.0                                                          MAIN 730
 74:         CMN=40.0                                                           MAIN 740
 75:         EMN=-1.0                                                           MAIN 750
 76:         EMX=3.0                                                            MAIN 760
 77:         SMN=-0.5                                                           MAIN 770
 78:         SMX=0.5                                                            MAIN 780
 79:         CEM=100.0                                                          MAIN 790
 80:         FMX=15.0                                                           MAIN 800
 81:         PHT=0.4                                                            MAIN 810
 82:         PLT=0.4                                                            MAIN 820
 83:         PHT=0.15                                                           MAIN 830
 84:         PLT=0.15                                                           MAIN 840
 85:         DELTAH=3.5                                                         MAIN 850
 86:         THETAH=7.5                                                         MAIN 860
 87:         ALPHOL=6.5                                                         MAIN 870
 88:         ALPHAH=11.5                                                        MAIN 880
 89:         SIGMAH=15.5                                                        MAIN 890
 90:         BETA1H=20.5                                                        MAIN 900
 91:         BETA2H=29.5                                                        MAIN 910
 92:         K=81                                                               MAIN 920
 93:         ITF=(DELTAH+0.5)/DELFF                                             MAIN 930
 94:         IAF=(THETAH+0.5)/DELFF                                             MAIN 940
 95:         ISF=(ALPHAH+0.5)/DELFF                                             MAIN 950
 96:         IOF=(ALPHOL+0.5)/DELFF                                             MAIN 960
 97:         IB1F=(SIGMAH+0.5)/DELFF                                            MAIN 970
 98:         IB2F=(BETA1H+0.5)/DELFF                                            MAIN 980
 99:         IFTF=(BETA2H+0.5)/DELFF                                            MAIN 990
100:         NF=10./DELFF+1                                                     MAIN1000
101:         READ(5,100) NSKIP                                                  MAIN1010
102:  100    FORMAT(I1)                                                         MAIN1020
103:         ISKIP=NSKIP+1                                                      MAIN1030
104:  C      IT IS THE # OF EPOCHS WITH ARTIFACTS AND IARTF IS THE ARRAY         MAIN1040
105:  C      CONTAINING THEIR NUMBERS                                           MAIN1050
106:         READ(5,110) ITA,(IARTF(I),I=1,ITA)                                 MAIN1060
107:  110    FORMAT(20I3)                                                       MAIN1070
108:         WRITE(6,510) ITA,(IARTF(I),I=1,ITA)                                MAIN1080
109:  510    FORMAT(50X,I4)                                                     MAIN1090
110:  C      TO READ THE STARING AND ENDING TIMES FOR THE PLOTS                 MAIN1100
111:         READ(5,111) XST,XTIME                                              MAIN1110
112:  111    FORMAT(2F10.0)                                                     MAIN1120
113:  C      TO READ THE EPOCH NO. WHERE THE PLOT IS TO BE PARTITIONED           MAIN1130
114:         ISS=1                                                              MAIN1140
115:         READ(5,112) ITT                                                    MAIN1150
116:  112    FORMAT(I3)                                                         MAIN1160
117:         DO 1000 JJ=1,2                                                     MAIN1170
118:         DO 300 J=1,800                                                     MAIN1180
119:         DELTAF(J)=0.0                                                      MAIN1190
120:         THETAF(J)=0.0                                                      MAIN1200
121:         ALPHAF(J)=0.0                                                      MAIN1210
122:         ALPHOF(J)=0.0                                                      MAIN1220
123:         SIGMAF(J)=0.0                                                      MAIN1230
124:         BETA1F(J)=0.0                                                      MAIN1240
125:         BETA2F(J)=0.0                                                      MAIN1250
126:         FASTFF(J)=0.0                                                      MAIN1260
127:  300    CONTINUE                                                           MAIN1270
128:         GO TO (30,31,32),ISKIP                                             MAIN1280
129:  30     WRITE(6,200)                                                       MAIN1290
130:  200    FORMAT(20X,'ALL EPOCHS ARE BEING PROCESSED'//)                     MAIN1300
131:         DELT=2.5                                                           MAIN1310
132:         GO TO 33                                                           MAIN1320
133:  31     WRITE(6,210)                                                       MAIN1330
134:  210    FORMAT(20X,'ONLY ODD EPOCHS ARE BEING PROCESSED'//)                MAIN1340
135:         DELT=5.0                                                           MAIN1350
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136:          GO TO 33                                                          MAIN1360
137:    32    WRITE(6,220)                                                      MAIN1370
138:    220   FORMAT(20X,'ONLY EVEN EPOCHS ARE BEING PROCESSED'//)              MAIN1380
139:          DELT=5.0                                                          MAIN1390
140:    33    IC=0                                                              MAIN1400
141:          IC1=0                                                             MAIN1410
142:          IC2=-1                                                            MAIN1420
143:          DO 71 IB=ISS,ITT                                                  MAIN1430
144:          READ(1,120,END=99) PNORM                                          MAIN1440
145:    120   FORMAT(9F10.6)                                                    MAIN1450
146:          GO TO (12,19,20),ISKIP                                            MAIN1460
147:    20    IF(IFLAG) 12,21,12                                                MAIN1470
148:    21    KT=(IB/2)*2                                                       MAIN1480
149:          IF(KT-IB) 71,12,71                                                MAIN1490
150:    19    IF(IFLAG) 12,22,12                                                MAIN1500
151:    22    KT=(IB/2)*2+1                                                     MAIN1510
152:          IF(KT-IB) 71,12,71                                                MAIN1520
153:    12    DO 24 M=1,ITA                                                     MAIN1530
154:          IF(IB-IARTF(M)) 24,25,24                                          MAIN1540
155:    25    IFLAG=IFLAG+1                                                     MAIN1550
156:          WRITE(6,651) IB                                                   MAIN1560
157:    651   FORMAT(10X,I3)                                                    MAIN1570
158:          IF(IFLAG-2) 71,26,71                                              MAIN1580
159:    26    IFLAG=0                                                           MAIN1590
160:          GO TO 71                                                          MAIN1600
161:    24    CONTINUE                                                          MAIN1610
162:          IFLAG=0                                                           MAIN1620
163:          IC=IC+1                                                           MAIN1630
164:          DELTA(IC)=0.0                                                     MAIN1640
165:          THETA(IC)=0.0                                                     MAIN1650
166:          ALPHA(IC)=0.0                                                     MAIN1660
167:          ALPHO(IC)=0.0                                                     MAIN1670
168:          SIGMA(IC)=0.0                                                     MAIN1680
169:          BETA1(IC)=0.0                                                     MAIN1690
170:          BETA2(IC)=0.0                                                     MAIN1700
171:          FASTF(IC)=0.0                                                     MAIN1710
172:          TPOWR=0.0                                                         MAIN1720
173:    C     COMPUTE THE TOTAL POWER                                           MAIN1730
174:          DO 1 J=1,NC                                                       MAIN1740
175:          TPOWR=TPOWR+PNORM(J)                                              MAIN1750
176:    1     CONTINUE                                                          MAIN1760
177:          SKEW(IC)=PNORM(85)                                                MAIN1770
178:          EXKURT(IC)=PNORM(86)-3.0                                          MAIN1780
179:          XSQR(IC)=PNORM(87)                                                MAIN1790
180:          ID=1                                                              MAIN1800
181:          IT=ITF                                                            MAIN1810
182:          IA=IAF                                                            MAIN1820
183:          IO=IOF                                                            MAIN1830
184:          IS=ISF                                                            MAIN1840
185:          IB1=IB1F                                                          MAIN1850
186:          IB2=IB2F                                                          MAIN1860
187:          IFT=IFTF                                                          MAIN1870
188:          IC1=IC1+2                                                         MAIN1880
189:          IC2=IC2+2                                                         MAIN1890
190:          DO 2 I=1,NF                                                       MAIN1900
191:          ID=ID+1                                                           MAIN1910
192:          IF(ID-ITF) 3,3,4                                                  MAIN1920
193:    3     DELTA(IC)=DELTA(IC)+PNORM(ID)                                     MAIN1930
194:          IF(DELTAF(IC1) -PNORM(ID)) 50,4,4                                 MAIN1940
195:    50    DELTAF(IC1) =PNORM(ID)                                            MAIN1950
196:          DELTAF(IC2)=(ID-1)*DELFF                                          MAIN1960
197:    4     IT=IT+1                                                           MAIN1970
198:          IF(IT-IAF) 5,5,6                                                  MAIN1980
199:    5     THETA(IC)=THETA(IC)+PNORM(IT)                                     MAIN1990
200:          IF(THETAF(IC1) -PNORM(IT)) 51,6,6                                 MAIN2000
201:    51    THETAF(IC1) =PNORM(IT)                                            MAIN2010
202:          THETAF(IC2)=(IT-1)*DELFF                                          MAIN2020
203:    6     IO=IO+1                                                           MAIN2030
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204:          IF(IO-ISF) 60,60,66                                                    MAIN2040
205:    60    ALPHO(IC)=ALPHO(IC)+PNORM(IO)                                          MAIN2050
206:          IF(ALPHOF(IC1)-PNORM(IO)) 61,66,66                                     MAIN2060
207:    61    ALPHOF(IC1)=PNORM(IO)                                                  MAIN2070
208:          ALPHOF(IC2)=(IO-1)*DELFF                                               MAIN2080
209:    66    IA=IA+1                                                                MAIN2090
210:          IF(IA-ISF) 7,7,8                                                       MAIN2100
211:    7     ALPHA(IC)=ALPHA(IC)+PNORM(IA)                                          MAIN2110
212:          IF(ALPHAF(IC1) -PNORM(IA)) 52,8,8                                      MAIN2120
213:    52    ALPHAF(IC1)=PNORM(IA)                                                  MAIN2130
214:          ALPHAF(IC2)=(IA-1)*DELFF                                               MAIN2140
215:    8     IS=IS+1                                                                MAIN2150
216:          IF(IS-IB1F) 9,9,10                                                     MAIN2160
217:    9     SIGMA(IC)=SIGMA(IC)+PNORM(IS)                                          MAIN2170
218:          IF(SIGMAF(IC1)-PNORM(IS))  53,10,10                                    MAIN2180
219:    53    SIGMAF(IC1)=PNORM(IS)                                                  MAIN2190
220:          SIGMAF(IC2)=(IS-1)*DELFF                                               MAIN2200
221:    10    IB1=IB1+1                                                              MAIN2210
222:          IF(IB1-IB2F) 40,40,41                                                  MAIN2220
223:    40    BETA1(IC)=BETA1(IC)+PNORM(IB1)                                         MAIN2230
224:          IF(BETA1F(IC1)-PNORM(IB1))54,41,41                                     MAIN2240
225:    54    BETA1F(IC1)=PNORM(IB1)                                                 MAIN2250
226:          BETA1F(IC2)=(IB1-1)*DELFF                                              MAIN2260
227:    41    IB2=IB2+1                                                              MAIN2270
228:          IF(IB2-IFTF) 42,43,43                                                  MAIN2280
229:    42    BETA2(IC)=BETA2(IC)+PNORM(IB2)                                         MAIN2290
230:          IF(BETA2F(IC1)-PNORM(IB2))55,43,43                                     MAIN2300
231:    55    BETA2F(IC1)=PNORM(IB2)                                                 MAIN2310
232:          BETA2F(IC2)=(IB2-1)*DELFF                                              MAIN2320
233:    43    IFT=IFT+1                                                              MAIN2330
234:          IF(IFT-NC) 44,44,2                                                     MAIN2340
235:    44    FASTF(IC)=FASTF(IC)+PNORM(IFT)                                         MAIN2350
236:          IF(FASTFF(IC1)-PNORM(IFT))56,2,2                                       MAIN2360
237:    56    FASTFF(IC1)=PNORM(IFT)                                                 MAIN2370
238:          FASTFF(IC2)=(IFT-1)*DELFF                                              MAIN2380
239:    2     CONTINUE                                                               MAIN2390
240:          CALL PIKCK(PNORM,DELTAF,DELFF,0   ,ITF,IC2,PLT,PHT,FRT(1))             MAIN2400
241:          CALL PIKCK(PNORM,THETAF,DELFF,ITF,IAF,IC2,PLT,PHT,FRT(2))              MAIN2410
242:          CALL PIKCK(PNORM,ALPHOF,DELFF,IOF,ISF,IC2,PLT,PHT,FRT(3))              MAIN2420
243:          CALL PIKCK(PNORM,ALPHAF,DELFF,IAF,ISF,IC2,PLT,PHT,FRT(4))              MAIN2430
244:          CALL PIKCK(PNORM,SIGMAF,DELFF,ISF,IB1F,IC2,PLT,PHT,FRT(5))             MAIN2440
245:          CALL PIKCK(PNORM,BETA1F,DELFF,IB1F,IB2F,IC2,PLT,PHT,FRT(6))            MAIN2450
246:          CALL PIKCK(PNORM,BETA2F,DELFF,IB2F,IFTF,IC2,PLT,PHT,FRT(7))            MAIN2460
247:          CALL PIKCK(PNORM,FASTFF,DELFF,IFTF,NC,IC2,PLT,PHT,FRT(8))              MAIN2470
248:    C                                                                            MAIN2480
249:    C     COMPUTE THE PERCENTAGE OF POWER IN EACH BAND                           MAIN2490
250:    C                                                                            MAIN2500
251:          DELTA(IC)= DELTA(IC)/TPOWR*100.0                                       MAIN2510
252:          THETA(IC)=THETA(IC)/TPOWR *100.0                                       MAIN2520
253:          ALPHA(IC)=ALPHA(IC)/TPOWR *100.0                                       MAIN2530
254:          ALPHO(IC)=ALPHO(IC)/TPOWR *100.0                                       MAIN2540
255:          SIGMA(IC)=SIGMA(IC)/TPOWR*100.0                                        MAIN2550
256:          BETA1(IC)=BETA1(IC)/TPOWR *100.0                                       MAIN2560
257:          BETA2(IC)=BETA2(IC)/TPOWR *100.0                                       MAIN2570
258:          FASTF(IC)=FASTF(IC)/TPOWR *100.0                                       MAIN2580
259:          CALL FMED(FRT,FMEAN,8,IC)                                              MAIN2590
260:    71    CONTINUE                                                               MAIN2600
261:    99    CONTINUE                                                               MAIN2610
262:          X(1)=XST                                                               MAIN2620
263:          DO 74 J=2,IC                                                           MAIN2630
264:          X(J)=X(J-1)+DELT                                                       MAIN2640
265:    74    CONTINUE                                                               MAIN2650
266:          IF(XTIME.EQ.0.0) XTIME=X(IC)                                           MAIN2660
267:          IC2=2*IC                                                               MAIN2670
268:          RJ=0.0                                                                 MAIN2680
269:          DO 80 J=1,IC                                                           MAIN2690
270:          IF(XSQR(J)-CHISQT) 80,80,81                                            MAIN2700
271:    81    RJ=RJ+1.0                                                              MAIN2710
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272:  80     CONTINUE                                                          MAIN2720
273:         RJ=(RJ/FLOAT(IC))*100.0                                           MAIN2730
274:         DO 75 J=1,2                                                       MAIN2740
275:         CALL SMOOTH(DELTA,IC)                                             MAIN2750
276:         CALL SMOOTH(THETA,IC)                                             MAIN2760
277:         CALL SMOOTH(ALPHA,IC)                                             MAIN2770
278:         CALL SMOOTH(ALPHO,IC)                                             MAIN2780
279:         CALL SMOOTH(SIGMA,IC)                                             MAIN2790
280:         CALL SMOOTH(BETA1,IC)                                             MAIN2800
281:         CALL SMOOTH(BETA2,IC)                                             MAIN2810
282:         CALL SMOOTH(FASTF,IC)                                             MAIN2820
283:         CALL SMOOTH(FMEAN,IC)                                             MAIN2830
284:         CALL SMOOTH(XSQR,IC)                                              MAIN2840
285:         CALL SMOOTH(EXKURT,IC)                                            MAIN2850
286:         CALL SMOOTH(SKEW,IC)                                              MAIN2860
287:  75     CONTINUE                                                          MAIN2870
288:         YMAX=0.0                                                          MAIN2880
289:         YMIN=10.0                                                         MAIN2890
290:         CALL NERKA(DELTAF,IC,YMAX,YMIN)                                   MAIN2900
291:         CALL NERKA(THETAF,IC,YMAX,YMIN)                                   MAIN2910
292:         CALL NERKA(ALPHAF,IC,YMAX,YMIN)                                   MAIN2920
293:         CALL NERKA(ALPHOF,IC,YMAX,YMIN)                                   MAIN2930
294:         CALL NERKA(SIGMAF,IC,YMAX,YMIN)                                   MAIN2940
295:         CALL NERKA(BETA1F,IC,YMAX,YMIN)                                   MAIN2950
296:         CALL NERKA(BETA2F,IC,YMAX,YMIN)                                   MAIN2960
297:         CALL NERKA(FASTFF,IC,YMAX,YMIN)                                   MAIN2970
298:         YMAX=SQRT(YMAX)                                                   MAIN2980
299:         YMIN=SQRT(YMIN)                                                   MAIN2990
300:         CALL PLOTR2(X,YSQR,YW,IC,1,400,1,XST,XTIME,CMN,CMX,ICHAR,XUNIT2,  MAIN3000
301:        1YQ,0.0,0.0,0)                                                     MAIN3010
302:         CALL SPARM(XSQR,IC)                                               MAIN3020
303:         WRITE(6,233) RJ                                                   MAIN3030
304:  233    FORMAT(//59X,'PERCENTAGE OF REJECTIONS=',F5.2)                    MAIN3040
305:         CALL PLOTR2(X,DD,YW,IC,1,400,1,XST,XTIME,0.0,CEM,ICHAR,XUNIT2,    MAIN3050
306:        1YDELTA,0.0,0.0,0)                                                 MAIN3060
307:         CALL VOST(DELTA,IC)                                               MAIN3070
308:         CALL PLOTR2(X,SI,YW,IC,1,400,1,XST,XTIME,0.0,CEM,ICHAR,XUNIT2,    MAIN3080
309:        1YSIGMA,0.0,0.0,0)                                                 MAIN3090
310:         CALL VOST(SIGMA,IC)                                               MAIN3100
311:         CALL PLOTR2(X,FM,YW,IC,1,400,1,XST,XTIME,0.0,FMX,ICHAR,XUNIT2,    MAIN3110
312:        1YMF,0.0,0.0,0)                                                    MAIN3120
313:         CALL FPARM(FMEAN,IC)                                              MAIN3130
314:         CALL PLOTR2(X,YSKEW,YW,IC,1,400,1,0.0,X(IC),SMN,SMX,ICHAR,XUNIT2, MAIN3140
315:        1YV,0.0,0.0,0)                                                     MAIN3150
316:         CALL SPARM(SKEW,IC)                                               MAIN3160
317:         CALL PLOTR2(X,YEXKUR,YW,IC,1,400,1,0.0,X(IC),EMN,EMX,ICHAR,XUNIT2,MAIN3170
318:        1YK,0.0,0.0,0)                                                     MAIN3180
319:         CALL SPARM(EXKURT,IC)                                             MAIN3190
320:  1006   CONTINUE                                                          MAIN3200
321:         CALL RAIZ(DELTAF,Y,IC2)                                           MAIN3210
322:         CALL PLOTR2(X,Y,YW,IC,1,400,1,0.0,X(IC),YMIN,YMAX,ICHAR,XUNIT2,   MAIN3220
323:        1DELTAP,0.0,0.0,0)                                                 MAIN3230
324:         CALL WRTE(DELTAF)                                                 MAIN3240
325:         CALL ARRAY(DELTAF,Y,IC2)                                          MAIN3250
326:         CALL PLOTR2 (X,Y,YW,IC,1,400,1,0.0,X(IC),0.25,4.75,ICHAR,XUNIT2,  MAIN3260
327:        1YUNIT3,0.0,0.0,0)                                                 MAIN3270
328:         CALL WRTE(DELTAF)                                                 MAIN3280
329:         CALL PLOTR2(X,TT,YW,IC,1,400,1,0.0,X(IC),0.0,CEM,ICHAR,XUNIT2,    MAIN3290
330:        1YTHETA,0.0,0.0,0)                                                 MAIN3300
331:         CALL VOST(THETA,IC)                                               MAIN3310
332:         CALL RAIZ(THETAF,Y,IC2)                                           MAIN3320
333:         CALL PLOTR2(X,Y,YW,IC,1,400,1,0.0,X(IC),YMIN,YMAX,ICHAR,XUNIT2,   MAIN3330
334:        1THETAP,0.0,0.0,0)                                                 MAIN3340
335:         CALL WRTE(THETAF)                                                 MAIN3350
336:         CALL ARRAY(THETAF,Y,IC2)                                          MAIN3360
337:         CALL PLOTR2 (X,Y,YW,IC,1,400,1,0.0,X(IC),3.0,8.0,ICHAR,XUNIT2,    MAIN3370
338:        1YUNIT3,0.0,0.0,0)                                                 MAIN3380
339:         CALL WRTE(THETAF)                                                 MAIN3390
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340:          CALL PLOTR2(X,AL,YW,IC,1,400,1,0.0,X(IC),0.0,CEM,ICHAR,XUNIT2,    MAIN3400
341:         1YALPHA,0.0,0.0,0)                                                  MAIN3410
342:          CALL VOST(ALPHA,IC)                                                MAIN3420
343:          CALL RAIZ(ALPHAF,Y,IC2)                                            MAIN3430
344:          CALL PLOTR2(X,Y,YW,IC,1,400,1,0.0,X(IC),YMIN,YMAX,ICHAR,XUNIT2,    MAIN3440
345:         1ALPHAP,0.0,0.0,0)                                                  MAIN3450
346:          CALL WRTE(ALPHAF)                                                  MAIN3460
347:          CALL ARRAY(ALPHAF,Y,IC2)                                           MAIN3470
348:          CALL PLOTR2 (X,Y,YW,IC,1,400,1,0.0,X(IC),7.5,12.5,ICHAR,XUNIT2,    MAIN3480
349:         1YUNIT3,0.0,0.0,0)                                                  MAIN3490
350:          CALL WRTE(ALPHAF)                                                  MAIN3500
351:          CALL PLOTR2(X,AO,YW,IC,1,400,1,0.0,X(IC),0.0,CEM,ICHAR,XUNIT2,    MAIN3510
352:         1YALPHO,0.0,0.0,0)                                                  MAIN3520
353:          CALL VOST(ALPHO,IC)                                                MAIN3530
354:          CALL RAIZ(ALPHOF,Y,IC2)                                            MAIN3540
355:          CALL PLOTR2(X,Y,YW,IC,1,400,1,0.0,X(IC),YMIN,YMAX,ICHAR,XUNIT2,    MAIN3550
356:         1ALPHOP,0.0,0.0,0)                                                  MAIN3560
357:          CALL WRTE(ALPHOF)                                                  MAIN3570
358:          CALL ARRAY(ALPHOF,Y,IC2)                                           MAIN3580
359:          CALL PLOTR2 (X,Y,YW,IC,1,400,1,0.0,X(IC),6.5,12.5,ICHAR,XUNIT2,    MAIN3590
360:         1YUNIT3,0.0,0.0,0)                                                  MAIN3600
361:          CALL WRTE(ALPHOF)                                                  MAIN3610
362:          CALL RAIZ(SIGMAF,Y,IC2)                                            MAIN3620
363:          CALL PLOTR2(X,Y,YW,IC,1,400,1,0.0,X(IC),YMIN,YMAX,ICHAR,XUNIT2,    MAIN3630
364:         1SIGMAP,0.0,0.0,0)                                                  MAIN3640
365:          CALL WRTE(SIGMAF)                                                  MAIN3650
366:          CALL ARRAY(SIGMAF,Y,IC2)                                           MAIN3660
367:          CALL PLOTR2 (X,Y,YW,IC,1,400,1,0.0,X(IC),11.0,16.0,ICHAR,XUNIT2,   MAIN3670
368:         1YUNIT3,0.0,0.0,0)                                                  MAIN3680
369:          CALL WRTE(SIGMAF)                                                  MAIN3690
370:          CALL PLOTR2(X,B1,YW,IC,1,400,1,0.0,X(IC),0.0,CEM,ICHAR,XUNIT2,     MAIN3700
371:         1YBETA1,0.0,0.0,0)                                                  MAIN3710
372:          CALL VOST(BETA1,IC)                                                MAIN3720
373:          CALL RAIZ(BETA1F,Y,IC2)                                            MAIN3730
374:          CALL PLOTR2(X,Y,YW,IC,1,400,1,0.0,X(IC),YMIN,YMAX,ICHAR,XUNIT2,    MAIN3740
375:         1BETA1P,0.0,0.0,0)                                                  MAIN3750
376:          CALL WRTE(BETA1F)                                                  MAIN3760
377:          CALL ARRAY(BETA1F,Y,IC2)                                           MAIN3770
378:          CALL PLOTR2 (X,Y,YW,IC,1,400,1,0.0,X(IC),15.5,21.0,ICHAR,XUNIT2,   MAIN3780
379:         1YUNIT3,0.0,0.0,0)                                                  MAIN3790
380:          CALL WRTE(BETA1F)                                                  MAIN3800
381:          CALL PLOTR2(X,B2,YW,IC,1,400,1,0.0,X(IC),0.0,CEM,ICHAR,XUNIT2,     MAIN3810
382:         1YBETA2,0.0,0.0,0)                                                  MAIN3820
383:          CALL VOST(BETA2,IC)                                                MAIN3830
384:          CALL RAIZ(BETA2F,Y,IC2)                                            MAIN3840
385:          CALL PLOTR2(X,Y,YW,IC,1,400,1,0.0,X(IC),YMIN,YMAX,ICHAR,XUNIT2,    MAIN3850
386:         1BETA2P,0.0,0.0,0)                                                  MAIN3860
387:          CALL WRTE(BETA2F)                                                  MAIN3870
388:          CALL ARRAY(BETA2F,Y,IC2)                                           MAIN3880
389:          CALL PLOTR2 (X,Y,YW,IC,1,400,1,0.0,X(IC),20.5,30.0,ICHAR,XUNIT2,   MAIN3890
390:         1YUNIT3,0.0,0.0,0)                                                  MAIN3900
391:          CALL WRTE(BETA2F)                                                  MAIN3910
392:          CALL PLOTR2(X,FF,YW,IC,1,400,1,0.0,X(IC),0.0,CEM,ICHAR,XUNIT2,     MAIN3920
393:         1YFASTF,0.0,0.0,0)                                                  MAIN3930
394:          CALL VOST(FASTF,IC)                                                MAIN3940
395:          CALL RAIZ(FASTFF,Y,IC2)                                            MAIN3950
396:          CALL PLOTR2(X,Y,YW,IC,1,400,1,0.0,X(IC),YMIN,YMAX,ICHAR,XUNIT2,    MAIN3960
397:         1FASTFP,0.0,0.0,0)                                                  MAIN3970
398:          CALL WRTE(FASTFF)                                                  MAIN3980
399:          CALL ARRAY(FASTFF,Y,IC2)                                           MAIN3990
400:          CALL PLOTR2 (X,Y,YW,IC,1,400,1,0.0,X(IC),29.0,40.0,ICHAR,XUNIT2,   MAIN4000
401:         1YUNIT3,0.0,0.0,0)                                                  MAIN4010
402:          CALL WRTE(FASTFF)                                                  MAIN4020
403:          XST=X(IC) + 5.0                                                    MAIN4030
404:          XTIME=0.0                                                          MAIN4040
405:          ISS=ITT+1                                                          MAIN4050
406:          IF(ISS.GT.240) STOP                                                MAIN4060
407:          ITT=400                                                            MAIN4070

408:    1000  CONTINUE                                                           MAIN4080
409:          STOP                                                               MAIN4090
410:          END                                                                MAIN4100
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 1:          SUBROUTINE NERKA(BAND,IC,YMAX,YMIN)                          NERK  10
 2:          DIMENSION BAND(1)                                            NERK  20
 3:          IC2=2*IC                                                     NERK  30
 4:          JJ=IC                                                        NERK  40
 5:          SUMP1=0.0                                                    NERK  50
 6:          SUMF1=0.0                                                    NERK  60
 7:          SUMF2=0.0                                                    NERK  70
 8:          SUMP2=0.0                                                    NERK  80
 9:          FMIN=100.0                                                   NERK  90
10:          PMIN=100.0                                                   NERK 100
11:          PMAX=0.0                                                     NERK 110
12:          FMAX=0.0                                                     NERK 120
13:          DO 10 I=1,IC2,2                                              NERK 130
14:          IF(BAND(I))11,12,11                                          NERK 140
15:   11     SUMF1=SUMF1+BAND(I)                                          NERK 150
16:          SUMF2=SUMF2+BAND(I)*BAND(I)                                  NERK 160
17:          SUMP1=SUMP1+BAND(I+1)                                        NERK 170
18:          SUMP2=SUMP2+BAND(I+1)*BAND(I+1)                              NERK 180
19:          FMAX=AMAX1(FMAX,BAND(I))                                     NERK 190
20:          PMAX=AMAX1(PMAX,BAND(I+1))                                   NERK 200
21:          FMIN=AMIN1(FMIN,BAND(I))                                     NERK 210
22:          PMIN=AMIN1(PMIN,BAND(I+1))                                   NERK 220
23:          GO TO 10                                                     NERK 230
24:   12     JJ=JJ-1                                                      NERK 240
25:   10     CONTINUE                                                     NERK 250
26:          FIC=JJ                                                       NERK 260
27:          SUMF1=SUMF1/FIC                                              NERK 270
28:          SUMP1=SUMP1/FIC                                              NERK 280
29:          SUMF2=SUMF2/FIC                                              NERK 290
30:          SUMP2=SUMP2/FIC                                              NERK 300
31:          STDF=SQRT(SUMF2-SUMF1**2)                                    NERK 310
32:          STDP=SQRT(SUMP2-SUMP1**2)                                    NERK 320
33:          YMAX=AMAX1(YMAX,PMAX)                                        NERK 330
34:          YMIN=AMIN1(YMIN,PMIN)                                        NERK 340
35:          BAND(493)=FMAX                                               NERK 350
36:          BAND(494)=SUMF1                                              NERK 360
37:          BAND(495)=PMAX                                               NERK 370
38:          BAND(496)=SUMP1                                              NERK 380
39:          BAND(497)=FMIN                                               NERK 390
40:          BAND(498)=STDF                                               NERK 400
41:          BAND(499)=PMIN                                               NERK 410
42:          BAND(500)=STDP                                               NERK 420
43:          RETURN                                                       NERK 430
44:          END                                                          NERK 440
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 1:          SUBROUTINE FPARM(BAND,IC)                                    FPAR  10
 2:          DIMENSION BAND(1)                                            FPAR  20
 3:          FIC=IC                                                       FPAR  30
 4:          SUM1=0.0                                                     FPAR  40
 5:          SUM2=0.0                                                     FPAR  50
 6:          BMAX=0.0                                                     FPAR  60
 7:          BMIN=10.0                                                    FPAR  70
 8:          DO 10 I=1,IC                                                 FPAR  80
 9:          SUM1=SUM1+BAND(I)                                            FPAR  90
10:          SUM2=SUM2+BAND(I)*BAND(I)                                    FPAR 100
11:          BMAX=AMAX1(BMAX,BAND(I))                                     FPAR 110
12:          BMIN=AMIN1(BMIN,BAND(I))                                     FPAR 120
13:   10     CONTINUE                                                     FPAR 130
14:          SUM1=SUM1/FIC                                                FPAR 140
15:          SUM2=SUM2/FIC                                                FPAR 150
16:          STD=SQRT(SUM2-SUM1**2)                                       FPAR 160
17:          WRITE(6,200) BMAX,SUM1,BMIN,STD                              FPAR 170
18:   200    FORMAT(//53X,'MAX FREQ=',F5.2,10X,'MEAN FREQ=',F5.2/53X,     FPAR 180
19:         1'MIN FREQ=',F5.2,10X,'STAND DEV=',F5.2)                      FPAR 190
20:          RETURN                                                       FPAR 200
21:          END                                                          FPAR 210
```

```
 1:          SUBROUTINE PIKCK(PNORM,BANDF,DELFF,ILF,IHF,IC2,PLT,PHT,CMP)        PIKC  10
 2:    C                                                                        PIKC  20
 3:    C     ***************************************************************** PIKC  30
 4:    C                                                                        PIKC  40
 5:    C     THIS SUBROUTINE CHECKS FOR THE FREQUENCY PEAK IN EACH BAND         PIKC  50
 6:    C                                                                        PIKC  60
 7:    C     ***************************************************************** PIKC  70
 8:    C                                                                        PIKC  80
 9:          COMPLEX CMP                                                        PIKC  90
10:          DIMENSION PNORM(1),BANDF(1),PSPEC(200)                             PIKC 100
11:          IL=ILF+1                                                           PIKC 110
12:          IFLAG=0                                                            PIKC 120
13:    50    IFR=BANDF(IC2)/DELFF+1                                             PIKC 130
14:          ICC=0                                                              PIKC 140
15:          IF(PNORM(IFR)-PNORM(IFR+1)) 20,20,1                                PIKC 150
16:    1     IF(IFR-1) 35,35,2                                                  PIKC 160
17:    2     IF(PNORM(IFR)-PNORM(IFR-1)) 20,20,3                                PIKC 170
18:    3     IF(PNORM(IFR+1)-PNORM(IFR+2))20,20,4                               PIKC 180
19:    4     ICC=ICC+1                                                          PIKC 190
20:          PH=(PNORM(IFR)-PNORM(IFR+2))/PNORM(IFR)                            PIKC 200
21:          IF(PNORM(IFR+2)-PNORM(IFR+3))6,6,5                                 PIKC 210
22:    5     ICC=ICC+1                                                          PIKC 220
23:          PH=(PNORM(IFR)-PNORM(IFR+3))/PNORM(IFR)                            PIKC 230
24:    6     IF(IFR-2)35,35,7                                                   PIKC 240
25:    7     IF(PNORM(IFR-1)-PNORM(IFR-2))20,20,8                               PIKC 250
26:    8     ICC=ICC+1                                                          PIKC 260
27:          PL=(PNORM(IFR)-PNORM(IFR-2))/PNORM(IFR)                            PIKC 270
28:          IF(IFR-3) 11,11,9                                                  PIKC 280
29:    9     IF(PNORM(IFR-2)-PNORM(IFR-3))11,11,10                              PIKC 290
30:    10    ICC=ICC+1                                                          PIKC 300
31:          PL=(PNORM(IFR)-PNORM(IFR-3))/PNORM(IFR)                            PIKC 310
32:    11    IF(ICC-3)20,29,29                                                  PIKC 320
33:    29    IF(PL-PLT)30,77,77                                                 PIKC 330
34:    30    IF(PH-PHT)20,77,77                                                 PIKC 340
35:    20    IF(IFLAG-1)21,22,22                                                PIKC 350
36:    21    DO 22 I=IL,IHF                                                     PIKC 360
37:          PSPEC(I)=PNORM(I)                                                  PIKC 370
38:    22    CONTINUE                                                           PIKC 380
39:          PSPEC(IFR)=-1.0                                                    PIKC 390
40:          PMAX=0.0                                                           PIKC 400
41:          DO 24 J=IL,IHF                                                     PIKC 410
42:          IF(PMAX-PSPEC(J))23,24,24                                          PIKC 420
43:    23    BANDF(IC2+1)=PSPEC(J)                                              PIKC 430
44:          BANDF(IC2)=(J-1)*DELFF                                             PIKC 440
45:          PMAX=PSPEC(J)                                                      PIKC 450
46:    24    CONTINUE                                                           PIKC 460
47:          IFLAG=IFLAG+1                                                      PIKC 470
48:          IF(IFLAG-(IHF-IL ))50,50,35                                        PIKC 480
49:    35    BANDF(IC2)=0.0                                                     PIKC 490
50:          BANDF(IC2+1)=0.0                                                   PIKC 500
51:    77    CMP=CMPLX(BANDF(IC2),BANDF(IC2+1))                                 PIKC 510
52:          RETURN                                                             PIKC 520
53:          END                                                                PIKC 530
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1:          SUBROUTINE WRTE(BAND)                                                  WRTE  10
2:          DIMENSION BAND(1)                                                      WRTE  20
3:          WRITE(6,200)                                                           WRTE  30
4:   200    FORMAT(//,58X,'PARAMETERS FOR THE BAND'//)                             WRTE  40
5:          WRITE(6,210) (BAND(I),I=493,500)                                       WRTE  50
6:   210    FORMAT(30X,'MAX FREQ=',F5.2,5X,'MEAN FREQ=',F5.2,10X,'MAX PEAK=',      WRTE  60
7:         1F6.2,5X,'MEAN PEAK=',F6.2,/30X,'MIN FREQ=',F5.2,5X,'STAND DEV=',      WRTE  70
8:         2F5.2,10X,'MIN PEAK=',F6.4,5X,'STAND DEV=',F6.2//)                     WRTE  80
9:          RETURN                                                                 WRTE  90
10:         END                                                                    WRTE 100
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1:          SUBROUTINE FMED(FFW,FMEAN,NB,IC)                                       FMED  10
2:    C                                                                            FMED  20
3:    C     ***************************************************************        FMED  30
4:    C                                                                            FMED  40
5:    C     THIS SUBROUTINE COMPUTES THE MEAN FREQUENCY IN EACH EPOCH              FMED  50
6:    C                                                                            FMED  60
7:    C     ***************************************************************        FMED  70
8:    C                                                                            FMED  80
9:          DIMENSION FMEAN(1),FFW(1)                                              FMED  90
10:         FFW(5)=0.0                                                             FMED 100
11:         FFW(6)=0.0                                                             FMED 110
12:         SUMF=0.0                                                               FMED 120
13:         SUMW=0.0                                                               FMED 130
14:         NBT=2*NB                                                               FMED 140
15:         DO 10 J=1,NBT,2                                                        FMED 150
16:         SUMF=SUMF+FFW(J)*FFW(J+1)                                              FMED 160
17:         SUMW=SUMW+FFW(J+1)                                                     FMED 170
18:   10    CONTINUE                                                               FMED 180
19:         FMEAN(IC)=SUMF/SUMW                                                    FMED 190
20:         RETURN                                                                 FMED 200
21:         END                                                                    FMED 210
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1:          SUBROUTINE ARRAY(XF,Y,IC2)                                             ARRA  10
2:          DIMENSION XF(1),Y(400,1)                                               ARRA  20
3:          I=0                                                                    ARRA  30
4:          DO 10 J=1,IC2,2                                                        ARRA  40
5:          I=I+1                                                                  ARRA  50
6:          Y(I,1)=XF(J)                                                           ARRA  60
7:    10    CONTINUE                                                               ARRA  70
8:          RETURN                                                                 ARRA  80
9:          END                                                                    ARRA  90
```

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      SUBROUTINE SPARM(BAND,IC)                                          SPAR  10
      DIMENSION BAND(1)                                                  SPAR  20
      FIC=IC                                                             SPAR  30
      SUM1=0.0                                                           SPAR  40
      SUM2=0.0                                                           SPAR  50
      BMAX=BAND(1)                                                       SPAR  60
      BMIN=BAND(1)                                                       SPAR  70
      DO 10 I=1,IC                                                       SPAR  80
      SUM1=SUM1+BAND(I)                                                  SPAR  90
      SUM2=SUM2+BAND(I)*BAND(I)                                          SPAR 100
      BMAX=AMAX1(BMAX,BAND(I))                                           SPAR 110
      BMIN=AMIN1(BMIN,BAND(I))                                           SPAR 120
10    CONTINUE                                                           SPAR 130
      SUM1=SUM1/FIC                                                      SPAR 140
      SUM2=SUM2/FIC                                                      SPAR 150
      STD=SQRT(SUM2-SUM1**2)                                             SPAR 160
      WRITE(6,200) BMAX,SUM1,BMIN,STD                                    SPAR 170
200   FORMAT(//52X,'MAX      =',F6.2,10X,'MEAN      =',F6.2/52X,        SPAR 180
     1'MIN      =',F6.2,10X,'STAND DEV=',F6.2)                          SPAR 190
      RETURN                                                             SPAR 200
      END                                                                SPAR 210
```

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      SUBROUTINE VOST(BAND,IC)                                           VOST  10
      DIMENSION BAND(1)                                                  VOST  20
      FIC=IC                                                             VOST  30
      SUM1=0.0                                                           VOST  40
      SUM2=0.0                                                           VOST  50
      BMAX=0.0                                                           VOST  60
      BMIN=10.0                                                          VOST  70
      DO 10 I=1,IC                                                       VOST  80
      SUM1=SUM1+BAND(I)                                                  VOST  90
      SUM2=SUM2+BAND(I)*BAND(I)                                          VOST 100
      BMAX=AMAX1(BMAX,BAND(I))                                           VOST 110
      BMIN=AMIN1(BMIN,BAND(I))                                           VOST 120
10    CONTINUE                                                           VOST 130
      SUM1=SUM1/FIC                                                      VOST 140
      SUM2=SUM2/FIC                                                      VOST 150
      STD=SQRT(SUM2-SUM1**2)                                             VOST 160
      WRITE(6,200) BMAX,SUM1,BMIN,STD                                    VOST 170
200   FORMAT(//53X,'MAX PERC=',F5.2,10X,'MEAN PERC=',F5.2/53X,           VOST 180
     1'MIN PERC=',F5.2,10X,'STAND DEV=',F5.2)                            VOST 190
      RETURN                                                             VOST 200
      END                                                                VOST 210
```

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      SUBROUTINE RAIZ (XF,Y,IC2)                                         RAIZ  10
      DIMENSION XF(1),Y(400,1)                                           RAIZ  20
      IC=IC2/2                                                           RAIZ  30
      I=0                                                                RAIZ  40
      DO 10 J=2,IC2,2                                                    RAIZ  50
      I=I+1                                                              RAIZ  60
      Y(I,1)=SQRT(XF(J))                                                 RAIZ  70
10    CONTINUE                                                           RAIZ  80
      RETURN                                                             RAIZ  90
      END                                                                RAIZ 100
```