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Noise Analysis of the Seismic System Employed in the Northern and  
Southern California Seismic Nets

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## I. Introduction

The seismic networks have been designed and operated to support recording on Develocorders (less than 40db dynamic range) and analog magnetic tape (about 50db dynamic range). The principal analysis of the records has been based on Develocorder films; and background earth noise levels have been adjusted to be about 1 to 2 mm p-p on the film readers. Since the traces are separated by only 10 to 12 mm on the reader screen, they become hopelessly tangled when signal amplitudes on several adjacent traces exceed 10 to 20 mm p-p. Thus, the background noise level is hardly more than 20db below the level of largest readable signals. The situation is somewhat better on tape playbacks, but the high level of background noise set to accomodate processing from film records effectively limits the range of maximum-signal to background-earth-noise on high gain channels to a little more than 30db.

Introduction of the PDP 11/44 seismic data acquisition system has increased the potential dynamic range of recorded network signals to more than 60db. To make use of this increased dynamic range we must evaluate the characteristics and performance of the seismic system. In particular, we must determine whether the electronic noise in the system is or can be made sufficiently low so that background earth noise levels can be lowered significantly to take advantage of the increased dynamic range of the digital recording system.

To come to grips with the complex problem of system noise, we have carried out a number of measurements and experiments to evaluate critical components of the system as well as to determine the noise characteristics of the system as a whole. This report is composed of the following sections:

### Introduction

Overview of noise sources in various parts of the system

Analysis of preamp noise versus combined modulator/discriminator noise

Network-wide analysis of noise on Dec. 20, 1983 from magnetic tape playbacks

Analysis of noise on low-gain channels -Dec. 20, 1983

Analysis of system noise during the automatic calibration cycle (March 22, 1984)

Summary and conclusions

## II Overview of noise sources

Relative to the signals produced by earthquakes, there are two types of noise to consider:

1) the seismic ground noise, etc., that enters the system through the seismometer in the same manner as earthquakes, and 2) the electronic noise generated in the system itself. The level of background earth noise at the discriminator output should be sufficiently above the level of the electronic noise that the combined signal has the general character of the earth noise, not the electronic noise. This condition requires that the ground noise be about 12db above the electronic noise. Provided that the preamp noise, referred to the preamp input, is sufficiently smaller than the signal produced

by the seismometer, the foregoing condition can be met by adjusting the field unit attenuator.

Our primary task is to analyze the electronic system noise in order to understand where it originates and how it can be controlled. In this analysis it is generally convenient to measure the strength of a noise source by the level of noise it produces at the discriminator output. The accompanying schematic diagram (fig 1) shows how the system is composed and indicates its principal sources of noise.

#### Ng

A moving coil seismometer converts ground motion into a very low level low frequency signal that is communicated to the field preamp/VCO unit through the seismometer cable. For a normally operating seismometer the noise signal, Ng, produced by the seismometer is due to normal background microseismic and cultural seismic noise. From the viewpoint of the seismic system, the ground noise is a perfectly valid signal that should not be treated as system noise.

#### Nsc

Occasional defects in the seismometer cable or in the electrical isolation of the seismometer from ground, or pick-up of other induced signals from locally strong, time varying radio frequency sources (nearby radar installations or other radio transmitters), can introduce noise, Nsc, to the seismometer signal before it reaches the preamp. These problems are rare and/or intermittent and must be treated on a case by case basis. Noise induced by bad contacts in the calibration circuit relays can also be included here.

#### Np

Low level internal noise is a normal characteristic of electronic amplifiers. Under normal operating conditions and with a zero level input signal, the amplifier output signal is not zero but a spectrally rich random signal that resembles seismic background noise if viewed through the bandpass filter employed in the seismic system. Because the level of internal noise at the amplifier output depends on the amplifier gain, it is normally "referred" to the amplifier input and characterized by the level of an equivalent input signal that would match the internal noise at the amplifier output. In a multistage amplifier with moderate gain in the first (or preamplifier) stage, it is the preamplifier input noise level that characterizes the overall amplifier noise and limits the dynamic range of the amplifier.

The J302 and J402 field units employ a fixed gain preamplifier followed by an attenuator and a fixed gain second amplifier stage. In this system the preamplifier input noise is superposed on the seismic signal in the preamplifier. At the amplifier output the preamp input noise has undergone the same amplification as the seismic signal (which includes background earth noise).

#### Na/a

The second amplifier stage follows an attenuator that adjusts the signal to the second stage. The internal noise of the second stage is very low compared to the (amplified) preamp noise at the second stage input; so it can be neglected.

Nm

The modulator, or VCO (voltage controlled oscillator), which converts the amplified seismic signal to a frequency-modulated audio-frequency subcarrier signal also adds noise to the transmitted signal. Under normal operating conditions, but with a steady DC voltage applied to its input, the modulator produces an output carrier that is not entirely constant in frequency. This problem is analogous to the internal noise of the preamplifier: the stability of the circuit that uses the amplifier output signal to modulate the frequency of the subcarrier signal sets a lower limit on the level of the signal that can be "encoded" and recovered. Moreover, noise introduced by the modulator cannot be identified until the modulating signal is recovered by the discriminator (which also introduces noise).

Nt

When the VCO is not connected to the discriminator by a good short cable but by a complex telemetry system that picks up the modulated subcarriers from a number of stations, combines them into a more complex multiplexed signal, and transports the multiplexed signal via radio links or phone lines to the network recording center, the individual subcarriers can be substantially degraded, with a consequent addition of noise to the seismic signals that they carry. As in the case with VCO noise, the noise introduced by telemetry is not visible until the seismic signal is recovered by the discriminator. Telemetry induced noise can be extremely variable, ranging from a complete interruption of signal due to telemetry failure, through intermittent episodes of noise due to telemetry signal degradation, to continuous near-harmonic noise on one or more subcarrier channels due to multiplexed-signal distortion in faulty electronics or generation of interfering harmonics by non-sinusoidal subcarrier wave forms.

Nd

The discriminator, like the modulator, has an "internal noise" characteristic that is broadly analogous to the preamp internal noise. Even for a steady unmodulated subcarrier input, the discriminator output signal is not a steady DC level but a spectrally rich random signal that is similar in character to the background earth noise. Moreover, it is in the discriminator output that noise generated by the modulator and by telemetry is first made visible.

The characteristics of the discriminators themselves can be determined in a laboratory environment where very stable modulators directly coupled to the discriminators are substituted for signals from the field. However, the discriminator performs a complex function, and its internal noise depends on many factors, including the frequency passband of the seismic signals it must reproduce.

The principal elements of the discriminator include:

- 1) an input bandpass filter to select the appropriate modulated subcarrier from the set of signals multiplexed onto a single communications channel,
- 2) a detector circuit that translates subcarrier-frequency modulation into output voltage level,



- 3) an output hi-cut filter that eliminates signal frequencies that are higher than permitted in the system design, including the carrier frequency and high frequency noise caused by cross modulation of the processed channel by adjacent channels or carrier noise picked up during transmission.

The irreducible noise in a discriminator is that due to the instability of the detector circuit. The principal sources of additional noise are the instability of the input bandpass filter (if it is an active filter), interchannel modulation (particularly for large deviations of adjacent channels), and modulation noise in the discriminator input filter passband due to poor carrier waveform and/or nonlinear interaction of subcarriers in defective telemetry electronics. The principal noise suppressing element of the system is the output data filter that strongly attenuates frequencies that are higher than the data pass-band.

There is also a systematic channel to channel variation in the intrinsic discriminator noise. We use a constant bandwidth multiplexing system(  $\pm 125$  hz modulation) with 8 equally spaced audio frequency subcarriers ( 680,1020, ... 3060 hz ). In this system the relative modulation of a particular channel is inversely proportional to its center frequency and the intrinsic noise is directly proportional to its center frequency.

$N_c$

Noise pickup in the cables that connect the discriminator to the A/D converter can further contaminate the seismic signal. Care must be taken to design and test these cables adequately.

$N_{a/d}$

The multiplexer and A/D converter that captures the network signals for input to the computer is also a complex electronic device. When installed and configured for operation with the network this device must be carefully tested to insure that it is not adding noise to the seismic signals.

In the analysis that follows it is assumed that  $N_c$  and  $N_{a/d}$  will be controlled by good electronic procedure and testing.  $N_{sc}$  is generally rare and intermittent in occurrence, and it will be excluded from the analysis. Under normal conditions  $N_{a/a}$  is also small and will be neglected.

The sources of noise that we will consider further are  $N_p, N_m, N_t$ , and  $N_d$ . Unless otherwise specified these symbols refer to noise levels at the discriminator output. Of these sources, only  $N_p$  is affected by amplifier gain. The other three are independent of amplifier gain, but they are inseparably mixed together in any single experiment. They can be studied separately in a series of experiments that focusses first on the discriminator, then on the discriminator-modulator pair, and then on the modulator-telemetry-discriminator combination.

In order to estimate noise levels at the discriminator output,  $N$ , due to a combination of noise components,  $N_i$ , we shall use the relationship  $N = N_1 + N_2 + \dots + N_k$ . A number of simple observations about the relationship of  $N$  to the noise components  $N_i$  are in order:

- 1)  $N$  will be at least as large as the largest noise component,
- 2) if the  $k$  noise components in  $N$  are all equal to  $n$ ,  $N=kn$ ,
- 3) if an upper limit of  $N$ , say  $N^*$ , is prescribed and if one of four components is  $0.7N^*$ , then the remaining components of  $N$ , if all equal, cannot exceed  $N'=0.1N^*$ .

Our goal in Calnet is to achieve a system dynamic range of 60db if possible. The output level of the discriminators is 4.0 volts p-p. Thus, for a 60db system dynamic range we require that the sum of all noise components at the discriminator output be:  $N \leq 4$  mv p-p. This condition is not met by the present system, but it appears that the combination of  $N_p$ ,  $N_m$ , and  $N_d$  might be held as low as 4 mv p-p. It also appears feasible to upgrade the telemetry system and its maintenance to reduce  $N_t$  over many telemetry channels to permit a 60db system.

The dynamic range of the maximum recordable earthquake signal relative to the background earth noise is another matter. It depends not only on the electronic dynamic range of the system but also on the choice of the ratio of background noise level to electronic noise level at which the system is operated. If the background earth noise level is set to be four times the electronic noise level (by adjustment of the amplifier gain), then the ground-noise to maximum-recordable-earthquake-signal dynamic range is 12db lower than the dynamic range discussed above.

### III Analysis of preamp noise versus combined modulator/discriminator noise

Noise/calibration tests were performed on four J302 field units combined with either J101 or J110 discriminators. The preamp inputs were terminated with 10K resistors. Five-hz sine wave signals at 1000 microvolts rms and 10 microvolts rms were introduced from the standard "test box" on the repair bench. The VCO output signals were introduced to J101 or J110 discriminators in the repair bench set-up and were displayed at appropriate sensitivity levels on a strip chart recorder. Sine wave calibration was provided by the 1000 microvolt rms signal with the attenuator at 36db and the 10 microvolt rms signal with the attenuator at 0db. Noise analysis was provided by a series of tests with no input signal (but with a 10K resistor across the preamp input) and with the attenuator at 0db, 6db, 12db, 18db, 24db, and 42db.

The noise tests provide a means of separating noise introduced before the attenuator (i. e. in the preamplifier) from that introduced after the attenuator (predominantly in the VCO and discriminator). As the tests show, the output signal is dominated by preamp noise at low attenuator settings (high gain) and by VCO/discriminator noise at high attenuator settings (low gain). These tests do not separate noise generated in the VCO from that generated in the discriminator. Results from these tests are presented in table 1 and fig 2.

The preamp input noise for three of the four units is within the nominal design range, but that for the fourth is about twice too high. The average gain of the four units is about 3db low at 0db attenuation and 4db low at 36db attenuation. The VCO/disc noise increases uniformly with increasing center frequency with little regard for discriminator type. The ratio of VCO/discr noise to center frequency averages 2.21 and increases from 1.96 at 1020hz to 2.57 at 2720hz. A straight line through these data suggest that the VCO/disc

noise increases from a minimum of 1 to 2 mv p-p at the 680hz channel to 7 to 8 mv p-p at the 3060 channel. The J110 appears to have a slight advantage over the J101 on the higher frequency channels.

To examine the dependence of dynamic range of the preamp/VCO pair on the preamp input noise and on the VCO/discriminator noise, the expected noise levels for several combinations of source noise levels were computed for attenuator settings of 0 to 42 db. These results are shown in fig 3. In table 2 the dynamic range of a system with a 4.0v p-p maximum output is shown as a function of noise at the discriminator output.

#### VI Network-wide noise analysis - Dec 20, 1983

To survey the background earth noise and electronic noise characteristics of stations of the central California network, a study was made of the traces just before the onset of waves from the Dec 20, 1983 Cape Mendocino earthquake. A complete set of Siemens playbacks with a sensitivity of 25 mv/mm and a 15hz, 12db/octave hi-cut filter had been made for the analysis of the earthquake and were, therefore, already available for the noise study. The overall quality of the records appeared to be representative of network performance over the last several years. Representative records are shown in figs 4a-d.

Setting aside cases with many spikes, sporadic severe noise from telemetry dropouts, etc., the noise on Calnet records appears to have three predominant components:

- 1) rather long period (0.8 to 2.5 sec) microseisms,
- 2) high frequency ( $\geq 10$ hz) continuous noise, much of which is thought to originate in the telemetry,
- 3) cultural noise with frequencies of 2 to 5 hz.

The long period microseisms and the high frequency (electronic?) noise are so distinct that both components were measured. When the intermediate period cultural noise dominated the high frequency noise, it was measured instead of the high frequency noise. In fact, some cases of "cultural" noise may be system noise caused by faulty preamp/VCO electronics. The 25mv/mm sensitivity of the records is rather low for a noise study, particularly at quiet stations. Nonetheless, a useful overall picture of network noise is provided by these records.

Both amplitudes and periods of the microseism and high frequency components of the noise were measured systematically for all functioning stations. These data were analyzed by a program that combined the noise data with an augmented station list and calculated the following:

- 1) background earth noise (long period) measured at each station, ampm, in millivolts at the discriminator output
- 2) background earth noise corrected to correspond to a 12db attenuator setting, ampc, in mv at the discriminator output
- 3) high frequency (electronic?) noise measured at each station, in mv at the discriminator output
- 4) histograms of ampm, ampc, and ampe
- 5) histogram of attenuator settings

- 6) averages of ampm, ampc, and ampe for each attenuator setting
- 7) averages of ampm, ampc, and ampe for each telemetry channel
- : 8) averages of ampm, ampc, and ampe for each network region -
  - a. coastal band
  - b. first inland band } west of the San Andreas
  - c. second inland band }
  - d. San Andreas band
  - e. wedge between the San Andreas and the Hayward-Healdsburg fault zones
  - f. Coast Range east of d and e
  - g. western edge of the Great Valley
  - h. Sierra foothills
  - i. Sierra Nevada, except for the Walker Pass - Coso region
  - j. Lassen, Shasta, Lake Shasta region
  - k. Walker Pass - Coso region
  - l. all other
- 9) averages of ampm, ampc, and ampe as a function of the number of radio links in the transmission path.

#### Attenuation histogram and average noise vs attenuation setting

Field unit attenuation settings are strongly peaked at 12db and 18db (table 3). The distribution for stations with attenuations from 6db to 24db (which includes all non-lo-gain and non-pathological sites) is:

- 6db, 34 stations
- 12db, 129 stations
- 18db, 114 stations
- 24db, 26 stations.

There are 48 lo-gain instruments set at 42db.

The average measured background earth noise level (table 3) increases slowly from 71 mv at 6db sites to 111 mv at 24db sites, while the average adjusted (to 12db) background earth noise level increases dramatically from 34 mv at 6db sites to 444 mv at 24db sites. The average measured high frequency noise level increases slowly from 79 mv at 6db sites to 109 mv at 24db sites. The 42db sites are a special case; and they appear to be much quieter than the normal high gain instruments. The measured long period background earth noise was almost too low to estimate (on our 25 mv/mm playouts) at most of the 42db sites, with an average of about 9 mv. The high frequency noise was also correspondingly low, averaging only 15 mv at the 42db sites.

The fact that the average high frequency noise and the average background earth noise are very nearly equal at all attenuator settings is inconsistent with our earlier assumption that the earth noise, but not the high frequency noise, was amplified in the preamplifier. This inconsistency suggests that a substantial part of the high frequency noise at the system output actually arises in or in front of the preamplifier. Another explanation of the equality is that, in practise, the ground noise is systematically set high enough to be seen above the prevailing electronic noise. This question is presently unresolved and requires further work.

#### Telemetry channel vs average noise (table 4)

The averages of all three noise values discussed above do not appear to vary significantly from channel to channel.

#### Region vs average noise (table 5)

Region a, along the coast, and region g, at the western edge of the Great Valley, are substantially noisier than the average with regard to both background earth noise and high frequency noise. Region h, the Sierra foothills, is the quietest region. Regions i, j, and k (the Sierra-Lassen-Shasta region, and Coso-Walker Pass region) have only moderate levels of ground noise but high levels of high frequency noise. The persistent sinusoidal character of the high frequency noise suggests that it arises in the telemetry.

#### Number of radio links vs average noise level (table 6)

Only the cases of 0, 1, and 2 radio links have sufficient numbers to be significant. High frequency noise is lowest for the case of no radio link, intermediate for the case of two radio links, and largest for the case of one radio link. The differences are not large but are probably significant.

#### Noise histograms (table 7 and fig 5)

From the noise histograms one can see the following:

- 1) 44% of stations have high frequency noise  $\leq 40\text{mv}$ , or 40db below the 4v maximum output level,
- 2) 70% of stations have high frequency noise  $\leq 70\text{mv}$ , or about 34db below 4v.
- 3) 70% of stations have ground noise  $\leq 100\text{mv}$ , or about 32db below 4v.

#### V Analysis of noise on lo-gain stations -Dec. 20, 1983

For stations operating at 42db attenuation we expect the ground noise and preamplifier noise to be no more than 2 or 3 mv and 1mv, respectively. Thus, the background noise recorded on those channels in the absence of earthquakes should be dominated by VCO, telemetry, and discriminator noise. The noise levels observed for selected N-S lo-gain channels are listed in table 8. The observations were made under a variety of circumstances:

- 1) measured from the Dec. 20 playbacks through the TRICOM discriminators and a 15hz hi-cut filter
- 2) measured with an oscilloscope at the discriminator signal distribution rack in the recording center,
- 3) measured with an oscilloscope at the A/D input block in the computer center,
- 4) digitized and plotted back by hand.

To test the lines from the discriminator output block to the A/D input block, several discriminators were removed and the corresponding cables were terminated with 125 ohm resistors. The signals then appearing on the A/D input

were measured with a portable (not grounded to the building) oscilloscope and were digitized and recovered from the PDP 11/44. The various measurements were not simultaneous; so exact agreement cannot be expected. Table 8 supports the following observations:

- 1) noise levels measured on the Siemens playbacks ranged from 5mv to 50mv and averaged 18mv,
- 2) noise levels measured at the discriminator distribution rack ranged from 10mv to 100mv and averaged 43mv,
- 3) noise levels measured at the A/D input ranged from 15mv to 100mv and averaged 33mv,
- 4) when the lines linking the discriminator signal distribution rack and the A/D input rack were disconnected from the discriminators and terminated with 125 ohm resistors, the signal at the A/D input was 2mv (five lines were measured),
- 5) a plot of the digital signals from the previous test (i.e. #4) showed peak to peak noise signals of 10mv and 9mv for the two cases that were plotted (fig 6).

Cases 2 and 3, above, are sufficiently similar to suggest that the signals appearing at the A/D input are the same as those at the discriminator distribution rack. Case 1, compared with cases 2 and 3, suggests that the combination of the TRICOM discriminators and the 15hz hi-cut filters reduces the noise by about one half. This result is not surprising in view of the average period of 0.07 sec of the noise. Signals read from the scope at the A/D input and those plotted from the digital signals when the discriminators are in place are in good agreement. However, the digitized noise signal is 4 to 5 times larger than the signal measured by the oscilloscope at the A/D input for the case in which the discriminators were removed and replaced by 125 ohm resistors.

## VI Analysis of system noise during the automatic calibrator cycle

The automatic calibrator in the field unit interrupts the normal seismometer signal once per day to produce the calibration signal illustrated in figure 7:

- 1) with the seismometer disconnected and the preamp input terminated with a resistor to preserve balance, the seismometer is displaced by a calibrated current while, first, an I D code and, then, an interval of system noise only is transmitted,
- 2) the seismometer is disconnected from the mass deflecting voltage and reconnected to the preamp through a 24db attenuator. The ensuing signal is the seismometer mass release test superposed on system noise and attenuated ground noise,
- 3) the preamp is disconnected from the seismometer and connected to a calibrated voltage source that has an internal impedance that preserves preamp balance. The ensuing signal is the system voltage step test superposed on system noise,
- 4) the preamp is disconnected from the calibrated voltage source and reconnected to the seismometer, and normal operation resumes.

Analysis of the recorded seismic trace before the calibration signal and during the separate stages of the calibration signal permits us to distinguish

system noise from background noise and to detect such malfunctions as channel-to-channel crosstalk.

Calibration signals were played back from 9 tracks of Calnet tape B for March 22, 1984 (fig 8). A 20 minute interval centered on 1200 GCT (nominal calibration time) was played back, and good calibration signals were recovered from 55 out of 72 seismometers. Eighteen of the 55 calibration signals were from lo-gain channels, and 37 were from high-gain channels.

For normal playback of the calibration signals, the Siemens Oscillomink is at the 1.0 sensitivity setting ( $lmm=100mv$ ) so that the peak excursions of the seismometer release test and the amplifier step test will be on scale (fig 8a). For analysis of system noise the  $lmm=100mv$  sensitivity is completely inadequate; so for this study the Siemens sensitivity was set at 0.1 ( $lmm=10mv$ ). (fig 8a-n). To quantify the noise characteristics of the records before and during the calibration signals, the following measurements were made:

- 1) peak amplitudes and associated periods of the predominantly long period (ca. 1 sec.) and short period (ca. 0.1 sec.) noise components just before the onset of the calibration signal,
- 2) peak amplitude and period of the predominant noise following the calibration code transmission while the seismometer was disconnected from the system. This noise is predominantly short period; so no measurement of a long period component was attempted,
- 3) large excursions of the trace during the seismometer release test and amplifier step test (with a consequent large deviation of the carrier of the tested system) are sometimes accompanied by significant noise on either the tested trace, on other traces, or on both. The peak amplitudes and periods of such disturbances were recorded as x-talk interference on the tested trace and as x-talk to other traces.

The results of these measurements are presented in table 9, along with channel identification, field attenuator setting, and number of radio links in the transmission path. The entries are grouped according to the tape recorder track from which they were derived. The calibrations summarized in table 9 were made with a 12db/octave 15hz hi-cut filter to reduce high frequency noise on the traces.

Additional tests were run to assess the effect of the 15hz filter on the calibration tests. The results can be summarized as follows:

- 1) for low noise stations, the noise increases by a factor of 2 when the 15hz filter is removed. The increase is somewhat greater for channels with high subcarrier frequencies than for those with low subcarrier frequencies,
- 2) for noisier stations, the effect is smaller. The noise spectrum for such stations has shifted to lower frequencies, which are not affected by the filter.



The overall quality of a phone line can be characterized by the average noise level during the "seismometer out" part of the calibration cycle for stations on the line. Excluding clearly aberrant stations, the averages for the lines we have studied are:

B2	26mv
B3	14mv
B5	18mv
B6	64mv
B8	12mv
B9	20mv
B10	70mv
B13	15mv
B14	11mv

If we exclude B10 and B6, which have severe problems, the average line noise level is 16mv, 48db below the maximum signal output level. If we consider only the 14 low-gain components of this sub-set, the average noise level is 9.5mv, 52db below the maximum signal output level. Previous tests, in which J202 modulators produced signals that were recorded on the B-H 3700B recorder and were then played back through Develco discriminators, using subtractive compensation, indicate a dynamic range of about 50db for the system. In these earlier tests the 15hz filters were not used.

It appears that the system noise in the signals from the normal stations transmitted over well functioning telemetry is approaching the noise level of the tape record/reproduce system. Testing to verify further reduction of system noise will require a quieter record/reproduce system. Potentially, the PDP11/44 data acquisition system will suffice; but the tests on noise at the A/D converter input reported above suggests that the 11/44 system currently is no quieter than the tape system.

## VI Summary and conclusions

To attain a dynamic range of 60db in a system with a maximum output level 4 volts p-p, the system noise must not exceed 4mv p-p. Because we are dealing with transient signals, the output noise resulting from the noise generated in separate components of the system is the sum of the noise signals that compose it. In the Calnet seismic system there are four principal sources of noise: preamp input noise, modulator noise, telemetry noise, and discriminator noise. In a faulty system, any one of these can far exceed 4 mv; so we can hope to attain a 60db dynamic range only in a finely tuned, well maintained system. Moreover, it appears very difficult to get the discriminator noise below several mv, particularly for the higher frequency channels. The target levels for preamp noise, modulator noise, and telemetry noise must therefore be of the order of 1mv or less.

The 0db gain of the nominal Calnet amplifier is 91.3db, or 36.7K, and the modulator/discriminator gain factor is 4.0/6.0; so the effective preamp-input to discriminator-output "0db" gain is 24.5K. In the best of the units we tested the equivalent input preamp noise was 1.4  $\mu$ v p-p. For the nominal "0db" gain, such a preamp noise level would produce an output noise level of 34mv p-p. However, we want to operate the system at a much reduced gain to



enhance the background-earth-noise to maximum-output-signal dynamic range. Let us assume a site with a background earth noise 4 times the preamp noise, or  $5.6 \mu\text{v}$  p-p. Next let us calculate the signal levels and dynamic range of the system set at 24db attenuation. The effective gain would be 1.55K; so the  $1.4 \mu\text{v}$  p-p preamp noise would be 2.16mv p-p and the  $5.6 \mu\text{v}$  p-p ground noise would be 8.64mv p-p at the discriminator output. In this case the preamp noise and the ground noise would be 65db and 53db, respectively, below the maximum output. At a noisier site requiring greater attenuation to hold the ground noise below 8 or 9 mv p-p, the preamp noise would be even farther suppressed. But at a quieter site requiring less attenuation, the preamp noise would be increased at the discriminator output. From table 3 we can calculate the average discriminator output level corresponding to a gain setting of 24db by dividing AVAMPC (12db gain) by 4. We find that this number for various gain settings is:

6db - 8mv p-p, 34 cases  
 12db - 20mv p-p, 129 cases  
 18db - 41mv p-p, 114 cases  
 24db - 111mv p-p, 26 cases.

Thus, the situation assumed as a test case above (8.6mv p-p background earth noise level) in fact corresponds to the 34 quietest network sites on Dec. 20, 1983.

Neglecting telemetry noise for the moment, if we could hold the combined modulator/discriminator noise to 2mv p-p the total preamp plus modulator/discriminator noise would be about 4mv p-p for our assumed system operating at 24db attenuation. Given the difficulty in keeping the mod/disc noise down to 2mv p-p, it is extremely important to keep the preamp noise as low as possible. A practical goal for the preamp input noise appears to be about  $0.75 \mu\text{v}$  p-p, which would produce an output noise level of 1.15mv p-p at the 24db attenuation setting.

In the analysis of network noise just prior to the Dec. 20, 1983 Cape Mendocino earthquake it appears that, on high gain channels, the ratio of long period noise (microseisms?) to short period noise (electronic?) is not a strong function of attenuator setting. This surprising result suggests either that 1) a large fraction of the short period noise is introduced from the ground or from electronic noise in front of the second amplifier, or 2) attenuator settings are chosen, in practice, so that the background earth noise is approximately equal to the system electronic noise, whatever its source might be.

Analysis of system noise at 55 instruments for which calibration signals were played back from tape recorder B on March 22, 1984, helps to clarify this question. The stations analyzed in this set are in a region with higher than average coastal and cultural microseismic noise; and the playback trace sensitivity was 2 1/2 times higher than for the Dec. 20, 1983 records (1mm=10mv instead of 1mm=25mv). Long and short period noise levels and associated periods were read just before the onset of the calibration signals, and short period noise and associated periods were measured during the calibration interval in which the seismometer was disconnected from the preamp. The average long period noise levels (referred to 24db attenuation) as a function of attenuator setting are quite comparable to those for the Dec. 20, 1983 study:

6db - 16mv p-p, 3 cases  
 12db - 26mv p-p, 9 cases  
 : 18db - 64mv p-p, 20 cases  
 24db - 160mv p-p, 3 cases

The behavior of the short period noise is more complex. Perhaps the most revealing measure of the short period noise is the average noise level at all stations on a given phone line while their respective seismometers were disconnected from their preamps. In order of increasing average noise levels these results are:

B14 - 11mv p-p  
 B8 - 12mv p-p  
 B3 - 14mv p-p  
 B13 - 15mv p-p  
 B5 - 18mv p-p  
 B9 - 20mv p-p  
 B2 - 26mv p-p  
 B6 - 64mv p-p  
 B10 - 70mv p-p

The seismic traces for instruments on lines B10 and B6 show clear, strong evidence of channel-to-channel cross modulation both before and during the calibration tests, while the traces on other lines generally do not. Moreover, on the very noisy phone lines the level of crosstalk is a function of the ambient carrier frequencies on the line, as is shown by the varying amplitude of crosstalk signals that appear when the large carrier deviations induced by the calibration tests occur. This evidence suggests that the very high short period electronic noise is caused by interaction among carrier signals in the telemetry system. Experience has shown that such problems arise from improper signal levels or malfunctioning hardware on phone lines or radio links and from harmonics generated in the system as a result of non-sine-wave carrier signals from one or more field units served by the telemetry circuit.

However, such telemetry interaction is not the only cause of excessive short period noise. A measure of the excess of short period noise in the complete system (including the seismometer), over that generated in the electronics and telemetry alone, is the ratio of the short period noise just before the calibration cycle to that during the mass deflection (seismometer out) part of the calibration. For the 55 calibration signals considered here this ratio is less than 1.5 for 60% of the cases, less than 2.0 for 70% of the cases, less than 3.0 for 85% of the cases, and greater than 3 for 15% of the cases. For the 30% of cases in the last two categories (ratio greater than 2), the predominant source of short period noise appears to be entering the system in front of the preamplifier and may be either ground noise (perhaps of cultural origin) or noise picked up in the seismometer cable or in the seismometer connect/disconnect relay in the field unit.

Even for the quieter phone lines examined in the calibration study the system electronic noise (including tape playback noise) is excessive, averaging 16.6mv p-p on the 7 "normal" lines. This level of noise is only 48db below the maximum output level. For the quietest individual stations the system noise with the seismometer disconnected appears to be about 5mv p-p, 58db below the

maximum output level. System noise levels above this figure very likely result from milder forms of the same problems that produce the very noisy lines. If we could insure that the carrier signals produced in the field units were clean sine waves and if we could manage and maintain the telemetry system to avoid serious distortion of the multiplexed carriers during transmission, it seems reasonable to expect that we could reduce the system noise level to 5mv p-p or somewhat less.

The high frequency noise passed by the discriminator is very strongly dependent on its high frequency cutoff. The TRICOM discriminator cuts off (30db/octave) at 30 hz. In the noise tests described here the signals were passed through an additional 12db/octave 15hz hi-cut filter. The proposed network discriminator for use with the 11/44 data acquisition system has a 30db/octave high cut filter with a corner frequency of 20hz. It is anticipated that this discriminator will suppress the very high frequency telemetry noise about as well as the TRICOM discriminator followed by the 15hz 12db/octave hi-cut filter.

Tests on the A/D input to the 11/44 show that it sees a noise level of about 10mv p-p when an independent measurement by oscilloscope across the A/D input terminals sees only a 2mv p-p noise level. This internal(?) noise must be suppressed if we are to approach the 60db dynamic range. With its present apparent internal noise level, the A/D-11/44 system is no better than the analog tape system.

Finally, we must repeat that most of the noise sources that we have examined must be reduced to very low levels, 1mv p-p or less, if the 60db goal is to be realized. If the preamp, modulator, telemetry, discriminator, and A/D converter each contribute only 2mv p-p of system noise, then the 10mv p-p sum will be only 52db below the maximum system output level. Such a condition would be far better than the average network performance at present, but it would not fully utilize the recording potential of the digital system.

Table 1	Measured values and results from noise tests on four field units.
Table 2	Discriminator output noise versus system dynamic range in a system with a maximum output of 4v p-p.
Table 3	Histogram of field attenuator settings and average noise values (and number of cases) as a function of attenuator setting.
Table 4	Telemetry channel versus average noise level.
Table 5	Geographic region versus average noise level. The regions, a through l, are described in the text.
Table 6	Number of radio links versus average noise level.
Table 7	Interval and cumulative histograms of noise levels on Dec. 20, 1983.
Table 8	Noise levels measured on low-gain N-S component channels during December 1983 and January 1984. The different columns correspond to different measurements at different times and places in the output recording system.
Table 9	Noise levels before and during the automatic calibration cycle at instruments on selected tracks from tape recorder B on March 22, 1984. Trace ID and operational parameters are in the first 5 columns. The next three columns show short and long period noise just before the calibration cycle. The last three columns show short period noise during the "seismometer out" part of the cycle as well as x-talk interference on the tested trace and x-talk to other traces during large deviations of the calibrated trace.

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- Figure 1 Schematic diagram of one channel of the Calnet seismic system and designations applied to noise generated in its several parts.
- Figure 2 Output noise level versus attenuator setting for four seismic systems.
- Figure 3 Noise level versus attenuator setting for various combinations of preamp and VCO/discriminator noise. Preamp noise, in uv, is referred to the preamp input. VCO/discriminator noise and total system noise, in mv, are at the discriminator output.
- Figure 4 Playouts of representative tape tracks for the December 20, 1983 Cape Mendocino earthquake.
- Track A10 Stations SW of Clear Lake.
  - Track A2 Stations near Eureka.
  - Track A12 Stations east of San Francisco Bay.
  - Track D5 Stations in the Sierra near Sacramento.
- Figure 5 Cumulative histograms of seismic and electronic noise on Dec. 20, 1983. The ordinate shows number of cases and the abscissa shows both noise levels in mv p-p and noise levels in db relative to 4v p-p, the maximum system output.
- Figure 6 Hand plots of digitized signals from low-gain stations HPLN and BSGN for the cases:
- discriminator removed and transmission line terminated with a 125 ohm resistor, and
  - discriminator in place. The corresponding signal levels (mv p-p) as measured on an oscilloscope at the A/D input terminals are shown in parentheses.
- Figure 7 Automatic calibration switching circuit diagram and nominal calibration signal, with a description of the phases of the test sequence.
- Figure 8 Calibration signals played back under a variety of conditions from stations on selected tracks of recorder B on March 22, 1984.
- Track B10, sens.=100mv/mm, 15hz filter in
  - " sens.=10mv/mm, " in
  - " " " out
  - Track B8 sens.=10mv/mm, 15hz filter in
  - " " " out
  - " " " in
  - " " " out
  - " " " in/out
  - Track B14, sens.=10mv/mm, 15hz filter in
  - " " " out
  - " " " in/out
  - Track B2 sens.=10mv/mm, 15hz filter in
  - " " " out
  - " " " in/out

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Table 1 Measured values and results from noise tests on four field units.

preamp/VCO discr center freq		J302 J110 1020hz	J302 J101 1360hz	J302 J110 2380hz	J302 J101 2720hz	nominal system
signal	atten					
1mv rms	36db	640mv pp	675mv pp	725mv pp	650mv pp	1094mv pp
10uv rms	0db	460mv pp	550mv pp	525mv pp	500mv pp	690mv pp
0uv (10K)	0db	25mv pp	50mv pp	26mv pp	30mv pp	-
"	6db	10mv pp	30mv pp	12mv pp	12mv pp	-
"	12db	4.5mv pp	18mv pp	7mv pp	9mv pp	-
"	18db	3mv pp	10mv pp	6mv pp	8mv pp	-
"	24db	2.5mv pp	6mv pp	6mv pp	8mv pp	-
"	42db	2mv pp	3mv pp	5mv pp	7mv pp	-
ampl gain at 36db atn		50.6db	51.1db	51.7db	50.8db	55.3db
ampl gain at 0db atn		87.8db	89.3db	88.9db	88.5db	91.3db
ampl magn at 0db atn		24.5K	29.3K	27.9K	26.6K	36.7K
preamp (disc out)		25mv pp	60mv pp	25mv pp	25mv pp	19-43mv pp
noise at (ampl out)		38mv pp	90mv pp	38mv pp	38mv pp	28-64mv pp
0db atten (preamp in)		1.6 $\mu$ v pp	3.1 $\mu$ v pp	1.4 $\mu$ v pp	1.4 $\mu$ v pp	.75-1.25 $\mu$ v pp
VCO/disc noise (out)		2mv pp	3mv pp	5mv pp	7mv pp	-
" noise/cent freq		1.96	2.21	2.10	2.57	-

Table 2 Discriminator output noise versus system dynamic range in a system with a maximum output of 4v p-p

Noise (mv p-p)	18	16	14	12	10	8	6	4	2
Dynamic range (db)	46.9	48.0	49.1	50.5	52.0	54.0	56.5	60.0	66.0

Table 3 Histogram of field attenuator settings and average noise levels in mv p-p (and number of cases) as a function of attenuator setting

ATTEN	NUMBER		NO	AVAMPM	NO	AVAMPC		NO	AVAMPE
	NO	CUM				12db	24db		
0 db	0	0	0	0.	0	0.	0.	0	0.
6 db	34	34	32	71.02	32	33.99	8.5	34	78.68
12 db	129	163	125	79.70	125	79.70	20.	128	81.82
18 db	114	277	109	81.88	109	163.35	41.	113	88.10
24 db	26	303	24	111.35	24	443.51	111.	25	108.50
30 db	1	304	1	20.00	1	158.86		1	75.00
36 db	3	307	1	87.50	1	1390.03		2	150.00
42 db	48	355	48	9.17	48	289.59		48	14.90
48 db	1	356	0	0.	0	0.		1	75.00

Table 4 Telemetry channel versus average noise levels in mv p-p

	NO	AVAMPM	NO	AVANPC	NO	AVAMPE
CHANNEL 1	39	84.74	36	141.06	38	75.33
CHANNEL 2	45	72.67	41	160.46	46	104.95
CHANNEL 3	49	64.80	44	120.00	51	67.16
CHANNEL 4	45	66.83	43	183.54	47	68.09
CHANNEL 5	45	69.78	42	130.30	46	74.24
CHANNEL 6	45	74.56	42	139.67	51	114.02
CHANNEL 7	44	72.33	42	179.73	48	75.42
CHANNEL 8	44	76.59	40	249.65	46	72.34
CHANNEL 9	11	107.27	9	137.22	11	80.68

Table 5      Geographic region versus average noise level in mv p-p.  
The regions, a through l, are described in the text.

		NO	AVAMPM	NO	AVAMPC	NO	AVAMPE
REGION	a	11	150.00	10	381.03	13	97.69
REGION	b	19	74.47	19	193.18	19	43.95
REGION	c	37	82.97	37	219.42	37	48.85
REGION	d	39	81.73	39	225.24	40	55.38
REGION	e	35	95.36	35	156.63	35	77.50
REGION	f	100	64.85	97	156.65	102	74.04
REGION	g	16	117.03	12	331.99	15	92.50
REGION	h	21	29.40	20	41.17	23	51.41
REGION	i	38	63.16	23	109.26	46	142.01
REGION	j	25	54.60	23	37.64	25	116.50
REGION	k	15	49.00	15	51.55	16	106.88
REGION	l	12	72.92	10	92.91	14	97.32

Table 6      Number of radio links vs average noise level in mv p-p

		NO	AVAMPM	NO	AVAMPC	NO	AVAMPE
RADLKS	0	263	68.98	239	184.69	272	68.20
RADLKS	1	67	73.36	66	105.28	72	111.70
RADLKS	2	30	108.17	29	102.46	31	96.37
RADLKS	3	2	112.50	2	112.50	3	183.33
RADLKS	4	3	108.33	3	216.12	4	268.75
RADLKS	5	1	50.00	0	0.	1	75.00
RADLKS	6	2	53.75	1	14.96	2	100.00



Table 7 Interval and cumulative histograms of noise levels in mv p-p on Dec.20, 1983

NOISE	AMPM		AMPC		AMPE	
0 mv to 10 mv	48	48	8	8	21	21
10 mv to 20 mv	28	76	21	29	51	72
20 mv to 30 mv	53	129	33	62	52	124
30 mv to 40 mv	19	148	11	73	45	169
40 mv to 50 mv	0	148	36	109	0	169
50 mv to 60 mv	52	200	2	111	46	215
60 mv to 70 mv	20	220	10	121	14	229
70 mv to 80 mv	40	260	28	149	53	282
80 mv to 90 mv	2	262	2	151	1	283
90 mv to 100 mv	0	262	33	184	0	283
100 mv to 110 mv	30	292	0	184	22	305
110 mv to 120 mv	4	296	2	186	0	305
120 mv to 130 mv	20	316	16	202	21	326
130 mv to 140 mv	0	316	0	202	0	326
140 mv to 150 mv	0	316	29	231	0	326
150 mv to 160 mv	15	331	12	243	13	339
160 mv to 170 mv	0	331	0	243	0	339
170 mv to 180 mv	11	342	5	248	8	347
180 mv to 190 mv	0	342	0	248	0	347
190 mv to 200 mv	0	342	15	263	0	347
200 mv to 210 mv	10	352	0	263	8	355
210 mv to 220 mv	0	352	0	263	0	355
220 mv to 230 mv	4	356	2	265	3	358
230 mv to 240 mv	0	356	23	288	0	358
240 mv to 250 mv	0	356	6	294	0	358
> 250 mv	12	368	46	340	27	385

Table 8 Noise levels measured on lo-gain N-S component channels during December 1983 and January 1984. The different columns correspond to different measurements at different times and places in the recording system. Voltages are all in millivolts peak-to-peak

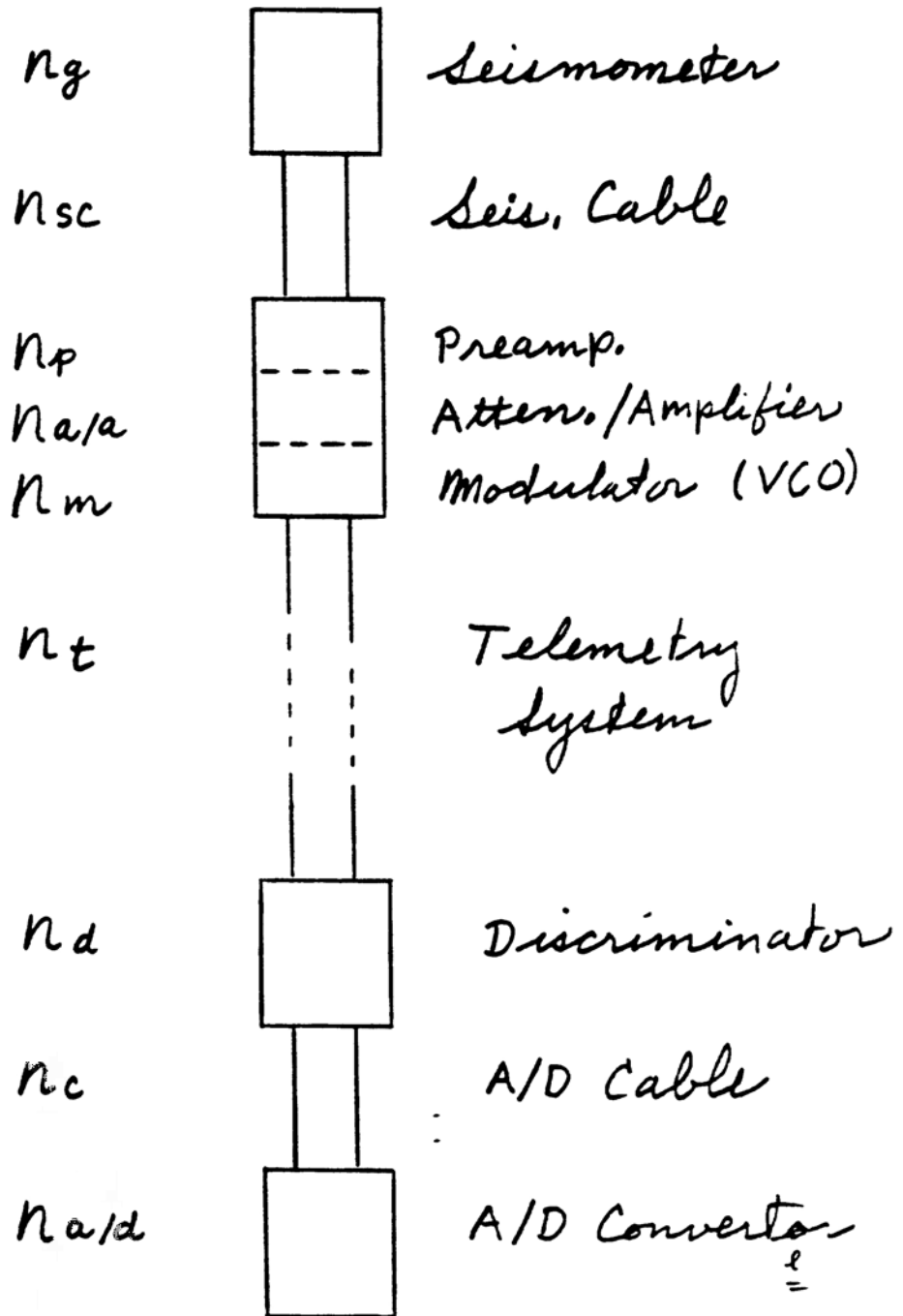
STN	Dec 83		Jan 84	Jan 84	Jan 84	Jan 84
	Dec. 20, 1983	15hz hi-cut	Discr rack downstairs	A/D input upstairs	A/D input (scope)	A/D output
	AMP(mv)	PER(sec)	AMP(mv)	AMP(mv)	AMP(mv)	AMP(mv)
KMPN	38	0.05		80		
NMHN	25	0.08	100	100?		
NVEN	38	0.07	80	30		
CDVN	8	0.06	30	30		
JSFN	13	0.15	40	30		
JBLN	13	0.14		20		
CAON	5	0.08	60	100?		
CALN	8	0.06	50	40?		
HPLN	38	0.06	60	40	2	10
HQRN	13	0.12	60	20		
BAVN	13	0.10	10	20	2	
BSGN	13	0.25	20	15	2	9
BPCN	13	0.12		20		
BSRN	8	0.05	20	20	2	
BPFN	20	0.06		20		
PJLN	13	0.05	30	30		
PHRN	13	0.10	30	15		
PMPN	25	0.11				
PRCN	50	0.20		20		
PHGN	13	0.06	20	50		
PMCN	13	0.05	40	30		
BSCN	5	0.05		15	2	
AVE	18	0.07	43	33	2	9.5

Table 9 Noise levels before and during the automatic calibration cycle at instruments on selected tracks from tape recorder B on March 22, 1984. Trace ID and operational parameters are in the first five columns. The next three columns show short and long period noise levels just before the calibration cycle. The last three columns show short period noise during the "seismometer out" part of the cycle as well as x-talk interference on the tested trace and x-talk to other traces during large deviations of the calibrated trace. Noise levels are in mv p-p.

TAPE	STN	CH	ATTN	RAD	PRE-CALIBRATION NOISE			CALIBRATION TEST		
					ampl(mv)/period(sec)			ampl(mv)/period(sec)		
					LP	(24DB)	SP	SEIS	X-TALK	X-TALK
					LP			OUT	INTERF	OTHER CH
B10	COS	3	18	2	30/1.7	(15)	120/.08	80/.06	220/.06	60-240/.07
"	CBS	4	18	3	600/.40	(300)	300/.08	30/.35	220/.09	50-180/.12
"	CMP	5	18	2	30/1.0	(15)	90/.06	70/.08	80/.07	100-300/.06
"	HCP	7	18	2	140/.60	(70)	180/.06	100/.06	130/.06	70-210/.07
"	BPR	8	18	2	80/2.0	(40)	80/.06	70/.06	150/.06	150/.06
B8	CAOV	1	6	0	120/3.0	(15)	20/.06	15/.05	-	-
"	CAOZ	2	42	0	2/1.7	(16)	8/.06	5/.10	-	-
"	CAOE	3	42	0	-	-	13/.05	15/.05	-	-
"	CALZ	4	42	0	10/2.5	(80)	10/.06	8/.06	-	-
"	CAON	5	42	0	-	-	13/.08	8/.14	slight	-
"	CALV	6	6	0	230/1.7	(29)	280/.25	18/.12	25/.10	-
"	CALN	7	42	0	5/3.0	(40)	7/.10	12/.06	25/.10	-
"	CALE	8	42	0	5/2.0	(40)	15/.06	15/.06	-	-
B5	JSC	1	18	0	160/2.0	(80)	30/.06	18/.06	-	-
"	JBC	2	18	0	200/1.6	(100)	170/.16	10/.06	-	-
"	JBZ	4	18	0	190/1.3	(95)	60/.05	10/.05	-	-
"	HCO	5	18	0	420/1.1	(210)	80/.10	30/.13	-	-
"	JTG	7	18	0	200/1.0	(100)	30/.06	20/.06	-	-
B14	BEM	1	12	1	70/1.8	(17)	30/.06	15/.15	20/.12	40/.07
"	BMS	3	18	0	40/1.4	(20)	20/.07	5/.05	-	30/.07
"	BAVZ	4	42	0	-	-	8/.07	10/.06	-	-
"	BAVN	5	42	0	-	-	8/.07	5/.05	15/.14	-
"	BAVV	6	6	0	100/1.3	(13)	15/.05	15/.12	-	-
"	BAVE	7	42	0	-	-	8/.07	5/.08	20/.11	-
"	BEH	8	18	0	60/1.4	(30)	40/.06	20/.10	50/.05	-
B13	HJS	2	12	0	80/1.0	(20)	130/.04	100/.10	70/.08	-
"	BSL	3	12	0	230/1.4	(29)	200/.10	30/.06	-	-
"	HQRV	4	12	0	110/1.5	(27)	40/.04	20/.07	slight	slight
"	HQRZ	5	42	0	-	-	10/.35	10/.35	30/.09	slight
"	HQRN	6	42	0	-	-	10/.35	10/.35	15/.06	30/.10
"	HQRE	7	42	0	-	-	10/.35	10/.35	-	-
"	HLT	8	12	0	60/1.4	(15)	30/.04	25/.10	slight	-
B9	HPLN	1	42	0	-	-	80/.05	70/.05	slight	-
"	JRR	2	12	0	100/2.5	(25)	40/.06	25/.10	50/.08	-
"	HPLV	4	18	0	150/1.6	(75)	160/.20	25/.14	slight	slight
"	HGS	5	12	1	50/1.4	(13)	25/.18	10/.30	25/.09	-
"	HPLE	6	42	0	-	-	15/.20	15/.18	slight	-
"	HGW	7	12	0	140/1.6	(70)	60/.06			
"	HPLZ	8	42	0	-	-	25/.06	25/.06	-	-

Table 9 continued

TAPE	STN	CH	ATTN	RAD	PRE-CALIBRATION NOISE			CALIBRATION TEST			
					ampl(mv)/period(sec)			ampl(mv)/period(sec)			
					LP	(24DB)	SP	SEIS	X-TALK	X-TALK	
								OUT	INTERF	OTHER	CH
B6	JBLV	1	18	0	100/2.0	(50)	100/.05	70/.06	?		?
"	HSL	2	18	0	100/1.2	(50)	100/.07	80/.07	?		?
"	JRG	6	18	0	120/1.4	(60)	80/.07	50/.06	?		?
"	MYL	7	18	2	90/.50	(45)	70/.05	70/.07	?		?
"	JBLE	8	42	0	-	-	60/.07	50/.07	?		?
B3	JSFV	1	24	0	120/1.8	(120)	20/.05	5/.10	-		slight
"	JSFN	2	42?	0	100/1.6	(800)	5/.07	5/.06	-		-
"	JPS	3	18	0	290/1.8	(145)	15/.08	10/.08	slight		-
"	JLT	5	24	0	170/2.0	(170)	60/.08	30/.05	slight		-
"	JBG	7	24	0	310/1.3	(310)	20/.08	20/.16	slight		-
"	JSFZ	8	42	0	10/1.6	(80)	15/.10	15/.15	-		-
B2	CMR	1	12	0	70/1.8	(17)	25/.07	20/.06	40/.09		-
"	CDO	3	24	0	50/3.0	(50)	40/.07	35/.07	-		-
"	CMO	4	18	0	70/1.2	(35)	60/.08	20/.09	40/.06		-
"	CVA	5	18	0	20/2.2	(10)	20/.15	30/.09	slight		-
"	CSH	8	18	1	50/2.0	(25)	70/.05	25/.09	-		-



Output noise versus attenuator  
setting for four seismic systems

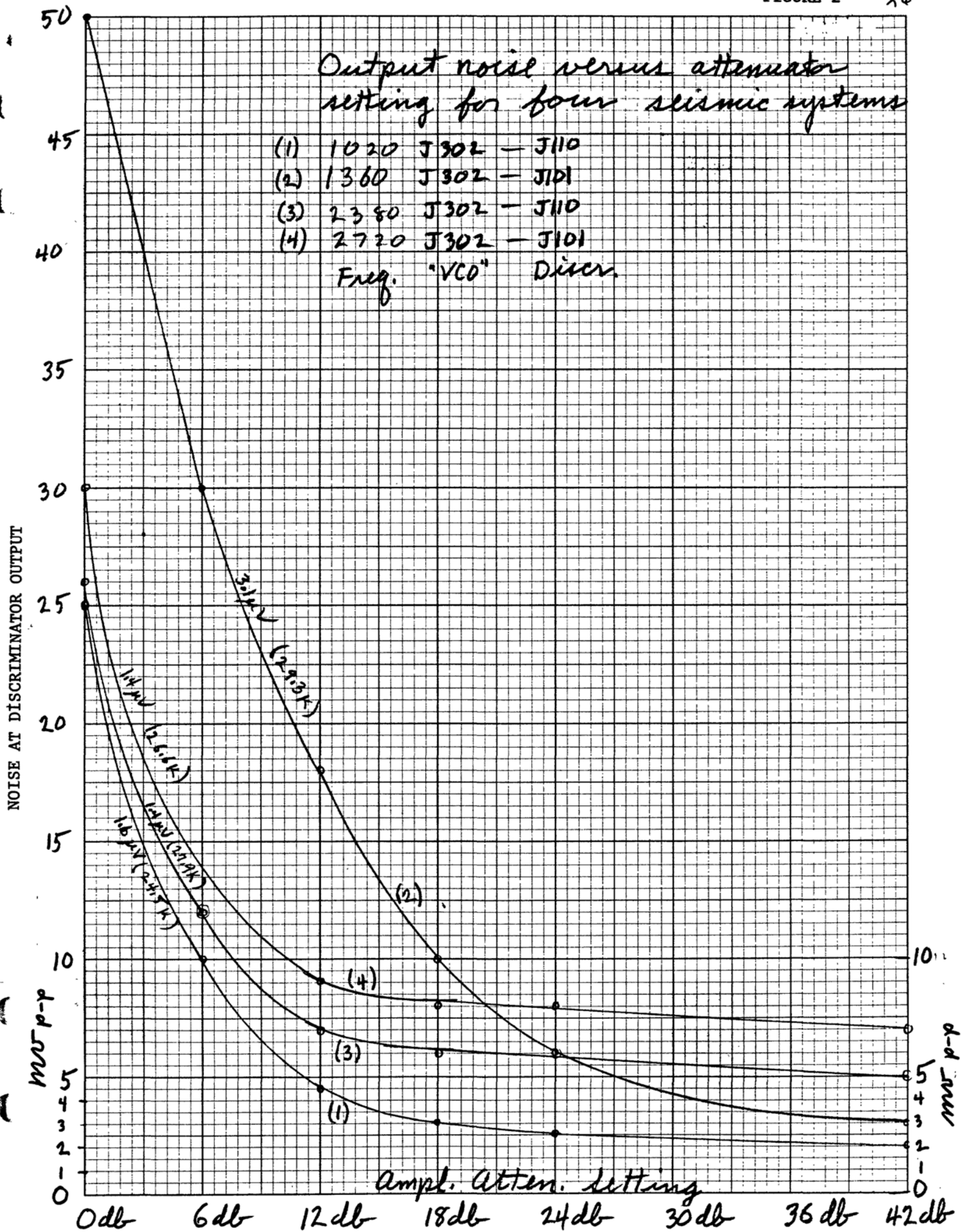
(1) 1020 J302 - J110

(2) 1360 J302 - J101

(3) 2380 J302 - J110

(4) 2720 J302 - J101

Freq. "VCO" Discr.



system dynamic range versus preamp  
and mod./disc. noise and attenuator setting

	Noise	attenuator setting	
		18 db	24 db
(1)	1 $\mu$ V / 2 mV	62 db	64 db
(2)	" / 4 mV	58 db	59 db
(3)	" / 6 mV	56 db	56 db
(4)	" / 8 mV	53 db	53 db
(5)	2 $\mu$ V / 2 mV	56 db	61 db
(6)	" / 4 mV	55 db	57 db
(7)	3 $\mu$ V / 4 mV	52 db	57 db
(8)	" / 8 mV	50 db	53 db

Preamp noise      Mod/disc noise

System Dynamic Range

DISCRIMINATOR OUTPUT

mV p-p

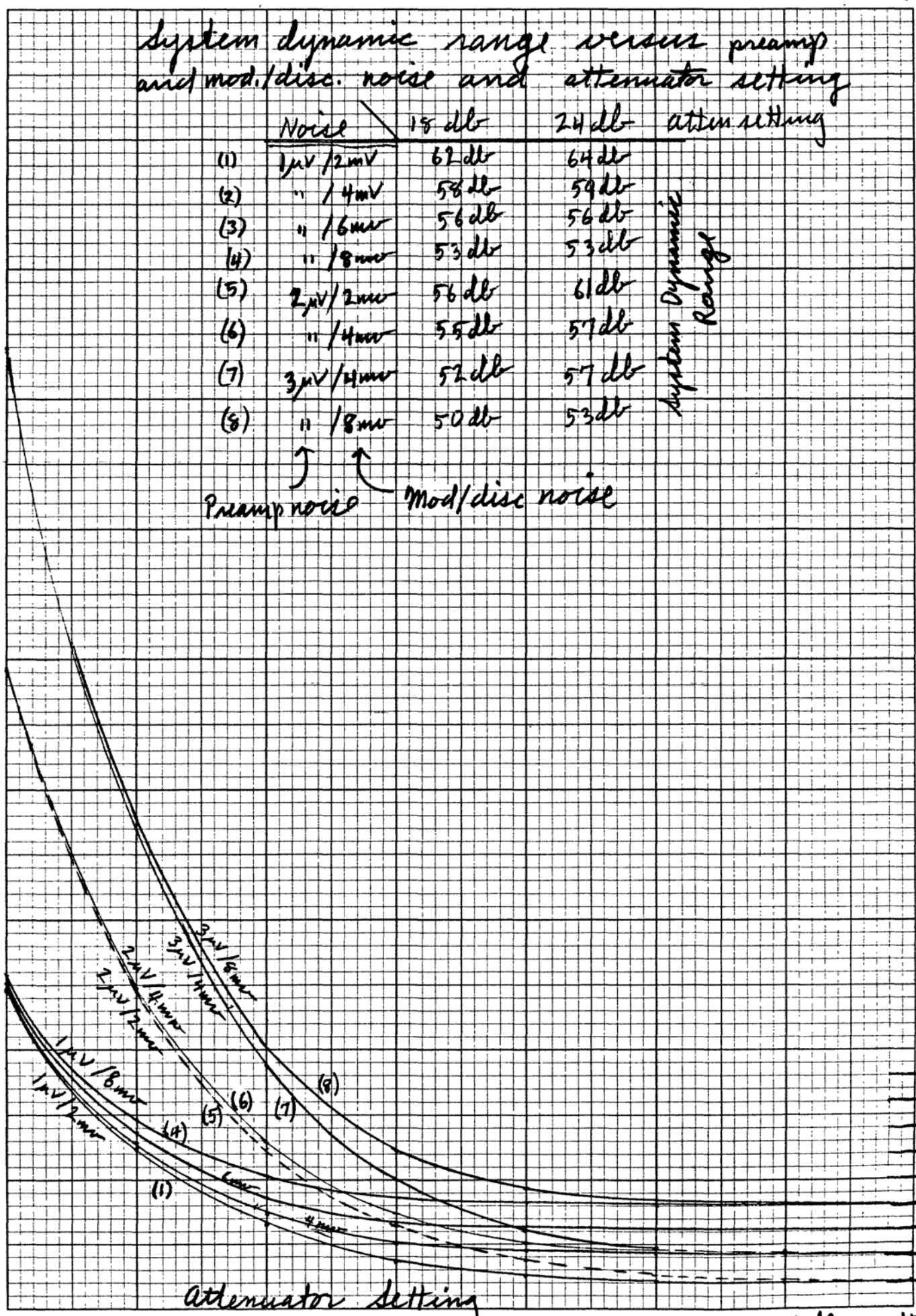
Dynamic Range of System

db

46.9  
48.0  
49.1  
50.5  
52.0  
54.0  
56.5  
60.0  
66.0

Attenuator setting

0 db    6 db    12 db    18 db    24 db    30 db    36 db    42 db



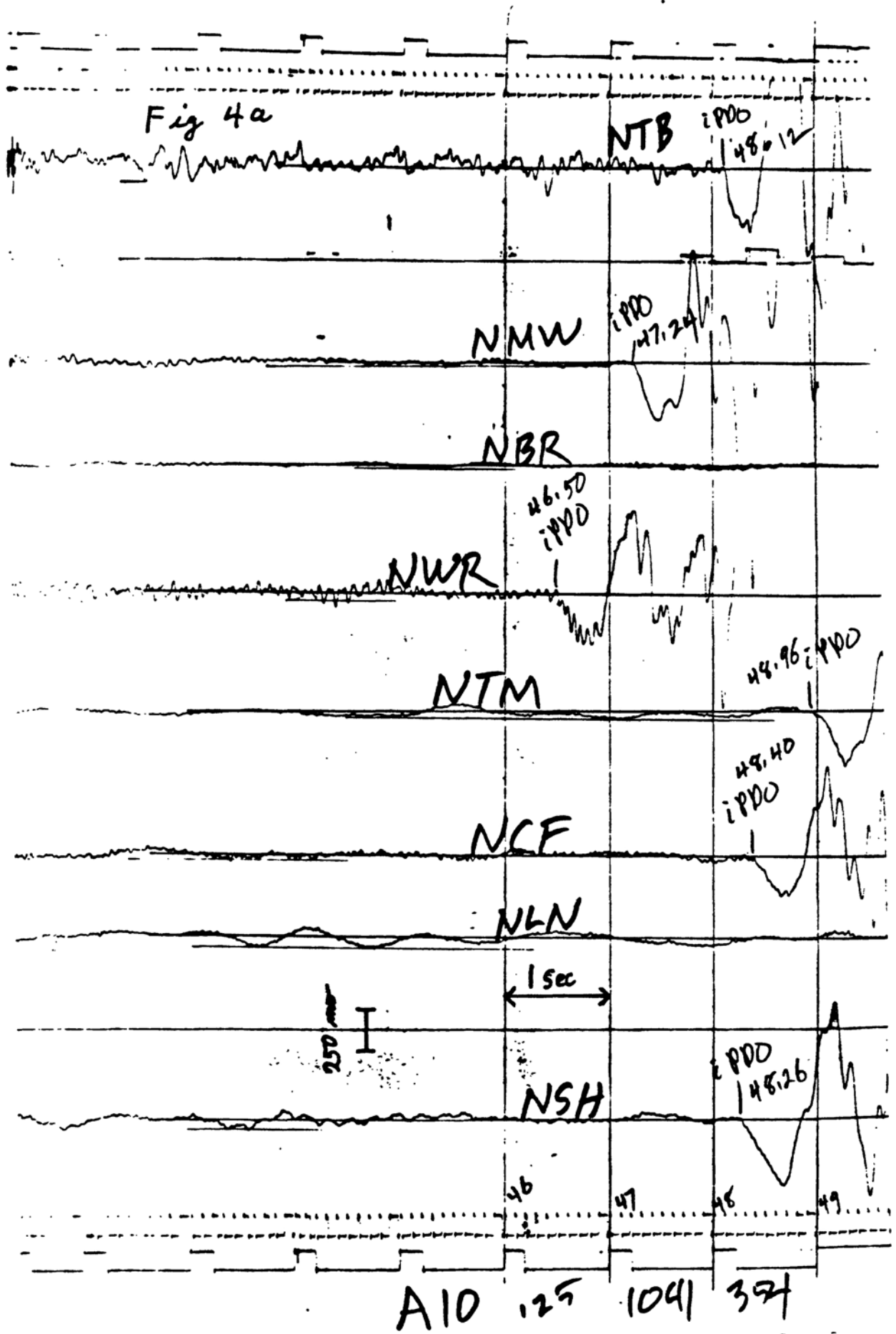
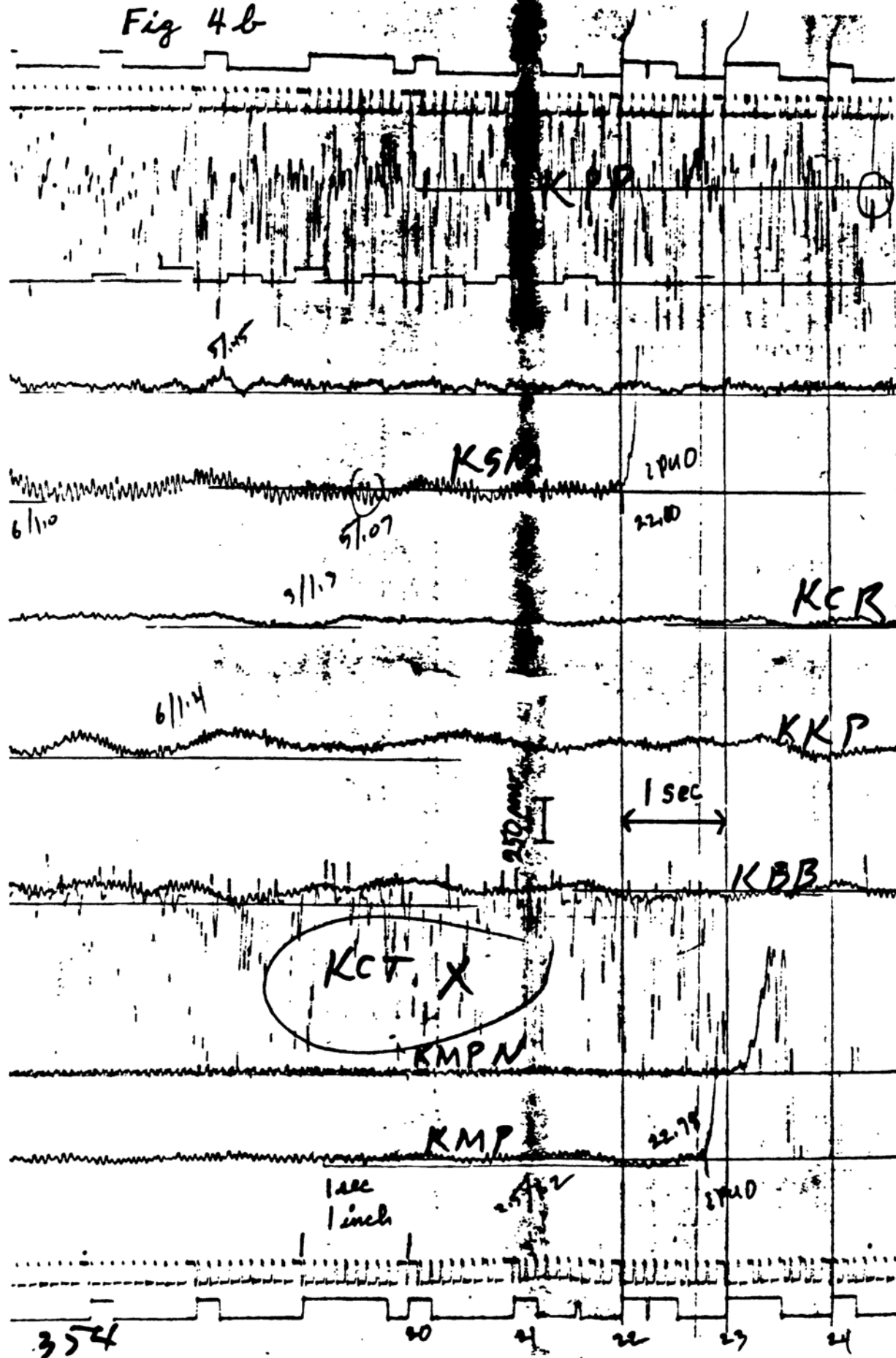




Fig 4b



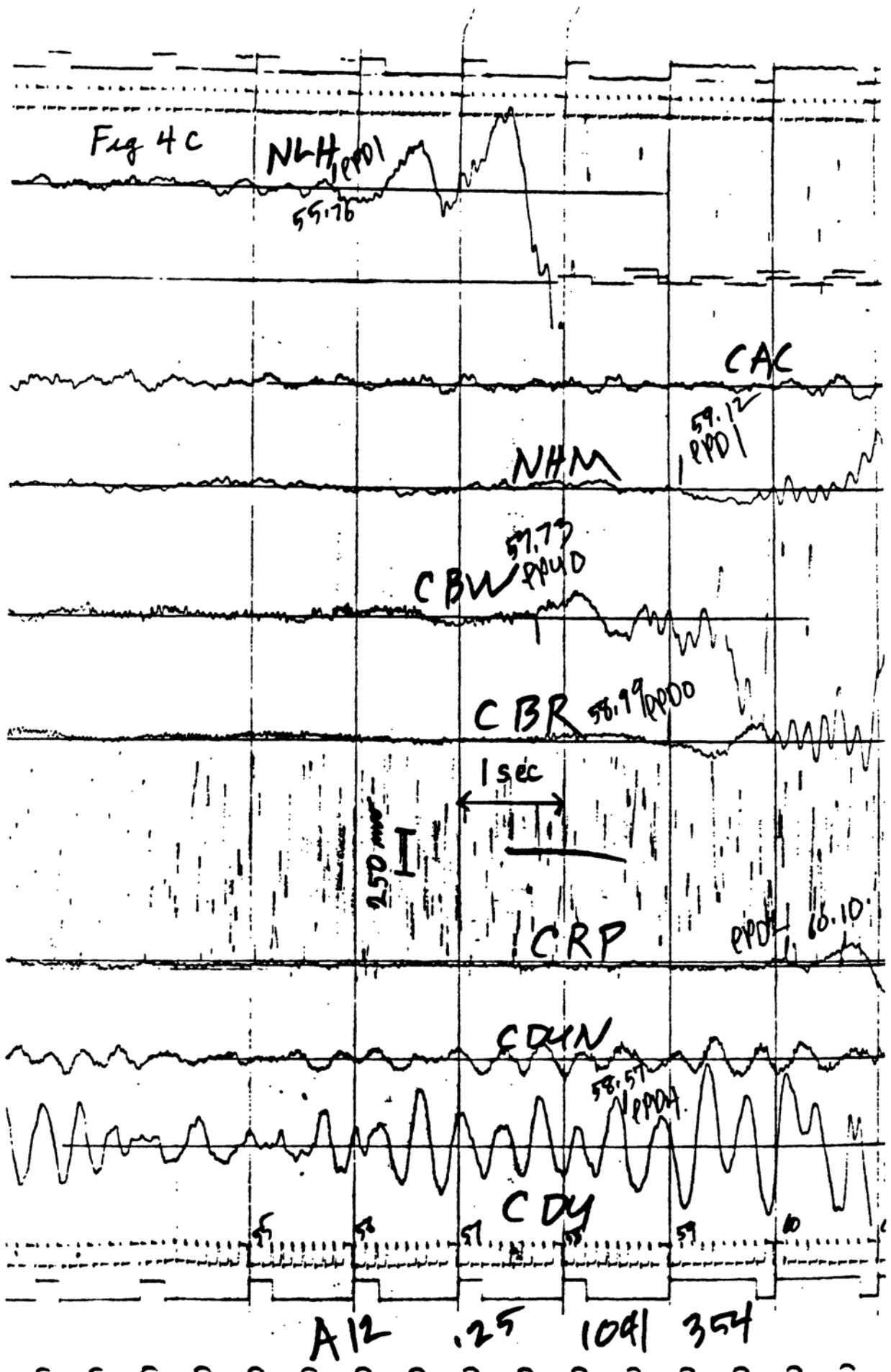
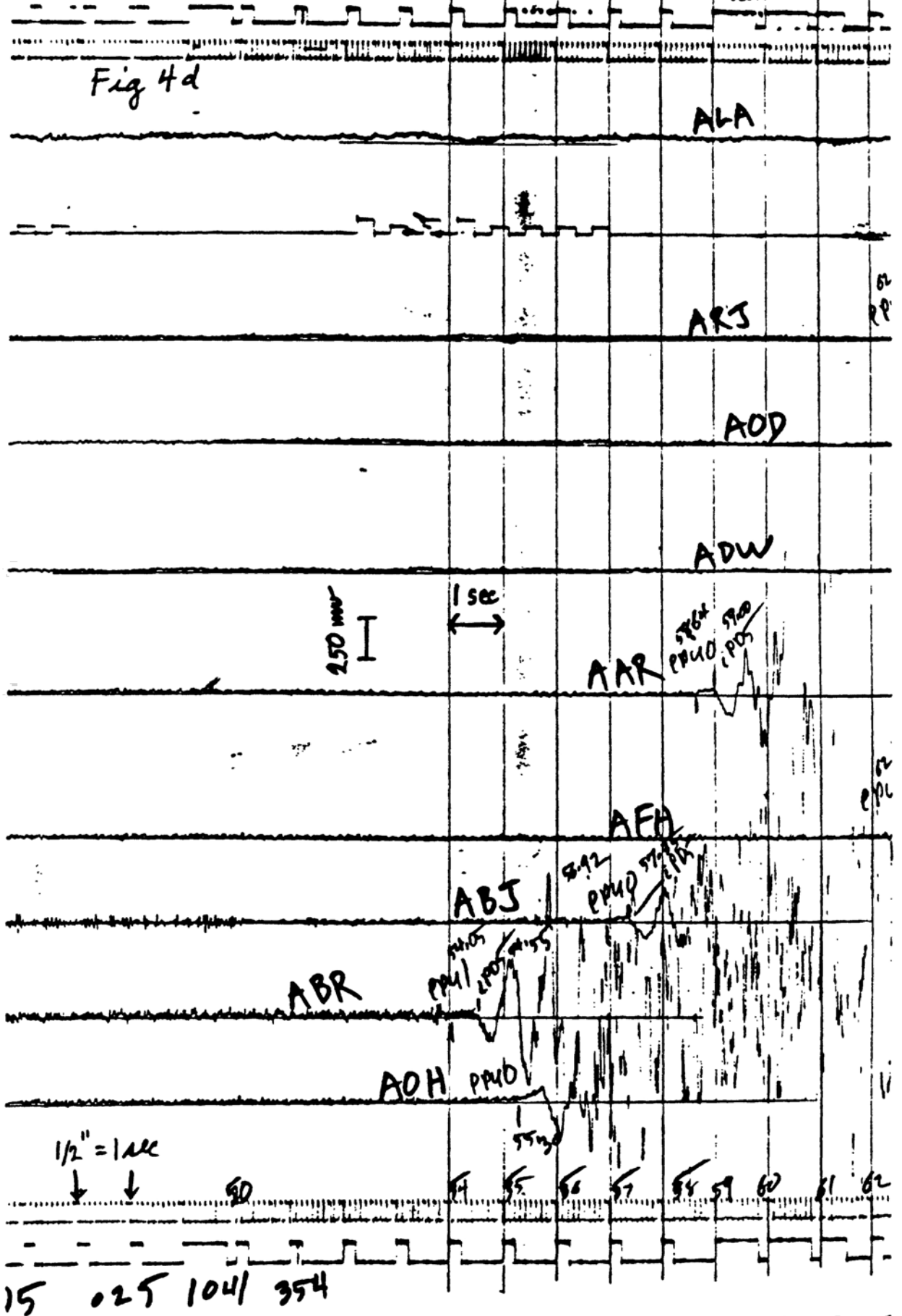


Fig 4d



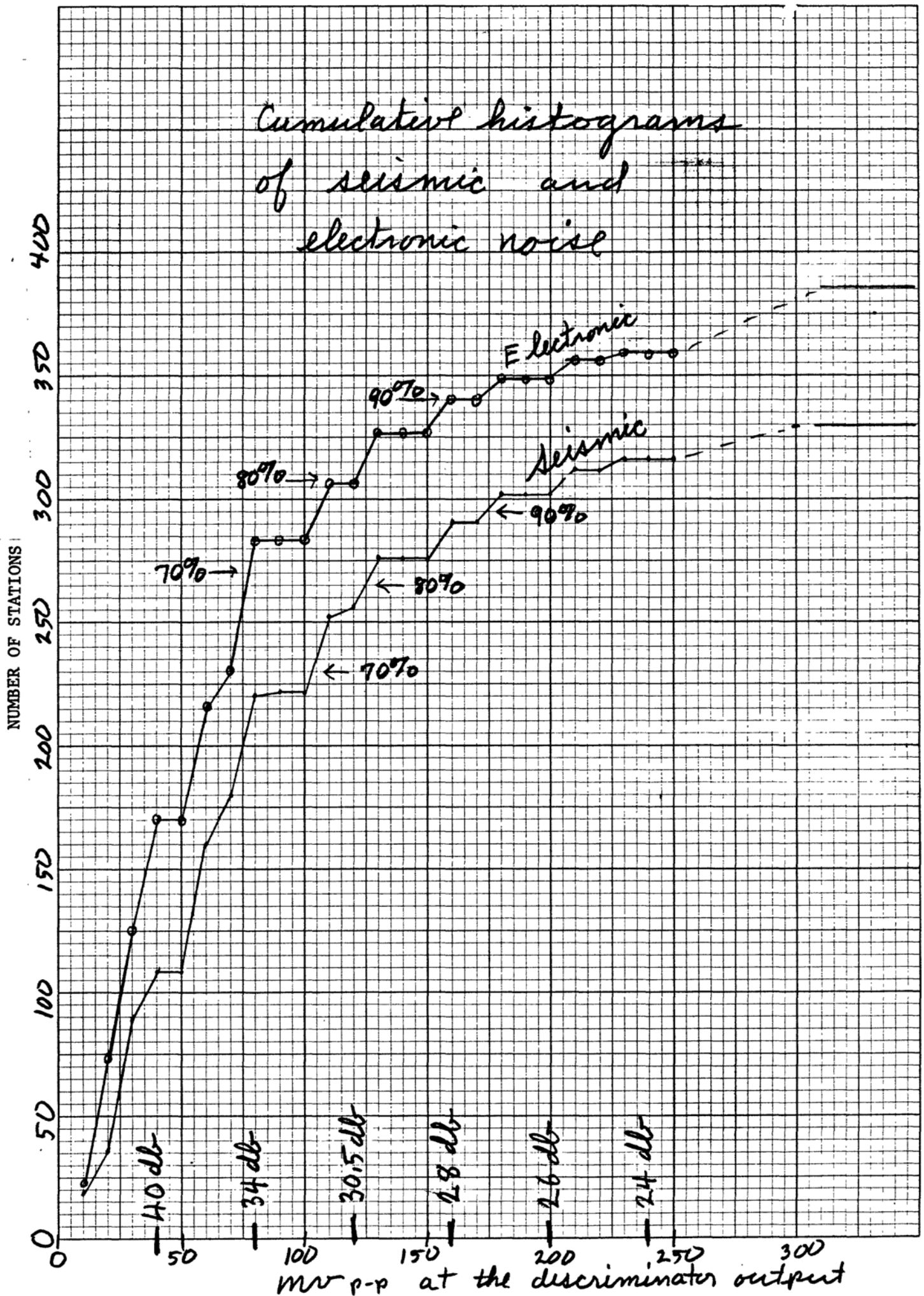
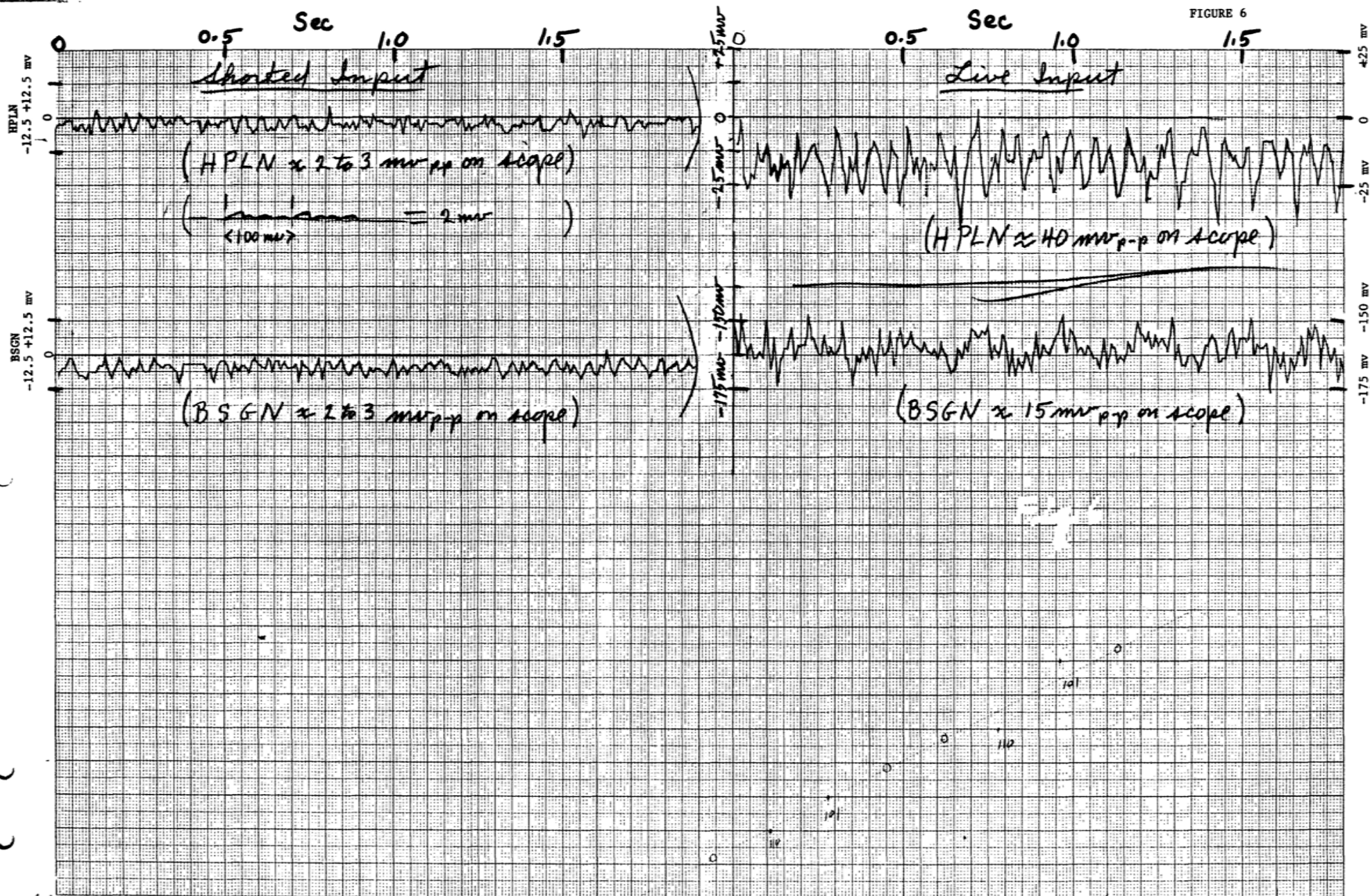


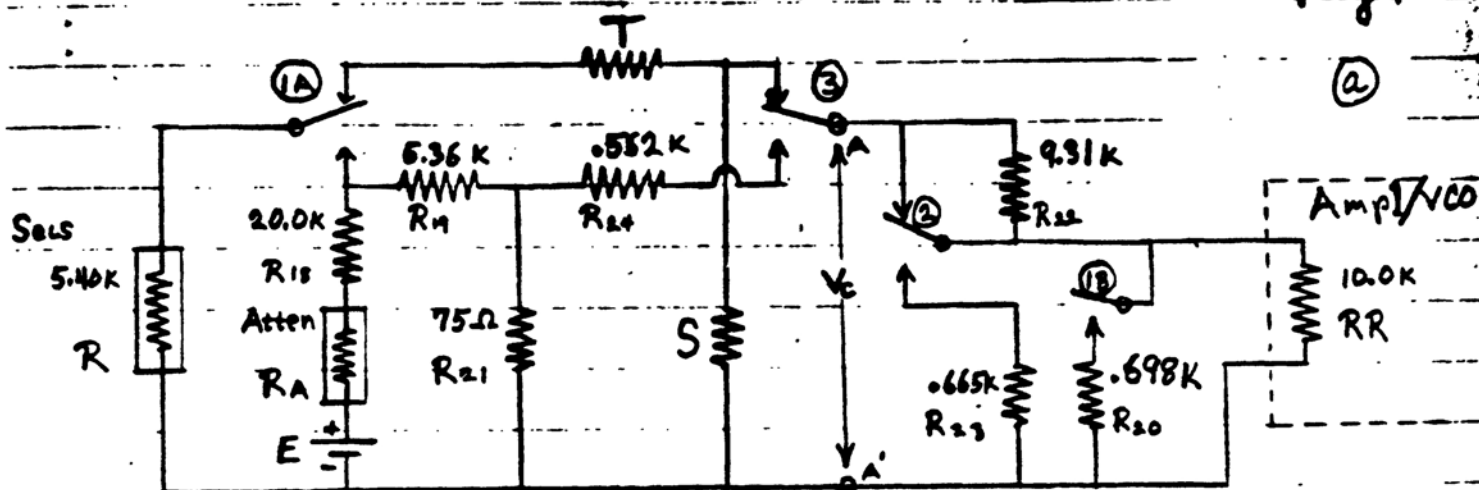
FIGURE 6



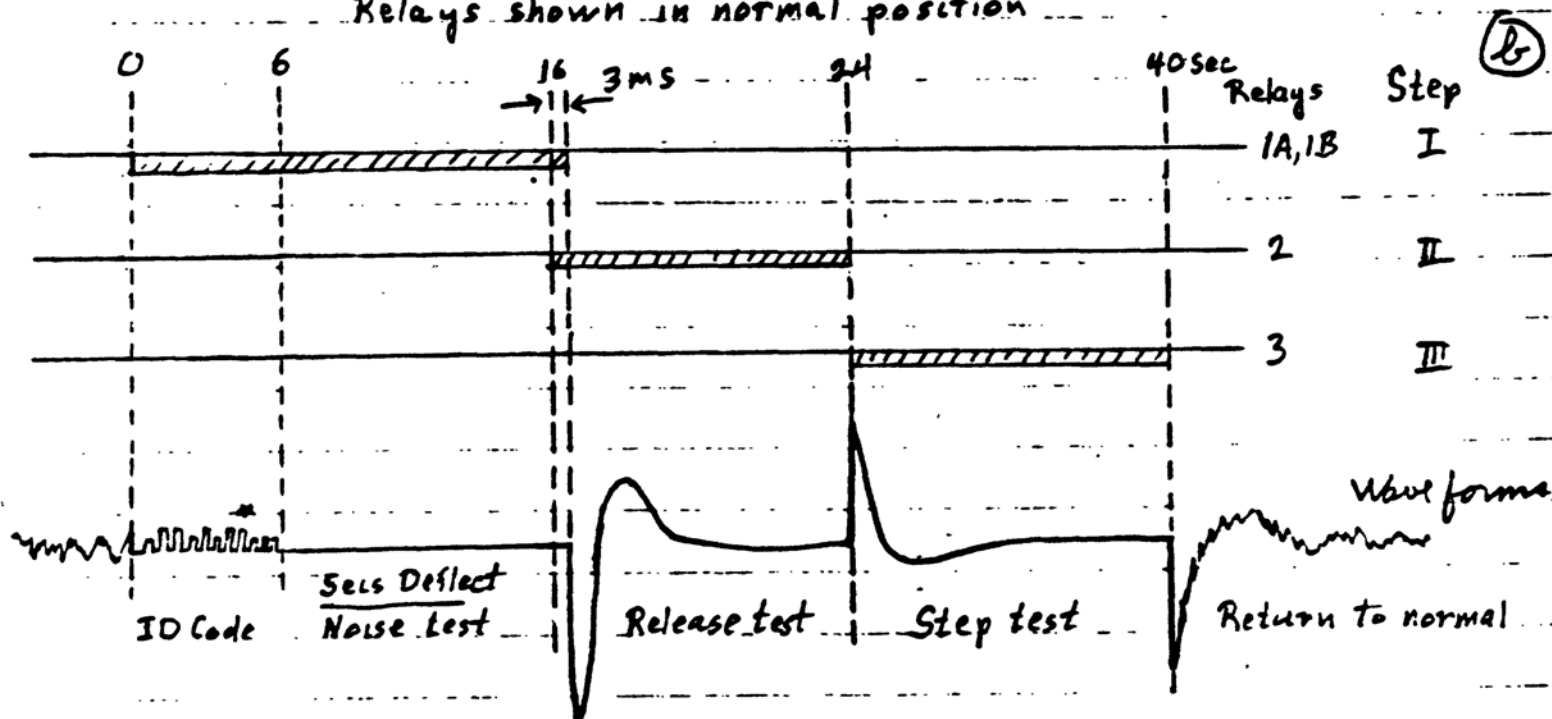


C5 Calib

Fig 7



Relays shown in normal position



Step I: a) Accelerometer mass offset (ID code supplied by ID unit)  
 b) Amplifier terminated to preserve balance

II: a) 24 db pad inserted  
 b) Mass released 3ms later

III: a) Voltage step applied to amplifier  
 b) Station returned to normal 16 sec later

\* Input directly to VCO by code generator unit

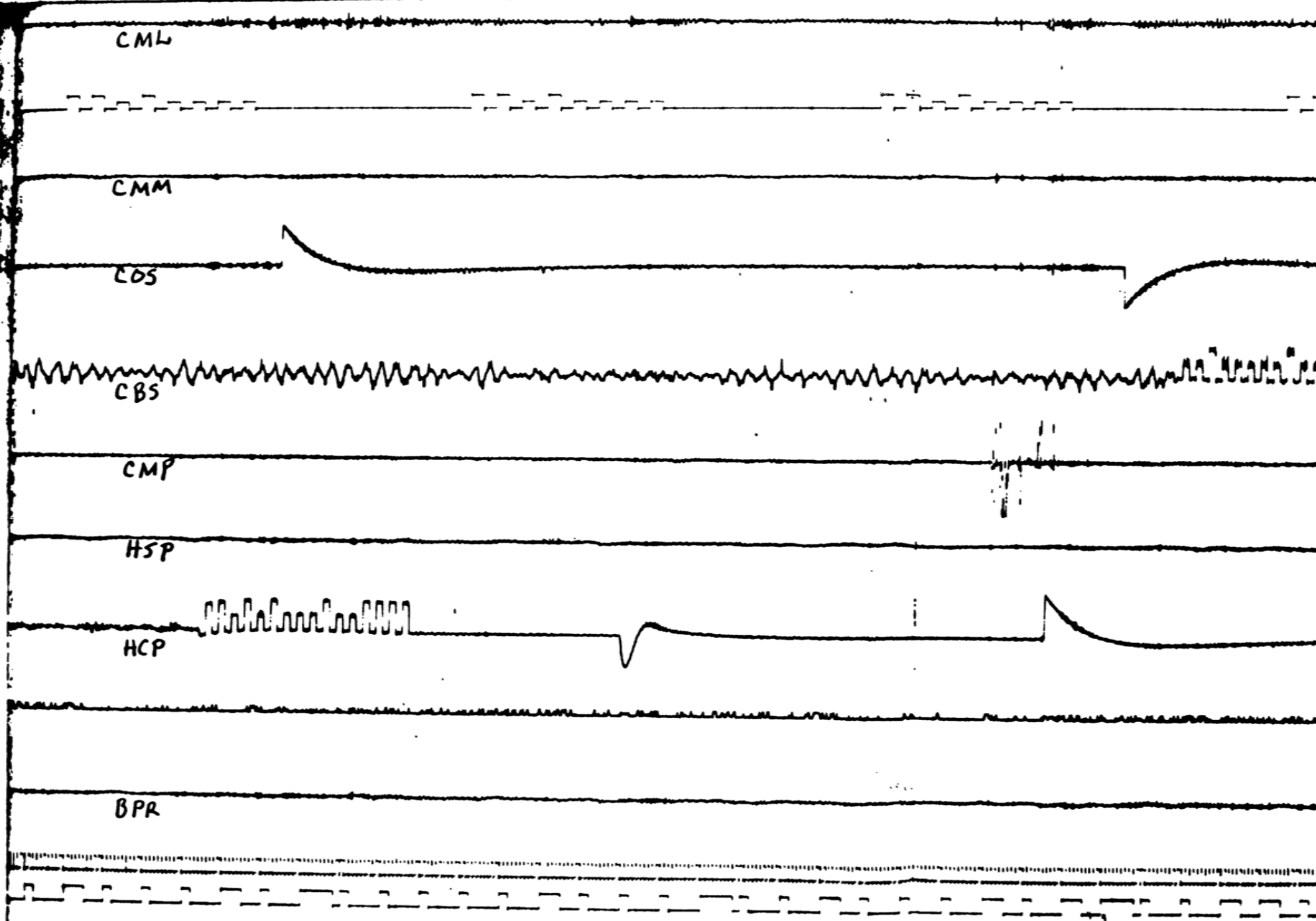


Fig 8a

sens. = 100 mV/mm

B10 110

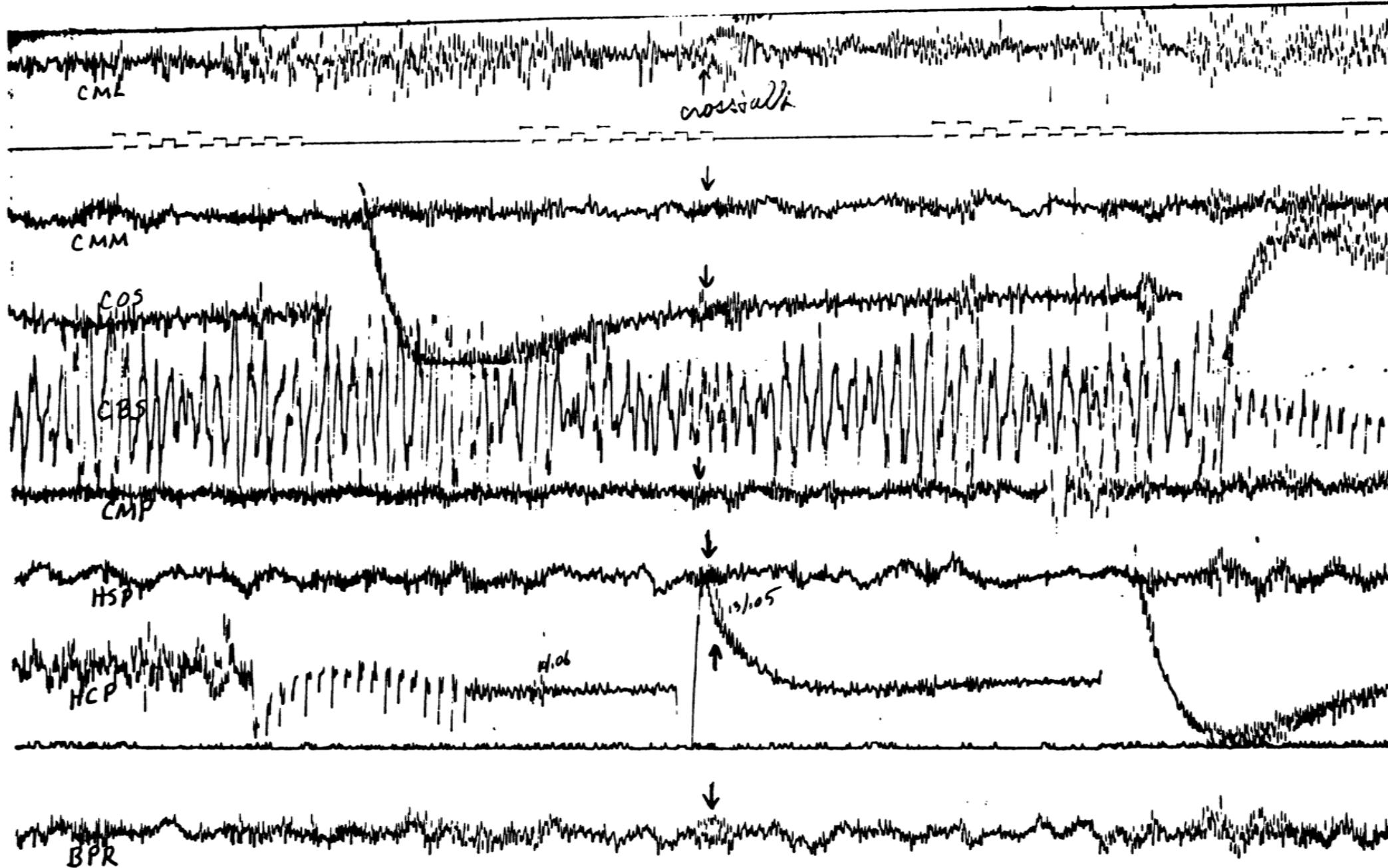


Fig 8b

Sens. = 10 mv/mm

B10 0.1 filter in 2



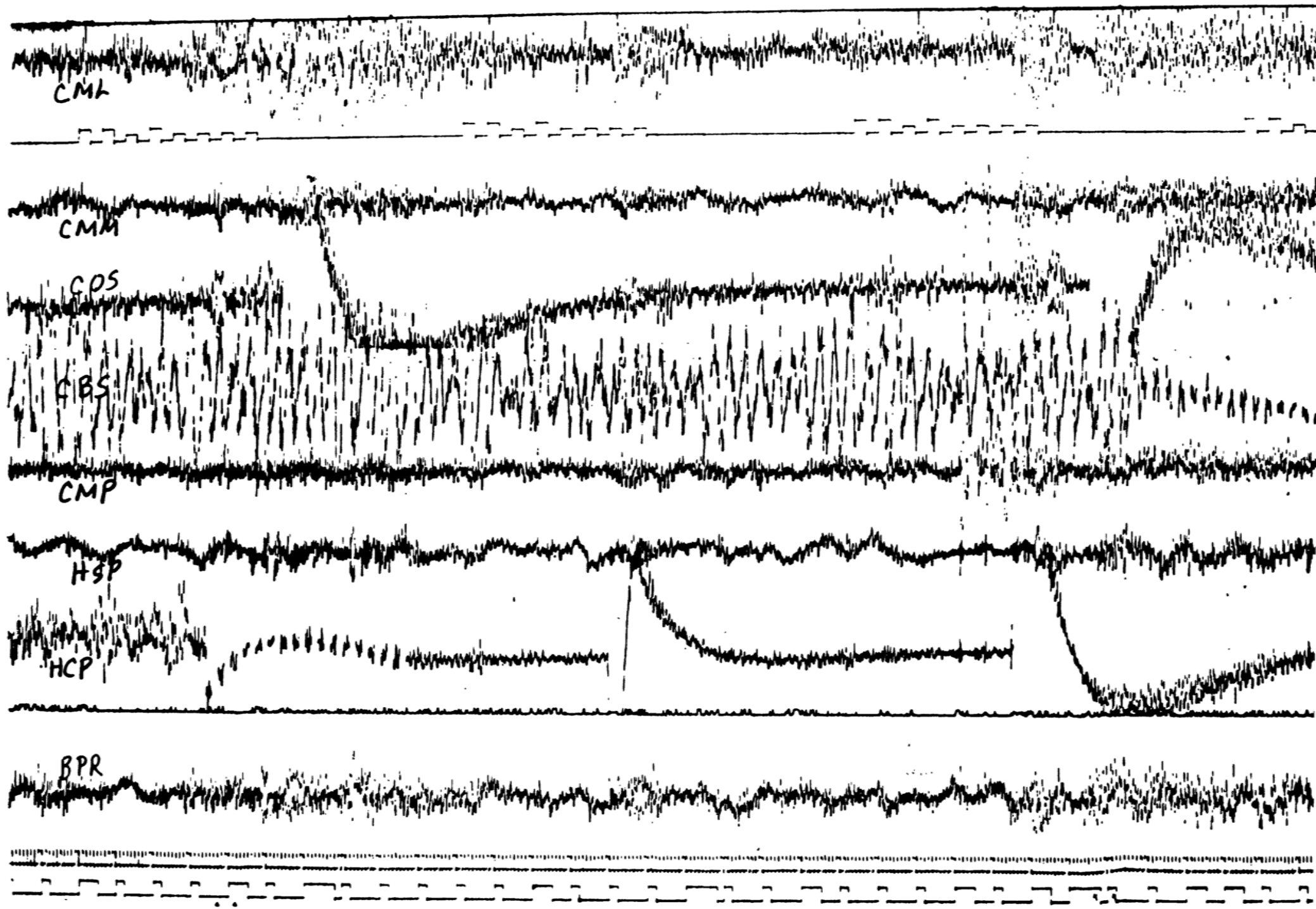


Fig 8c

SENS = 10 mV/mm B10 0.1 filter out 37

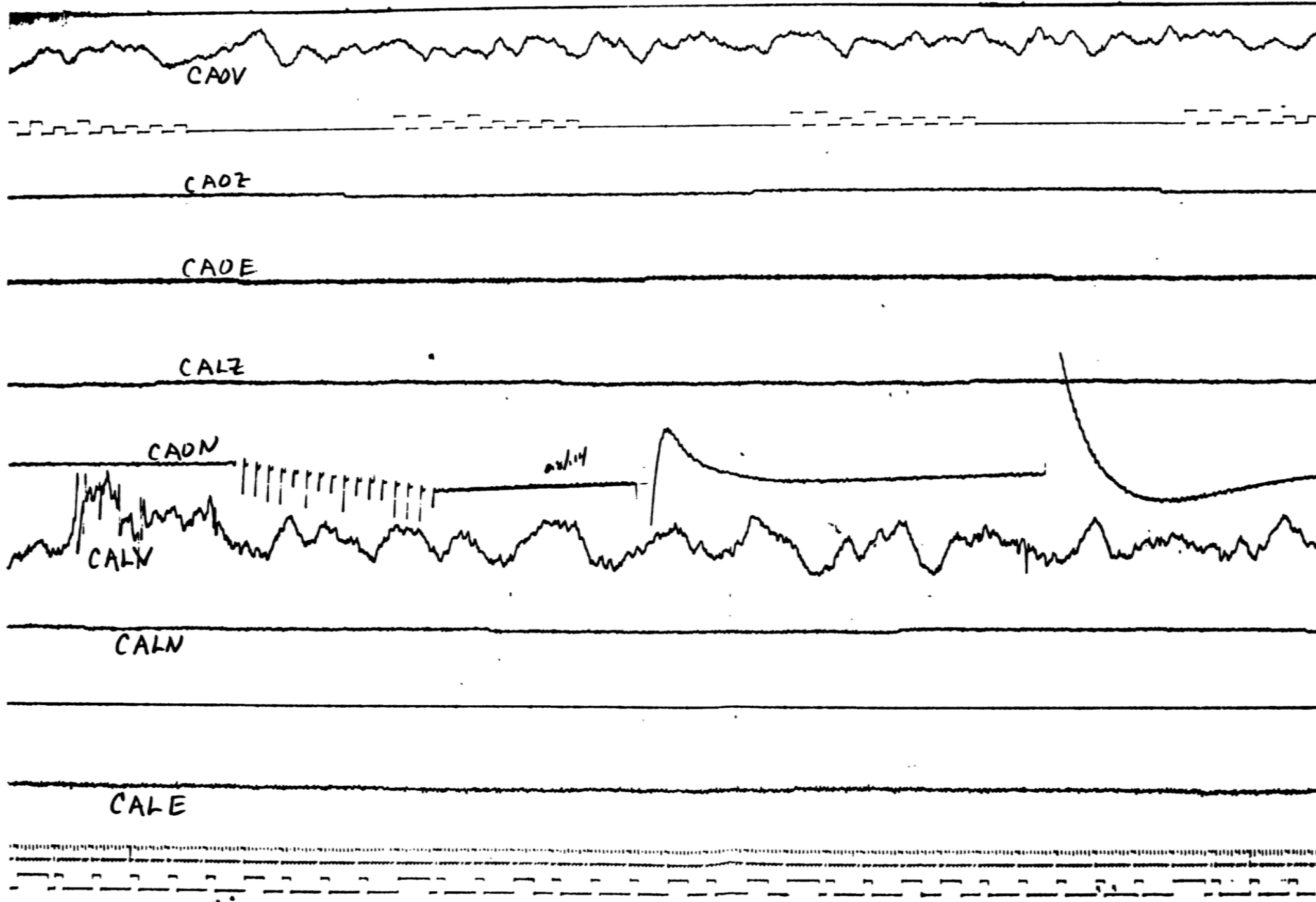


Fig 8d

Sens. = 10 mV/mm

B8 0.1 filter in 38

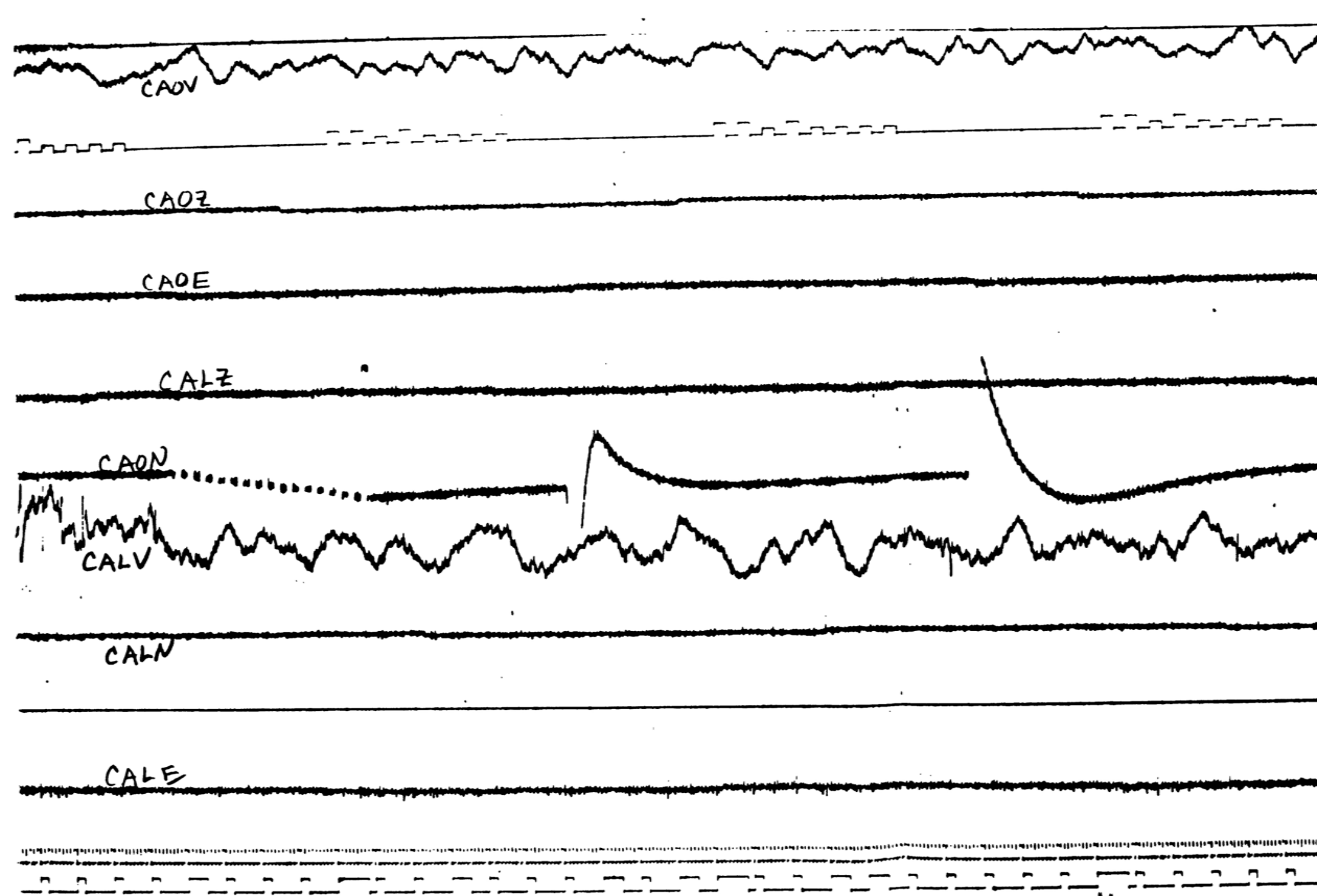


Fig 8e

Sens. = 10 mV/mm B8 0.1 filter out



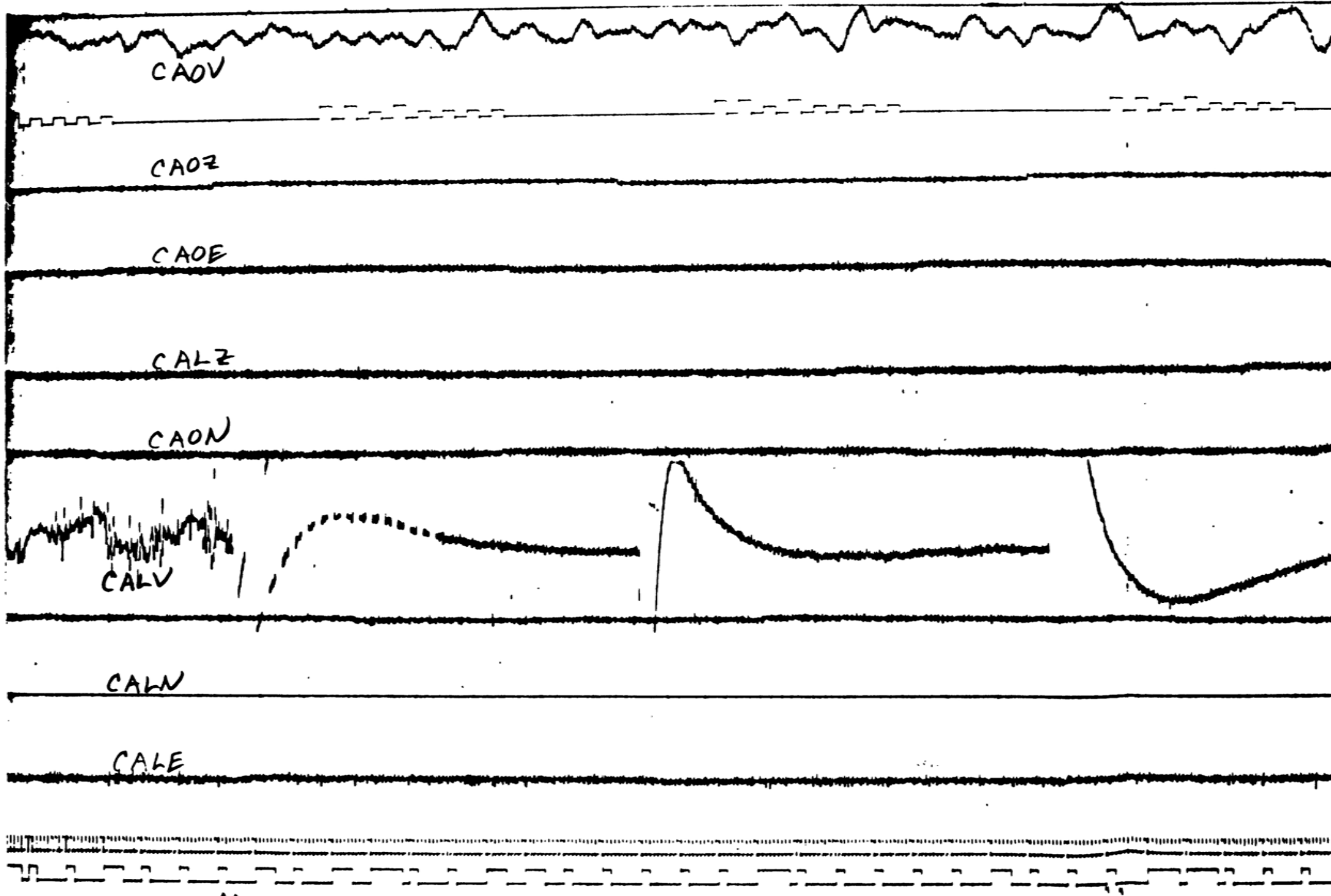


Fig 8g

Scale = 10 mv/mm B8 0.1 filter out

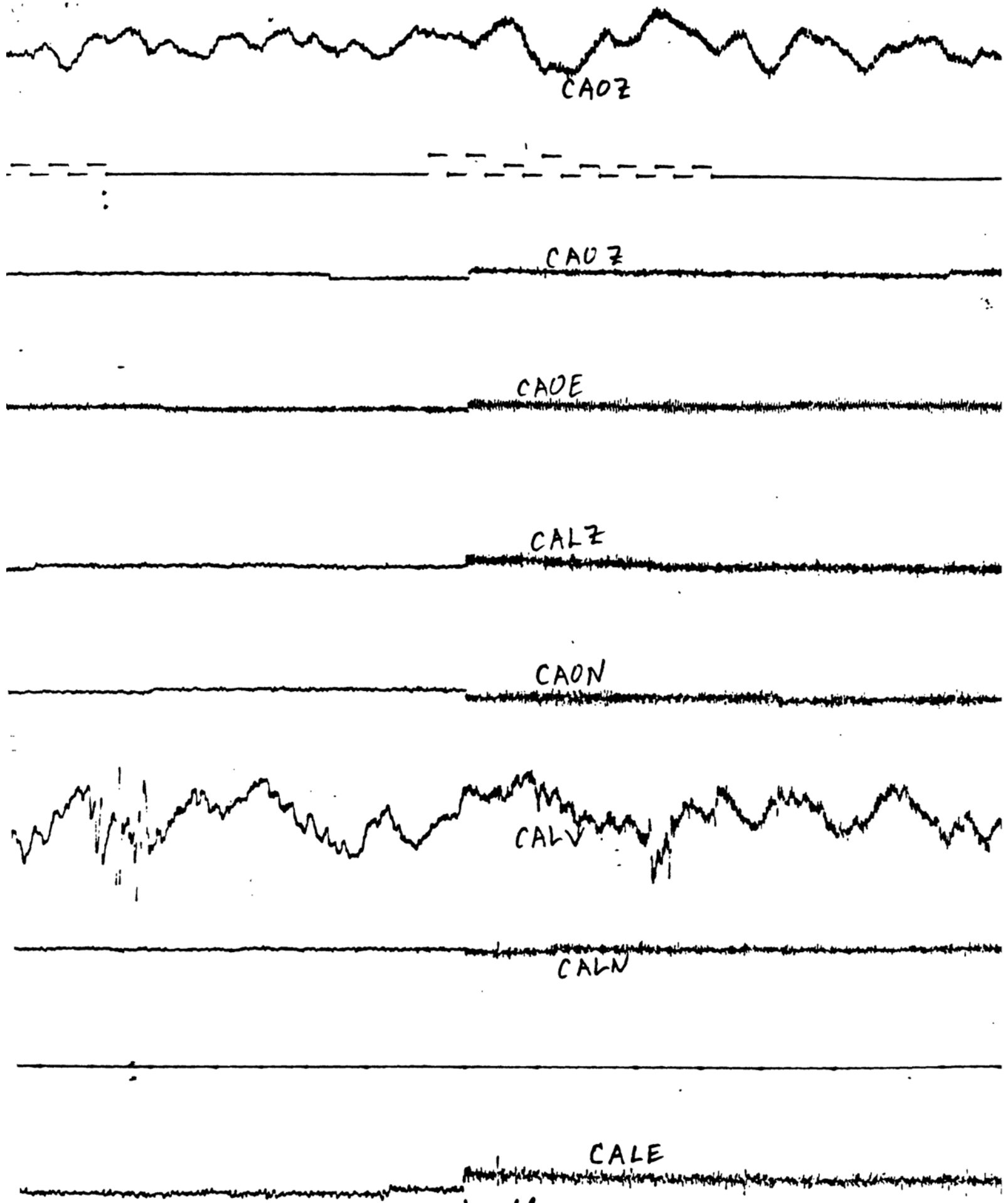


Fig 8 h

on | off  
filter

sent. = 10mv/mm B8 0.1

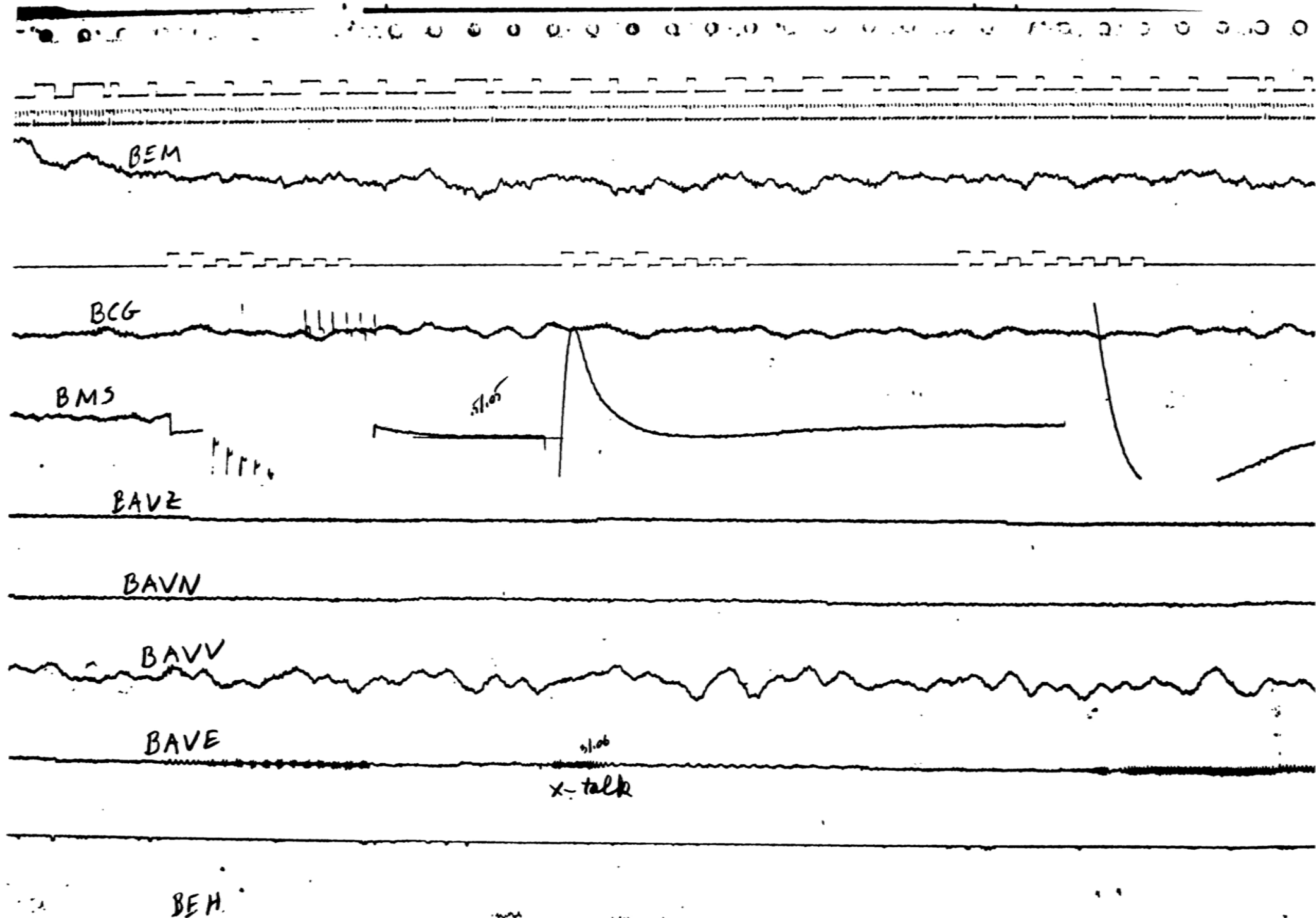


Fig 8 i

Sens. = 10mv/mm B14 0.1 filter in

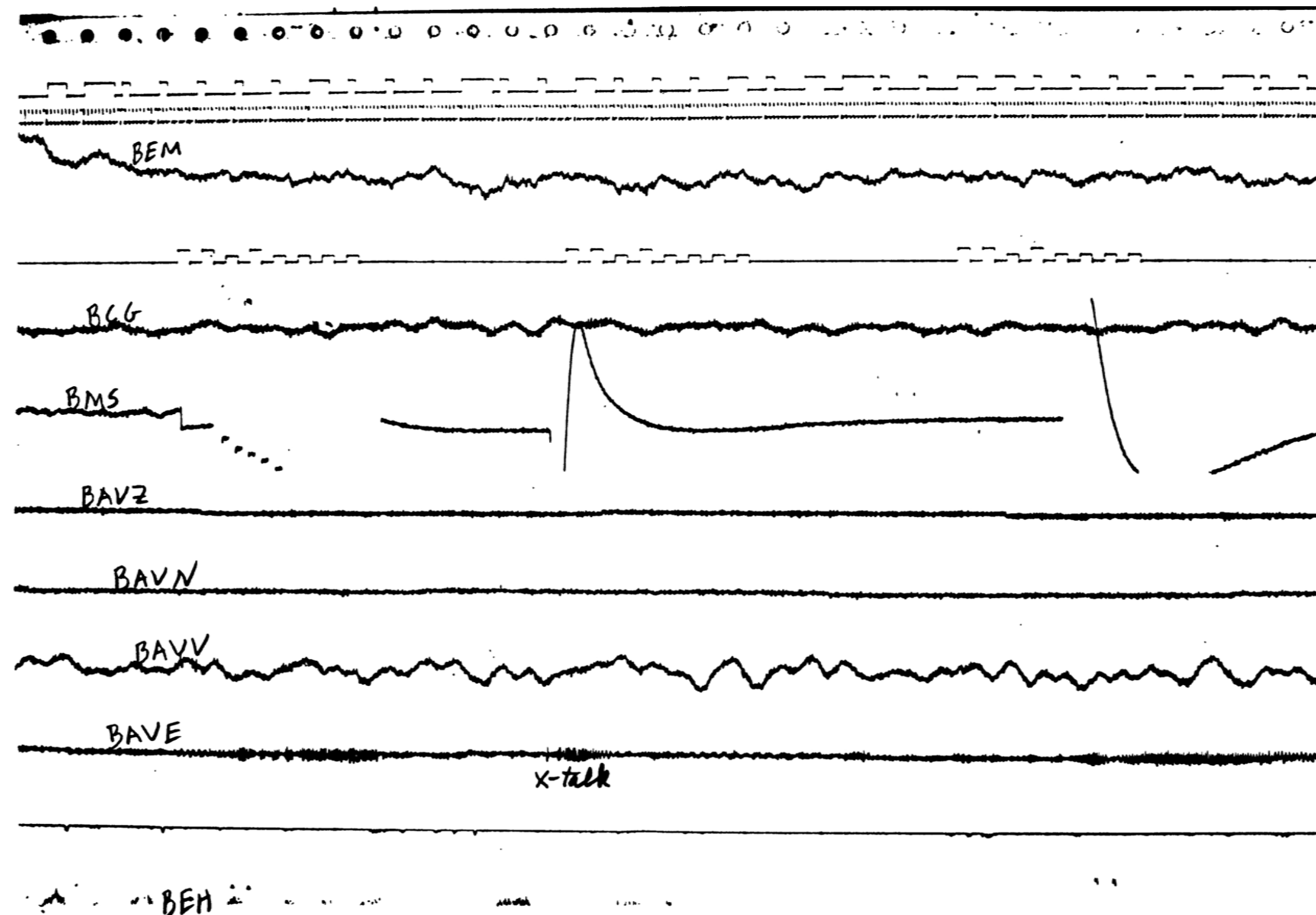


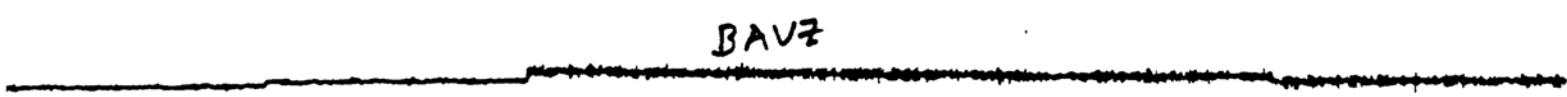
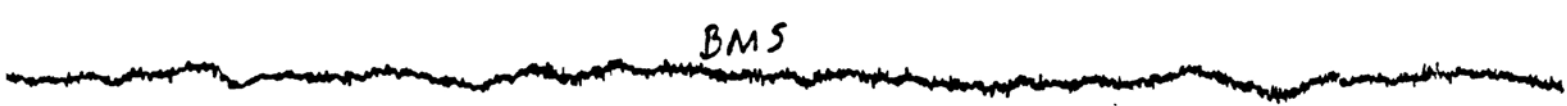
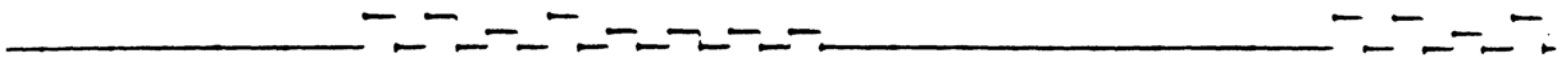
Fig 8j

sens. = 10 mv/mm B14 0.1 filter out <sub>HF</sub>



B14

PA. 47 follow



scale = 10 mm / mm

B14 0.1

Fig 8k



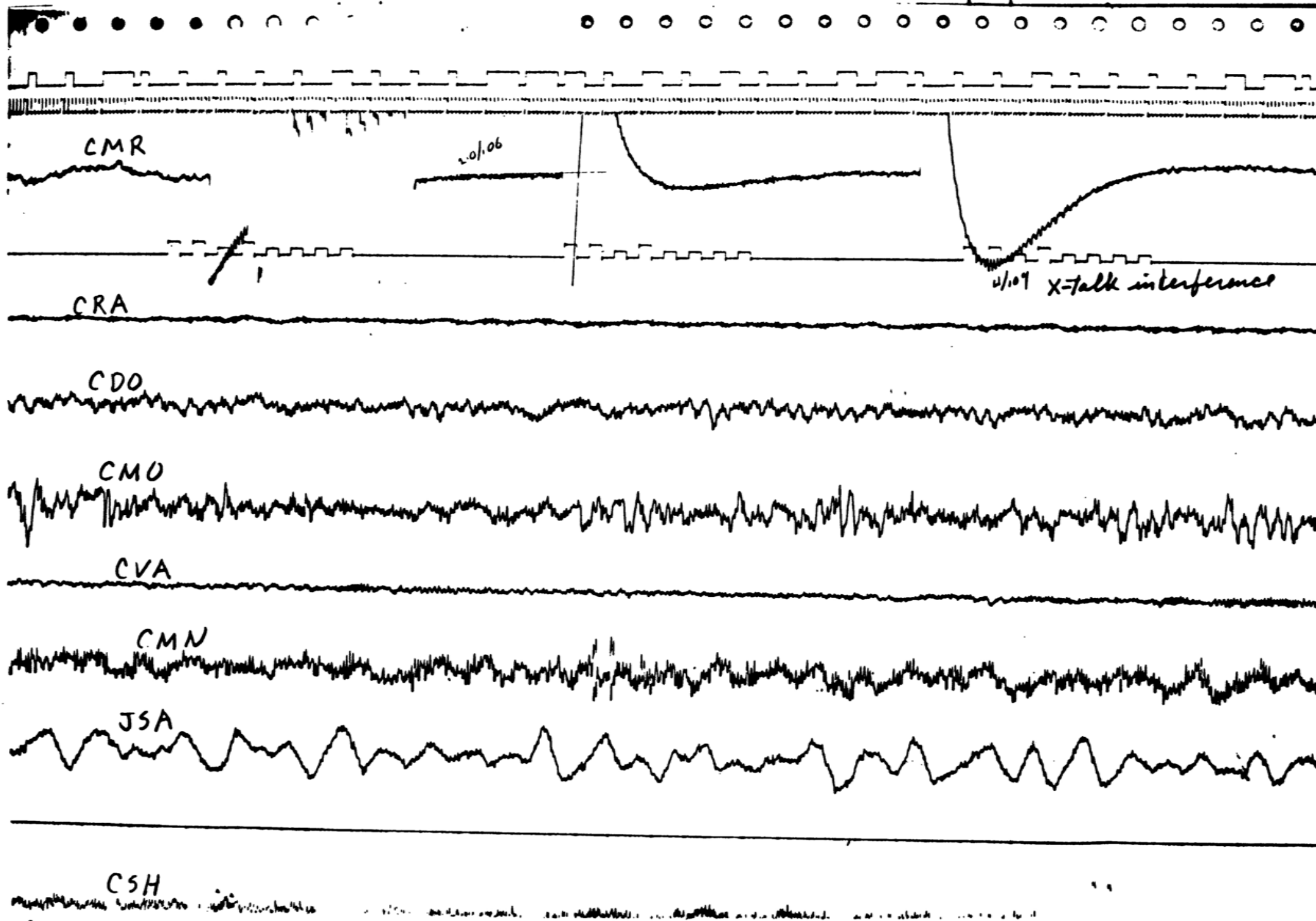


Fig 8l

sens. = 10mv/mm B2 0.1 filter in 1/17

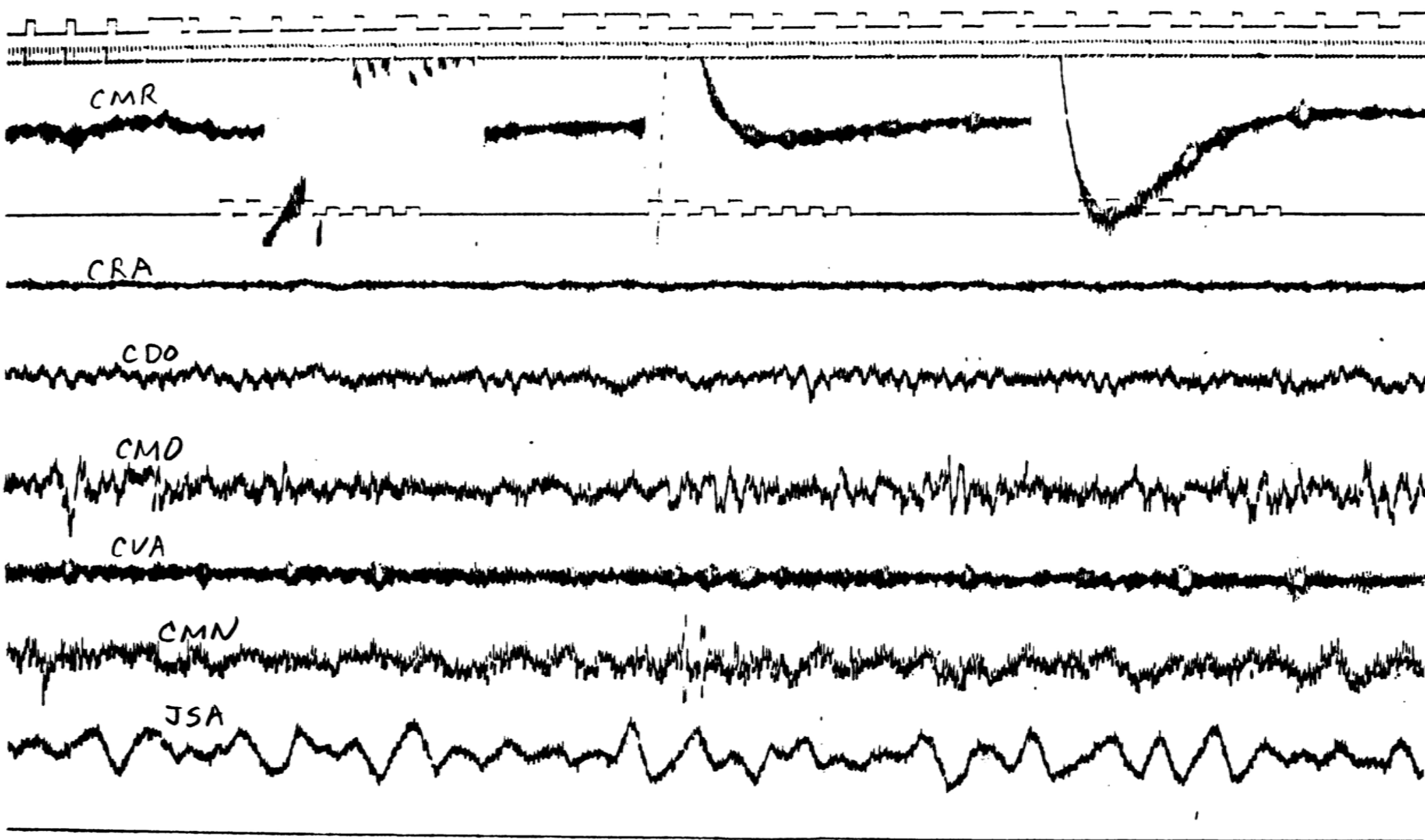


Fig 8m

Amplitude = 10mv/mm B2 0.1 filter out

filter

BZ

49

CMR

CRA

CDO

CMO

CVA

CMN

JSA

on filter off

sens. = 10 mv/mm

BZ 0.1

Fig 8n

CSH