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NOTES ON SOME EXPERIMENTS ON THE APPLICATION OF SUBTRACTIVE COMPENSATION TO USGS SEISMIC MAGNETIC TAPE RECORDING AND PLAYBACK SYSTEMS

by

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Open-file Report 75-663
1975

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I Introduction

The purpose of these experiments is to lay the groundwork for the implementation of subtractive compensation of the USGS seismic network tape playbacks utilizing the Develco model 6203 discriminators at a x1 playback speed. Although the Develco discriminators were designed for this application and a matching Develco compensation discriminator was purchased, effective use of this system for subtractive compensation has been blocked by the inadequate (frequency dependent) matching of the phase of the compensation signal to that of the data signal at the point compensation is carried out in the data discriminators.

John Van Schaack has ameliorated the phase mismatch problem by an empirical alteration of the compensation discriminator input bandpass filter. We have selected a set (of eight) Develco discriminators and adjusted their compensation signal input levels to minimize spurious signals (noise) originating from tape speed irregularities. The sensitivity of the data discriminators was adjusted so that deviations of +125 Hz and -125 Hz produced output signals of +2.00 volts and -2.00 volts, respectively. The eight data discriminators are driven by a multiplex signal on a single tape track (subcarriers 680, 1020, 1360, 1700, 2040, 2380, 2720, and 3060 Hz). The Develco-supplied compensation discriminator requires an unmodulated 3125 Hz signal on a separate tape track.

This set of 9 discriminators (8 for data and 1 for compensation) was set up in conjunction with the seismic network playback machine (B & H VR-3700B associated with the Control Data Corporation model 1700 digital computer in the computer room) for testing.

The standard calibration signals produced by Jim Chan's automatic tape system calibrator, which are recorded daily on all three network recorders, were used to evaluate the dynamic range of the tape recording and playback system and the effectiveness of the subtractive compensation system. The calibration signal is produced by a full set of 8 test VCO's with their outputs multiplexed onto a single channel. The calibration signal consists of 3 parts: (1) Eleven seconds of unmodulated subcarriers; (2) one cycle of a 2 Hz square wave, simultaneously applied to all subcarriers, in which each subcarrier is deviated first +4.17 Hz then -4.17 Hz (3.33% of the $\pm$ 125 Hz full deviation); (3) an additional 4 seconds of unmodulated subcarriers. When these calibration signals were played back through the bank of discriminators that had been set up for subtractive compensation, the results were disappointing:

a. Considerable variation was observed in the quality of playbacks from different tape recorders, from different tape tracks on the same recorder, and from different day's calibration signals on the same track of the same recorder.

b. Use of subtractive compensation produced a consistent but only minor improvement in the playbacks.

c. Some clear "glitches" that correlated across the data channels (with relative amplitudes roughly proportional to the channel subcarrier frequencies) were not present on the compensation channel output.

d. Much of the noise that established background noise levels did not correlate across the subcarrier channels, either with or without subtractive compensation.

e. Operation of the playback recorder in the "tape" speed control mode (i.e. with capstan compensation) introduced considerable low-frequency

(7 to 8 Hz) noise that correlated across the data channels. This noise was virtually entirely removed by subtractive compensation.

We concluded that the following factors were combining to produce the high noise levels observed in playbacks of the calibration signals:

a. Old, dirty, or inadequately degaussed tape.

b. Noisy VCO's in the calibration signal generator.

c. Noisy or incorrectly adjusted electronics in the "record" or "playback" tape machines.

In further tests, factor "a" was minimized by the use of new tape and by careful cleaning of the tape recorder heads and associated transport components.

To evaluate factor "b", the selected Develco discriminators were used in conjunction with available types of VCO's to evaluate the relative noise levels produced by the discriminator-VCO combinations. Because the output noise level of the Develco discriminators is very low when driven by a stable frequency source (a good Wavetek generator, for example), these experiments provided measurements of the frequency stability of the different types of VCO tested. Note that the dynamic range of the record-playback system is calculated from the discriminator output for full modulation (4000 mv peak to peak for $\pm$ 125 Hz deviation) divided by the discriminator output (peak to peak noise signal, in mv) for an unmodulated carrier. Noise levels corresponding to dynamic range values of interest are: 40 mv p-p for 40 db, 13 mv p-p for 50 db, 4 mv p-p for 60 db. VCO stability tests were carried out for three types of VCO, with the following results:

1. VCO's used in Jim Chan's automatic calibrator - noise 20 to 40 mv p-p, limiting the system dynamic range to 40 to 46 db.

2. New test VCO's employed in the alignment of new discriminators - noise about 20 mv p-p, limiting the system dynamic range to about 46 db.

3. VCO units from the J302 seismic amplifier/VCO field units - noise about 4 mv p-p, limiting the system dynamic range to about 60 db.

II Test VCO Bank Design and Performance

These tests indicated that the dynamic range determined from playbacks of the automatic calibrator signals was limited by the stability of the test VCO's, not by tape speed variations, and that subtractive compensation could not reduce the noise because it was not coherent from channel to channel or track to track. To proceed further with tests of the compensation system, we next assembled a set of J302 VCO units in a special test modulator bank (figure 1). VCO's for the eight standard subcarrier frequencies plus one additional VCO for a multiplexed timing channel and a second additional VCO for a compensation reference signal (with options for multiplex or separate track recording) are included in the set. For multiplexing, the outputs of the individual VCO's are combined in a standard USGS network signal summing amplifier. Individual switches on the VCO outputs permit any VCO to be included in or excluded from the multiplexed signal. The last VCO (compensation) can be either included in the multiplexed signal or output separately. In our experiments we used the signal supplied by the 50Ω output of a Wavetek generator to modulate the VCO bank. Individual switches on the VCO inputs permit each VCO to be modulated in one of two different modes or to be left unmodulated. In mode 1, each VCO is deviated the same amount (± 125 Hz for an applied voltage of ± 3.00V). In mode 2, each VCO is deviated in an amount proportional to its center frequency ($\delta f_i = \pm 125 \times \frac{F_{ci}}{3125}$ Hz for a ± 3.00 V applied voltage). The first mode is useful for setting discriminator output levels and for system noise tests. The second mode simulates the effect of tape speed variations and is useful for setting compensation signal input levels on the data discriminators and for testing the effectiveness of compensation as a function of amplitude and frequency of signals generated by tape speed irregularities.

A test of the noise level of the test VCO's in combination with the selected set of Develco discriminators is shown in Figure 2. In this case modulation mode 1 was used to produce an 0.5 Hz square wave at levels of -30 db, -40 db, -50 db, and -60 db (3.2%, 1.0%, 0.32%, 0.10%) of $\pm$ 125 Hz, and the playout was on a Siemens Oscillomink model U liquid jet recording oscillograph at a sensitivity of 6 mv/mm and a paper speed of 25 mm/sec. The compensation discriminator was in operation, but its VCO (4688 Hz) was unmodulated. Atthe -60 db modulation level, the system noise was approximately the same as the played-back signal.

The effectiveness of subtractive compensation (using the 4688 Mx reference) with the Develco discriminators is illustrated in Figure 3. In this case modulation mode 2 was used to produce modulation levels of 32% x ($\pm$ 125 x $\frac{F_{ci}}{3125}$) on all channels, including the 4688 Hz reference channel and the 3700 Hz timing channel. Such a pattern of "modulation" would result from a $\pm$ 1.3% tape speed variation. In this, as in the previous case, the signal from the VCO bank was introduced directly into the discriminator inputs without recording and playback from tape. The record was played out on the Oscillomink at a paper speed of 25 mm/sec. Data channels were compensated and played out at a sensitivity setting of 6 mv/mm. The timing channel (3700), which was not compensated, and the compensation channel were played out at a sensitivity setting of 60 mv/mm. The record begins with a 1 Hz square wave, which can be used as a convenient index of compensation for adjusting the compensation signal input level on the individual data discriminators to optimize compensation. The modulation was then changed to a sine wave (amplitude still $\pm$ 0.32 x $\frac{F_{ci}}{3125}$ x 125 Hz) and its frequency was swept slowly from 1 Hz to 10 Hz, then 10 Hz to 100 Hz. At all frequencies from 1 to 100 Hz, noise rejection on all channels was at least 32 db, except for channel 1 (680 Hz) for which it was at least 28 db.

The effect of strong modulation of one channel on other channels was studied by applying a signal at the 100% modulation level to each data channel and to the 3700 Hz timing channel, one at a time, while the other channels remained unmodulated and were played out at high sensitivity (Figure 4a, 4b). The output of the test VCO bank was applied directly to the discriminators without recording and playback from tape. The frequency of a modulating sine wave was swept from 1 HZ TO 10 Hz. Then steady 2 Hz square wave and 2 Hz sine wave modulations were applied. Intermodulation effects were small. In general, the square wave modulation produced spike-like transients on adjacent channels. Also, third harmonics of the lower channel carriers produced low-level noise on higher frequency channels when such harmonics swept across the higher channel passbands. The 4688 Hz compensation channel was entirely unaffected by all of the tests applied to other channels, although strong modulation of data channel 8 (3060 Hz) did induce low-level noise on the 3700 Hz timing channel.

III Compensation Tests on the B & H VR-3700B

Compensation tests were carried out by using modulation mode 1 (equal deviation of all data subcarriers) of the test VCO bank to impress a low-level square wave modulation on all data channels. Frequencies of 0.5 Hz and 1.0 Hz and levels of -40 db (1.0%) and -50 db (0.32%) were used. These signals were recorded in direct record mode on one of the B & H VR-3700B's now being readied for use. The Mx data signal was inroduced to the recorder at a level of 1.0 V p-p; and bias and modulation levels were set at 1.1 V p-p and 50 mv p-p, respectively, in accordance with tests carried out separately by Jim Chan and Ron Kaderabek. On playback, the output level was set at 3-1/2 V $\pm$ 1/2 V and the output signal was introduced into the selected set of Develco discriminators. The discriminator outputs were then recorded on the Siemens Oscillomink. Dynamic range and noise levels of individual channels can be measured directly against the amplitudes of the played back square wave signals of known deviation.

In our early attempts to work out an effective compensation scheme, it appeared important that the reference signal be recorded as clearly as possible. Accordingly, tape track 8 was reserved exclusively for the 3125 Hz compensation reference signal. This frequency was chosen because it could be used directly for capstan speed control as well as for subtractive compensation.

Figure 5a-5b shows playouts of a 0.5 Hz square wave at the -50 db level (0.32% modulation) imposed on all of the data channels simultaneously and recorded successively on all of the tape tracks of the VR-3700B available for data recording. The 3125 Hz compensation signal was recorded on tape track 8 (with 1.1 V p-p bias and 50 mv p-p modulation) and applied, on playback, to the discriminators by the 3125 Hz compensation discriminator supplied by Develco and modified by John Van Schaack. The compensation signal was also passed through a 30 Hz low-pass filter and recorded on the Oscillomink. Noise levels were slightly lower than -50 db (relative to

100% modulation) on the low-frequency data channels and somewhat above -50 db on the high frequency data channels.

The noise on channel 8 (3060 Hz) was quite variable from tape track to tape track and had a predominant frequency near 60 Hz (Figure 5a). Experimentation at higher modulation levels revealed that the frequency of this noise was the difference between the 3125 reference and the ambient frequency of the "3060" carrier. The extreme unpredictability of the performance of channel 8 suggested that changes in the compensation scheme were needed.

Previously we had noted that the spectrum between about 3200 Hz (upper band edge of channel 8) and 5000 Hz (upper limit of response of the VR-3700B recording in direct mode at 15/16 ips) was unused. Plans were underway to multiplex a broad band timing channel with a center frequency of 4500 Hz onto the data channels. Because it appeared advantageous to use a high frequency compensation reference signal, we decided to try to use the 4500 Hz "timing" frequency multiplexed on the data channel for subtrative compensation. Following the general plan of the modification Develco applied to a standard data discriminator to convert it to a compensation discriminator, we modified a standard channel 8 (3060) discriminator to provide a compensation signal from the 4500 Hz reference.

The effectiveness of the separate track 3125 Hz compensation system is compared with that of the Mx 4500 Hz system in Figure 6. Playouts of the eight data tracks and the compensation signal for an 0.5 Hz square wave at -40 db modulation (1.0%) are compared for the cases of (a) no compensation, (b) 3125 Hz ref. compensation, and (c) 4500 Hz ref. compensation. Both compensation schemes are great improvements over the uncompensated case, and the 4500 Hz ref. system is clearly superior to the

3125 Hz ref. system.

Results of applying the 4500 Hz ref. system to all of the tape tracks (including track 8 which is free for data under this system) are shown in Figure 7a-7b. Noise levels on all channels of all tape tracks are at or below -50 db. This test revealed that at this level we are approaching noise levels in the VR-3700B electronics. The record amplifier on tape track 13 was originally noisy (Figure 7b, extreme right) and was replaced by the track 14 record amplifier for this test (Figure 7b, third from the right).

On further reflection, it appeared that a reference frequency of 4688 Hz (i.e. 3/2 x 3125 Hz) should be adopted to permit its use (with appropriate division) for capstan speed control. It also appeared feasible to introduce a broad band time channel at 3700 Hz. Accordingly, VCO's and discriminators were prepared for these purposes.

Figure 8 compares the results of this new system (4688 Hz compensation reference and 3700 Hz time channel multiplexed on the data channel) with those of the 3125 Hz separately recorded compensation reference system. Again, both are significant improvements over the uncompensated case, and the new system (4688 Hz) is clearly superior to the old (3125 Hz). The high level of compensation attained by the 4688 Hz system is further illustrated in Figure 9 (-40 db modulation) and Figure 10 (-50 db modulation).

The advantages of the 4688 Hz system over the 3125 Hz system are sufficiently great that it is clear that we should adopt the former for use with our seismic data recording and playback system.

IV Performance of the System Under Strong Modulation and with Timing Signals

To examine the behavior of the system under a wide range of modulation levels, a 1 Hz square wave modulation was imposed on the data and timing VCO's at levels of -60 db (0.1% modulation), -50 db, -40 db, -30 db, -20 db, -10 db, and 0 db (100% modulation). The resulting multiplex signal (including the 4688 Hz compensation reference) was recorded on the VR-3700B, played back on the same machine (in playback after record mode), and played out through the discriminator bank (with subtractive compensation on the data, but not timing, channels) onto the Siemens Oscillomink. The results of this experiment are shown in Figure 11. Noise levels on all channels at modulation levels of -60 db, -50 db, and -40 db were at or below -50 db. At the -30 db level the noise on channel 1 increased over its value at lower modulation levels, but remained near -50 db. At -20 db modulation the channel 1 noise level decreased again, and noise levels on the other channels remained low. At the -10 db modulation level, the noise on channel 6 (2380 Hz) increased to about -27 db, but noise on the other channels remained low. At 100% modulation, the noise on all channels was too low to read at the reduced sensitivity of the Siemens required for such large signals.

Both cases of increased noise appeared on only one half of the square wave (increased output voltage) and consisted of uniform sinusoidal disturbances of relatively low frequency (30 Hz on channel 1 and about 7 Hz on channel 6). This noise may result from nonlinear interaction between the subcarriers in the record/playback process and may be a part of the price we must pay for the dense packing of data channels in our telemetry scheme. Further work is required to resolve this problem.

It is important that the onset of timing signals be clearly resolvable. Passing square wave timing pulses through low-frequency low-pass filters as in the Develco data discriminators, seriously impairs their use for precise timing. The discriminator prepared for the 3700 hz timing signal was originally set up as a compensation discriminator with somewhat broadened input filter band-width and a significantly increased low-pass output filter cutoff frequency. Figure 12 compares the output of the time channel discriminator with the standard data channel discriminators for square waves of 10 Hz, 20 Hz, and 50 Hz (all at the -10 db, or 32%, modulation level). The advantage of the timing channel discriminator is most apparent for the 20 Hz and 50 Hz signals, for which the data discriminators produce rather good sine waves instead of square waves. The rise time of a step on the 3700 Hz time channel is about 3 milliseconds. The noise level on this channel is quite high; but for modulation levels of 50% or more it should not interfere with time code interpretation.

V Compensation Tests with the Sony TC-126 Cassette Recorder

Tape speed variations on the VR-3700B appear to be only a few tenths of one per cent, and the resulting noise which must be removed by compensation is quite low. The Sony TC-126 stereo tape recorders used in the experimental "stake-out" refraction systems have tape speed variations above 1% and therefore provide a much larger signal that must be removed by compensation. As a further test of the compensation system proposed for use with the USGS VR-3700B network recorders, some of the same tests were carried out with the Sony as with the VR-3700B. These tests are summarized in Figure 13. A 1 Hz square wave at the -40 db modulation level on all of the data channels and an unmodulated 4688 Hz reference signal were recorded (in multiplex form) on the Sony and then played back from the Sony through the compensated Develco discriminators onto the Siemens Oscillomink. Note on Figure 13 that the playout sensitivity of the compensation channel is 60 mv/mm as opposed to 6 mv/mm (0.1 setting) for the data channels on the left side of the figure. Noise levels were below -40 db on all data channels. To compare compensated and uncompensated data channels it was convenient to reduce the data channel playout sensitivity to 60 mv/mm. Midway along the record on the right side of Figure 13 the compensation discriminator was removed and the output noise level on all data channels increased tremendously, up to 20 db on channel 8 (3060 Hz). The relatively high noise on the compensated channel 1 and channel 3 records was due to 60 cycle pickup in the discriminators and was greatly reduced by better shielding of the discriminators. With care, it appears that a dynamic range of about 46 db can be achieved on all channels of the system tested here.

VI <u>Influence of the Discriminator Output Filter and of the Subcarrier Channel Density on Frequency Response and Dynamic Range of the Data Channel</u>

The frequency response of the data channels is limited by a number of factors which also affect the dynamic range (noise levels) of the channels. The most obvious factor limiting the high frequency response is the low-pass output filtering in the discriminators, which normally is set to cutoff rather sharply above about 30 Hz. In the Develco discriminator this filtering is accomplished in two locations: A parallel R-C feedback path around the discirminator amplifier (6 db/octave?) and a multi-stage active low-pass filter section between the discriminator amplifier and the output amplifier. For still higher frequencies, the limited band with of the input bandpass filter must also affect the response of the discriminator.

To study the effect of the output filter a Krohn-Hite model 335 variable low-pass filter was substituted for the discriminator active low-pass filter section and output amplifier; and a series of frequency response tests were carried out for K-H cutoff frequencies of 30 Hz, 50 Hz, 75 Hz, 100 Hz, 125 Hz, 150 Hz, 200 Hz, and 300 Hz and for 3 separate values of the discriminator amplifier feedback capacities— .033μF (44 Hz), .015μF (97 Hz), .0068μF (215 Hz). For these tests the discriminator was driven by a variable frequency sine wave modulation at a level of -20 db (10% modulation) and the output of the K-H filter was displayed on an oscilloscope. The results of these tests are shown in Figure 14 (1020 Hz discr. with the usual 0.033μF feedback capacitor), Figure 15 (2040 Hz discr. with an 0.015μF feedback capacitor), and Figure 16 (2040 Hz discr. with an 0.0068μF feedback capacitor). In these figures log (relative response) is plotted against log (frequency) and the K-H cutoff frequency is shown as a variable parameter on the separate response curves.

To estimate the influence of the output filter on data channel noise, the Sony TC-126 cassette recorder was used to record and playback multiplexed signals for playout through the experimental discriminators. Two different signals were recorded: (1) -40 db (1% mod) square wave signals on all eight data channels and the timing channel plus the unmodulated 4688 Hz compensation reference frequency, and (2) -40 db (1% mod) square wave signals on the 1020 Hz, 2040 Hz, and 3060 Hz data channels (the other data channels and time channel carriers were turned off) and the unmodulated 4688 Hz compensation reference signal. During playback of these signals (with compensation) through the test discriminators, the noise level corresponding to each K-H cutoff frequency setting was estimated from the oscilloscope display and was recorded. These noise levels were then converted to figures representing their levels, in db, below the data signals that would result from 100% modulation. Pairs of noise levels for the full set of carriers and for the 3 selected carriers are also written as parameters on the appropriate response curve - i.e., on the curve for the K-H cutoff frequency setting for which they were measured.

Analysis of Figure 16 suggests that a 3-channel system with 70% response to 100 Hz and a dynamic range of 42 db could be built around a Develco discriminator with a 125 Hz low-pass output filter and an 0.0068μF feedback capacitor even without broadening the input bandpass filter nor increasing VCO deviation. Considering that two channels of the present system are dropped out between each pair of the three that would be retained, it appears that deviation might well be doubled, with a possible increase of 6 db in dynamic range to approximately 48 db. Considering the many unexpected elements of this problem, however, further tests must be carried out to determine whether this system is feasible.

Figure 16 also suggests that the input bandpass filter becomes effective in limiting signals above about 125 Hz.

Figure Captions

Figure 1 Test VCO bank schematic. Provides individual or multiplexed subcarriers of data, timing, or compensation channels. Modulation is d.c. coupled and can be in the form of either equal deviation of all subcarriers or deviation of each subcarrier in the same proportion of its center frequency. VCO bank is used to set up and test discriminators, including setting compensation input levels on individual discriminators, and to test the overall performance of the tape record/playback system.

Figure 2 Square wave test of VCO's and discriminators, without tape record/playback, to establish the noise levels of the VCO-discriminator pairs.

Figure 3 Square wave and swept frequency sine wave test of the effectiveness of the subtractive compensation feature of the Develco discriminators in eliminating test signals simulating spurious signals induced by tape speed variations. In the frequency range d.c. to 100 Hz the minimum rejection (-28 db at ca 10 Hz) is on channel 1; all other channels have rejection levels of 32 db or more at all frequencies.

Figure 4 Intermodulation test of the VCO/discriminator banks for multiplexed signals without tape record/playback. In each test (vertical frame) one channel only is modulated at the 100% level while all others are unmodulated and played out at high sensitivity (6 mv/mm). Adjacent channels are disturbed slightly, and 3rd harmonics of the lower frequencies disturb some higher channels slightly.

Figure 5 Compensation test employing the Develco-supplied/Van Schaack-modified compensation discriminator using a 3125 Hz reference signal recorded on a separate tape track. Each vertical panel, labeled ch 1, ch 2, etc., displays the results for a separate tape track on the B & H VR-3700B. The 0.5 Hz square wave modulation is at the -50 db level (0.32%).

Figure 6 Comparison of tape playbacks employing compensation obtained with (1) a 4500 Hz reference signal multiplexed on the data channel and with (2) the 3125 Hz reference signal recorded on a separate track with a tape playback without compensation. The 1 Hz square wave modulation is at the -40 db level (1%).

Figure 7 Compensation test employing the 4500 Hz reference signal multiplexed on the data channel. Each vertical panel, labeled ch 1, ch 2, etc., displays the results obtained from a separate track on the B & H VR-3700B. The 1 Hz square wave modulation is at the -50 db level (0.32%). Compare with Figure 5.

Figure 8 Comparison of tape playbacks with compensation employing the 3125 Hz reference signal recorded separately and the 4688 Hz reference frequency multiplexed (along with a 3700 Hz timing subcarrier) on the data channel with a tape playback without compensation. The square wave modulation (0.5 or 1.0 Hz) is at the -50 db (0.32%) level.

Figure 9 Tape playbacks showing a 1 Hz square wave at the -40 db modulation level made without compensation and with compensation employing the 4688 Hz multiplexed reference signal.

Figure 10 Tape playbacks showing a 1 Hz square wave at the -50 db modulation level made without compensation and with compensation employing the 4688 Hz multiplexed reference signal.

Figure 11 Performance of the tape record/playback system, with 4688 Hz multiplexed-signal compensation, for square wave modulation levels of -60 db, -50 db, -40 db, -30 db, -20 db, -10 db, and 0 db. Intermodulation effects, perhaps involving carrier waveform distortion in record/playback, can be seen on channel 1 for the -30 db and -20 db modulation levels and on channel 6 for the -10 db modulation level.

Figure 12 Recovery of square waves with frequencies of 10, 20, and 50 Hz from the broad-band time channel and from the standard data channels.

Figure 13 Compensation test employing the 4688 Hz multiplexed reference signal applied to signals recorded on and played back through the Sony TC-126 cassette tape recorder. The 1 Hz square wave was recorded at a -40 db (1%) modulation level. On the left, the data channels are played out at a sensitivity of 6 mv/mm and the compensation channel, at 60 mv/mm. In the center, the playout sensitivity is 60 mv/mm for all channels, and compensation is still functioning. On the right, the playout sensitivity is still 60 mv/mm, but the compensation discriminator has been removed.
Noise reduction achieved by compensation on the higher frequency data channels is greater than 20 db.

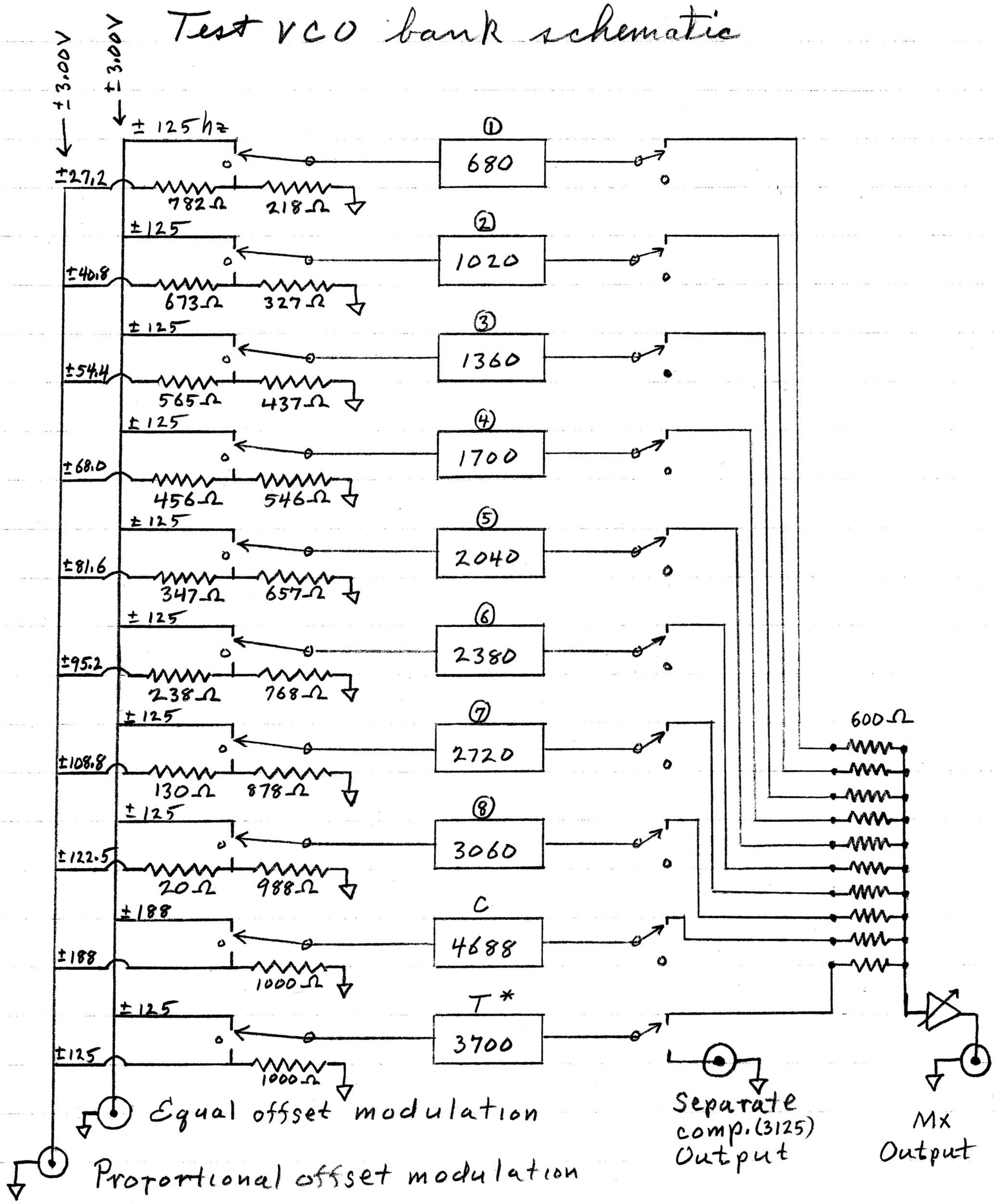
Figure 14 Frequency response of a standard Develco discriminator (1020 Hz with 0.033μF discriminator amplifier feedback capacitor) as a function of output filter cutoff frequency. Output noise levels of this discriminator, with compensation, are also shown for signals recorded on and played back through the Sony TC-126 cassette recorder (for the cases of (1) all data subcarriers plus timing and compensation subcarriers, and (2) only the 1020, 2040, 3060, and compensation subcarriers) as a function of output filter cutoff frequency.

Figure 15 Frequency response of a modified 2040 Hz Develco discriminator (0.015μF discriminator amplifier feedback capacitor) as a function of output filter cutoff frequency. Output noise levels of this discriminator, with compensation, are also shown (for the cases of (1) all data subcarriers plus timing and compensation subcarriers, and (2) only the 1020, 2040, 3060, and compensation subcarriers) as a function of output filter cutoff frequency.

Figure 16 Frequency response of a modified 2040 Hz Develco discriminator (0.0068μF discriminator amplifier feedback capacitor) as a function of output filter cutoff frequency. Output noise levels of this discriminator, with compensation, are shown (for the cases of (1) all data subcarriers plus timing and compensation subcarriers, and (2) only the 1020, 2040, 3060, and compensation subcarriers) as a function of output filter cutoff frequency.

Fig 1

Test VCO bank schematic



* For separate track compensation $f_c = 3125$, $\delta f = \pm 125$ hz; and timing put on 4688 Mx with $\delta f = \pm 125$ hz

Fig 2


10 mm/sec
(3/4 : 1 scale)
-30 db
.1
Comp. — unmodulated 4688 hz
Time 3700 hz
-30db (3.2%)
-40db (1%)
-50db (.32%)
-60db (.1%)
1mm = 6 mv at 0.1 setting

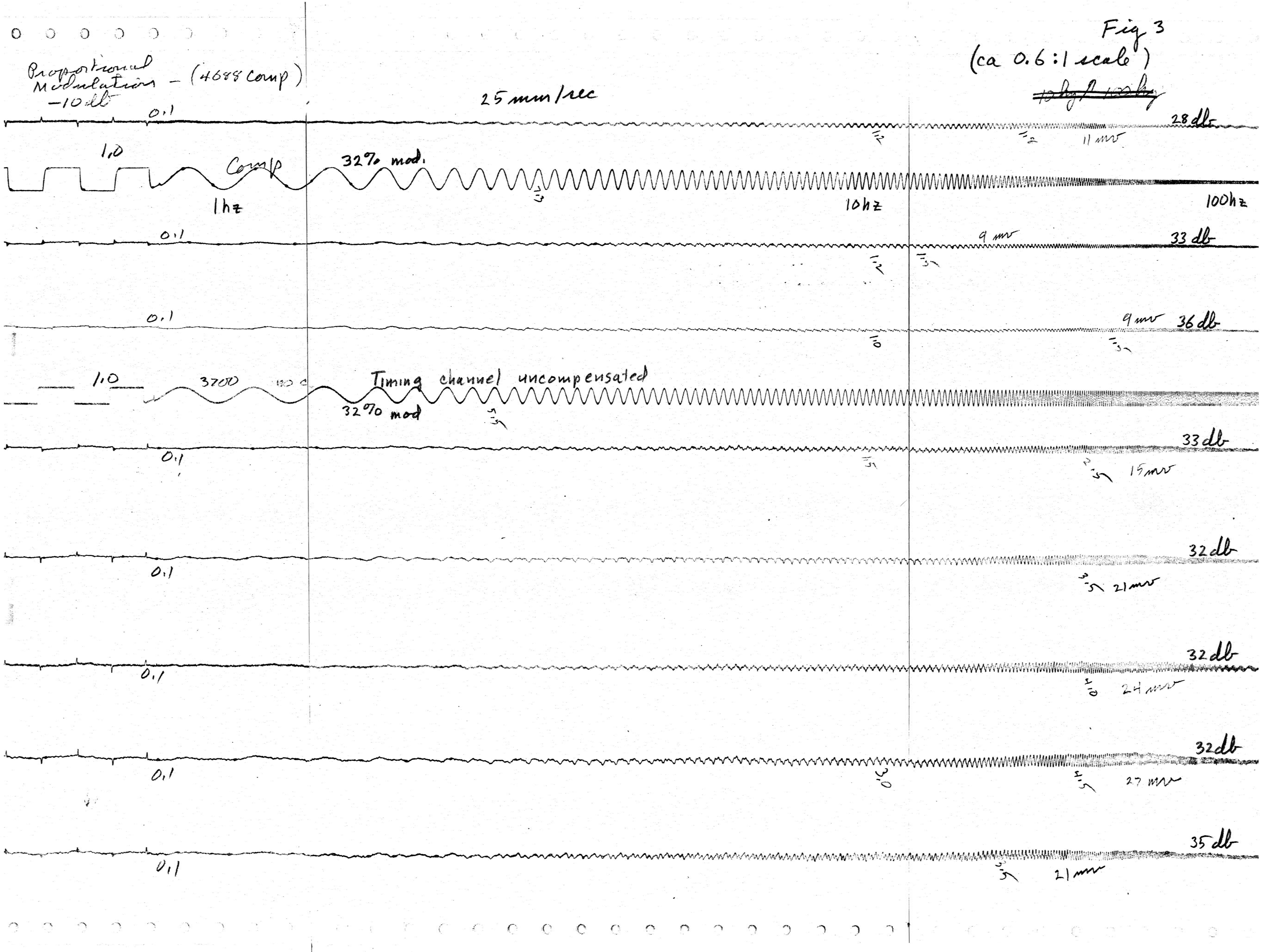


Fig 3
(ca 0.6:1 scale)

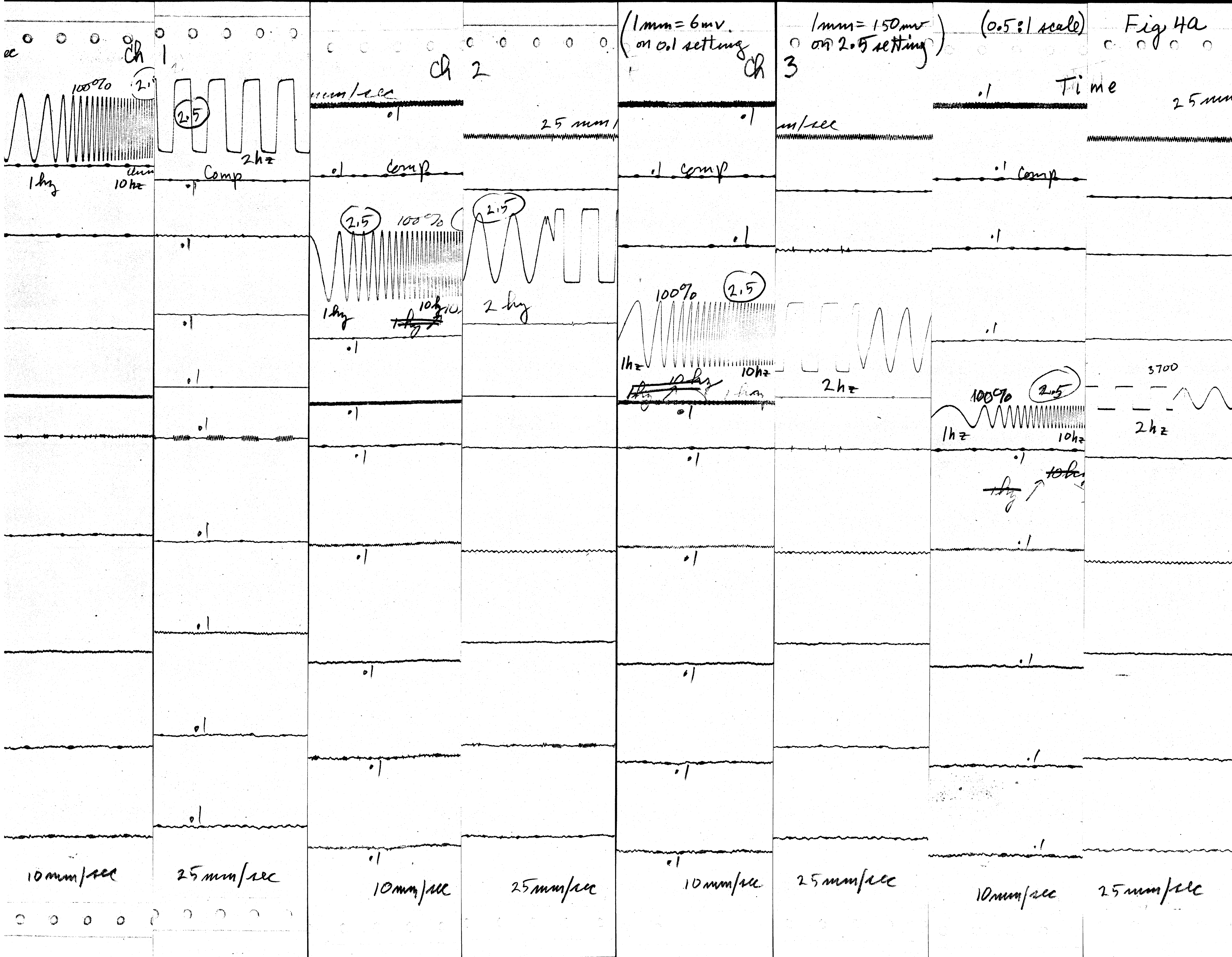


Fig 4a
Ch 1
Ch 2
Ch 3
Time
(1mm = 6mv. on 0.1 setting)
1mm = 150mv on 2.5 setting)
(0.5:1 scale)
100%
2.5
1hz
10hz
2hz
Comp
.1
.1 Comp
25 mm/
mm/sec
3700
10mm/sec
25mm/sec
10mm/sec
25mm/sec
10mm/sec
25mm/sec
10mm/sec
25mm/sec

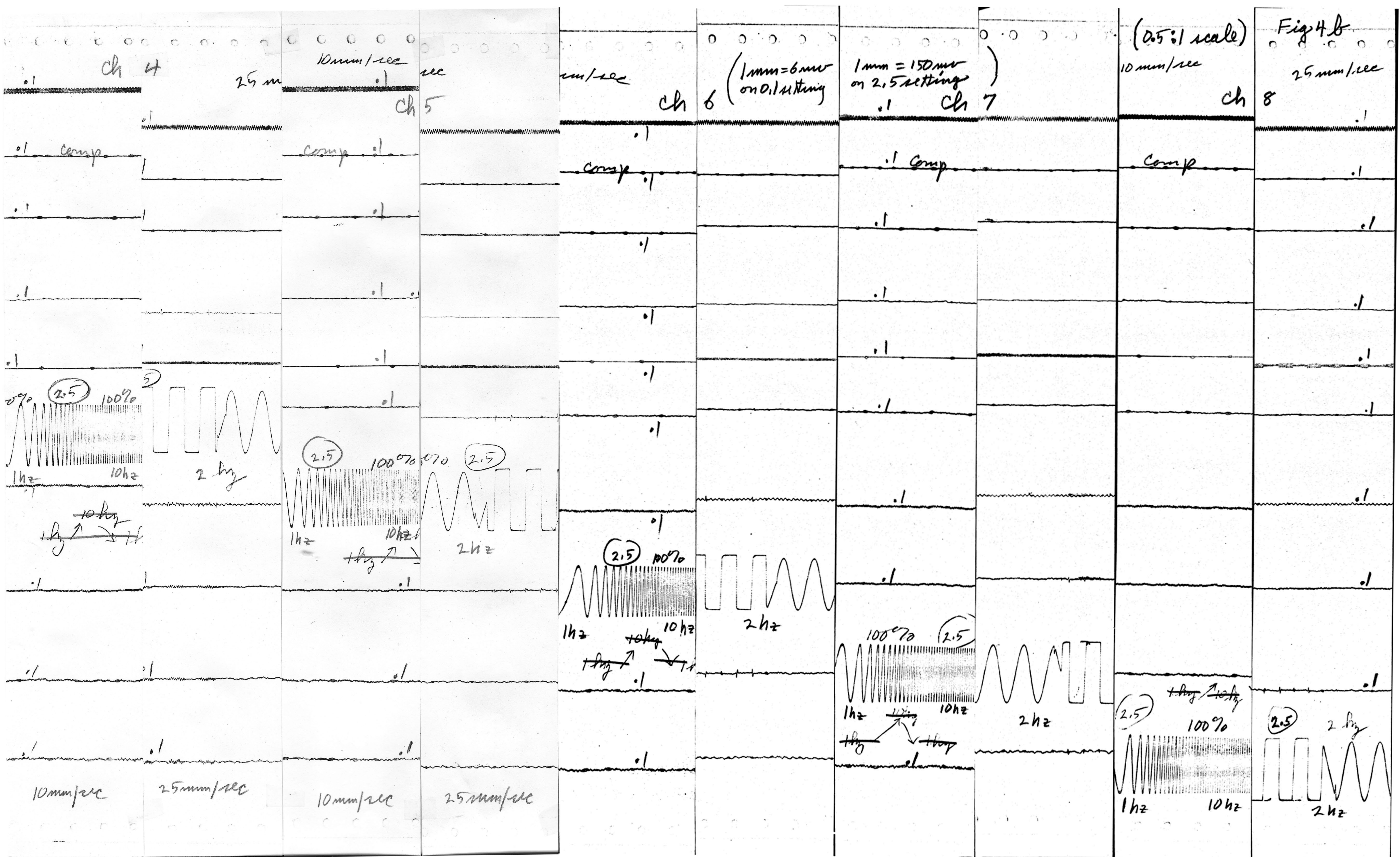
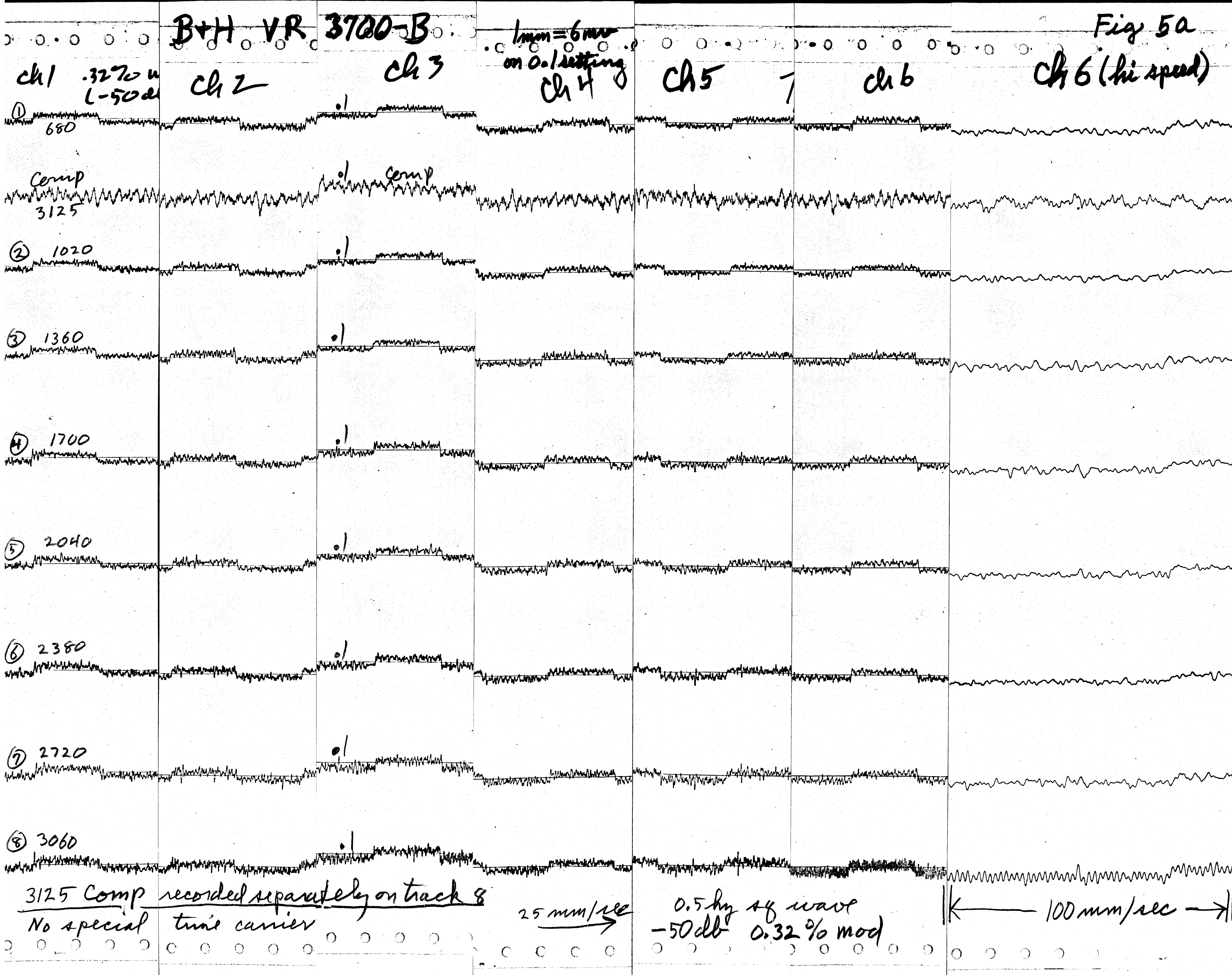
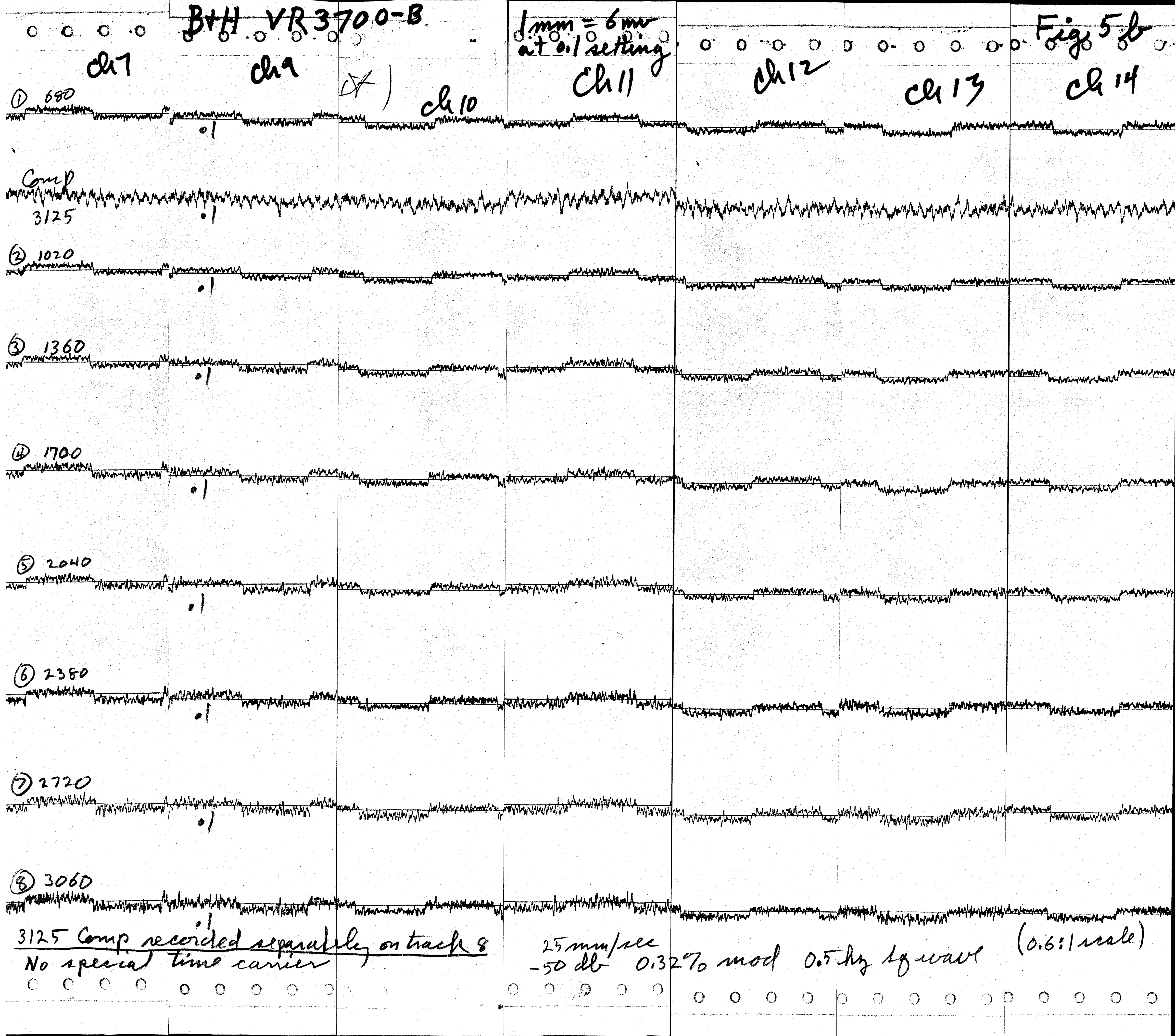
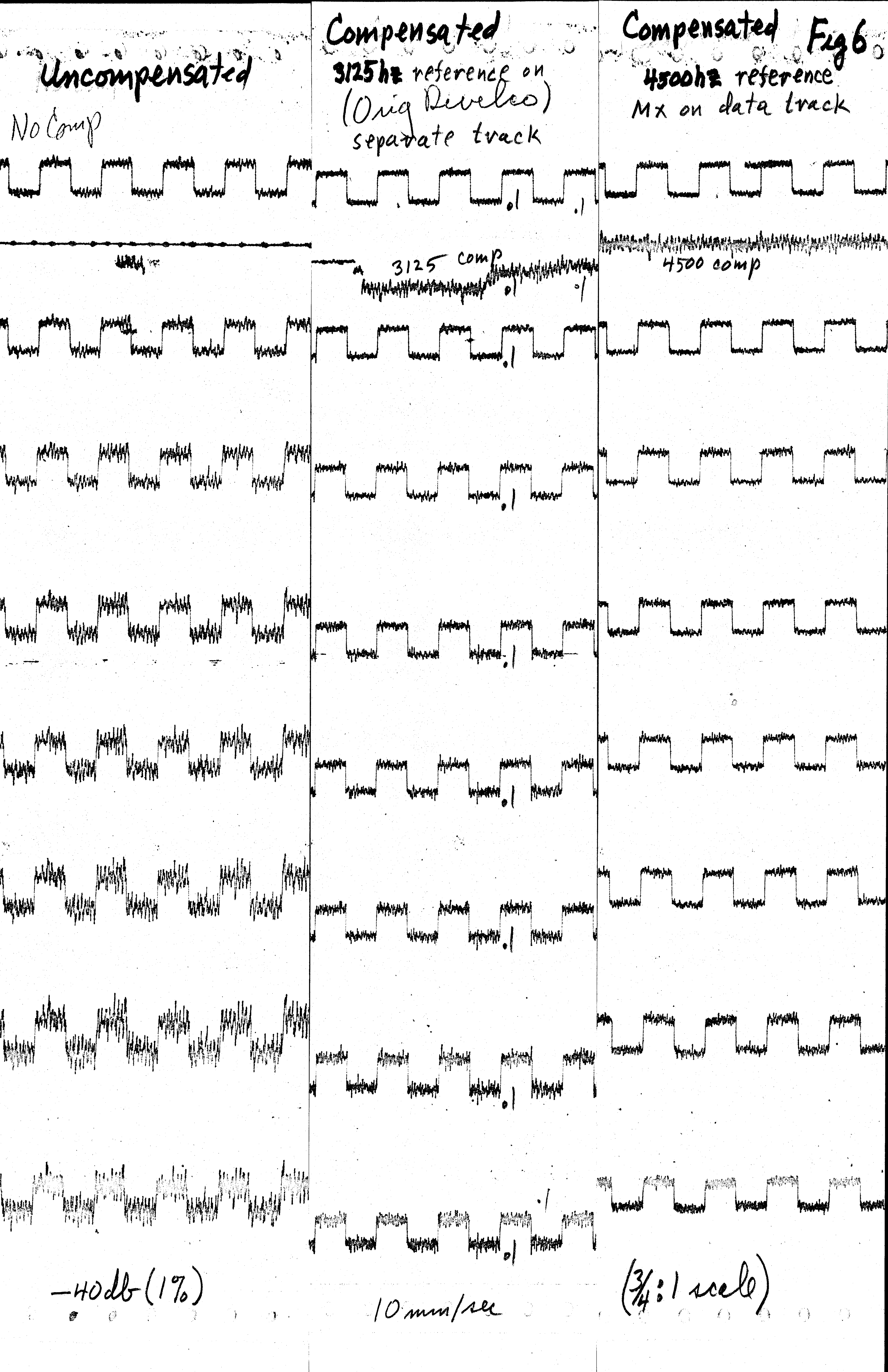


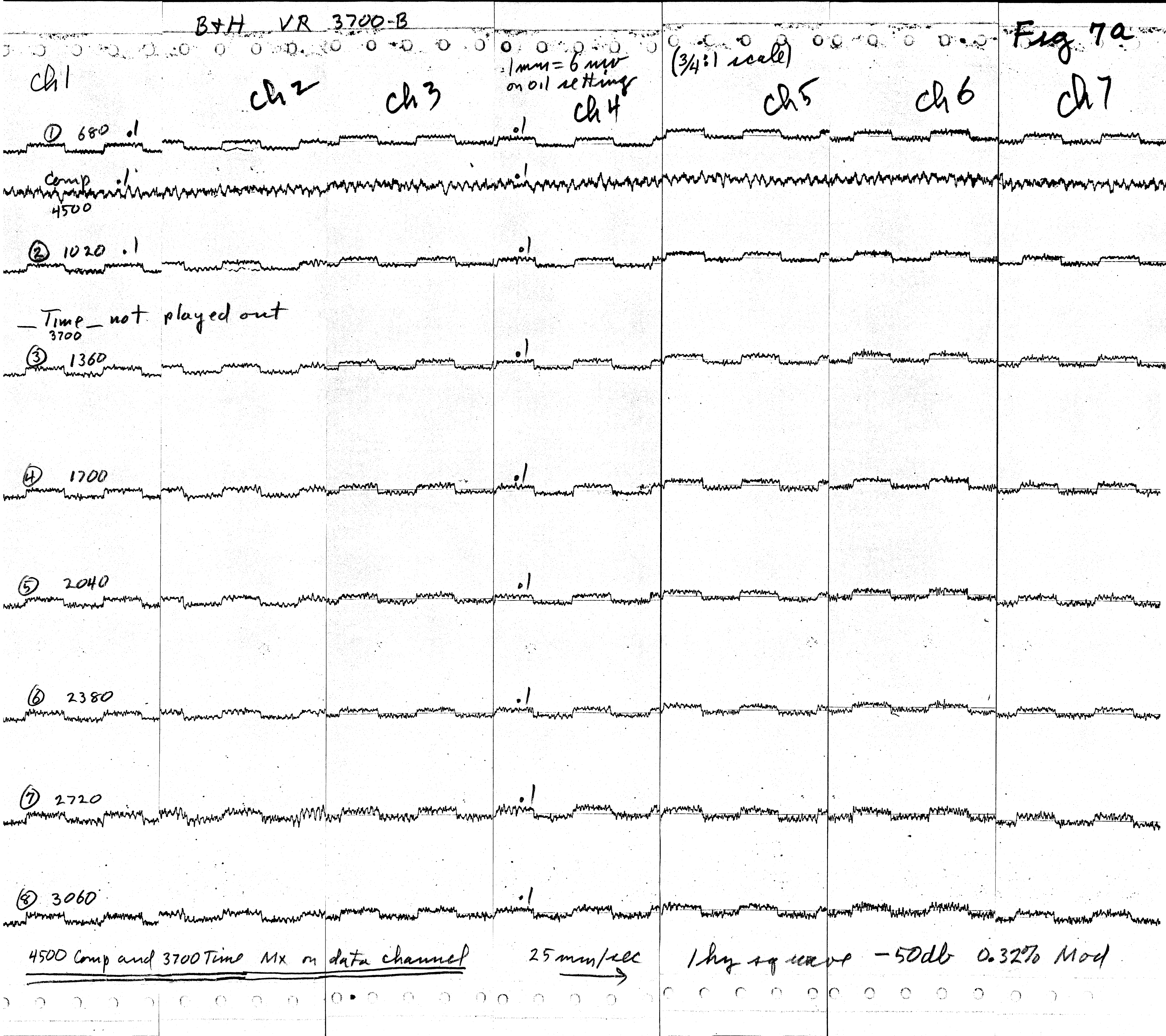
Fig 4b
(0.5:1 scale)
Ch 4
Ch 5
Ch 6
Ch 7
Ch 8
10mm/sec
25mm/sec
(1mm = 6mv on 0.1 setting
1mm = 150mv on 2.5 setting)
comp
2.5
100%
1hz
10hz
2hz



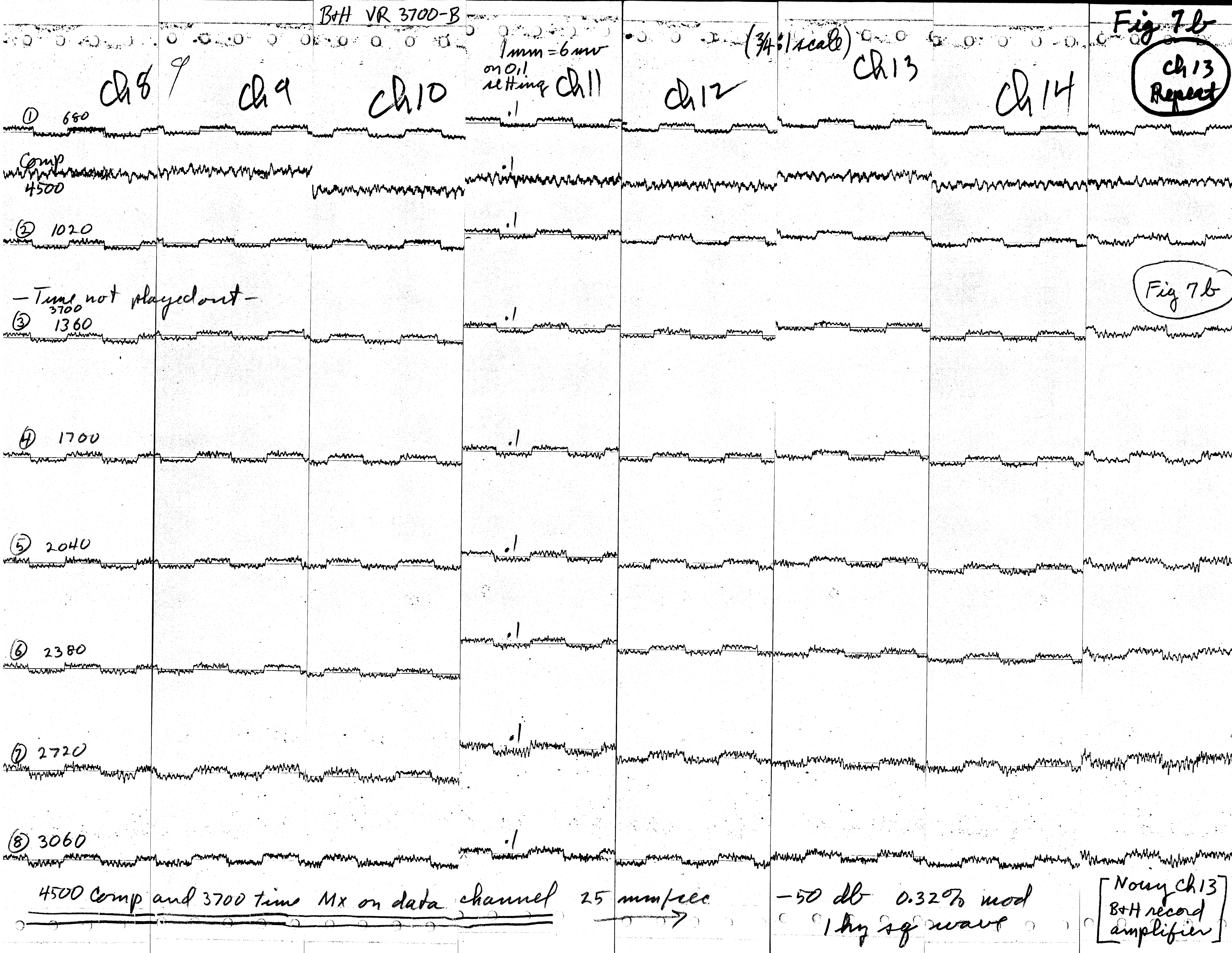
B+H VR 3700-B
Fig 5a
1mm = 6mv
on 0.1 setting
ch1
.32% u
(-50db
Ch 2
Ch 3
Ch 4
Ch 5
ch 6
Ch 6 (hi speed)
① 680
comp
3125
comp
② 1020
③ 1360
④ 1700
⑤ 2040
⑥ 2380
⑦ 2720
⑧ 3060
.1
3125 Comp recorded separately on track 8
No special time carrier
25 mm/sec
0.5 hz sq wave
-50db 0.32 % mod
100 mm/sec


B+H VR3700-B
1mm = 6mv at 0.1 setting
Fig 5b
ch7
ch9
ch10
Ch11
ch12
ch13
ch14
① 680
Comp 3125
② 1020
③ 1360
④ 1700
⑤ 2040
⑥ 2380
⑦ 2720
⑧ 3060
.1
3125 Comp recorded separately on track 8
No special time carrier
25 mm/sec
-50 db
0.32% mod
0.5 hz sq wave
(0.6:1 scale)


Uncompensated
No Comp
Compensated
3125hz reference on
(Orig Develco)
separate track
Compensated
Fig 6
4500hz reference
Mx on data track
3125 comp
4500 comp
-40db (1%)
10 mm/sec
(3/4:1 scale)



B+H VR 3700-B
Fig 7a
(3/4:1 scale)
1mm = 6 mv on oil setting
Ch1
Ch2
Ch3
Ch4
Ch5
Ch6
Ch7
① 680 .1
Comp .1
4500
② 1020 .1
Time not played out
3700
③ 1360
④ 1700
⑤ 2040
⑥ 2380
⑦ 2720
⑧ 3060
4500 Comp and 3700 Time Mx on data channel
25 mm/sec
1hz sq wave -50db 0.32% Mod



B+H VR 3700-B
Fig 7b
(3/4:1 scale)
1mm = 6mv
on 0.1 setting
Ch8
9
Ch9
Ch10
Ch11
Ch12
Ch13
Ch14
Ch13 Repeat
① 680
Comp 4500
② 1020
— Time not played out —
3700
③ 1360
Fig 7b
④ 1700
⑤ 2040
⑥ 2380
⑦ 2720
⑧ 3060
.1
4500 Comp and 3700 time Mx on data channel
25 mm/sec
-50 db 0.32% mod
1 khz sq wave
[Noisy Ch13 B+H record amplifier]

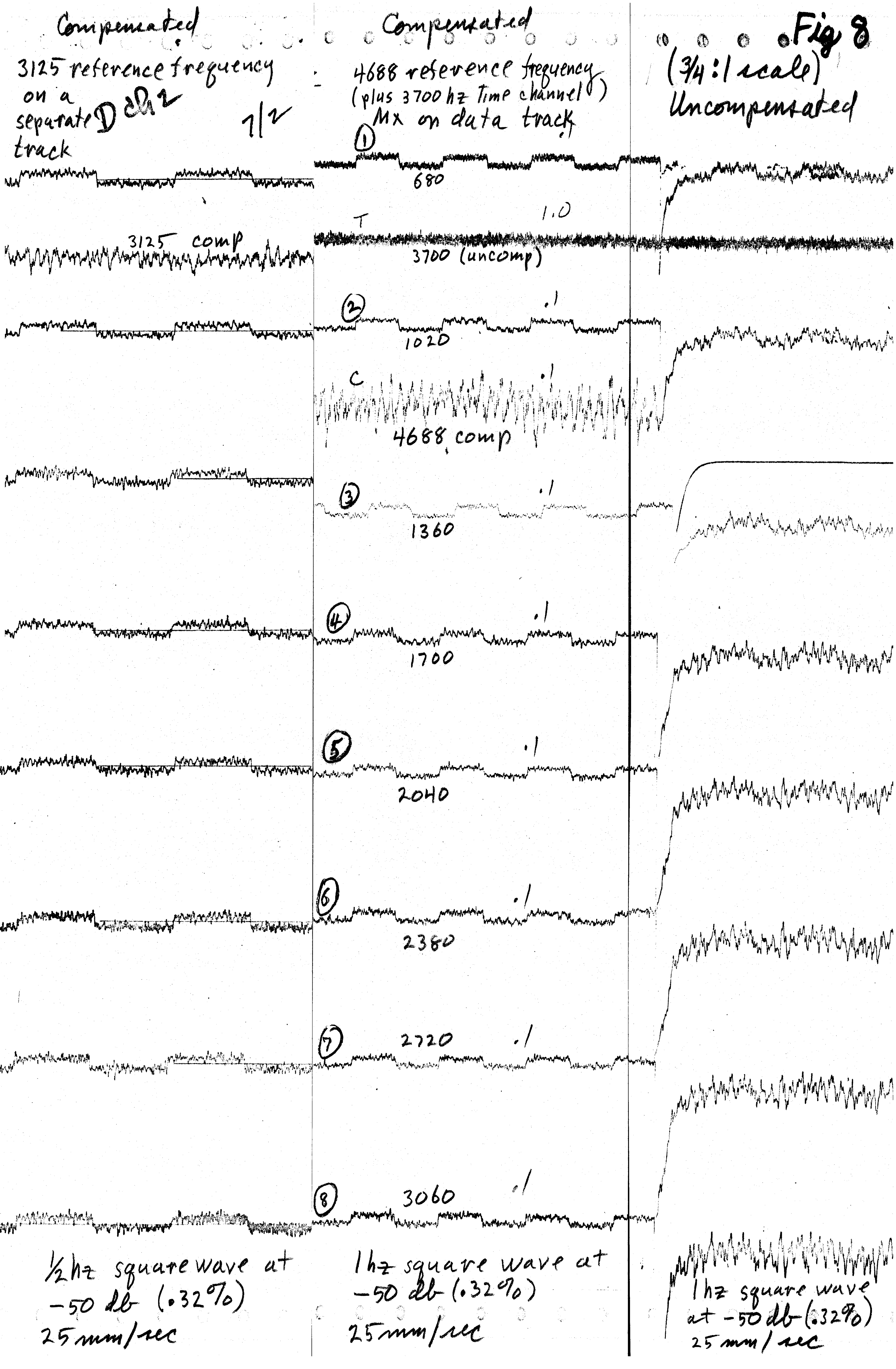

Compensated
3125 reference frequency on a separate D Ch2 track
1/2
3125 comp
Compensated
4688 reference frequency (plus 3700 hz Time channel) Mx on data track
1
680
T
1.0
3700 (uncomp)
2
.1
1020
C
.1
4688 comp
3
.1
1360
4
.1
1700
5
.1
2040
6
.1
2380
7
2720
.1
8
3060
.1
Fig 8
(3/4:1 scale)
Uncompensated
1/2 hz square wave at -50 db (.32%)
25 mm/sec
1 hz square wave at -50 db (.32%)
25 mm/sec
1 hz square wave at -50 db (.32%)
25 mm/sec

Fig 9

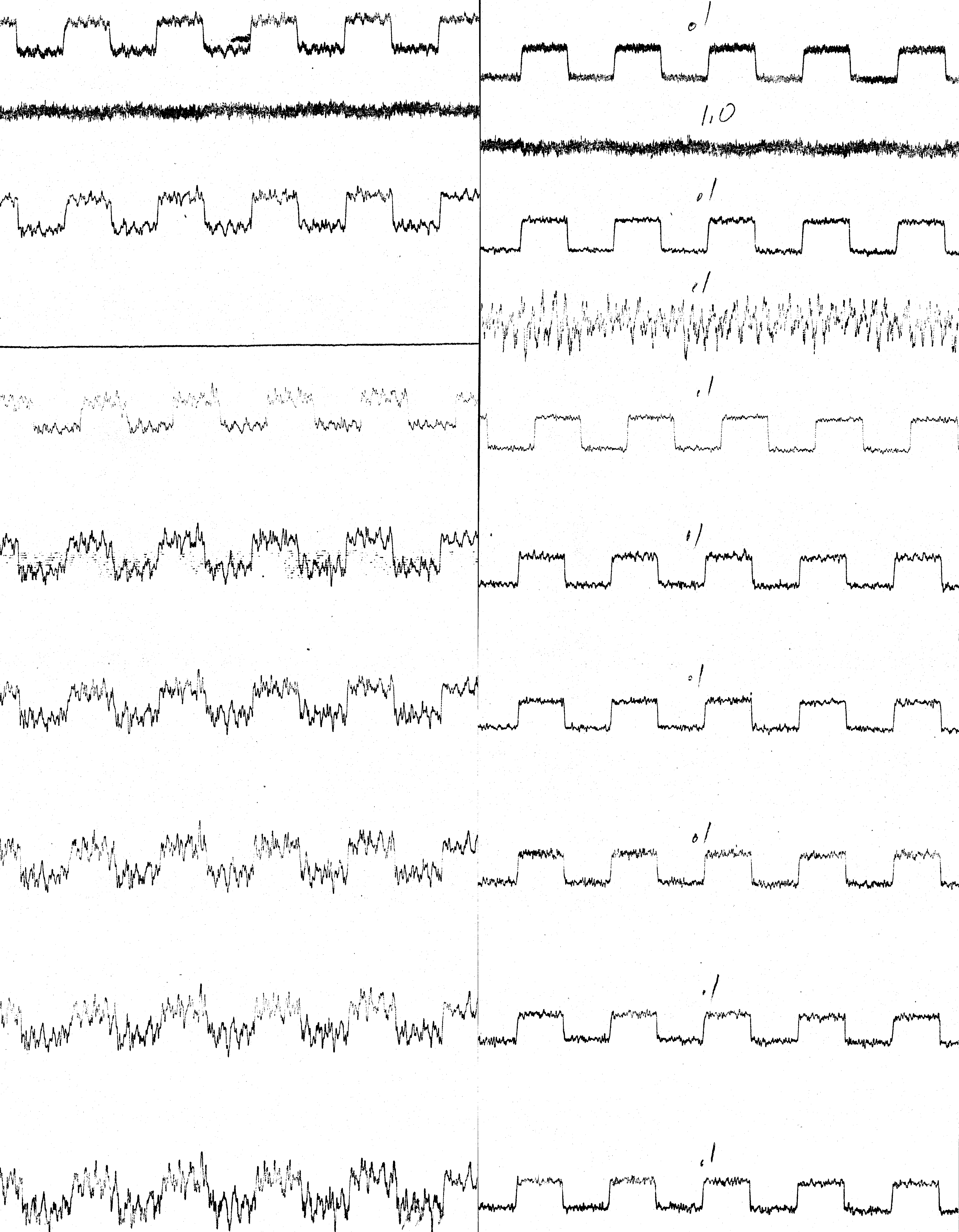
-40 no comp

-40 db (1.0%) Uncompensated

-40 db (1.0%)

Compensated: 4688hz Mx ref

-40 db



1hz sq. wave. 25 mm/sec (3/4:1 scale)

1mm ≈ 6 mv at 0.1 setting

Fig 10

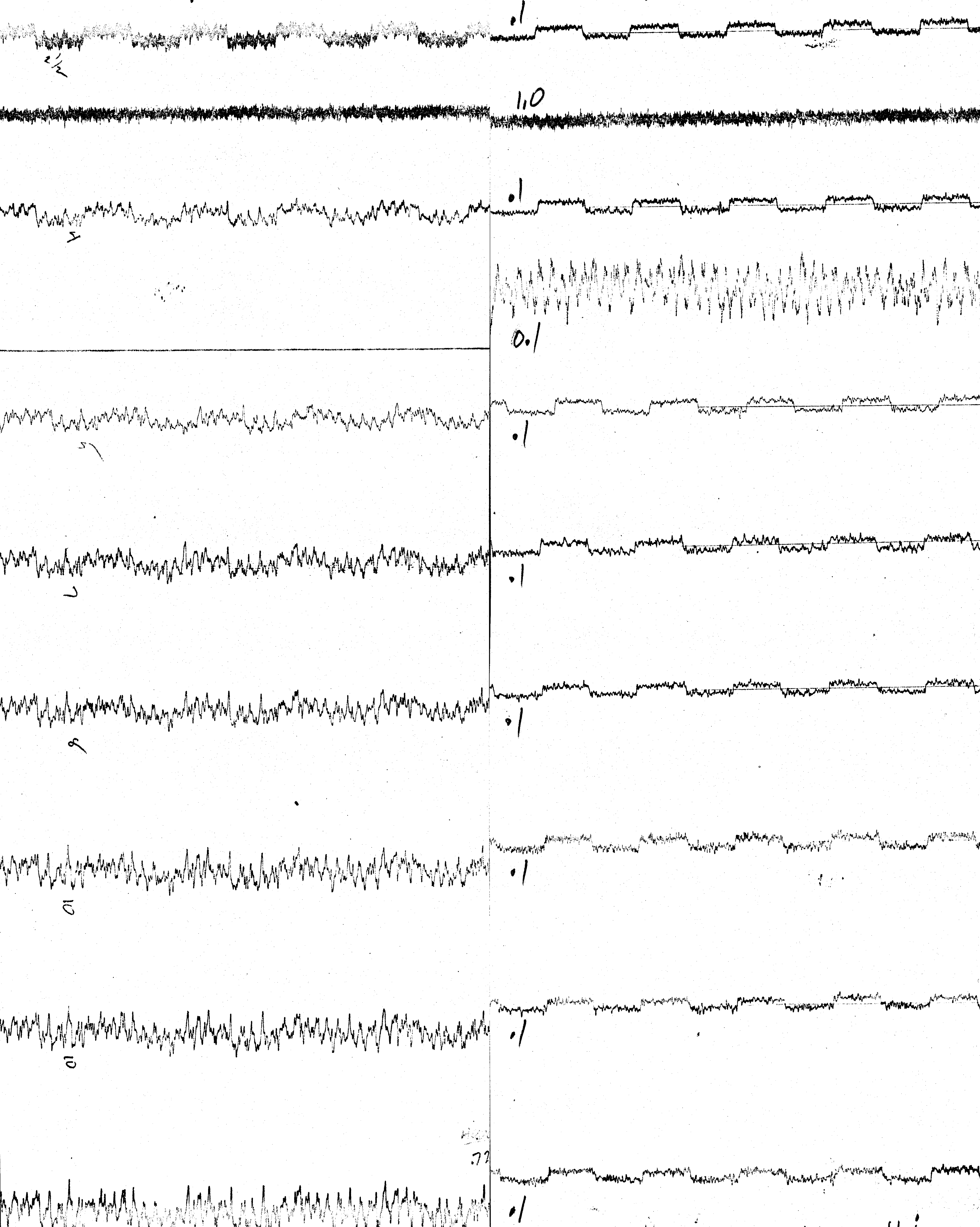
— 50 db (.32%)

Uncompensated -50 no co

25 mm/sec

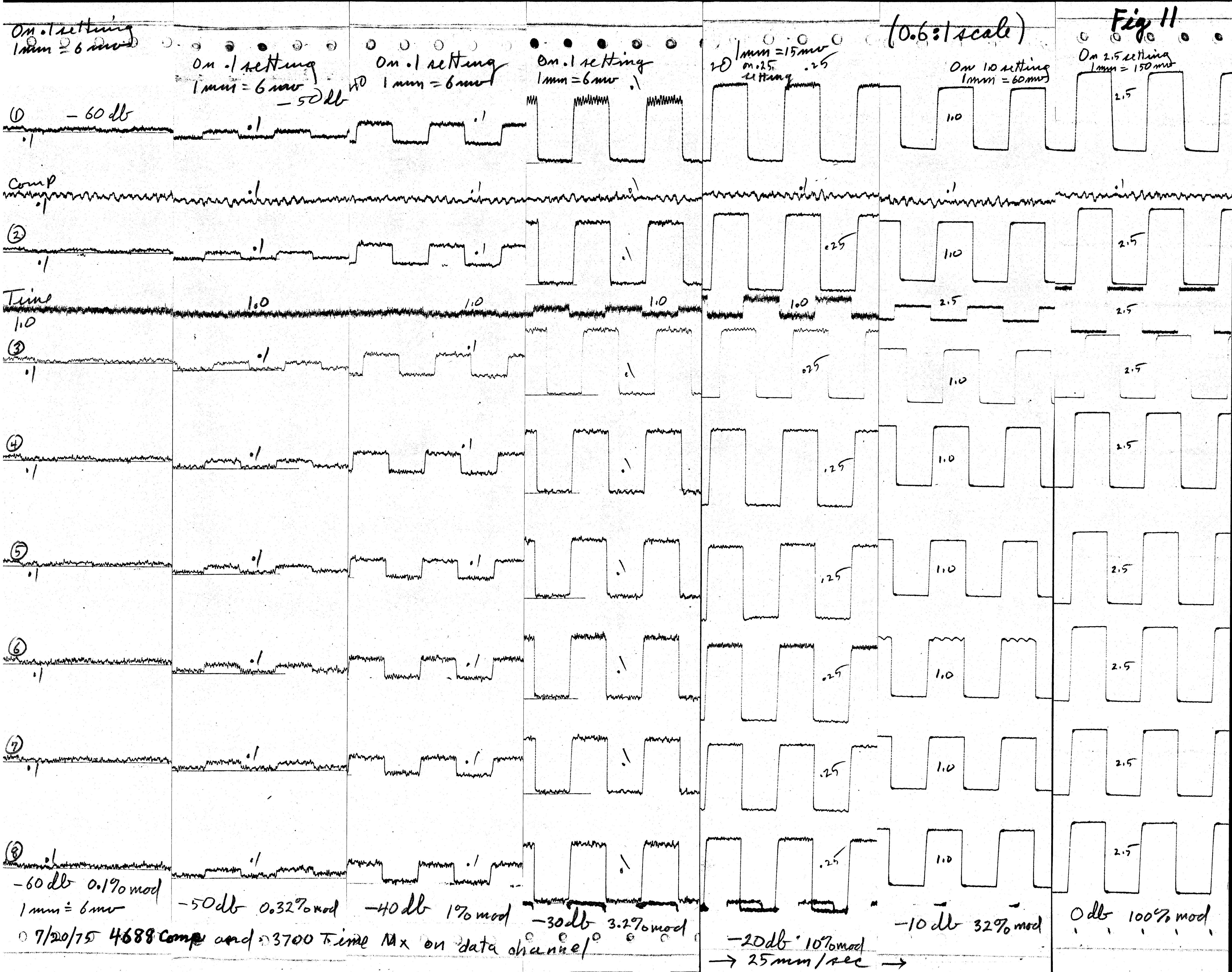
Compensated: 4688hz Mx ref

-50 comp



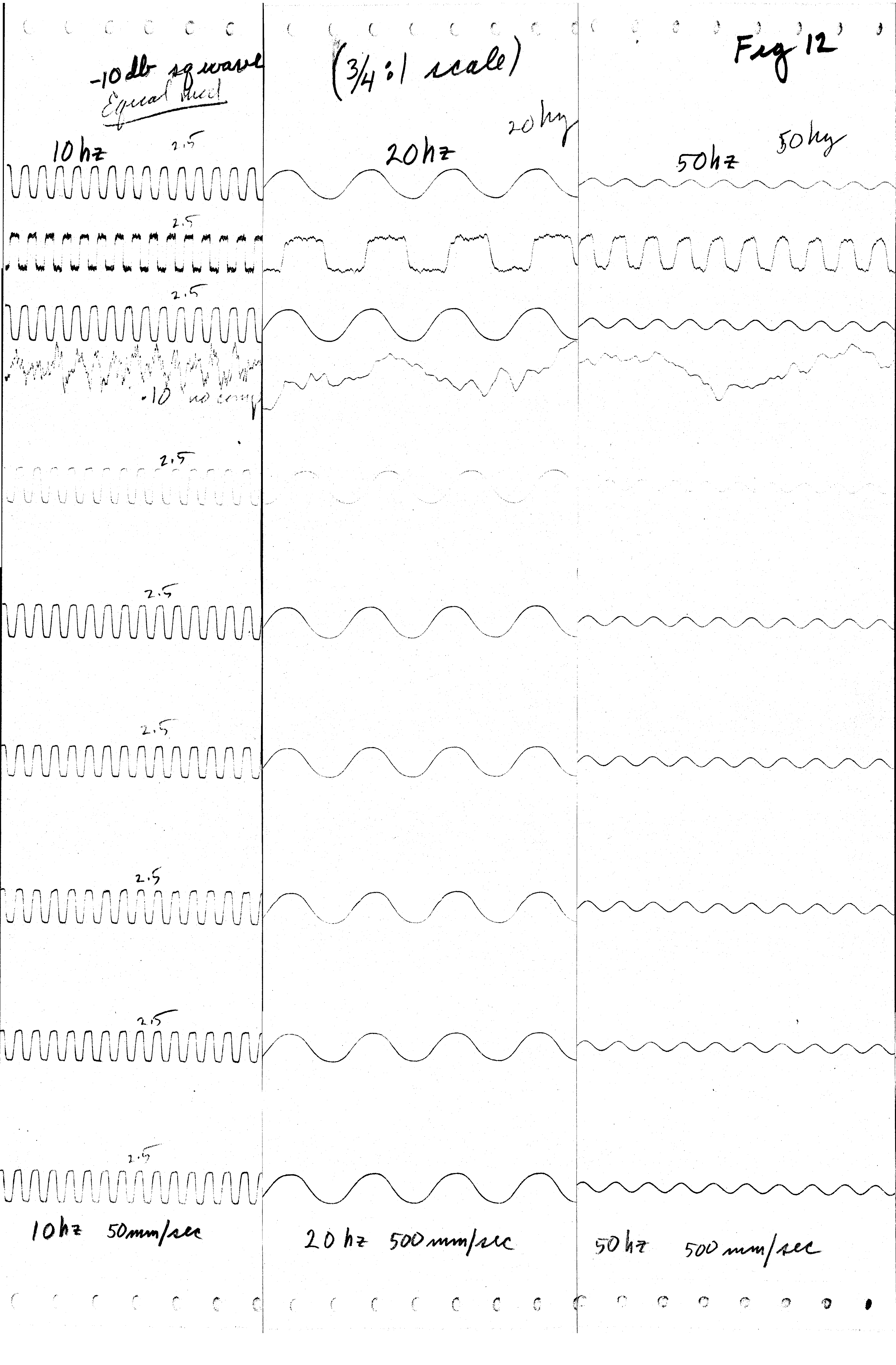
1 mm ≈ 6mv at 0.1 setting

1hz sq wave (3/4:1 scale)
25 mm/sec

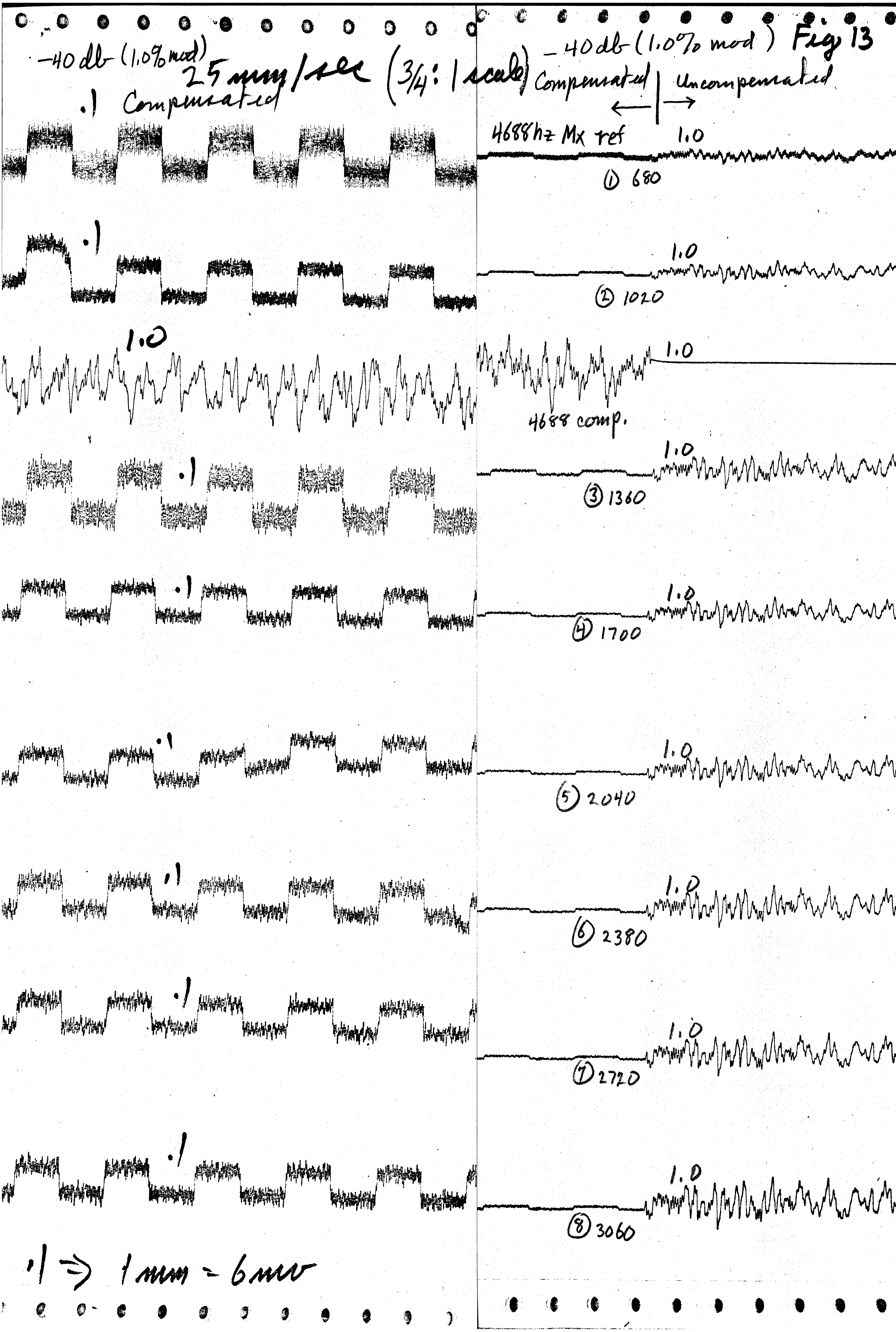


On .1 setting
1 mm = 6 mv
① -60 db
Comp
②
Time
1.0
③
④
⑤
⑥
⑦
⑧
-60 db 0.1% mod
1 mm ≐ 6 mv
On .1 setting
1 mm = 6 mv
-50 db
-50 db 0.32% mod
On .1 setting
1 mm = 6 mv
-40 db 1% mod
On .1 setting
1 mm = 6 mv
-30 db 3.2% mod
1 mm = 15 mv
On .25 setting
-20 db 10% mod
(0.6:1 scale)
On 10 setting
1 mm = 60 mv
-10 db 32% mod
On 2.5 setting
1 mm = 150 mv
0 db 100% mod
7/20/75 4688 Comp and 3700 Time Mx on data channel
→ 25 mm/sec →

Fig 11



-10db sq wave
Equal Med
(3/4 : 1 scale)
Fig 12
10hz
2.5
20hz
20hz
50hz
50hz
-10 no comp
10hz 50mm/sec
20 hz 500mm/sec
50hz 500mm/sec


-40 db (1.0% mod)
25 mm/sec (3/4 : 1 scale)
.1 Compensated
.1
1.0
.1
.1
.1
.1
.1
.1
.1 ⇒ 1 mm = 6 mv
-40 db (1.0% mod)
Fig 13
Compensated ← | → Uncompensated
4688 hz Mx ref
1.0
① 680
1.0
② 1020
1.0
4688 comp.
1.0
③ 1360
1.0
④ 1700
1.0
⑤ 2040
1.0
⑥ 2380
1.0
⑦ 2720
1.0
⑧ 3060

Develco Discr

(1020) Standard Discrim. Ampl. Capacitor (0.033 µF)

Fig 14

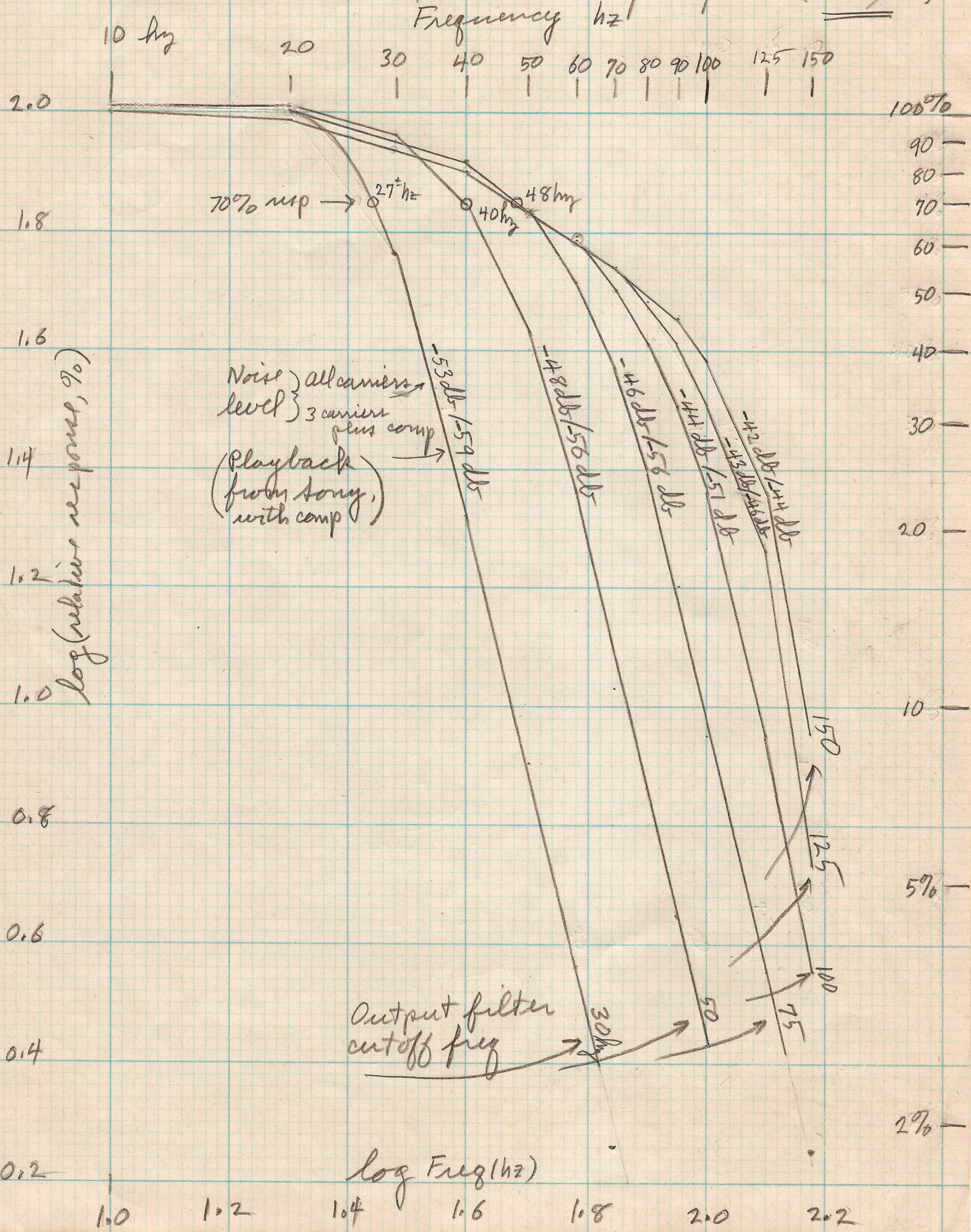


Fig 15

Develco Discr

(20HC) Discr with 0.015 μF Discrim Ampl Capacitor

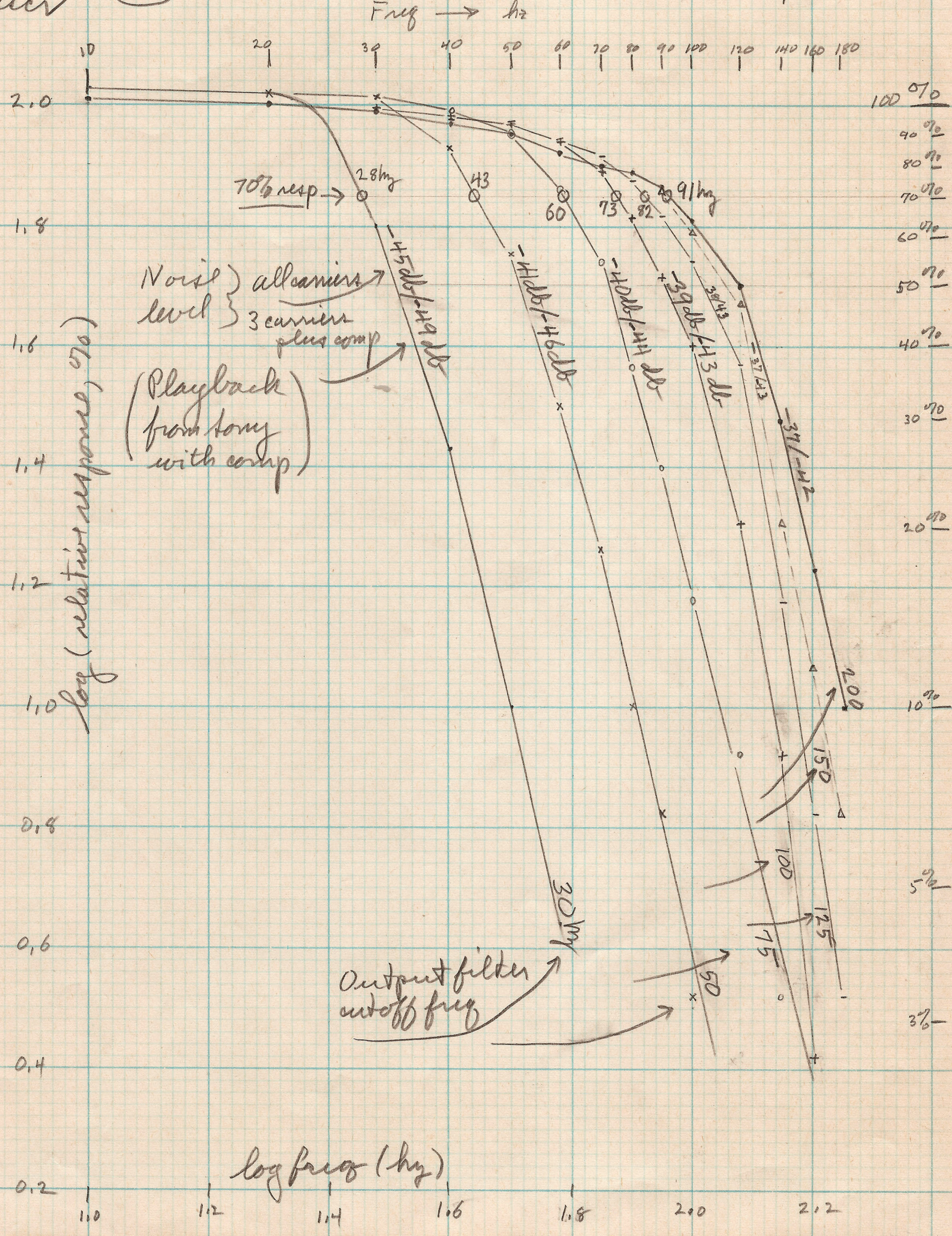


Fig 16

Dwelco Discr (2040) Discr with 0.0068 Discr Ampl Capacitor