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APP. C

APPENDIX C

LINEAR S/N SUMMER NOISE POWER DENSITY
TEST RESULTS

Submitted as part of the Final Report
for RF Test Console on JPL

Contract No. 950144

NAS 7-100

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Westinghouse Defense and Space Center

Surface Division

Advanced Development Engineering

MDE 5070

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TABLE OF CONTENTS

65-335
App C

LIST OF ILLUSTRATIONS

65-335
APP.C

LIST OF TABLES

65-335
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I. INTRODUCTION

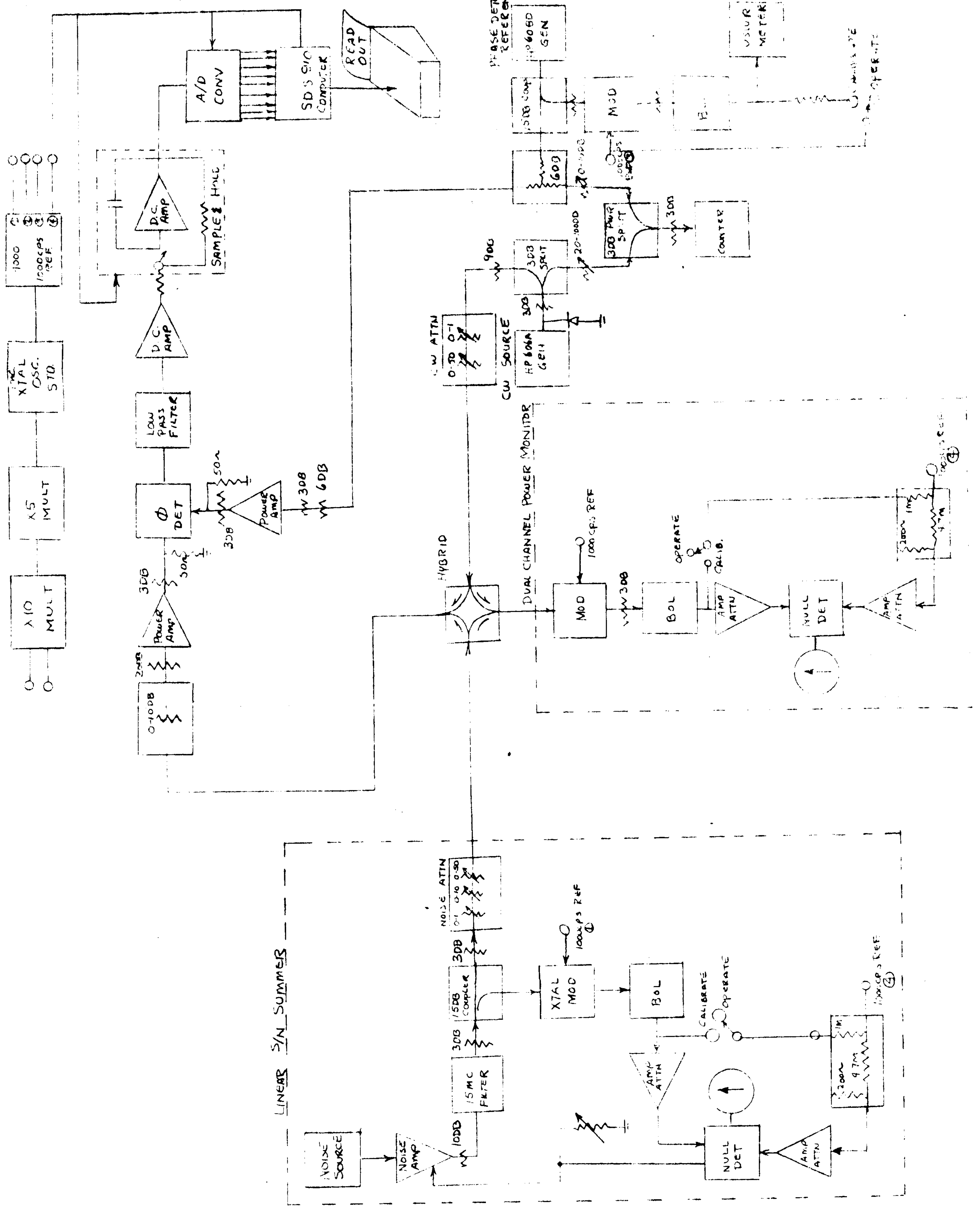
The noise power spectral density of the Linear Signal/Noise Summer was tested in accordance to the J.P.L. Specification GPG-15062-DSN. This specification requires that the noise power spectral density shall be constant within ± 0.05 db over a bandwidth of ± 2 mc centered at 50 mc. The report herein contains a write-up of the technique employed for this measurement along with the results and a discussion of the results.

The measurement technique employed for this test is stated briefly as follows: The noise power, centered at discrete frequency points in the ± 2 mc bandwidth at 50 mc, was translated to video by multiplying the noise with a stable reference frequency in a phase detector. The translated noise bandwidth was accurately established by a 3 pole, low pass, Butterworth filter. The filter noise voltage was sampled at 1000 samples/sec, converted to a digital number and processed on the SDS-910 computer. A group of runs at the same frequency of the mean RMS voltage and standard deviation, were computed and printed out.

II. MEASUREMENT TECHNIQUE

The test set-up used for the noise spectral density test is shown in Figure 1. The technique is basically one of comparison of a noise power output/input ratio in DB to a reference CW power output/input ratio in DB. The input and output power was measured simultaneously both in the case of noise and the CW tone. A comparison between these ratios was made with measurements following one another to insure nearly identical conditions at the time of measurement. That is, with the CW power attenuated, the noise power at the output of the S/N Summer was measured on the dual channel power monitor while at the same time the translated noise power at the output of the phase detector and low pass filter was measured on the computer. A ratio of the power input (dual channel reading) to the power output (computer reading) was made. An identical measurement was made on the CW tone immediately following the noise measurement. The difference of these two ratios, taken following one another, was a measure of the noise power density over the bandwidth set by the low pass filter at the phase detector reference frequency.

By comparing the noise with a CW tone input, variables in the measurement system such as amplifier gain changes, phase detector and d.c. amplifier drifts were compensated. The measurement was therefore relative and depended only on the accuracy with which power readings were made on the dual channel and the computer and also on the bandwidth stability of the low pass filter and the 15 mc noise filter in the Summer. The rate of drift and rate of gain changes in the



ENG.
APPROVED
CHARGE

ENGINEERING SKETCH

TITLE LINEAR S/N
SUMMER NOISE
POWER DENSITY
TEST SET-UP

FIGURE 1

WESTINGHOUSE ELECTRIC CORPORATION
UNDERSEAS DIVISION
BALTIMORE, MD., U. S. A.

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measurement set-up was obviously a source of error but this was measured and found to be insignificant over any particular measurement period. The noise bandwidth was controlled by stabilizing the ambient temperature conditions throughout the test.

The noise power at the S/N Summer output was split through the hybrid with half the power coupled to the dual channel power monitor and half the power fed to the phase detector. The power fed to the power monitor was chopped at 1000 cps in the crystal modulator and demodulated in the bolometer. The bolometer operated square law and performed as an envelope detector giving a 1000 cps output that was a function of the total noise power output of the Summer. The 1000 cps demodulated signal was then compared to the 1000 cps reference signal in a phase sensitive synchronous detector with a resolution of .001 db and an accuracy of .002 db/10 db. The 1000 cps reference signal was derived from the 1 mc standard which was divided down and hard limited at the reference output. The reading recorded on the dual channel was a relative power reading in db of the power out of the Summer relative to the 1000 cps reference level.

The other half of the power split from the hybrid was amplified in a linear power amplifier operated class A and translated about DC zero by mixing in the phase detector. The noise power measured was determined by the low pass filter bandwidth. The noise power was then amplified in the DC amplifier (gain of 100) and sampled every millisecond in the sample and hold circuit (gain of 2). The sampled voltages were quantized, squared and summed in the Computer over the measurement period to determine the rms output voltage. The voltage was converted to a db value by comparison with a reference voltage

65-335
APP. C

and used to compute an equivalent gain with respect to the input db value measured in the dual channel power monitor.

After the noise db gain measurement was made, the noise attenuator in the S/N Summer was set such that the hybrid continued to see its characteristic 50 ohm impedance at the Summer port but the noise power was attenuated to zero. The CW tone was then applied to the CW port of the hybrid with this power splitting in the same fashion as did the noise power. A CW db ratio was computed and used as a calibration of the measurement system with respect to the noise db gain described above. A total of six such comparisons were made at specified discrete frequency parts within the measurement band and then averaged to give a mean and standard deviation for a set of six readings. A plot of the mean gain difference vs frequency provides a representation of the noise power spectrum for the prescribed noise bandwidth and frequency range.

As mentioned above, the drift was measured and found to be insignificant over any group of measurements. However, over longer periods the drift was significant and therefore was balanced before each group of six readings. This was done by first balancing the DC amplifier and sample/hold circuit with the phase detector terminated in its characteristic impedance. The reference to the phase detector was then applied and balanced for zero at the sample/hold output. The balance held over the group of readings within 50 uv.

Throughout the density measurements the making and breaking of connectors was found to be detrimental and therefore eliminated. This was achieved through the use of the plunger action of the precision attenuators in S/N Summer and CW tone channels. The attenuator repeatibility was within .001 db. When either the noise or CW power was not being measured, the precision attenuator was set to 50 db at the hybrid port and opened at the input side of the attenuator. This allowed the hybrid to always see a 50 ohm match without breaking connectors or changing terminations. Repeatibility for any frequency at any one measurement time was generally better than .02 db.

6C-325
APP. C

III. DESCRIPTION OF TEST SET-UP AND EQUIPMENT

The density test was divided into three measurement ranges according to filter bandwidths: (1) 50 kc bandwidth with a frequency coverage of 50 mc ± 2 mc in 200 kc steps; (2) 5 kc bandwidth with a frequency coverage of 50 mc ± 100 kc in 20 kc steps; (3) 500 cps bandwidth with a frequency coverage of 50 mc ± 10 kc in 2 kc steps.

For range 1 a Hewlett Packard Signal Generator powered by a line regulator provided the reference for the phase detector. Frequency stability of better than ± 75 cps over the measurement period was achieved with this generator. The eleven frequencies used for the 20 kc steps in range 2 were obtained with eleven crystals cut for about 1 mc and multiplication to 50 mc. For the last range, 5 crystals were used and capacitatively pulled in frequency before multiplication to provide eleven mixing frequencies 2 kc apart.

The 1000 cps constant amplitude signal used as the clock rate for the A/D converter and also as the reference for the S/N Summer and the total noise power out of the Summer, was derived by dividing the 1 mc frequency standard output down by 1000. The output was hard limited referenced to the divider power supplies and split into 4 reference outputs. As shown in Figure 1, outputs 1, 2 and 3 provided the modulating drive signals to respectively the Summer and dual channel noise modulators, and the power level monitor for the phase detector reference. The fourth output provided the sample rate for the sample and hold circuit and clock rate for the computer while at the same time providing the 1000 cps reference signal used for comparison in the S/N Summer feedback and the dual channel power monitor. The 1000 cps reference therefore had the frequency stability of the 1 mc

65-335
App C

crystal oscillator and amplitude stability determined by the limiter circuit power supplies. The 8 volt power supply was continuously monitored on a differential voltmeter with 1 mv resolution.

To compensate for the reduction in noise power by the bandwidth reduction, linear power amplifiers were employed both at the reference input and noise input of the phase detector. The power amplifiers exhibited linearity up to 1 watt output, and have a bandwidth of approximately 1 mc. Throughout the density test, the operating point on the power amplifiers was at least 10 db below saturation.

The output of the S/N Summer for each measurement point in the three bandwidth ranges was measured on a Weinschel dual channel comparison bridge. The output of the S/N Summer was continuously sampled and envelope modulated by the 1000 cps square wave. The modulated noise power was then demodulated in a bolometer and amplified in a 1000 cps amplifier for comparison in the synchronous null detector with the stable 1000 cps reference from the divider output. The resolution of the dual channel measurement system was .001 db and the relative accuracy of the noise power reading was tied directly to the 1000 cps reference signal and the 1 kc limiter's power supply which was maintained better than ± .005 db.

The phase detector, used for this test, was fabricated with a 50 ohm halfwave tuned transmission line instead of the conventional transformer as shown in the schematic in Figure 2. The linearity was established by the level of the reference signal which was 6 volts rms. The drift of the phase detector was measured on a strip chart recorder with the signal input to the phase detector terminated in 50 ohms. The results of these tests were 8.46 u Vrms per one second interval and 131.6 u Vrms per one minute interval. The low drift exhibited by the phase detector eliminated

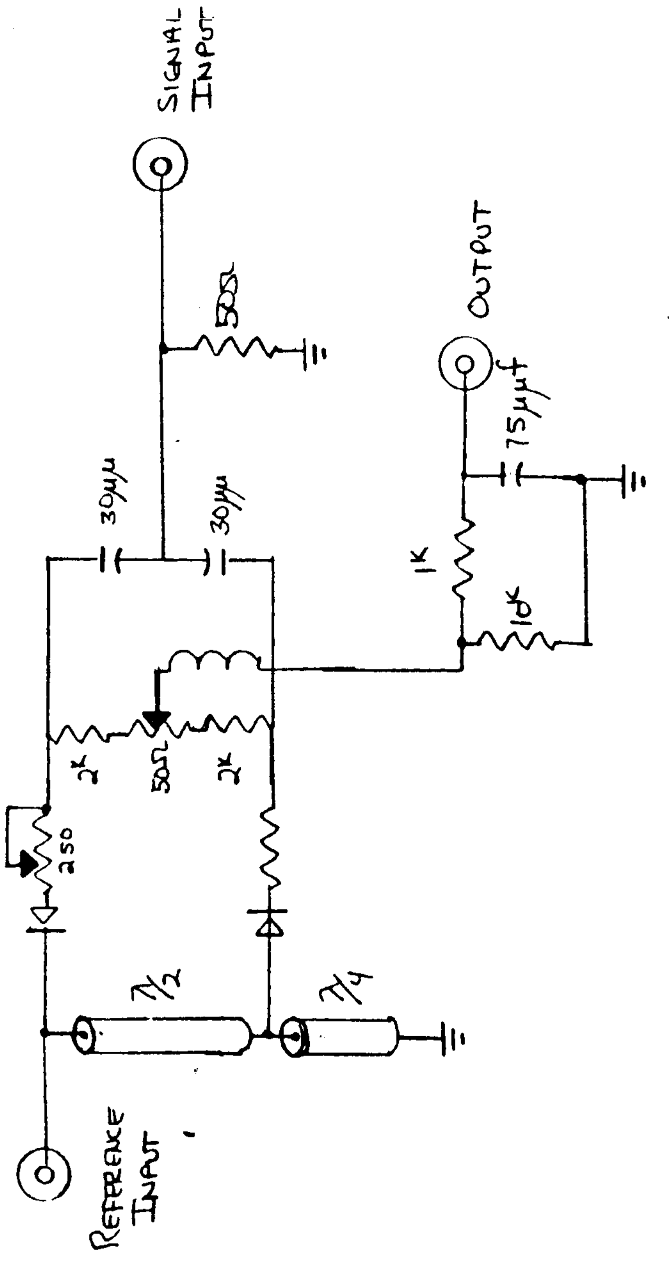

Figure 2. Transmission Line Phase Detector

the necessity for chopper stabilization of the phase detector input. The bandwidth of the phase detector was measured to be 8.0 mc at the 3 db points and down .7 db from center 50 mc at 48 mc and 52 mc.

The bandwidth ranges of 50 kc, 5 kc and 500 cps are achieved with 3 pole low pass filters at the output of the phase detector. The response characteristics of the low pass filters are shown in Figures 3, 4 and 5.

The DC amplifier shown in Figure 6 is an integrated amplifier with an open loop gain of approximately 70 db and closed loop gain of 100. External frequency compensation gave a 3 db bandwidth of greater than 2 mc. An emitter follower was added at the output to yield a symmetrical output capability of ± 5 volts peak out.

The amplitude box car circuit was a high gain DC amplifier with a stable feedback capacitor. The DC amplifier was preceded by a diode switch which was enabled to connect the input signal to be sampled to the amplifier and storage capacitor; and was disabled to disconnect the input signal and hold the sampled value. During the sampling operation the amplifier had resistive feedback giving a closed loop gain of 6 db and during the hold position the amplifier had capacitative feedback only. The schematic of the amplitude box car circuit is shown in Figure 7. The closed loop frequency response with the diode switch enabled was measured to be approximately 1 mc.

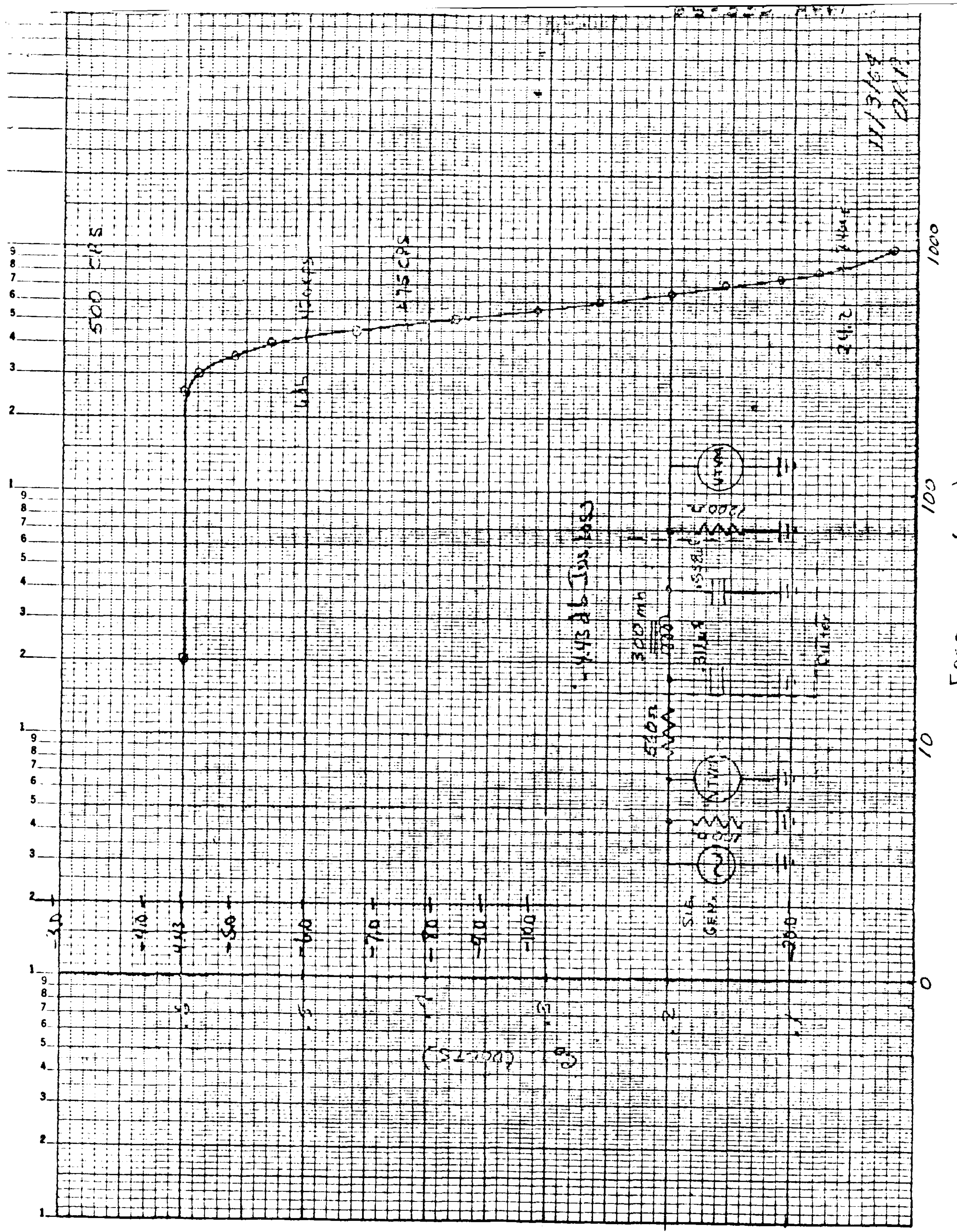

Figure 3. 500 cps Low Pass Filter

65-335 App. C

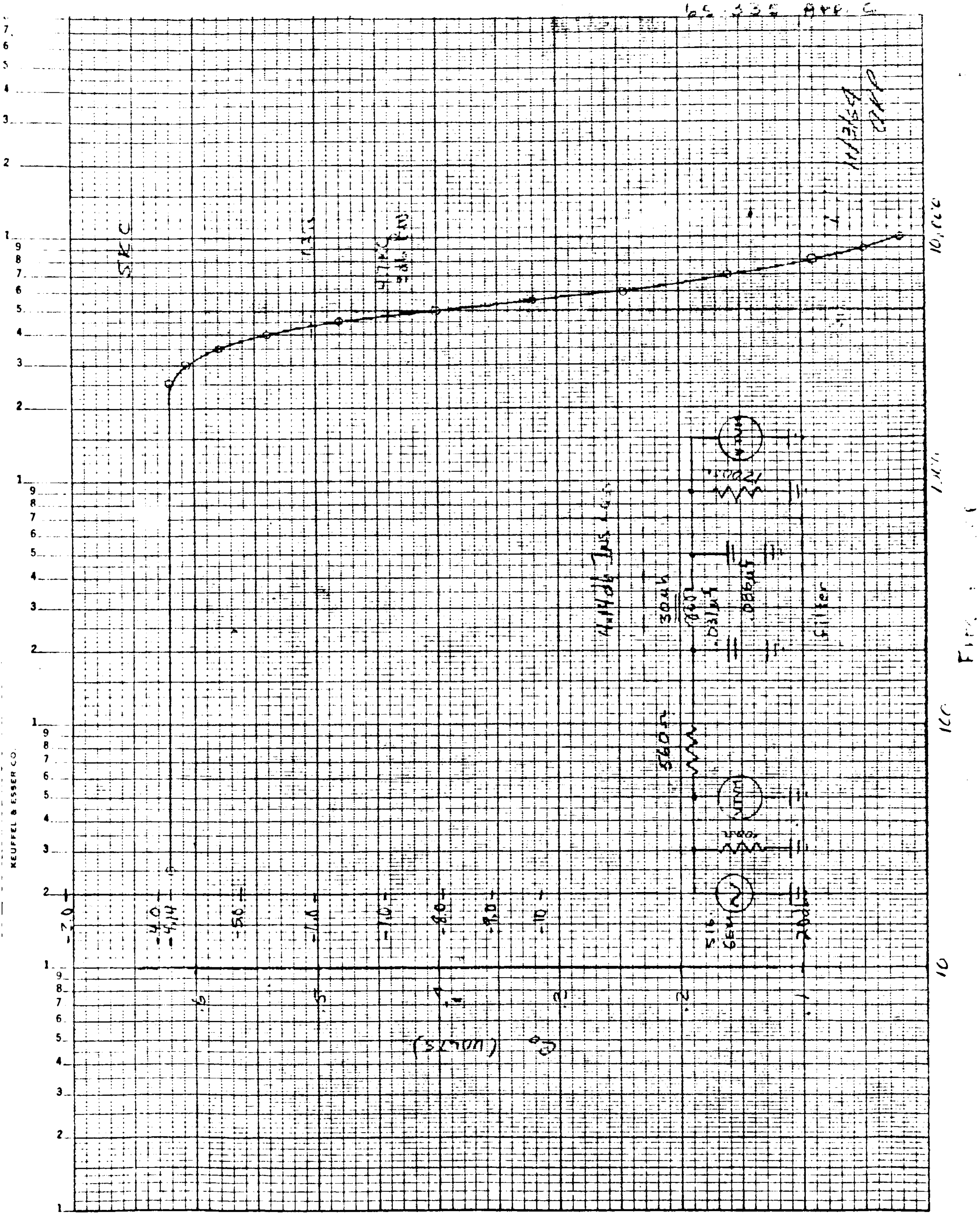

Figure 4. 5000 cps Low Pass Filter

16

LS-335 APP 6

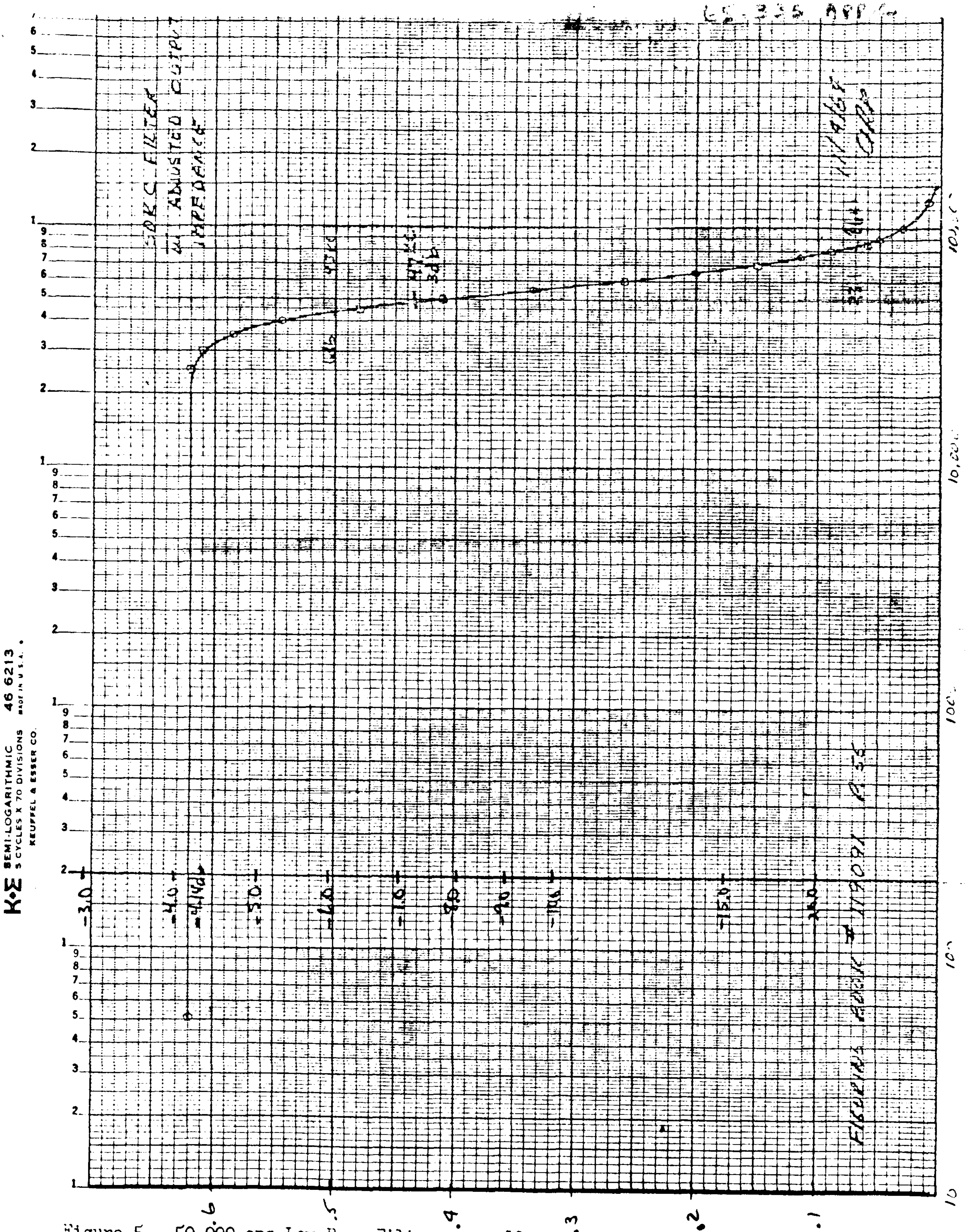

Figure 5. 50,000 cps Low Pass Filter

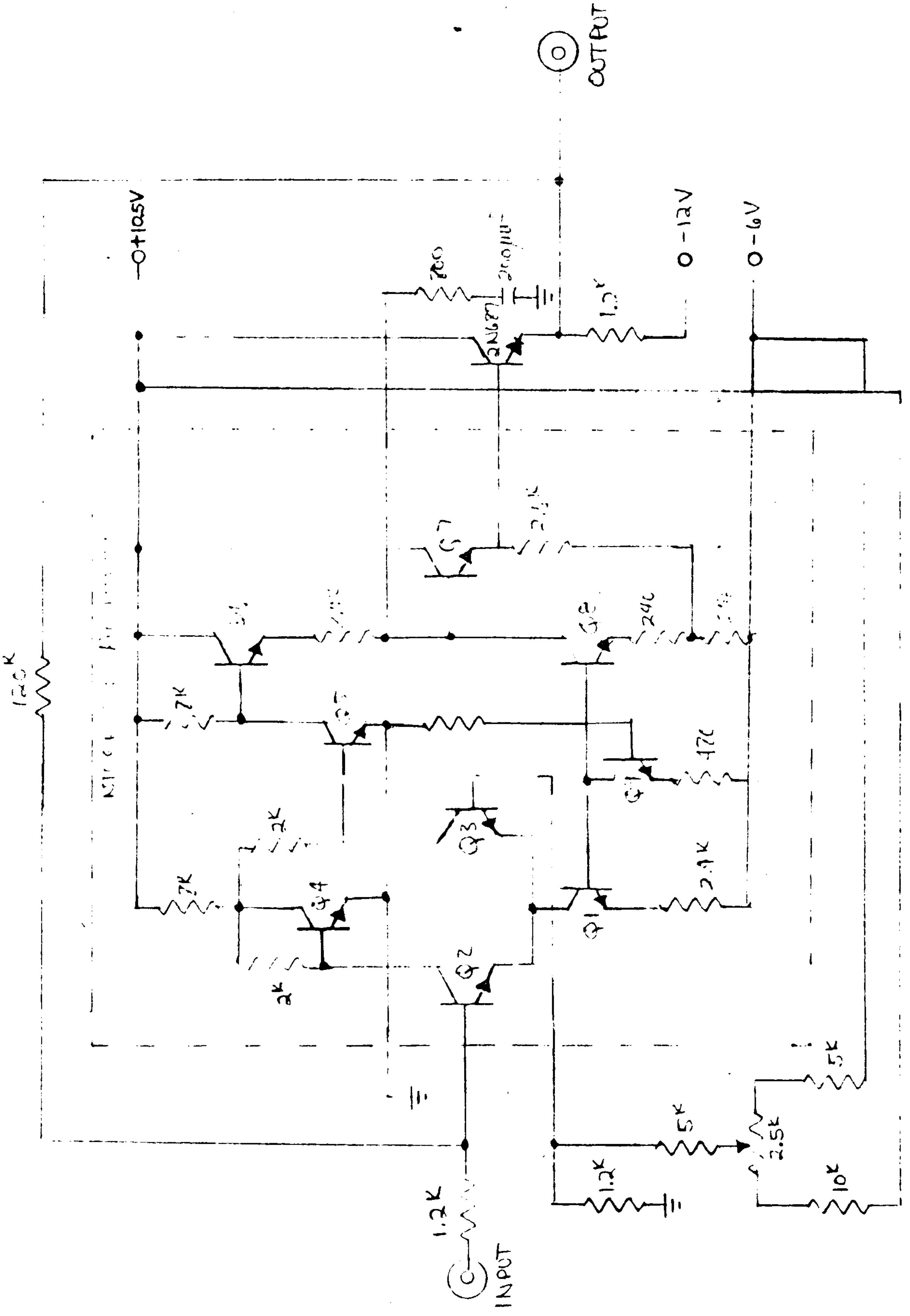

Figure 6. DC Amplifier Schematic

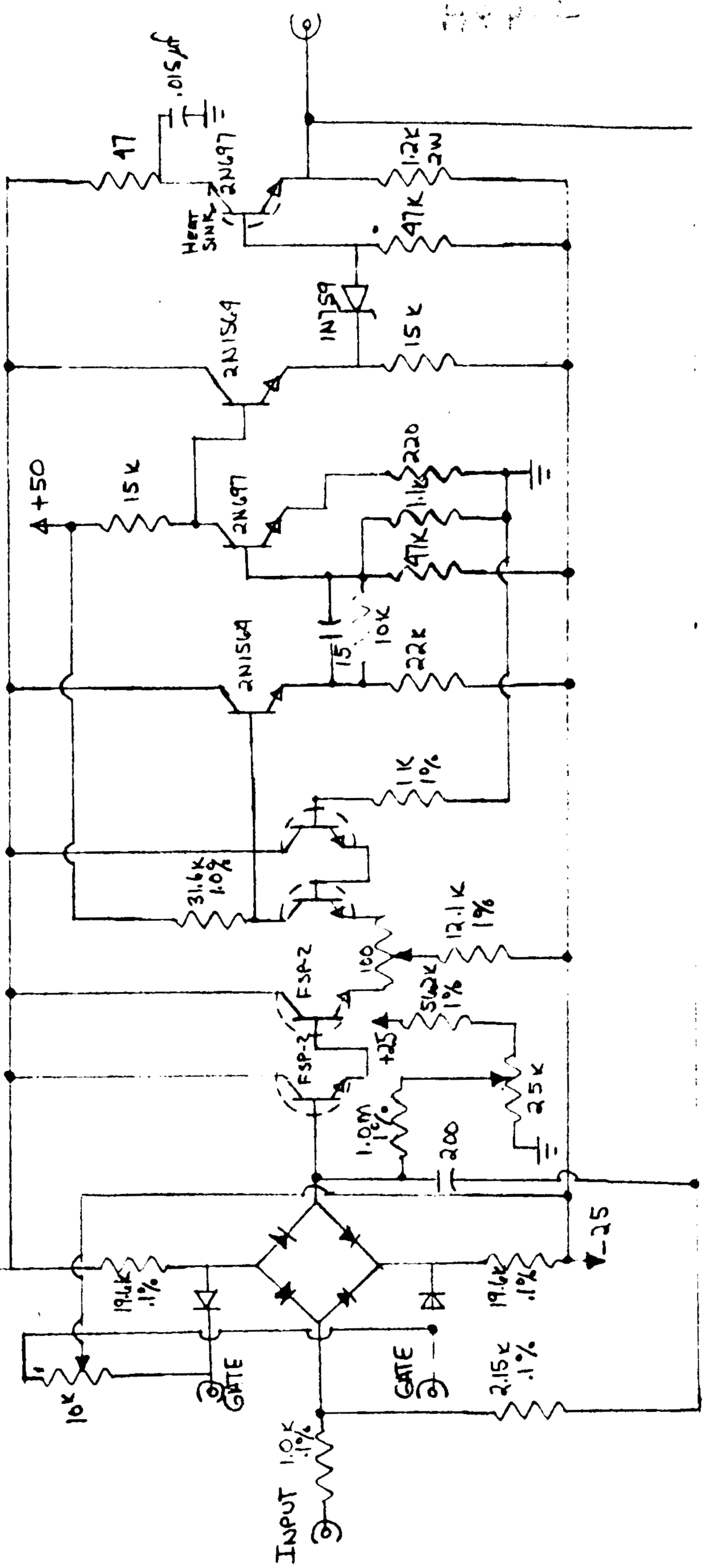

Figure 7. Amplitude Box Car Schematic

IV. OPERATION OF THE A/D CONVERTER AND THE SDS 910 COMPUTER

A. Basic Measurement Techniques

It was desired to measure the noise or CW power transmitted through a low-pass filter to an accuracy of ± .01 db (± 0.1% in voltage). The technique employed was to sample the signal voltage at 1 millisecond intervals and convert from analog to digital form. The digital sample measurements were fed to the SDS 910 computer and the rms value computed by squaring the sample values, summing and dividing by the total number of samples, then finding the square root. The advantages of this technique were that the A/D converter had very good voltage stability and low drift while the computer gave perfect "square-law" operation, integration without drift and printed output. The disadvantages were that modifications were necessary to the sample-hold circuit and the A/D converter output logic levels and that a program for the SDS 910 computer had to be written and debugged.

B. Operation of the A/D Converter

The A/D converter (Packard Bell) accepted an input voltage in the range zero ± 10.0 v. On receipt of a "start conversion" pulse, the converter determined first the sign bit, the most significant bit, then the next bit, and so on until the least significant bit was determined when the converter generated an "end of conversion" pulse. The conversion process for 10 bits plus sign bit required 96 usec and the digital output was retained by a flip-flop register until the next "start conversion" pulse. The digital output was a binary number, with negative numbers represented in modulo-2 form (e.g. + ten = ... 001010, - ten = ... 110110) except that the sign bit was zero for negative numbers, one for positive numbers. This representation agreed with the SDS 910 number system except for the sign bit which was complemented by inversion.

The timing sequence for the sample-hold circuits and the A/D converter is shown in Figure 8. The operation was synchronized to a 1 kc/s square wave by using one-shot multivibrators and trailing edge logic. The 30 usec sample-hold gate pulse allowed the turn-on transient to decay before the gate was disabled. A delay of 30 usec was inserted to allow the turn-off transient to decay before the A/D conversion was initiated. The conversion was completed in 100 usec and the end-of conversion pulse initiated an interrupt signal to the computer.

The timing diagram shows it was necessary to hold the analog signal for only 130 usec, during which the sample-hold output drifted less than 5 mv. The zero-stability of the sample-hold circuit plus the A/D converter proved to be generally within ± 20 - 30 mv for periods of 5 to 10 minutes. Including stray pickup, mostly 60 c/s and harmonics, the total spurious signal level at the sample-hold output was less than 30 mv rms. Since the noise level at this point was about 2 v rms for adequate A/D conversion linearity, the signal to spurious power ratio was 35 db or 3000 to 1. Therefore, the measured power was in error by .033% or .0017 db because of spurious signals and drift.

Another possible source of error was the quantization process inherent in the A/D conversion. The 10 bit digital output corresponded to quantizing a voltage from zero to 10 volts into 1024 levels. Therefore, the quantization interval was approximately 10 mv and the quantization noise was $10/\sqrt{12}$ or 3 mv rms. By comparison with the 30 mv rms spurious amplitude, the quantization noise gave negligible error.

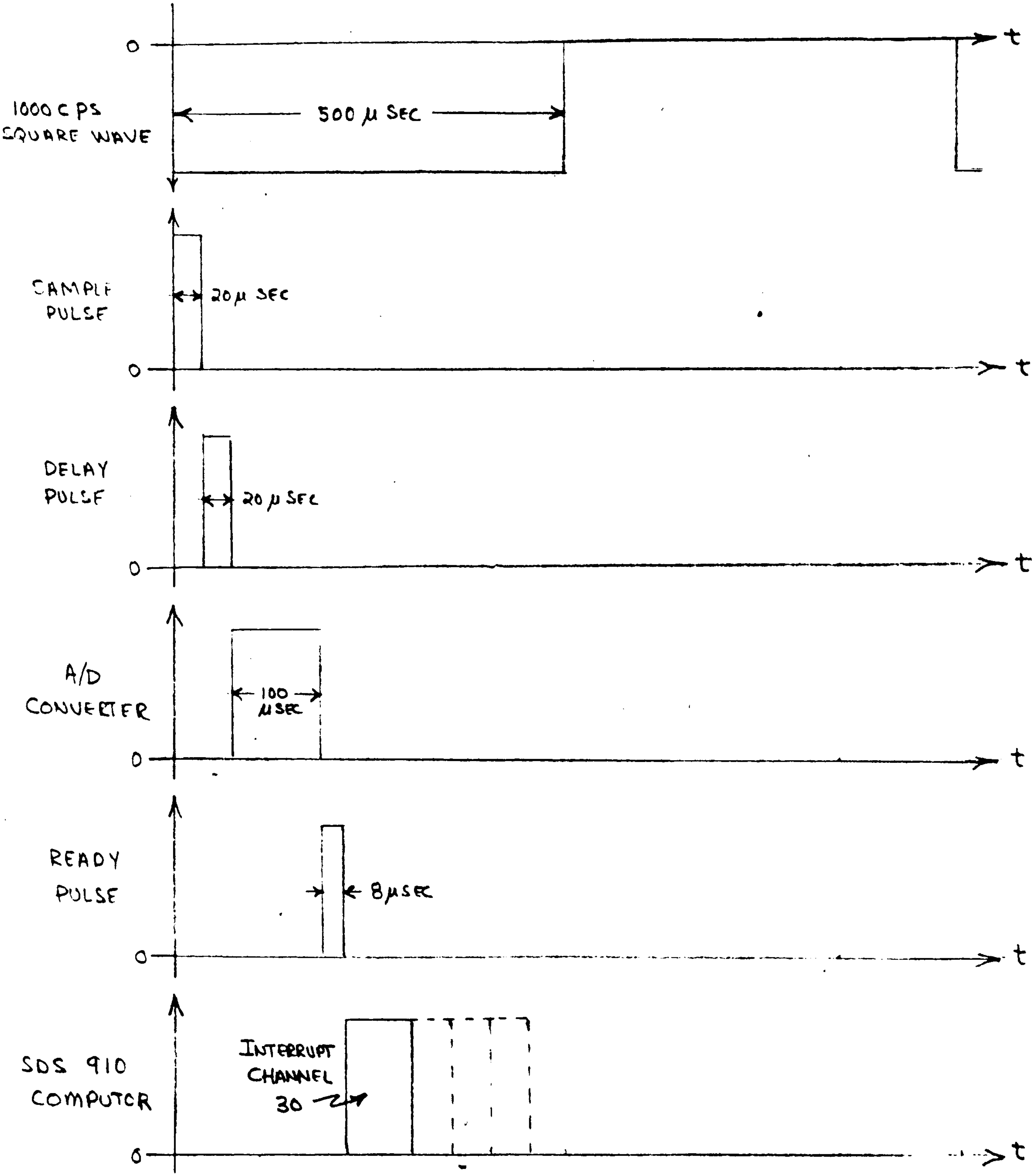

Figure 8. Timing Sequence

C. Data Input to the Computer and Computation

The computer program was divided into two main parts, the data input routine and the power computation routine. Depending on the path followed, the computation routine could require more than one millisecond to complete and it was necessary to provide a buffer area in core storage to prevent loss of input data. Therefore, the data input routine was entered by interrupting the main computation whenever the A/D converter signaled the end of conversion. As the computer did not have any extra interrupt channels, the W buffer end of word channel (30) was used for this purpose.

The input data buffer was capable of storing 100 input values and was operated in a "circular" manner so that the computation routine used the data in the correct sequence. The program checked that the computation routine was never more than 95 values behind the latest input to prevent the loss of 100 input data values by buffer overflow. The digital input was transferred in parallel from the A/D converter to the data buffer and also to one of two 1000 word blocks in core storage. When one block was filled, the data input was transferred to the other block and break point switch 4 was tested. If this was set, the filled block of 1000 input words was output under interlace control as a single record on magnetic tape. Thus the program was capable of accepting data, computing and storing the input data on magnetic tape simultaneously at more than 1000 samples per second.

Besides accepting the input data, squaring and summing over the required number of samples, then calculating the RMS value, the computation program was to simulate low pass filtering of the data. The Z-transform synthesis of three-pole Butterworth low-pass filters of 50 cps and 5 cps bandwidth was to extend the range of the noise power density tests. However, because the tests at 50 kc/s, 5 kc/s and 500 c/s bandwidth took more time and effort than expected, this feature was not implemented.

The usual operation of the measurement system was to take a group of about 12 runs at each reference frequency in the set appropriate to the filter bandwidth. The runs were in pairs with the one having a CW signal, at a suitable frequency difference from the reference, being a calibration for a noise measurement run adjacent in time. As mentioned in previous sections, the noise and CW-input levels (I) were measured with the Weinschel dual-channel equipment during the run. The computed RMS values (M) were than used to establish an equivalent gain from the S/N summation point to the A/D converter, relative to a preset reference level (R), by the following equation.

$$G_{db} = 20 \log_{10} (M/R) - I_{db}$$

where R = 2.0 v for noise, 5.0 v for CW.

The difference Δ between the noise gain G_N and the CW gain G_{CW} was

$$\Delta_{db} = G_N - G_{CW} = 10 \log_{10}(2 N_o B) + K$$

where N_o = Noise power density in the vicinity of the reference

B = Low-pass filter bandwidth

K = Correction for differences of attenuations, input levels and reference levels between noise and CW.

In practice, the I values were entered by the keyboard at the end of each run, with constants identifying the pair number and CW/noise input, and the value of G was computed and stored. At the end of a group of runs, breakpoint 3 was set and the gain differences Δ were computed and typed out. The mean $\bar{\Delta}$ and standard deviation S_Δ of Δ was also computed and typed. The standard deviation S_Δ was generally in the range .01 db to .03 db and gave a good indication of the degree of control of the measurements. The mean $\bar{\Delta}$ was used to determine the noise power density relative to the other mean values in the same set. This assumed that N_o, B and K were constant with time and that K was not a function of B or of the reference frequency, except for the 50 kc/s bandwidth measurements when the noise amplifier frequency response was measured independently and used as the noise power density reference curve.

V. TEST RESULTS

A. 50 kc Bandwidth Measurements

Measurements of noise power through a low pass filter of 50 kc noise bandwidth were taken over a reference frequency range of 50.0 ± 2.0 Mc in steps of 200 kc. Over this range the frequency response of the noise power amplifier within the Signal/Noise Summer was not flat as the tuning had not been adjusted since the equipment was moved. Rather than retune the amplifier, it was decided to run an accurate frequency response with the AGC voltage held at its normal value and to measure the noise power deviations from this curve. The response was measured dual channel at 0.5 Mc increments from 48 Mc to 52 Mc several times with the frequency order permuted randomly in order to randomize the effect of any drift in gain during the process.

Figure 9 shows the mean frequency response of the amplifier with the mean noise/CW gain differences $\bar{\Delta}$ superimposed. All noise means $\bar{\Delta}$ are plotted relative to the original 50.0 Mc values. The noise measurements from 50.0 Mc to 48 Mc were taken in descending order of frequency over a period of 5 days. No unusual results were noticed until the frequency was retuned to 50.2 Mc to take measurements with ascending frequency. It was suspected that this result was too low. This was confirmed by repeating the 50.0 Mc measurements, which gave 2 groups close together but .03 db lower than the original readings. These 50.0 Mc readings and others from 50.2 Mc to 51.0 Mc were taken in one day and are shown connected together. The next day the 50.0 Mc readings were repeated and found to be now 0.65 db below the original pair taken a week earlier. The drift in the 50 Mc reading was thereby confirmed and must be taken as evidence that some uncontrolled variable was causing significant changes in the measuring equipment or the noise power density at the summer terminals. The remaining measurements from 51.2 mc to 52.0 mc were completed the same day and are shown joined to the corresponding 50.0 mc values in figure 19.

It was decided that time did not permit the readings from 50 mc to 48 mc to be repeated,and checking the 50 mc repeatability from day to day. It was also decided not to stop the tests to search for the cause of the variation because past experience had shown that this could consume a great deal of time. Since the other sets of measurements consisted of 11 points each instead of 21 it was felt that a set could be completed in 2 days and repetition of one point would serve to tie the results together. Therefore, the 50 kc results are shown replotted in in figure 10 with the results adjusted for agreement at the 50.0 mc point and corrected for the frequency response of the noise amplifier. All points lie within a range of ± 0.05 db.

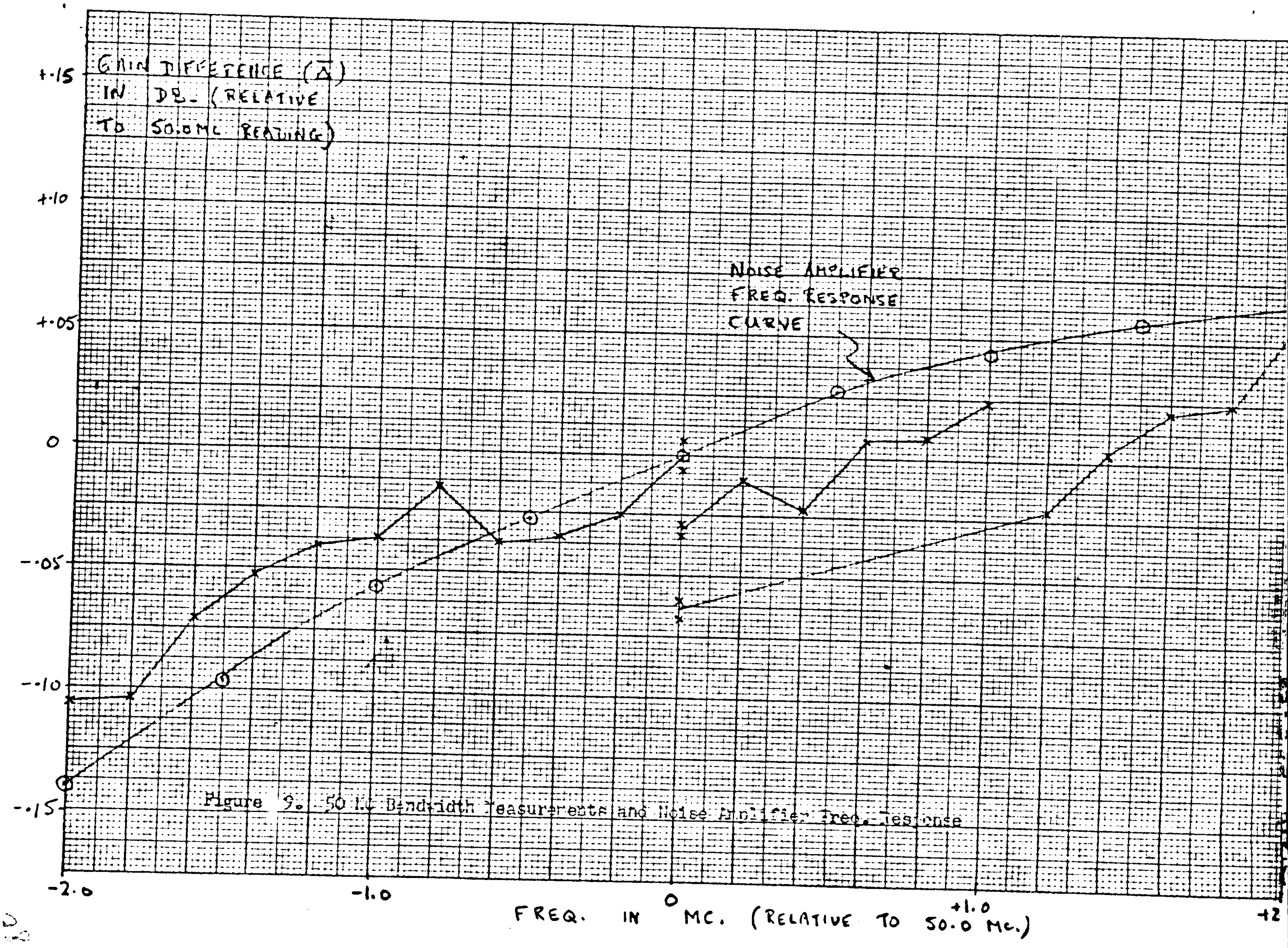

Figure 9. 50 Mc Bandwidth Measurements and Noise Amplifier Freq. Response

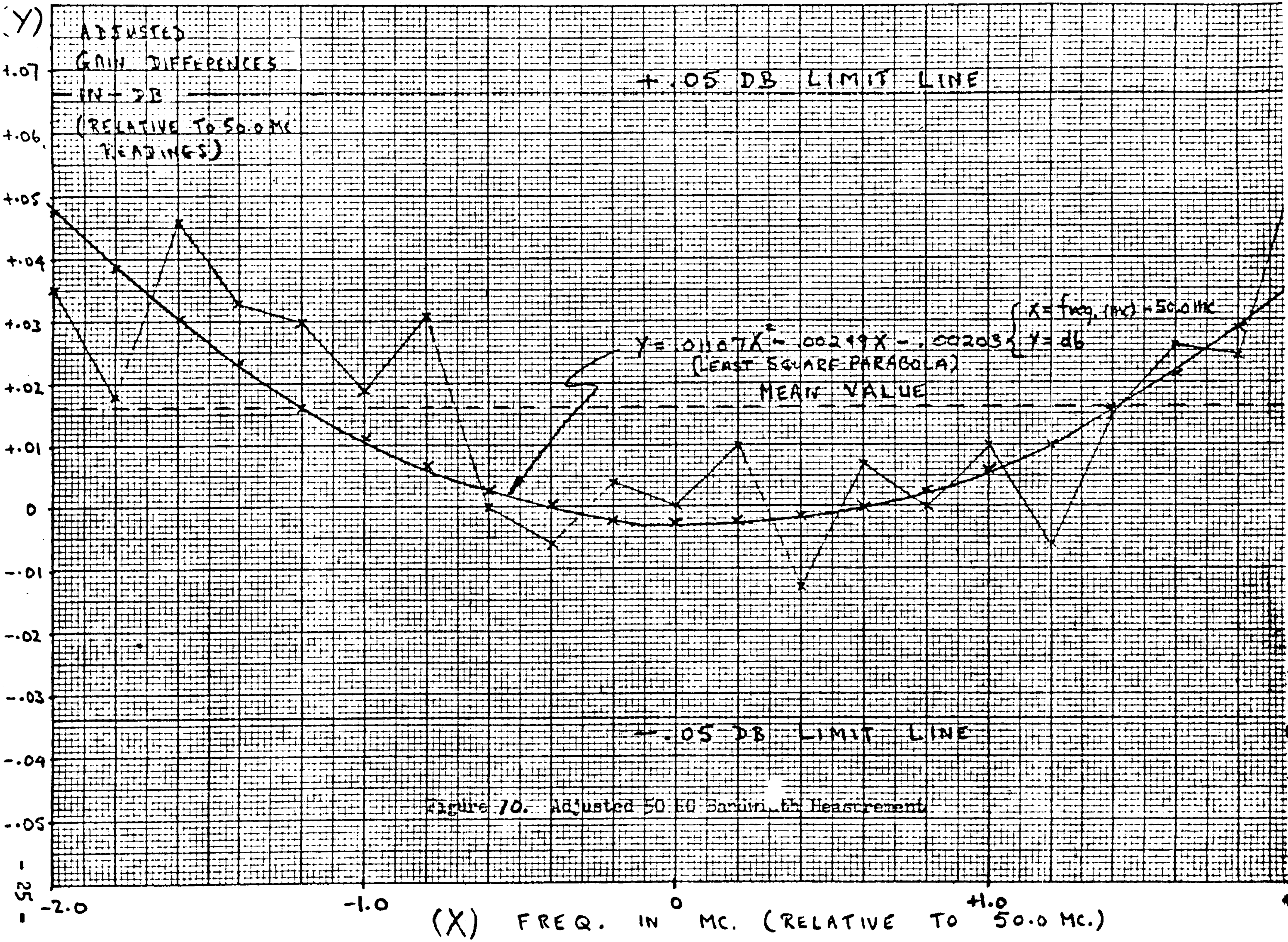

Figure 70. Adjusted 50 KC Bandwidth Measurement

B. 5 kc Bandwidth Measurements

A total of 18 groups of measurements was made in a period of 3 days over the frequency range 50.0 ± 0.10 Mc in 20 kc steps. The measurement at 50.04 Mc was taken 3 times, once each day, but no significant drift was evident. Therefore, the mean noise/CW gain differences $\overline{\Delta}$ are plotted in figure 11 without adjustment.

The overall mean value is 13.602 db and limit lines of ± .05 db about the mean are drawn on the diagram, allowing also a tilt of + .010 db from 49.90 Mc to 50.01 Mc for the noise amplifier frequency response. It will be seen that all the measured points be within the limits.

C. 500 cps Bandwidth Measurements

Again 18 groups of measurements were made in 3 days, but over the frequency range 50.0 Mc ± 10 kc in 2 kc steps. The first day readings were taken from 50.0 Mc down to 49.990 Mc and are shown in figure 12. The second day the range from 50.002 Mc to 50.010 Mc was covered and 49.998 Mc repeated. As will be seen from figure 12, there was a difference of about .07 db between the means for the two days, which is almost four times the pooled standard deviation and definitely indicates drift.

The reason for the drift is unknown but several equipment problems could contribute. To maintain the level out of the low pass filter and DC amplifier at 1V.rms, the noise input to the wideband phase detector was increased 10 db. This necessitated an increase in the reference amplifier output to maintain phase detector linearity which increased the dissipation and voltage drop of the detection diodes

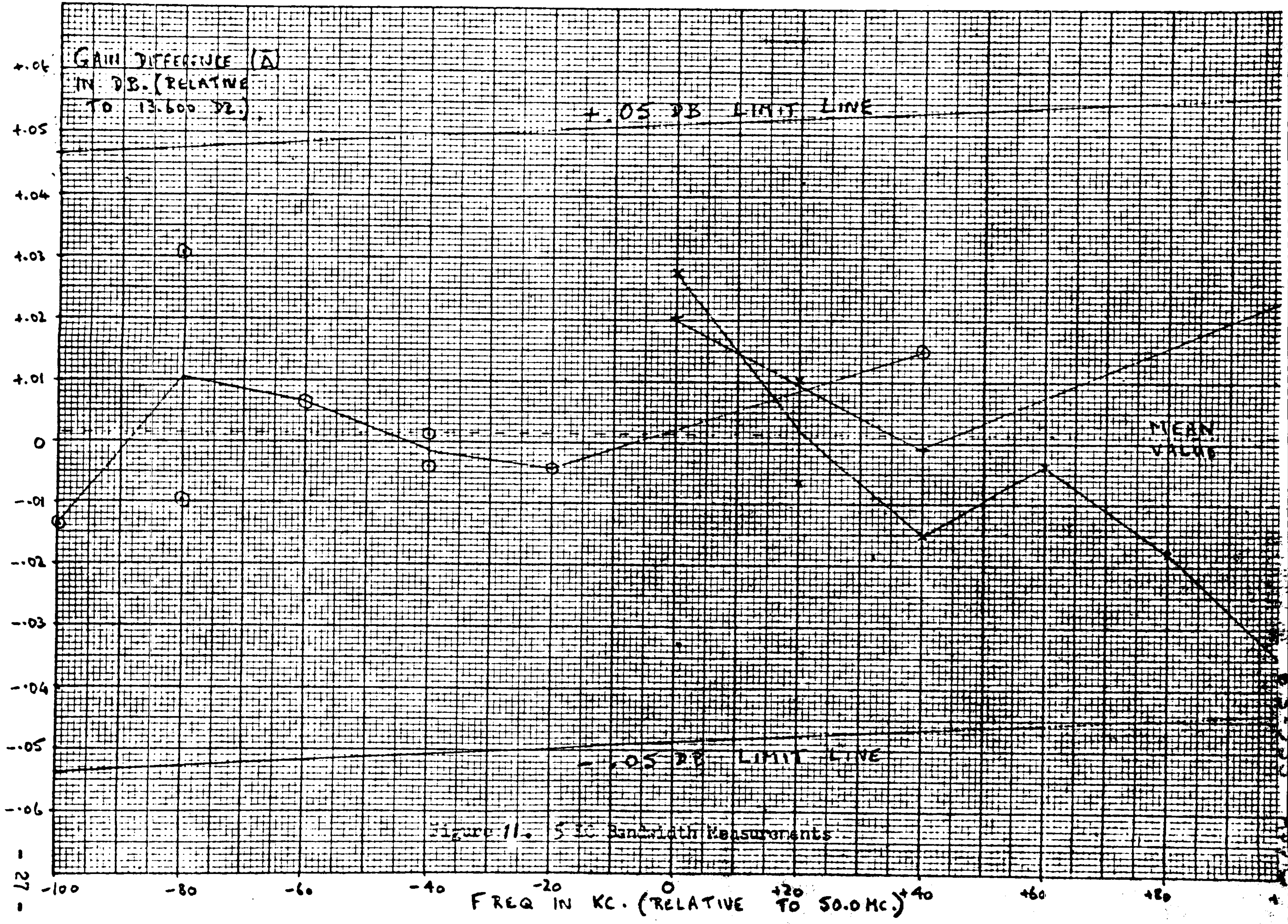

Figure 11. 5 KC Bandwidth Measurements

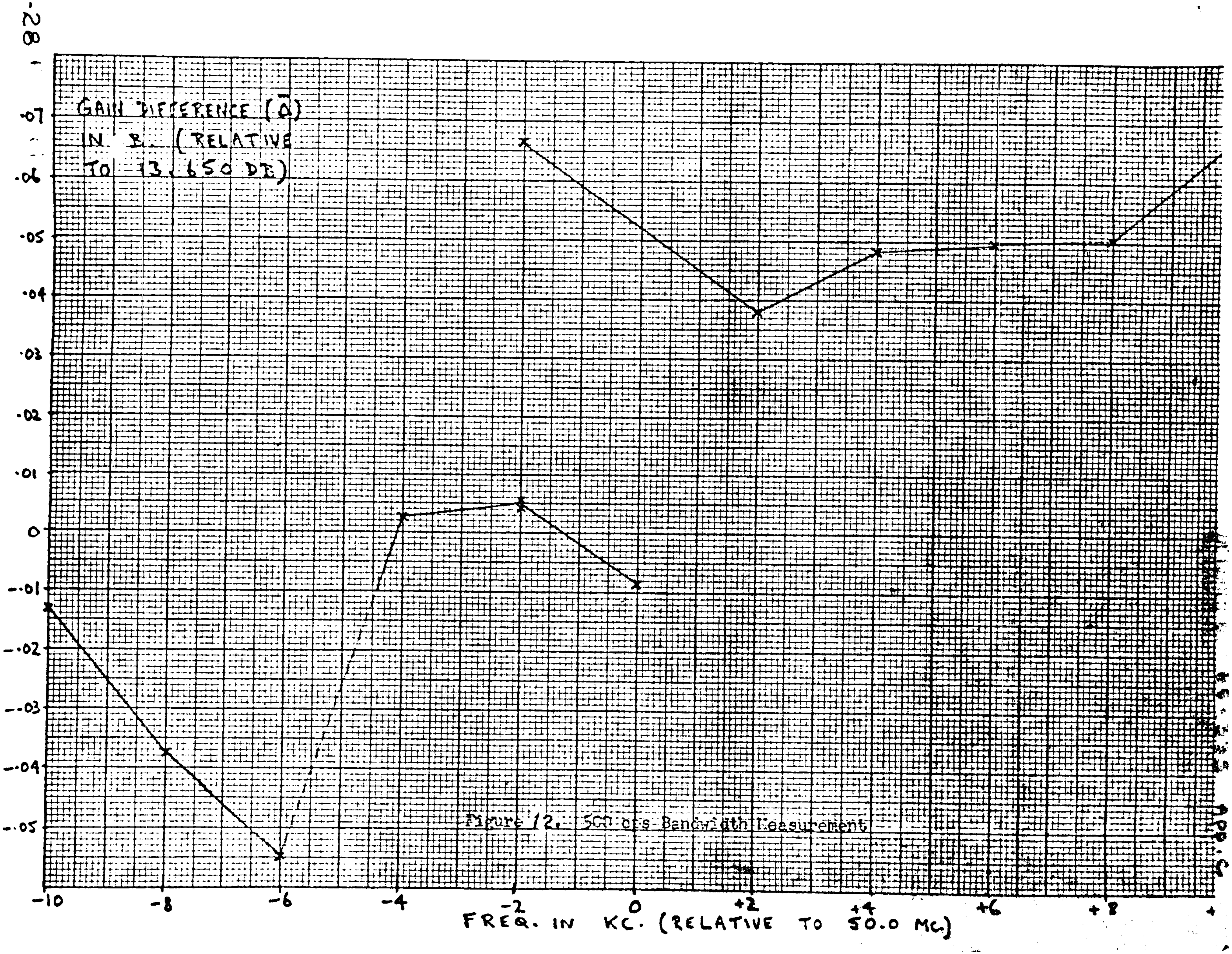

Figure 12. 500 c/s Bandwidth Measurement

and reduced the dc balance stability. The increased noise power output of the amplifier driving the phase detector also caused it to approach its overload point and possibly gave increased output variation with 60 cps supply variations. At this level and bandwidth, leakage from the reference oscillator, frequency multiplier and power amplifier into the noise amplifier became evident. It gave a dc signal out of the phase detector which depended on the phase of the leakage signal relative to the reference and was about 10 db below the 500 cps noise output.

The leakage appeared to be fairly stable in amplitude and in phase, which means that it did not have any significant effect on the 5 kc bandwidth measurements at 10 db lower level. However, since the leakage appeared to be via ground loops and common 60 cps bus lines and could not be suppressed more than 3 db, it was decided to cancel out the dc signal for the measurements by readjusting the phase detector balance. The noise input line length was adjusted for maximum dc output (to provide a greater margin against phase drift) and the potentiometer adjusted for zero ± 0.1 v dc output before each run, using a long meter time constant.

On a third day, considerably later, four points were taken across the whole 20 kc frequency range, to see if any real difference existed between the two sets taken earlier, and they too are shown in figure 12. These measurements were taken with the noise input level reduced 6 db for greater gain stability. The points show that any difference was small and figure 13 shows the earlier sets adjusted to agree at 49.998 Mc with the four later points superimposed to give the same mean value. There is no appreciable tilt for the noise amplifier

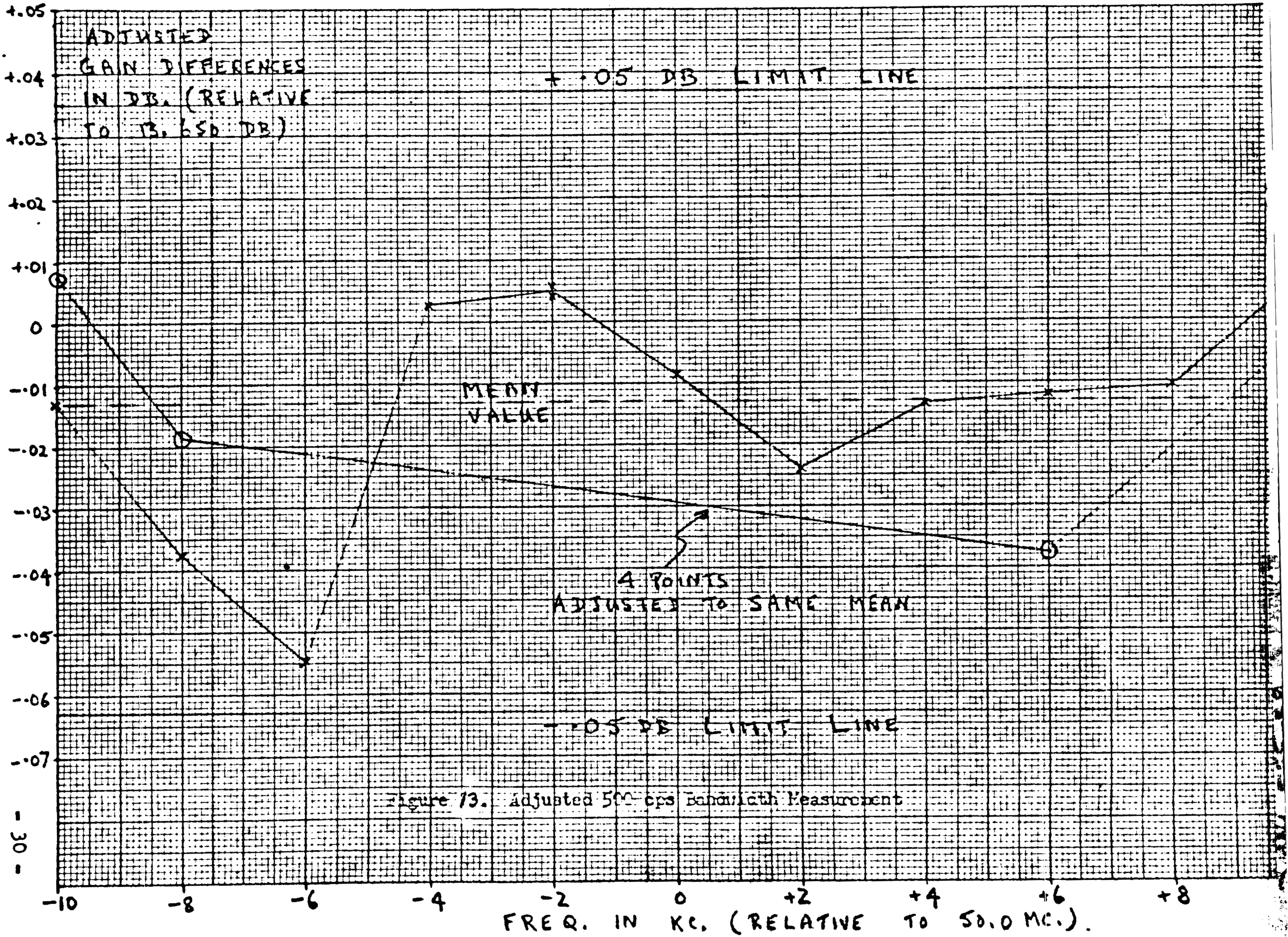

Figure 13. Adjusted 500 cps Bandwidth Measurement

34

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frequency response over this range and it will be seen that all points be within limit lines ± .05 db from the overall mean.

D. 50 cps and 5 cps Bandwidth Measurements

Because of the increasing difficulty of the measurements and the possibility of not achieving the desired resolution it was decided by JPL and Westinghouse that the noise power density tests at these bandwidths were unlikely to be worth the cost in time and effort. In addition, reasoning based on the physics of the noise generation process and the frequency response of the amplifier, tuned circuits, lines, attenuators and other components in the noise circuit shows that fine grain frequency structure of the noise power density should not exist. This conclusion is verified by the negative results obtained in the 5 kc and 500 cps bandwidth measurements and strongly indicates that negative results would be obtained by 50 cps and 5 cps measurements also.

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TABULATION OF RESULTS

Table I Results of 50 Kc Bandwidth Measurements

Date	Time	Pairs	Mean	Std. Dev.	Mean Difference	Freq.
2/5	1150	5	3.4779	.020	+.006	50.0 Mc
2/5	1413	5	3.4658	.010	-.116	50.0
COMBINED RESULT		10	3.47185	.0162	---	50.0
2/5	1718	6	3.3809	.069	+.092	49.8*
2/6	1550	6	3.4786	.025	-.0067	49.8
2/8	1025	6	3.5001	.013	-.028	49.6
2/8	1128	6	3.5036	.023	-.032	49.4
2/8	1500	6	3.4849	.012	-.013	49.2
2/9	910	7	3.5091	.025	-.037	49.0
2/9	1400	6	3.5119	.021	-.040	48.8
2/9	1505	6	3.5250	.027	-.053	48.6
2/9	1607	6	3.5284	.025	-.057	48.4
2/10	1400	6	3.5752	.028	-.103	48.2
2/10	1453	6	3.5847	.028	-.105	48.0
2/10	1545	6	3.5073	.026	-.035	50.2
2/11	900	6	3.4937	.013	-.022	50.4
2/11	1005	6	3.5021	.030	-.030 .031	50.0
2/11	1125	6	3.5043	.013	-.032	50.0
2/11	1350	5	3.4823	.010	-.010	50.2
2/11	1440	6	3.4651	.011	+.007	50.6
2/11	1533	6	3.4626	.013	+.008	50.8
2/11	1615	6	3.4475	.014	+.024	51.0

* Problem in equipment, reading not used

65 - 235 [illegible]

TABULATION OF RESULTS

Date	Time	Pairs	Mean	Std. Dev.	Mean Difference	Freq.
2/12	945	6	3.5324	.021	-.061	50.0
2/12	1460	6	3.5412	.019	.065 -.069	50.0
2/12	1445	6	3.4925	.019	-.021	51.2
2/12	1530	6	3.4669	.008	+.0050	51.4
2/12	1610	6	3.4600	.026	+.021	51.6
2/12	1650	6	3.4487	.010	+.0232	51.8
2/12	1730	6	3.4139	.016	+.059	52.0

Table II Results of 50 Kc Bandwidth Measurements

2/15	1600	6	13.5936	.018	-.0064	50.02	
2/16	945	6	13.6280	.015	+.0280	50.00	
2/16	1025	6	13.6104	.017	+.0104	50.02	
2/16	1345	6	13.5850	.022	-.0150	50.04	
2/16	1440	6	13.5965	.012	-.0035	50.06	
2/16	1520	6	13.5820	.017	-.0180	50.08	
2/16	1600	6	13.5632	.012	-.0368	50.100	
2/17	935	6	13.5957	.014	-.0043	49.980	
2/17	1012	6	13.6010	.032	+.0010	49.960	
2/17	1040	6	13.5960	.023	-.0040	49.960	
2/17	1130	6	13.6063	.033	+.0063	49.940	
2/17	1205	6	13.6313	.022	+.0313	49.920	
2/17	1400	6	13.5861	.016	-.0139	49.900	
2/17	1530	6	13.5902	.008	-.0098	49.920	
2/17	1645	6	13.4227	.023	-.1773	50.04*	Data Error
2/17	1745	6	13.6157	.026	+.0157	50.04	
2/18	915	6	13.5994	.033	-.0006	50.04	
2/18	955	6	13.6244	.021	+.0244	50.100	
2/18	1130	6	13.6217	.024	+.0217	50.000	
2/18	1405	3	13.6213	.009	+.0213	50.000*	Incomplete

* Reading not used

Table III. Results of 500 cps Bandwidth Measurements

Date	Time	Pairs	Mean	Std. Dev.	Mean Difference	Freq.	
2/18	1615	6	13.5657	.021		50.000*	3 VRMS
2/19	900	6	13.5292	.022		50.000*	on Ø Ref
2/19	1130	6	13.8511	.011		49.998*	Ø Ref 5V
2/19	1430	6	13.7941	.020		49.998*	Bad Offset
2/20	1130	6	13.9052	.030		49.996*	Offset Cor
2/20	1210	6	13.8845	.013		49.996*	Expts.
2/26	1300	6	13.7511	.033		49.996*	Bad Bal.
2/26	1400	6	13.8237	.018		49.998*	Sample - Hold
2/26	1600	6	13.6545	.016	+.0045	49.998	
2/27	1115	6	13.6557	.022	+.0057	49.998	
2/27	1210	6	13.6415	.012	-.0085	50.00	
2/27	1300	6	13.6529	.012	+.0029	49.996	
2/27	1355	6	13.5951	.020	-.0549	49.994	
2/27	1535	6	13.6370	.019	-.0130	49.990	
2/27	1630	6	13.6126	.009	-.0374	49.992	
3/1	1050	6	13.6880	.016	+.0380	50.002	
3/1	1150	6	13.7344	.012	+.0844	50.004*	Ref level error
3/1	1330	6	13.6985	.020	+.0485	50.004	
3/1	1515	6	13.6998	.024	+.0498	50.006	
3/1	1600	6	13.7005	.035	+.0505	50.008	
3/1	1645	6	13.7176	.018	+.0676	50.010	
3/1	1740	6	13.7160	.026	+.0668	49.998	
3/16	1000	6	3.2807	.037	-.119	50.006*	Operator error
3/16	1120	6	3.4050	.010	+.005	50.010	
3/16	1330	6	3.4160	.043	+.016	49.990	
3/16	1425	6	3.3905	.018	-.010	49.992	
3/16	1550	6	3.3714	.014	-.029	50.006	

* Reading not used

VI CONCLUSIONS

The graphs of the adjusted results show that all measured points lie within the limit lines of ± .05 db about the noise amplifier frequency response curve. The standard deviations of the plotted points are .0183 db for 50 kc bandwidth, .0179 db for 5 kc bandwidth and .0181 db for the 500 cps bandwidth measurements. However, the adjusted 50 kc results shown in Figure 10 display a strong tendency to follow a parabolic curve while the other results show only random variations about the mean values.

Therefore, the adjusted results show that the combination of measurement errors and noise power density variation has a standard deviation of .018 db for the 5 kc and 500 cps bandwidth measurements. It is not possible to say what fraction of the scatter is due to measurement errors or to the spectral density variation. Statistically, it is possible to make a statement about the percentage of measurements which would fall outside the limit lines, though none did in the actual results. From 21 points with a standard deviation of .018 db, with 95% confidence at least 95% of all measured mean differences ($\bar{X}$) will fall within ± .050 db of the mean value. By adding a straight line to the points and recalculating the standard deviation it is possible to determine confidence intervals for the slope of the straight line. For both the 5 kc and the 500 cps bandwidth measurement, a slope of zero gives the least standard deviation (least squares fit) and with 90% confidence the straight line tilt is less than ± .05 db over the frequency range of the measurements.

The 50 kc bandwidth results show strong evidence that the noise power density was not flat over the range 50 ± 2.0 Mc. The least squares fit of a parabolic curve to the data reduces the standard deviation of the residual scatter to approximately .012 db. The curve which shows a spectral deviation of .04 db over the frequency range in figure 10 is not the only possible curve. A series of curves could be fitted and the confidence that a true fit was obtained could be estimated from the recalculated standard deviation. However in this case, it was not thought practical to determine the confidence limits for the fitted parabolic curves.

In summary, the 50 kc results show evidence of a hump of about .040 db in the spectral density, due to the noise generator, cable matching or drift in the noise amplifier frequency response, while the 5 kc and 500 cps results show only random variation and no definite spectral tilt. However all measurements fall within limit lines of ± .05 db and at least 95% of all such measurements would continue to do so.