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FINAL REPORT

HIGH FREQUENCY RADIO STUDY

1 May 1955 thru 31 July 1956

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Section A

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Section B

SUMMARY

An evaluation of the operation of the AN/FGC-29 channeling system was performed over the 5000 mile radio circuit between Kahuku, T.H. and Riverhead, N.Y. One of the purposes of these tests was to determine how well the AN/FGC-29 would operate using keying speeds appreciably faster than that for which it was designed. It was found that with keying speeds up to 104.166-- bits per second there was no appreciable degradation in performance.

Another purpose of these tests was to determine the relative improvement in operation to be gained by substituting the AN/FGC-29 for the AFSAY D-806 channeling system. In terms of percent errors the AN/FGC-29 averaged 1/5 the error rate when the AFSAY D-806 was producing 1% errors. Normally the AFSAY D-806 handles 250 bits per second per channel (4 ms bits). To provide the same information rate in approximately the same bandwidth the 16 channels of the AN/FGC-29 would have to be keyed at a rate of only 100 bits per second (10 ms bits). It was to be expected that a given amount of multipath delay would have relatively more effect on signal elements of 4 milliseconds in length than on signal elements of 10 milliseconds.

Other effects of radio circuit propagation on the AN/FGC-29 channel were determined and are briefly listed below.

1. An 11 db signal-to-noise ratio measured in the channel* is required in order to average 1% errors using diversity

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*The method used to measure signal-to-noise ratio is described in Appendix BB, page BB1.

reception and keying speeds of 71.42 and 100 bits per second.

2. Error rates in one channel due to interference from one keyed adjacent channel will average less than 1% for adjacent channel levels not more than 38 db greater than the level in the channel.

3. When the error rate with a single receiver is 1%, the application of diversity reception will reduce the error rate by a factor of about 6.

The operation of the AN/FGC-29 using 100 word-per-minute teletypewriter was related to the bit errors produced in a synchronous 48-element electronically generated pattern. It was found that in comparing a 71.4-bit per second keying rate with the 100 wpm teletypewriter character errors, an average of 7 times more percent teletypewriter errors occurred when the 71.4 bit-per-second keying was producing 0.5 to 0.05% errors.

Additional ionospheric propagation information is reported in the appendix of the report. This information is a reduction of the signal intensity recording into hourly medians for the month for the Kahuku, T.H. - Riverhead, N.Y. radio circuit covering the period of November 1953 to May 1956 and Orleans, France - Riverhead, N.Y. circuit covering the period of August 1954 to November 1954.

Section C

ABSTRACT

For about six months covering the period of December 1955 through May 1956 two channels of an AN/FGC-29 terminal were tested over the 5000-mile Kahuku, T.H. - Riverhead, N.Y. radio circuit. The chief objects of these tests were to determine the relative performance of the AN/FGC-29 channels at keying speeds appreciably faster than their design rating, and to determine their relative improvement when compared to the AFSAY D-806 channeling system. These evaluations were performed on both daytime and nighttime frequencies so as to have comparisons with relatively small and large multipath distortions. In order to facilitate testing, an electronic short pattern generator was used to provide synchronous keying for the channels. The pattern consisted of 48 elements in various mark and space combinations. Synchronism was supplied from a highly stable source of frequency for both the Kahuku and Riverhead terminals.

Error rates taken simultaneously and expressed in percent were used to measure the performance of the AN/FGC-29 channel at keying speeds of 71.42--, 100, 104.166 and 125 bits per second. It was found that the 29 channel will handle 104.166 bits per second with no appreciable degradation. This is an information rate of 1666 bits per second for the entire system of 16 channels.

Presuming that an average of 1% errors represents the lower limit of usable information, an AN/FGC-29 channel using diversity reception requires a signal-to-noise (S/N) ratio of about 11 db

measured in a channel* for keying speeds of 71.42 and 100 bits per second. Since it was found that there is little difference between the relative performance of the 100 and 104.166 bit rates, it may be inferred that the 11 db S/N ratio would also apply to the 104.166 bit rate. Appreciable degradation of the 125 bits-per-second rate however, was observed, a S/N ratio of at least 13 db being required for 1% errors. Using a local laboratory single sideband generator and "white noise" injected into the receiver input, 1% errors resulted for 71.42 and 100 bit-per-second keying rates with S/N ratios of about 7 db. This value is smaller than that on the radio circuit because no fading is involved. It was also determined using the local test setup that when "noise" was due to an adjacent channel keying, an average of 1% errors were produced for adjacent channel levels not more than 38 db greater than the level in the channel.

Diversity and single receiver reception were compared over the radio circuit for the AN/FGC-29 channeling system. On the average, diversity operation reduced the error rates from about 25 to 1 when single receiver reception was producing 0.3% errors to about 6 to 1 for 1.0% errors.

The AFSAY D-806 system normally handles keying rates of 250 bits per second per channel (4 ms bits). In ordor for the AN/FGC-29 to transmit the same information rate in the same bandwidth each channel would have to be keyed at only 100 bits per second (10 ms bits). As the length of the signal element is increased, a given amount of multipath delay variation will produce

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*The method used to measure S/N ratio is described in Appendix BB, page BB1.

a smaller relative variation in the length of the detected signal element and consequently less difficulty should be experienced from this cause.

When compared to the AFSAY D-806 system the AN/FGC-29 produced a lower error rate, the improvement averaging about 5 to 1 when the AFSAY D-806 was producing 1% errors. Similarly when the AN/FGC-29 produced 1% errors the AFSAY D-806 averaged 66 to 100% more errors. It was also found that the AN/FGC-29 diversity combining system was equal to or slightly better in performance than the AFSAY D-806 diversity system, the ratio between the two being 1.5 or less for AN/FGC-29 error rates greater than 0.03%.

Recordings of the keying element transition on facsimile equipment were made, the deviation of the transitions (or recorded dots) from a straight line being a measure of the jitter. In order to reduce the effects of noise, only those recordings whose signal-to-noise ratios were equal to or greater than 20 db were scaled. On the average less than 0.1% AN/FGC-29 errors resulted for 100 bit-per-second keying when 1% jitter values in a one-minute sample were less than 4 milliseconds. It was further found that for daytime operation of 14, 15, 16, 19, and 20 mc and nighttime operation of 7, 8, and 16 mc 99% of all the 1% jitter values in a one-minute sample gave less than about 4.0 milliseconds of jitter. This indicates that multipath jitter was not a problem for the AN/FGC-29 during these tests. An additional relationship established was that when the F/MUF 3000 KM (where F is the operating frequency and MUF is the measured maximum usable frequency for a 3000 km path) is greater than 0.5, all the 1% jitter values (for one minute samples) were less than 4 milliseconds.

Comparison of the amounts of jitter produced through the AFSAY D-806 and AN/FGC-29 indicated no substantial difference when the two systems were operated at the same bit rate and using the same low pass filter cut-off frequency on the detected signal.

Since it is expected that the AN/FGC-29 terminal will be used on many of the important military world-wide ratio circuits to provide communications by teletypewriter, a large amount of teletypewriter performance data may be accumulated. It was, therefore, of interest to relate teletypewriter character error rates and short pattern error rates. In these comparisons the teletypewriter was operated at 100 words per minute and the pattern generator at 71.4 bits per second (14 ms bits). It was found that when the error rates of the short pattern tests ran between 0.05% and 0.5%, the character error rates for start/stop teletypewriter were about 7 times greater.

A brief series of comparisons were also made between the character error rates of a 2 channel time division teletypewriter signal operating at a keying speed of about 86 bits per second in the aggregate and the error rates of the pattern generator signal operating at 100 bits per second. These tests resulted in corresponding ratios of from 5 to 17.

In addition to the above data taken on the channeling equipment simultaneously, recordings of signal intensities were also taken. Hourly median values for the month were determined and classification of the distribution of the day-to-day variations for each hour were also made.

It was found that on the average, winter signal-intensities were stronger than in the spring and summer during daytime operation. More than 3/4 of the day-to-day variations for each hour followed a log-normal distribution with the standard deviation varying between 1.5 and 27 db. A correlation of daytime signal intensities with the smoothed Zurich sunspot numbers indicated that there was an inverse relationship between the two.

Included in these results are signal intensity recordings not previously analyzed from contract DA49-170-sc-1131 for the Kahuku, T.H. - Riverhead, N.Y. circuit November 1953 - November 1954 and Orleans, France - Riverhead, N.Y. August 1954 - November 1954.

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Section D

INTRODUCTION

The chief object of this study was to determine the suitability of the AN/FGC-29 transmission system for handling the information stream from such equipment as the AFSAY D-806. This called for operating the AN/FGC-29 equipment at keying speeds considerably higher than the keying rate of 100 word per minute teletypewriter signals, the rate for which this equipment was designed. Error rates at keying speeds of 71.4, 100, 104.166 and 125 bits-per-second were compared and evaluated over a 5000 mile radio circuit from Kahuku, T.H. to Riverhead, N.Y. As a further aid in performance evaluation, simultaneous comparisons were made over this radio circuit using an AN/FGC-29 channel operating at 100 bits-per-second and an AFSAY D-806 channel operating at 250 bits-per-second.

Another object was to determine the relation between signal-to-noise ratio and percent errors of an AN/FGC-29 channel operating at the above keying rates and also the percent errors when the channel carried 100 wpm teletypewriter (TTY) and when it carried 60 wpm diplex TTY.

Still another object was to test and compare the AN/FGC-29 diversity system with the diversity system used in the previous radio circuit tests of the AFSAY D-806.

Jitter recordings were made and their scaled values related to short pattern errors, AFSAY D-806 jitter, and the ratio of operating frequency to maximum usable frequency (F/MUF).

Continuous signal strength recordings were made and their analysis included as supplementary data.

Section E

RADIO AND TERMINAL FACILITIES

Transmitting Facilities at Kahuku, T.H.

An LD-T2 Western Electric single sideband transmitter was used to send test signals from the RCA transmitting station at Kahuku, T.H. This transmitter provided for operation in the range of 4 to 23 mc, and was capable of accepting two independent audio frequency bands of from 100 to 6000 cps. These bands would appear in the radio frequency output signal as upper and lower sidebands of a pilot carrier. The transmitter also provided automatic frequency changing by push button control, permitting selection of any one of 10 preselected frequencies. The time required to accomplish the frequency change was about 15 seconds.

This transmitter was rated to have a peak-envelope power (PEP) output of 4 kw. During most of the testing only half of the rated PEP was used or an average of 1 kw output. Since only two tones (on one sideband) and a suppressed pilot carrier were transmitted at any one time there was about 0.5 kw average available for each tone. The pilot carrier was normally operated at an average level of 0.1 kw output.

A rhombic antenna was used to direct the signal toward Riverhead. The dimensions of this antenna were as follows.

Azimuth	53°27'
Side length	420.4'
Average height above ground	107.6'
1/2 Side Angle	66°
Slope of plane of antenna	5° rising in forward direction
Design frequency	11 MC/s

A number of frequencies were made available on a loan basis by the Army, Air Force, Navy, and RCA Communications, for use with this transmitter. These frequencies are listed below.

Frequency	Service	Limit Hours in GMT
20,288	Air Force	
18,870	RCA Communications	
16,189	Air Force	
15,665	Navy	
14,615	Air Force	1330-2230
14,550	Air Force	
14,450	Air Force	
12,127.5	Navy	
11,515	Navy	2330-0230
11,015	RCA Communications	
10,738	Air Force	
10,115	Air Force	
8,180	Army	
7,922.5	Air Force	
7,710	Army	2330-0430
7,520	RCA Communications	
6,790	Army	

Use of the above frequencies was subject to prior coordination with the military and civilian services listed. In practice it was found that due to interference from other radio stations most of the frequencies were unsatisfactory. By selection of the sideband with the least interference and using a 4 kc instead of a 6 kc receiver IF bandwidth, a satisfactorily interference-free radio circuit could usually be found.

The terminal equipment used to provide audio test signals to modulate the transmitter was located in a shielded room. Included with the terminal equipment was a high precision 100 kc crystal oscillator for generating an accurate time base reference, pattern generating equipment, and four frequency shift oscillators. Appendix C describes 100 kc oscillator stability measurements. Two of the F.S. oscillators were for Channels 1 and 3 of the AN/FGC-29 and the remaining two were for Channels 3 and 4 of the AFSAY D-806. There were also available a 100 word-per-minute transmitter distributor, and through interconnecting line facilities with the Honolulu Central Office of RCA Communications, a transmitting diplex distributor.

Personnel of RCA Communications maintained and operated the LD-T2 transmitter, and an RCA Laboratories engineer operated the terminal equipment.

Receiving Facilities at Riverhead, N. Y.

The radio signals from Kahuku, T.H. were received at Riverhead, N.Y. with two rhombic antennas. The physical dimensions of these antennas were as follows:

	#283-R	#284-18R
Height above ground (center)	55'	106'
Height above ground (western end)	55'	165'
Length of side	328'	360'
1/2 of side angle	65.10°	71.3°
Azimuth	284°	284°
Damping resistor	850 ohm	850 ohm
Slope of plane of antenna	0°	9.88°
Length of 200 ohm 4-wire transmission line to antenna coupler (Bldg. 6)	1750'	559.5'

There was a loss of 1 db per 1000 feet at seven megacycles on the 4-wire transmission line and this loss varied as the square root of the frequency.

The antennas were fed over 4-wire lines to two antenna multicouplers each having a gain of about 10 db. The multicoupler outputs were fed through two 1000-foot lengths of 75 ohm coaxial cable and terminated in two receiver inputs. Western Electric LD-R1 receivers were used during the early part of the radio testing and these were later replaced by an AN/FRR-41 receiving system. The AN/FRR-41[1] consists of two sets of Collins R-390/URR receivers with Hoffman CV-157 single sideband converters.

When desired, "White Noise" was inserted between the receivers and the multicouplers. A photograph of these noise generators and the AN/FRR-41 receiving system is shown in Figure E1, and a schematic diagram of the noise generator is shown in Figure E2.

During the Kahuku to Riverhead tests continuous signal strength recordings were made. One of the LD-R1 receivers was fed from one of the antenna multicoupler outputs over an independent transmission line. The multicoupler used was the one receiving its signal from the sloping rhombic antenna.

A lead was brought out from the automatic gain control portion of the receiver, isolated with a 2.2 meg. resistor, and fed to a capacitor of 20 mfds. The dc potential across the capacitor was amplified and applied to an Engelhard recorder. The R-C time constant of 44 seconds was about right to reduce the recorder trace scatter due to fading to a reasonably well defined line.

The recorder was periodically calibrated by substituting a standard signal generator output for the antenna feed to the multicoupler. To speed up the process, the 44 second time constant was removed during calibration.

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[1] Instruction Book for Radio Receiving Sets AN/FRR-40 and AN/FRR-41, Order No. 26565-PH, 1 September 1954

At the receiver site were located a pair of distribution amplifiers, each fed from the audio output of a receiver and provided with three independent outputs. One pair of outputs was used to feed a monitor amplifier speaker system and a calibrated amplifier for signal-to-noise measurements. The second and third pairs of outputs were used to feed AN/FGC-29 and AFSAY D-806 signal detection equipment.

It was felt that the best and quickest way to evaluate system performance comparisons was to operate the two systems in question simultaneously over the same radio circuit at as near the same radio frequencies as possible and with identical or comparable transmitter powers. With this in mind, two adjacent AN/FGC-29 transmit channels were set up at Kahuku and the two corresponding AN/FGC-29 receive channels were set up at Riverhead. These were channels 1 and 3. Two adjacent AFSAY D-806 transmit and receive channels 3 and 4, were similarly set up. The center frequencies and shifts of the AN/FGC-29 and AFSAY D-806 channels appear below.

System	Channel	Center Frequency	Shift
AFSAY D-806	3	1390 cps	±100 cps
AFSAY D-806	4	1755 cps	±100 cps
AN/FGC-29	1	1785 cps	±42.5 cps
AN/FGC-29	3	1955 cps	±42.5 cps

(During the tests, channel 4 was never used.) In this way the radio frequency wave propagation for the two paths being tested was essentially equivalent since the radio frequency separation of the channels was but a few hundred cycles.

Test signals to modulate the channels were provided by two identical short pattern generators. Each of these produced a repetitive pattern 48 bits in length. The pattern consisted of 1, 3 and 9 unit length elements in various combinations. A photograph of the pattern is presented in Figure E3A. The length of the bit (or the bit-rate) was determined by the frequency applied which in turn was derived from the 100 kc frequency standard. For instance, when 100 cycles was applied to a short pattern generator, the bit length of the pattern was 10 milliseconds and the bit rate was 100 bits per second.

The following table shows the bit-lengths used and their corresponding bit-rates.

Bit Length	Bit Rate (and control frequency - cps)
14.00 ms	71.428--- bits/sec. (approximates 100 wpm TTY)
10.00 ms	100.0
9.60 ms	104.166---
8.00 ms	125.0

At Riverhead the above control frequencies were similarly developed to drive another two short pattern generators identical to those at Kahuku. However, at Riverhead there was also available two continuously variable phase changers arranged so that the phase of the applied frequencies, and hence the phase of the 48-element short patterns, could be adjusted to coincide in phase to the patterns arriving over the radio circuit from Kahuku.

At Riverhead the locally generated and properly phased short patterns together with their exciting frequencies were fed to two coincidence units. Into these units were also fed the corresponding Kahuku signals after having been demodulated by the terminal equipment (either one channel of the AN/FGC-29 and one channel of the AFSAY D-806 or two channels of the AN/FGC-29).

In the coincidence unit, a 20 microsecond pulse was used to sample the center of each bit of the short pattern from Kahuku to determine whether the bit was "high" or "low". Each sample was compared to the locally generated pattern. As long as the samples agreed with the locally generated pattern the coincidence unit produced no output. Figure E3B shows a portion of the 48-element pattern with the 20-microsecond sampling pulses, centered within the elements. If, however, a bit from Kahuku became mutilated due to some cause such as static or fading etc., and the sample did not agree with the corresponding bit of the locally generated pattern, the coincidence unit involved would produce an error output pulse. Each of the two coincidence unit outputs fed an RCA Time Interval Counter. By means of a single manually operated switch these two counters were started simultaneously, and by means of this same switch they were automatically stopped one minute later. However, during periods when the errors were few, the count was prolonged to 5, 10, and occasionally 20 minutes. In all cases, the data were reduced to the form of errors (or fractions of errors) per minute and this figure divided by the total number of bits received in a minute to give the error rate, which was expressed in percent.

Where % errors of 14 ms bits were compared with % character errors of 100 wpm TTY and 60 wpm diplex TTY, the TTY % errors were determined by dividing the number of TTY operation errors (including line feed, carriage return etc.) by the total number of operations during an interval of usually 5 minutes. To facilitate counting errors in the TTY copy the transmitter tape was punched up as follows:

First the letter "O" was punched, then "RYRY---" until 34 characters were punched, then the letter "I" was punched, followed by carriage return and line feed. This was repeated for 9 lines. The 10th line was punched in the same fashion except that the line finished with "W" instead of "I", followed by carriage return, line feed and five spaces. The five spaces were required to glue together the tape so as to make it a continuous loop.

At Riverhead the R-bar and the Y-bar were removed from the TTY machines. When receiving the above tape the TTY copy under perfect conditions appeared as a blank strip of paper with a column of "O"s along the left margin and a column of "I"s down the center, with every 10th I replaced by the letter W. Errors appeared as random letters between the columns of O's and I's. This made the errors easy to spot. If a carriage return was in error, it was indicated by the appearance of an I (or W) on the right hand margin of the paper. With this arrangement, almost all types of errors could be detected and identified. A transposition of R and Y was of course lost. It was felt that this method of detecting TTY operation errors was as accurate as visually counting errors in "Quick brown fox----" or solid "RY" copy, because in both these arrangements errors are occasionally overlooked.

The system referred to as "Diplex" is a synchronous commercial system in which two 60 wpm TTY are multiplexed, resulting in a bit-length of 11.66 ms or a bit-rate of 78.6 per second[2]. For further details of the frequency dividers, phase changers, pattern generators, coincidence units etc., see 1st, 2nd and 3rd quarterly reports for this project.

In all tests involving two channels of the AN/FGC-29, the channels were interchanged each half hour. That is, the test material on channel 3 would appear on channel 1 on alternate half hours. This was done to equalize the effects, if any, of QRM (interference). In comparisons involving the AFSAY D-806 and AN/FGC-29 channeling systems, power levels were adjusted according to the number of channels each system normally transmits. In the case of the AFSAY D-806 system the power was apportioned on the basis of 7 channels whereas the AN/FGC-29 was apportioned power based upon 16 channels. For the approximately 1 kw average sideband power transmitted the AFSAY D-806 channel contained about 695 watts and the AN/FGC-29 channel contained about 305 watts. Where two channels of the AN/FGC-29 system were compared, each contained approximately 0.5 kw average power.

The last five minutes of each half hour transmission was utilized to measure "noise". This was done by having all modulation removed from the transmitter during this period. The level of the noise in one of the AN/FGC-29 channels was then measured. When the modulation was returned to the transmitter the signal level in this same channel was measured. The ratio in db of these two levels was called the signal-to-noise ratio.

For further details of S/N measurements see Appendix BB.

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[2] See EM-63-62 "Recent Developments in Time Division Multiplex"

Two types of facsimile equipments were used to record multipath jitter and hit distribution. One was a relatively high speed RCA experimental machine and the other was a standard U.S. Army TT-1E/TXC-1 facsimile machine.

The RCA machine provided fax recordings on a strip of paper 8-1/2" wide fed continuously from a large roll at the rate of 10-7/16" per minute. The effect of a recording stylus moving across the paper was obtained by drawing the paper across a rotating drum 8-1/2" long, and 2-1/2" in diameter containing a one-revolution helix of 0.037 inch platinum iridium wire fastened to its cylindrical surface. This helix pressed the paper against a "striker bar" parallel to the axis of the drum. Each revolution of the drum caused the point of pressure on the paper between the helical wire and the striker bar to traverse the 8-1/2" dimension of the paper. By a wet chemical process the paper was treated so that if a current passed through it as it passed between the helix and the striker bar it changed color. If a steady voltage were applied between the striker bar and the helix, straight lines parallel to the short dimension of the paper would appear as the drum rotates. If, instead of a steady voltage, short pulses were applied of the appropriate frequency commensurate with the speed of rotation of the drum, then a series of dots would appear on the paper forming one or more straight lines parallel to its long dimension.

For these tests the speed of the rotating drum was adjusted so that frequency transitions of 50-cycle and later 25-cycle reversals produced at least two lines lengthwise on the paper.

Variations in the linearity of these lines were due to variations in the timing of the mark-to-space or space-to-mark transitions and were caused by "jitter". Random spots between the straight lines were due to noise crashes.

The Army machine TT-1E/TXC-1 was an electro-mechanical fax. transceiver of the revolving drum type for the transmission and reception of page copy. The drum normally rotated at a rate of one revolution per second as established by a tuning fork and motor-driven gear reduction arrangement. The equipment normally scanned a single 12" x 18" page of copy in 20 minutes.

In order to have this machine record two cycles of the short pattern when the short pattern had several repetition rates, a high precision variable frequency audio oscillator (General Radio Type 1107-A) was substituted for the fork frequency standard.

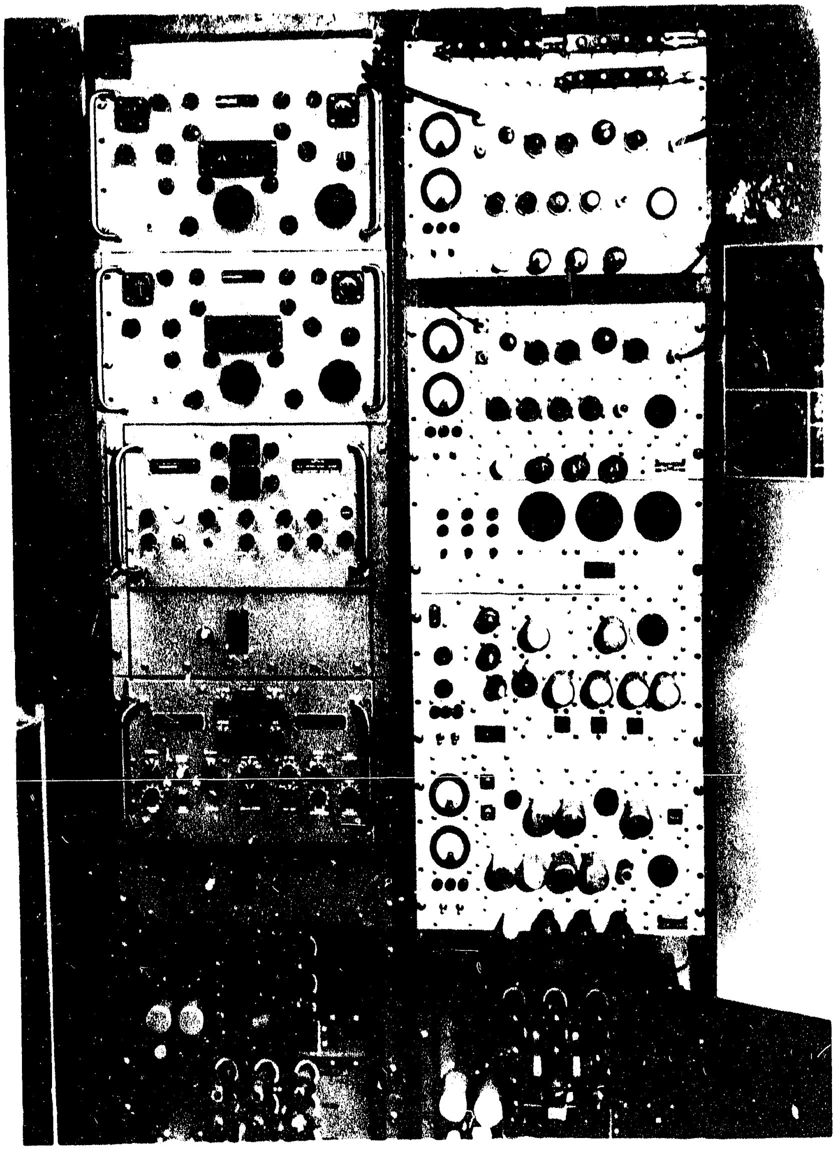
Recordings on this machine of the short pattern gave data that could be analyzed for jitter, and, when the output of the coincidence unit was recorded, gave an indication of the distribution of errors among the short pattern elements.

During a large part of the test one or more induced delay curves were taken daily and sent to the NSA for analysis by their personnel.

An induced delay curve was obtained by noting the % hits per minute obtained when the sampling pulse was alternately displaced by the phase changer various amounts either side of the short pattern bit center. If the transitions from mark to space or space to mark of the short pattern were instantaneous and the sampling pulse of infinitely short duration and there was no jitter there would be an instantaneous transition from zero % hits per minute to 50% hits per minute as the sampling pulse passed from the correct bit to either the preceding or following bit. If the short pattern consisted of 10 ms bits the calibrated phase changer would indicate that the sample pulse could be moved ±5 ms from element center before errors would be produced. Since the sampling pulse had finite duration (about 20 µs), the mark-space transitions were not instantaneous, and the frequency dividers produced some jitter, there would be some reduction of this ±5 ms figure in the back-to-back condition. The addition of transmit and receive roofing filters still further reduced the available bit length. The following table shows the % reduction of the bit length due to the pattern generating and sampling system and the roofing filters when operating back-to-back i.e., without the radio circuit link.

Rate Bits/Sec.	Bit Length	% Reduction Due to Generating System	% Reduction Due to Generating System and Filters
71.4	14 ms	0.5	7.1
100.	10 ms	0.7	14.5
250.	4 ms	0.75	10.0

Figs. E4, E5, and E6 show sample induced delay curves taken over the Kahuku-Riverhead radio circuit using 4, 10, and 14 ms bits respectively. Figs. E4 and E5 were taken simultaneously using a nighttime frequency (6790 kc) and illustrate a relatively large amount of jitter. These are typical of approximately 600 induced delay curves supplied to the NSA for the months of March and April 1956.



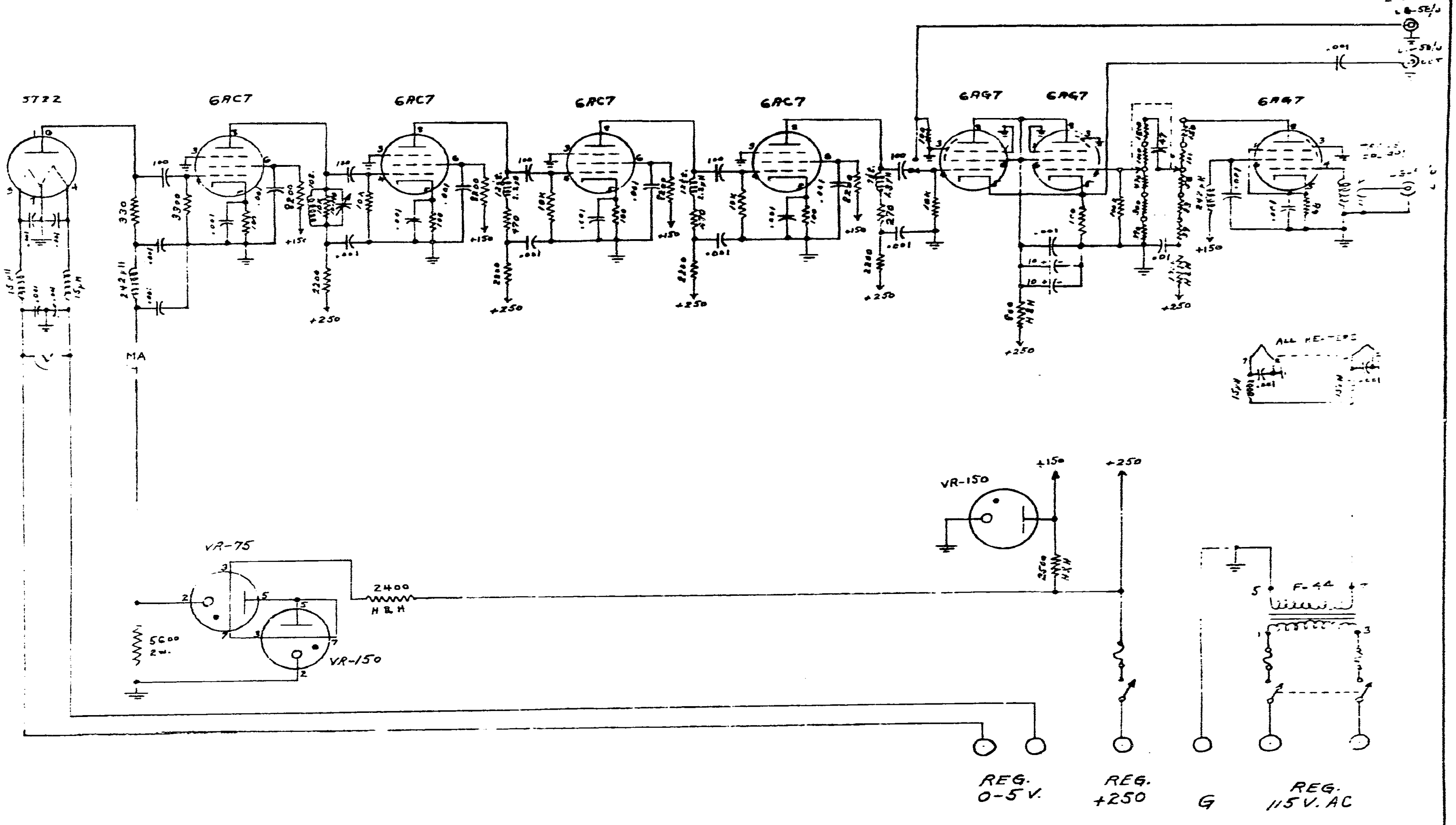
Photograph of AN/FRR-41 Receiving System
and Noise Generating Equipment

Figure 21

PRL-4750172

All Screw : to be Class 2 Fit (American Standards) Un' 'ervise Specified Dimensi 'ches.

-4750172



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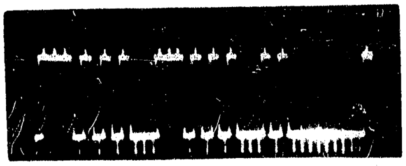
REF.

PRL-4750172

FORM C-102

Fig. E2

A. Pattern Generator Output
(48 Elements)



B. Illustration of Sampling
Performed
In The Coincidence Unit

KU-RD 1-30-56 6790KC 6:12-4 EST
'806 @ 250 Bits/Sec Diversity

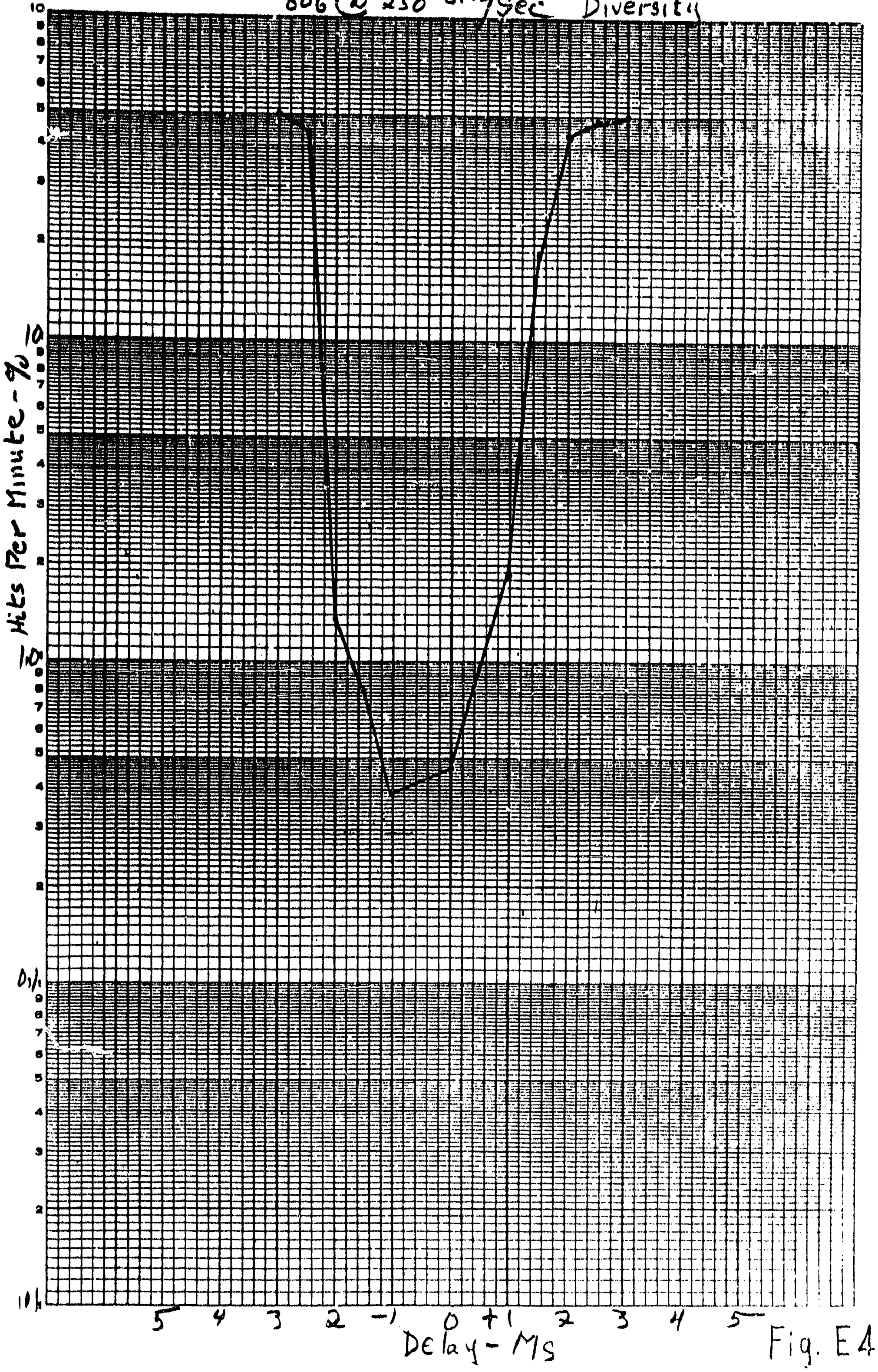


Fig. E4

EUGENE DIETZGEN CO.
MADE IN U.S.A.

NO. 340-L410 DIETZGEN GRAPH PAPER
SEMI-LOGARITHMIC
4 CYCLES X 10 DIVISIONS PER INCH

KURD 1-30-56 6790KC 6112 A EST
'29 @ 100 Bits/sec Diversity

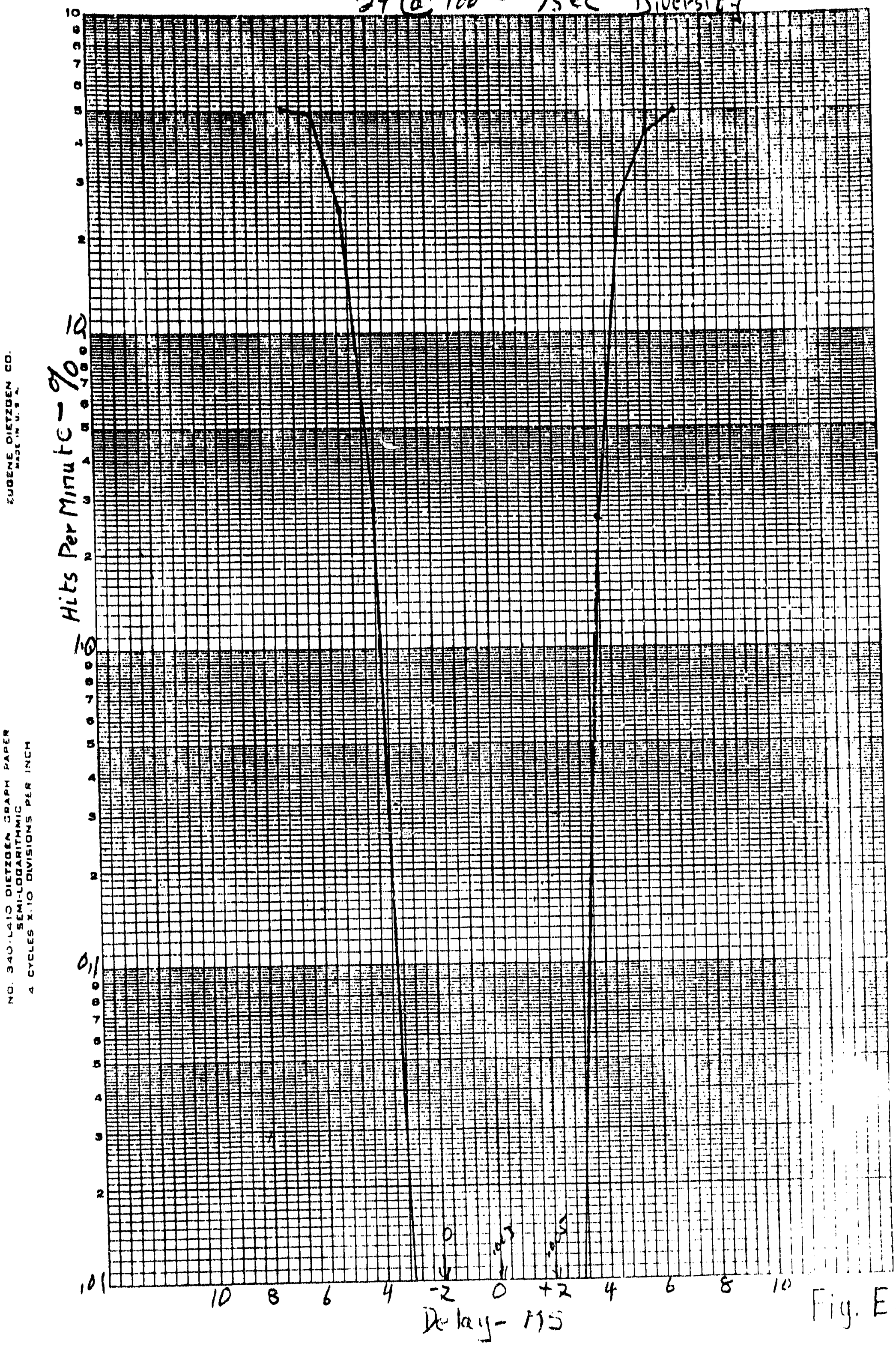


Fig. E5

ITU-RD Tests 3:40 A-EST

29 @ 71.4 Bits/sec 6790KC 2/7/56

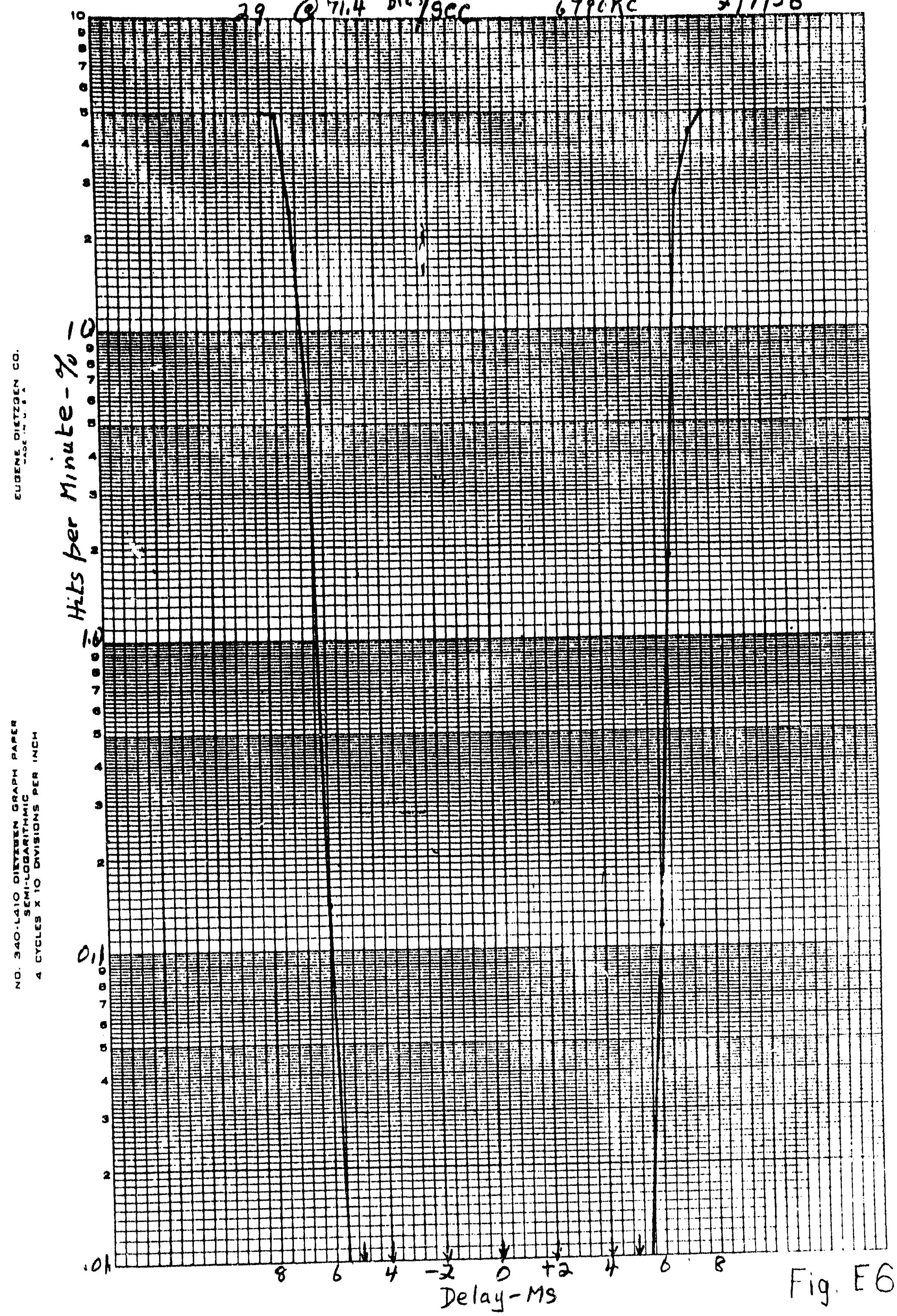


Fig. E6

Section F

CHARACTERISTICS OF THE AN/FGC-29 AND AFSAY D-806 CHANNELING SYSTEMS

AFSAY D-806 Channeling System

The AFSAY D-806 channeling system provides for the transmission of telegraphic information rates up to 250 bits per second per channel in an audio band extending from 560 to 2950 cps. The system is composed of seven channels, each consisting of a frequency shifted tone whose upper and lower frequency are separated by 200 cps.

In each channel of the transmit portion of the system, the tones are generated by frequency shifting a multivibrator oscillator. There is no shaping of the keying waveform before the output of the oscillator, but following the oscillator there is a bandpass filter, which is used to reduce adjacent channel interference. Typical transmission characteristics of the channel oscillator filters (as produced by two different manufacturers) are given in Figures F1 through F4.

In the course of this test program only channels 3 and 4 of the AFSAY D-806 system were available. The upper and lower frequencies of these channels are listed below:

Channel No.	Lower Frequency cps	Upper Frequency cps
3	1290	1490
4	1655	1855

The receiving portion of the system contains channel roofing filters whose transmission characteristics were identical to those illustrated in Figures F1 through F4. These filters are used to divide the received composite audio band into the seven frequency shifted channels. Following the roofing filters the channel keying is limited and detected by either a slope filter or discriminator type of system. The resultant d-c keying is filtered by a 250 cps low pass filter and then amplitude limited so as to produce a square wave output.

Channel diversity is provided only with the discriminator detection system. Diversity selection is based upon the relative amplitudes following the roofing filters. The differential voltage thus developed is used to select the strongest signal at the output of the detector.

A more complete description of the discriminator detection and diversity system is given in RCA Laboratories Engineering Report F-32-58, Diversity Combiner Equipment Instruction Book. Schematic diagrams for the 806 Frequency Shift Keyer, 806 Filter Amplifier, and Demodulator (slope detection) units can be found in the second quarterly report.

AN/FGC-29 Channeling System

The AN/FGC-29 channeling system consists of a transmit and receive terminal capable of handling 16 channels of teletypewriter (TTY) information at speeds up to 100 words per minute per channel. These channels extend at intervals of 170 cps from 425 cps to 2975 cps. During the course of the test program only channels 1 and 3 were used. The upper and lower frequencies of these channels are listed on the next page.

Channel No.	Lower Frequency cps	Upper Frequency cps
1	1742.5	1827.5
3	1912.5	1997.5

In the transmit terminal equipment, frequency shift is accomplished by diode switching of an oscillator's tuned circuit constants. These diodes are biased between their conduction and non-conduction states by on/off telegraphic loop current, no shaping of the keying elements being used. A plot showing the change in oscillator frequency with input current is given in Figure F5.

Following the oscillator a bandpass filter of the type illustrated in Figures F6 and F7 is used to reduce adjacent channel spurious responses. The resultant channel oscillator outputs are paralleled so as to provide a single input into the transmitter.

The normal frequency shift of the transmit oscillators is 85 cycles. Frequency measurements were made on several of these oscillators to determine their stability with time. By using an Eput meter counting over a 10 second time interval, readings were obtained with an accuracy of ±0.1 cps. Plots of these measurements are given in Figures F8, 9, 10, 11, 12, 13, 14 and 15. Data for Figures F8, 9, 10 and 11 were taken at Riverhead while Figures F12, 13, 14 and 15 represent data taken at Kahuku. The maximum temperature changes at Riverhead were between 25.4°C and 38.0°C as measured at the case of one of the channel oscillator filters. Both the oscillators at Riverhead and Kahuku appeared to follow a frequency drift with time. Most of them tended toward higher frequencies but one tended toward lower and one had no appreciable frequency change. These drifts may have been due to an aging coefficient in the core material of the oscillator's tuned circuit inductance. In general both mark and space (upper and lower) frequencies drift in the same direction resulting in only small changes in the absolute frequency shift. From the data in Figures F8 - F15 it is seen that the AN/FGC-29 oscillators maintained their frequency to within ±1.0 cps and their shift to ±0.35 cps during a one month period.

The receiving terminal of the AN/FGC-29 provides for the separation, and detection of the 16 transmitted frequency shift channels. Each of the channels are roofed by a bandpass filter having transmission characteristics similar to those illustrated in Figures F16 and F18. Corresponding phase shift curves are plotted in Figures F17 and F19. Deviations of the phase shift curves from a linear response in the transitional and pass band portions of the filter amplitude characteristics usually indicates that with keying there will be filter "bounce" or ringing. In a narrow band telegraph system, filter ringing should be controlled if serious degradation is to be avoided. This is because the duration of the ringing may be a large fraction of the shortest keying element length transmitted. This type of distortion can be considered as additional noise added to the signal, requiring a higher signal-to-noise ratio for the same excellence of performance. About 15% amplitude ringing has been measured out of the AN/FGC-29 channel roofing filters with on/off keying. A sketch of this waveform is given in Figure F20. The amplitude of the ring is referred to the amplitude of the steady state signal condition for this calculation. The duration of the transient lasts about 5 ms, however ringing of considerably smaller amplitude continues for 70 ms. The rise time of the filter as measured between 10% and 90% of steady state signal amplitude was found to be about 10 ms.

The optimum shape and width of the filter selectivity is dictated by the desire to accept maximum signal with a minimum of noise energy and to provide adequate protection from adjacent channel keying. It has been shown that filters whose amplitude-frequency characteristics follow a cosine squared function will have a minimum of ringing[1]. In order to obtain additional selectivity against adjacent channel interference the slope of the attenuation characteristics can be increased starting at a point 8 to 10 db down, and providing no sharp discontinuities are added, the transient response should not be seriously impaired[2].

Following the channel roofing filters the AN/FGC-29 receiving system provides an AGC amplifier whose gain is controlled so as to remove the amplitude effects of fading. The response time of this amplifier is slow by comparison to the lowest channel frequency. The transient response of the amplifier is illustrated in the photographs of Figure F21. The lower pattern represents the input to the AN/FGC-29 Receiver Unit, and is composed of a constant amplitude space frequency keyed on for a period of about 80 ms

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[1] NBS Report #2415 "Reduction of Adjacent-Channel Interference by Shaping of Transmitter Keying Wave Forms", A. Watt, R. Coon, and V. Zurick

[2] Cosmos Memo PR-54-62

and off for about 145 ms. The upper pattern is the resultant output of the Receiver Unit. It is seen that the AGC amplifier takes about 14 ms to reach steady state conditions after the signal is first turned on. Part of this delay is a result of the time required to build up energy in the channel roofing filter. There is about 70 ms required to discharge all the energy in the system after the input signal is turned off. This is due in part to the decay time constant of the filter (10 ms) and part to a decaying filter ring. This ring is in evidence because the AGC system raises up to normal output all signals down about 50 db below normal input. Details of the input-output characteristics of the AGC system are given in Figure F22. It is seen that the output from the amplifier is constant within 1.5 db for input levels -50 db below normal. (Normal input level is -8 dbm.)

Following the AGC amplifier is a logarithmic expander. This amplifier provides a 2:1 db ratio between output and input as shown in Figure F23. The response time of the expander is slower than that of the AGC amplifier so that expansion will be applied only to the fading component of the signal.

The output of the expander is fed to a conventional discriminator circuit for detection of the keying components from the frequency shift signal. Typical characteristic curves for the discriminator are given in Figures F24 and F25. These curves show that the discriminator sensitivity is about 0.5 volts per cps. The d-c keying out of the discriminator is fed through a low pass filter which passes the fundamental component of the 100 wpm teletypewriter keying and thence through a limiter. There is approximately 25 db of post detection limiting applied to the keying. The limiter controls a pair of parallel connected pentodes which key the receiving loop.

An indication of the overall response of the AN/FGC-29 receiving system to various keying speeds is presented in Figure F26. The input to the AN/FGC-29 frequency shift generator was a pattern of long and short elements whose repetition rate could be varied. The pattern consisted of three sizes of elements 1, 3, and 9 units in length. (see Section E, Figure E3A for a photograph of the pattern.) The output of the AN/FGC-29 receiving system was monitored on a calibrated oscilloscope. For keying speeds less than 50 bits per second all elements reached a steady state amplitude after an initial transient rise. This steady state amplitude was used as the base reference. At 60 bits per second the single elements never reached the steady state condition, but rather just about permitted the first transient bounce to reach full amplitude. The same situation occurred with the three unit elements at keying speeds of about 110 bits per second.

At 140 bits per second some failures were observed in the short elements of the pattern. It is seen that the unit elements had decreased in amplitude to 20% of the steady state condition. In other words the AN/FGC-29 system could be operated with success over high quality wire lines at keying rates up to 140 bits per second and by modifying some of the passive filters it is felt that even higher keying rates could be accomplished.

The AN/FGC-29 receiving system has provision for combining several signal sources in diversity. The combining is performed by a ratio squaring method as recommended by Crosby Laboratories, Inc.[3] Essentially this method provides for the addition of both signals after detection, with their contributions being proportional to the square of their relative input amplitude. By adding the signals together following detection the signal voltages add arithmatically in phase while the random noise components add in quadrature. A 3 db improvement in signal-to-noise ratio is thus realized when both signals are of equal amplitude. This gain is independent of the normal diversity improvement factor, but if one of the signals contributed only noise there would be a 3 db degradation. To avoid this degradation the signals contribute to the combined resultant in proportion to the square of their relative input levels.

A block diagram of the AN/FGC-29 diversity system is given in Figure F27. It is seen that signal detection is performed by two similar sets of circuits, interconnection between them being provided in the AGC amplifier control and in the final combination of the detected signals. A common AGC control is provided so that the gain of the amplifiers in both chains will be the same, the gain of the amplifiers being inversely proportional to the level of the strongest input level. The ratio of the two input signals is thus preserved to the input of the logarithmic expander. The logarithmic expanders provide a loss in db which is an inverse function of the input level in db. The amplitude ratio of the signals at the expander output thus follows the square of the input

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[3] Final Report - Signal Corps Contract No. DA-36-039-sc-15359

ratio. Combination of the detected signal is provided by adding the discriminator outputs in series aiding. A curve indicating the discriminator output with and without two-signal combination is given in Figure F28. Receiver B was held constant at -8 dbm (normal signal level input) and the input to Receiver A varied. It is seen that the discriminator output rises 6 db when both signals are equal and when the difference between the inputs is 6 db the discriminator output drops to about 3.2 db. From the ratio squaring theory the expected drop in discriminator output would have been to 2 db. The difference between the two is due to the departure of the expander response from the ratio squaring relationship.

An evaluation of design approval model of the AN/FGC-29 terminal was performed by personnel of Coles Signal Laboratories, wire communications branch, Fort Monmouth, N. J. Based upon the results of these tests it was recommended that the basic principles of the ratio squarer method of combining be retained for the preproduction of the AN/FGC-29 terminal[4]. At the beginning of the tests performed under the RCA Laboratories contract both the preproduction and design approval terminals were available. Evaluations were made using parts from both terminals. There was no significant difference found in the performance of these equipments.

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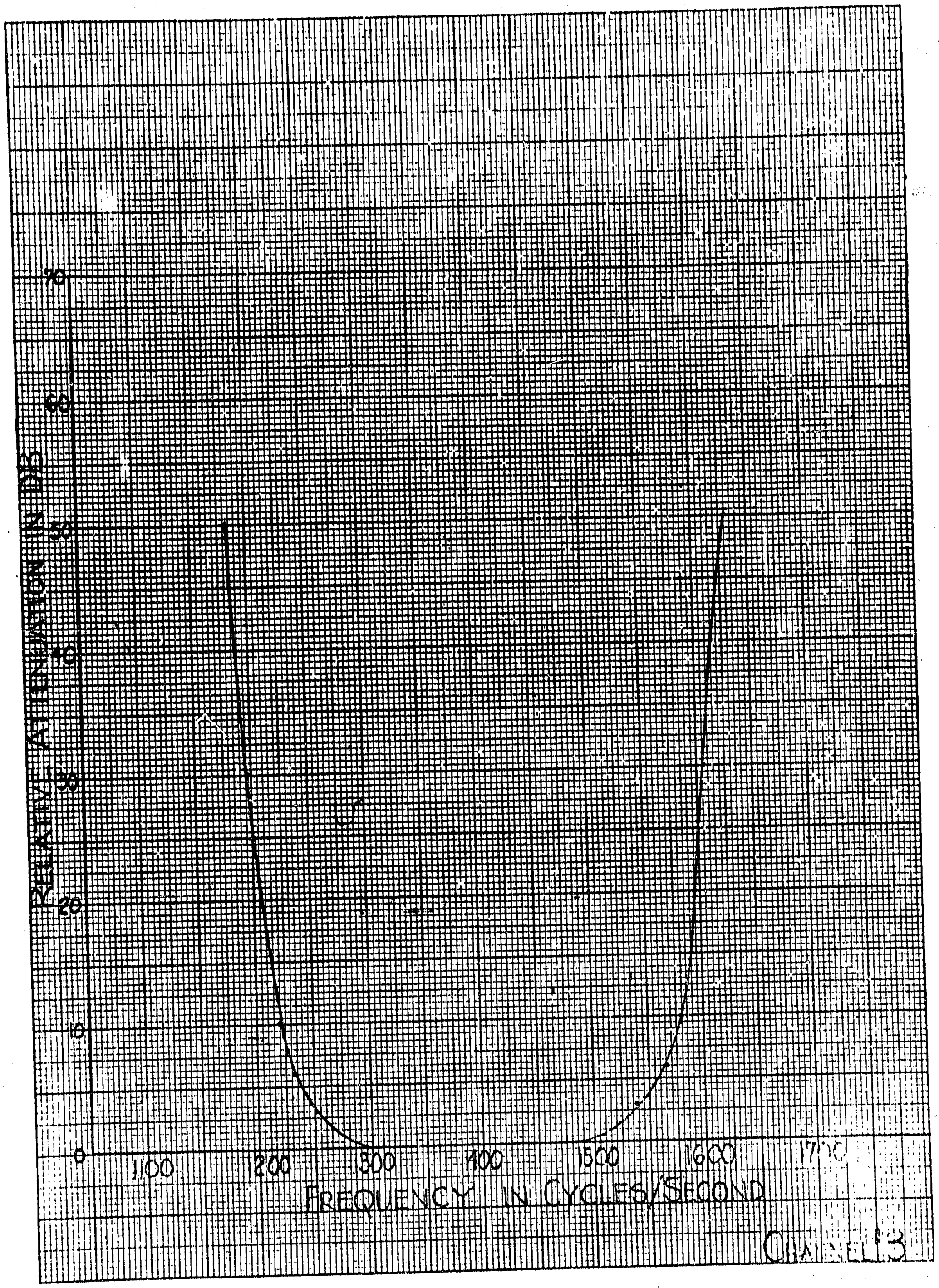
[4] Memorandum for Chief Wire Communication Branch CSL SIGEL-CWB-7 Project 501H dated February 17, 1954

Other references concerning the AN/FGC-29 are as follows:

Author	Title	Publication
J. E. Boughtwood	Telegraph Terminal AN/FGC-29 Circuit Design Aspects	Transactions of I.R.E. Professional Group on Communication Systems November 1954
F. H. Cusack	Telegraph Terminal AN/FGC-29 Equipment Features	Ditto
A. Mach & R. H. Levine	A New Multichannel Teletype Terminal for Use on Long-Range High-Frequency Radio System	Ditto
Crosby Labs.,Inc.	U.S. Patent Application No. 365964	

THIS MARGIN RESERVED FOR BINDING.

IF SHEET IS READ THIS WAY (HORIZONTALLY), THIS MUST BE TOP.
IF SHEET IS READ THE OTHER WAY (VERTICALLY), THIS MUST BE LEFT-HAND SIDE.



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DATA BY: JB DATE: 8/11/55	APPROVED BY: [illegible]
DRAWN BY: JB DATE: 11/3/55	SUB. NO.

Fig. F1

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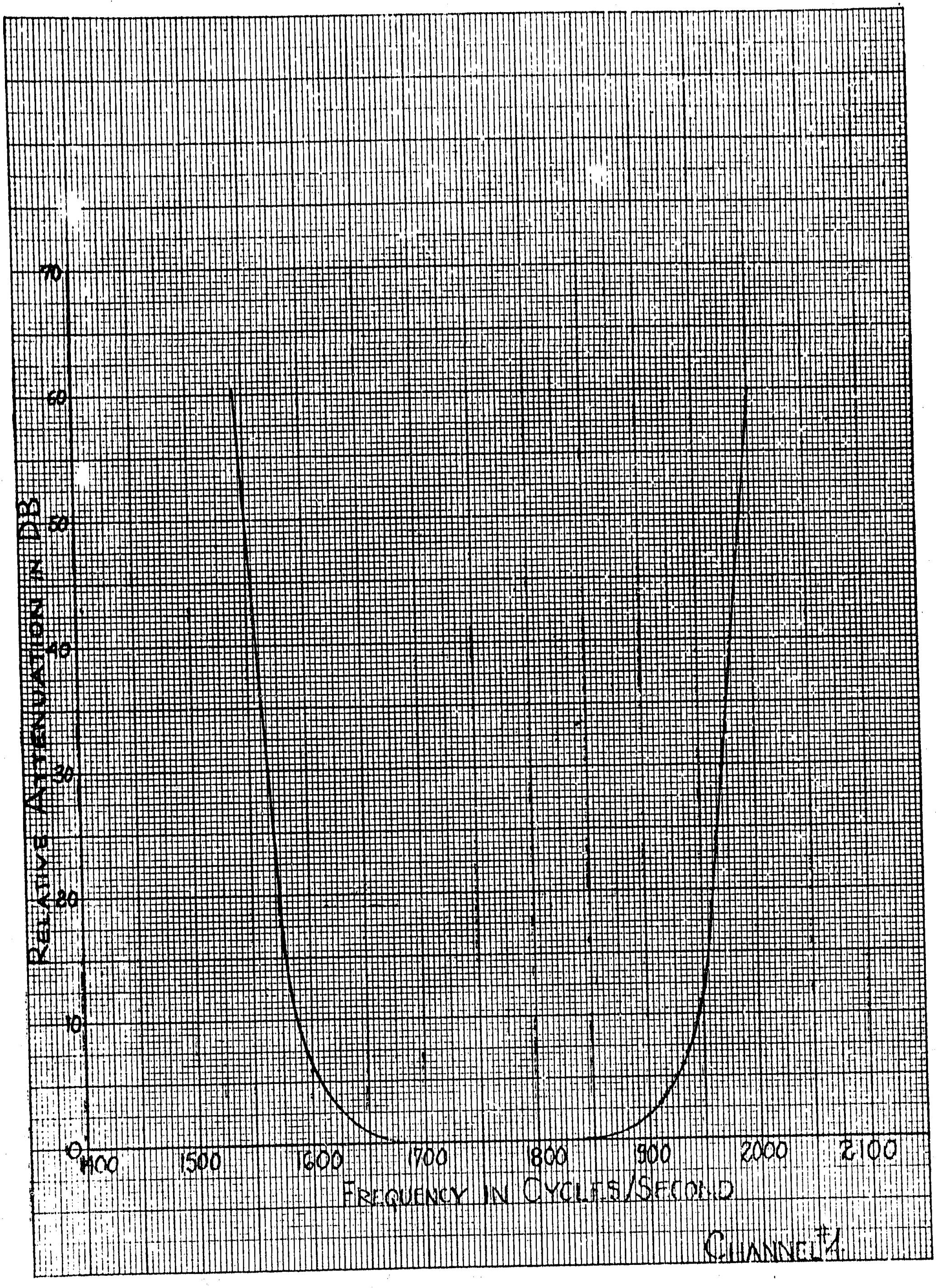
IF SHEET IS READ THE OTHER WAY (VERTICALLY), THIS MUST BE LEFT-HAND SIDE.



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	DATA BY: JB DATE: 7/27/55	APPROVED BY: 50-28031
LOCATION RIVERHEAD, N.Y. SEC. NO. 61	DRAWN BY: JB DATE: 11/20/55	SUB. NO.

Fig. F2

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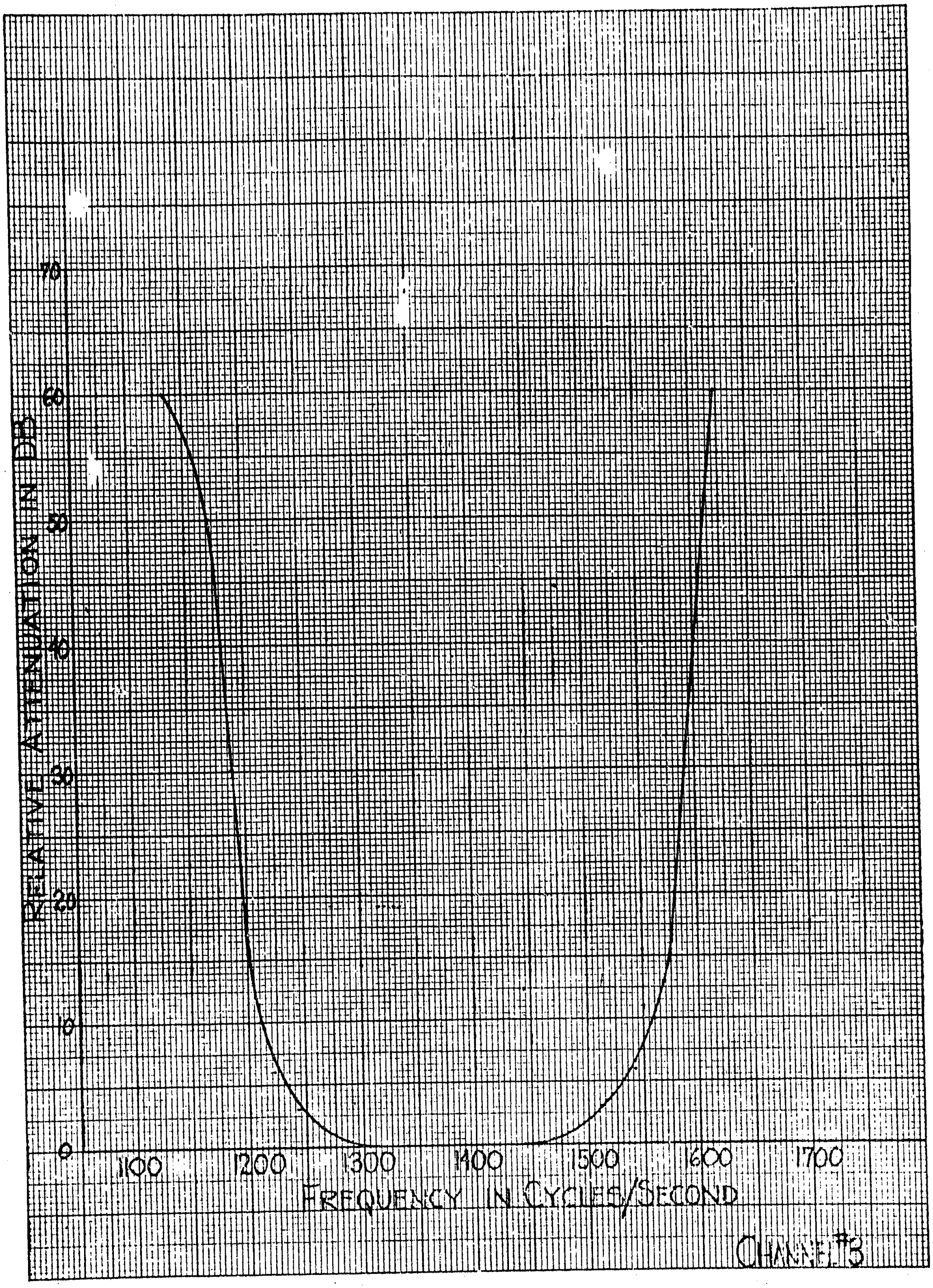
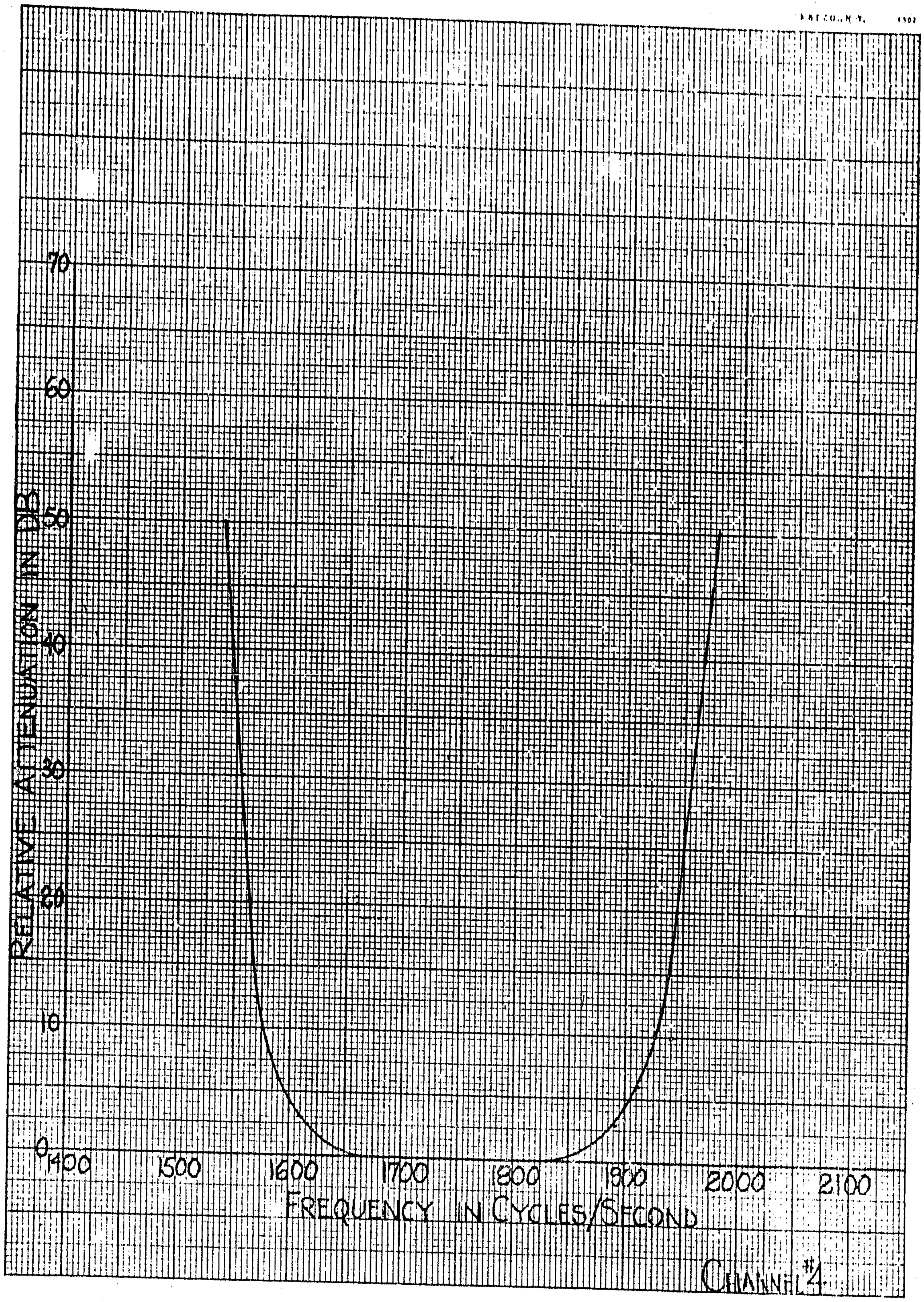


RADIO CORPORATION OF AMERICA RCA LABORATORIES DIVISION COMMUNICATIONS RESEARCH	TITLE:- FREQUENCY TRANSMISSION CHARACTERISTICS LENKURT TYPE 4201-3
LOCATION RIVERHEAD, N.Y. SEC. NO. 61	DATA BY: JB DATE: 7/27/55 APPROVED BY: 50-28031 DRAWN BY: JB DATE: 7/28/55 SUB. NO.

Fig. F 3



RADIO CORPORATION OF AMERICA RCA LABORATORIES DIVISION COMMUNICATIONS RESEARCH LOCATION RIVERHEAD, N.Y. SEC. NO. 61	TITLE:- FREQUENCY TRANSMISSION CHARACTERISTICS LENKURT TYPE 4201-1
DATA BY: JB DATE: 7/27/51	APPROVED BY: 50-28031
DRAWN BY: JB DATE: 7/29/51	SUB. NO.

Fig. F4

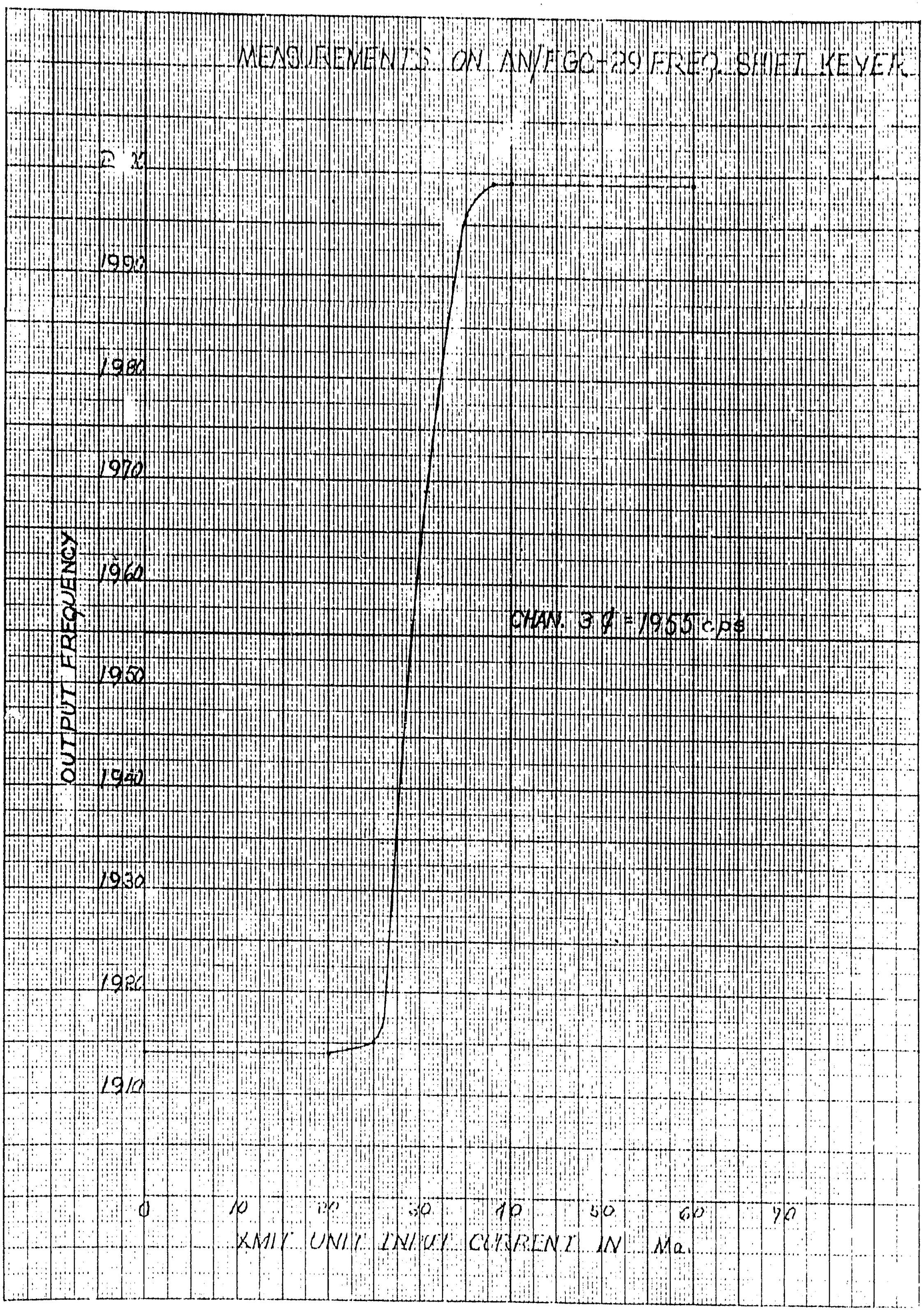
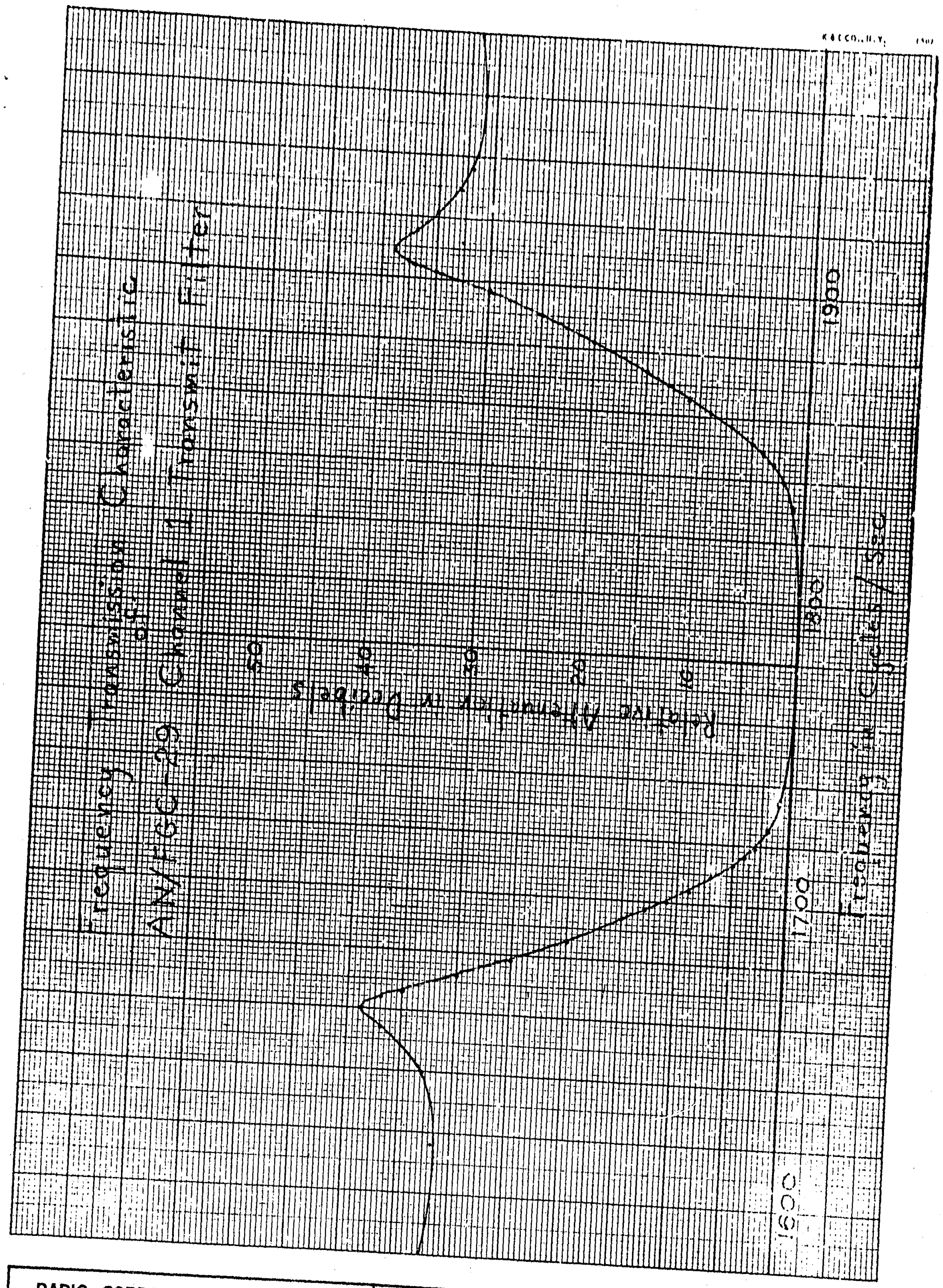

MEASUREMENTS ON AN/FGC-29 FREQ. SHIFT KEYER
OUTPUT FREQUENCY
2000
1990
1980
1970
1960
1950
1940
1930
1920
1910
CHAN. 3 ∅ = 1955 cps
0
10
20
30
40
50
60
70
XMIT UNIT INPUT CURRENT IN Ma.

Fig. 15



Frequency Transmission Characteristic of AN/FGC-29 Channel 1 Transmit Filter

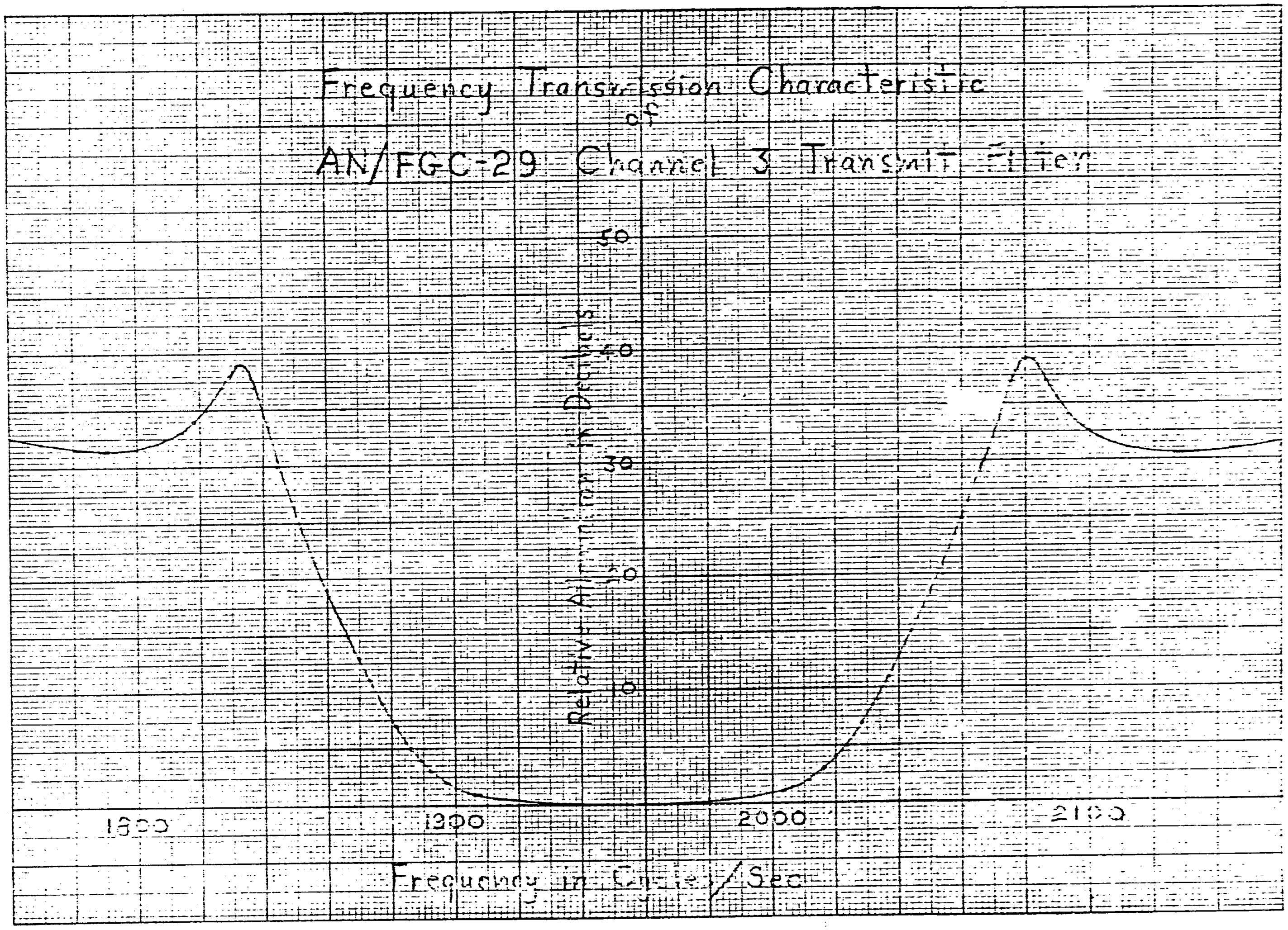
RADIO CORPORATION OF AMERICA
RCA LABORATORIES DIVISION
COMMUNICATIONS RESEARCH

LOCATION Riverhead, N.Y. SEC. NO. [illegible]

TITLE:- Frequency Transmission Characteristic of AN/FGC-29 Channel 1 Transmit Filter

DATA BY: HL DATE: [illegible]
DRAWN BY: HL DATE: [illegible]
APPROVED BY: [illegible]
SUB. NO.

Fig. F 6



RADIO CORPORATION OF AMERICA
RCA LABORATORIES DIVISION
COMMUNICATIONS RESEARCH
LOCATION Riverhead, N.Y. SEC. NO. 61

TITLE: Frequency Transmission Characteristics of AN/FGC-29 Channel 3 Transmit Filter
DATA BY: III DATE: [illegible]
DRAWN BY: III DATE: [illegible]
APPROVED BY: [illegible]
SUB. NO.

Fig. 17

FREQUENCY DRIFT IN AN/FGC-29 TYPE CHANNEL OSCILLATORS

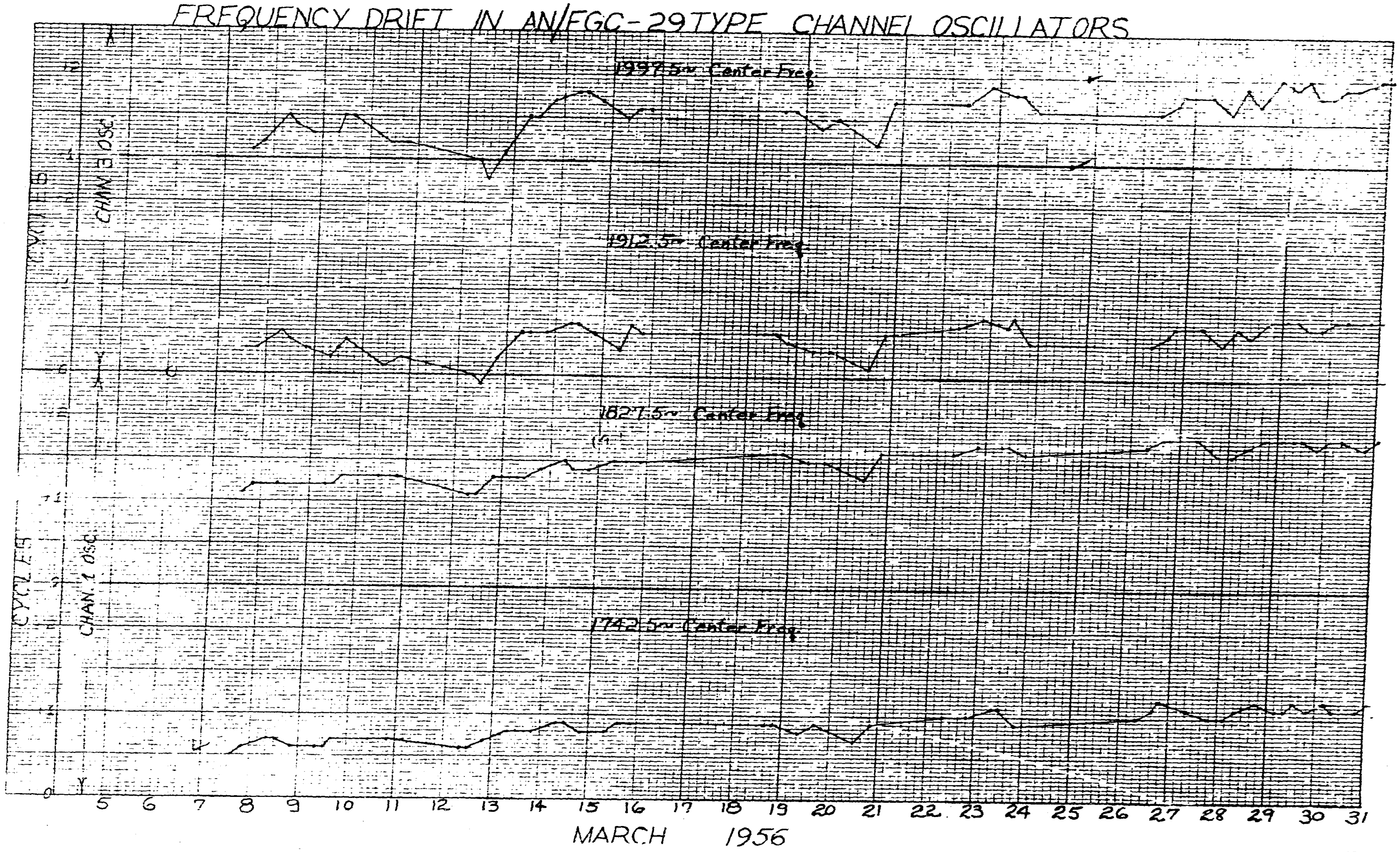


Fig. F8

FREQUENCY DRIFT IN AN/FGC-29 TYPE CHANNEL OSCILLATORS

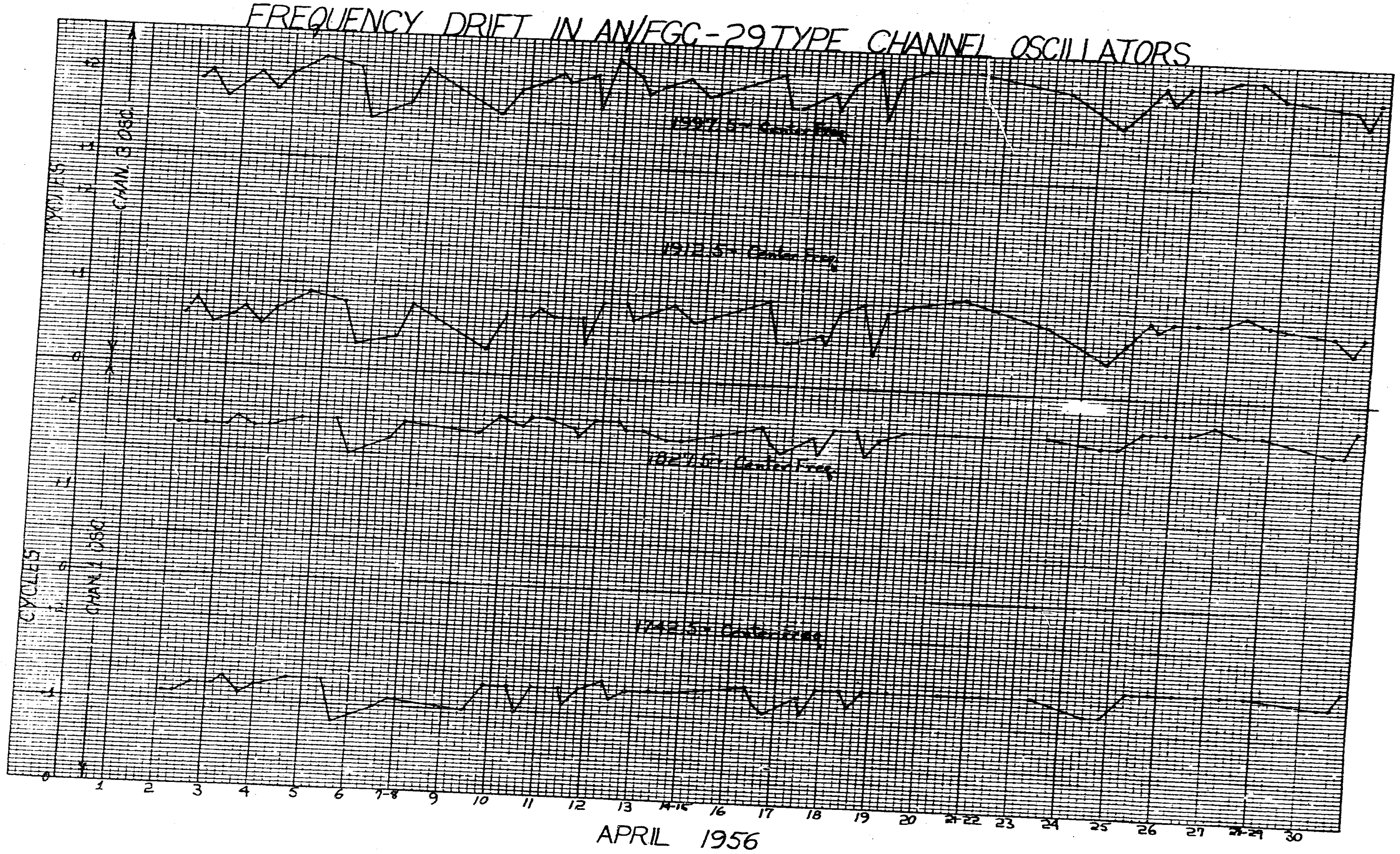


Fig. F9

FREQUENCY DRIFT IN AN/FGC-29 TYPE CHANNEL OSCILLATORS

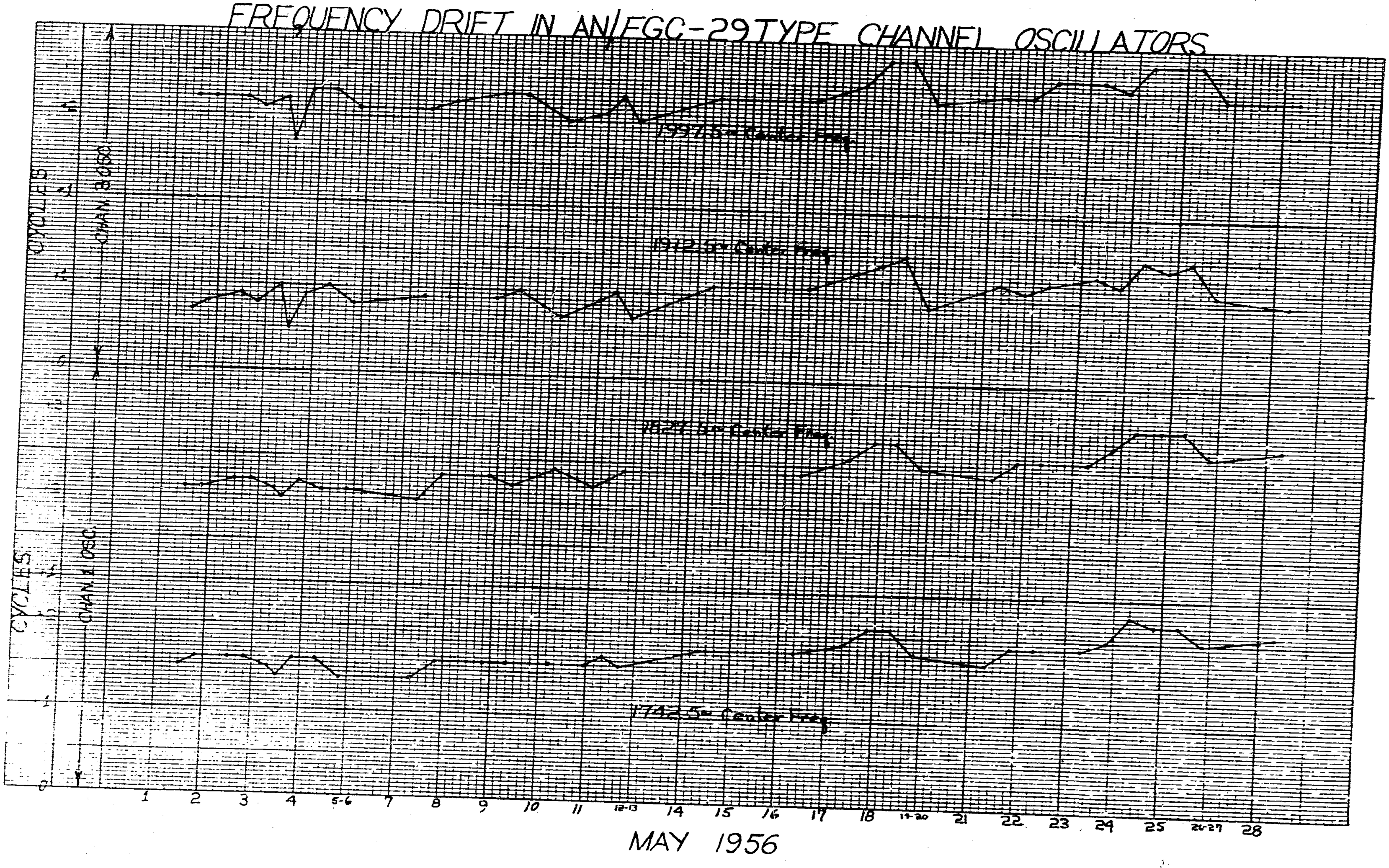


Fig. F10

FREQUENCY DRIFT IN AN/FGC-29 TYPE CHANNEL OSCILLATORS

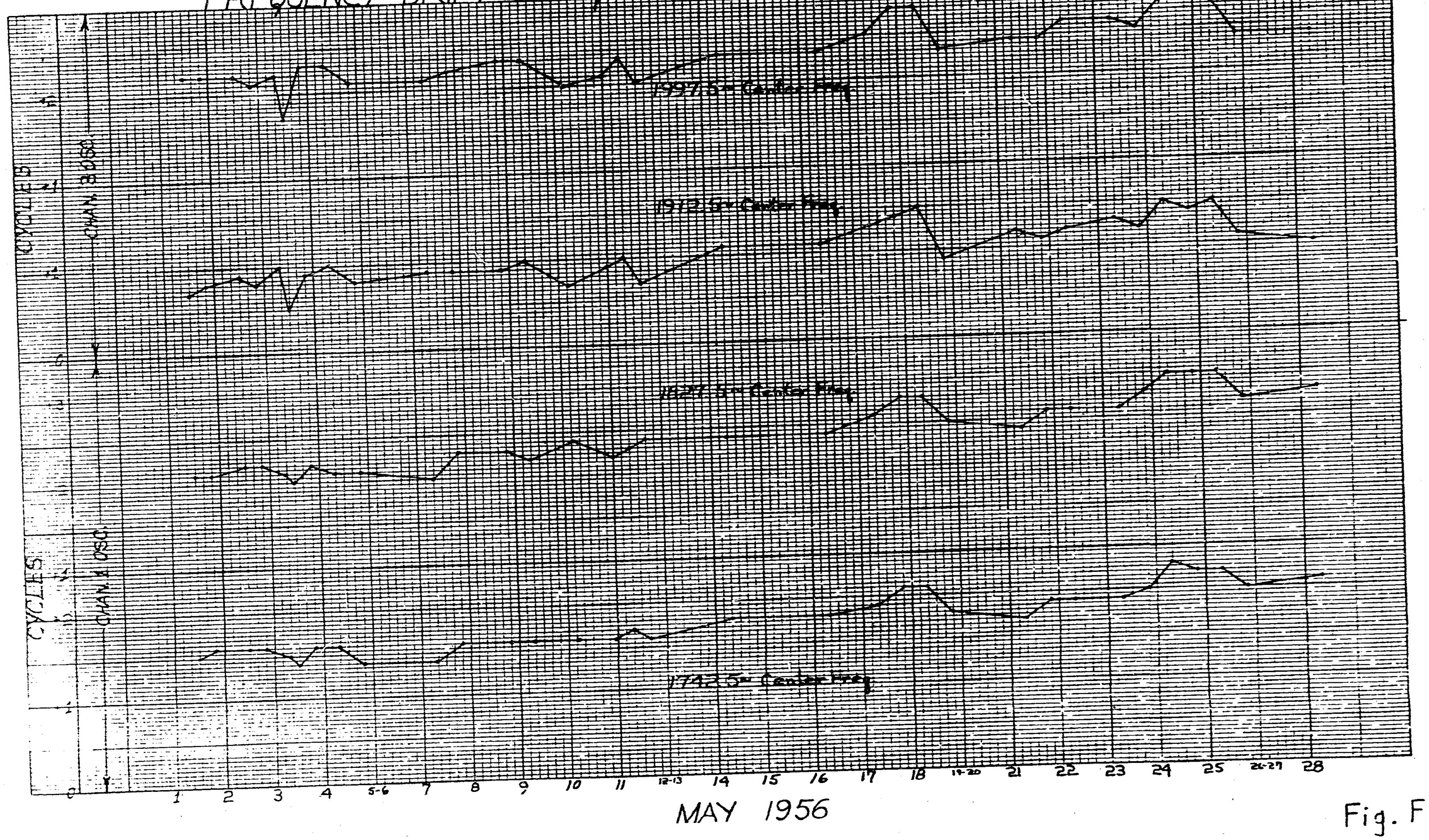


Fig. F10

FREQUENCY DRIFT IN AN/FGC-29 TYPE CHANNEL OSCILLATORS

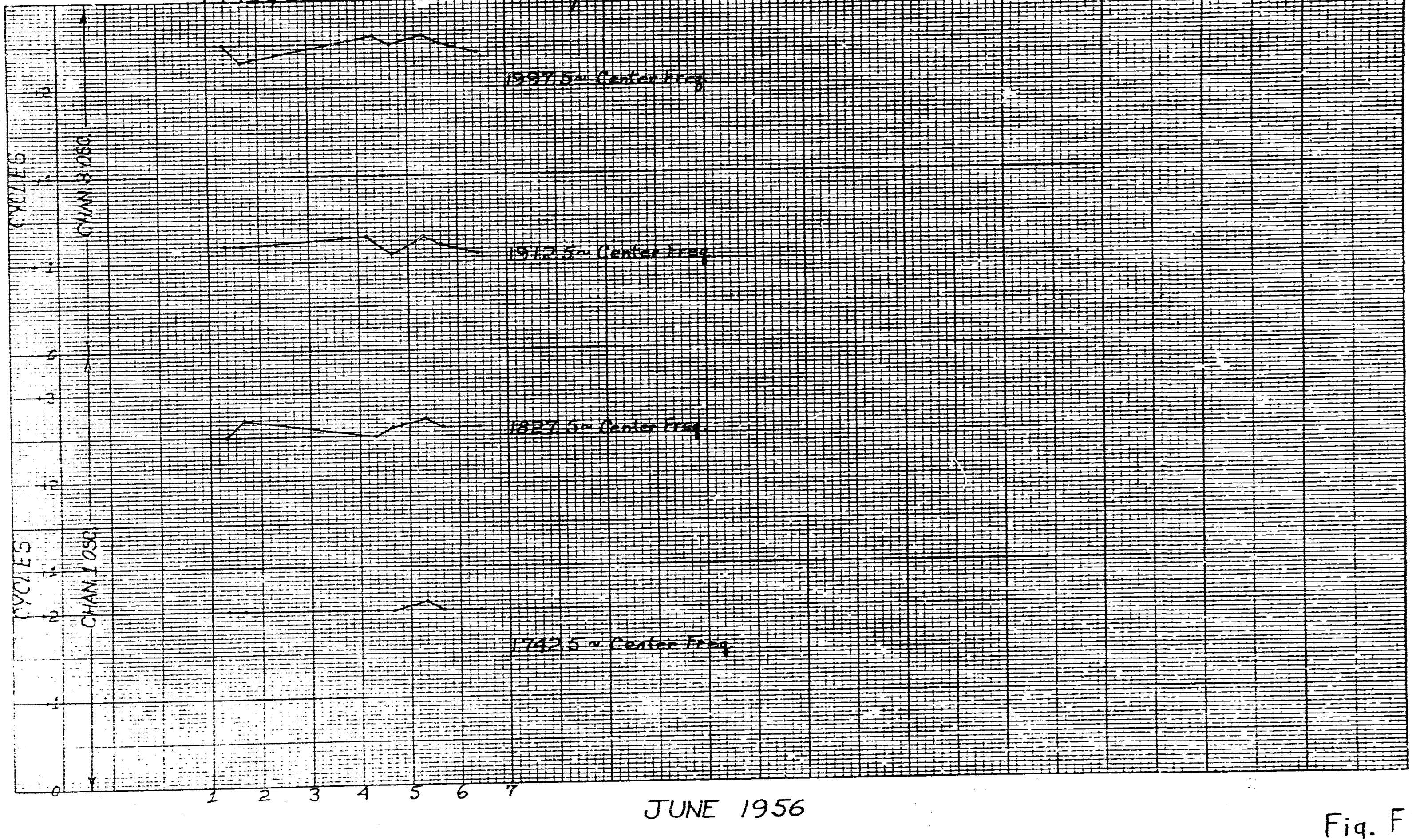
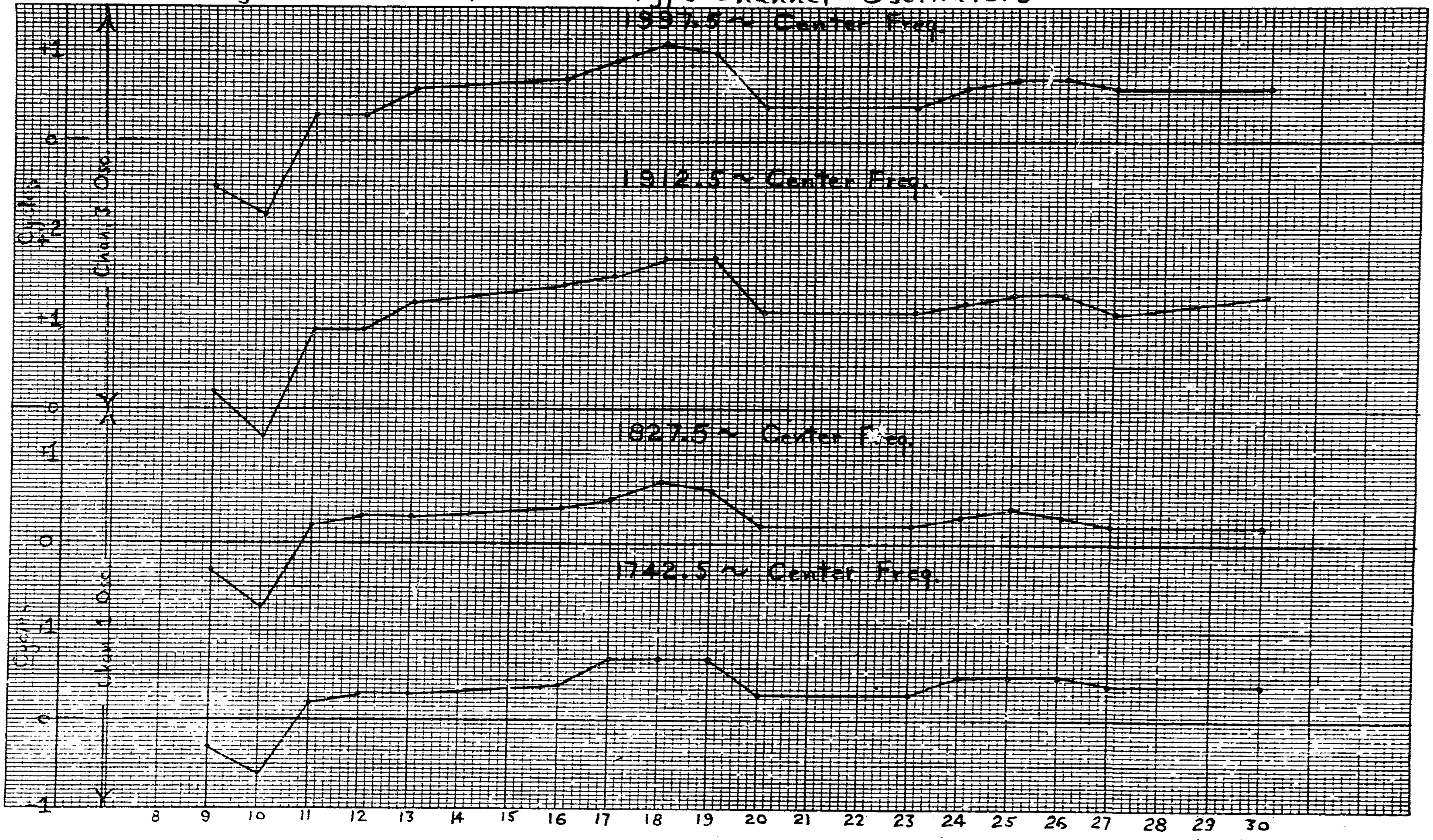


Fig. F11

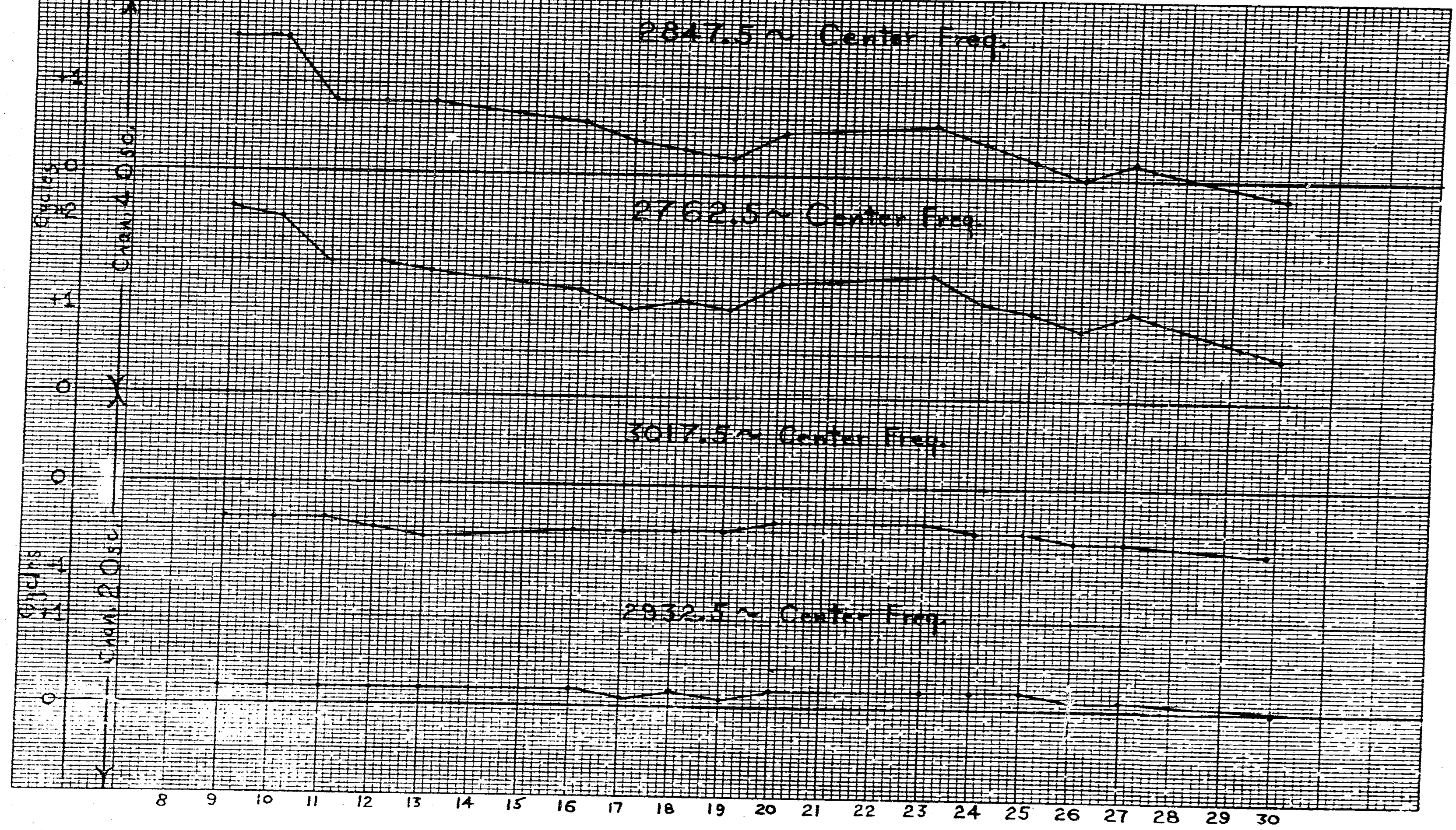
Frequency Drift in AN/FGC-29 Type Channel Oscillators



April 1956

Fig. F12

Frequency Drift in AN/FGC-29 Type Channel Oscillators



April 1956

Fig. F13

Frequency Drift in AN/FGC-29 Type Channel Oscillators

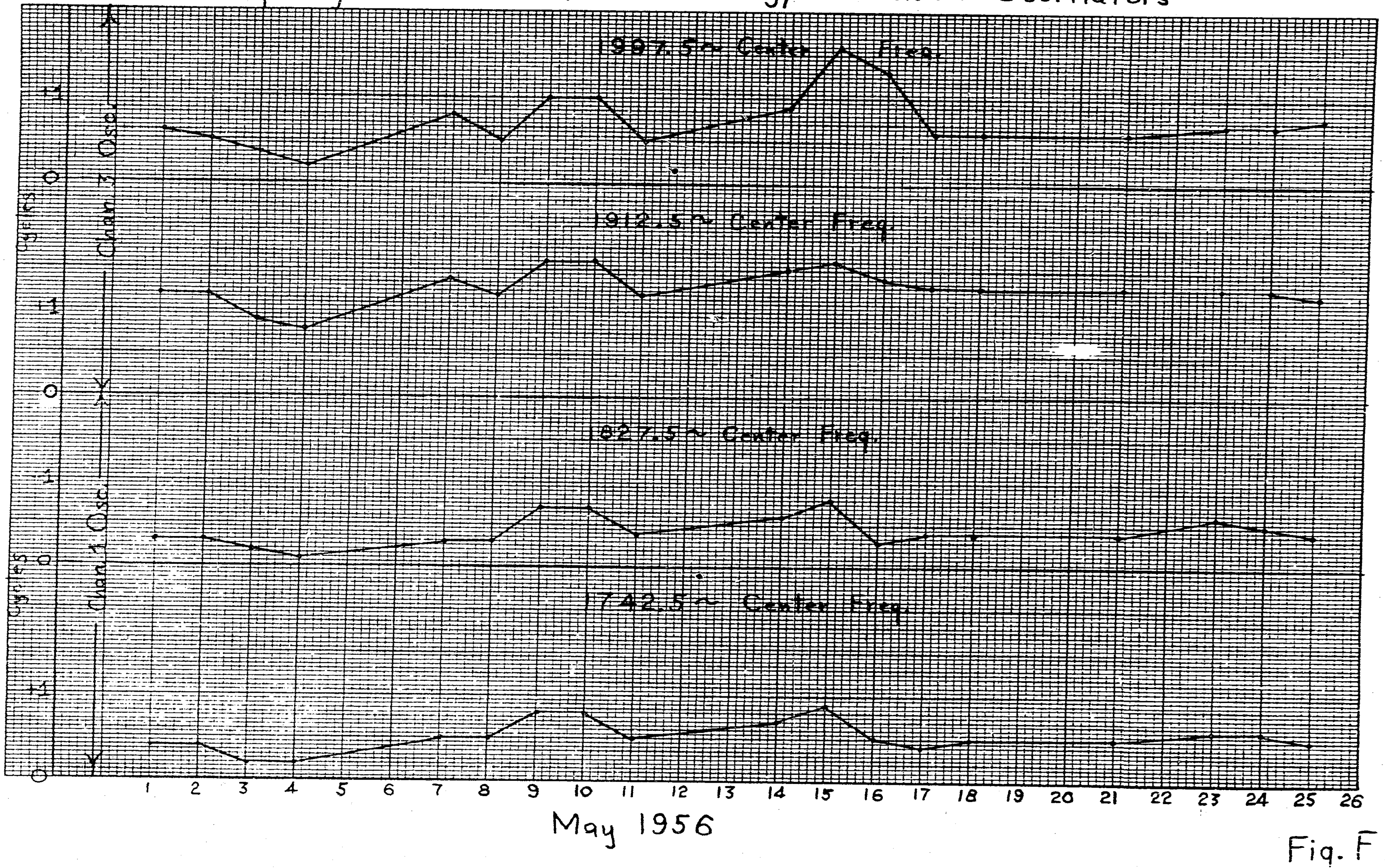


Fig. F14

Frequency Drift in AN/FGC-29 Type Channel Oscillators

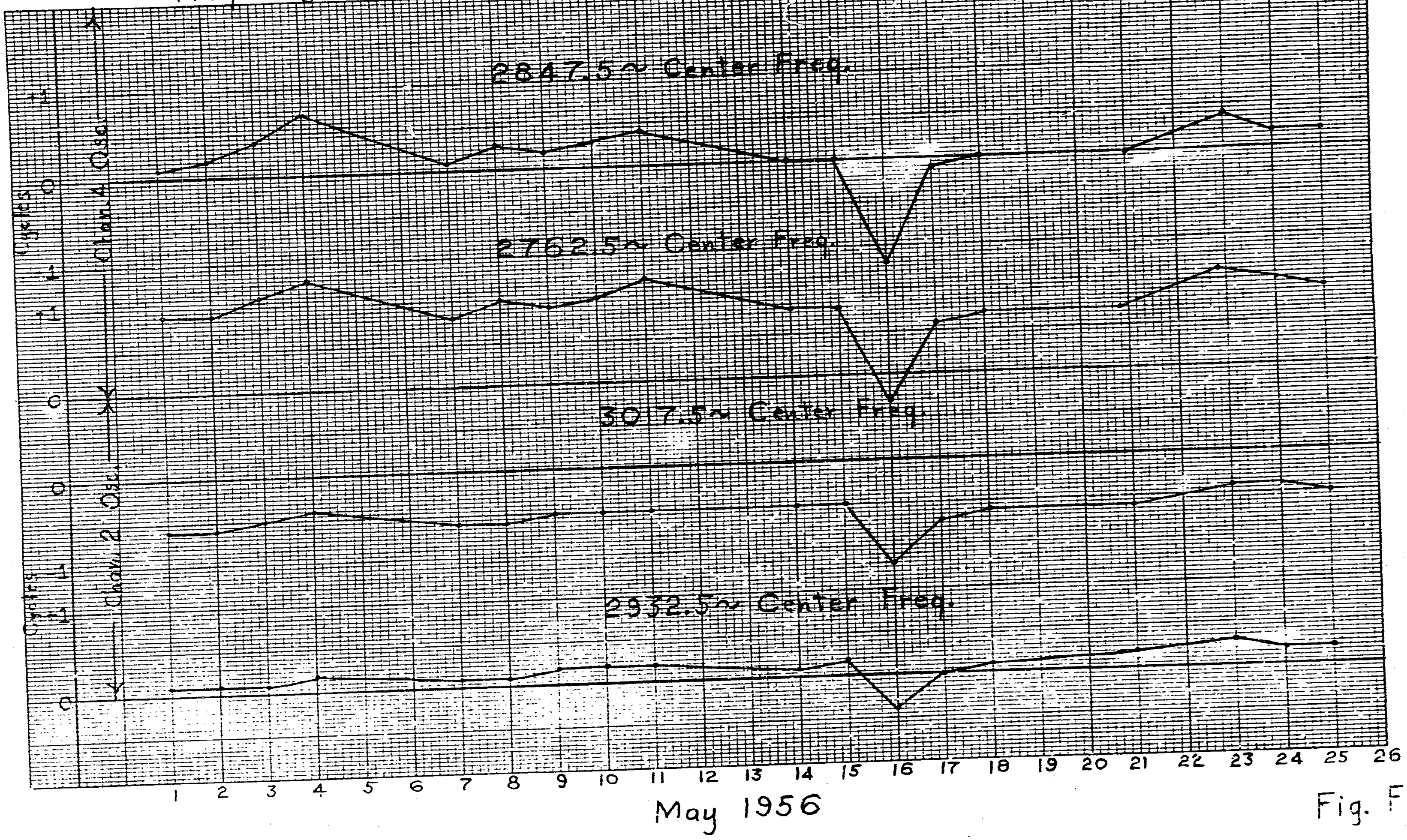


Fig. F15

FREQUENCY TRANSMISSION CHARACTERISTIC
OF
AN/FGC-29 CHANNEL 16/1 RECEIVING FILTER

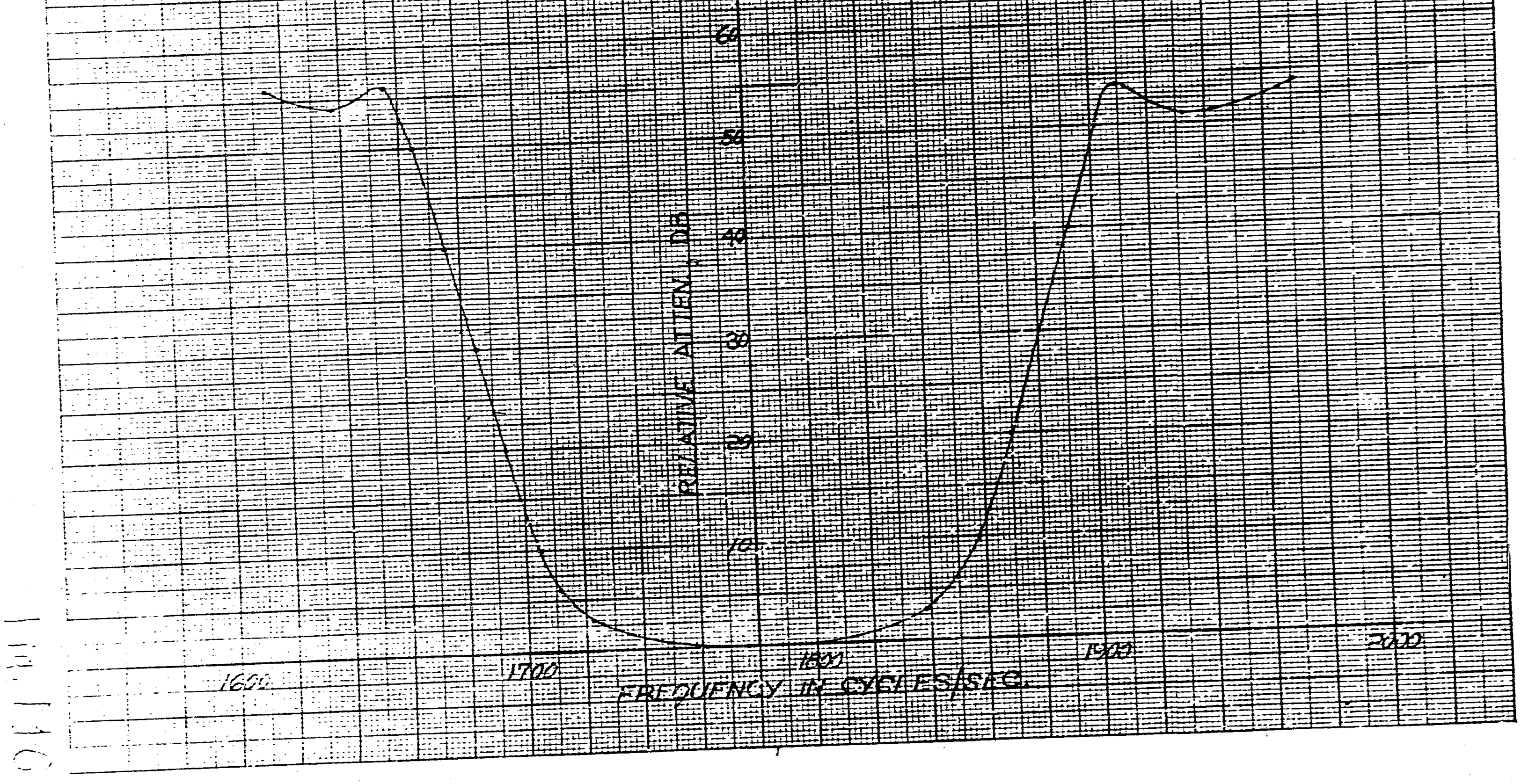
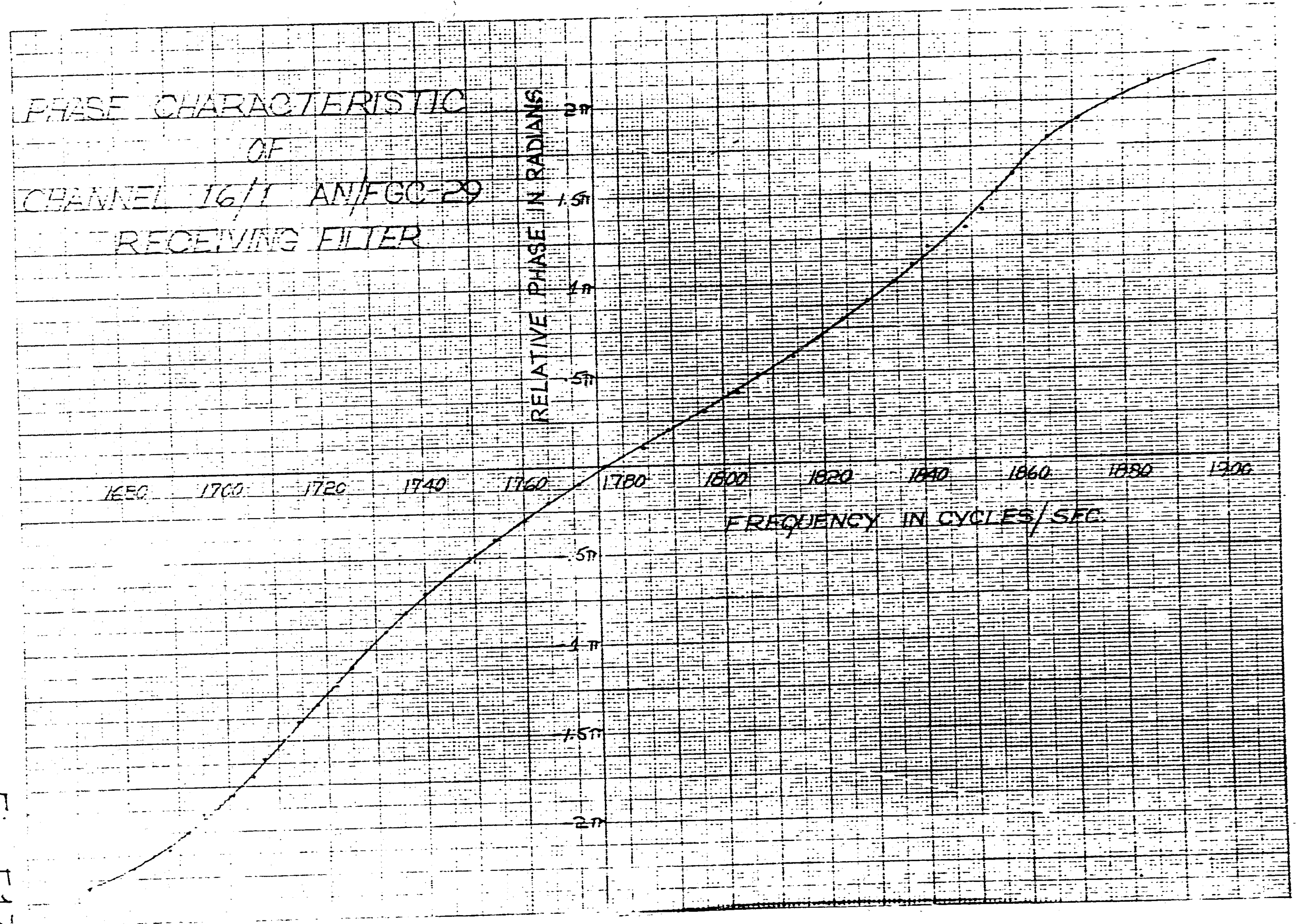


Fig. 116



PHASE CHARACTERISTIC
OF
CHANNEL 16/1 AN/FGC-29
RECEIVING FILTER

Fig. F17

FREQUENCY TRANSMISSION CHARACTERISTIC
OF
AN/FGC-29 CHANNEL 14/3 RECEIVER FILTER

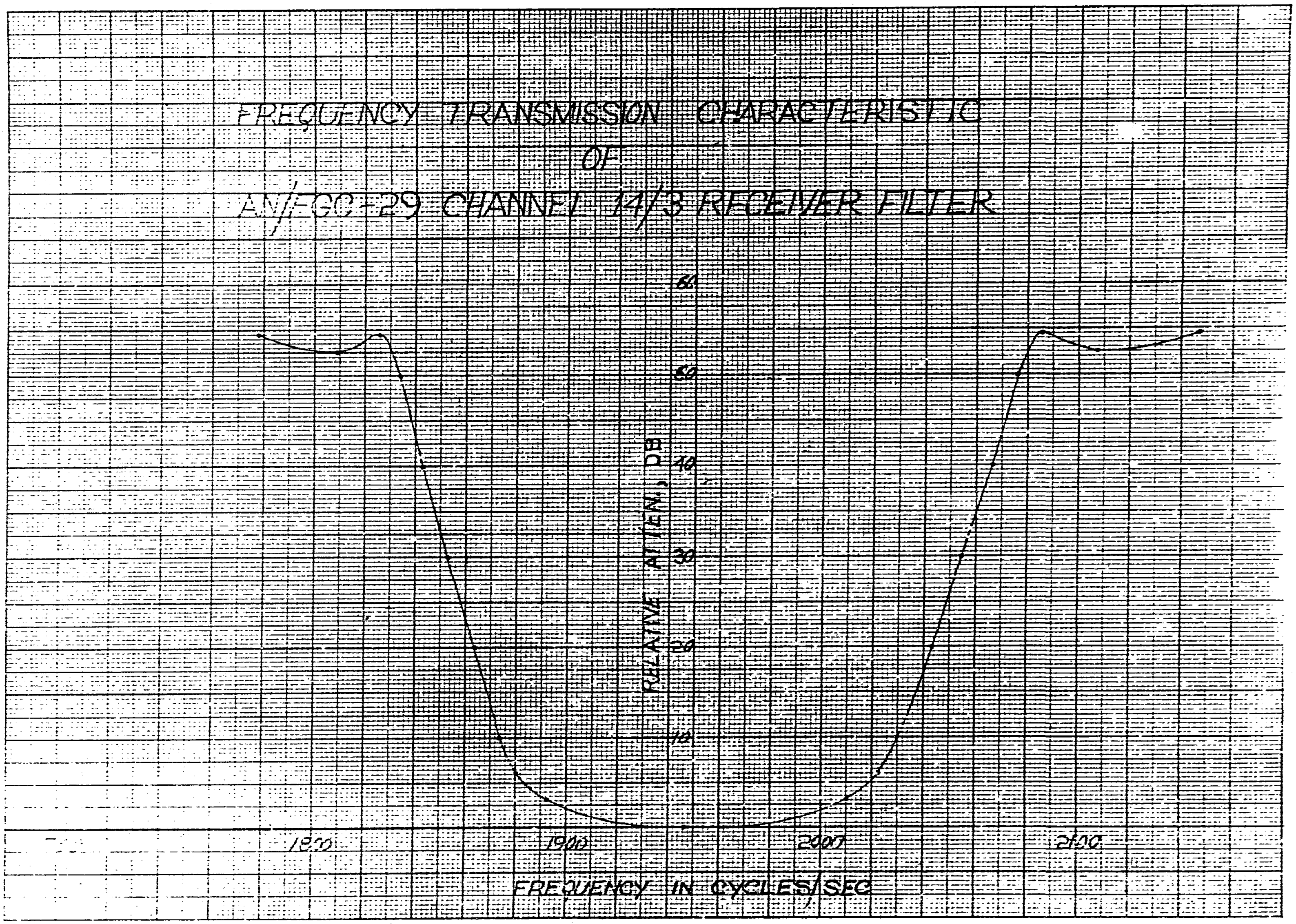


Fig. F18

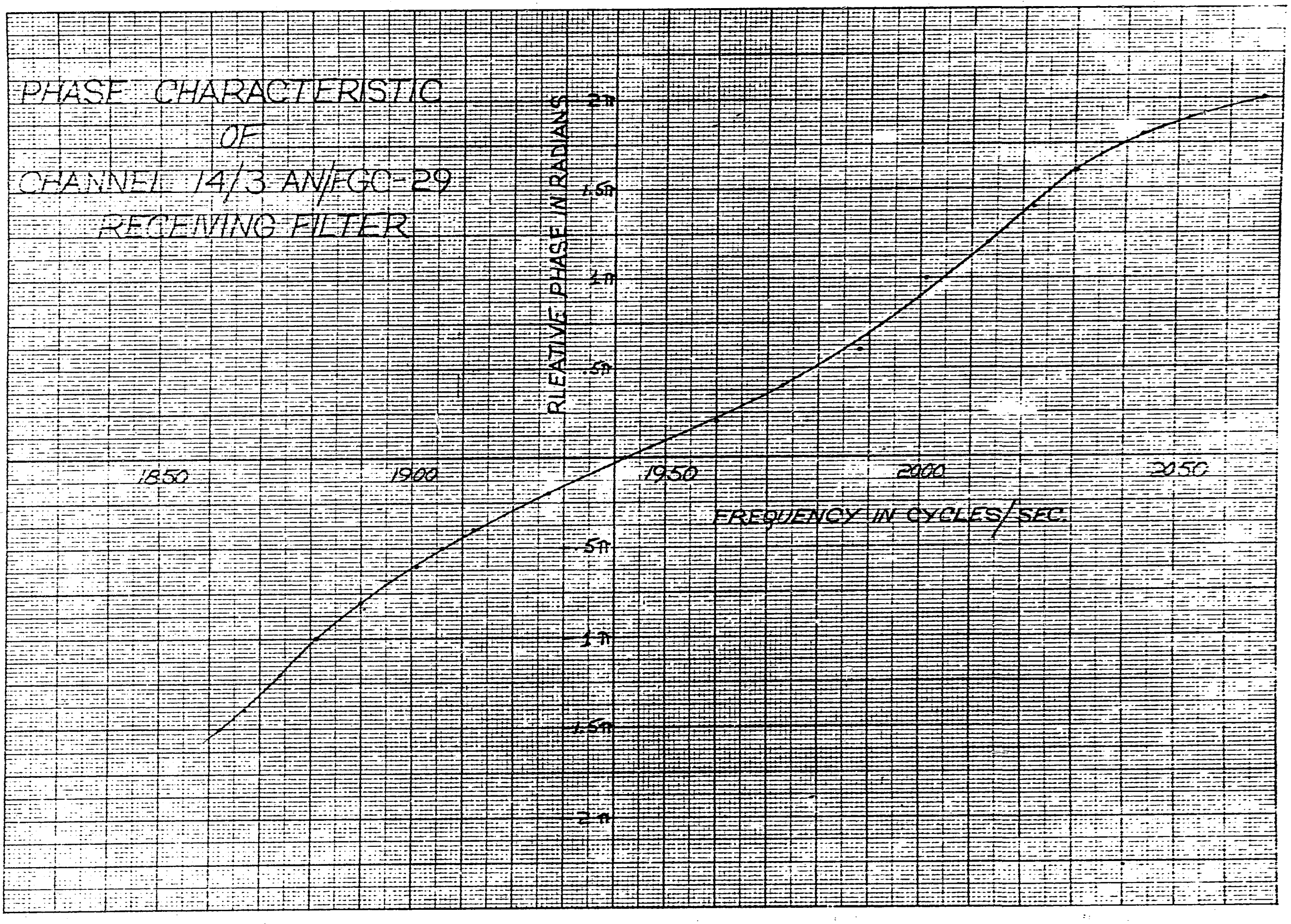
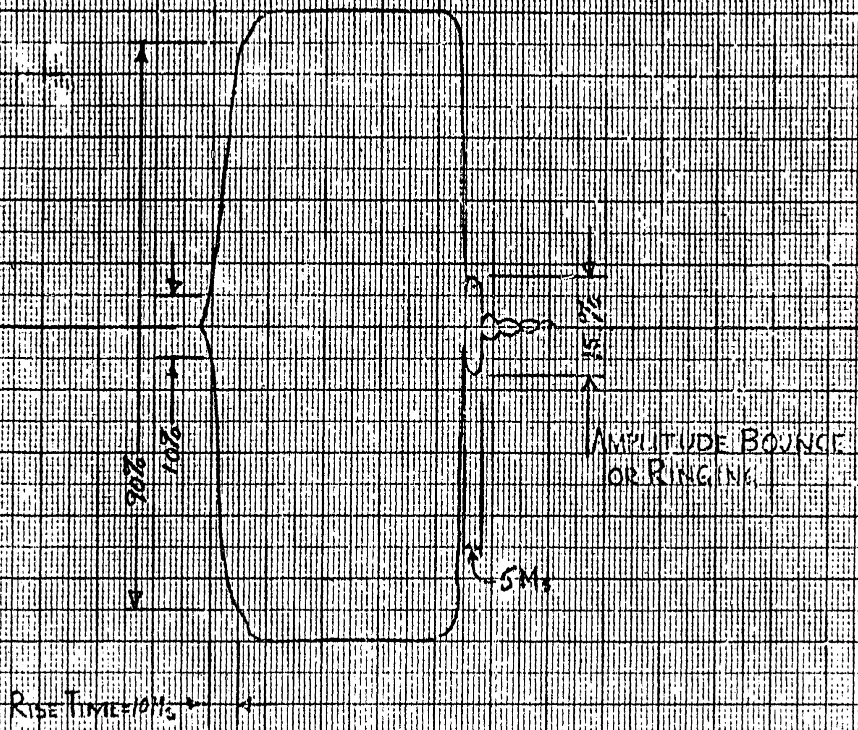
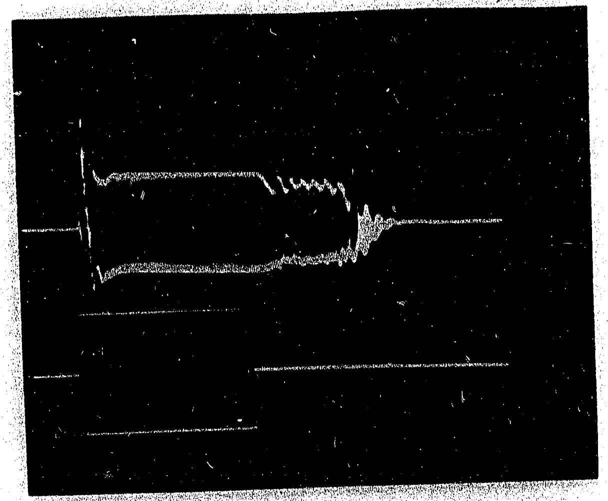

PHASE CHARACTERISTIC
OF
CHANNEL 14/3 AN/FGC-29
RECEIVING FILTER
RLEATIVE PHASE IN RADIANS
2π
1.5π
1π
.5π
-.5π
-1π
-1.5π
-2π
1850
1900
1950
2000
2050
FREQUENCY IN CYCLES/SEC.

Fig. Γ19



SKETCH OF AN/FGC-29 RECEIVING FILTER RESPONSE TO ON/OFF KEYING

Fig. F20



Upper Pattern: Output of AN/FGC-29 Receiver Unit

Lower Pattern: Input to AN/FGC-29 Receiver Unit

9-1265

Figure F21

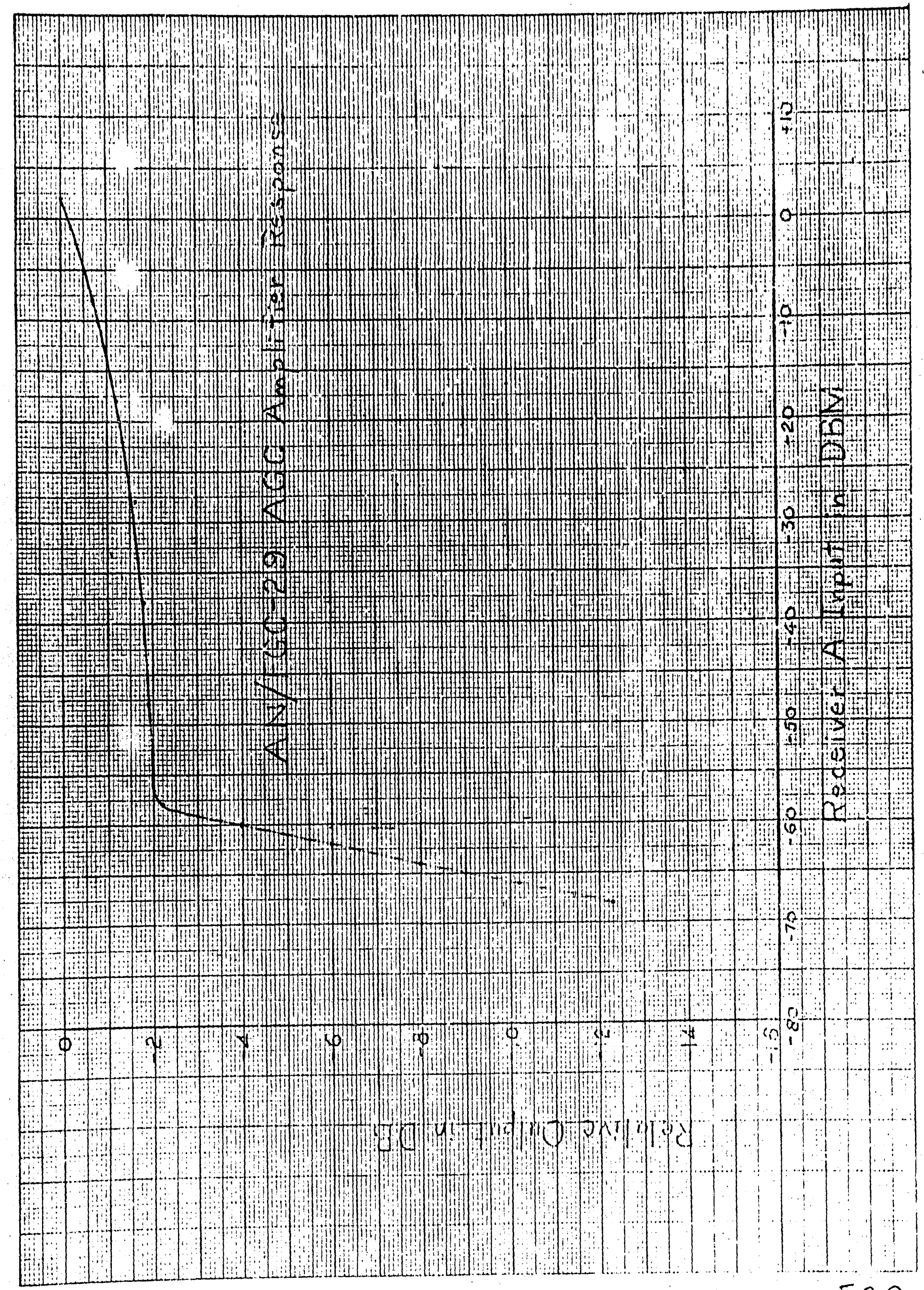

AN/FGC-29 AGC Amplifier Response
Receiver A Input in DBM
-80
-70
-60
-50
-40
-30
-20
-10
0
+10
Relative Output in DB
0
2
4
6
8
10
12
14
16

Fig. F22

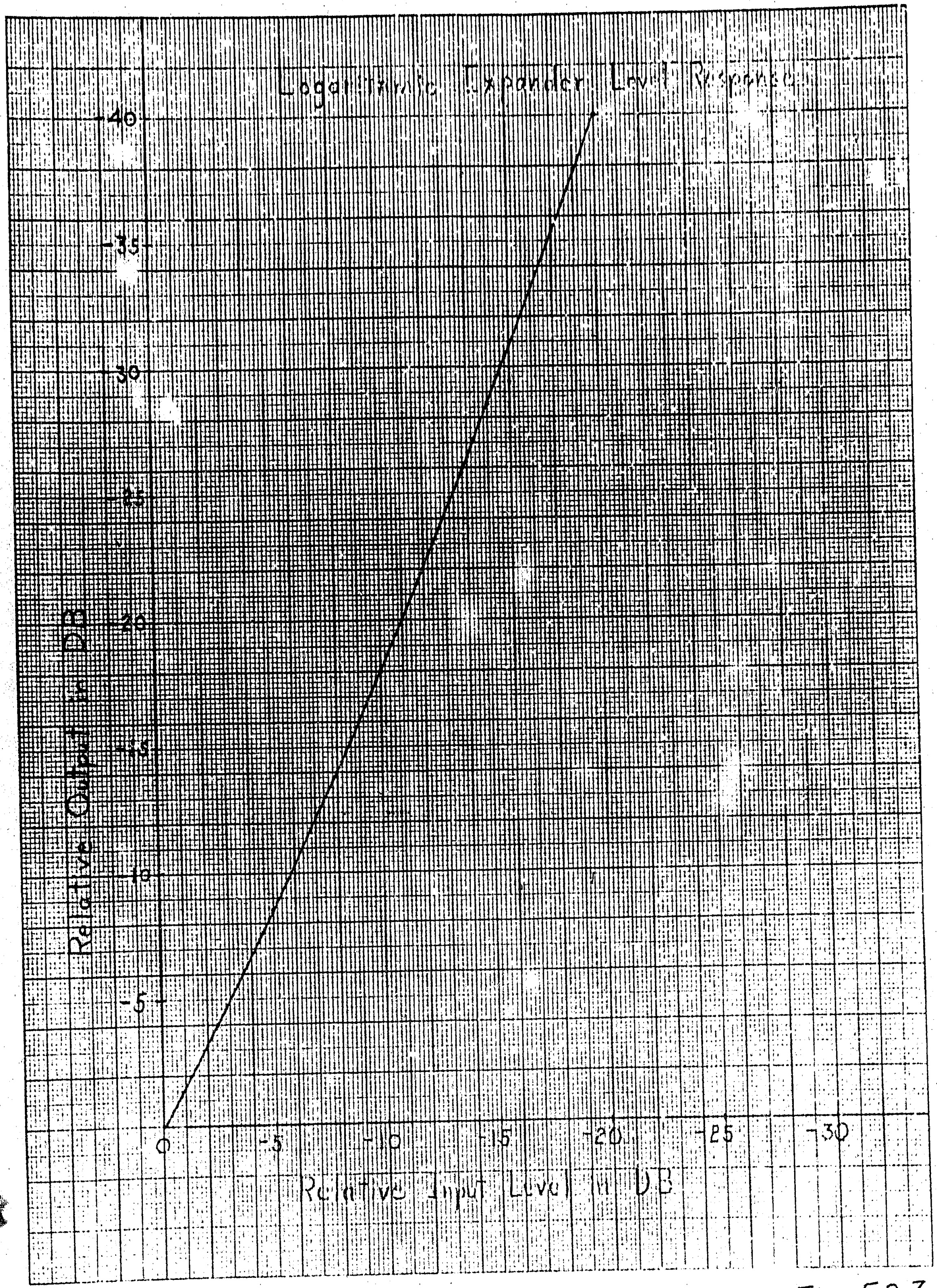

Logarithmic Expander Level Response
Relative Output in DB
-40
-35
-30
-25
-20
-15
-10
-5
0
-5
-10
-15
-20
-25
-30
Relative Input Level in DB

Fig. F23

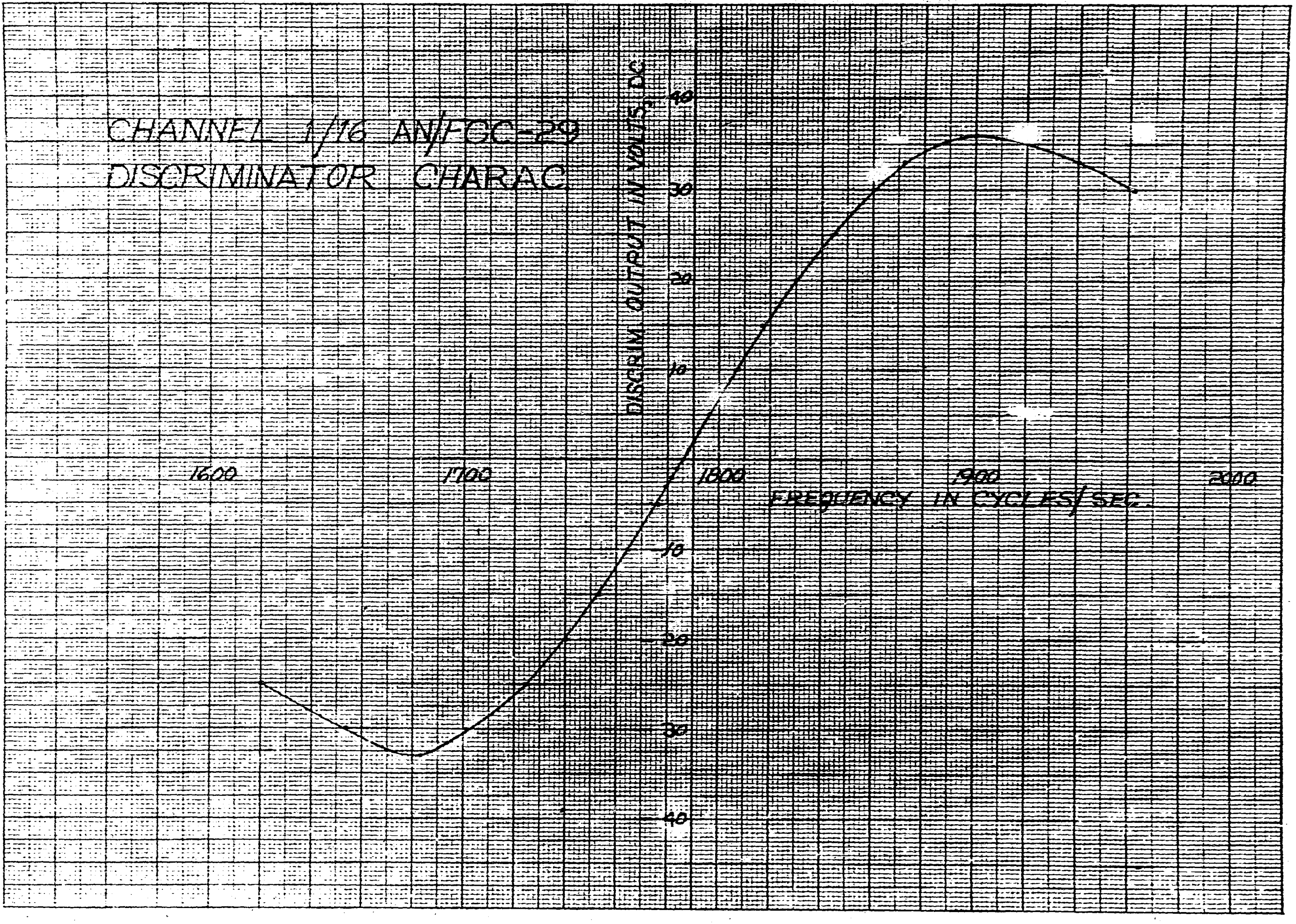
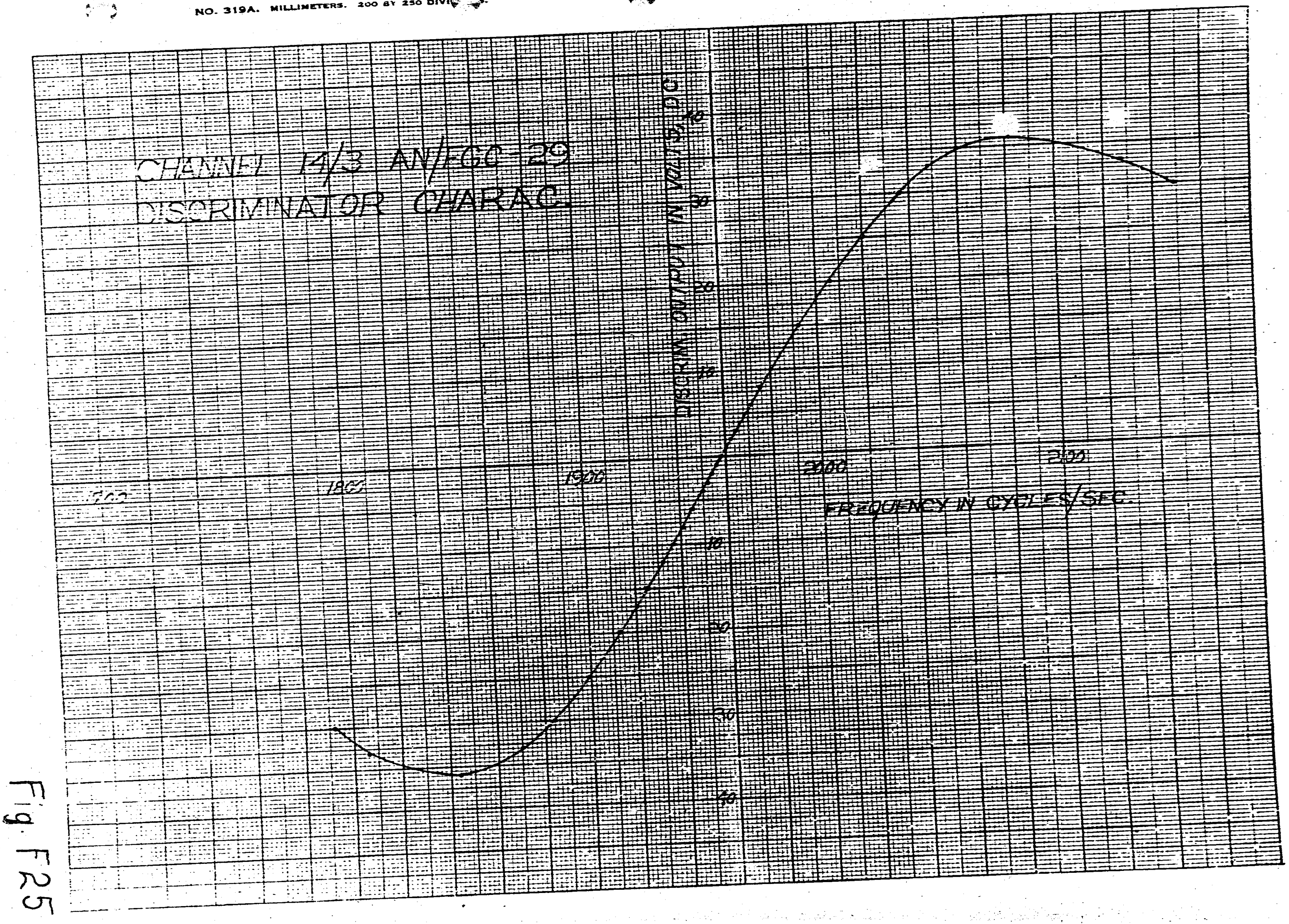

CHANNEL 1/16 AN/FGC-29
DISCRIMINATOR CHARAC
DISCRIM OUTPUT IN VOLTS, DC
40
30
20
10
-10
-20
-30
-40
1600
1700
1800
1900
2000
FREQUENCY IN CYCLES/SEC.

Fig. F24



CHANNEL 14/3 AN/FGC-29
DISCRIMINATOR CHARAC.

Fig. F25

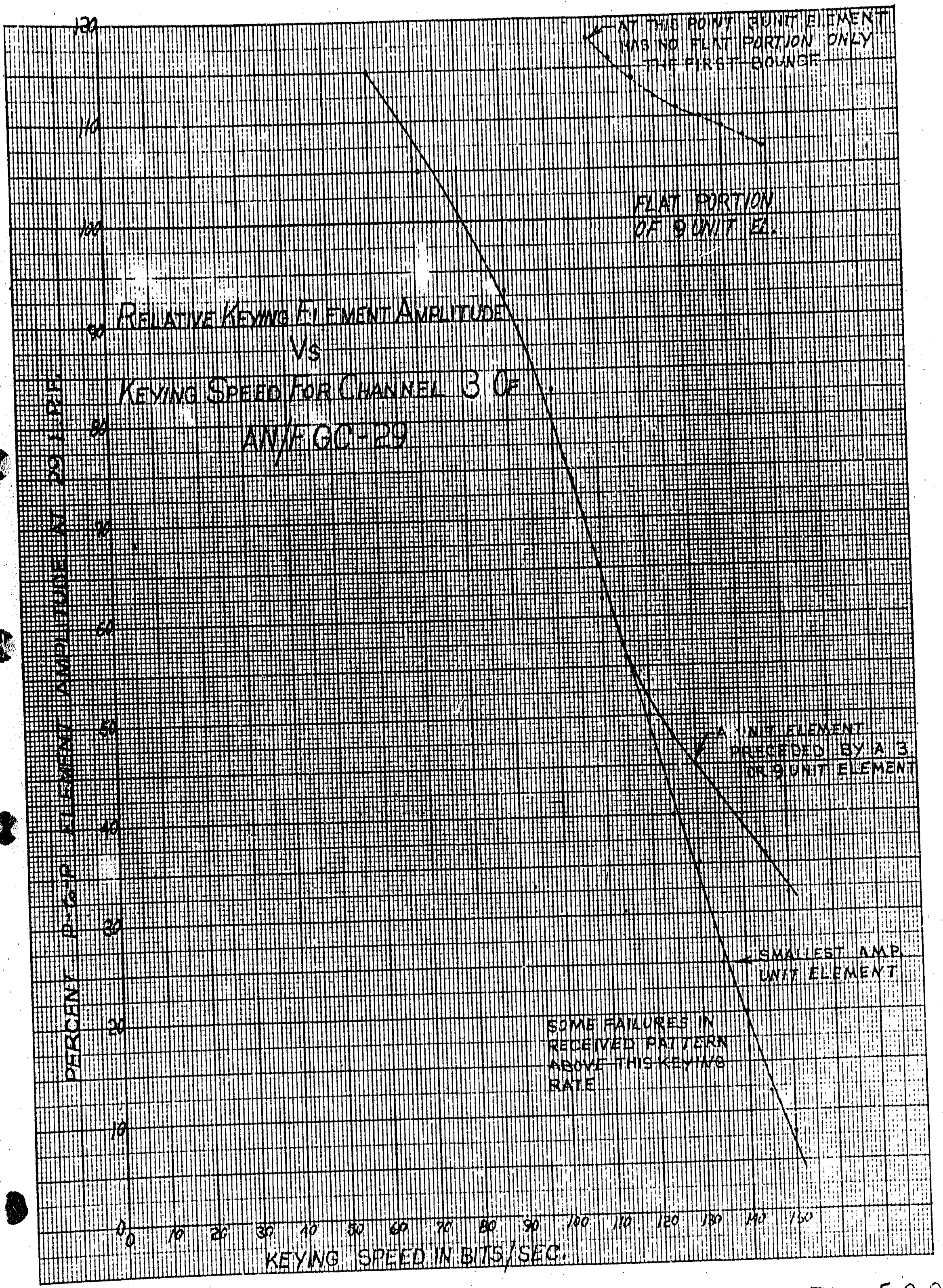

RELATIVE KEYING ELEMENT AMPLITUDE
VS
KEYING SPEED FOR CHANNEL 3 OF
AN/FGC-29
PERCENT P-to-P ELEMENT AMPLITUDE AT 29.1 RF
KEYING SPEED IN BITS/SEC.
120
110
100
90
80
70
60
50
40
30
20
10
0
0
10
20
30
40
50
60
70
80
90
100
110
120
130
140
150
AT THIS POINT 9UNIT ELEMENT HAS NO FLAT PORTION ONLY THE FIRST BOUNCE
FLAT PORTION OF 9 UNIT EL.
A UNIT ELEMENT PRECEDED BY A 3 OR 9 UNIT ELEMENT
SMALLEST AMP UNIT ELEMENT
SOME FAILURES IN RECEIVED PATTERN ABOVE THIS KEYING RATE

Fig. F26

AN/FGC-29 DIVERSITY COMBINING SYSTEM

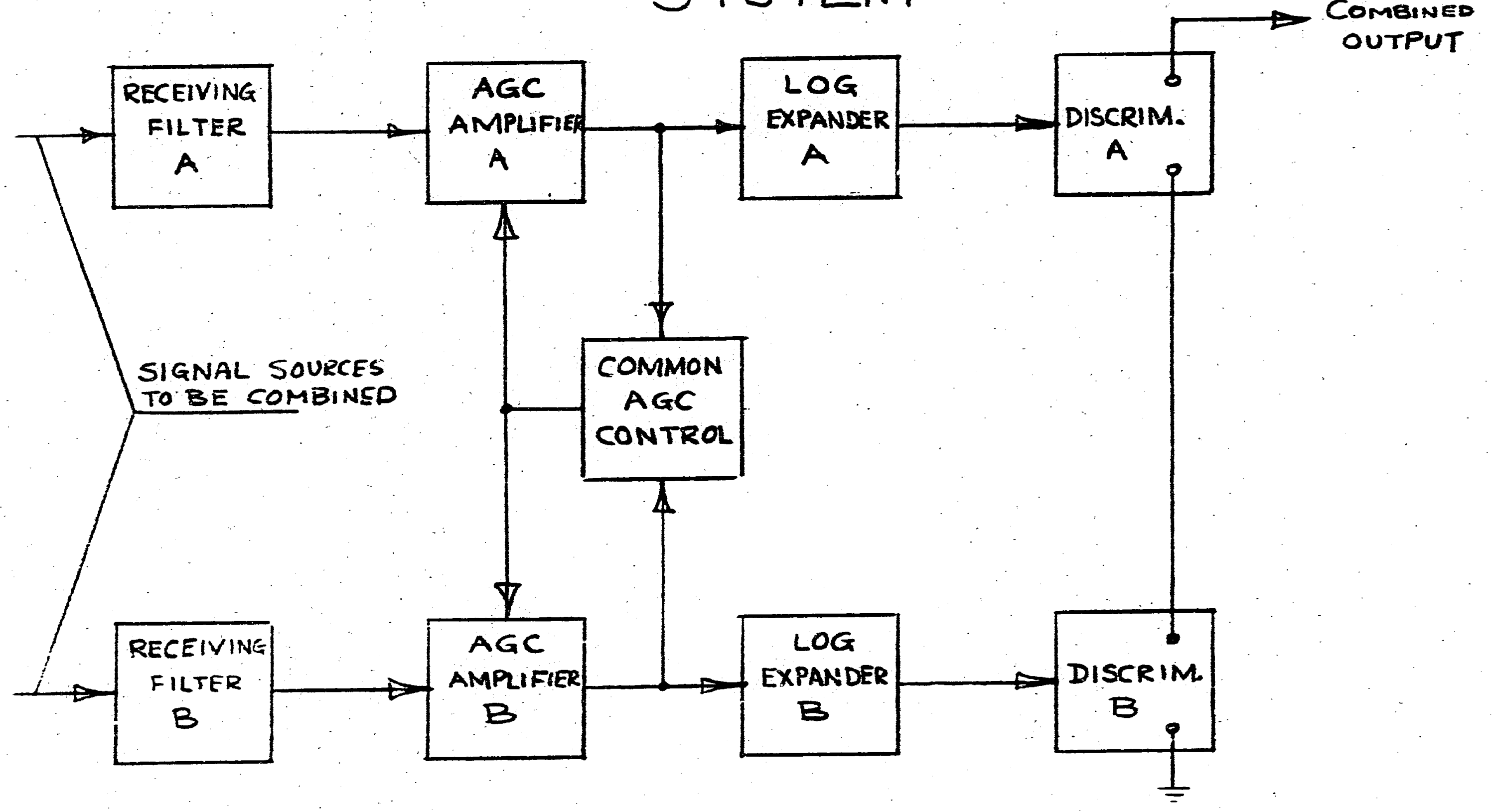
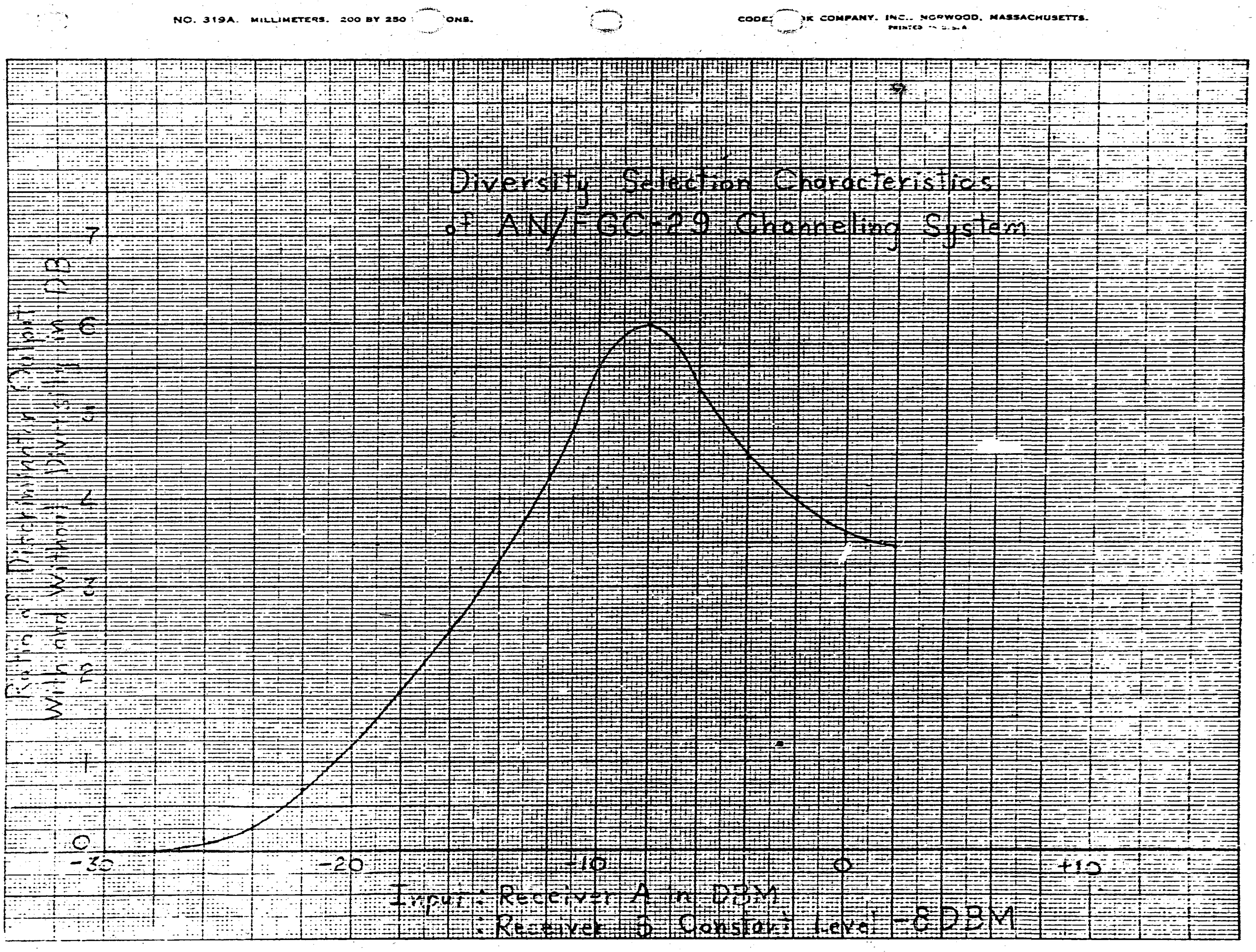


Fig. F27



Diversity Selection Characteristics
of AN/FGC-29 Channeling System

Fig. F28

Section G

PERFORMANCE OF THE AN/FGC-29 CHANNELING SYSTEM AND ITS RELATION TO THE AFSAY D-806

Introduction

One object of this study was to determine the suitability of the AN/FGC-29 16-channel system for transmission of an information stream from equipment similar to the AFSAY D-806. This would require each channel of the AN/FGC-29 to operate at a bit-rate considerably faster than 71.4 bits per second, the average bit-rate of a 100 word-per-minute teletypewriter (TTY) and the rate for which this equipment was designed. Error rates were compared for keying speeds of 71.42--, 100, 104.166--, and 125 bits per second. These corresponded to signal elements that were 14, 10, 9.6 and 8 milliseconds in length.

Two adjacent channels, #1 and #3 of the AN/FGC-29 system were set up to operate over the Kahuku to Riverhead radio circuit. Their center frequencies were 1785, 1955 cycles respectively with a frequency shift of 85 cycles for each. The 48-element short pattern signal (see Section E) operating at 100 bits per second was placed in one channel and compared in turn with each of the other bit-rates. In order to reduce possible inaccuracies due to QRM the modulation was interchanged between the channels half-hourly. One-minute simultaneous error counts were converted to error rates expressed in percent so that they could be compared directly. Each of the bit-rate comparisons was made using both daylight and nighttime frequencies in an attempt to get various degrees of multipath propagation. (See Section I for multipath considerations.)

Comparison of 8, 9.6, 10 and 14 MS AN/FGC-29 Error Rates

Figures G1 and G2 show mass plots of five-minute, simultaneous error rate comparisons of 14 ms vs 10 ms bits using daylight and nighttime frequencies respectively. Curves (broken lines) drawn through median values of the points indicate the error rates to be substantially equal down to about .02% errors. As the error rate decreases below this figure a marked decrease in percent errors becomes evident with the 10 ms bits. This improvement in AN/FGC-29 performance with 10 ms bits vs 14 ms bits was again observed in back-to-back S/N measurements, discussed later.

Figures G3 and G4 show mass plots of five-minute, simultaneous error rate comparisons of 9.6 ms vs 10 ms bits using daylight and nighttime frequencies respectively. Curves (broken lines) drawn through median values indicate that for daylight frequencies the error rates are substantially equal down to about .02% errors. Below this figure, the 9.6 ms bits appear to produce progressively less errors. This is not conclusive, as below this figure there are few points and they are rather badly scattered. In the case of nighttime frequencies, the points are scattered, and at best indicate a trend that the 9.6 and 10 ms bits produce comparable errors.

Figure G5 shows a mass plot of five-minute, simultaneous error rate comparisons of 8 ms vs 10 ms bits using a daylight frequency. A curve (broken line) drawn through median values indicates that the 8 ms bits suffer about 80% more errors than the 10 ms bits.

The above data indicate that the AN/FGC-29 system will handle information with a minimum bit length at least as short as 9.6 ms without degradation in performance. This represents a bit rate of at least 104.17 bits per second per channel or 1666 bits per second for the entire 16-channel system. By accepting some degradation (which could perhaps be compensated for by improved antenna directivity or the addition of a power amplifier at the transmitter) bits as short as 8 ms could be used giving the entire system a capacity of 2000 bits per second. For transmission over microwave relay or good quality land lines, a still higher bit rate appears to be possible (see Section F).

Relative Performance of the AN/FGC-29 Diversity System

The improvement produced by the AN/FGC-29 diversity system over single receiver reception is shown in Figures G6 and G7. These graphs show mass plots of 10 ms bit short pattern error rates using both daylight and nighttime frequencies respectively. Curves drawn through median values indicate that diversity operation yields a reduction in error rate that varies from about 25 to 1 when single receiver reception was producing about 0.3% errors to about 6 to 1 for 1.0% errors.

AN/FGC-29 Interchannel Crosstalk Measurements

Measurements were made to determine the degree of degradation produced in an AN/FGC-29 channel by the presence of keying in an adjacent channel. Figure G8 shows a mass plot obtained by comparing consecutive error rates in percent (10 ms short pattern) with and without an adjacent channel keying (14 ms short pattern). AN/FGC-29 channels 1 and 3 were used for this test, with the patterns alternated between channels half-hourly to reduce QRM differences.

The points on this curve are scattered, and hence the line through the median values is not conclusive.

In addition to the comparison of error rates, signal-to-noise measurements were made in the 10 ms short pattern channel with and without the adjacent 14 ms short pattern channel keying. The procedure followed was to average the peak db signal reading (using the noise meter discussed in Section E) for 5 consecutive one-minute samples, and compare this value alternately with the average of 5 consecutive one-minute peak "noise" readings with and without the adjacent channel keying. A mass plot of the results obtained appears in Figure G9. A dotted curve through the median values indicates that there is about a 2 db difference between the two types of signal-to-noise readings; however, the scattering of the data is such as to make this result somewhat questionable.

Since the radio circuit introduced such large variables that an accurate determination of interchannel crosstalk could not be made, a laboratory or bench setup was assembled. A laboratory model single sideband generator (operated so that spurious interchannel signals were at least 50 db down from a fully modulated channel) was set up and modulated to produce at 2.7 mc a SSB signal containing channels 1 and 3 of the AN/FGC-29. One channel was modulated by a 100 wpm TTY, and the other with the 10 ms bit short pattern. The r-f signal was received through the R-390/CV-157 equipment, demodulated, and errors counted in the short pattern as its amplitude was progressively decreased at the SSB generator. Figure G10 is a plot showing the results of this test. From this it is seen that a radio frequency-selective fade resulting in a

38-db difference in adjacent channel levels at the receiver would produce about 1% errors. A selective fade of this magnitude between channels as closely spaced as these does not occur often, and its duration is brief.

The above measurements do not provide a complete answer to the effect of adjacent channel keying because only one QRM channel was used. In the case of the AN/FGC-29 channeling system, this arrangement is correct only for the channels on the extreme edges of the transmission band (channels 2 and 15), while the remainder of the 14 channels have QRM from keying by channels adjacent to both sides. This effect is illustrated by the facsimile recording of Figure G11 for a single QRM channel. The recording was made using the local laboratory test setup in which the level of the desired channel was lowered until it was about 39 db relative to the adjacent channel. Each dot on the recording represents the position of a keying element transition. For convenience, the two types of transitions (mark-to-space and space-to-mark) are labelled 1 and 2. Displacements from a straight line indicate ambiguity in the timing of the transition caused by the adjacent channel keying. It is seen that the most serious displacements occur on transition No. 1. This is as expected since the QRM channel tends to disturb the transition which occurs closest to it in frequency. Transition No. 1 represents a shift from the high-to-low frequency of channel 1 (below channel 3 in frequency). It might, therefore, be expected that with QRM channels straddling the desired channel, both types of transitions would be disturbed. In the laboratory this disturbance would cause at least twice the number of errors indicated in Figure G10 for a single QRM channel. On the radio circuit, however, selective fading would modify this result since the channels would tend to fade independently of each other.

Interchannel crosstalk is not only the result of how well the filters at the transmitter and receiver roof the individual channels, but is also a result of non-linearity in the transmission system. From the data given above, it does not appear that the filters in the AN/FGC-29 system produce excessive interchannel crosstalk.

Using the same laboratory setup, the signal-to-interference ratio within the channel was measured. The results are plotted in Figure G12. This shows, for example, that when the signal-to-interference ratio within the channel is about 7 db, the error rate in the short pattern is about 1%. This, of course, should be true regardless of the number of nearby channels that are keying.

Relative Performance of the AFSAY D-806 and AN/FGC-29 Diversity Combining Systems

Figure G13 shows a comparison of the combining system used in the AN/FGC-29 and that used with the AFSAY D-806 type of channeling. Here again, simultaneous error rate measurements are compared. The AN/FGC-29 channel was operated in normal fashion with the 10 ms short pattern. The AFSAY D-806 channel also used the 10 ms short pattern, but in place of its normal filters, there were substituted AN/FGC-29 channel roofing filters and low-pass filters. The points in the mass plot are scattered, and hence a line drawn through the median points is inconclusive. However, in general, it would appear that the AN/FGC-29 system produced somewhat less errors than the AFSAY D-806 system, the ratio between the two being 1.5 or less for AN/FGC-29 error rates greater than 0.03%.

Comparative Error Rates for the AFSAY D-806 and AN/FGC-29 Channeling Systems

Figures G14 and G15 show the results of a direct comparison on daytime and nighttime frequencies respectively, of the AFSAY D-806 and AN/FGC-29 channeling systems. The AFSAY D-806 channel was operated at its normal bit rate of 250 per second (4 ms bits) and the AN/FGC-29 channel at 100 bits per second (10 ms bits). Both systems used the 48-element short pattern. Power in the channels was apportioned on the basis of the number of channels each system normally transmits. This means that 3.5 db less power was used in the AN/FGC-29 channel since it normally handles 16 as compared to 7 of the AFSAY D-806 channels. Evaluation of the systems were performed simultaneously, and the resulting error data expressed as percent. Mass plots of these data appear in Figures G14 and G15 along with a dotted line drawn through the median values. These values indicate that for daytime frequencies when the AFSAY D-806 is making 1% errors, the AN/FGC-29 makes about 0.25% errors and for nighttime frequencies the AN/FGC-29 makes roughly 0.2% errors. That is, if the AN/FGC-29 system were substituted for an AFSAY D-806 system operating over the Kahuku-Riverhead radio circuit at a time when it was averaging 1% errors, the former would average roughly 1/4 to 1/5 as many errors. It should be noted, however, that if the nighttime median curve be extrapolated, then, under conditions similar to the above the AFSAY D-806 would produce but 66 to 100% more errors than the AN/FGC-29, when the AN/FGC-29 was producing about 1% errors.

Figures G16 and G17 are plots similar to Figures G14 and G15 above except that both the equipments were operated single-set instead of diversity. The corresponding AN/FGC-29 improvement if substituted for an AFSAY D-806 system at a time the AFSAY D-806 was averaging 1% errors, would be about 1/6 the number of errors at night and 1/10 the errors during the day. For the condition where the AN/FGC-29 produces 1% errors, the AFSAY D-806 produces on the average 180% more errors at night and 270% during the day.

AFSAY D-806 Channel Filter Evaluation in Terms of Error Rates

One of the limitations to the operation of the AFSAY D-806 channeling system is the keying distortion introduced both at the transmitter and receiver by the channel roofing filters. Illustrations of this distortion are given in Figure 13 of the Second Quarterly Report. In order to determine the degradation due to the channel roofing filter, a test was performed in which error rates with and without this filter were compared. The tests were performed sequentially on a single AFSAY D-806 channel using a 48-element short pattern with 4 ms bits. Figure G18 shows a mass plot of the percent errors with and without the use of the receiving roofing filter. A dotted line has been drawn dividing the data equally on either side of it. When the AFSAY D-806 with the filter is making 1% errors, 1/2 that number of errors are produced without the channel receiving filter. It was inconvenient to remove the transmit filter during these tests. The results, therefore, indicate only part of the improvement that might be obtained.

From this it appears that the margin of difference between the AFSAY D-806 and AN/FGC-29 channeling systems as given above could possibly be reduced by changes in the filter design.

Relation of AN/FGC-29 8, 10, and 14 MS Pattern Error Rates and Signal-to-Noise

Using diversity reception short pattern error rates in the AN/FGC-29 system for 14, 10, and 8 ms bits were plotted against signal-to-noise ratio. These plots are shown in Figures G19, G20 and G21 respectively. Curves drawn through median values show almost identical performance for the 14 and 10 ms bits, while the 8 ms bits show appreciable degradation. Error rates of 1% are achieved with signal-to-noise ratios about 11 db for the 10 and 14 ms bits and about 13 db for the 8 ms bits.

Figure G22 shows a plot of error rates for both 14 and 10 ms bits vs S/N ratio taken in the laboratory under "back-to-back" conditions. From these data it is evident that, for equal percent errors, roughly 1 db higher S/N ratio is required for 14 ms bits than for 10 ms bits. 1% error rates occur at about 7 db signal-to-noise ratio. This value is smaller than that found on the radio circuit because no fading is involved.

Distribution of AFSAY D-806 and AN/FGC-29 Errors

While observing the short pattern from Kahuku as received by the AFSAY D-806 system (4 ms bits, 250 bits per second) on an oscilloscope, it was noted that certain of the elements of the pattern seemed to be mutilated more often than others. For verification, the AFSAY D-806 pattern was displayed on a facsimile record, and then, without disturbing synchronism, the errors from the coincidence unit substituted. By recording a small amount of the pattern, it served to identify in which portion of the pattern the errors were occurring. A typical record of the distribution of errors is shown in Figure G23.

Examination of Figure G23 shows that there are a total of 42 errors, 8 of which are scattered, and the remaining 34 of which occur at 3 particular points in the pattern. (The text and arrows do not mask any errors.) The fact that the errors appear to be biased toward one type of transition, leads to a conclusion that there is some asymmetry in the AFSAY D-806 transmission system. Such an asymmetry has been noted in the transient response of the channel bandpass filters. By redesign, a more symmetrical filter and one with less "bounce" could be produced, thus equalizing the distribution and tolerance of the system to errors. This appears to confirm the observations noted above in connection with the AFSAY D-806 filter test. (See Figure G18)

Figure G24 shows a facsimile record made in the same fashion as that discussed above, except that this record shows a portion of the 10 ms pattern (100 bits per second) as received through an AN/FGC-29 channel. By contrast to the AFSAY D-806 recording of Figure G23, inspection shows that the error distribution is reasonably uniform throughout the elements, except that the longer elements (which consist of several consecutive bits) appear to receive less than an average number of errors. This may be due to the fact that the 10 ms bits of the pattern only rise to about 83% of full amplitude or steady state in the filter, increasing their susceptibility to noise relative to the longer elements.

Conclusions

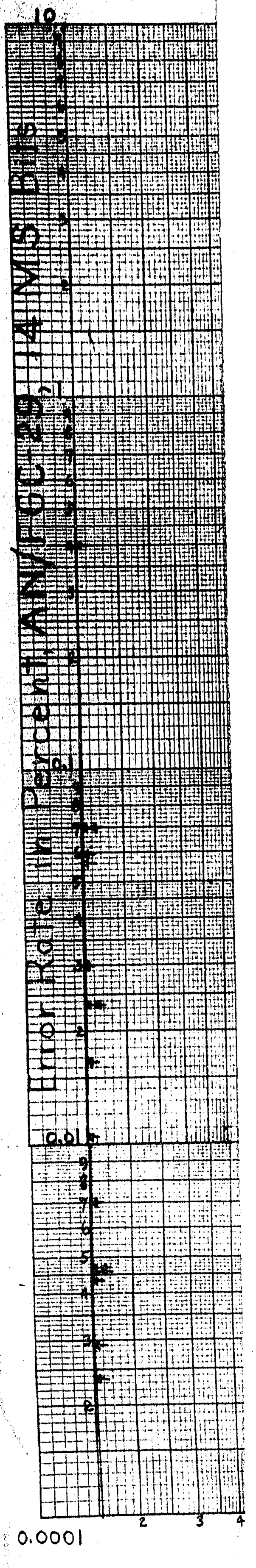
1. Keying speeds up to 104.16 bits per second (9.6 ms elements) are practical in the AN/FGC-29 channeling system without degradation in performance.
2. On the average the AN/FGC-29 diversity system reduced error rates from about 25 to 1 when single receiver reception was producing 0.3% errors to about 6 to 1 for 1% errors.
3. AN/FGC-29 interchannel crosstalk measurements indicate that adjacent channel keying does not average more than 1% errors when the signal-to-interference ratio within the channel is greater than about 7 db.
4. Error rates due to keying from an adjacent channel do not average more than 1% when the difference between the level within the channel and level of the adjacent channel are not greater than about 38 db.
5. The AN/FGC-29 diversity combining system is equal to or slightly better in performance than the AFSAY D-806 system, the ratio between the two being 1.5 or less for AN/FGC-29 error rates greater than .03%.
6. The AN/FGC-29 diversity channeling system produces less errors than the AFSAY D-806 channeling system, the improvement averaging about 5 to 1 when the AFSAY D-806 produces 1% errors. Similarly when the AN/FGC-29 produces 1% errors the AFSAY D-806 produces between 66 to 100% more errors.
7. There is a considerable amount of keying element distortion through the AFSAY D-806 channel roofing filters (25 to 40%

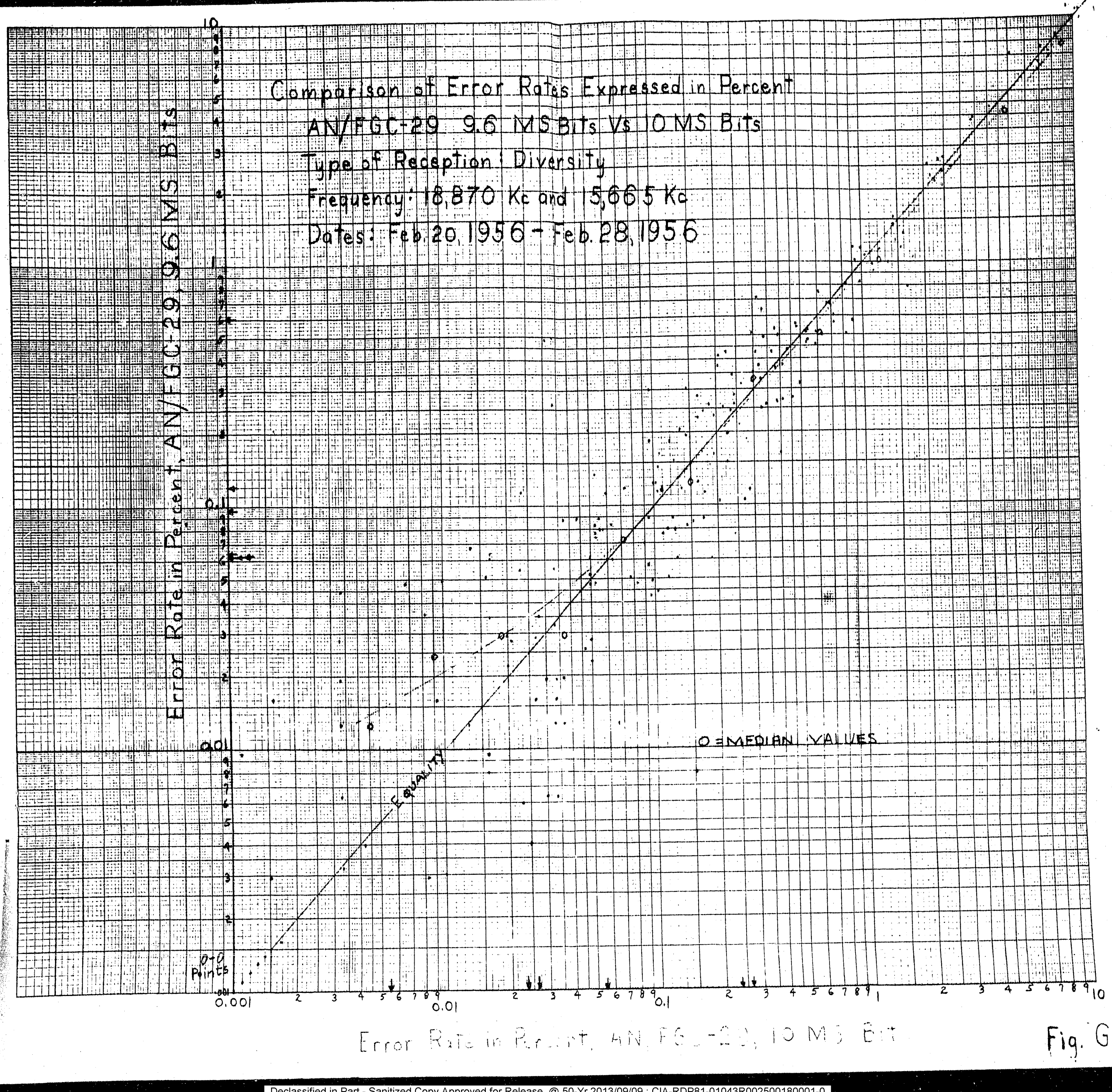
amplitude bounce). When the receive channel roofing filter is removed from the circuit, there is about a 2 to 1 reduction in errors over the 1% errors produced with the filter in the circuit.

8. Using diversity reception, the AN/FGC-29 requires about a 11 db signal-to-noise ratio within the channel in order to average less than 1% errors when using 14 or 10 ms bits.*

9. Distribution of errors through the AN/FGC-29 indicates that the longer elements of the 48-element pattern are less susceptible to failure. The AFSAY D-806 on the other hand, has an unsymmetrical distribution of element errors indicating some type of assymmetry in the system.

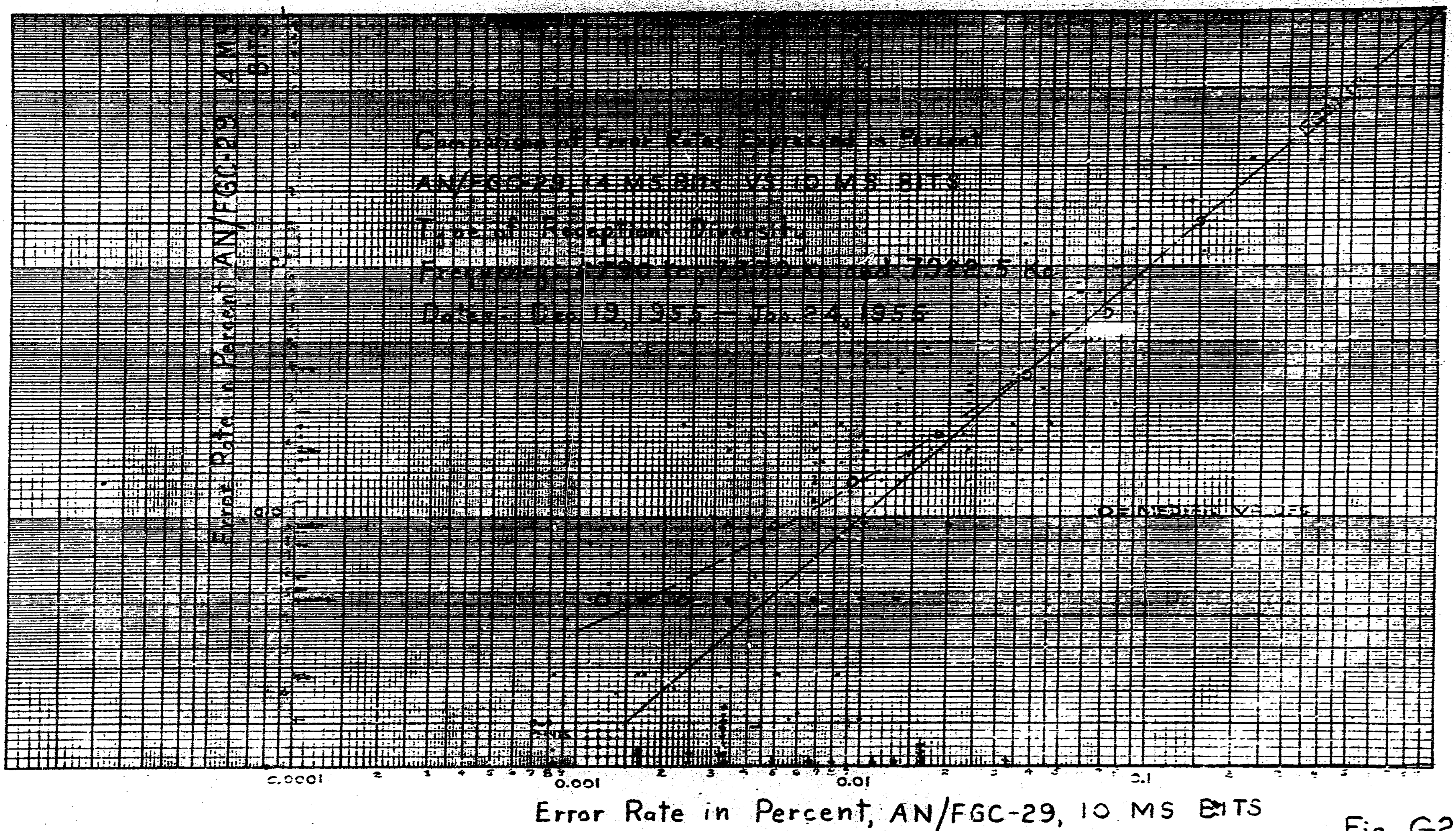
*The method used to measure signal to noise ratio is described in Appendix BB page 1.


Error Rate in Percent, AN/FGC 29, 14 MS Bits
10
1
0.1
0.01
0.0001
2
3
4



Comparison of Error Rates Expressed in Percent
AN/FGC-29 9.6 MS Bits Vs 10 MS Bits
Type of Reception: Diversity
Frequency: 18,870 Kc and 15,665 Kc
Dates: Feb. 20, 1956 - Feb. 28, 1956

Fig. G3



Comparison of Error Rates Expressed in Percent

AN/FGC-29, 4 MS Bits VS 10 MS BITS

Type of Reception: Diversity

Frequency: 7730 [illegible] 7922.5 kc

Dates: Dec 19, 1955 — Jan 24, 1956

Fig. G2

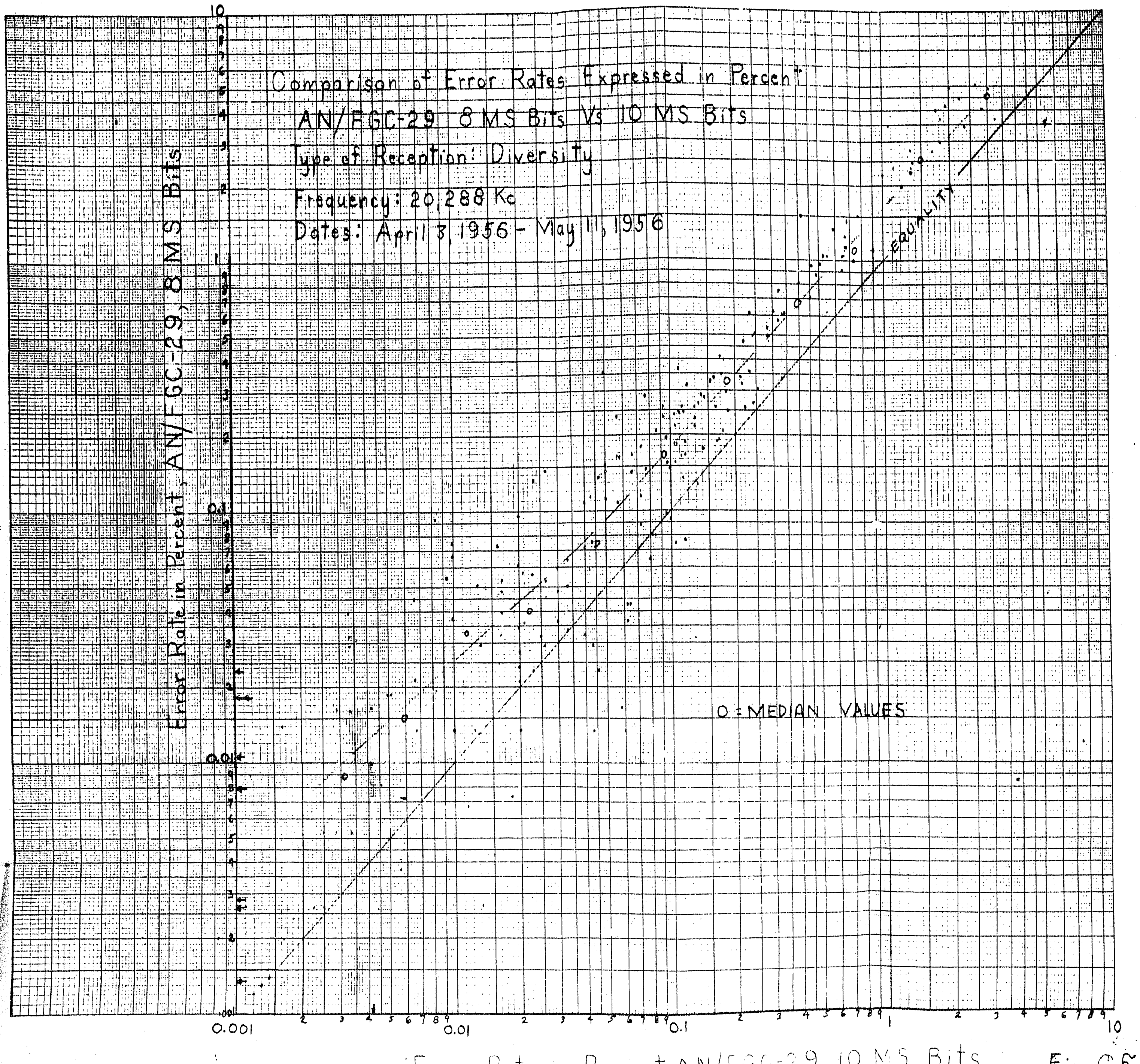
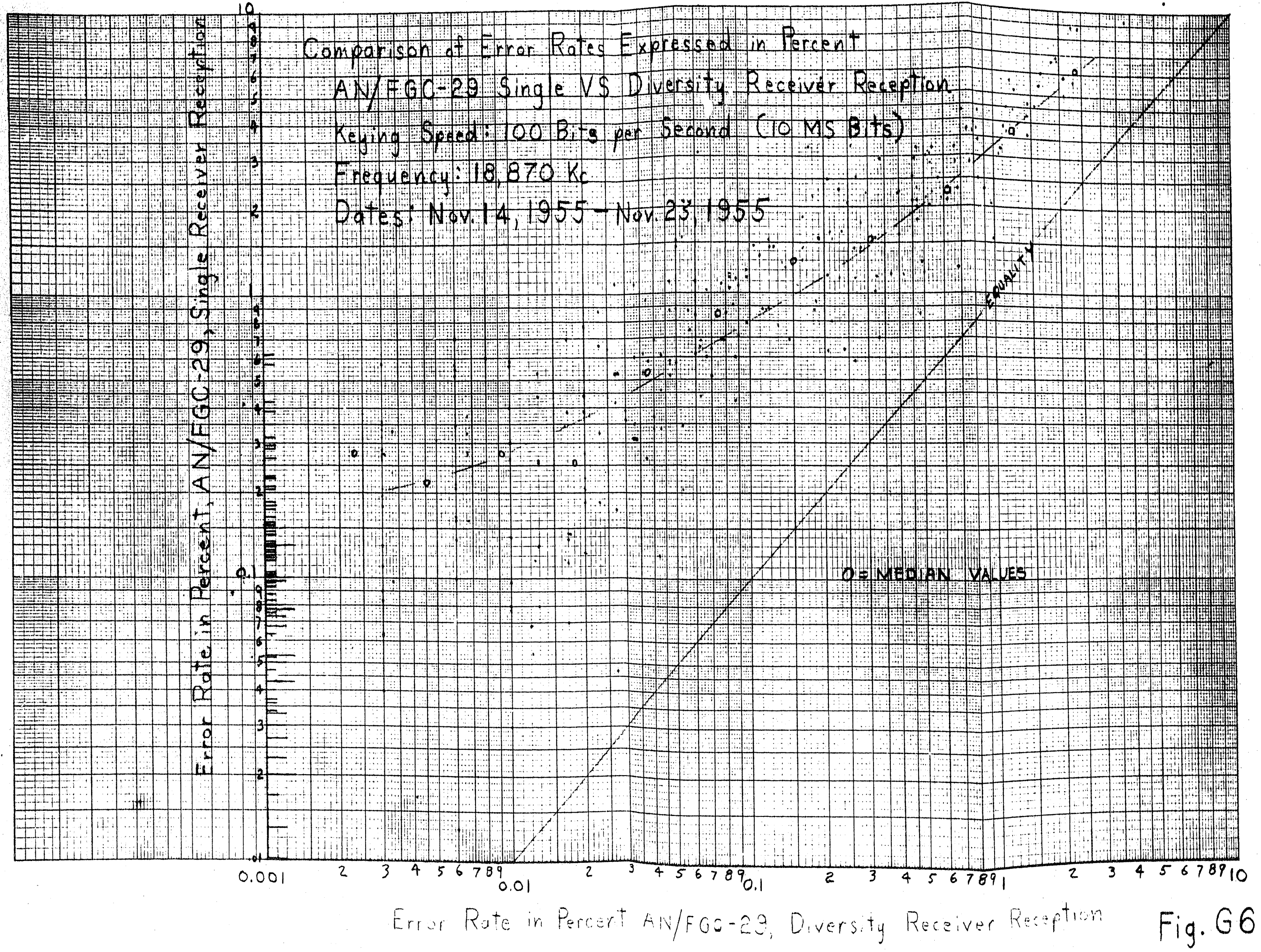

Comparison of Error Rates Expressed in Percent
AN/FGC-29 8 MS Bits Vs 10 MS Bits
Type of Reception: Diversity
Frequency: 20,288 Kc
Dates: April 3, 1956 - May 11, 1956
EQUALITY
o = MEDIAN VALUES
Error Rate in Percent, AN/FGC-29, 8 MS Bits
10
1
0.1
0.01
.001
0.001
0.01
0.1
1
10
Error Rate in Percent, AN/FGC-29, 10 MS Bits

Fig. G5



Comparison of Error Rates Expressed in Percent

AN/FGC-29 Single VS Diversity Receiver Reception

Keying Speed: 100 Bits per Second (10 MS Bits)

Frequency: 18,870 Kc

Dates: Nov. 14, 1955 - Nov. 23, 1955

Fig. G6

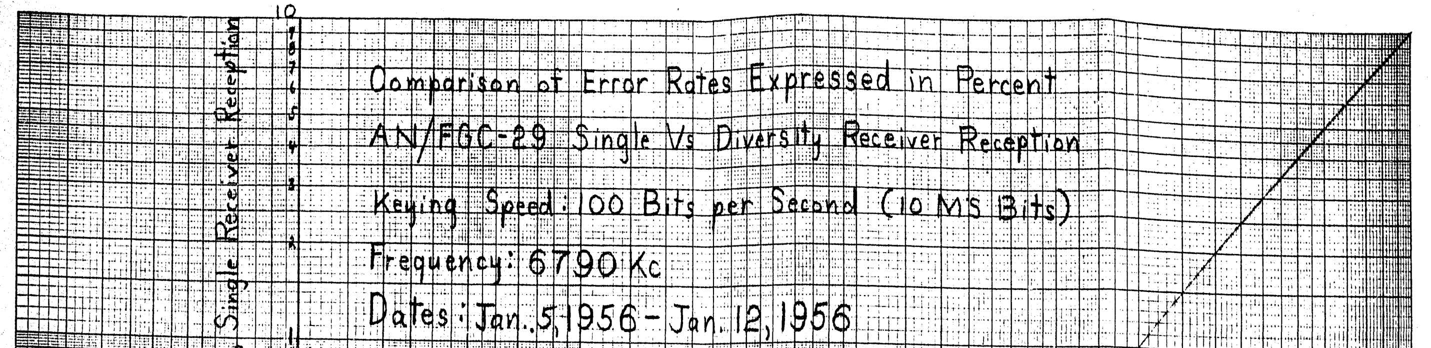
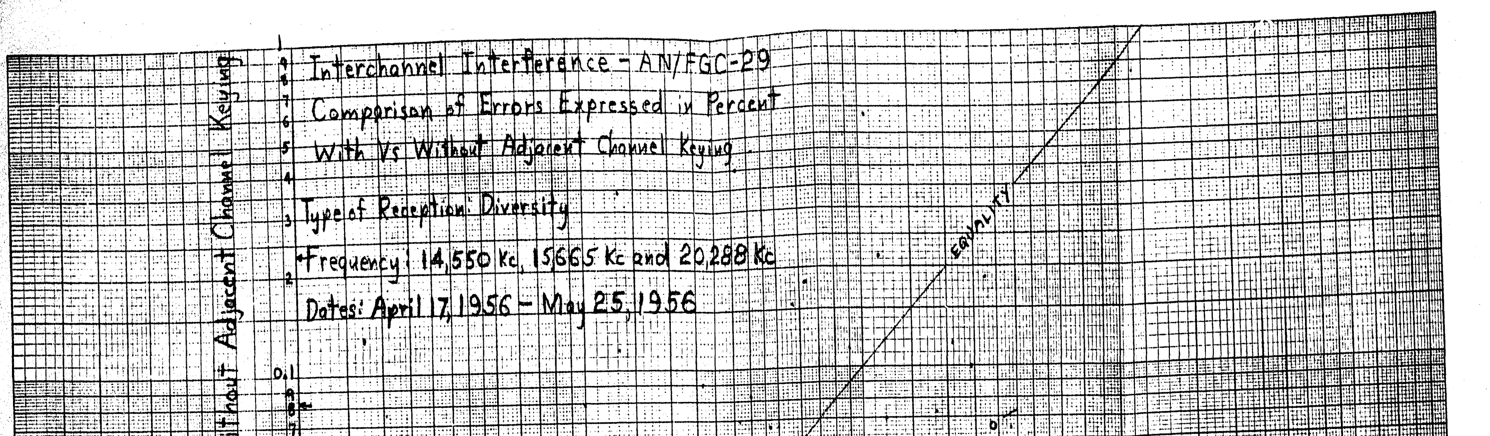

Comparison of Error Rates Expressed in Percent
AN/FGC-29 Single Vs Diversity Receiver Reception
Keying Speed: 100 Bits per Second (10 MS Bits)
Frequency: 6790 Kc
Dates: Jan. 5, 1956 - Jan. 12, 1956

Fig. G7



Interchannel Interference - AN/FGC-29

Comparison of Errors Expressed in Percent

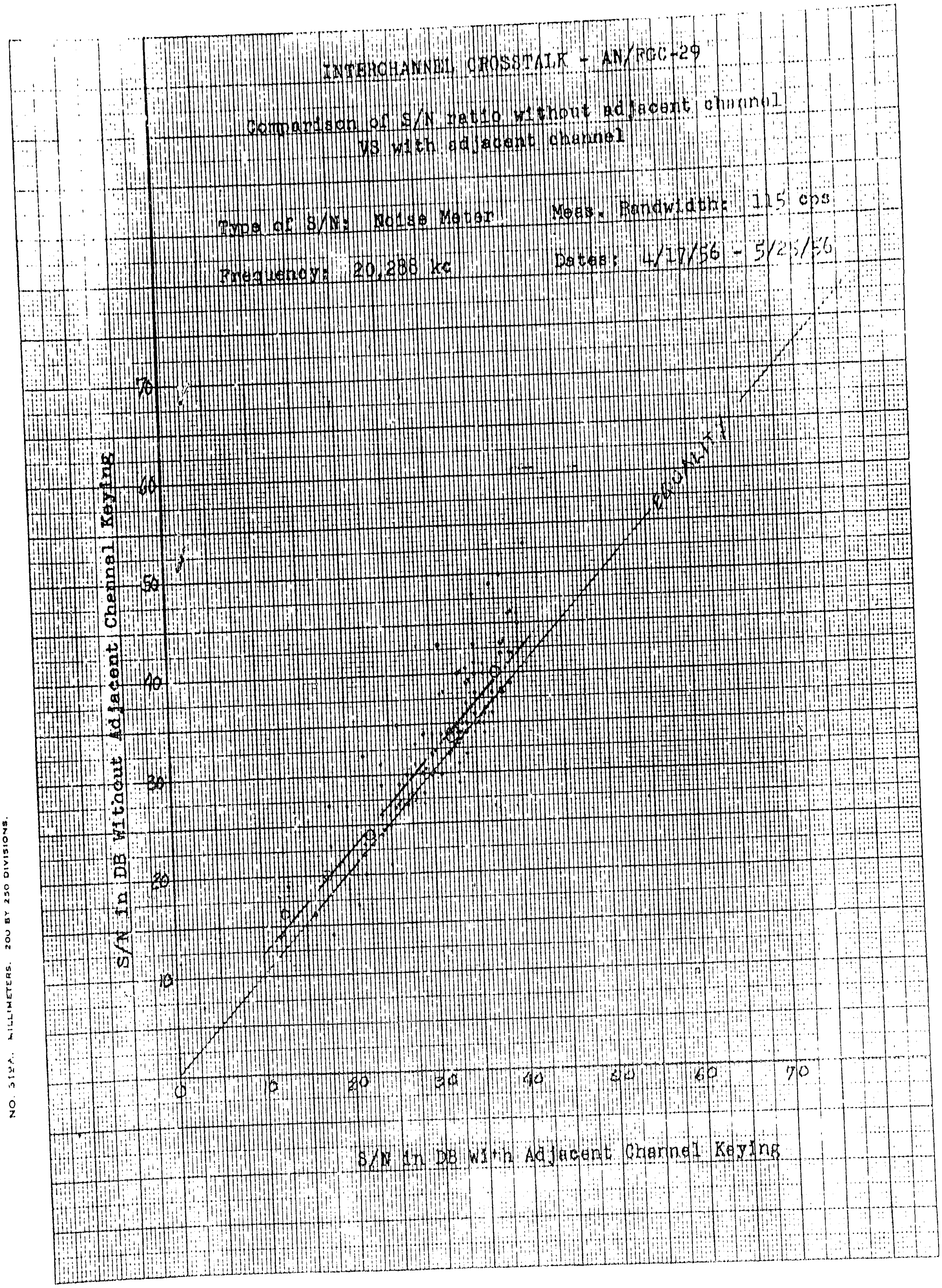
With Vs Without Adjacent Channel Keying

Type of Reception: Diversity

Frequency: 14,550 Kc, 15,665 Kc and 20,288 Kc

Dates: April 17, 1956 - May 25, 1956

Fig. G8



INTERCHANNEL CROSSTALK - AN/FGC-29

Comparison of S/N ratio without adjacent channel VS with adjacent channel

Type of S/N: Noise Meter Meas. Bandwidth: 115 cps

Frequency: 20,288 kc Dates: 4/17/56 - 5/25/56

FIGURE 69

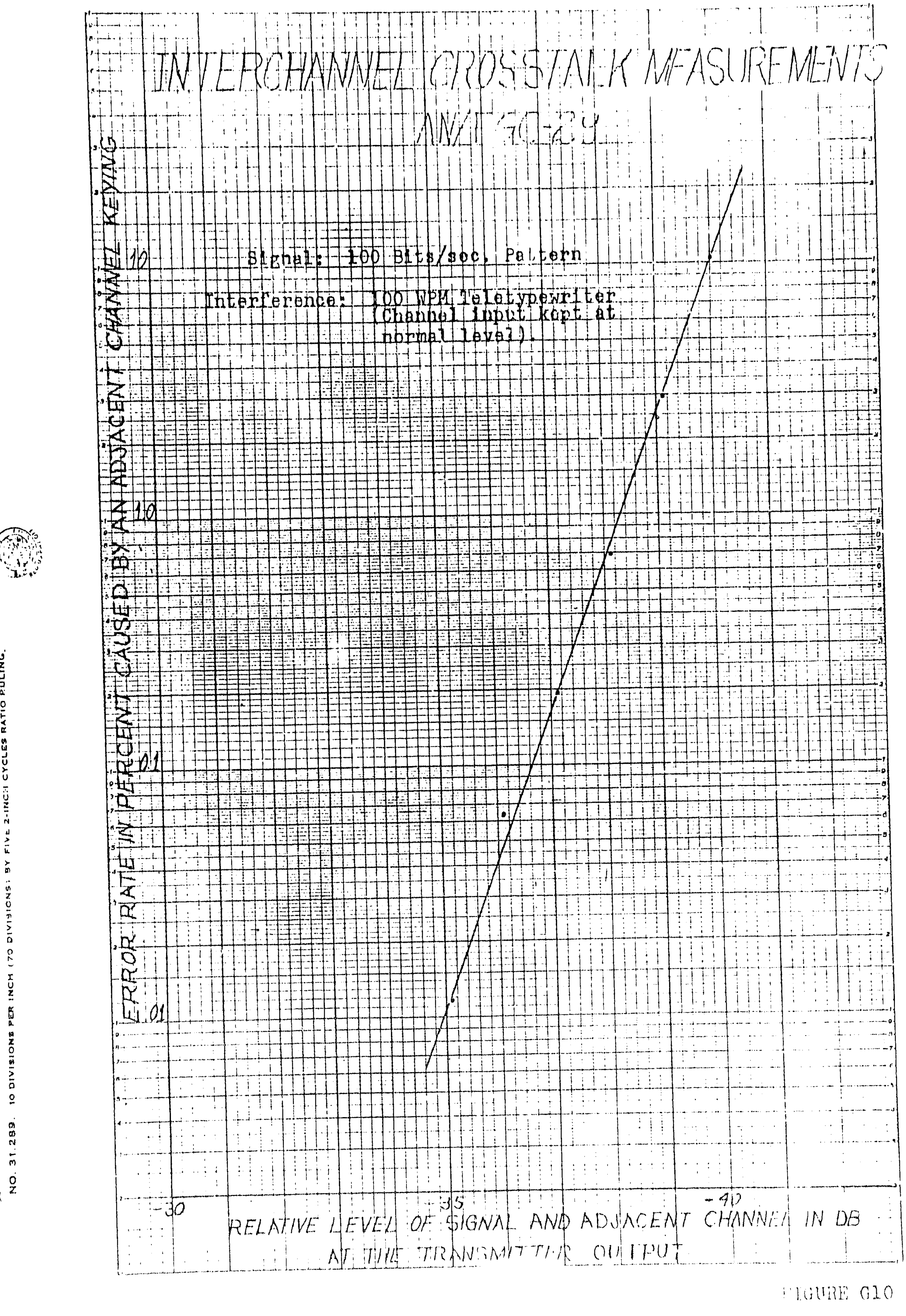
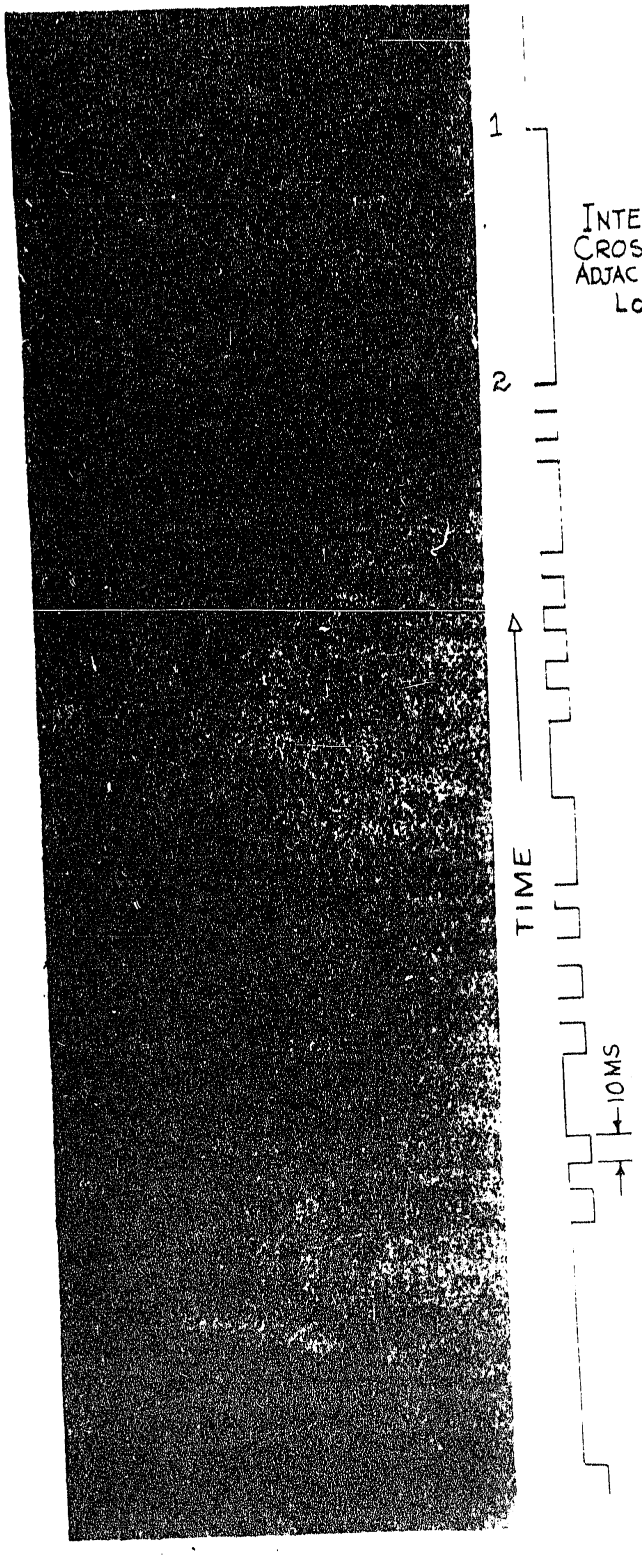

INTERCHANNEL CROSSTALK MEASUREMENTS
AN/FGC-29
Signal: 100 Bits/sec. Pattern
Interference: 100 WPM Teletypewriter (Channel input kept at normal level).
ERROR RATE IN PERCENT CAUSED BY AN ADJACENT CHANNEL KEYING
10
1.0
0.1
.01
-30
-35
-40
RELATIVE LEVEL OF SIGNAL AND ADJACENT CHANNEL IN DB AT THE TRANSMITTER OUTPUT
NO. 31,289. 10 DIVISIONS PER INCH (70 DIVISIONS) BY FIVE 2-INCH CYCLES RATIO RULING.

FIGURE G10



INTERCHANNEL CROSSTALK FROM ADJACENT CHANNEL LOCAL TEST

FIGURE G11

9-1266

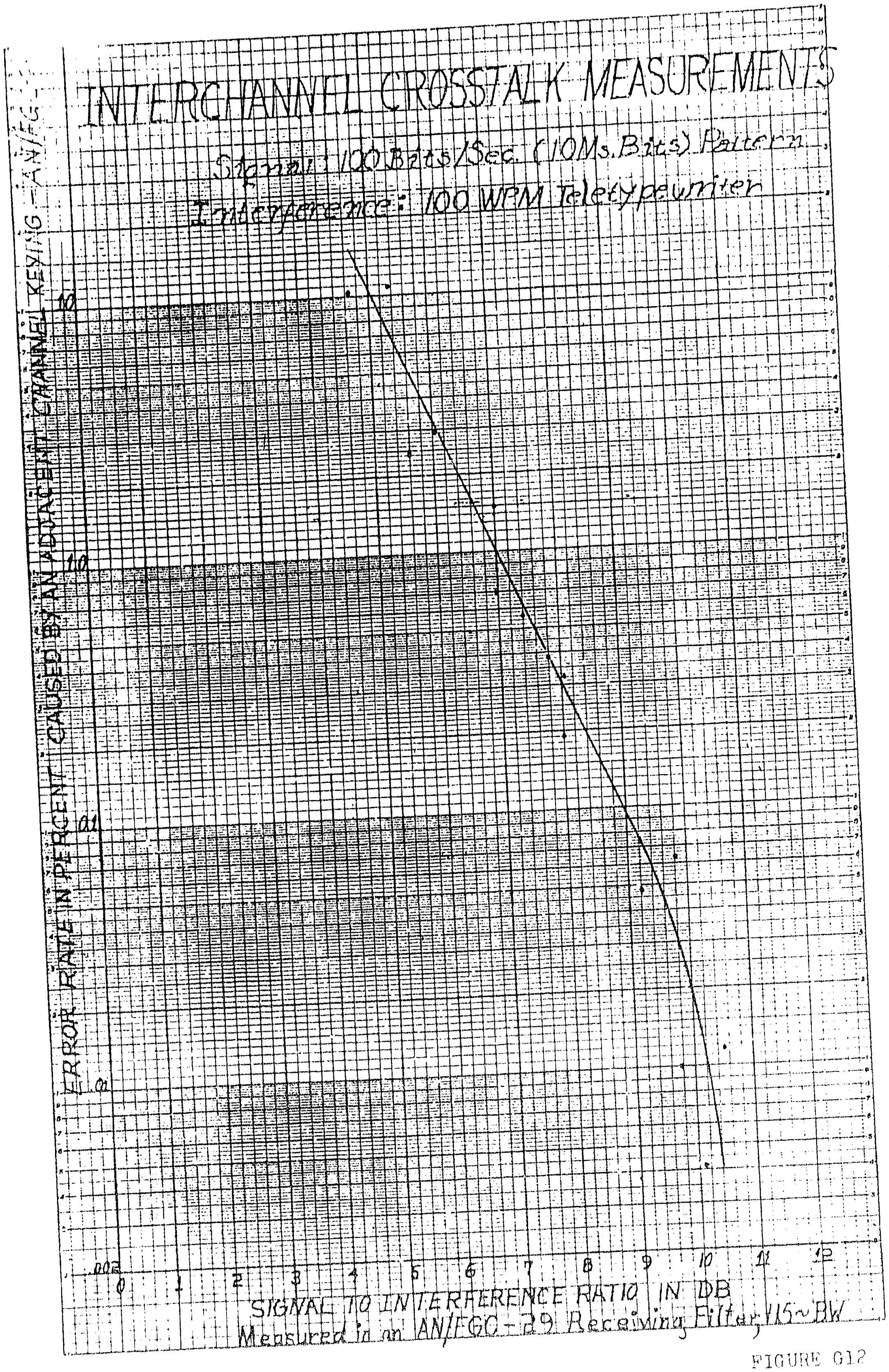
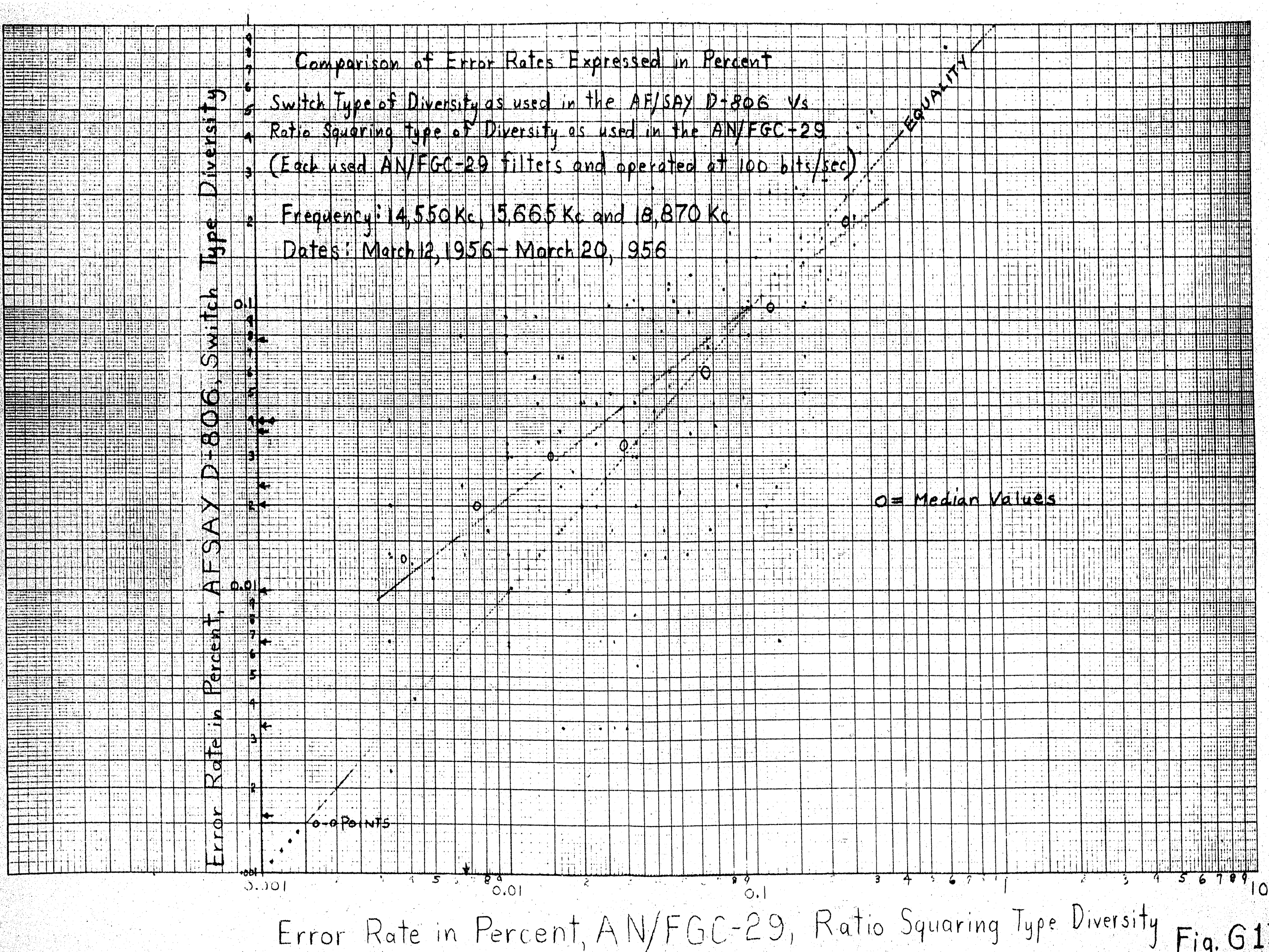

INTERCHANNEL CROSSTALK MEASUREMENTS
Signal: 100 Bits/Sec. (10Ms. Bits) Pattern
Interference: 100 WPM Teletypewriter
ERROR RATE IN PERCENT CAUSED BY AN ADJACENT CHANNEL KEYING - AN/FG
10
1.0
.1
.01
.002
0
1
2
3
4
5
6
7
8
9
10
11
12
SIGNAL TO INTERFERENCE RATIO IN DB
Measured in an AN/FGQ-29 Receiving Filter, 115~BW

FIGURE G12



Comparison of Error Rates Expressed in Percent

Switch Type of Diversity as used in the AF/SAY D-806 Vs Ratio Squaring type of Diversity as used in the AN/FGC-29 (Each used AN/FGC-29 filters and operated at 100 bits/sec)

Frequency: 14,550 Kc, 15,665 Kc and 18,870 Kc

Dates: March 12, 1956 - March 20, 1956

Fig. G13

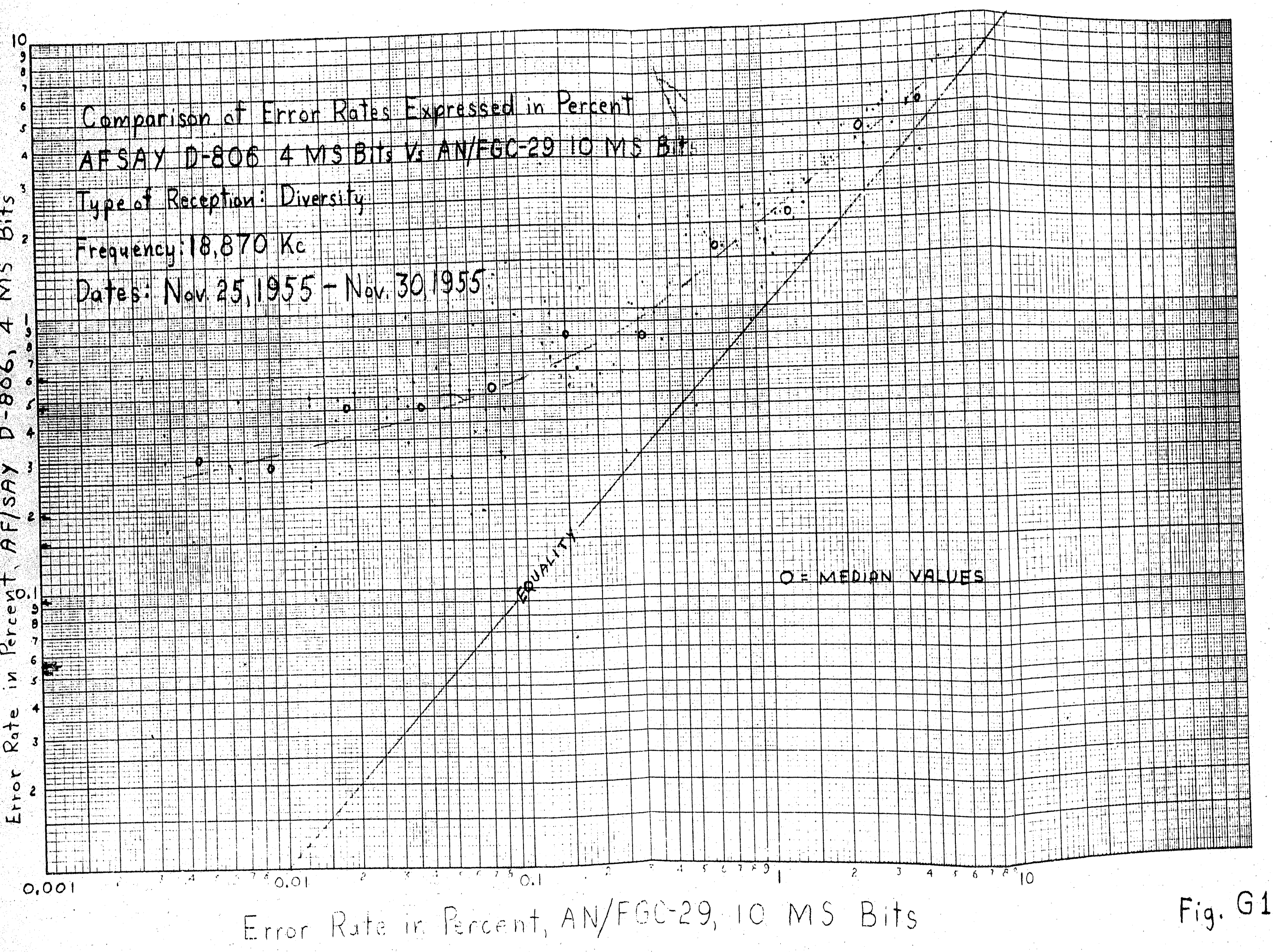
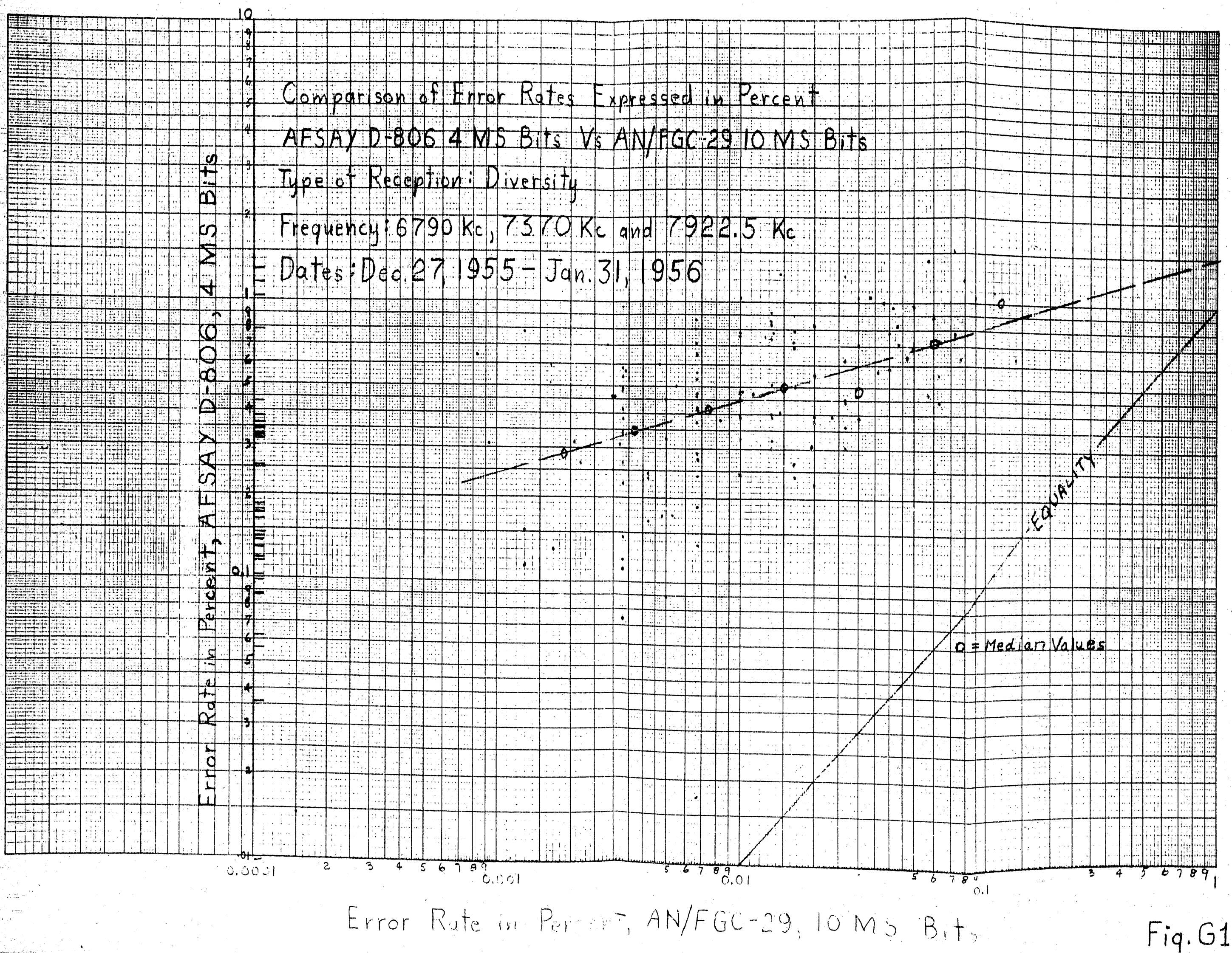

Comparison of Error Rates Expressed in Percent
AFSAY D-806 4 MS Bits Vs AN/FGC-29 10 MS Bits
Type of Reception: Diversity
Frequency: 18,870 Kc
Dates: Nov. 25, 1955 - Nov. 30, 1955
EQUALITY
O = MEDIAN VALUES
Error Rate in Percent, AF/SAY D-806, 4 MS Bits
Error Rate in Percent, AN/FGC-29, 10 MS Bits
0.001
0.01
0.1
1
10

Fig. G14



Comparison of Error Rates Expressed in Percent

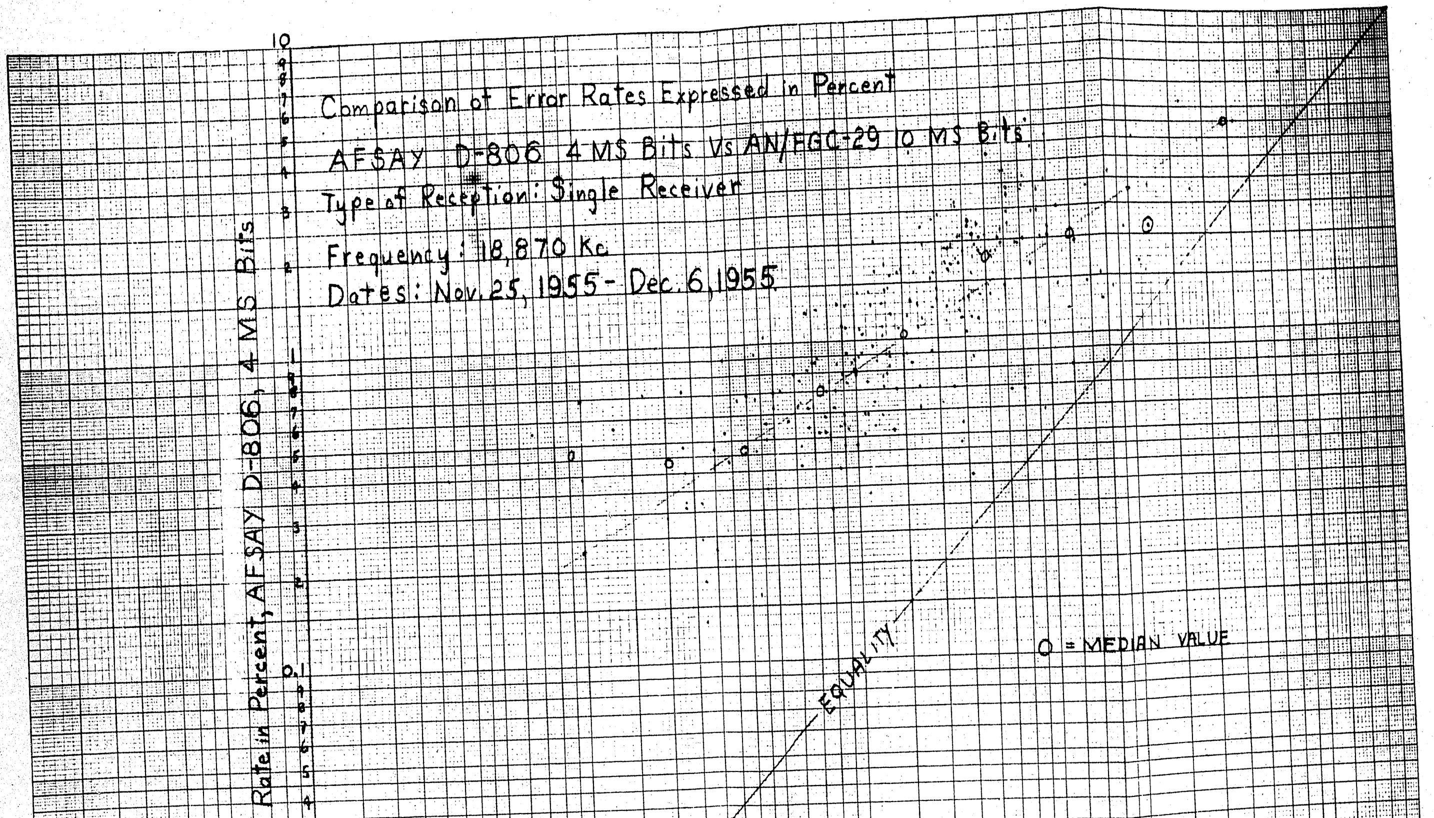
AFSAY D-806 4 MS Bits Vs AN/FGC-29 10 MS Bits

Type of Reception: Diversity

Frequency: 6790 Kc, 7370 Kc and 7922.5 Kc

Dates: Dec. 27, 1955 - Jan. 31, 1956

Fig. G15



Comparison of Error Rates Expressed in Percent

AFSAY D-806 4 MS Bits Vs AN/FGC-29 10 MS Bits

Type of Reception: Single Receiver

Frequency: 18,870 Kc

Dates: Nov. 25, 1955 - Dec. 6, 1955

Fig. G16

COMPARISON OF ERROR RATES EXPRESSED IN PERCENT

AFSAY D-806 With 4 MS Bits VS AN/FGC-29 With 10 MS Bits

Type of Reception: Single Receiver

Frequency: 6790 kc Dates: 12/22/55 - 12/23/55

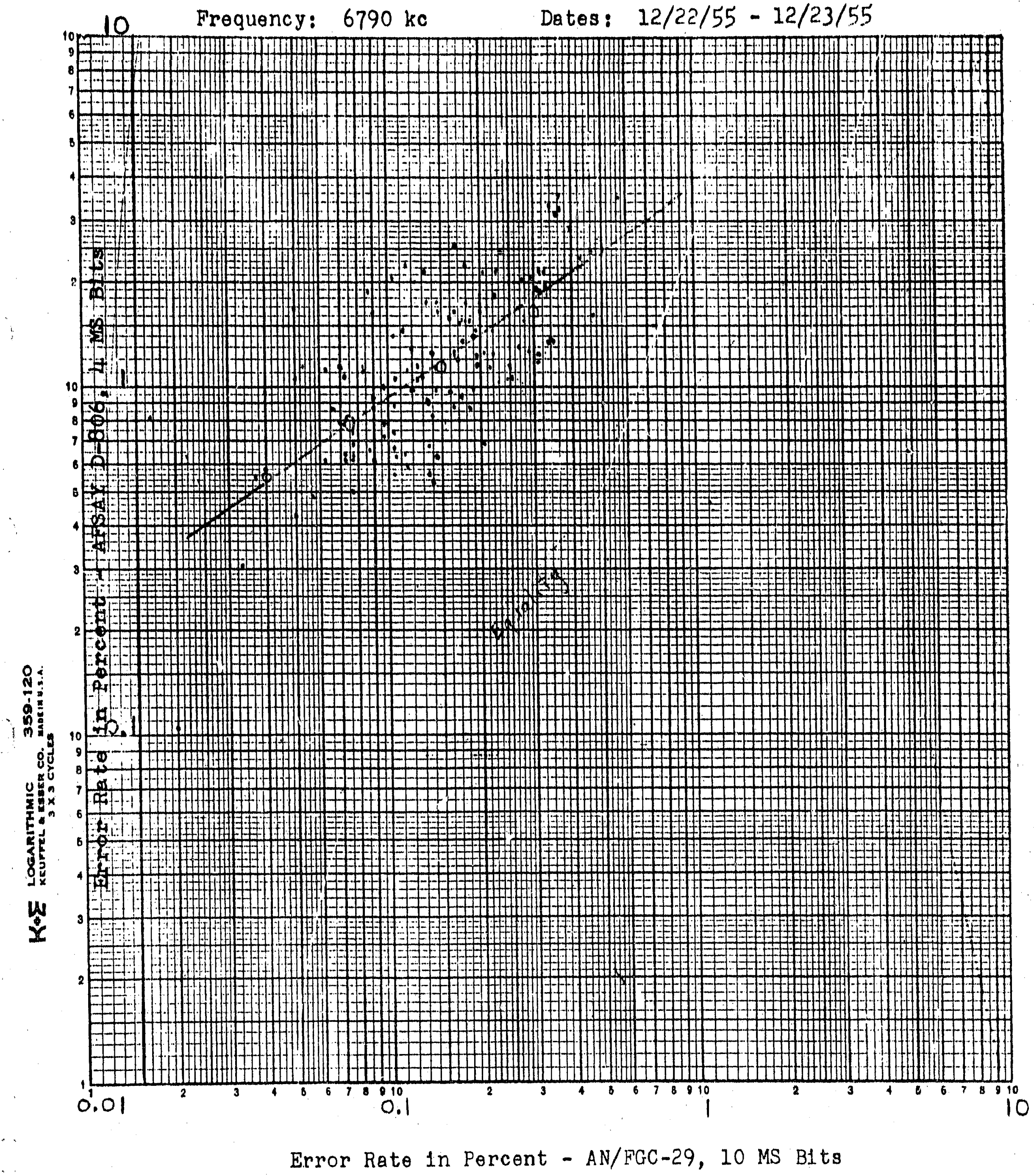


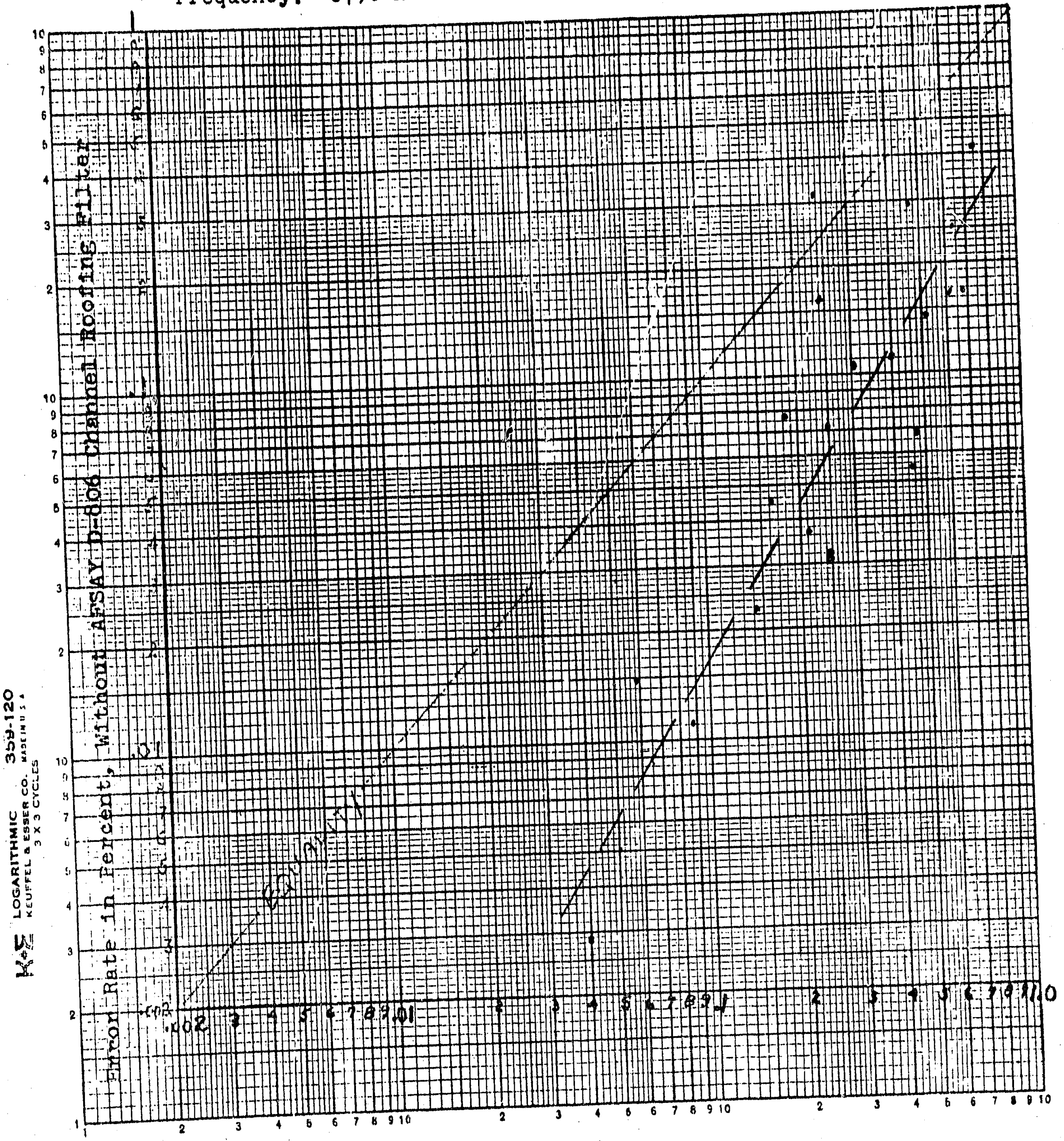
Fig. G17

AFSAY D-806 DEGRADATION DUE TO 300 CPS CHANNEL ROOFING FILTER

Comparison of Error Rates Without Filter VS With Filter

Keying Speed: 250 Bits/sec.

Frequency: 6790 kc Dates: 12/28/55 - 12/30/55



Error Rate in Percent, With AFSAY D-806 Channel Roofing Filter

Fig. G18

COMPARISON OF ERROR RATES IN PERCENT AN/FGC-29, 14 MS BITS VS SIGNAL-TO-NOISE RATIO IN DB

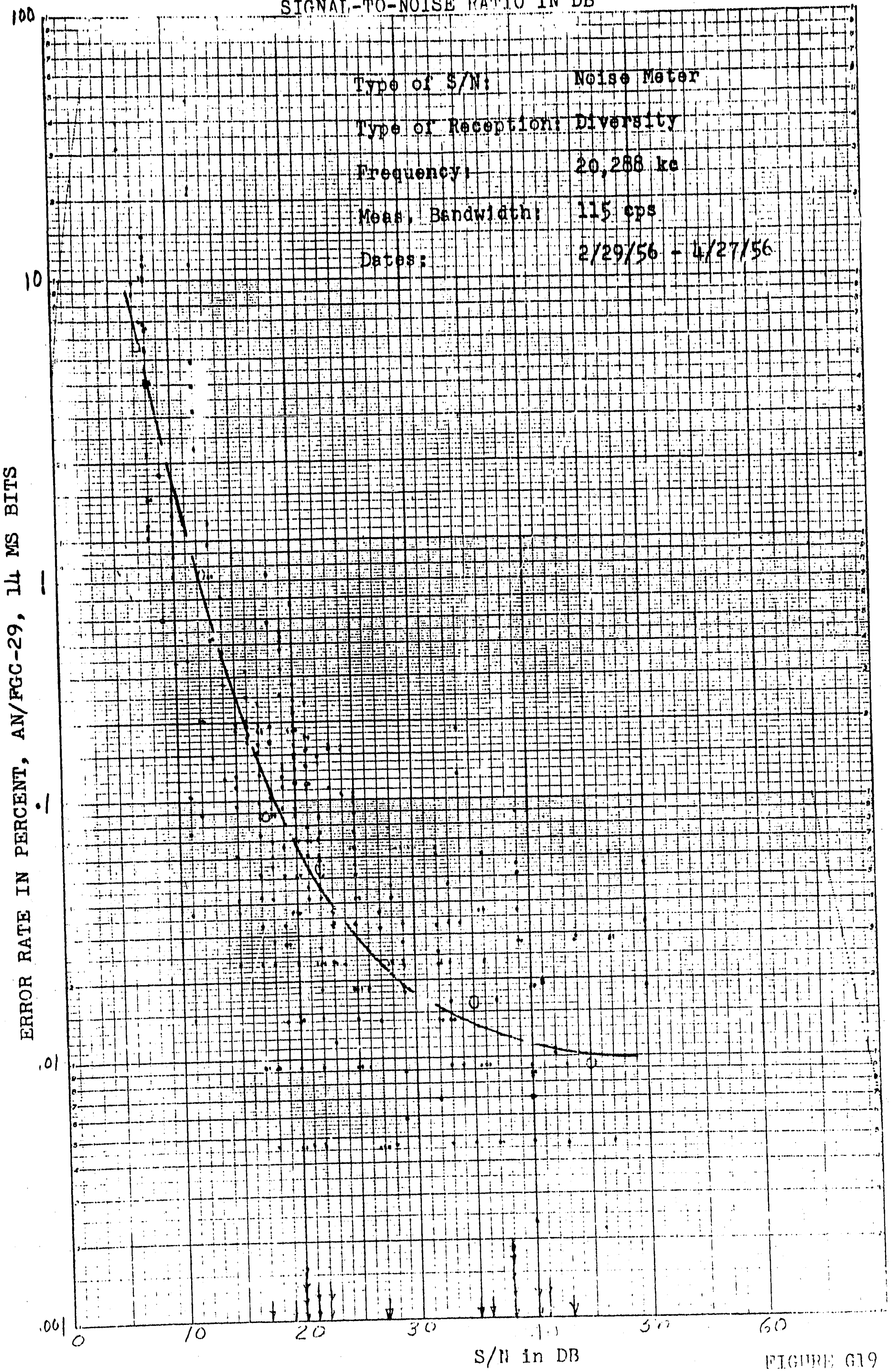

Type of S/N: Noise Meter
Type of Reception: Diversity
Frequency: 20,288 kc
Meas. Bandwidth: 115 cps
Dates: 2/29/56 - 4/27/56

FIGURE G19

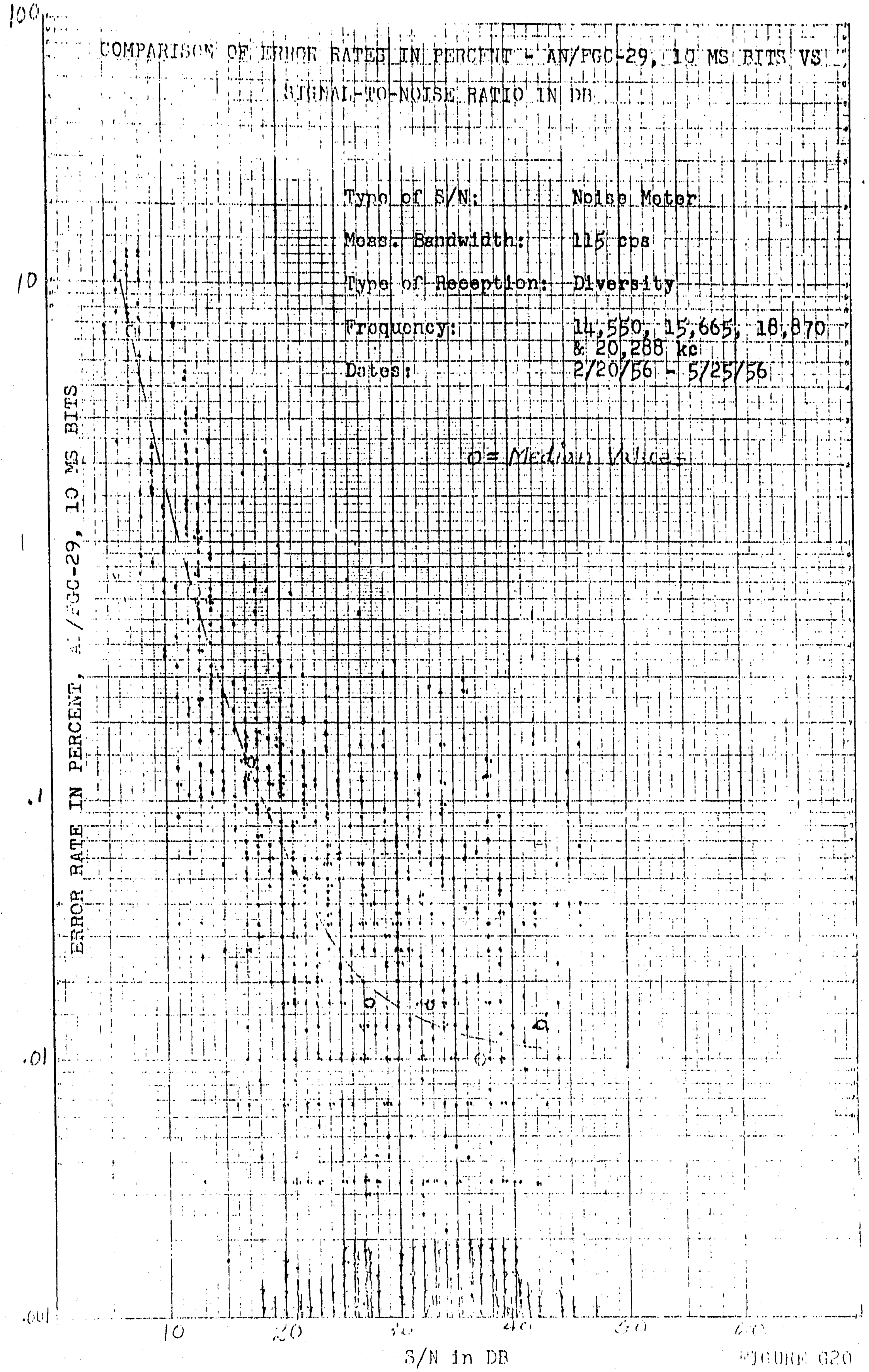
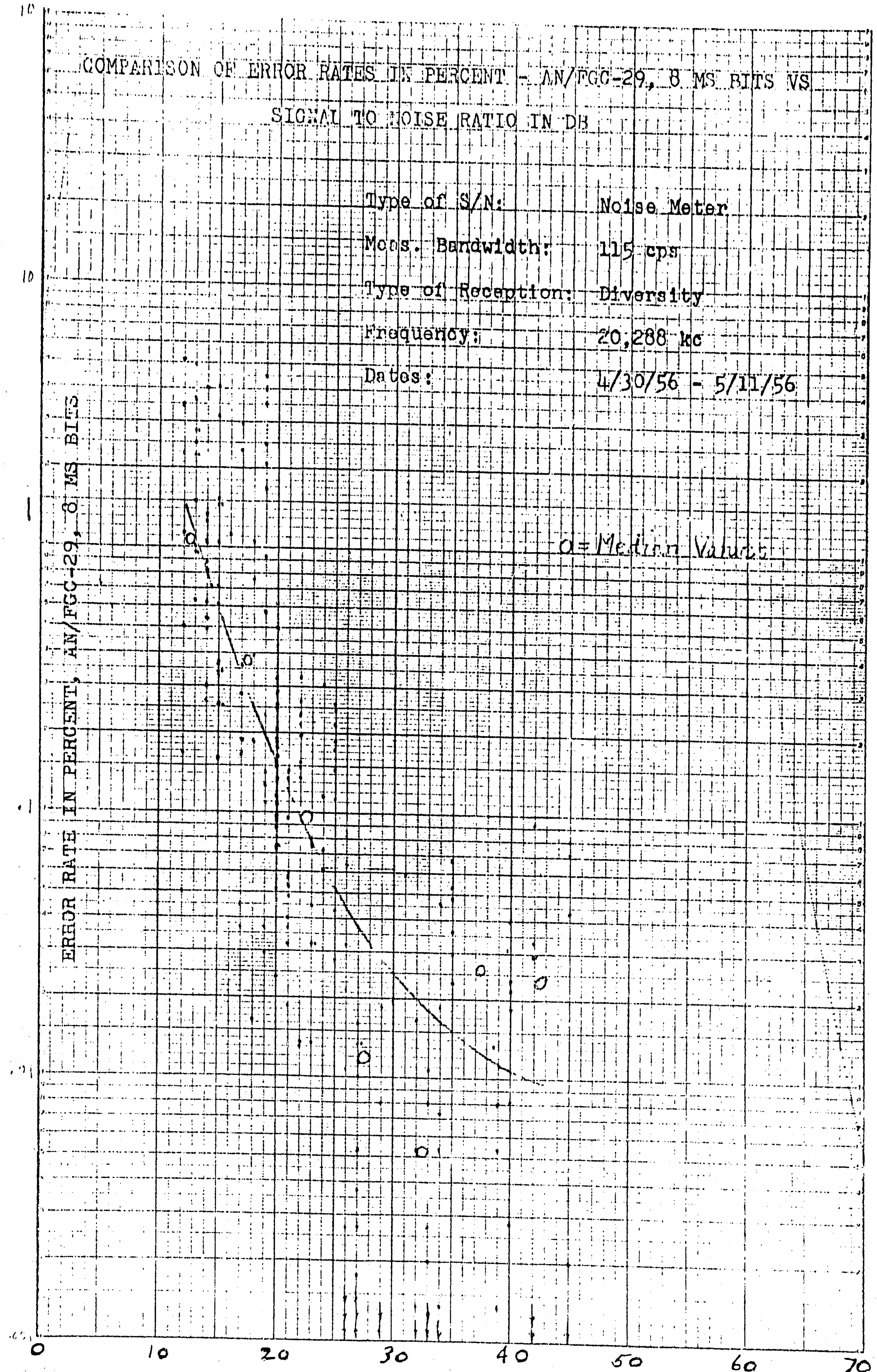

COMPARISON OF ERROR RATES IN PERCENT - AN/FGC-29, 10 MS BITS VS SIGNAL-TO-NOISE RATIO IN DB

FIGURE G20


COMPARISON OF ERROR RATES IN PERCENT - AN/FGC-29, 8 MS BITS VS SIGNAL TO NOISE RATIO IN DB

Type of S/N: Noise Meter
Meas. Bandwidth: 115 cps
Type of Reception: Diversity
Frequency: 20,288 kc
Dates: 4/30/56 - 5/11/56

o = Median Value

FIGURE G21

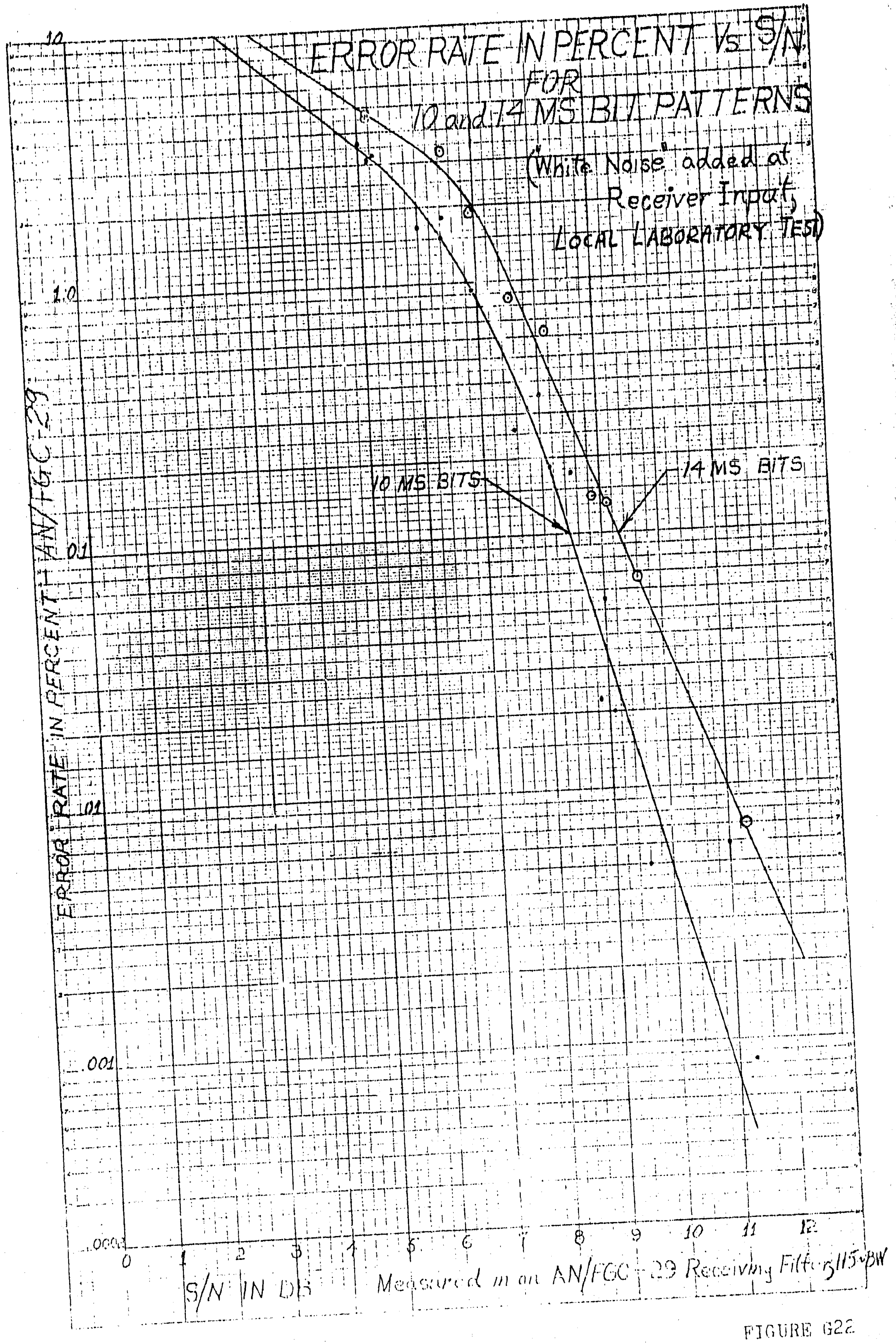
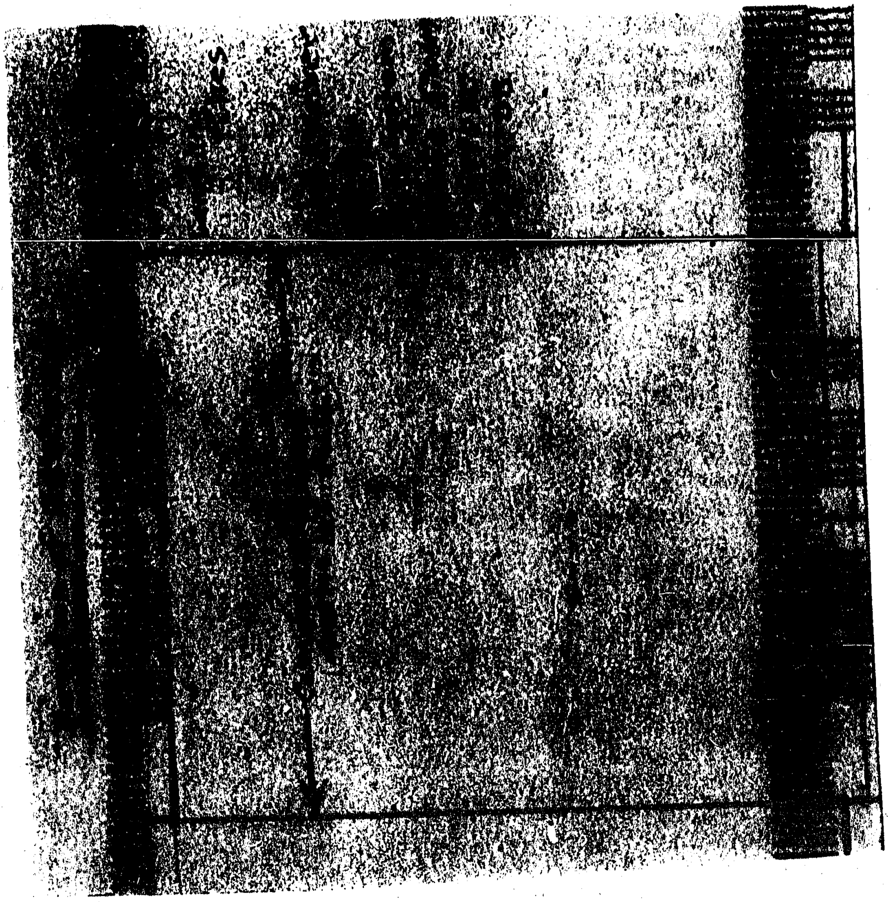
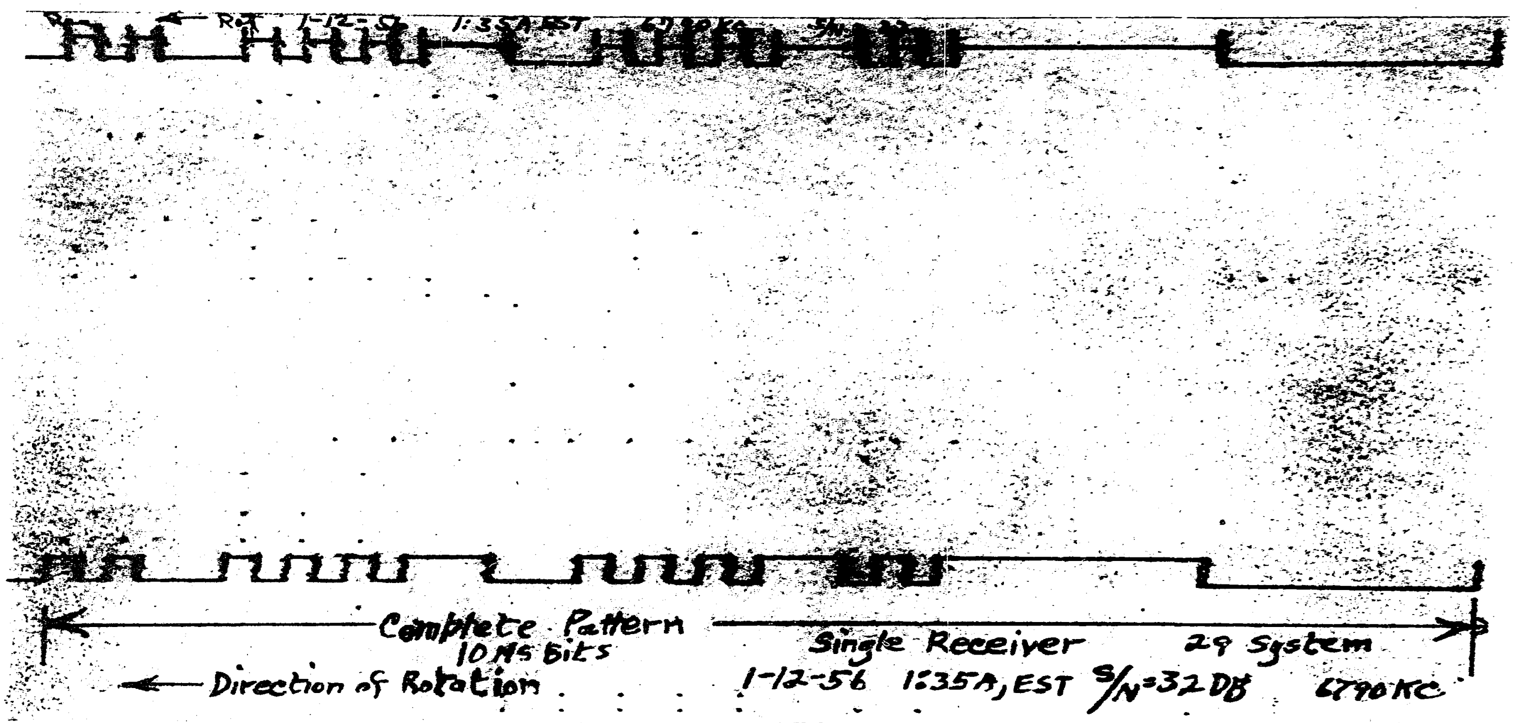

ERROR RATE IN PERCENT Vs S/N
FOR
10 and 14 MS BIT PATTERNS
(White Noise added at
Receiver Input,
LOCAL LABORATORY TEST)
10 MS BITS
14 MS BITS
ERROR RATE IN PERCENT - AN/FGC-29
10
1.0
0.1
.01
.001
.0001
0
1
2
3
4
5
6
7
8
9
10
11
12
S/N IN DB
Measured in an AN/FGC-29 Receiving Filters 115~BW

FIGURE G22



9-1267

FIGURE G23


← R.T. 1-12-5 1:35A EST 6790 KC S/N
Complete Pattern
10 MS Bits
Single Receiver
29 System
← Direction of Rotation
1-12-56 1:35A, EST S/N=32DB 6790KC

9-1268

Section H

RELATION OF SHORT PATTERN ERRORS AND TELETYPEWRITER CHARACTER ERRORS THROUGH AN AN/FGC-29 CHANNEL

It is expected that in the operation of many major military intercontinental radio circuits the AN/FGC-29 equipment will be used to provide 16 channels of 100-wpm teletypewriter. Since a large amount of teletypewriter performance data may thus be accummulated, it is of interest to establish the relationship between error rates obtained with the short pattern test signal and the character error rates obtained with a 100-wpm teletypewriter signal. This relationship will permit an estimate of the AN/FGC-29 performance over these military circuits using synchronous transmission at keying rates of 71.42, 100, 104.17 and 125 bits per second. Conversely, by knowing the performance of the AN/FGC-29 over a radio circuit using a short pattern test signal, an estimate of teletypewriter transmission may be made.

Two adjacent channels (1 and 3) of the AN/FGC-29 were set up, one keyed with a 14 ms short pattern and the other with a 100-wpm teletypewriter (TTY) tape. The short pattern consisted of 1, 3, and 9 unit length elements in various combinations, the shortest element being 14 ms long. The signal pattern used in these tests is presented in Figure H1.

The signalling code used to transmit the start-stop TTY intelligence consisted of seven elements. Five of these, in various marking and spacing combinations, specified the required letter or function. A start and stop impulse performed the function of synchronizing the TTY receiver with the transmitter. All the keying elements were of 13.2 milliseconds (ms) in length with the exception of the 18.6 ms stop pulse.

For convenience, a special TTY tape was used for transmission, details of which are outlined in Section E. The "R" and "Y" bars on the TTY receiving machines were removed, and when receiving the tape under perfect conditions, two columns of printing were produced. Along the left-hand margin there was a line of "O"s and through the center a line of "I"s with the exception that every tenth line a "W" was substituted for an "I". Most TTY character and function errors could thus be quickly identified. Transpositions of "R" and "Y" could not be detected, but it was felt that this method produced results as accurate as the occasional oversight of an error in a solid block of "RY" copy of a "Quick brown fox---" message.

The general procedure was to send the short pattern signal and the TTY signal simultaneously on the two adjacent AN/FGC-29 channels. At the receiving terminal, the 14 ms short pattern was sampled and compared with a locally generated 14 ms short pattern in phase synchronism, differences between them being recorded as errors on a time interval counter. The teletypewriter information was directly recorded on two TTY receiving machines operating in parallel. One of the TTY machines provided a check on the operation of the other, so that errors in received copy could be attributed to other sources. On a half-hourly basis the inputs to the transmit channels were reversed. This tended to equalize the effects of QRM, noise and equipment adjustment differences between the channels.

The data were taken in blocks of five minutes, which meant that a total of 21,430 bits of the short pattern and 3,000 characters of TTY were transmitted and examined during this period. (TTY characters refers to both letter and operational functions.) Simultaneous error counts in both AN/FGC-29 channels were converted to error rates expressed in percent.

Figures H2 and H3 are mass plots of percent 100 wpm TTY character errors versus percent short pattern 14 ms bit errors. Both figures are for single sideband, channel diversity reception. Figure H2 represents operation on 15,665 and 18,870 kc while Figure H3 is for 6790, 7370 and 7922.5 kc. Dotted curves representing median values are indicated on each plot. For Figure H2 in the region of 0.5 to 0.05% 14 ms bit errors, there are about 7 times more % TTY character errors. Between .05 and .005% 14 ms bit errors, this ratio increases to about 20 to 1. In Figure H3 there is an insufficiency of data in the region of 0.5 to 0.05% bit errors, but the trend is toward higher % TTY character errors as compared to the % short pattern bit errors. Between 0.05 and 0.005% bit errors the ratio between the systems increases from 4 to 1 to about 18 to 1. This trend corresponds to the results obtained from Figure H2, the difference in the 0.05% bit error ratios being probably due to an insufficiency of data in Figure H3.

There are several possible explanations for the differences in the percent errors of these systems. In every TTY character there are seven elements. A failure in one element causes at least one TTY character error. Therefore, if a single static crash causes a single bit error and a single TTY element or character error, there will be a 7:1 relationship between the percent error rates, TTY characters vs short pattern bits. If however, sufficient noise energy were to last over a period of a single TTY character, its seven elements would be mutilated as well as the 7 corresponding short pattern bits. The ratio between the percent errors would drop toward two.

Another consideration is what happens when the start or stop TTY synchronizing pulses are incorrectly received. A single error in one of these pulses can cause the teletypewriter to print several successive character errors, raising the ratio between the short pattern percent errors and TTY percent errors by factors of 2 or 3, for instance.

Another teletypewriter evaluation through the AN/FGC-29 channeling system was performed using "diplex" keying. "Diplex" refers to a synchronous transmission system in which two 60 wpm TTY codes are interleaved in time division. The resulting information had a bit rate of 78.6 bits per second (11.66 ms bits).

Multiplex transmitting terminal equipment was provided by RCA Communications at their Honolulu Central Office and its aggregate keying through interconnecting line facilities to the Kahuku transmitting test site. Here the diplex keying was used to key one channel of the AN/FGC-29. For comparison purposes, an adjacent AN/FGC-29 channel was actuated by a short pattern using 10 ms bits.

The signals were received at Riverhead, using diversity reception in each channel. Errors in the 10 ms bit short pattern were determined by comparison with a locally generated 10 ms pattern, while the diplex signal was taken through a demuxing unit and thence into 60 wpm TTY printers where the printed copy could be visually evaluated[1]. Special TTY tapes of the type indicated above were also used in these tests. TTY errors were only counted on one printer. The input to the AN/FGC-29 transmit channels were interchanged half hourly to equalize the effects of noise and QRM.

The data were examined for 5-minute intervals during which time 30,000 short pattern bits and 3600 TTY characters were transmitted. Since two 60 wpm TTY codes are interleaved in time, 1800 TTY characters are received per printer for the 5-minute period.

The tests consisted of simultaneous measurements of the short pattern errors and single channel TTY character errors. Both types of errors expressed in percent were plotted. Such a mass plot is given in Figure H4. A dotted line representing a median curve is also included in Figure H4. Data for short pattern error rates less than .02% and greater than 0.2% are too scattered to determine an accurate ratio between the systems. However, it appears that there are considerably more TTY % character errors than short pattern errors. In the intervening region (.02% to 0.2%) single channel TTY produces from about 5 to 17 times more percent character errors than short pattern percent errors.

Some of the difference between the two systems can be explained if it is presumed that the errors are caused by individual static crashes, a single crash causing a single element failure.

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[1] Recent Developments in Electronic Time Division Multiplex, E. R. Shenk, RCA Laboratories Memorandum EM-63-62

A single element failure in the TTY code causes at least one character failure. Since there are two TTY characters received (one for each of the machines) for each 163 ms, on the average a single static crash will cause a failure in one of the TTY machines only 50% of the time. Therefore, the ratio between the single TTY machine character error rate and the 10 ms bit pattern error rate should be about 8 to 1.

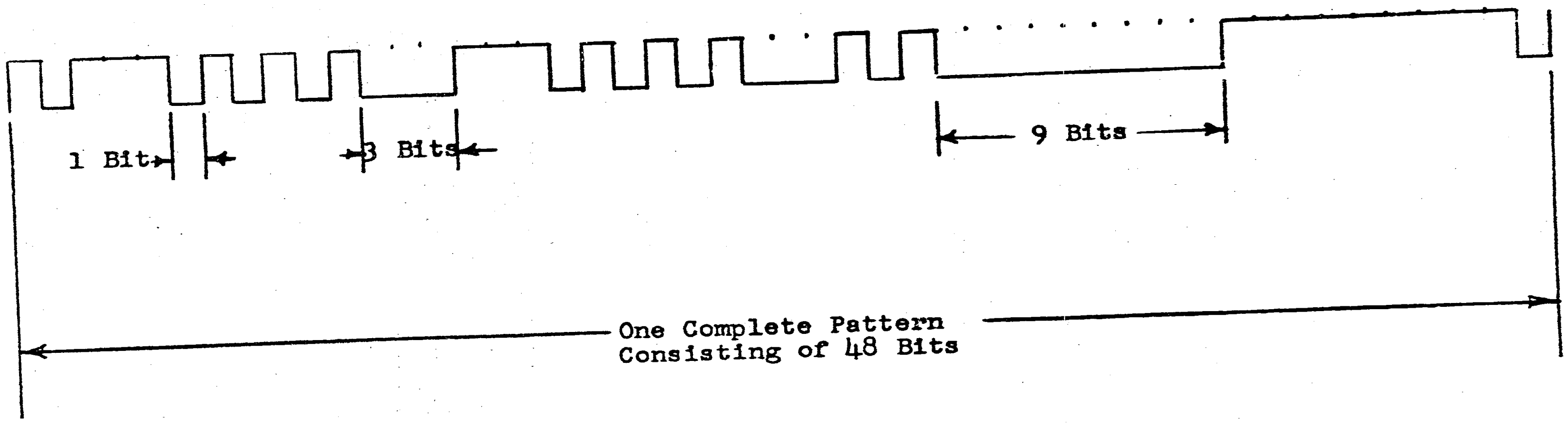
The failure of a synchronizing pulse produces an ambiguity in the number of TTY character errors as noted previously. The result of these failures is to increase the percent TTY error rates by factors of 2, 3, etc. depending upon the number of incorrect characters printed until synchronism is regained. It was observed that the 100 wpm printers tended to produce more character errors due to synchronizing troubles than the 60 wpm printers.

Conclusions

1. Relation of 14 ms short pattern bit errors and 100 wpm teletypewriter character errors as measured through an AN/FGC-29 channel:
    a. Where there are 0.5 to 0.05% 14 ms short pattern errors produced it can be expected that 100 wpm teletypewriter will produce about 7 times more percent character errors.
    b. In the region between 0.05 and 0.005% 14 ms short pattern errors, the ratio between the two systems increases to about 20 to 1.

2. Relation of 10 ms short pattern bit errors and character errors in one channel of a 60 wpm teletypewriter diplex system as measured through an AN/FGC-29 channel:

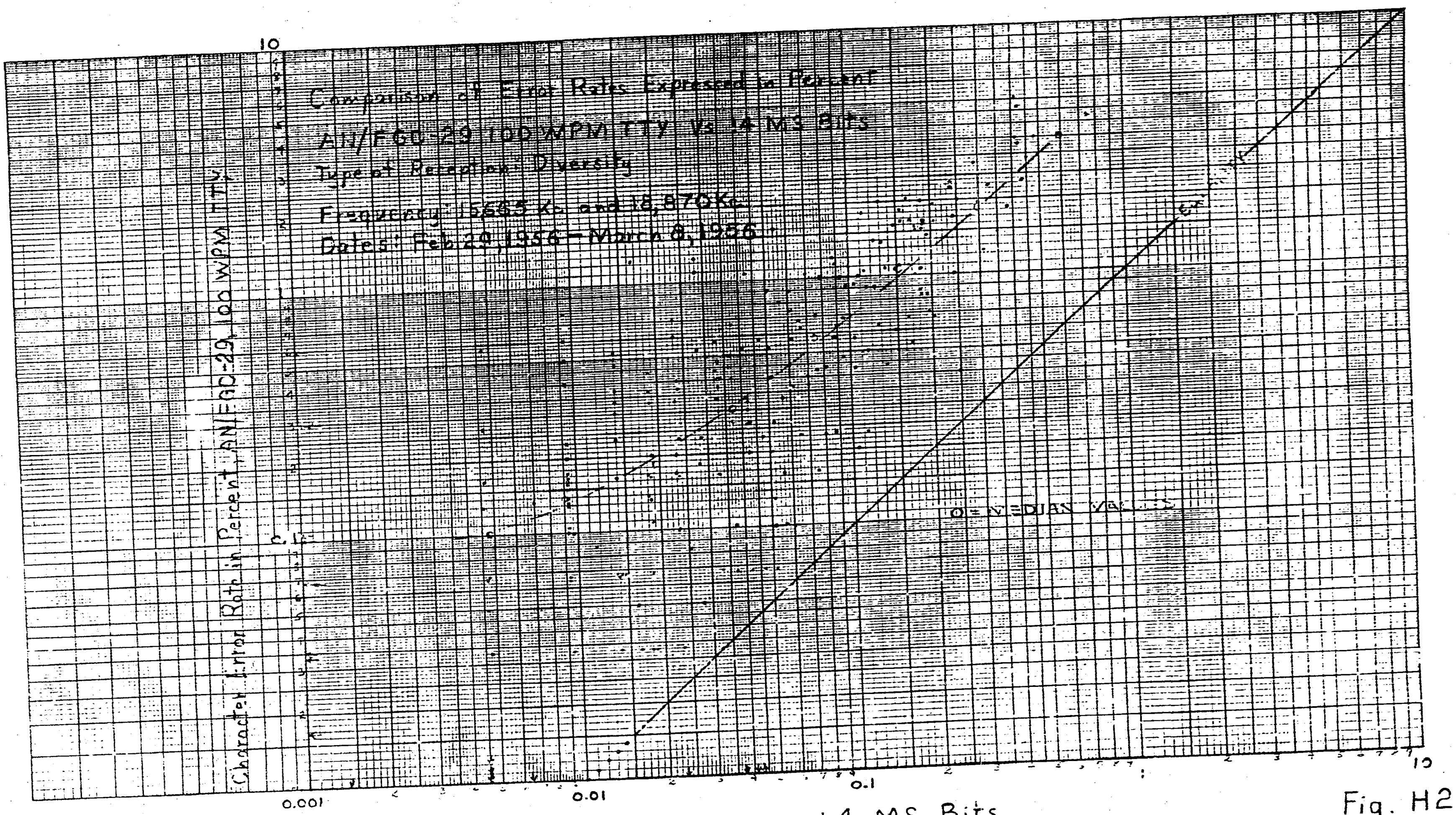
There were about from 5 to 17 times more percent teletypewriter character errors produced in the range of 0.2 to 0.02% 10 ms short pattern bit errors.



DRAWING OF SHORT PATTERN

AS USED IN KAHUKU-RIVERHEAD TESTS

FIGURE H1



Comparison of Error Rates Expressed in Percent
AN/FGC-29 100 WPM TTY Vs 14 MS Bits
Type of Reception: Diversity
Frequency: 15665 Kc and 18,870Kc
Dates: Feb 29, 1956 – March 8, 1956

Error Rate in Percent, AN/FGC-29, 14 MS Bits

Fig. H2

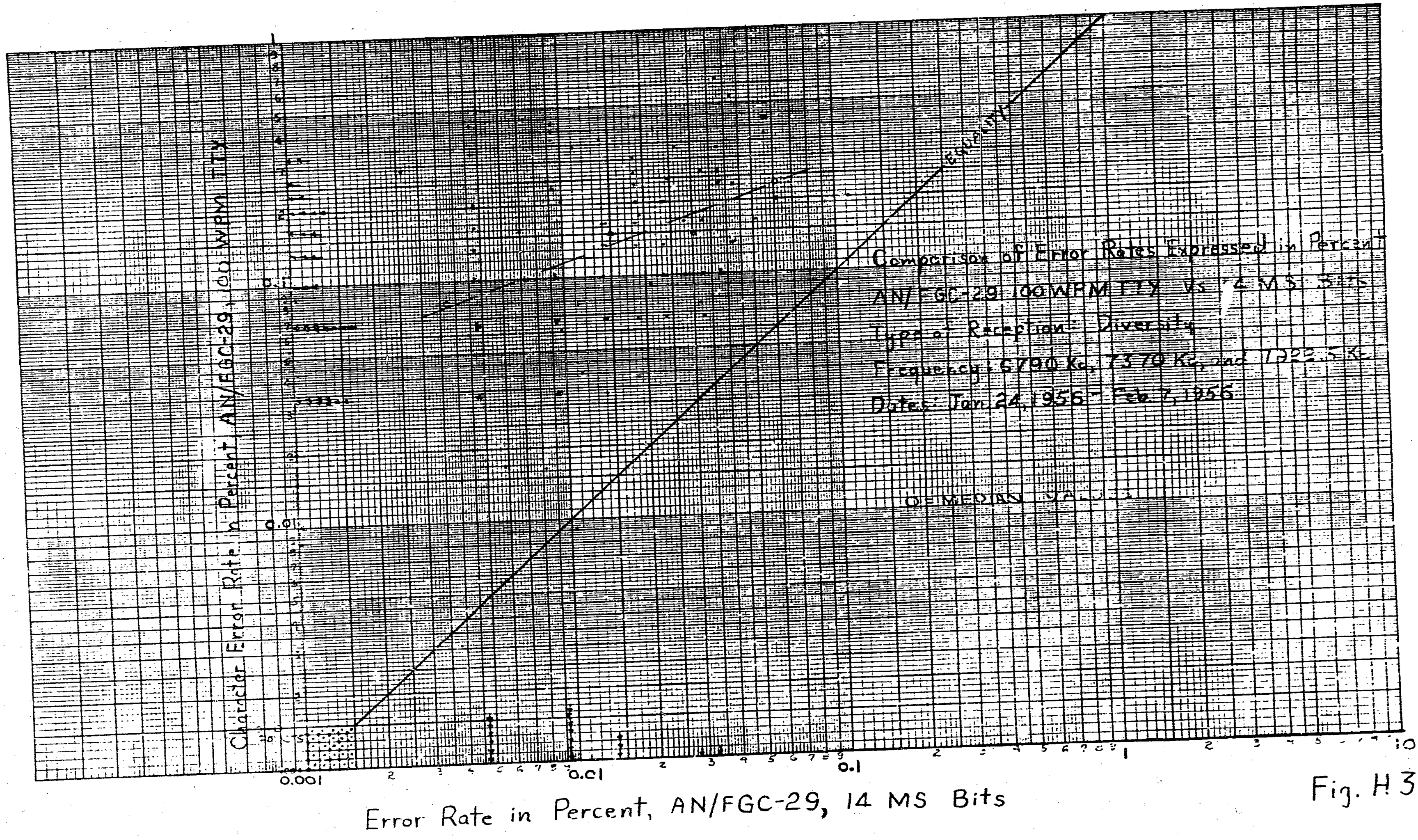

Comparison of Error Rates Expressed in Percent
AN/FGC-29 100 WPM TTY Vs 14 MS Bits
Type of Reception: Diversity
Frequency: 6790 Kc, 7370 Kc, and 7322.5 Kc
Dates: Jan. 24, 1956 - Feb. 7, 1956
O = MEDIAN VALUE
Equality
Character Error Rate in Percent, AN/FGC-29, 100 WPM TTY
Error Rate in Percent, AN/FGC-29, 14 MS Bits
0.001
0.01
0.1
1
10

Fig. H3

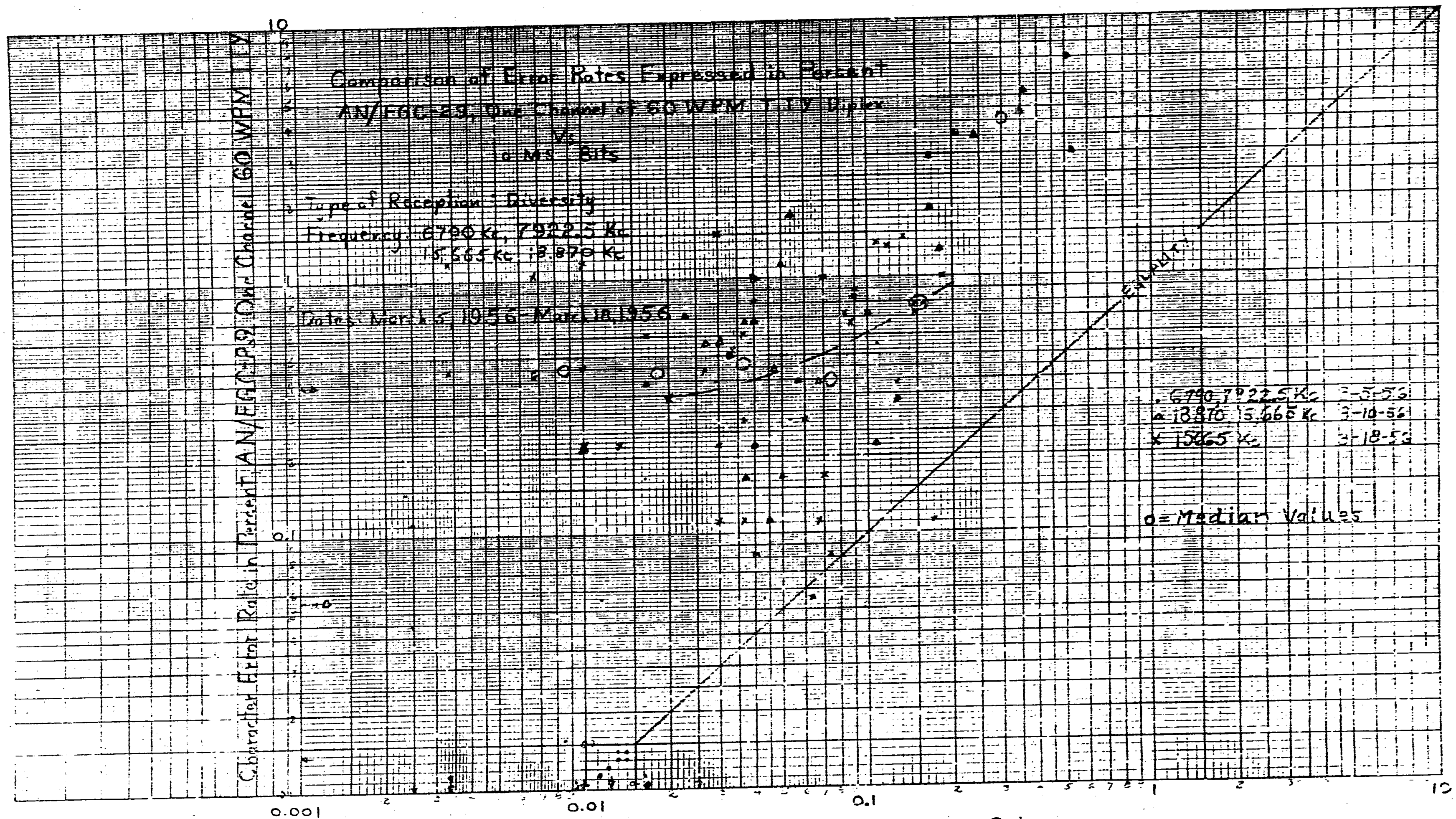

Comparison of Error Rates Expressed in Percent
AN/FGC-29, One Channel of 60 WPM TTY Duplex
Vs
10 MS Bits
Type of Reception: Diversity
Frequency: 6790 Kc, 7922.5 Kc
15,565 Kc, 13,870 Kc
Dates: March 5, 1956 - March 18, 1956
. 6790, 7922.5 Kc 3-5-56
▲ 13870 15,565 Kc 3-10-56
x 15565 Kc 3-18-56
o = Median Values
Equal
Character Error Rate in Percent AN/FGC-P59 One Channel 60 WPM TTY
Error Rate in Percent, AN/FGC-29, 10 MS Bits
10
0.1
0.001
0.01
1
10

Fig. H 4

Section I

MULTIPATH JITTER AND ITS RELATION TO THE AN/FGC-29 AND 806 CHANNELING SYSTEM

Introduction

Most high frequency radio circuits are subject to multipath propagation. That is, the received signal is a resultant of a number of components arriving via several different paths. This means that the component travelling the shortest path arrives first followed in succession by components arriving over progressively longer distances. These paths may differ in length by several hundred miles, resulting in differences of arrival times from less than one to several milliseconds. Therefore, when this condition is present the position of a keying element transition may be indeterminate within certain limitations. For instance if a frequency shifted signal is transmitted over a typical long distance high frequency radio circuit, the instant of transition from one frequency to the other may overlap, subjecting the receiving equipment to both frequencies at the same time. The time of transition will depend upon which frequency happens to be the strongest at the moment. This timing variation in the position of the transition has been called "Multipath Jitter" and its peak-to-peak amplitude expressed in milliseconds used as means for its evaluation.

In order to evaluate radio circuit jitter the keying element transitions are differentiated and imposed upon facsimile recording equipment. The speed of the recorder is made commensurate with the received pattern so that a straight line of dots is produced on the paper for each type of transition (mark-to-space and space-to-mark). By measuring the distance and the number of dots that depart from a straight line, a measure of the peak-to-peak jitter is obtained.

Description of Jitter Recording Equipment

Two kinds of facsimile instruments were used to measure multipath jitter. These were the high speed RCA experimental machine and a standard Army TT-1E/TXC-1 facsimile machine.

The RCA facsimile machine provided copy on a continuous roll of 8-1/2" wide paper fed at a rate of 10-7/16" per minute[1]. A single helix wound on a rotating drum produced the effect of a stylus moving across the paper. The helix pressed the paper against a bar which was parallel to the drum axis. A single rotation of the drum caused the helix to traverse the full 8-1/2" width of the paper. The paper was treated with chemicals prior to its entrance between the helix and bar. The passage of current from the bar to the helix turned the paper brown. If a group of pulses of the proper frequency were applied, a series of dots would appear on the paper forming one or more straight lines parallel to its long dimension. The color of the dots was fixed by passing the paper through ultraviolet light until it was dry.

For these tests the speed of the rotating drum was made commensurate with a 25 and 50 cps pulse repetition rate for which at least two lines of dots were produced lengthwise on the paper.

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[1] Final Report Contract DA49-170-sc-1131 (53-NSA/PR-2276-2006 NSA-53) Pages L3 and L4

Both the motor which drove the drum and equipment which generated the 25 and 50 cps reversals were referred back to a high precision standard frequency, so that the line of dots would not noticeably skew during the period of recording. Figures I1 and I2 are typical samples of the type of recordings obtained when using the AFSAY D-806 and AN/FGC-29 channeling systems for the transmission of 50 cps reversals. The radio circuit multipath is indicated by the deviation of the dots from a straight line.

The U. S. Army facsimile test TT-1E/TXC-1 is an electro-mechanical device which uses a revolving drum, photocell, and stylus arrangement to provide both transmission and reception of a single 12 by 18 inch page of copy[2]. The drum rotates at a rate of one revolution per second as established by an internal 1800 cps fork and reduction gear assembly. The peripheral speed is about 53 milliseconds per inch. In order to change the drum speed a highly stable General Radio interpolation oscillator was substituted for the tuning fork oscillator. It was found that operating speeds of from half to twice normal could be obtained.

Recordings were made on non-duplicating paper, one side of which had a conducting surface. The long dimension of the paper was wrapped around the perimeter of the drum and held in position by a metal clamp. This clamp and the drum provided one of the electrical contacts to the paper, and a metal stylus provided the other. Passing a pulse of current through the stylus burned a small section of the paper leaving a black spot. A lead screw

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[2] Technical Manual TM11-2258, "Facsimile Sets AN/TXC-1, 1A and 1B" Department of the Army, December 1947

advanced the drum horizontally so that each rotation provided a displacement of about 0.01 inches between adjacent scans. By applying pulses of the proper frequency a series of dots would be produced forming a line parallel to the axis of the drum. At a drum speed of one revolution per second it would take about 20 minutes to record the entire paper.

The speed of the drum was adjusted with the interpolation oscillator so that one rotation of the drum took the same length of time as two repetitions of the 48 element short pattern. For example the drum speed was 0.96 revolutions per second for the 10 ms bit 48 element short pattern recordings. Figure I3 shows a typical recording. The dots were produced by differentiating the mark-to-space and space-to-mark transitions. Because of the size only one of the two patterns is shown. Vertical lines were drawn to divide the copy into one minute segments. For jitter analysis each segment was enlarged to about 9-1/4 inches wide in a microcard reader. Multipath jitter is indicated by the deviation of the dots from a straight line, but scattered points usually are due to static crashes.

Data Reduction Methods

Jitter data taken by both types of facsimile recording machines were scaled in similar fashion. First the recorded lines of dots representing transitions were divided into intervals of about one-minute duration. Then by knowing the speed of the drum rotation, deviations from a straight line were calibrated in milliseconds. Tabulations were made of the number of dots in a particular sample that exceeded some fixed value of milliseconds peak-to-peak, where the timing reference is taken midway between the average excursions of the jitter. This number of dots was then expressed as a percent of the total number of dots in the sample. By examining several millisecond values a number of points were obtained, and a curve plotted representing the distribution of jitter in the particular sample. Figure I4 shows such a plot with jitter in milliseconds as the ordinate versus the percent time jitter is equal to or greater than the ordinate value for a one minute sample for the abscissa. From this curve an ordinate value in milliseconds may be read for an abscissa of 1%. This 1% value has been used for purposes of comparison between the AFSAY D-806 and AN/FGC-29 systems. An examination of a large number of these jitter distributions in a one minute sample have shown that by drawing a straight line through an arbitrary point at (0, 100%) and a measured point at about 5%, the 1% jitter value in milliseconds may be approximated by extrapolation. The dotted line on Figure I4 represents a typical extrapolation.

Comparison of AN/FGC-29 and AFSAY D-806 Jitter

A test was performed over the Kahuku-Riverhead circuit to determine the relative amounts of jitter produced through the AN/FGC-29 and AFSAY D-806 channeling systems. Comparisons were made both with 25 and 50 cps reversals. The AFSAY D-806 low pass filter was modified to provide the same degree of smoothing to the detected signal as that provided by the AN/FGC-29. Wet facsimile recordings of the revs signal as it was received through an AFSAY D-806 channel and an AN/FGC-29 channel were made sequentially. Each system was recorded for at least one minute. The recordings were scaled, and 1% jitter values in milliseconds extrapolated by the above method. Figure I5 shows a plot of the AFSAY D-806 vs the AN/FGC-29 jitter for these 1% values. Both the 25 and 50 cps rev signal recording data are included in Figure I5. A dotted line through the median values is indicated. From the data there does not appear to be a substantial difference in the amounts of jitter produced by these systems. This is not the result to have been expected as indicated by the data given in the Final Report Contract DA49-170-sc-1131. Indications were that as the frequency shift was decreased the relative jitter should have increased, or since the AFSAY D-806 uses 200 cps shift and the AN/FGC-29 only 85 cps shift, the AFSAY D-806 should have had less jitter. One plausible explanation for the result is that the AFSAY D-806 filters have about twice the amount of "bounce" as the AN/FGC-29 filters. The filter bounce tends to increase the effect of the radio circuit jitter.

Comparison of AN/FGC-29 Error Rates and Multipath Jitter

During the course of the radio circuit testing program the U. S. Army facsimile set TT-1E/TXC-1 was used to record the 10 ms bit short pattern transitions as received through an AN/FGC-29 diversity channel. These data were scaled and by extrapolation the 1% jitter values in milliseconds noted. Data were selected for signal-to-noise ratios equal to or greater than 20 db in order to considerably reduce the effects of noise. Characteristic noise scattering of the dots was also eliminated from the scaling.

Simultaneous recordings of jitter and errors were made and the results plotted in Figure I6. Jitter is expressed in terms of milliseconds for the extrapolated 1% values, and the errors in terms of percent of the total transmitted during the sampling period. A dotted line is indicated through the median values of Figure I6. The data are quite scattered but the trend indicates that on the average less than 0.1% errors result when the jitter is 4 milliseconds. In any case the error rate never exceeded 0.7% during these tests when the 1% jitter value was less than 4 milliseconds. It also appears that in the region of 1 to 4 milliseconds, the log of the percent errors is roughly proportional to the jitter.

Cumulative Distributions of Multipath Jitter Recorded Through an AN/FGC-29 Channel

Cumulative distributions of the 1% jitter values measured over the Kahuku-Riverhead radio circuit are given in Figures I7, 8, 9, 10 and 11. These plots are divided by frequency, daytime and nighttime recording hours. Tabulated on the next page are the values of jitter in milliseconds for 1 and 10% on the cumulative distribution curves.

Summary of Cumulative Distribution of 1% Jitter Values in A One-Minute Sample

Frequency	Time	MS of Jitter From Cumulative Distribution Curve 1%	10%
6,790 kc 7,922.5 kc	Night	4.04	3.40
14,550 kc 14,615 kc 15,665 kc	Day	3.6	2.83
15,665 kc	Night	4.0	2.5
18,870 kc	Day	3.48	2.85
20,288 kc	Day	4.06	3.0

All of the data included in these plots were taken during the period of January through May 1956. With the exception of the 20 mc frequency, the nighttime operation generally resulted in higher values of jitter, and the higher the frequency, the lower the jitter. There is a reverse in these trends on the 20 mc frequency. It should be noted that the data on this frequency were taken during the months of April and May, both of which were disturbed periods. A number of rather severe magnetic disturbances were encountered, and in general signal strengths were well below what they had been in previous months.

The highest amount of jitter in the above table is about 4.1 ms, which when compared to the 10 ms keying element length does not appear to be large enough to cause many errors.

Relation of AN/FGC-29 Multipath Jitter and Maximum Usable Frequency

Propagation of radio waves in the high frequency band over long distances depends upon the ability of the ionosphere to reflect the signal back to earth at the receiving location without excessive attenuation. Assuming for simplicity that only a single ionospheric layer exists and that it has a uniform height above the earth, frequencies less than the critical frequency of the layer reflect waves radiated at all vertical angles. At frequencies slightly above the critical value, waves entering the layer vertically are not reflected, but for incidence angles greater than 0°, reflection can still occur. The highest frequency for which the layer supports reflection may be considered to be proportional to the secant of the angle of incidence at the layer. Further, the angle of incidence increases as the number of hops to the receiving point decreases. There is a frequency above which even waves radiated horizontally along the earth's surface do not return to earth. It is seen that by operating at the higher frequencies the number of possible hops supported by the reflecting layer can be reduced, thus reducing the variability in the arrival time of the signal or multipath jitter. Another reason for operating at the highest possible frequency is that as the wave passes through the lower regions of the ionized layer, it suffers an attenuation roughly inversely proportional to the square of the frequency. Therefore, the optimum operating frequency for transmission is only slightly below the MUF (maximum usable frequency).

The relation of multipath jitter and F/MUF as measured through an AN/FGC-29 channel is presented in Figure I12. In this plot, F is the frequency used on the radio circuit.

MUF is the maximum usable frequency for a 3000 kilometer radio circuit at the time of day a particular measurement of jitter was made. The MUF's were scaled by personnel of Stanford University from ionospheric soundings made at Stanford, California. These data were subsequently converted to MUF for a 3000 kilometer radio path.

The values of jitter used for the plots were for 1% distribution in a one-minute sample. That is 1% of the points in a one-minute sample were equal to or greater than the particular scaled value of jitter in milliseconds. The 1% value was chosen as corresponding to a reasonable reliability factor for the operation of a radio circuit.

The mass of plotted points in Figure I12 are quite scattered, but an attempt at a median curve is indicated by the dotted line. It appears that if multipath jitter were the only factor to be considered in the transmission of the 10 ms bit short pattern through a AN/FGC-29 channel, all F/MUF (3000 km) values down to about 0.5 would have been acceptable. However, the signal-to-noise ratio must also be above certain limits for satisfactory operation.

Conclusions

1. There is no substantial difference between the amount of multipath jitter recorded through the AN/FGC-29 and AFSAY D-806 diversity channeling systems when using 25 and 50 cps reversals, and with the AFSAY D-806 low-pass filter modified so as to provide the same degree of smoothing to the detected signal as that provided by the AN/FGC-29.
2. On the average, less than 0.1% 10 ms AN/FGC-29 short pattern errors result when the 1% jitter values are less than 4 milliseconds.
3. Cumulative distributions of jitter for the AN/FGC-29 diversity channeling system handling 10 ms bits indicate that for daytime operation of 14,550, 14,615, 15,665, 18,870 and 20,288 kc, and nighttime operation of 6,790, 7,922.5, and 15,665 kc, 99% of all the 1% jitter values in one-minute samples produced less than about 4.0 ms jitter. This was for the period of January through May 1956.
4. Comparison of jitter and F/MUF (3000 km), where F is the operating frequency and MUF (3000 km) is the value as measured at Stanford, California, ratios of F/MUF (3000 km) greater than 0.5 resulted in all 1% jitter values (one-minute samples) being less than 4 milliseconds.

JITTER RECORDED AT RIVERHEAD

Frequency: 7922.5 kc
Scale: 1 inch = 5.62 milliseconds
Keying Speed: 50 cps reversals

Time (EST): 7:05 AM
Date: 2-15-56
806

← Paper Direction

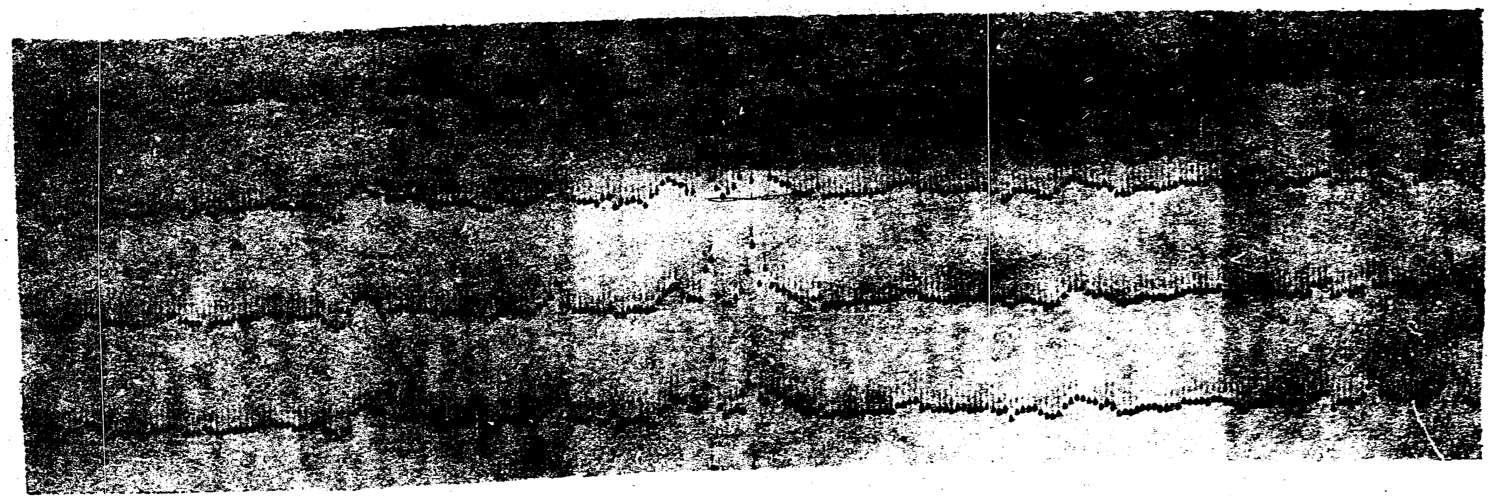


FIGURE I-1

9-1269

9-1270

JITTER RECORDED AT RIVERHEAD

Frequency: 7922.5 kc
Scale: 1 inch = 5.62 milliseconds
Keying Speed: 50 cps reversals

Time (EST): 7:05 AM
Date: 2-15-56
AN/FGC-29

← Paper Direction

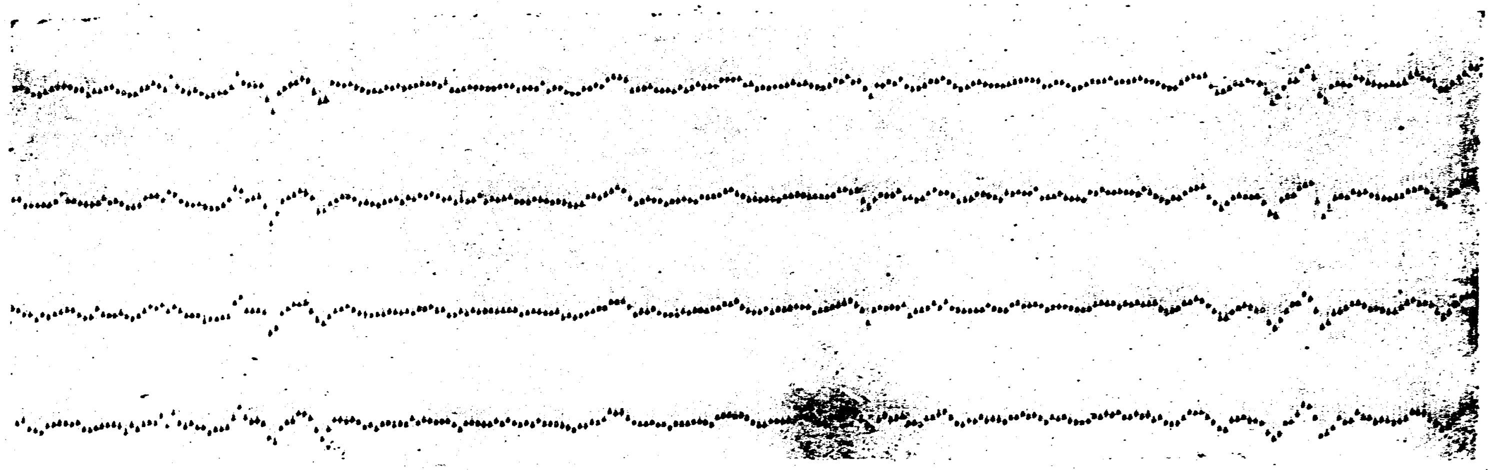
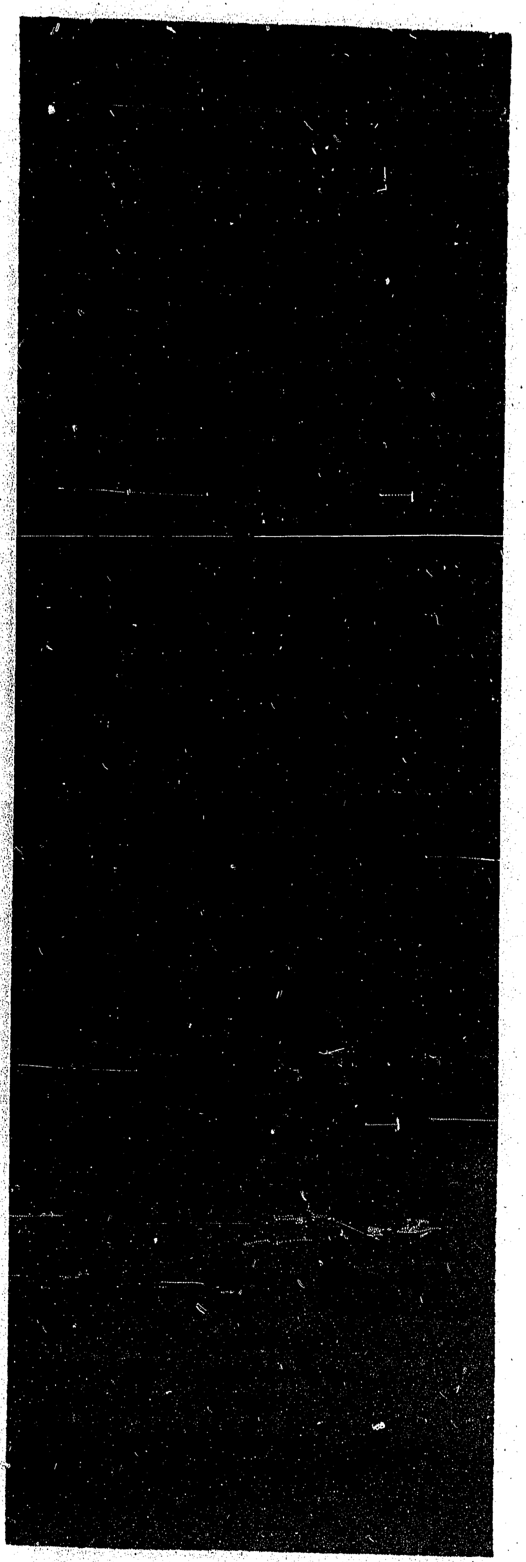


FIGURE I-2



JITTER RECORDED AT RIVERHEAD

Frequency: 15,615 kc
Scale: 1" = 51 ms
Keying Speed: 100 bits/sec.
Time (EST): 9:10 PM
Date: 3-29-56
S/N: 36 db

Direction of Paper Advance

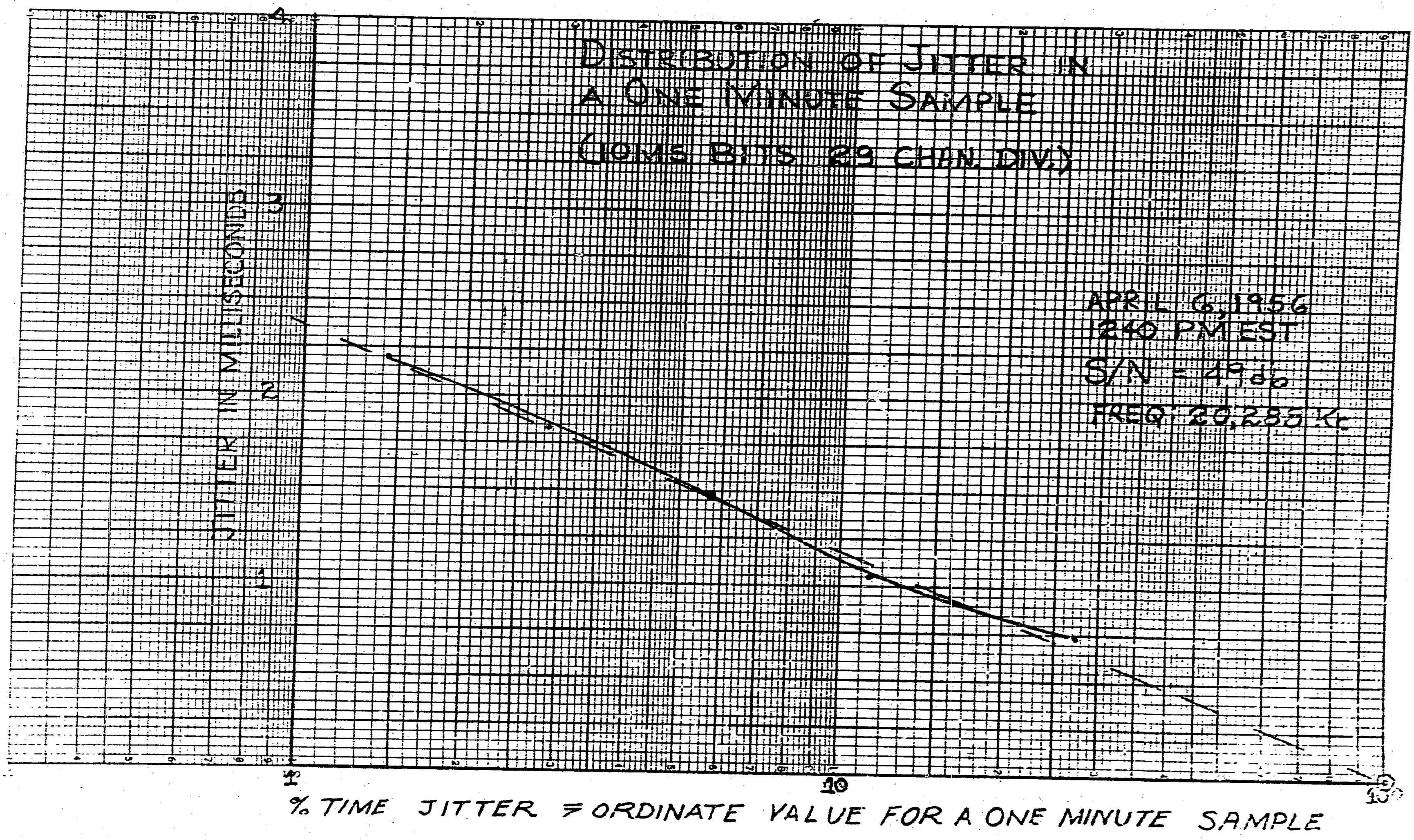
←

Direction of Drum Rotation

↓

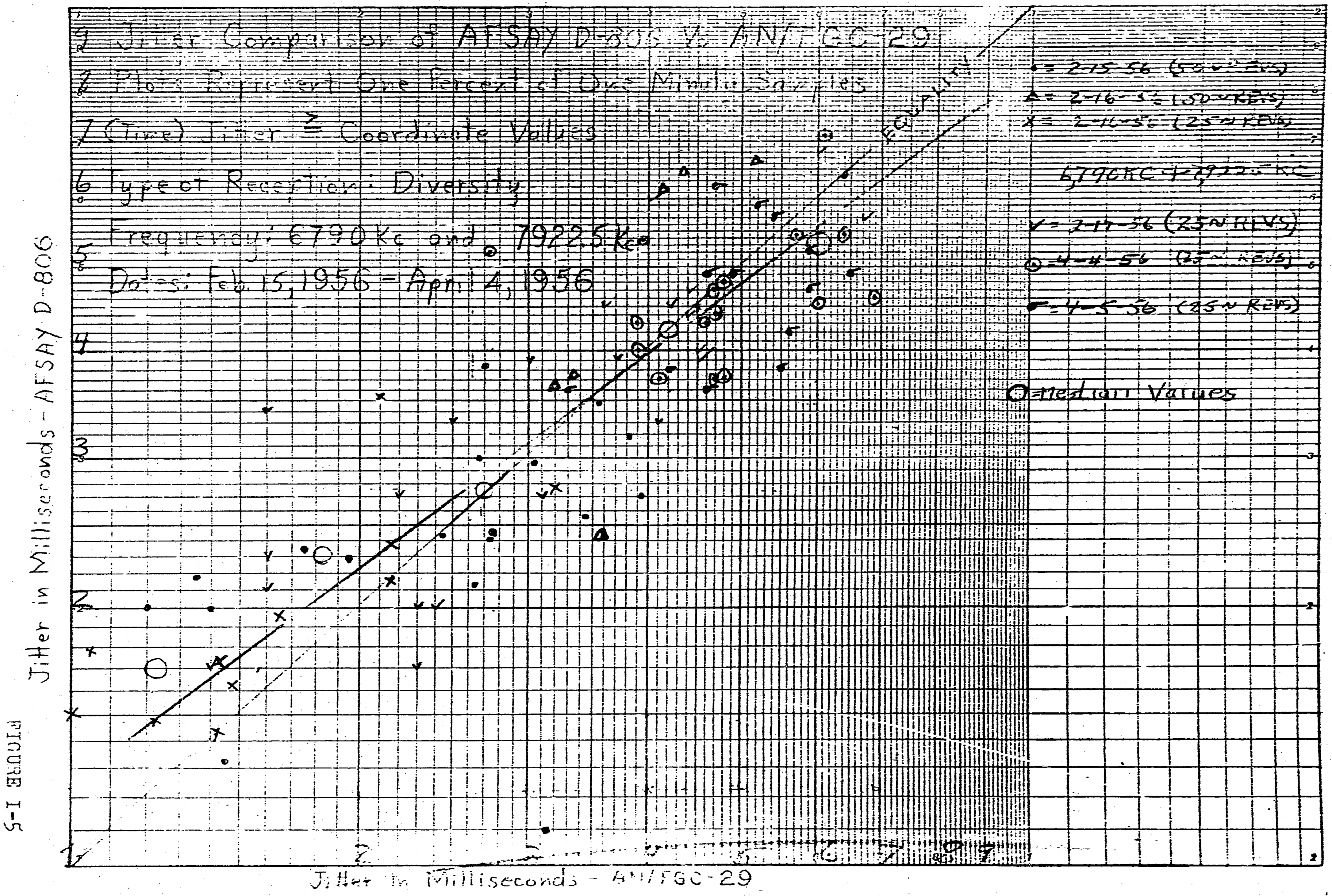
9-1262

FIGURE I-3



DISTRIBUTION OF JITTER IN A ONE MINUTE SAMPLE (10MS BITS 29 CHAN. DIV.)

FIGURE 1-4



Jitter Comparison of AFSAY D-806 Vs AN/FGC-29
Plots Represent One Percent of One Minute Samples
(Time) Jitter ≥ Coordinate Values
Type of Reception: Diversity
Frequency: 6790 Kc and 7922.5 Kc
Dates: Feb. 15, 1956 - April 4, 1956

FIGURE I-5

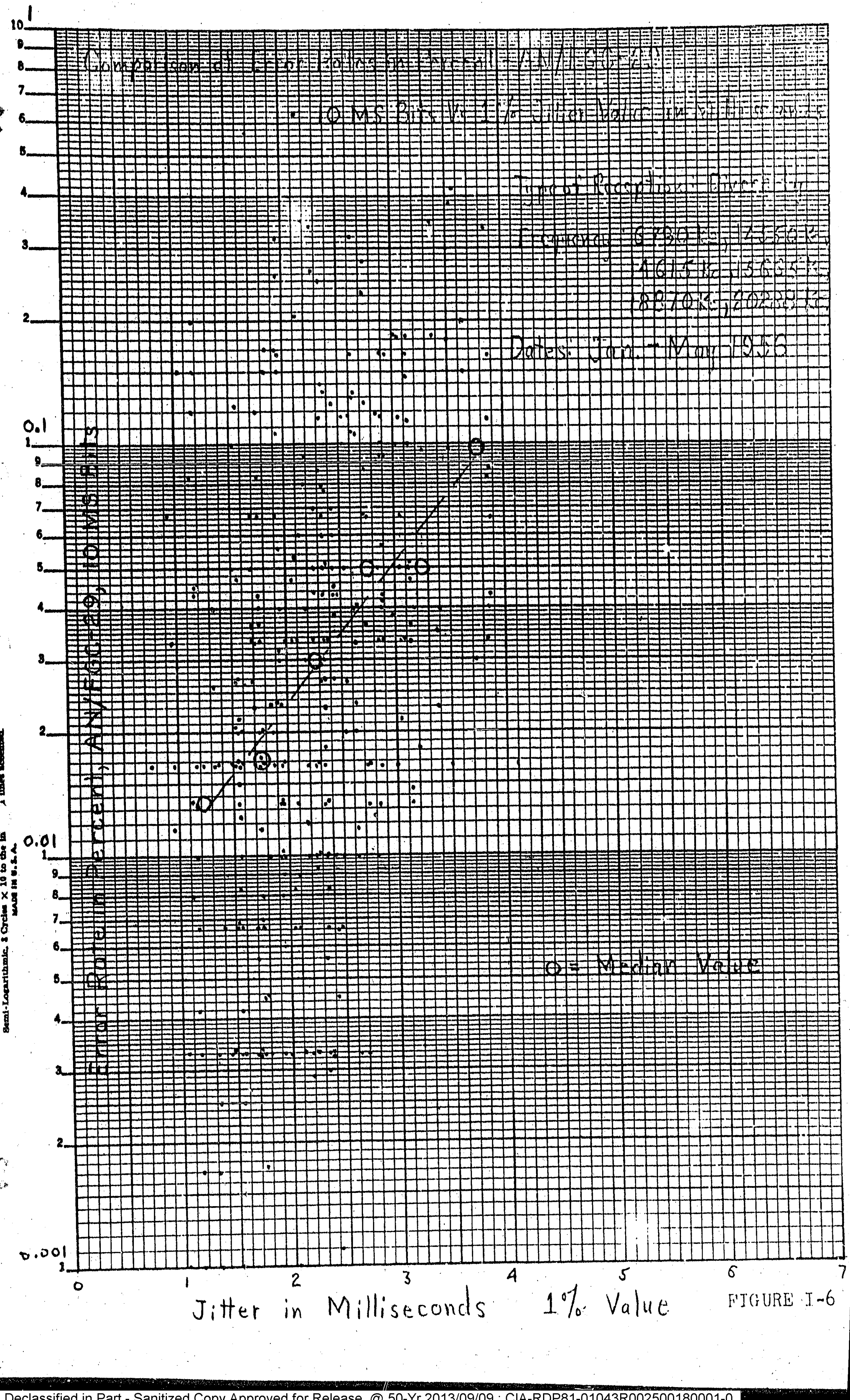
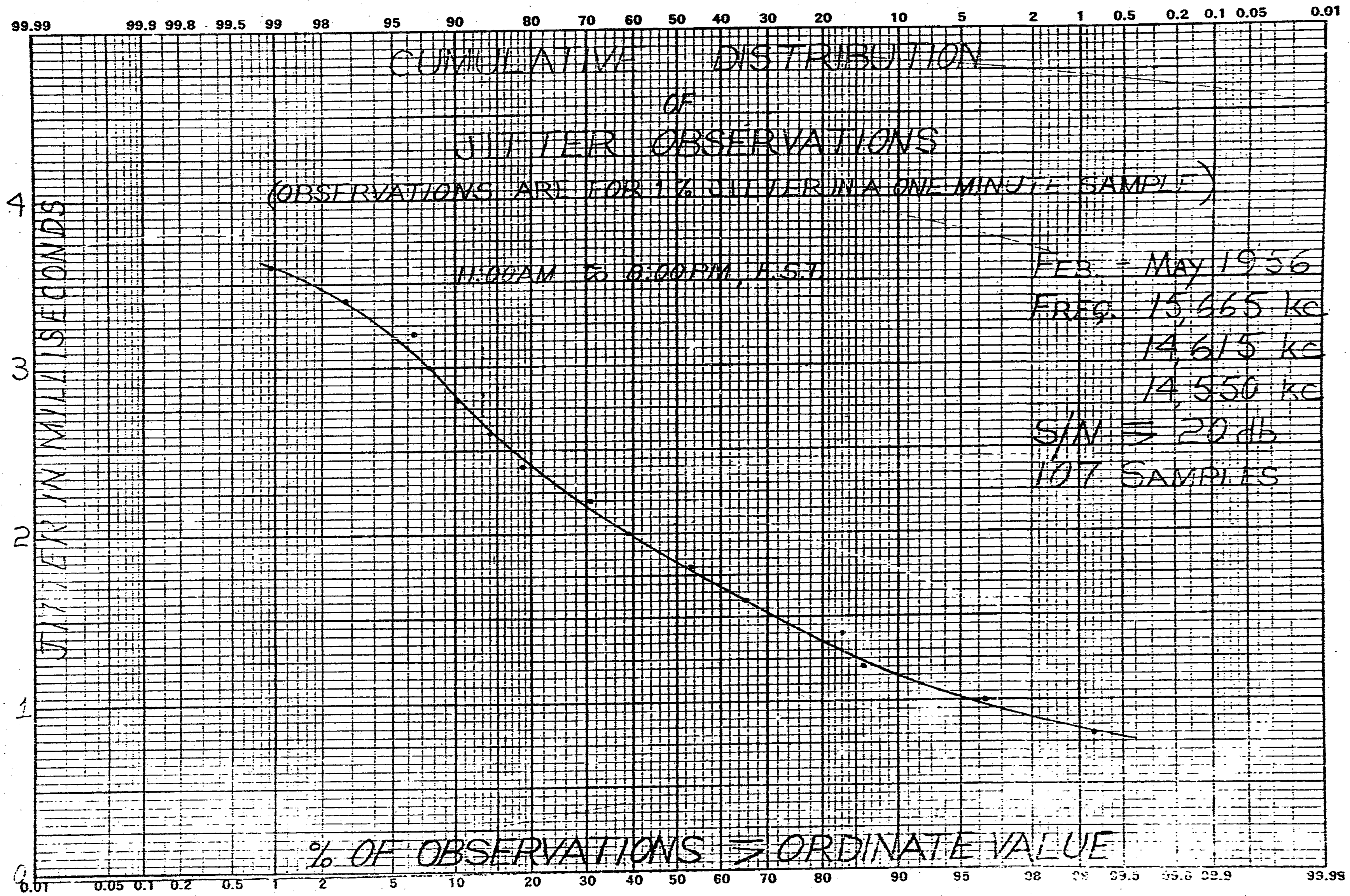

Comparison of Error Rates in Percent - AN/FGC-29
10 MS Bits Vs 1% Jitter Value in Milliseconds
Type of Reception: Diversity
Frequency: 6780 Kc, 14550 Kc
4615 Kc, 15665 Kc
8870 Kc, 20228 Kc
Dates: Jan. - May 1956
O = Median Value
Error Rate in Percent, AN/FGC-29, 10 MS Bits
Jitter in Milliseconds 1% Value
1
0.1
0.01
0.001
0
1
2
3
4
5
6
7
KEUFFEL & ESSER CO., N. Y.
Semi-Logarithmic, 3 Cycles × 10 to the in
MADE IN U.S.A.

FIGURE I-6


CUMULATIVE DISTRIBUTION
OF
JITTER OBSERVATIONS
(OBSERVATIONS ARE FOR 1% JITTER IN A ONE-MINUTE SAMPLE)

11:00AM to 8:00PM, E.S.T.

FEB. - MAY 1956
FREQ. 15,665 kc
14,615 kc
14,550 kc
S/N ≥ 20 db
107 SAMPLES

FIGURE I-7

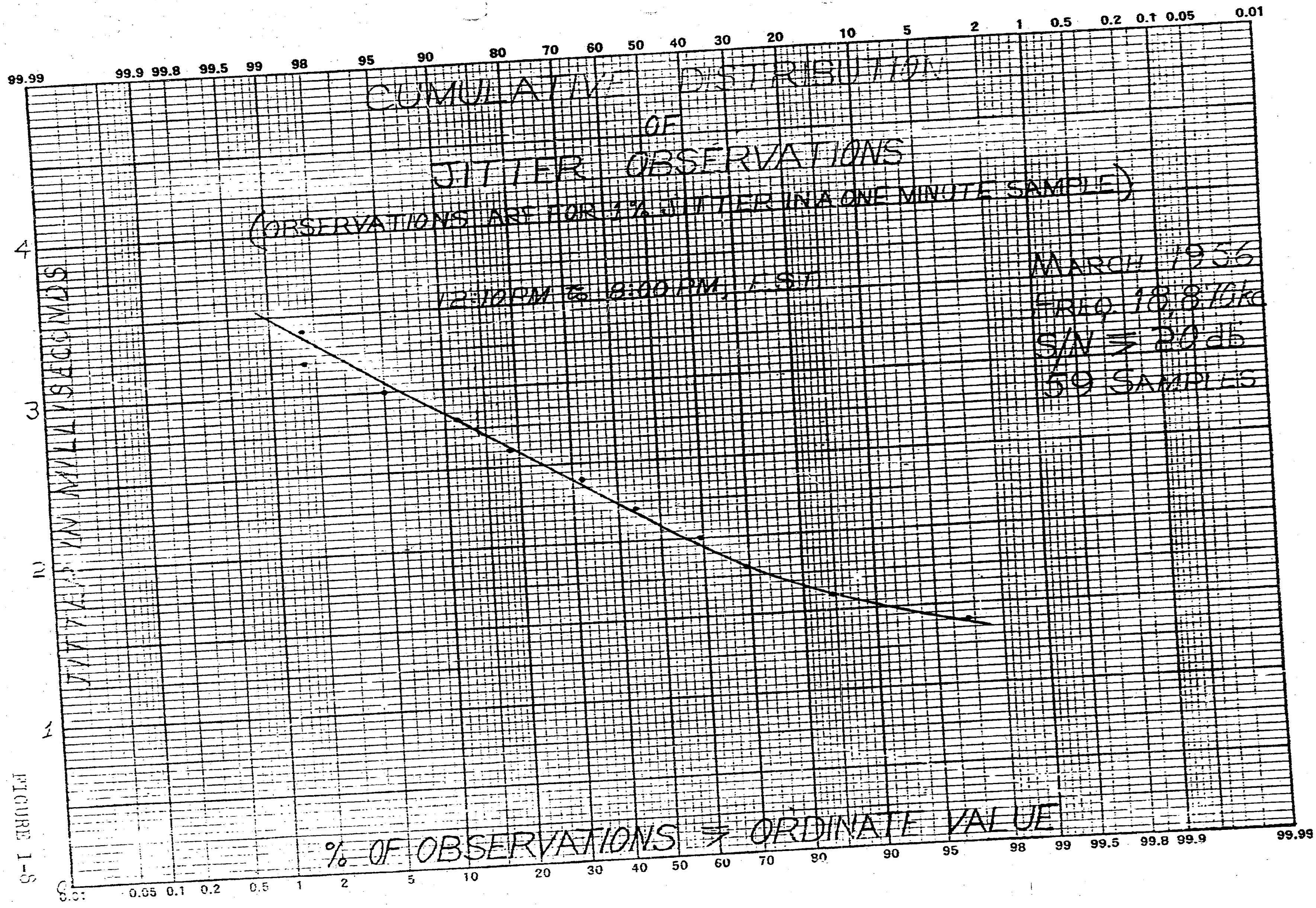

CUMULATIVE DISTRIBUTION
OF
JITTER OBSERVATIONS
(OBSERVATIONS ARE FOR 1% JITTER IN A ONE MINUTE SAMPLE)
12:10PM to 8:00PM, EST
MARCH 1956
FREQ. 18.87kc
S/N ≅ 20 db
59 SAMPLES
JITTER IN MILLISECONDS
4
3
2
1
% OF OBSERVATIONS ≅ ORDINATE VALUE
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.5
99.8
99.9
99.99

FIGURE 1-8

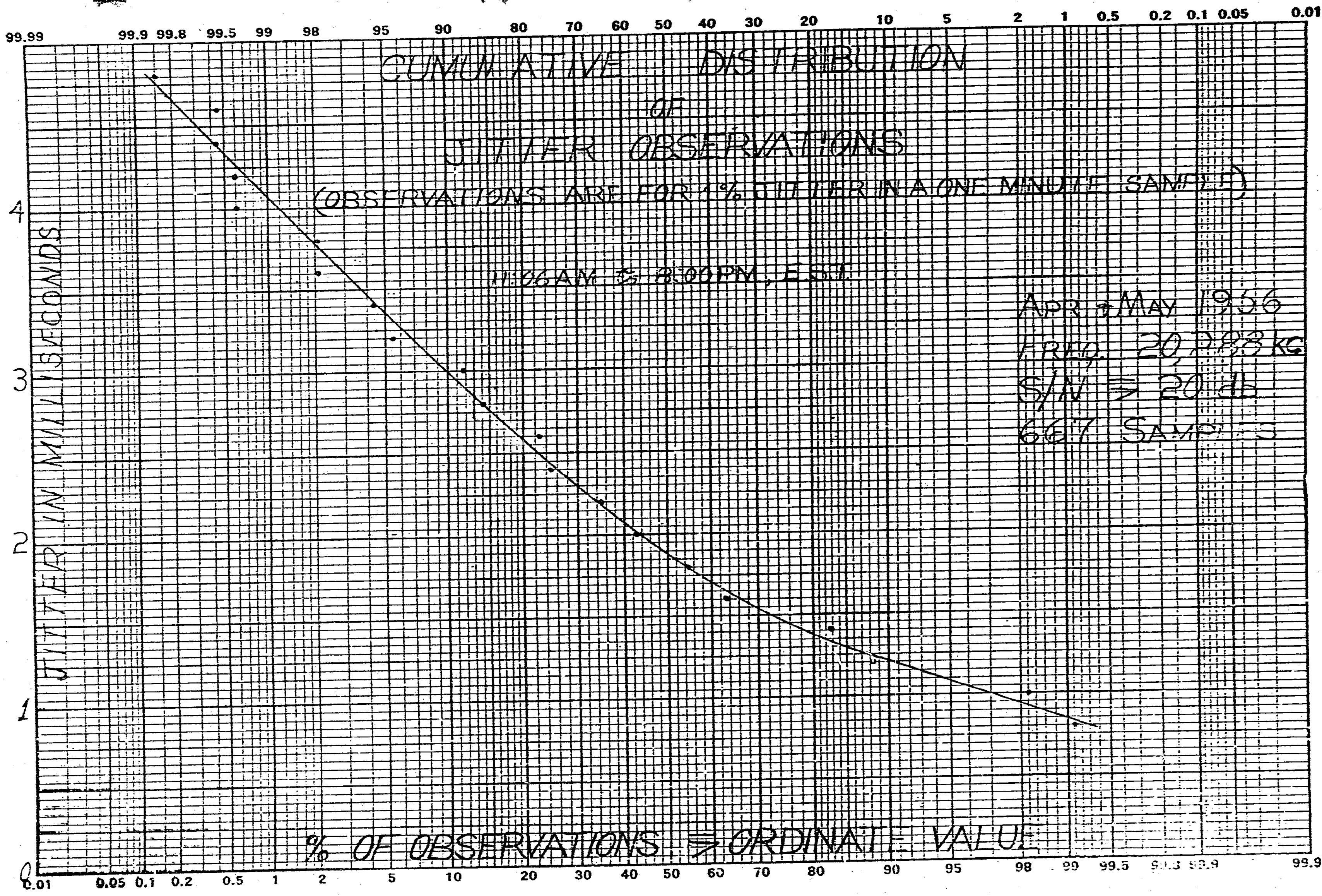

CUMULATIVE DISTRIBUTION
OF
JITTER OBSERVATIONS
(OBSERVATIONS ARE FOR 1% JITTER IN A ONE MINUTE SAMPLE)
11:06AM & 8:00PM, EST
APR + MAY 1956
FREQ. 20,288 KC
S/N ≥ 20 db
667 SAMPLES
JITTER IN MILLISECONDS
% OF OBSERVATIONS ≥ ORDINATE VALUE
0
1
2
3
4
99.99
99.9
99.8
99.5
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0.5
0.2
0.1
0.05
0.01
99.99

FIGURE I-9

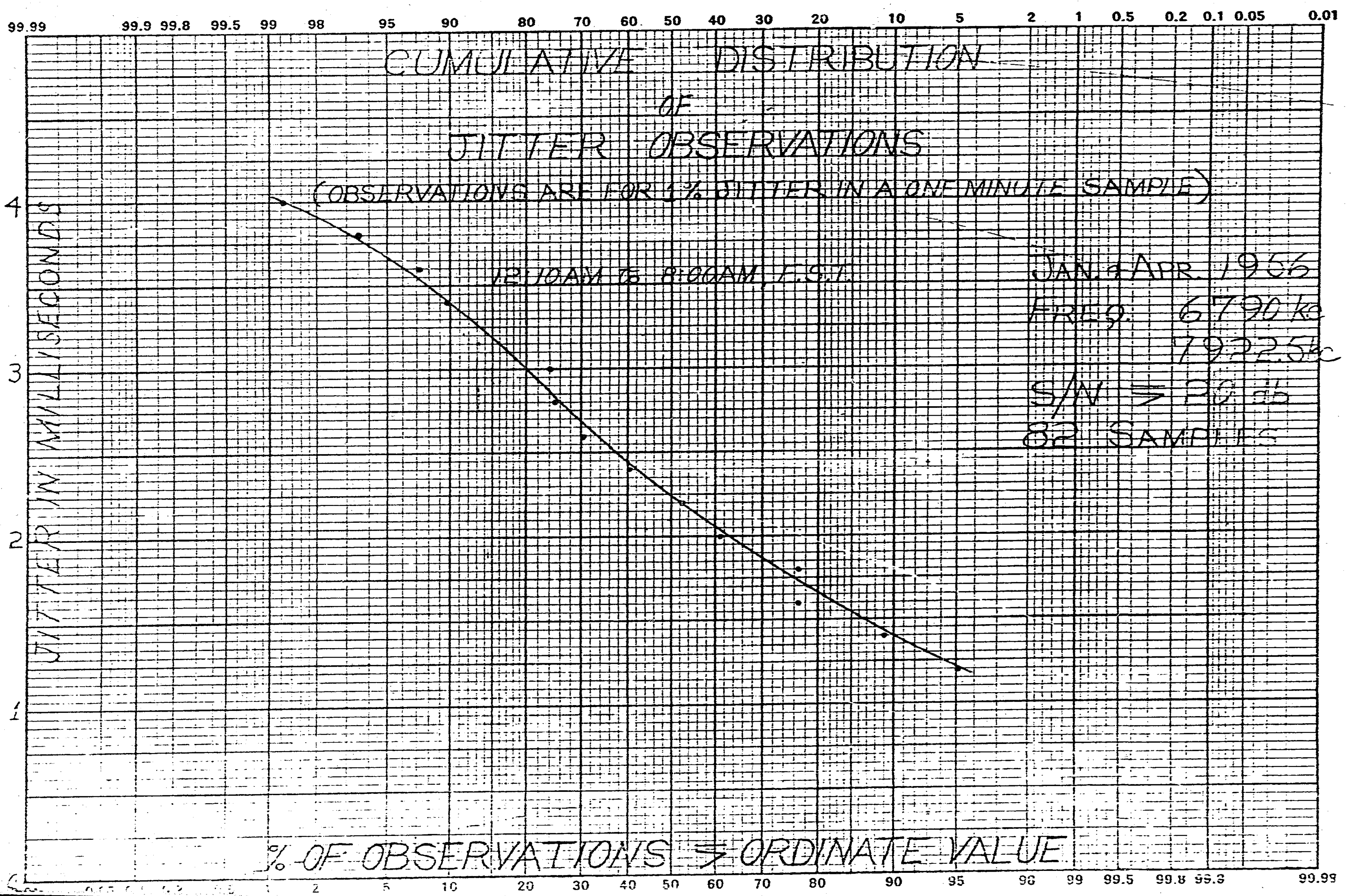

CUMULATIVE DISTRIBUTION
OF
JITTER OBSERVATIONS
(OBSERVATIONS ARE FOR 1% JITTER IN A ONE MINUTE SAMPLE)
12:00AM to 8:00AM, E.S.T.
JAN. & APR. 1956
FREQ. 6790 kc
7922.5kc
S/N ≥ 20 db
82 SAMPLES
JITTER IN MILLISECONDS
4
3
2
1
% OF OBSERVATIONS ≥ ORDINATE VALUE
99.99
99.9
99.8
99.5
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0.5
0.2
0.1
0.05
0.01

FIGURE 1-10

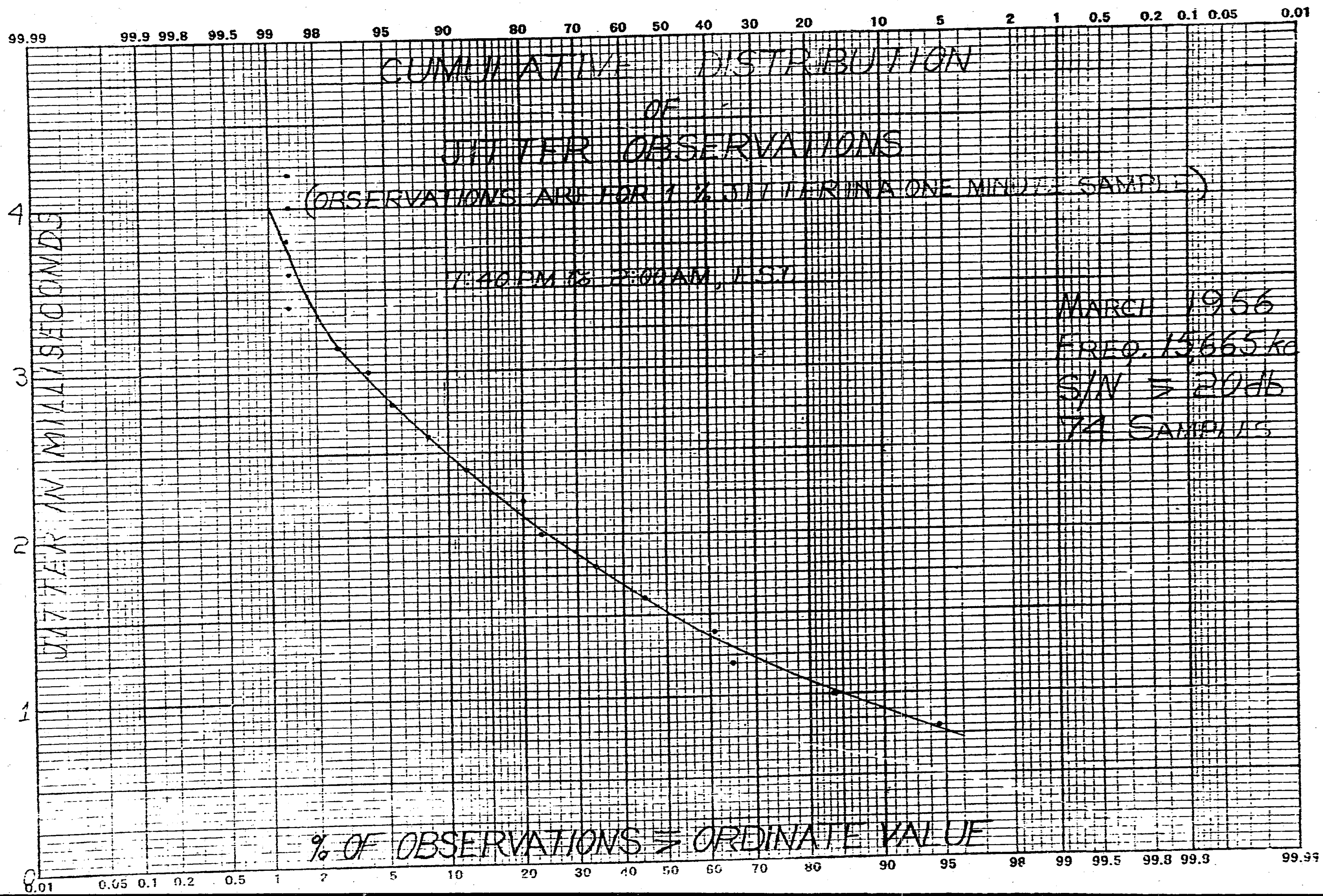
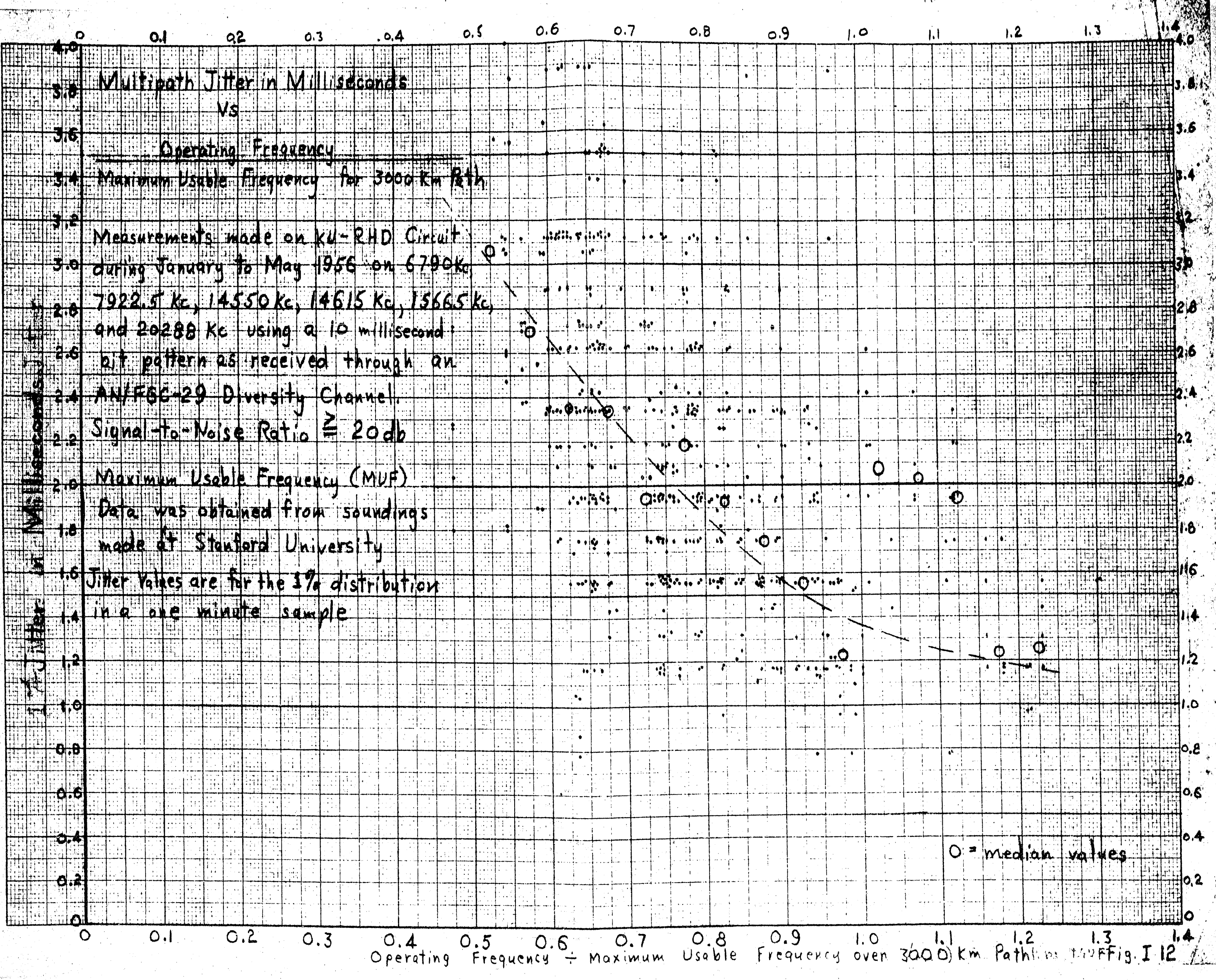

CUMULATIVE DISTRIBUTION
OF
JITTER OBSERVATIONS
(OBSERVATIONS ARE FOR 1% JITTER IN A ONE MINUTE SAMPLE)
7:40 PM to 2:00 AM, EST
MARCH 1956
FREQ. 15665 kc
S/N ≈ 20db
74 SAMPLES
JITTER IN MILLISECONDS
% OF OBSERVATIONS ≥ ORDINATE VALUE
0
1
2
3
4
99.99
99.9
99.8
99.5
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0.5
0.2
0.1
0.05
0.01

FIGURE I-11



Multipath Jitter in Milliseconds
Vs
Operating Frequency
Maximum Usable Frequency for 3000 Km Path

Measurements made on KU-RHD Circuit during January to May 1956 on 6790 Kc, 7922.5 Kc, 14550 Kc, 14615 Kc, 15665 Kc, and 20288 Kc using a 10 millisecond bit pattern as received through an AN/FGC-29 Diversity Channel.
Signal-to-Noise Ratio ≧ 20db

Maximum Usable Frequency (MUF) Data was obtained from soundings made at Stanford University

Jitter Values are for the 1% distribution in a one minute sample

O = median values

Fig. I 12

Appendix AA

ANALYSIS OF REDUCED CARRIER RECORDINGS

Introduction

This appendix presents the methods and results of an analysis of the reduced carrier recordings taken during the single sideband tests as described in the main body of the report. The results are presented in terms of the hourly average voltage at a given point along the transmission line from the antenna to receiver, its hourly median values for the month, the classification of the frequency distributions of the day-to-day voltage variations for each hour, and the standard deviations of these distributions.

Most of the data are for the Kahuku - Riverhead circuit, and the remainder are for the Orleans, France - Riverhead circuit.

Procedure for Recording the Carrier

The general procedure used in the measurements of the reduced carrier levels is described in Section E, for the Kahuku to Riverhead tests for the period November 14, 1955 to May 25, 1956.

Similar equipment was used in the measurements of transmissions from AEO, Orleans, France. All analyzed carrier data are exclusively based upon single receiver reception (non-diversity).

The carrier filter response at half power (3 db from maximum) was 30 cycles.

Antennas

During the November 1955 - May 1956 series the carrier was received on the sloping rhombic (#284-18R).

Carrier reception on the earlier series of tests, October 1953 to November 1954, was on the flat rhombic, except for a few short periods. In the analysis of the earlier Kahuku recordings only data associated with the flat rhombic, number 283-R, were used.

The dimensions of all antennas used at both ends of the Kahuku circuit are given in Section E.

The transmission antenna of AEO, Orleans, France was a 3-wire class A rhombic directed towards Washington, D.C. (practically same azimuth as Riverhead). The receiving antenna at Riverhead used for reception from AEO was a flat rhombic, #54-14R. The dimensions of these antennas are:

	AEO Transmitting	#54-14R Receiving
Azimuth	292°	54°
Height above ground	70'	46'
Leg length	375'	255'
Half side angle	70°	67.2°
Damping resistance	---	900 ohms
Length of transmission line to multicoupler	---	1767'
Type of transmission line	---	200 ohm, 4-wire, open
Design frequency		14 MC

Transmitter Power

The carrier power output from the transmitter during the Kahuku tests was varied from time to time by known amounts. The range was from 2.25 to 200 watts over the entire period of the tests.

All data were normalized to a carrier power of 100 watts.

Frequency Range

The data suitable for analysis of the carrier level fell in the frequency range of 6790 kc to 20,288 kc.

Transmission Line Loss

The lengths of transmission lines at the receiving end and their losses at the extreme frequency ranges are:

Frequency kc	DB Loss per 1000'	Total DB Loss Length of Xmn. Line 550'	1750'
6,790	1.0	.55	1.8
20,288	1.7	.94	3.0

Where the data for two or more nearly equal frequencies were combined, the errors attributable to differences in transmission line losses were negligible. For example, the loss differential between 7922.5 and 6790 kc is in the order of 0.1 db.

Data Analysis and Results

Recordings-Scaling Procedure - Mass Plots of Data

The reduced carrier level recordings were calibrated in microvolts in series with 200 ohms at the input of the antenna multicoupler. The average voltage for each hour was obtained by adjusting a straight line across the recorded excursions until the area between the straight line and the recording above it was equal to the area between the straight line and the recording below it. The average voltage in decibels was read at the intersection of the straight line and the half-hour line.

The calibration points were smoothed. Decibel scales were obtained from the smoothed calibration curves. It was these decibel scales that were actually used in taking the hourly readings from the chart.

Mass plots of these hourly reduced carrier levels, normalized to 100 watts transmitter output for the Orleans and Kahuku - Riverhead circuits, are shown in Figures AA1 to AA30. Hourly median values for the month are indicated by "X".

In the earlier Kahuku tests (November 1953 to November 1954, Figures AA1 - AA15) the hourly medians for frequencies which were close were combined in the same mass plot. The following frequency sets were used:

6,790 kc	11,410 kc	14,450 kc
7,922 kc	11,515 kc	14,615 kc

In the later series of recordings (November 1955 - May 1956, Figures AA16 - AA26) the various frequencies were plotted separately.

Median values were obtained only when there were four, or more, readings during a given hour of the month in the earlier tests. In later tests medians were obtained for five, or more, hourly values.

Mass plots of the Orleans data were for the period of August to November 1954 on a frequency of 10,925 kc, as shown in Figures AA27 - AA30.

Monthly Median Carrier Levels

The monthly median of the day-to-day variations of the hourly average reduced carrier levels for different hours of the day are shown in Figures AA31 - AA42.

Orleans - Riverhead: Seasonal Variations

The median plot, Figure AA31, for the Orleans path shows the carrier levels at 10,925 kc for the period of August through November 1954. At this frequency and for the all-daylight path, the winter (November) reduced carrier level was higher than for the summer (August) and fall equinox (September and October) periods.

During the hours that the path of this trans-Atlantic circuit was only partially illuminated by the sun (evening transition) the trend was reversed: the winter voltage was lower than for summer and fall.

There were not enough transmissions in November during the all-dark periods to give a significant median value.

The order of times when the carrier levels started to decrease followed the order of times of sunset on the path as the months progressed from August to November. This association strongly suggests that the voltage decrease at those times was due to penetration of the higher order of modes. In following this hypothesis the remaining, and possibly new and stronger, lower angle modes would have resulted in less voltage input due to relatively poorer low angle antenna response.

Kahuku - Riverhead: Seasonal Variations

The graphical presentations of the median carrier levels for the Kahuku circuit are obtainable in two forms: variations of the median at different months for the same or near-same frequencies; and for a given month the variations at different frequencies.

The Kahuku medians are given in Figures AA32 to AA42. Figures AA32 and AA33 are plots of the median carrier levels during nighttimes, for the frequencies of 6790 and 7922 kc. The indicated levels for March and April may not be significant because of too few hourly recordings at this frequency. Also, because of no data between April and December, conclusions regarding seasonal trends may be questionable.

All of the 11 MC data is shown in Figure AA34. March had comparatively few data.

Six months of median values are shown for the 14 MC band in Figure AA35. At this frequency, and for the all-daylight part of the path (centered roughly about 3 PM, EST), the Kahuku circuit showed greatest voltages in this order: winter, fall equinox, and summer. The maximum difference was in the order of 18 db at 3 PM.

For the months shown on this 14 MC graph, the time (during the evening transition) when darkness first impinges on the path occurs earliest in November. This graph shows that the voltage definitely decreases also in November, earlier than the other months, with the exception of August which had few and unreliable data.

The middle of the transitional period for the path during the months of May to September is around 9 to 10 PM, EST. There were no data during that period at 14 MC up until that hour.

There were too few data around 15 MC (Figure 36) to warrant any comparisons.

Practically all of the data for 18,870 kc and 20,288 kc, Figures AA37 - AA39, falls in the period during which the path is in all-daylight. For the period of November to March, the middle of the times of an all-daylight path is between 2 and 3 PM, EST. Figures AA37 and AA38 show the amounts by which the carrier levels for 18,870 kc, during the all-daylight path, decreases from the winter months to the spring equinox (March). There were too few months of data for 20,288 kc to warrant seasonal comparisons

(Figure AA39).

Figure AA44 compares the receiver input voltages at 3 PM, EST (all-daylight path) at 18,870 kc, to the smoothed Zurich sunspot number published in the CRPL-F Series. A broad minimum of the smoothed sunspot number[1] occurred from November 1953 to November 1954. This broad minimum suggests a negligible annual variation in receiver input during that period, assuming long term correlation between sunspot number and daytime receiver input voltage.

Day/Night Median Voltages

Figures AA40 and AA41 are included to show the relative median voltages for day and night operation, on the respective frequencies. In December 1955 and February 1956 the nighttime voltages were higher than for daytime, as shown in Figures AA40 and AA41. The 12 db drop in voltage from the hours of 4-5 and 5-6 PM, Figure 41, between frequencies 6790 and 7922.5 kc is noted without explanation.

In Figure AA42 the 15 MC and 18 MC band frequencies do not extend into the night. However, when the median levels of the daytime and evening transitional frequencies overlapped at 5-6 PM, the 18 MC level was only about 4 db stronger than for 15 MC.

Correlation with Sunspot Number

Figures AA43 and AA44 attempt to correlate the smoothed Zurich sunspot number with receiver input voltage. Figure AA43 is for night frequencies (6790 kc and 7922 kc) used on the all-darkness path. If the median data were sufficiently reliable the curves indicate that the receiver input voltage, on a night frequency operated during the period when the entire path is in darkness, increases with the smoothed sunspot number. However, there were only 4 or 5 hourly readings for each of the all-darkness hours for each of the months of March and April 1954. Median f°F2 frequencies at Washington, D.C., dropped to about 2.5 MC resulting in a median MUF-3000 km of approximately 6.5 MC. A note on the published median f°F2 at San Francisco showed the values to be higher, but questionable.

Figure AA44 shows that the receiver input voltage, on a day frequency operated during the period when the entire path is illuminated by the sun, decreases with an increase of the smoothed sunspot number.

There wasn't sufficient useful data to attempt correlation with the sunspot number in the summer season, when both daytime and nighttime effects are noticeable.

Cumulative Frequency Distributions

For each of the circuits (Kahuku and Orleans) cumulative frequency distributions were drawn on arithmetic probability coordinate paper. The ordinates were linear in decibels. These showed the day-to-day variations for each hour of the month and for each frequency.

Figures AA45 - AA47 are sample distribution curves of the following types: log-normal, linear-normal, and unidentified type. Samples of Rayleigh curves (extremely few) are not shown.

Identification of a Rayleigh and linear-normal distribution was simplified by drawing a sample Rayleigh, and linear-normal curves with various standard deviations, on an overlay having the same coordinates. This overlay is illustrated in Figure AA48.

The standard deviation, σ , of a linear-normal distribution, when stated in units of decibels, can be converted into units of voltage only when the median value is known and when the reference percentage at + σ or - σ is given. In this appendix the reference percentage for the linear-normal curves is 15.9% (- σ).

Number of Various Types of Distribution Curves

The number of various types of distribution curves found for the Kahuku and Orleans circuits is shown in Table I. These were determined for all hours and frequencies.

TABLE I

TYPES OF DISTRIBUTION OF THE HOURLY AVERAGE LEVELS FOR A STATED HOUR OF DAY OVER A PERIOD OF ONE MONTH

	Number of Samples	%
Kahuku to Riverhead:		
Log-normal	133	83.1
Linear-normal	20	12.5
Rayleigh	4	2.5
Unclassified	3	1.9
Orleans to Riverhead:		
Log-normal	39	71.0
Linear-normal	11	20.0
Rayleigh	1	2.0
Unclassified	4	7.0

Table I shows that the log-normal distribution was the most predominant type found during these tests for both circuits. Next in order, but considerably down the scale, was the linear-normal distribution. There were only a few Rayleigh and unclassified types.

Standard Deviations: Orleans - Riverhead

The range of the standard deviations for all distributions for the Orleans circuit was from 3.0 to 22.5 db. As indicated in the previous section, most of the distributions were log-normal. The standard deviations for the log-normal distributions for the Orleans circuit is tabulated on an hourly basis in Table II.

TABLE II

ORLEANS TO RIVERHEAD STANDARD DEVIATION, σ, OF DAY-TO-DAY VARIATIONS FOR LOG-NORMAL DISTRIBUTIONS HOURLY VALUES

Hour EST	Standard Deviation, σ -DB 1954			
	Aug.	Sept.	Oct.	Nov.
5 - 6 AM	12.8	----	----	----
6 - 7	5.5	10.0	7.3	----
7 - 8	8.0	10.0	----	----
8 - 9	10.8	13.0	6.5	----
9 - 10	9.2	12.8	6.2	----
10 - 11	6.9	12.5	7.6	----
11 - 12	4.5	11.3	----	----
12 - 1 PM	4.3	14.9	7.5	4.0
1 - 2	8.6	10.8	6.4	----
2 - 3	----	11.2	3.2	18.5
3 - 4	10.0	----	4.0	20.6
4 - 5	4.6	9.5	----	12.8
5 - 6	----	----	14.8	----
6 - 7	13.7	----	----	----
7 - 8	15.2	10.8	22.5	----
8 - 9	----	----	17.8	----
Average	8.8	11.5	9.4	14.0

Table II shows the range of the log-normal, hourly day-to-day variations of the standard deviations to be from 3.2 to 22.5 db. The monthly average σ for the log-normal distributions ranged from 8.8 to 14.0 db for the months of August - November 1954.

Standard Deviation: Kahuku - Riverhead

The range of the standard deviations for all distributions for the Kahuku circuit was from 1.5 to 27 db. Most types of distributions, as indicated in a previous section, were log-normal. The range of the hourly standard deviations for the log-normal distributions was also from 1.5 to 27 db.

TABLE III

STANDARD DEVIATION, σ, OF DAY-TO-DAY VARIATIONS
KAHUKU TO RIVERHEAD
MONTHLY AVERAGES FOR ENTIRE PATH

		Log-Normal			
Year	Month	Morn. Trans.	All-Day	Eve. Trans.	All-Dark
1953	Nov.		8.6		
	Dec.		4.0	15.5	
Sum of hourly σ	for 1953		50.5	15.5	
Average	for 1953		6.3	15.5	
1954	Jan.		19.2		
	Feb.		10.5		
	Mar.		5.1	10.3	18.2
	April	3.0	3.6	7.1	7.1
	May		7.4		
	June		6.1		
	July		6.2		
	Aug.		8.5		
	Sept.		6.9	8.0	
	Nov.			14.0	
Sum of hourly σ	for 1954	3.0	318.5	103.0	83.0
Average	for 1954	3.0	6.8	8.6	11.9
1955	Nov.		5.8	5.4	
	Dec.	5.7	3.1	2.8	3.7
Sum of hourly σ	for 1955	11.3	50.8	19.2	22.3
Average	for 1955	5.7	4.6	3.8	3.7
1956	Jan.	5.8			8.2
	Feb.	8.25	2.3		5.85
	Mar.		4.5		
	April		6.4	6.0	
	May		4.8		
Sum of hourly σ	for 1956	28.0	92.0	6.0	72.4
Average	for 1956	7.0	5.1	6.0	7.2
Sum of hourly σ	for all months	42.3	511.8	143.7	177.7
Average	for all months	6.0	6.1	7.6	7.7

The monthly average standard deviations for the log-normal distribution and for different periods of the day are tabulated in Table III. As shown in this table the range of the monthly average σ was from 2.3 to 18.2 db. The averages for all months are as follows: morning transition 6.0 db, all-daylight 6.1 db, evening transition 7.6 db, and all darkness 7.7 db.

The hourly standard deviations of the log-normal distributions of the Kahuku circuit were sorted out according to the amount of light or darkness over the path. The hourly values of the day-to-day variations of σ for different periods of the day are presented in Figure AA49.

Figure AA49 is a cumulative frequency distribution of the log-normal standard deviations of the Kahuku circuit for all frequencies and months. This figure shows that the 50% values for all periods of the day were nearly equal, falling in the range of 6.3 to 6.9 db. (The range of the arithmetical averages was from 6.0 to 7.7 db.)

In the lower half of the figure there is a relatively small spread of the σ's for all periods. In the upper quartile there is an interesting digression of pairs of curves. The curves for the all-dark and evening transition periods run close to each other. The curves for the all-day and morning transition periods tend to run close to each other. But the former pair and the later pair substantially digress. This behavior may be at least partially explained in terms of the ratio of the working frequency to the MUF's as the time of day progresses. Also, the effects of the antenna patterns cannot be discounted.

For example, if the working frequencies at any of the periods of the day were well below the MUF, then you would expect relatively small day-to-day variations of the receiver input levels. This would be represented by the lesser values of σ in Figure AA49. When the all-daylight frequency, say 18 MC, is used well into the evening transition period there will be days (upper quartile in this figure) when the path MUF is so low as to depress the receiver input levels (see also Figure AA45). This would account for an increase in the standard deviations from the all-day to the evening transition periods.

The opposite effect is obtained when the all-dark period frequency is used well into the morning transition. During some days of the month in the all-darkness period and in a low part of the sunspot cycle, 6 or 7 MC tends to approach the MUF of this circuit. As this frequency is continued to be used well into the morning transition period, when the circuit MUF's are increasing, you would expect less variability in the day-to-day variations of the received signal levels. This is represented in the upper quartile of Figure AA49 as a decrease from the all-dark to morning transition standard deviations.

Conclusions

Median Receiver Voltage Seasonal Variations

Day

Both the Orleans - Riverhead and Kahuku - Riverhead reduced carrier levels, during the all-daylight path periods, and for daytime frequencies, were found to occur in the following order of magnitude: winter, fall (or spring), and summer.

The Orleans median carrier levels at 11 MC around noon, EST, were in the order of winter, fall, and summer: 50 , 38 , and 33 db >1 μv.

For the Kahuku circuit, at 14 MC, around 2-3 PM, EST, the median in the winter and summer, was respectively 28 and 10 db >1 μv.

The Kahuku 18 MC median levels, around 2-3 PM, EST, for the winter of 1953-4, and spring of 1954, respectively, were 47 and 29 db >1 μv. The medians were lower for the corresponding seasons of 1955-6.

Night

For the Kahuku 6 to 7 MC night frequencies, the median levels around 2 AM, EST, in the spring of 1954 were around 18 and 31 db >1 μv. In the winter of 1955-6, the 2 AM medians were around 48 and 51 db >1 μv.

Correlation with Sunspot Number

During the all-daylight path period, using the day frequency, and based upon a limited number of months there was a strong trend that the receiver input decreased with an increase of the smoothed sunspot number.

Types of Frequency Distributions

Most of the day-to-day variations of the carrier levels followed a log-normal distribution. The occurrences of log-normal distributions were 83.1% and 71% for the Kahuku and Orleans circuits respectively.

Standard Deviation (σ)

The following were the extreme ranges of the hourly values of the log-normal distributions:

Kahuku - Riverhead	1.5 - 27 db
Orleans - Riverhead	3.2 - 22.5 db

The following were the monthly range of average monthly σ, for all hours, and average σ for all months, for Orleans:

Orleans: Aug. - Nov., 1954	Log-normal
monthly range (all hours)	8.8 - 14 db
average for all months	10.3 db

For the Kahuku circuit the monthly range of average monthly σ, for all hours, are 2.3 - 18.2 db for the log-normal distribution. The average σ for all months, for different parts of the day are:

	Morning Transition	All-Daylight	Evening Transition	All-Darkness
Log-normal	6.0 db	6.1 db	7.6 db	7.7 db

For the Kahuku to Riverhead circuit, much greater day-to-day variability was observed during the evening transition and all-darkness periods than during the morning transition and the all-daylight periods.

Bibliography

1. CRPL-F Series, plot of sunspot numbers
2. Signal Corps RPU No. 9, August 1950
3. RCA Engineering Report F-43-100, S. Goldman

MASS PLOT OF HOURLY AVERAGE SUPPRESSED CARRIER SIGNAL LEVELS FROM KAHUKU'S SSB TRANSMISSIONS RECEIVED AT RIVERHEAD

NOVEMBER 1953

18,870 kc

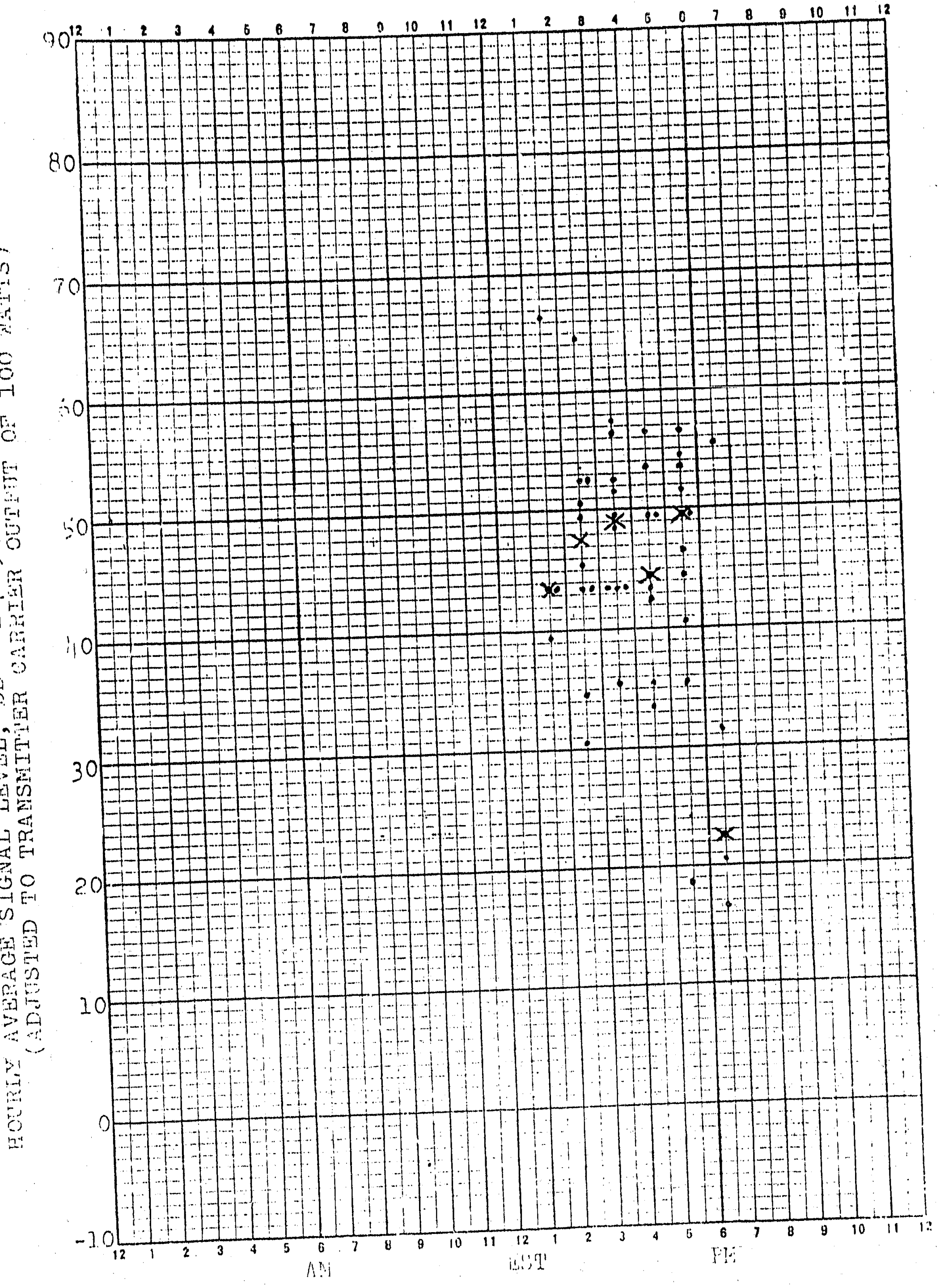


Figure AA1

MASS PLOT OF HOURLY AVERAGE SUPPRESSED CARRIER SIGNAL LEVELS FROM KAHUKU'S SSB TRANSMISSIONS RECEIVED AT RIVERHEAD

18,870 kc

DECEMBER 1953

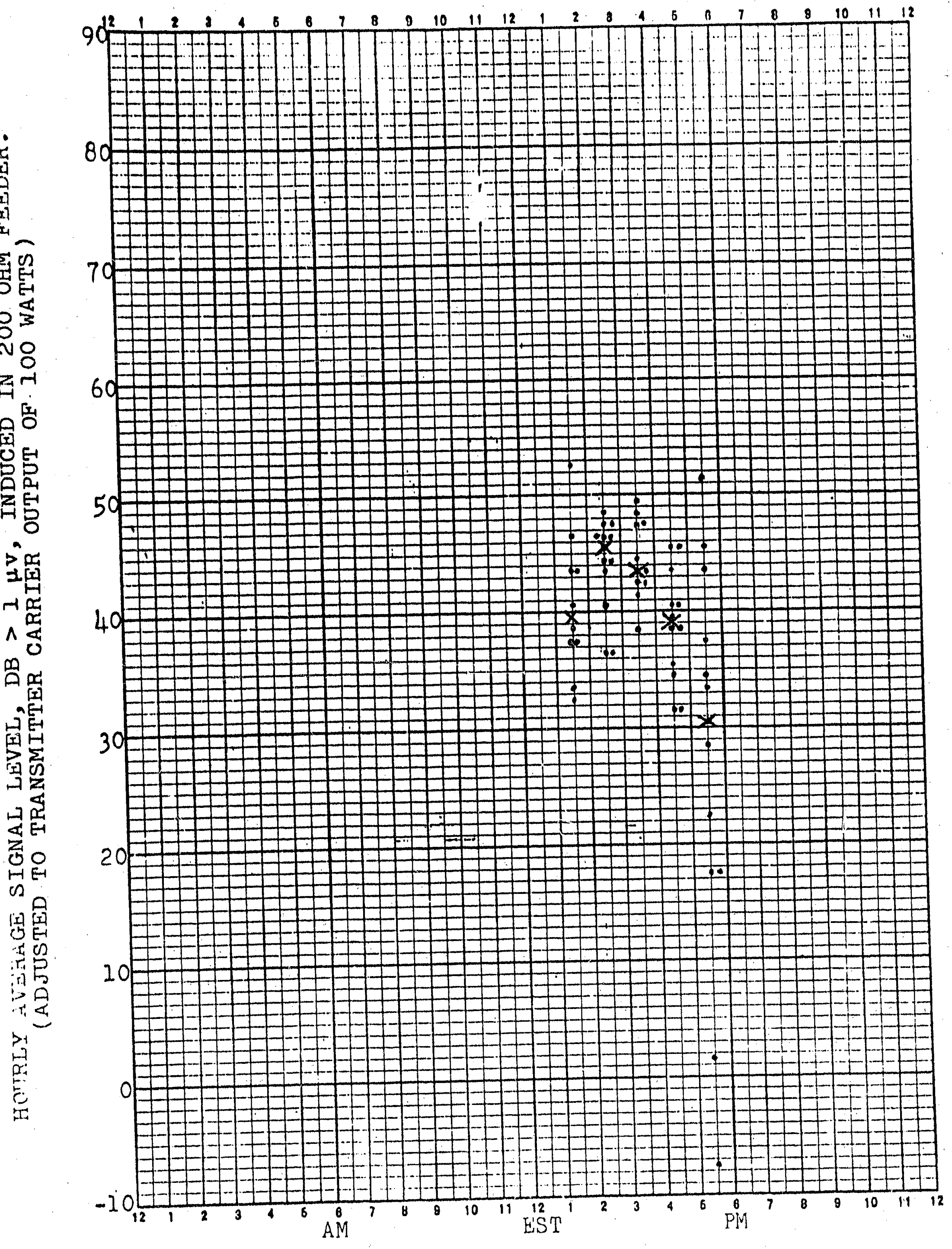


Figure AA2

MASS PLOT OF HOURLY AVERAGE REDUCED CARRIER LEVELS FROM KAHUKU'S SSB TRANSMISSIONS RECEIVED AT RIVERHEAD

January 1951

18,870 kc

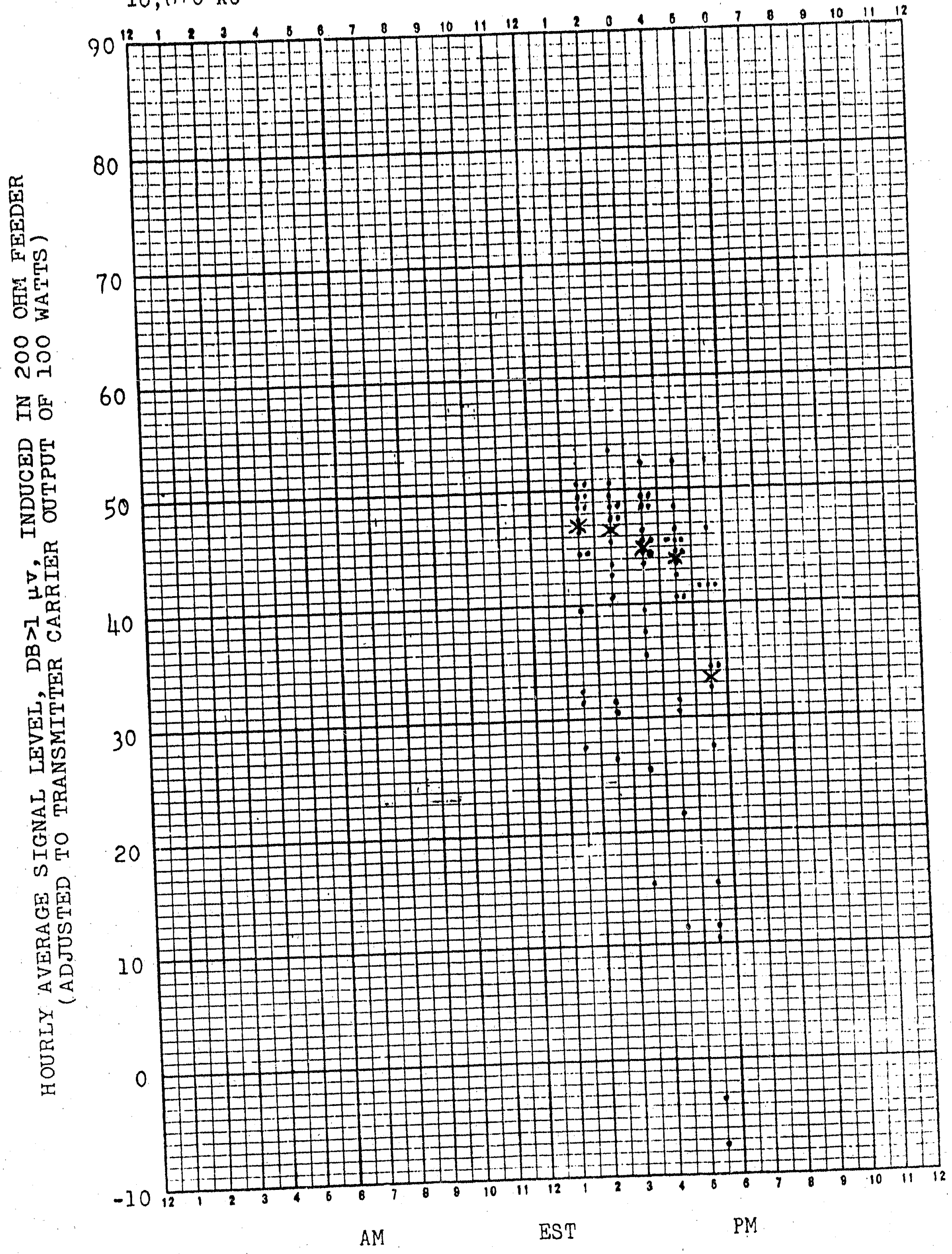
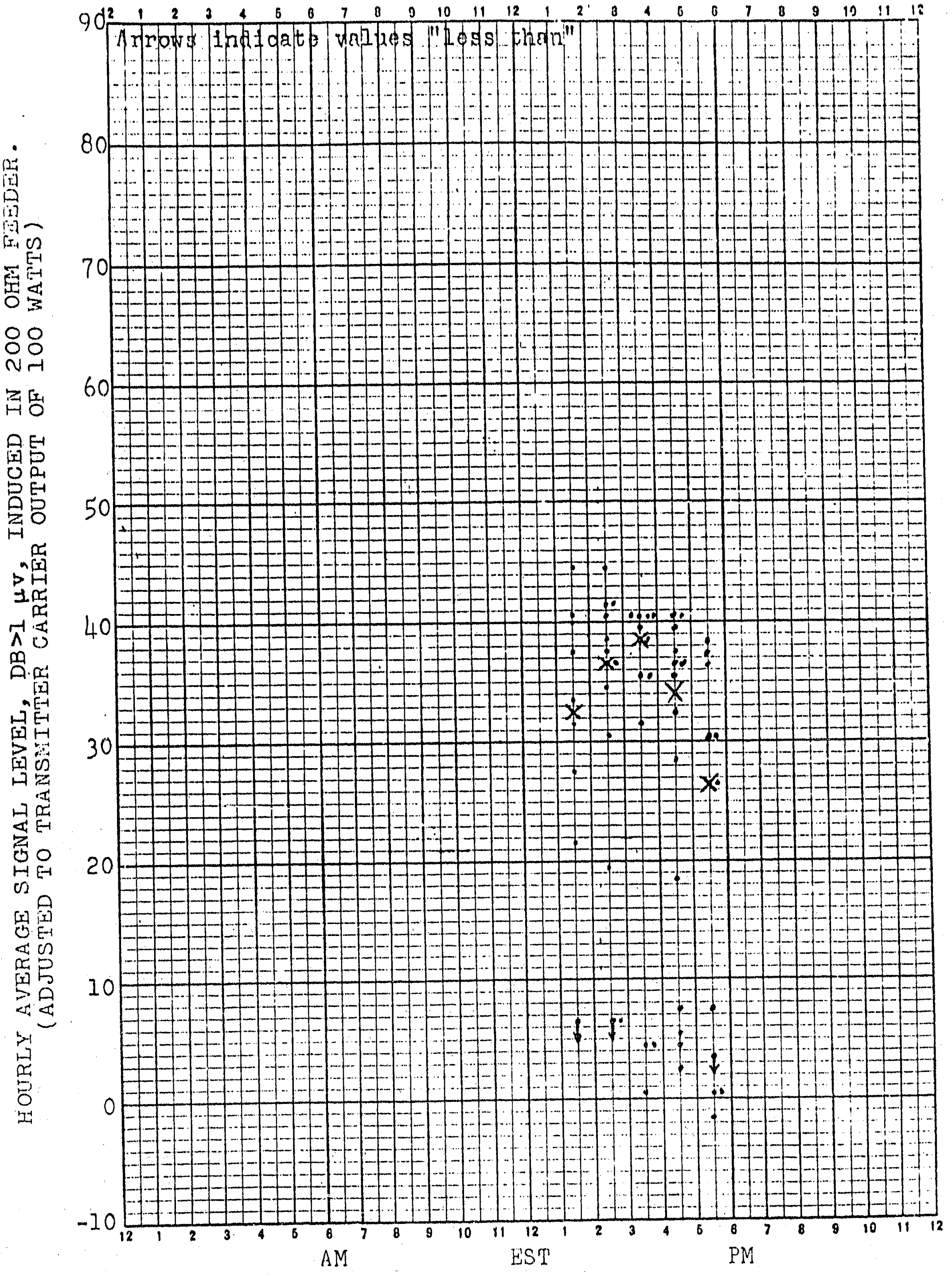


Figure AA

MASS PLOT OF HOURLY AVERAGE SUPPRESSED CARRIER SIGNAL LEVELS FROM KAHUKU'S SSB TRANSMISSIONS RECEIVED AT RIVERHEAD

18,870 kc FEBRUARY 1954

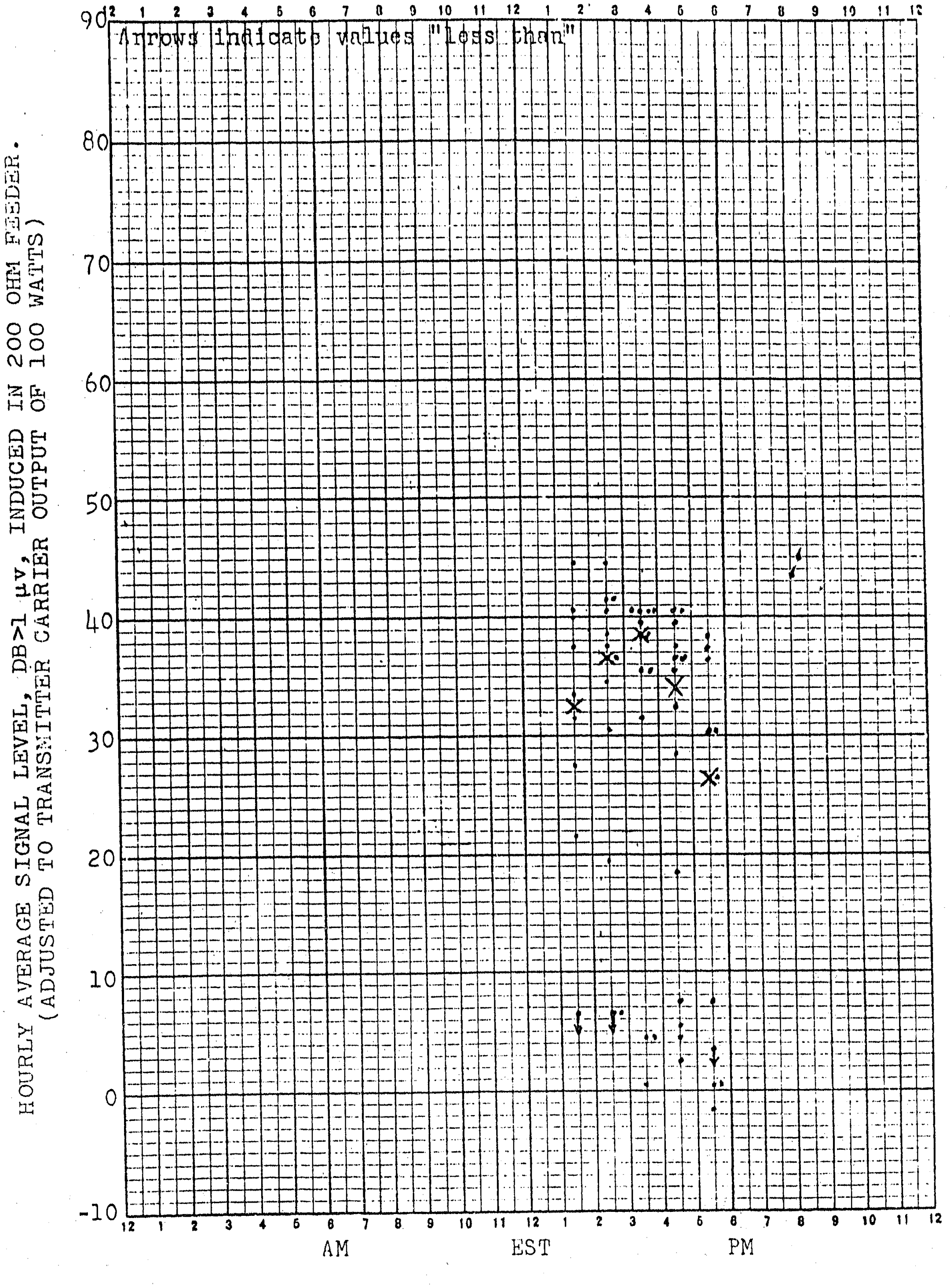


Arrows indicate values "less than".

Figure AA4

MASS PLOT OF HOURLY AVERAGE SUPPRESSED CARRIER SIGNAL LEVELS FROM KAHUKU'S SSB TRANSMISSIONS RECEIVED AT RIVERHEAD

18,870 kc FEBRUARY 1954



Arrows indicate values "less than".

Figure AA4

MASS PLOT OF HOURLY AVERAGE SUPPRESSED CARRIER SIGNAL LEVELS
FROM KAHUKU'S SSB TRANSMISSIONS RECEIVED AT RIVERHEAD

18,870 kc.

MARCH 1954

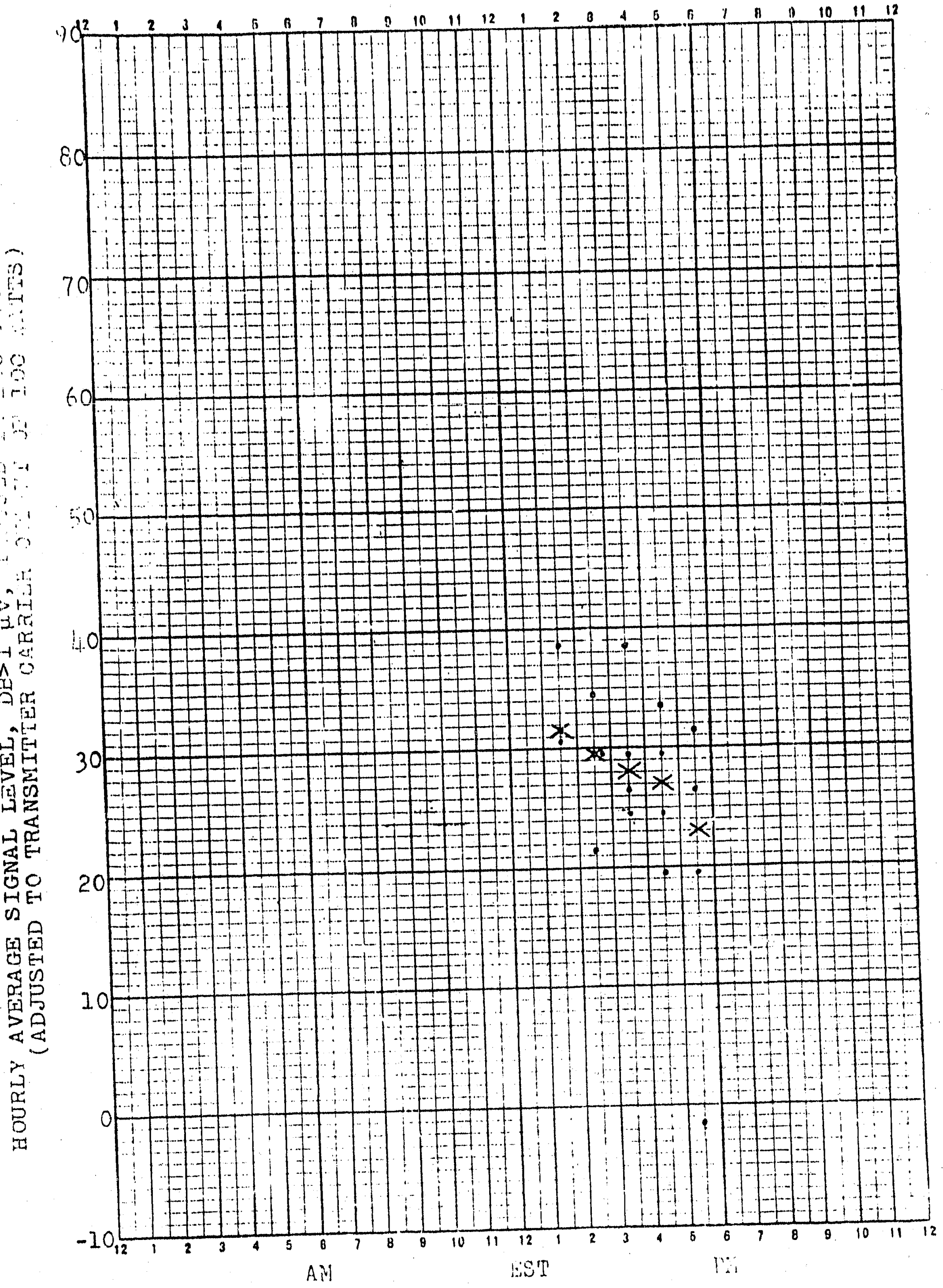


Figure AA5

MASS PLOT OF HOURLY AVERAGE SUPPRESSED CARRIER SIGNAL LEVELS FROM KAHUKU'S SSB TRANSMISSIONS RECEIVED AT RIVERHEAD

MARCH 1954

12,127.5 kc
11,410 kc

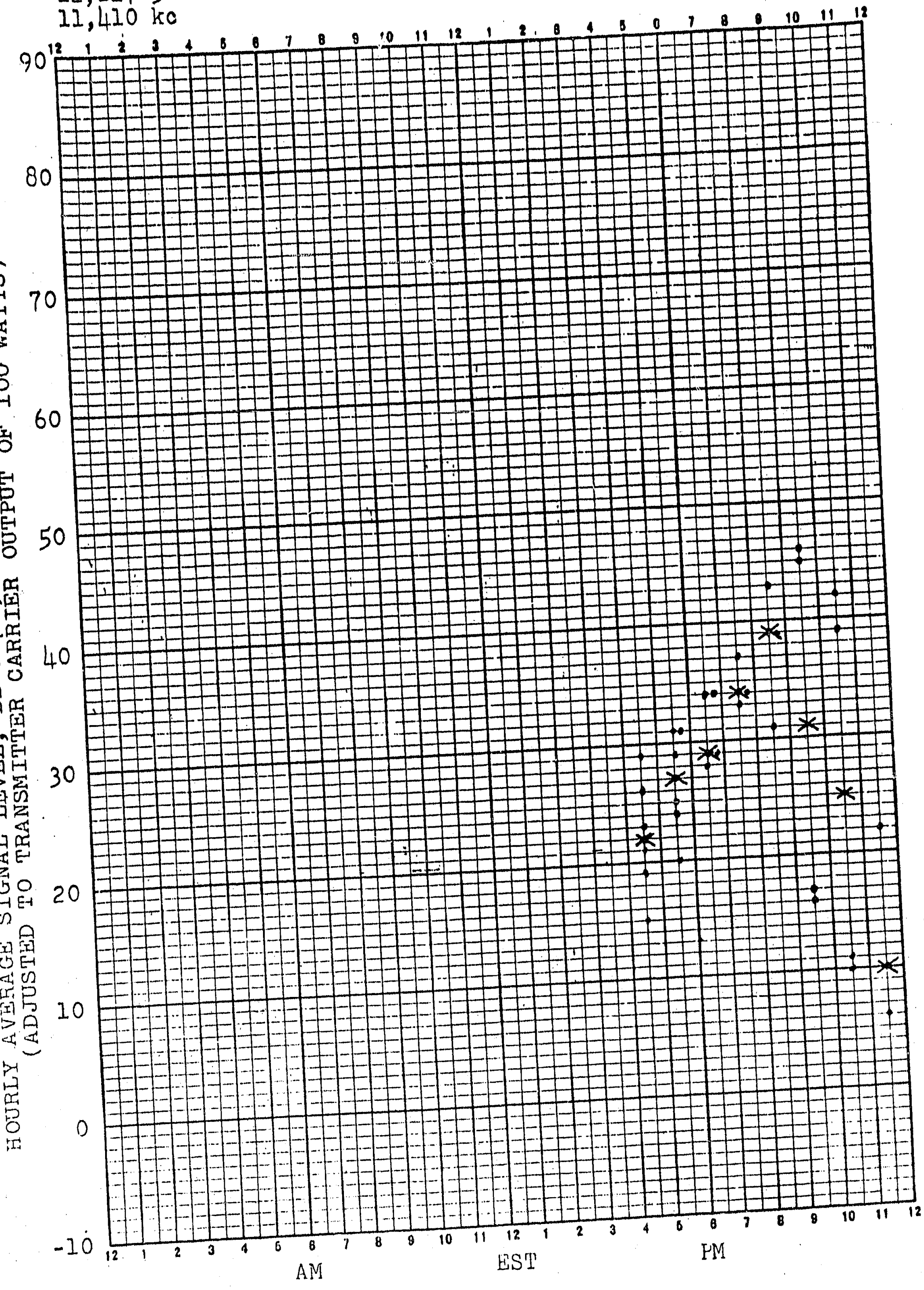


Figure AA6

MASS PLOT OF HOURLY AVERAGE SUPPRESSED CARRIER SIGNAL LEVELS
FROM KAHUKU'S SSB TRANSMISSIONS RECEIVED AT RIVERHEAD

MARCH [illegible]

6790 kc
7922 kc

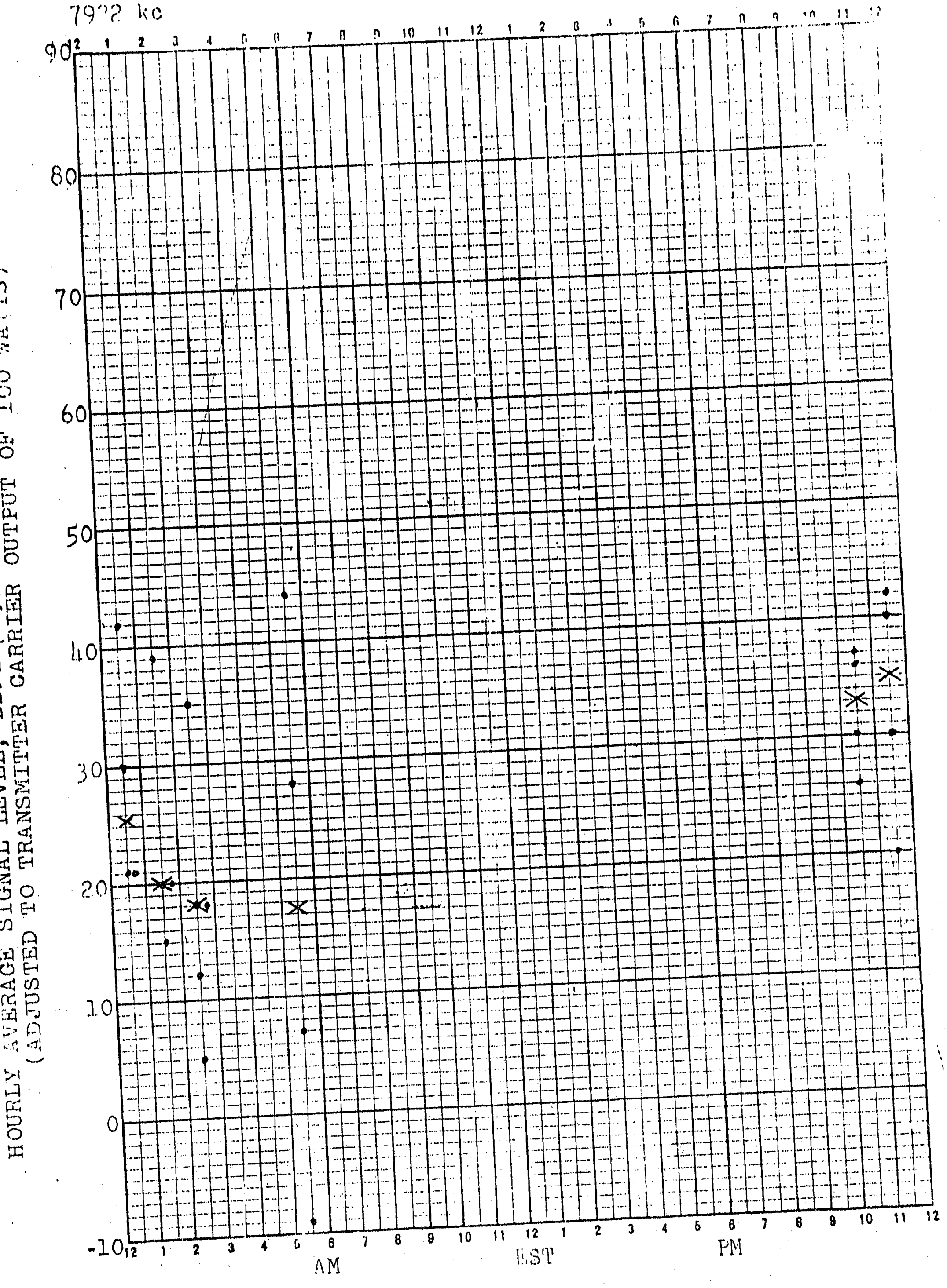


Figure AA7

MASS PLOT OF HOURLY AVERAGE SUPPRESSED CARRIER SIGNAL LEVELS FROM KAHUKU'S SSB TRANSMISSIONS RECEIVED AT RIVERHEAD

6790 kc
7922.5 kc
8180 kc

APRIL 1954

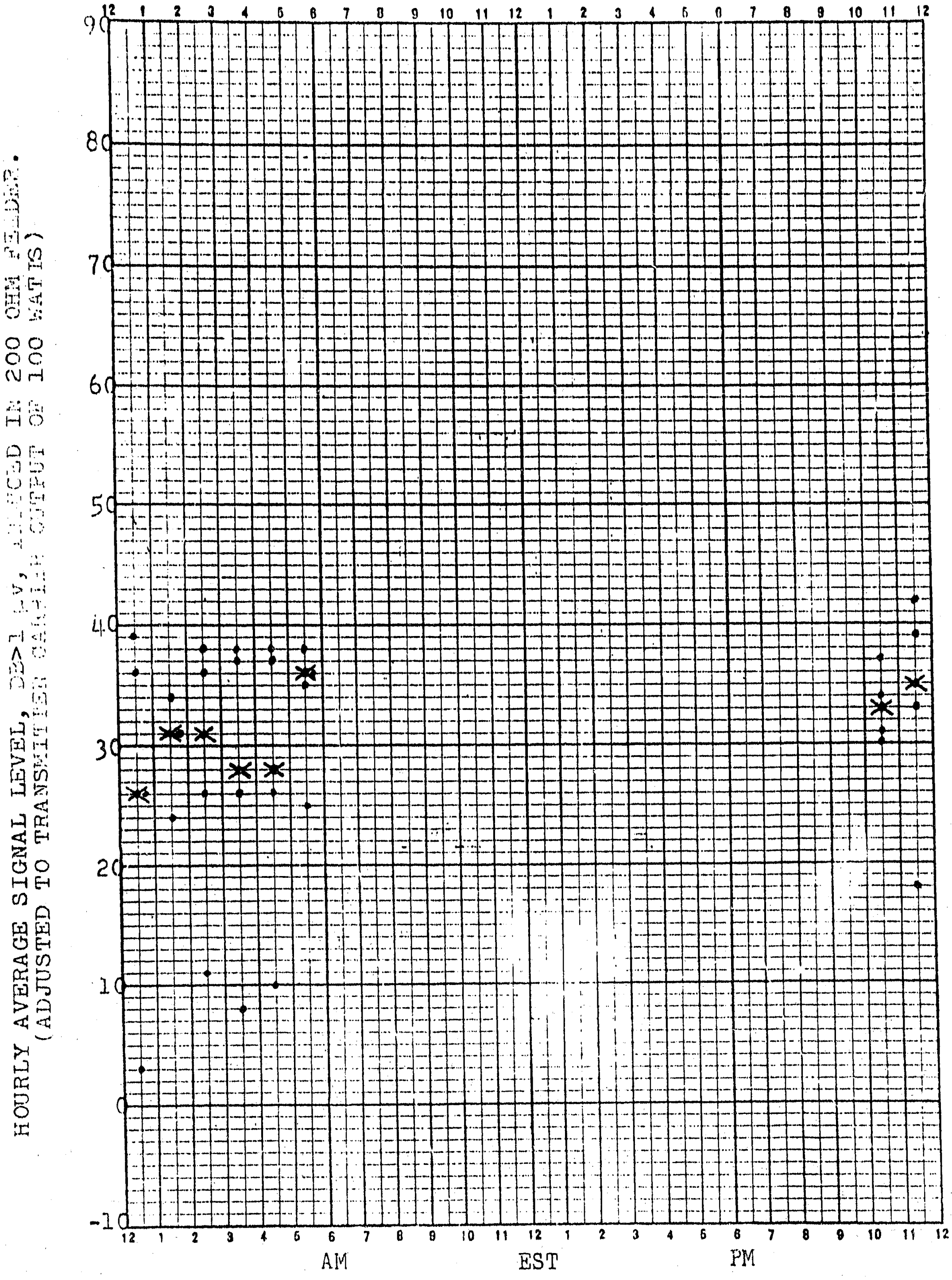


Figure AA8

MASS PLOT OF HOURLY AVERAGE REDUCED CARRIER LEVELS FROM KAHUKU'S SSB TRANSMISSIONS RECEIVED AT RIVERHEAD

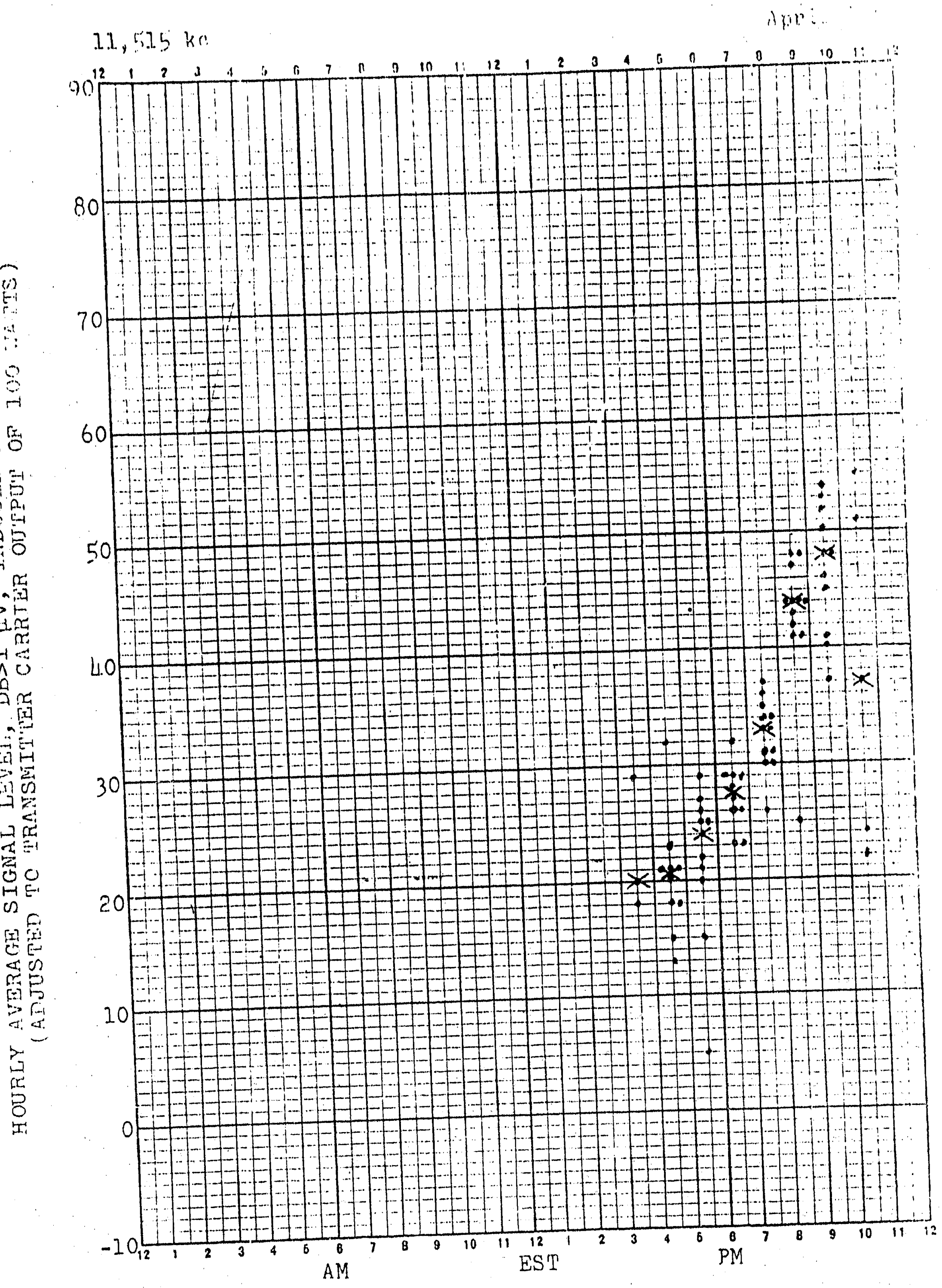


Figure AA9

MASS PLOT OF HOURLY AVERAGE SUPPRESSED CARRIER SIGNAL LEVELS FROM KAHUKU'S SSB TRANSMISSIONS RECEIVED AT RIVERHEAD

MAY 1954

14,450 kc
14,615 kc

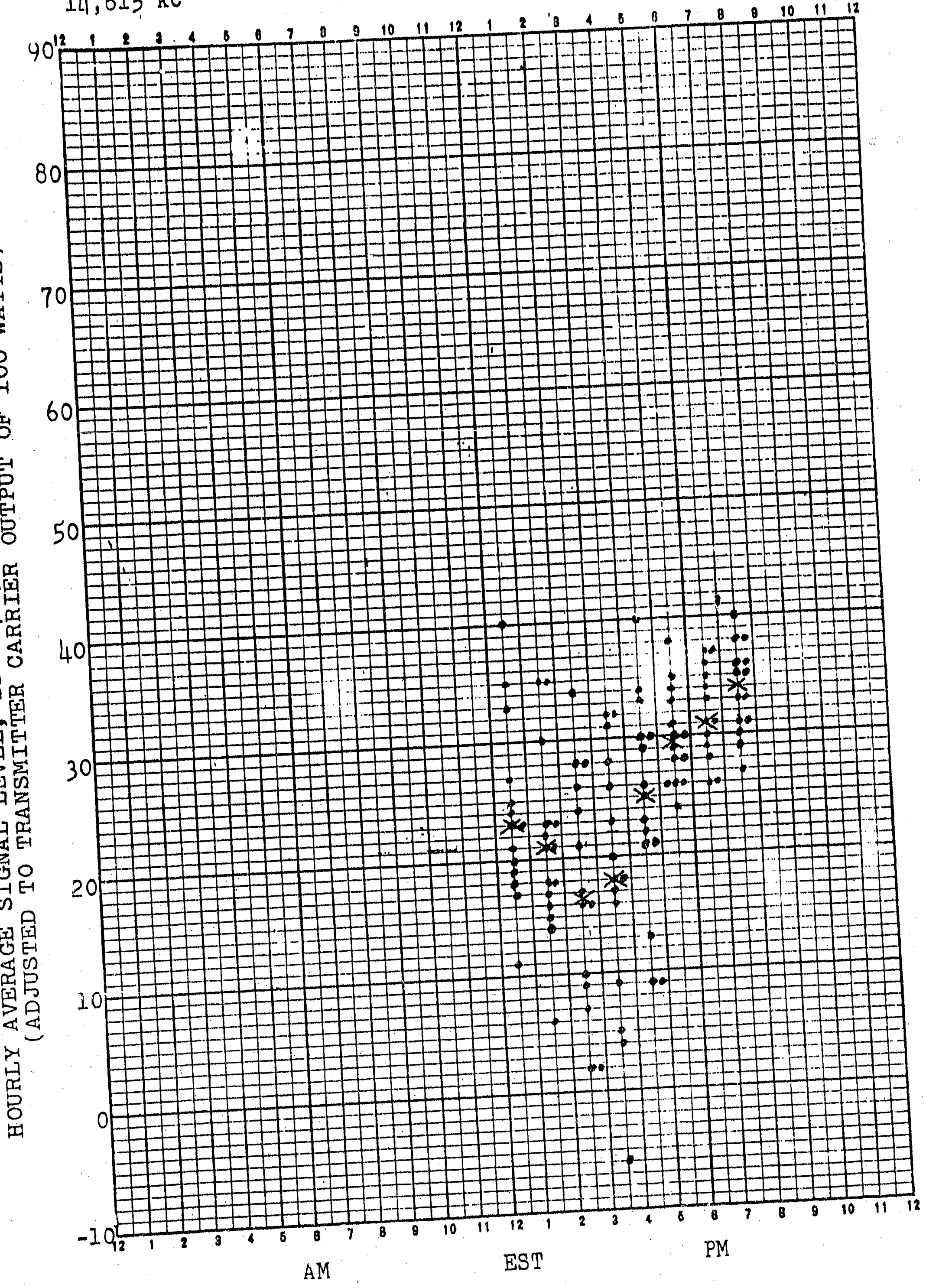


Figure AA10

MASS PLOT OF HOURLY AVERAGE REDUCED CARRIER LEVELS FROM KAHUKU SSB TRANSMISSIONS RECEIVED AT RIVERHEAD

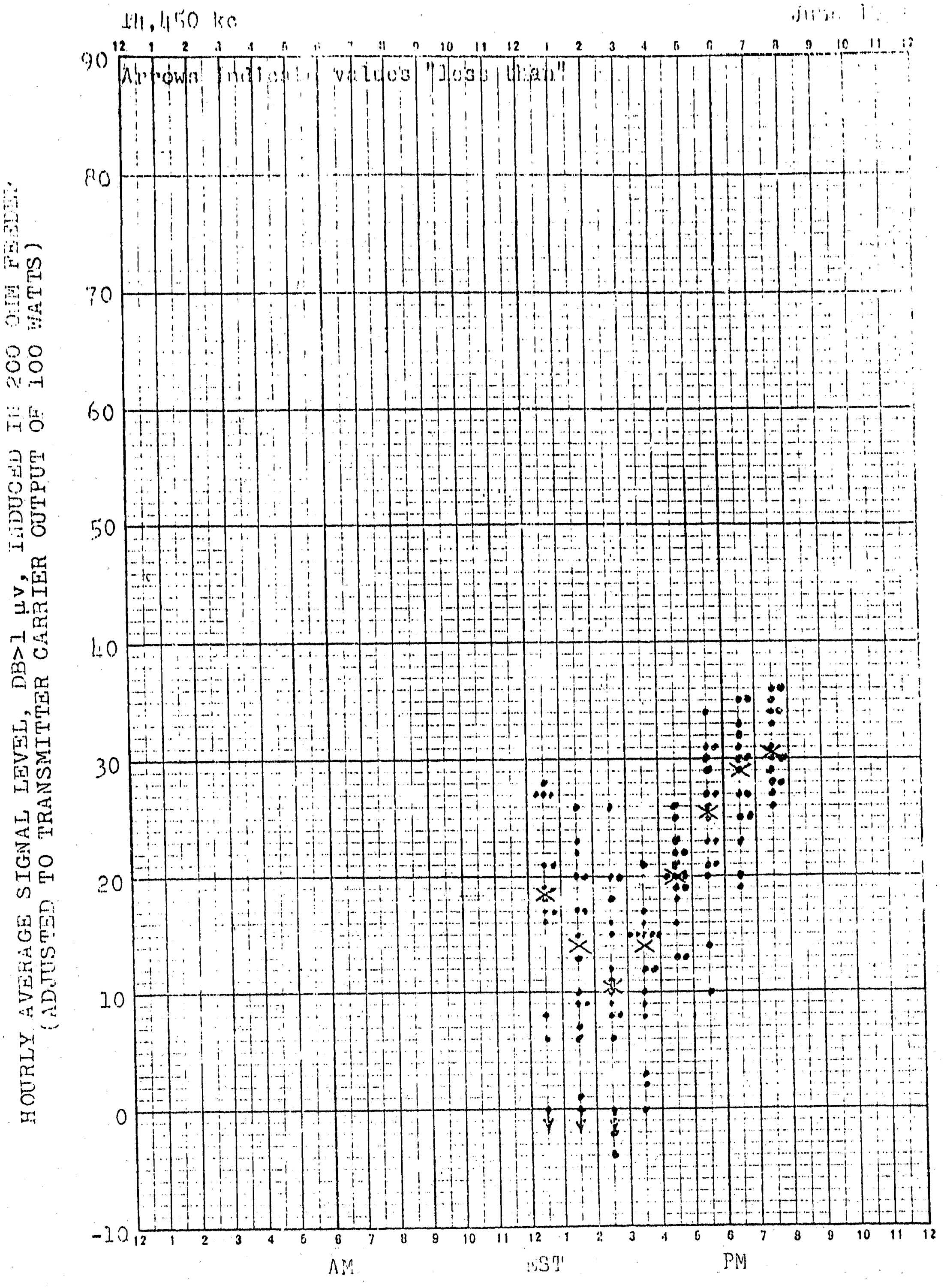


Figure AA11

MASS PLOT OF HOURLY AVERAGE SUPPRESSED CARRIER SIGNAL LEVELS FROM KAHUKU'S SSB TRANSMISSIONS RECEIVED AT RIVERHEAD

14,450 kc

JULY 1954

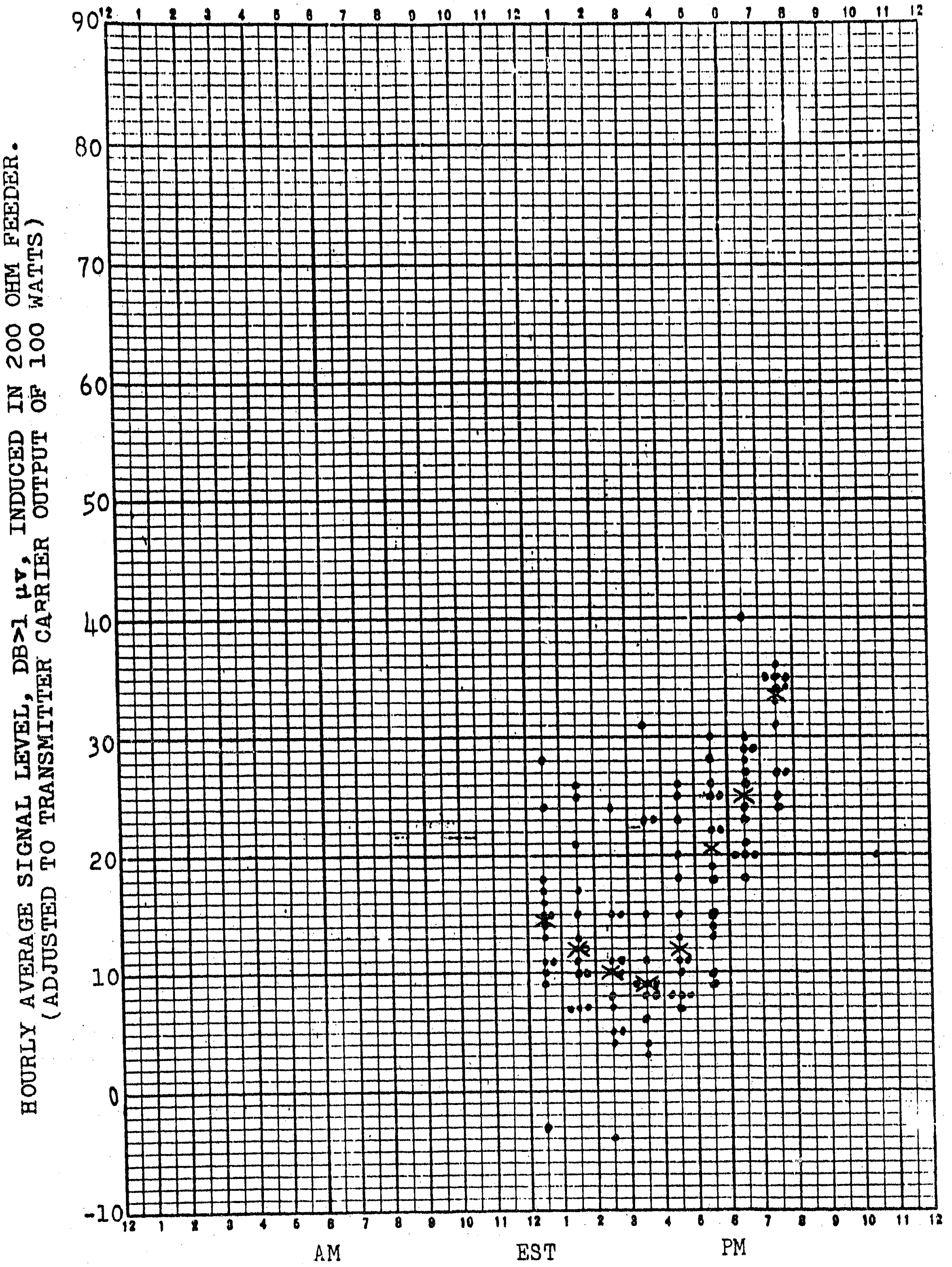


Figure AA12

MASS PLOT OF HOURLY AVERAGE SUPPRESSED CARRIER SIGNAL LEVELS FROM KAHUKU'S SSB TRANSMISSIONS RECEIVED AT RIVERHEAD

14,450 kc

AUGUST 1954

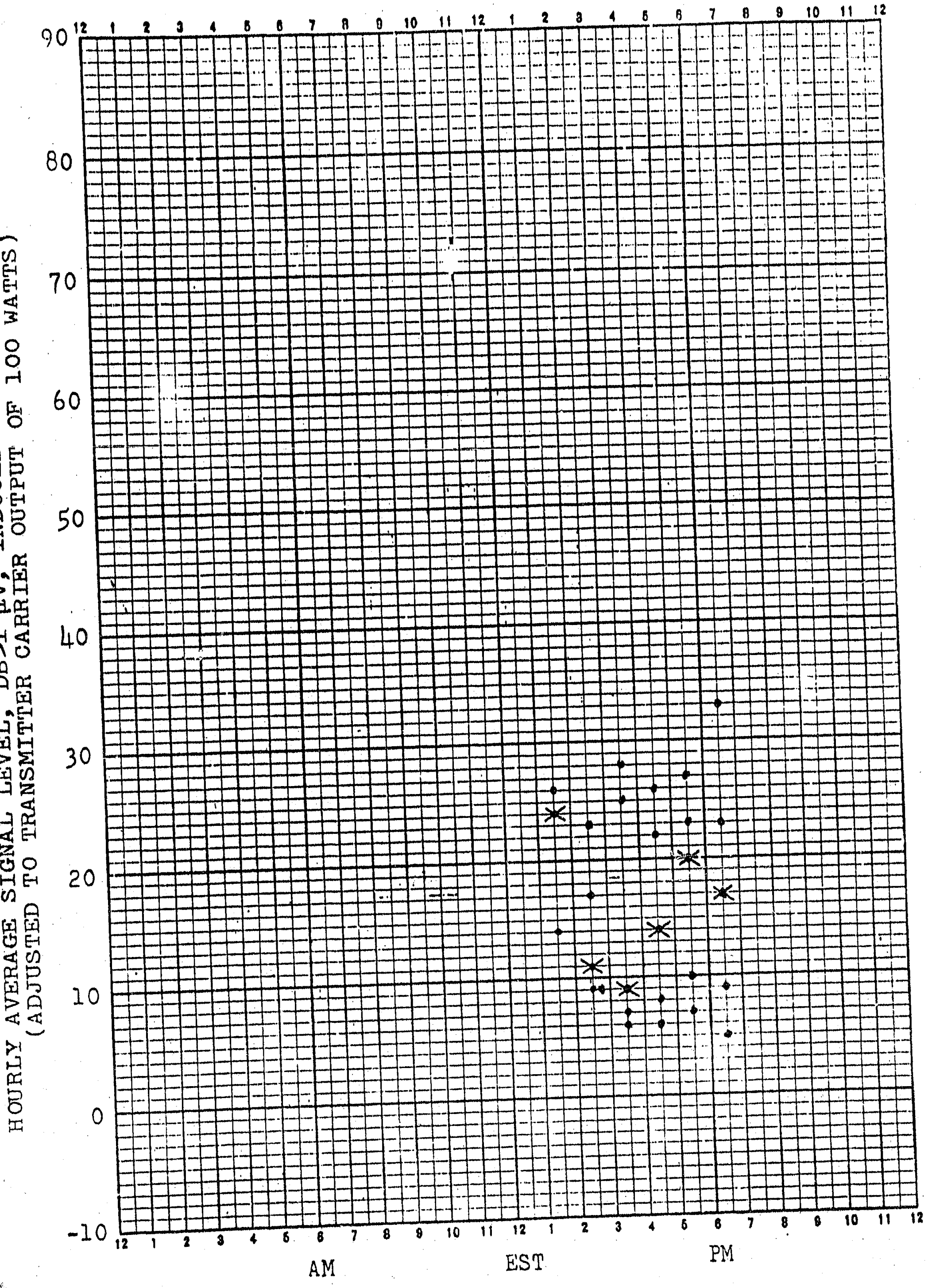


Figure AA13

MASS PLOT OF HOURLY AVERAGE SUPPRESSED CARRIER SIGNAL LEVELS FROM KAHUKU'S SSB TRANSMISSIONS RECEIVED AT RIVERHEAD

14,450 kc

SEPTEMBER 1954

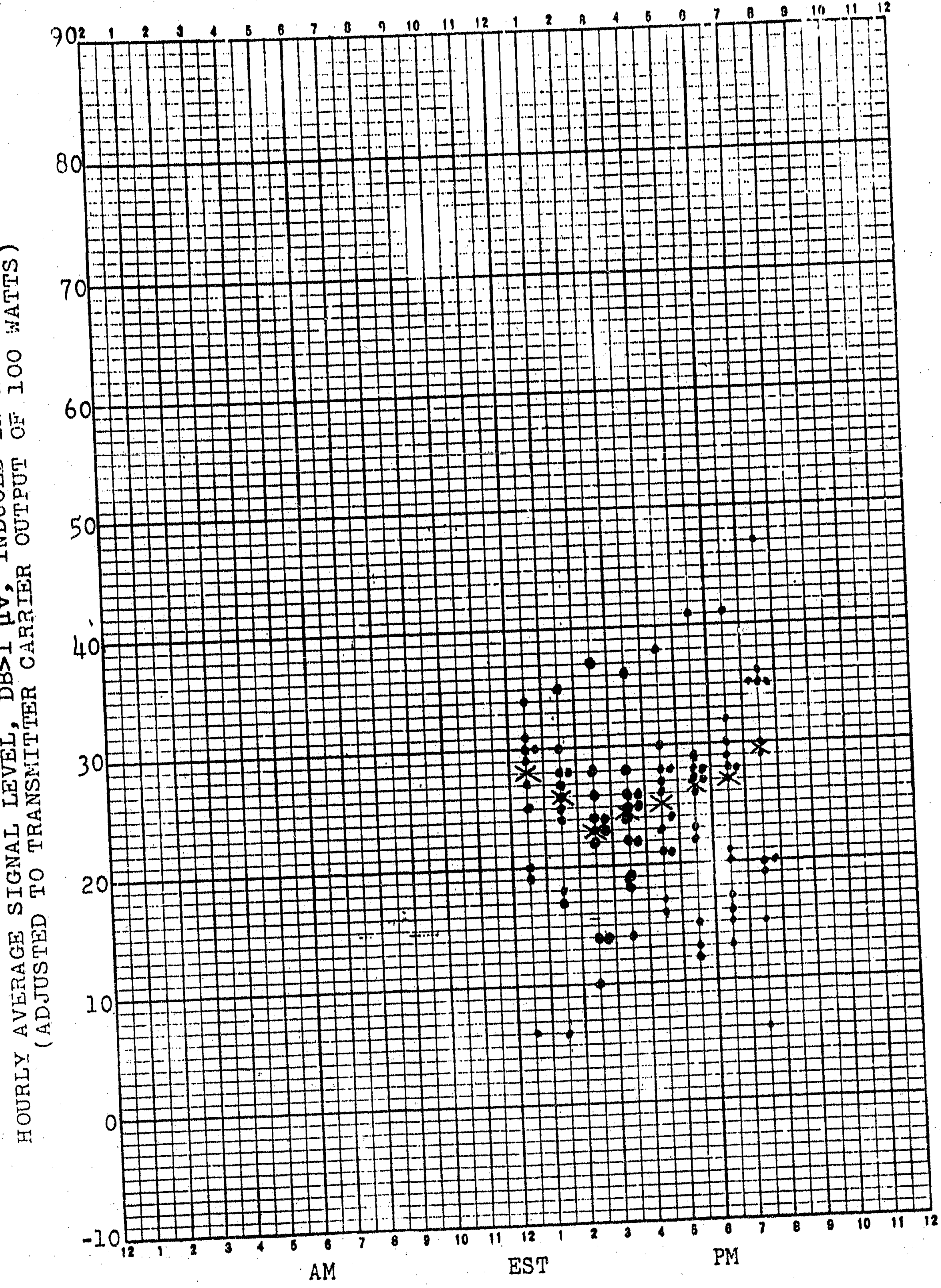


Figure AA14

MASS PLOT OF HOURLY AVERAGE SUPPRESSED CARRIER SIGNAL LEVELS FROM KAHUKU'S SSB TRANSMISSIONS RECEIVED AT RIVERHEAD

14,450 kc

NOVEMBER 1954

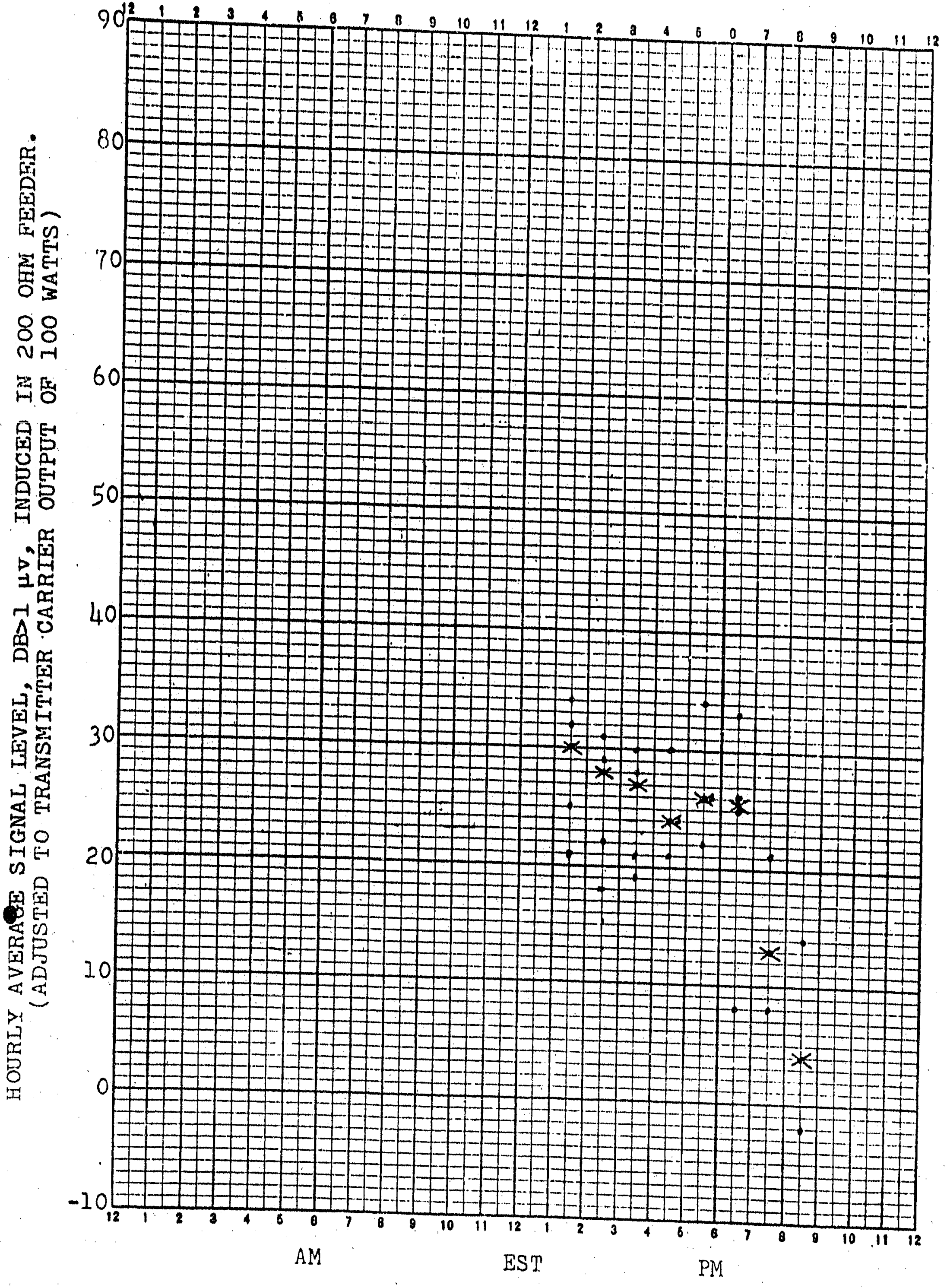


Figure AA15

MASS PLOT OF HOURLY AVERAGE SUPPRESSED CARRIER LEVELS FROM KAHUKU, SSB TRANSMISSIONS RECEIVED AT RIVERHEAD

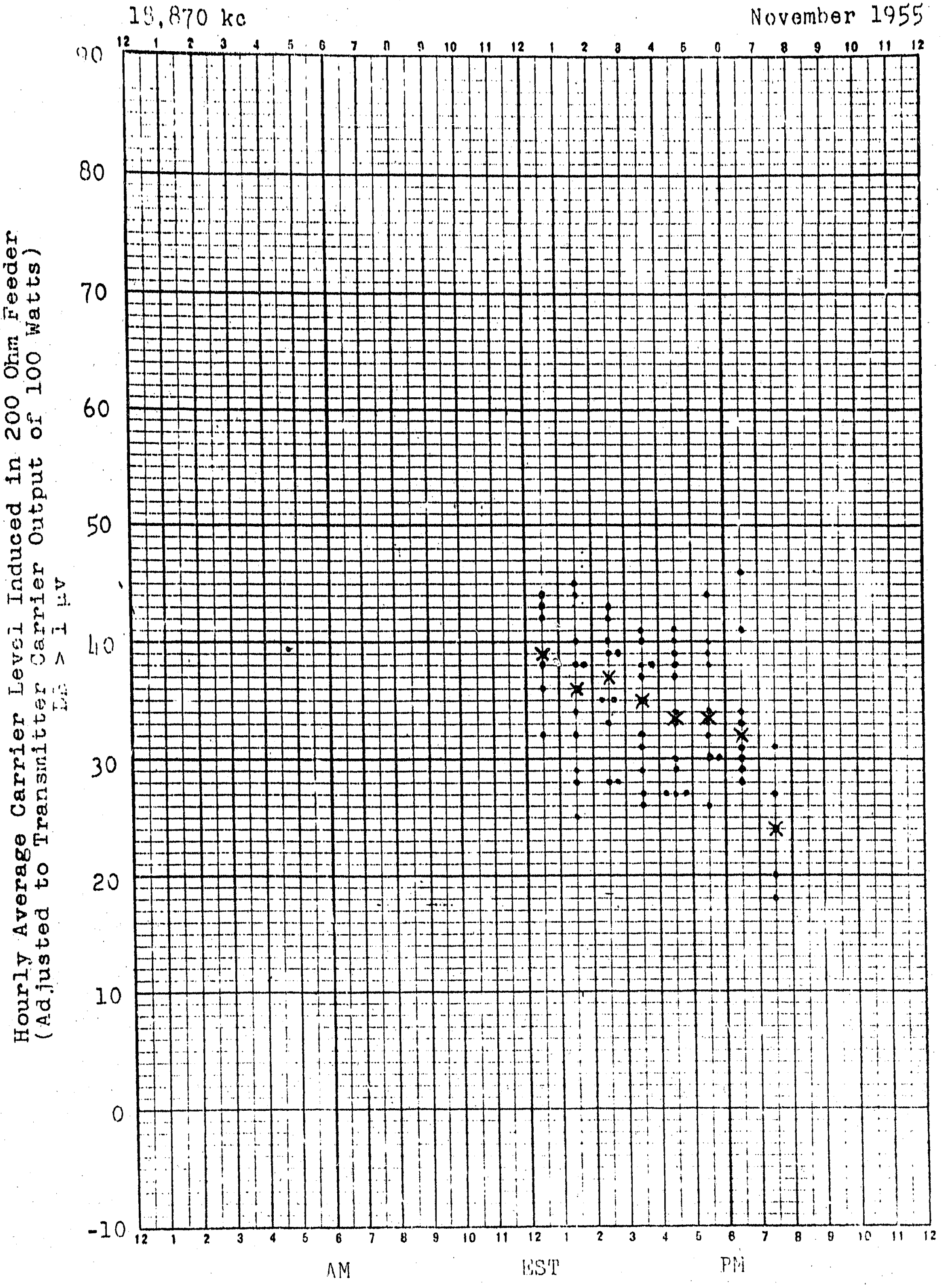


Figure A16

MASS PLOT OF HOURLY AVERAGE SUPPRESSED CARRIER LEVELS FROM KAHUKU, SSB TRANSMISSIONS RECEIVED AT RIVERHEAD

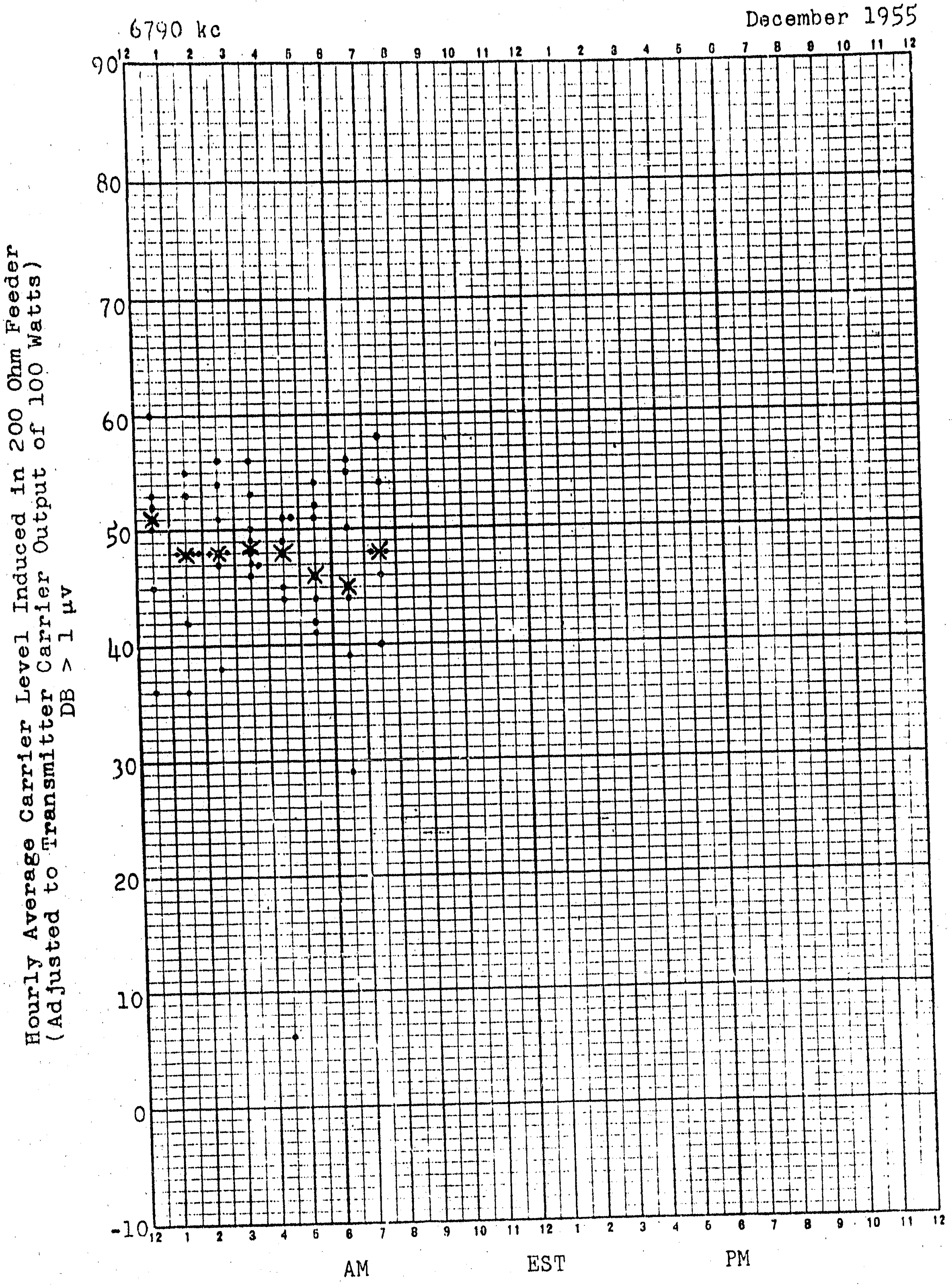


Figure AA

MASS PLOT OF HOURLY AVERAGE SUPPRESSED CARRIER LEVELS FROM KAHUKU, SSB TRANSMISSIONS RECEIVED AT RIVERHEAD

December 1955

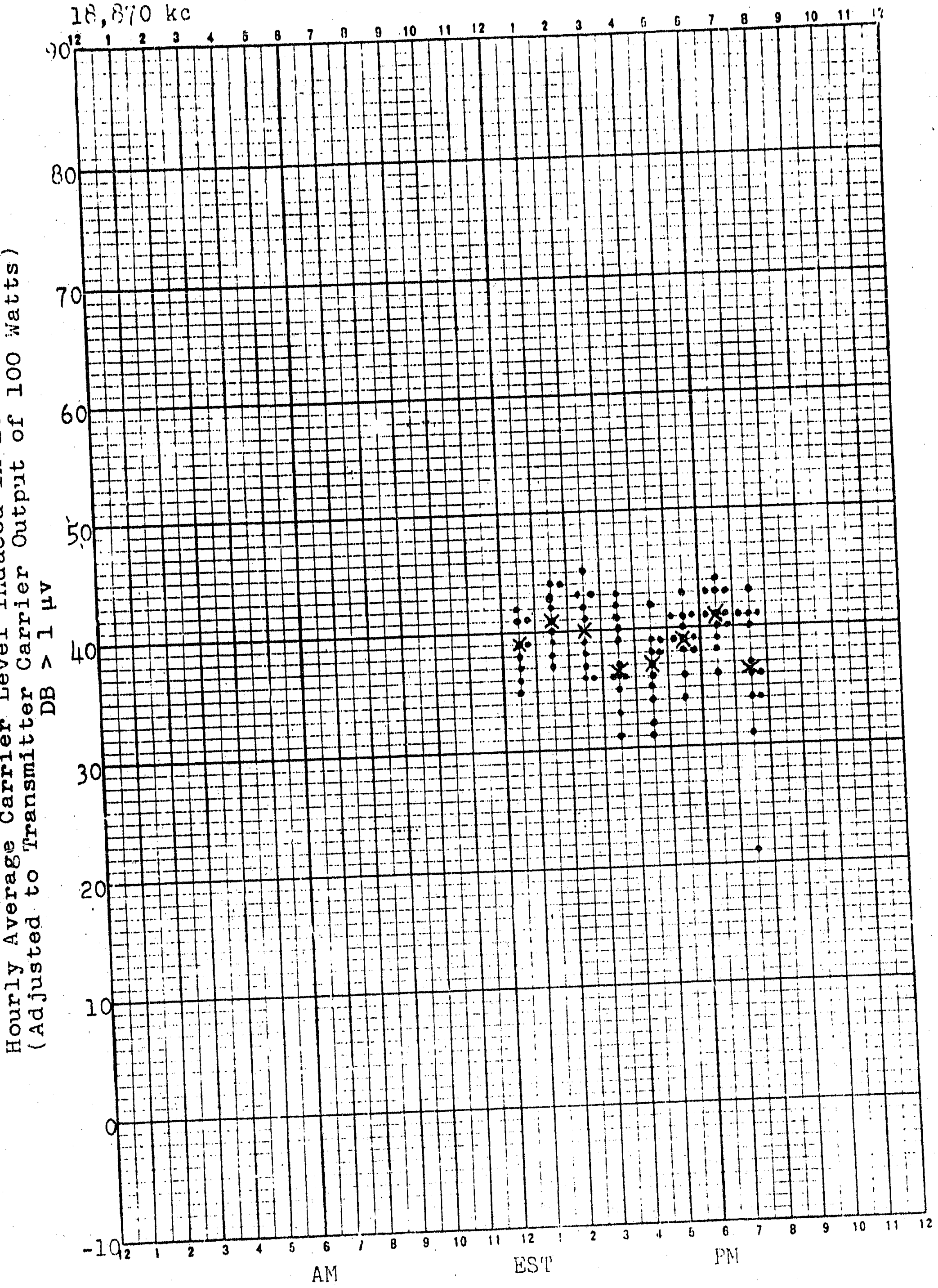


Figure AA18

MASS PLOT OF HOURLY AVERAGE SUPPRESSED CARRIER LEVELS FROM KAHUKU, SSB TRANSMISSIONS RECEIVED AT RIVERHEAD

January 1956

6790 kc

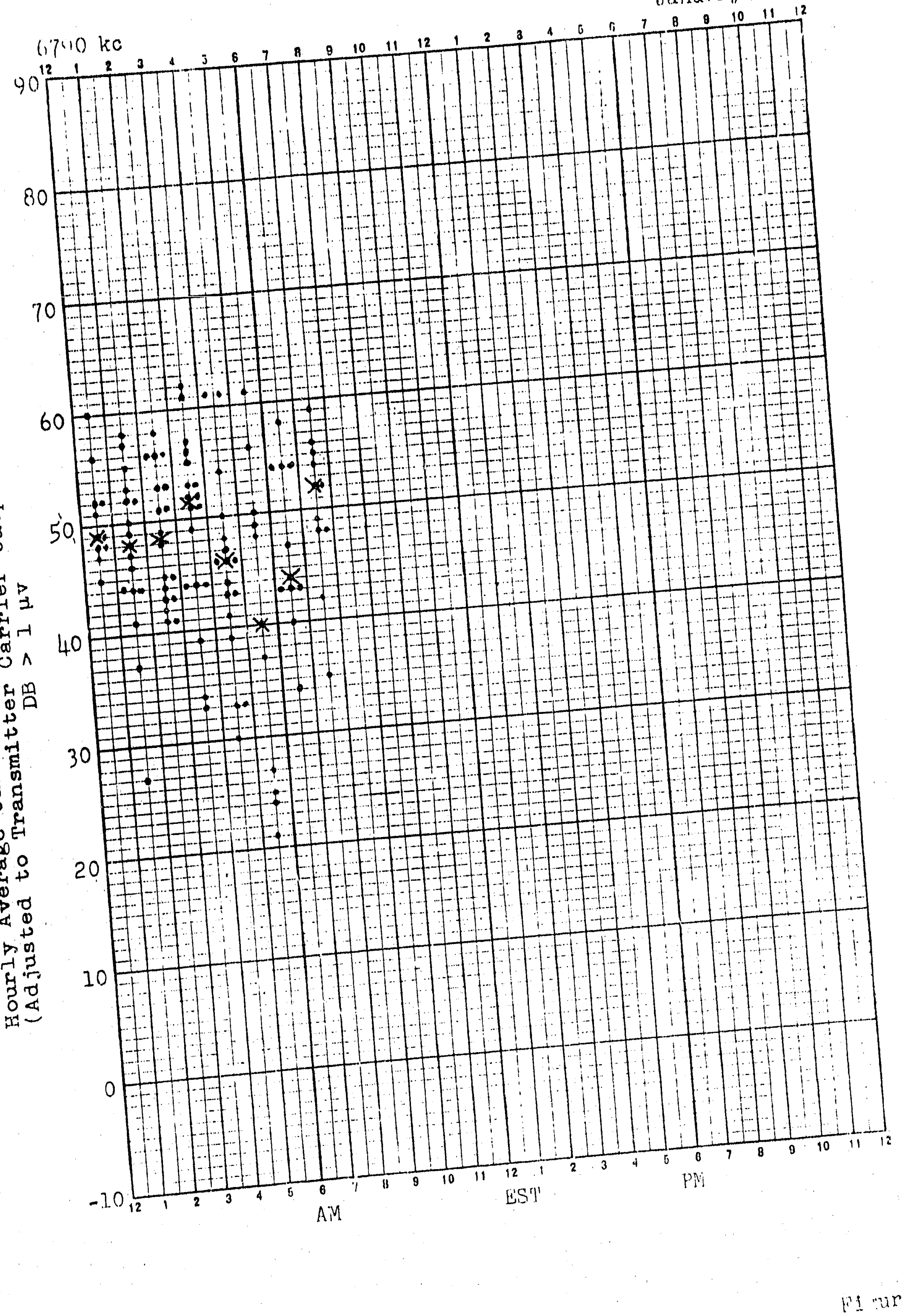


Figure AA19

MASS PLOT OF HOURLY AVERAGE SUPPRESSED CARRIER LEVELS FROM KAHUKU, SSB TRANSMISSIONS RECEIVED AT RIVERHEAD

February 1956

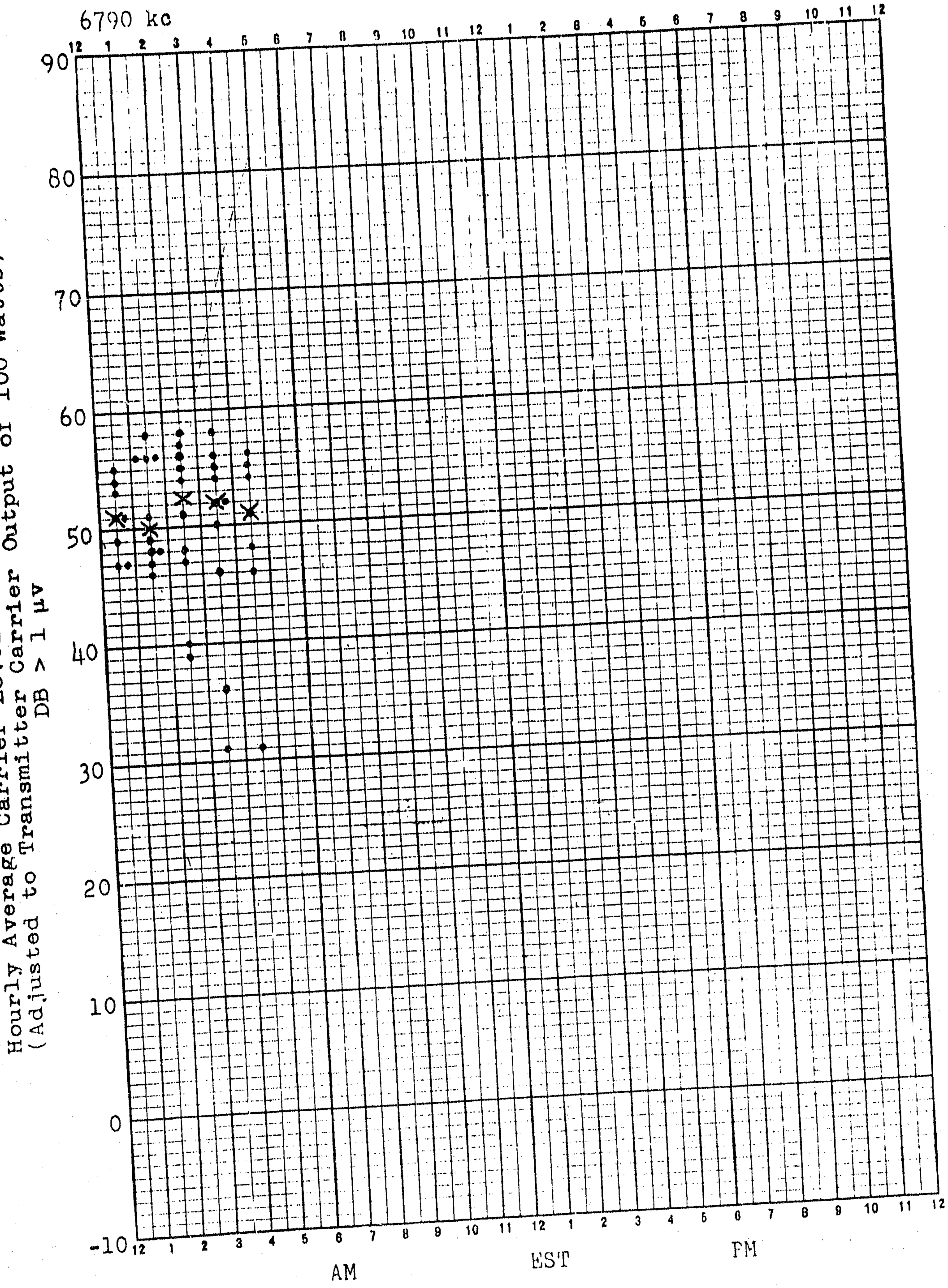


Figure AA20

MASS PLOT OF HOURLY AVERAGE SUPPRESSED CARRIER LEVELS FROM KAHUKU, SSB TRANSMISSIONS RECEIVED AT RIVERHEAD

7922.5 kc

February 1956

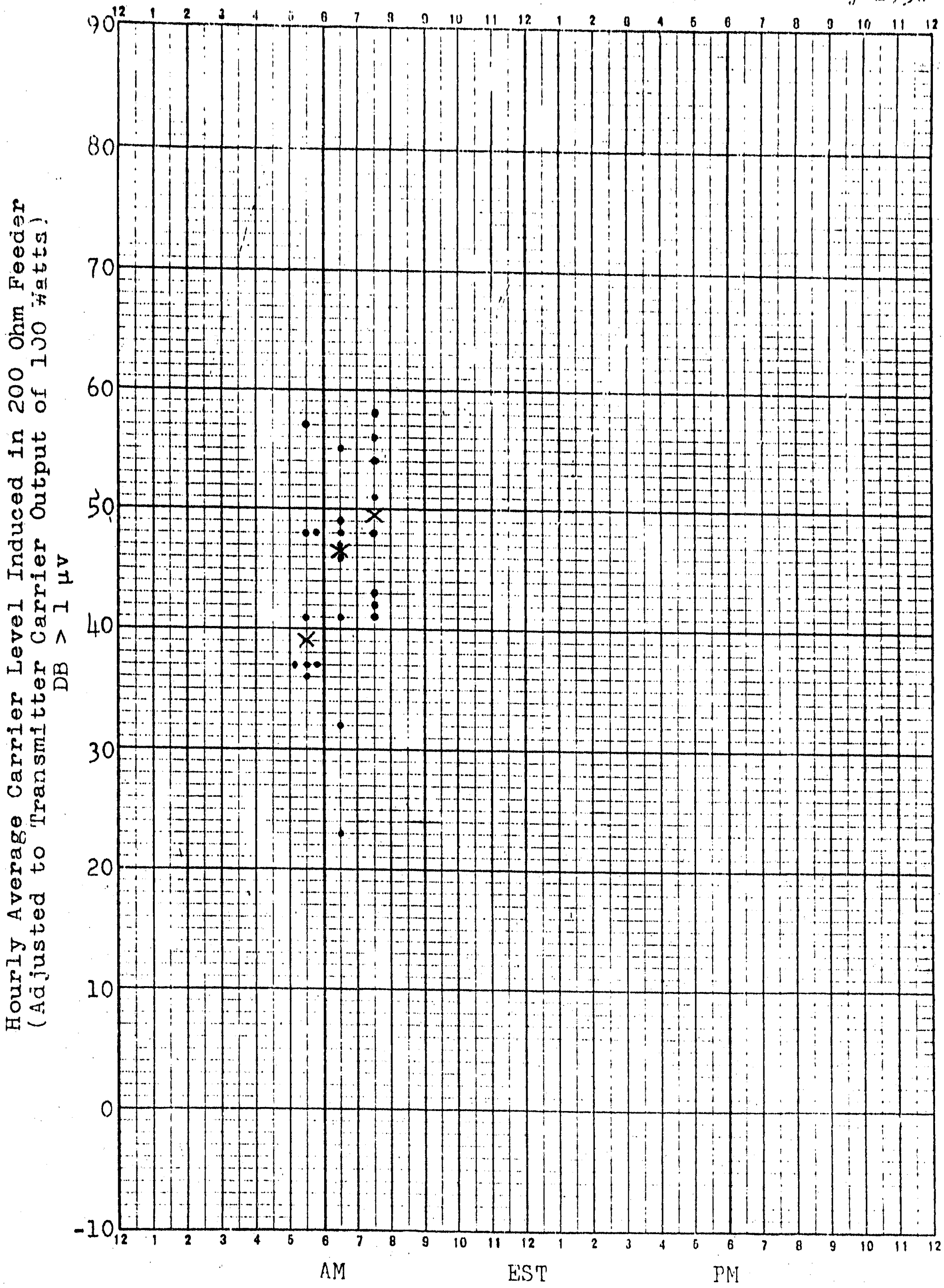


Figure AA21

MASS PLOT OF HOURLY AVERAGE SUPPRESSED CARRIER LEVELS FROM KAHUKU, SSB TRANSMISSIONS RECEIVED AT RIVERHEAD

18,870 kc

February 1956

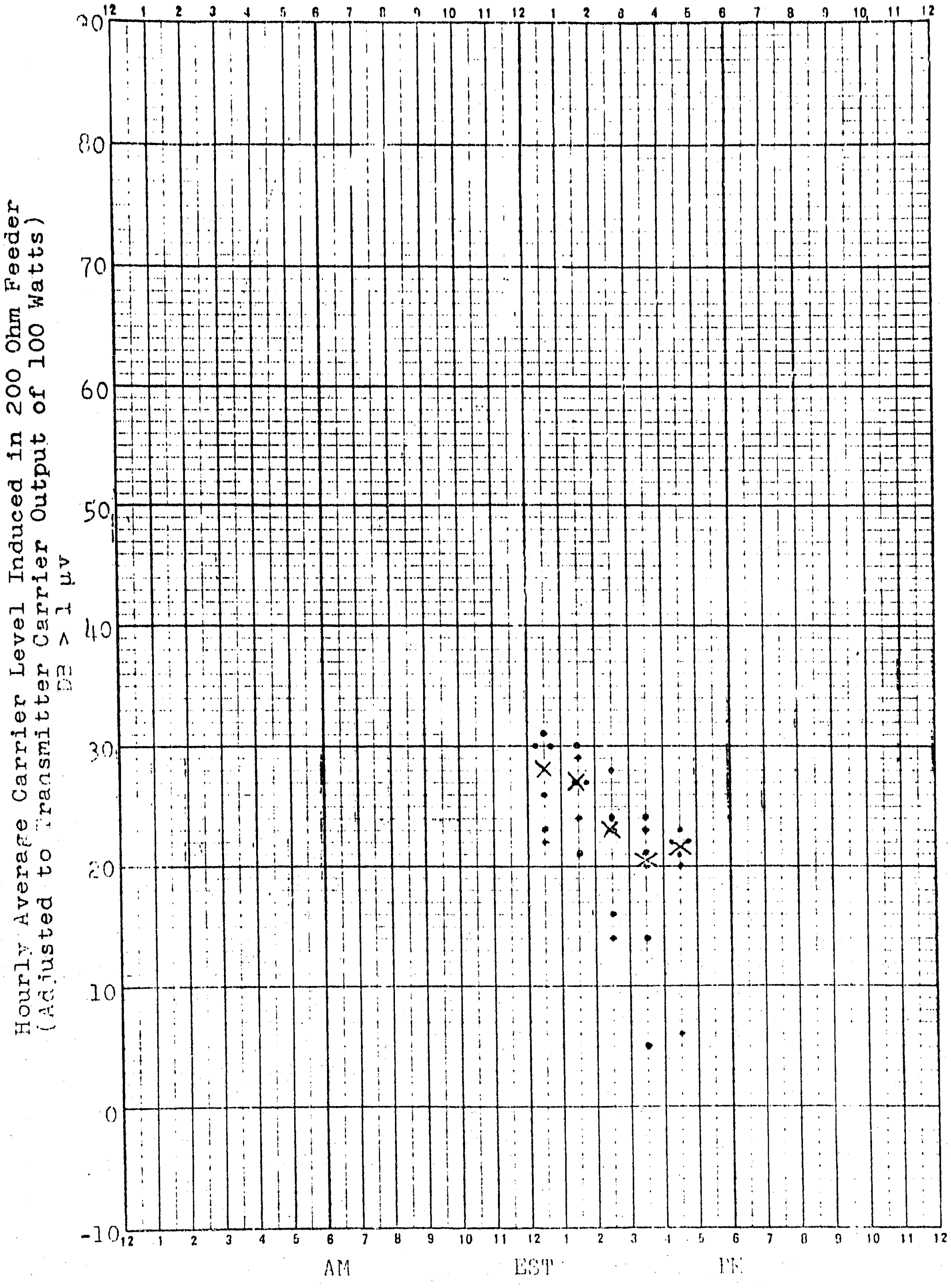


Figure AA22

MASS PLOT OF HOURLY SUPPRESSED CARRIER LEVELS (AVERAGE) FROM KAHUKU, SSB TRANSMISSIONS RECEIVED AT RIVERHEAD

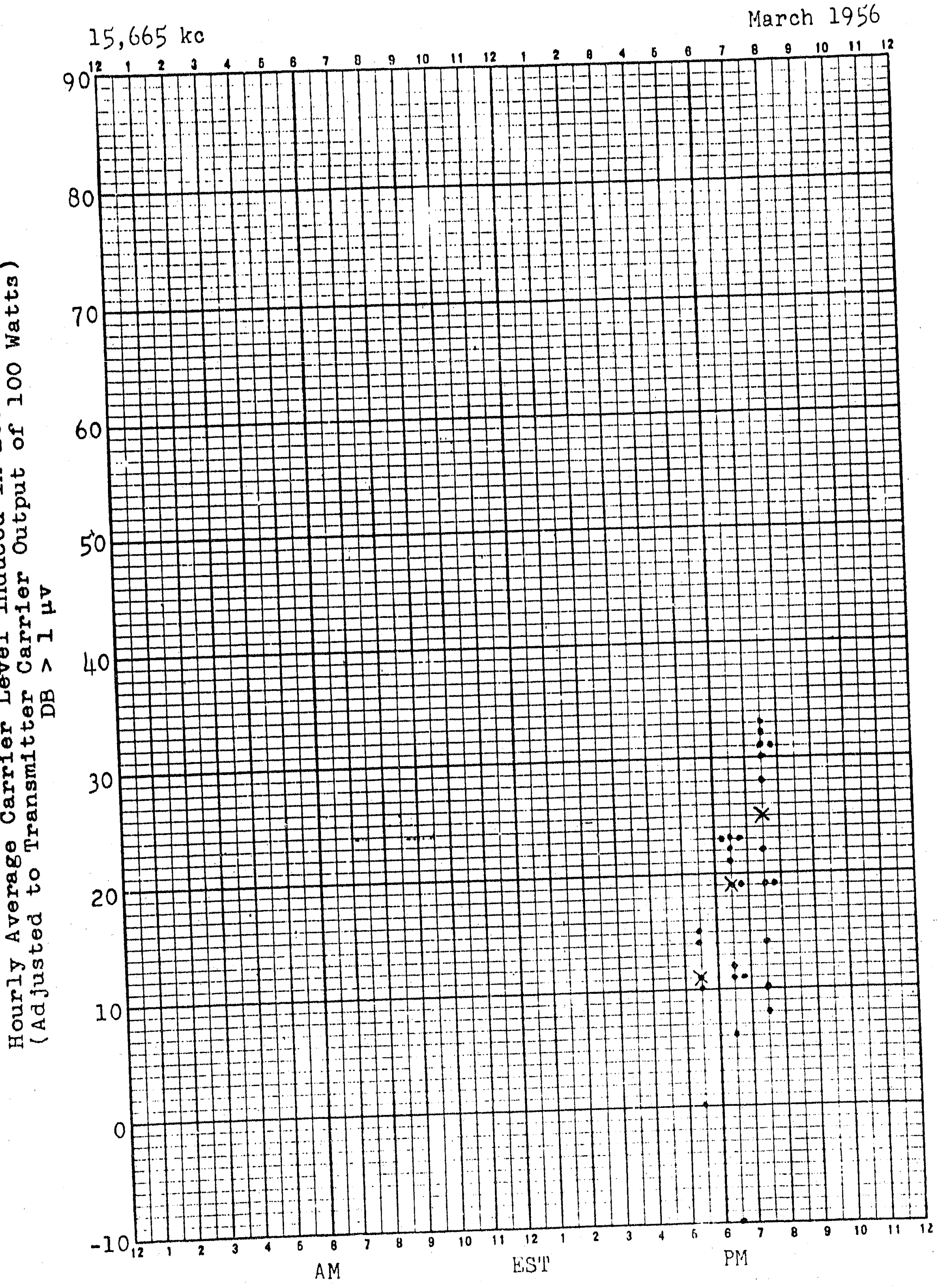


Figure AA23

MASS PLOT OF HOURLY AVERAGE SUPPRESSED CARRIER LEVELS FROM KAHUKU, SSB TRANSMISSIONS RECEIVED AT RIVERHEAD

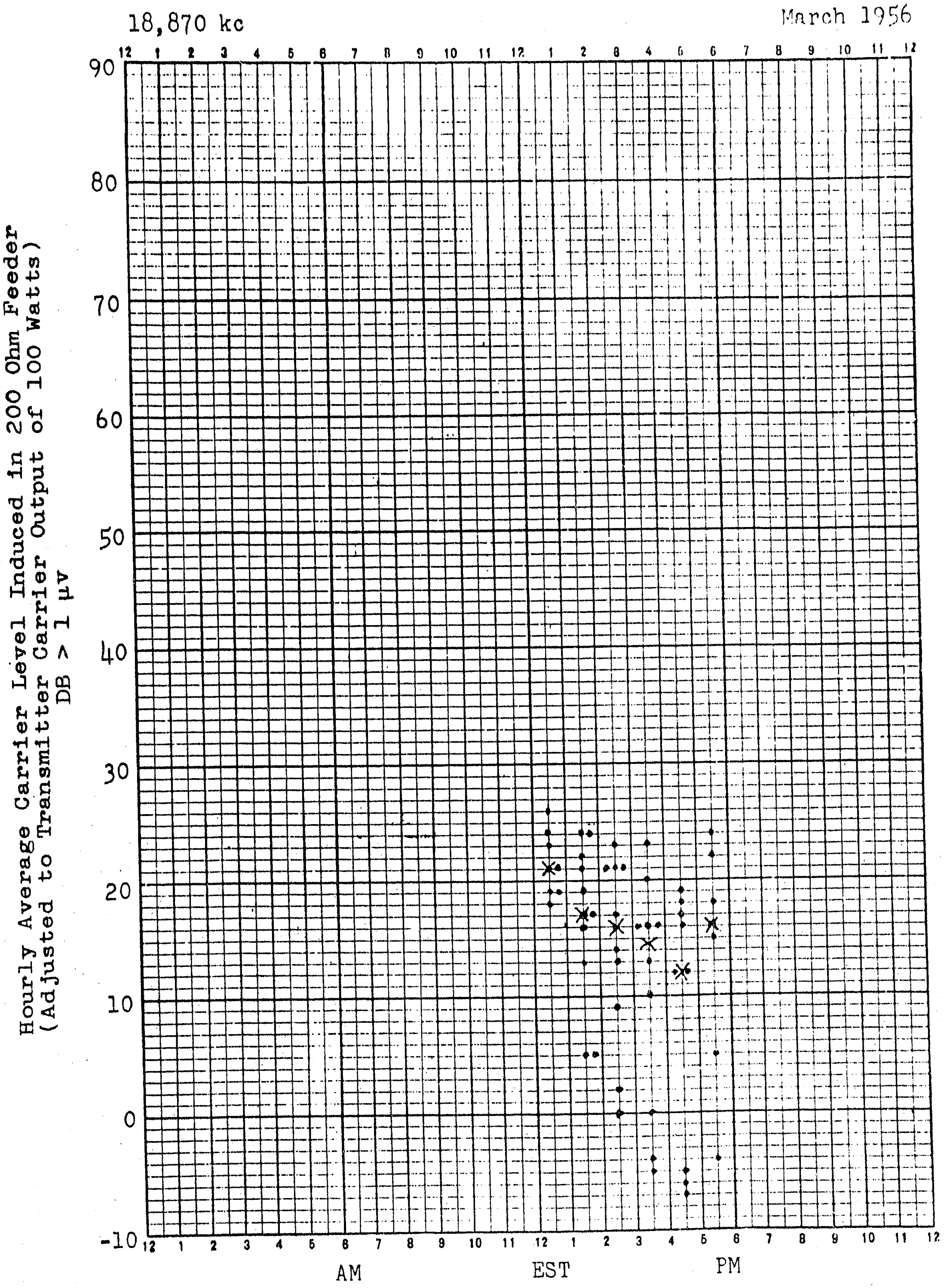


Figure AA2

MASS PLOT OF HOURLY AVERAGE SUPPRESSED CARRIER LEVELS
FROM KAHUKU, SSB TRANSMISSIONS
RECEIVED AT RIVERHEAD

20,288 kc

April 1956

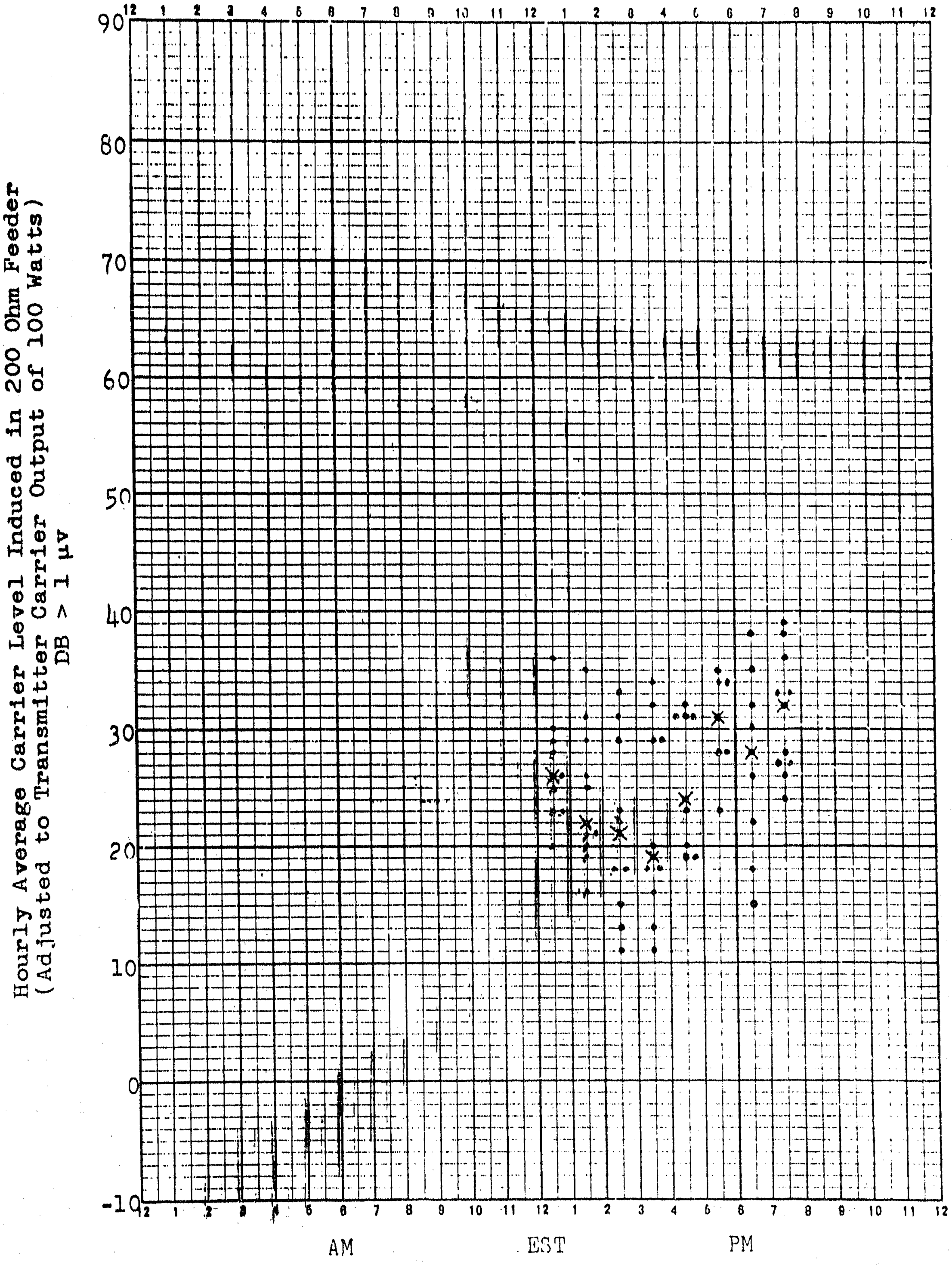


Figure AA25

MASS PLOT OF HOURLY AVERAGE SUPPRESSED CARRIER LEVELS FROM KAHUKU, SSB TRANSMISSIONS RECEIVED AT RIVERHEAD

20,288 kc

May 1956

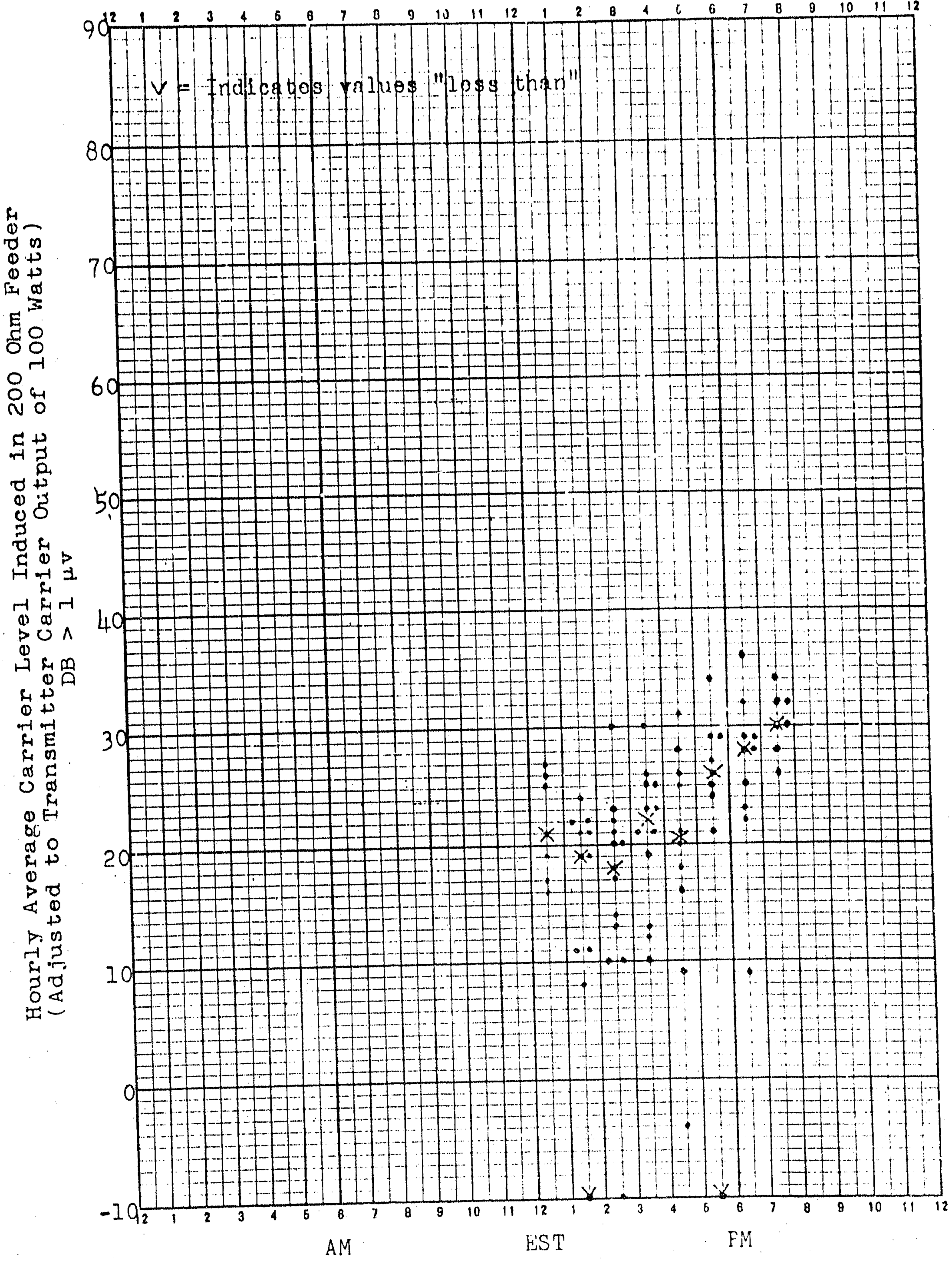
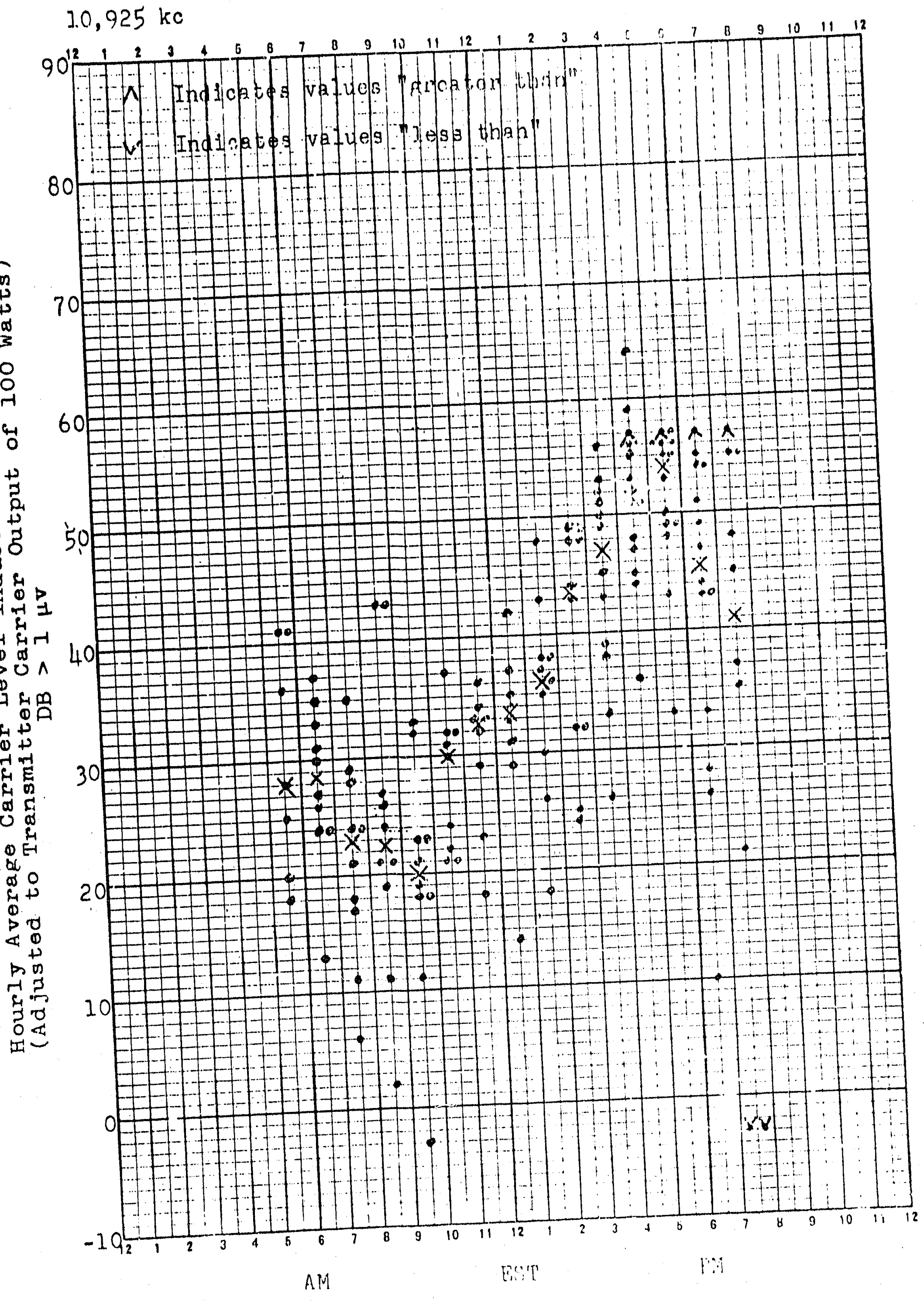


Figure AA2

MASS PLOT OF HOURLY AVERAGE SUPPRESSED CARRIER LEVELS FROM ORLEANS, FRANCE, SSB TRANSMISSIONS RECEIVED AT RIVERHEAD

August 1954

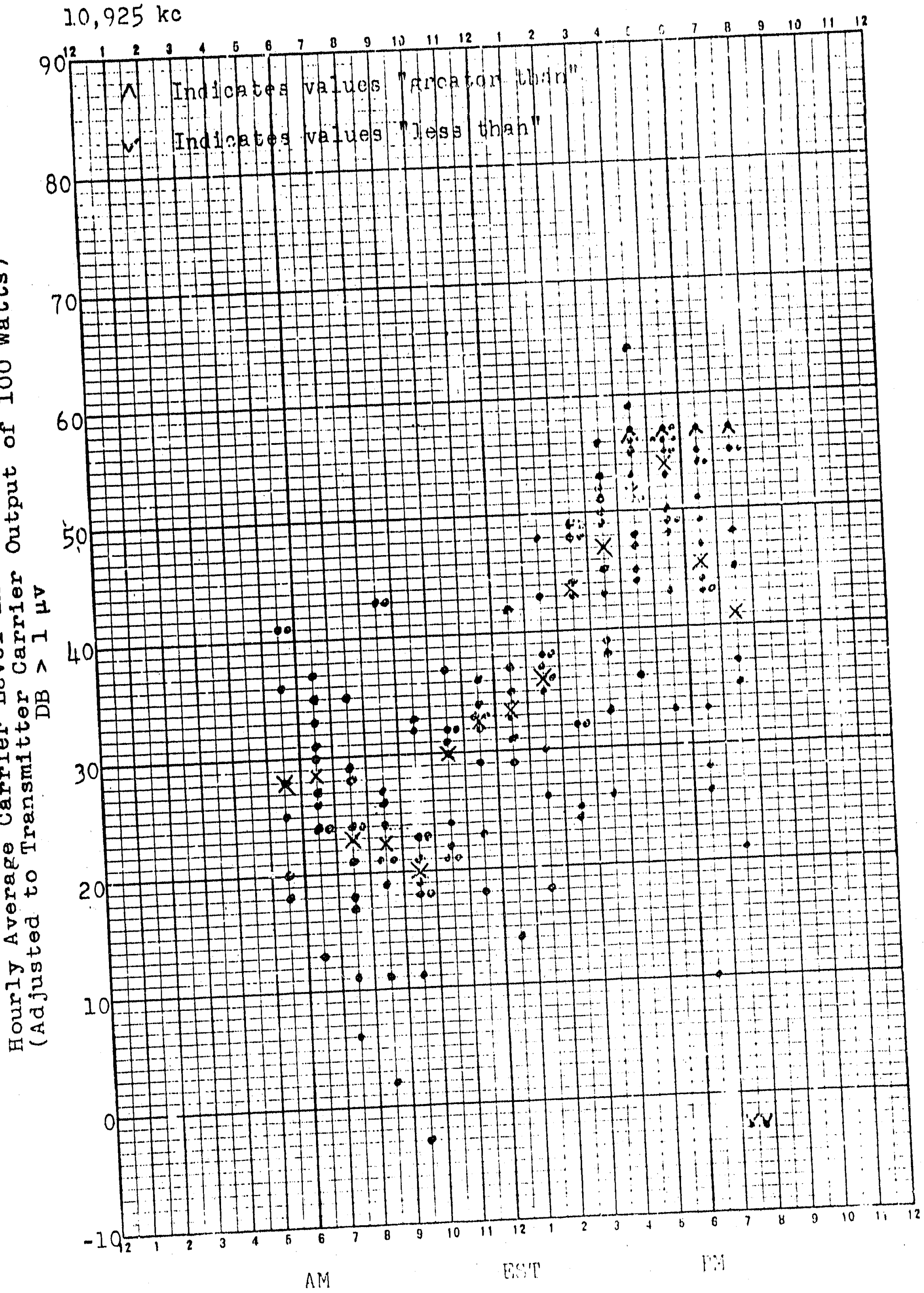


ure A

MASS PLOT OF HOURLY AVERAGE SUPPRESSED CARRIER LEVELS FROM ORLEANS, FRANCE, SSB TRANSMISSIONS RECEIVED AT RIVERHEAD

August 1954

10,925 kc



igure A

MASS PLOT OF HOURLY AVERAGE SUPPRESSED CARRIER LEVELS FROM ORLEANS, FRANCE, SSB TRANSMISSIONS RECEIVED AT RIVERHEAD

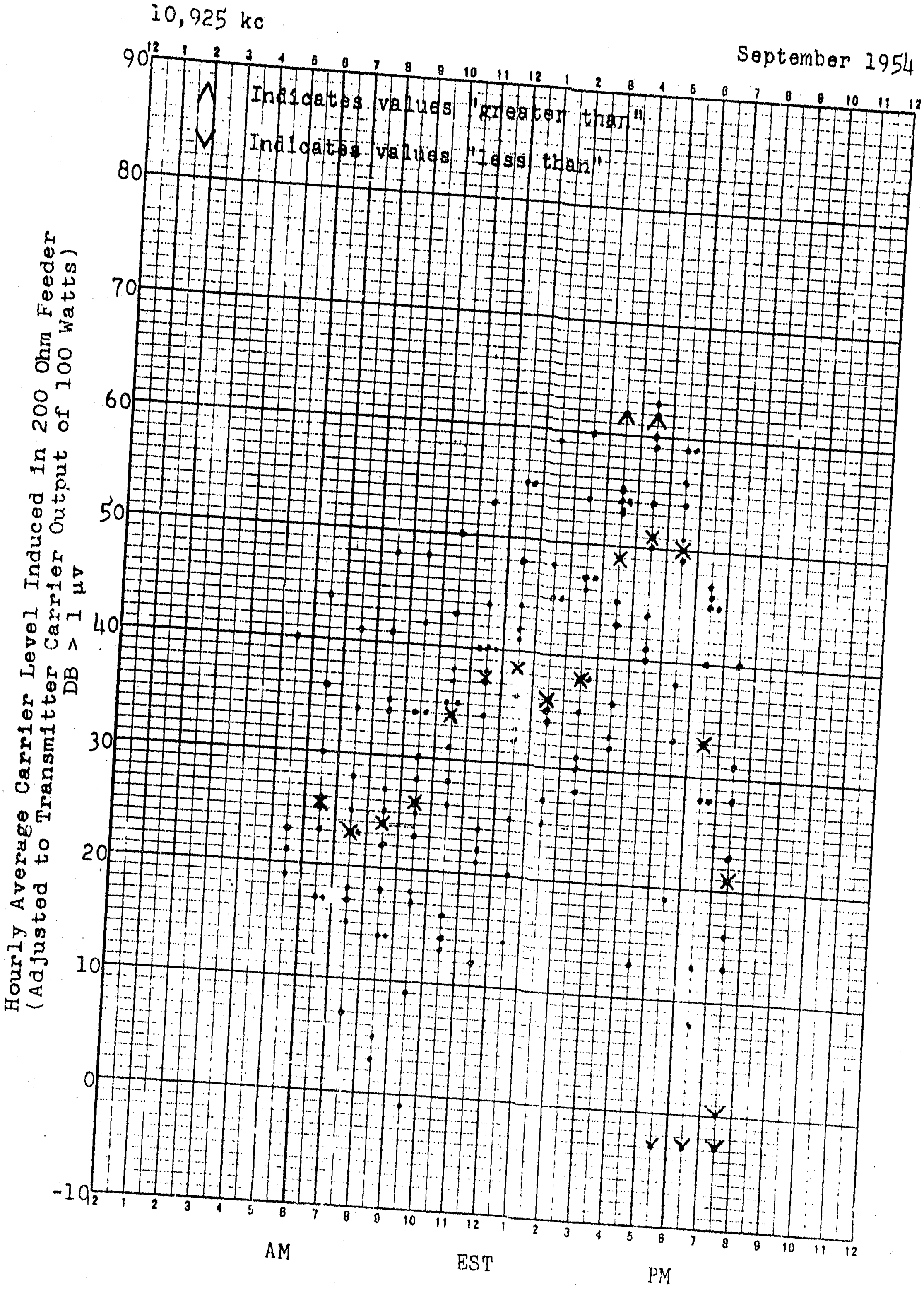


Figure A128

MASS PLOT OF HOURLY AVERAGE SUPPRESSED CARRIER LEVELS FROM ORLEANS, FRANCE, SSB TRANSMISSIONS RECEIVED AT RIVERHEAD

October 1954

10,925 kc

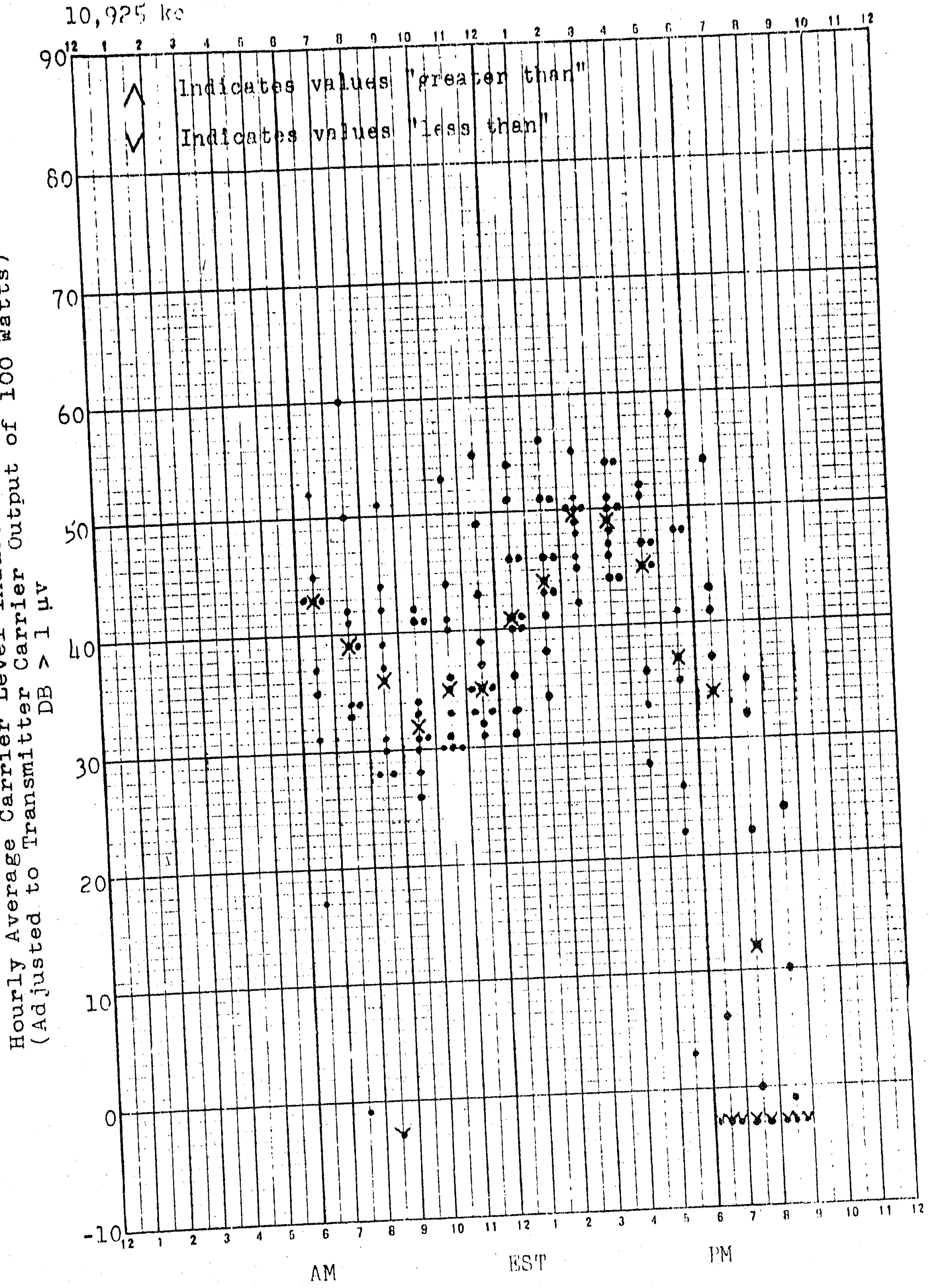


Figure AA29

MASS PLOT OF HOURLY AVERAGE SUPPRESSED CARRIER LEVELS FROM ORLEANS, FRANCE, SSB TRANSMISSIONS RECEIVED AT RIVERHEAD

November 1954

10,925 kc

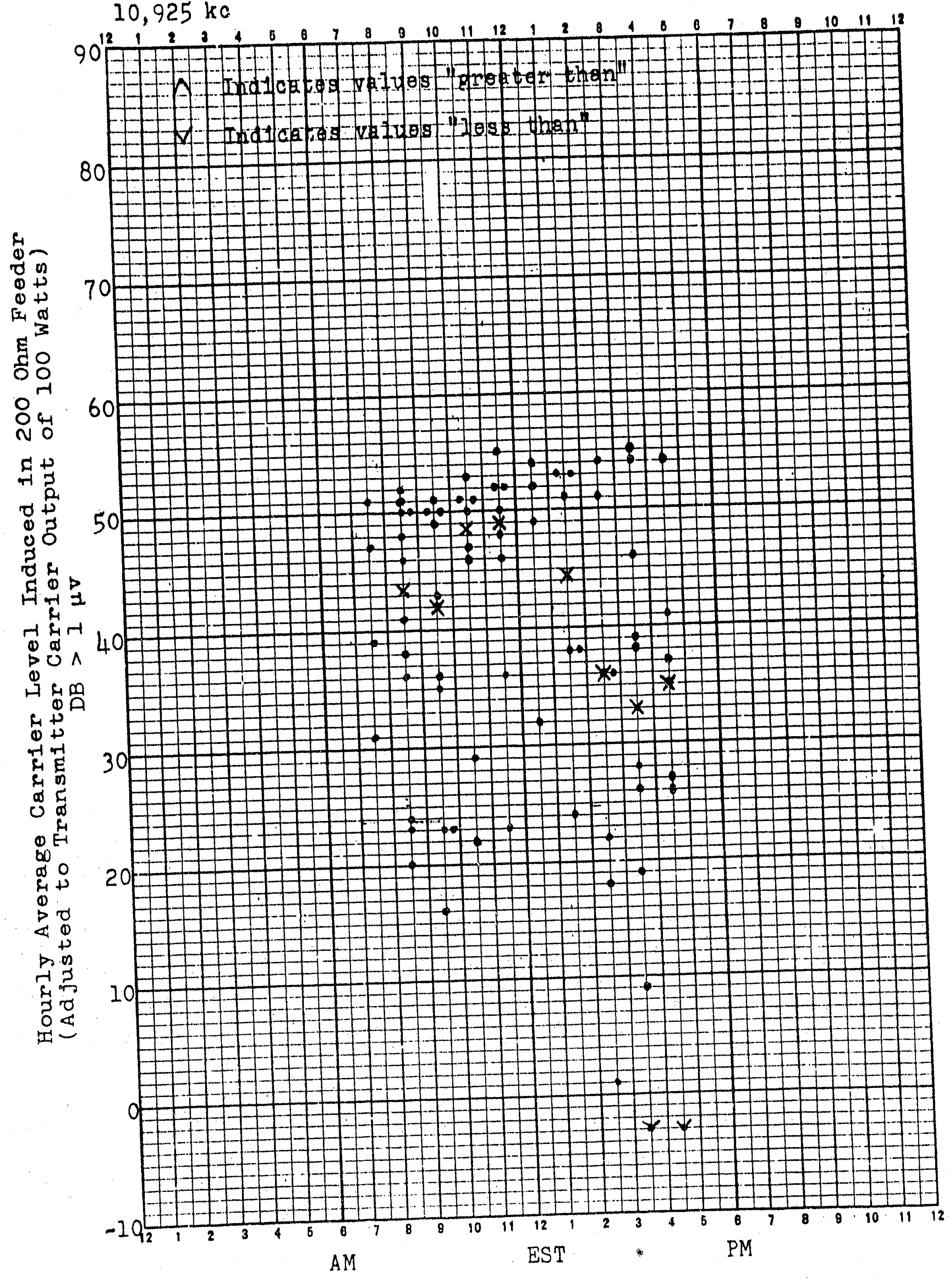


Figure AA30

MONTHLY MEDIAN SUPPRESSED CARRIER LEVELS FROM ORLEANS, FRANCE, SSB TRANSMISSIONS RECEIVED AT RIVERHEAD

10,925 kc

1954

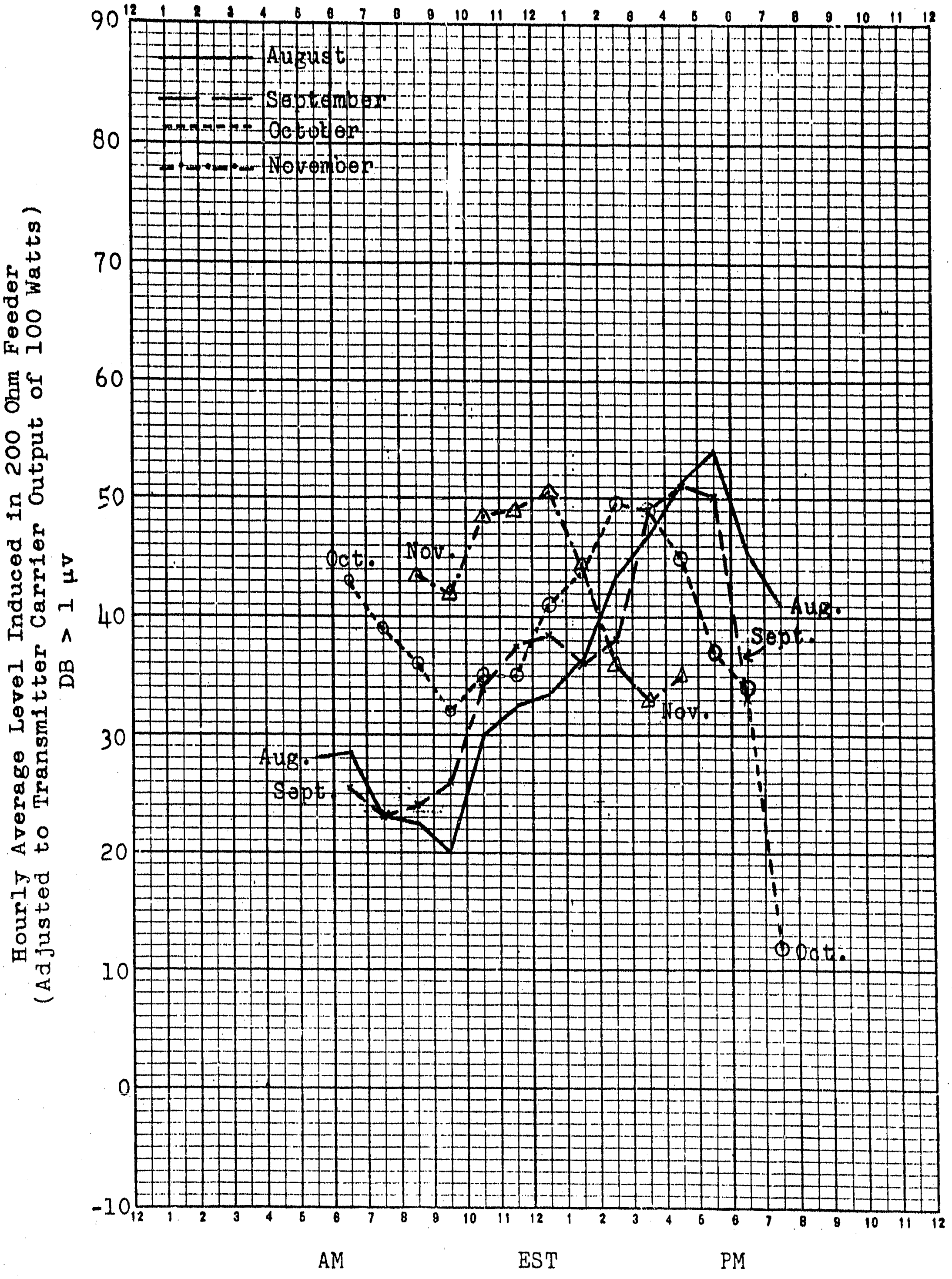


Figure AA31

MONTHLY MEDIAN SUPPRESSED CARRIER LEVELS
FROM KAHUKU'S SSB TRANSMISSIONS
RECEIVED AT RIVERHEAD

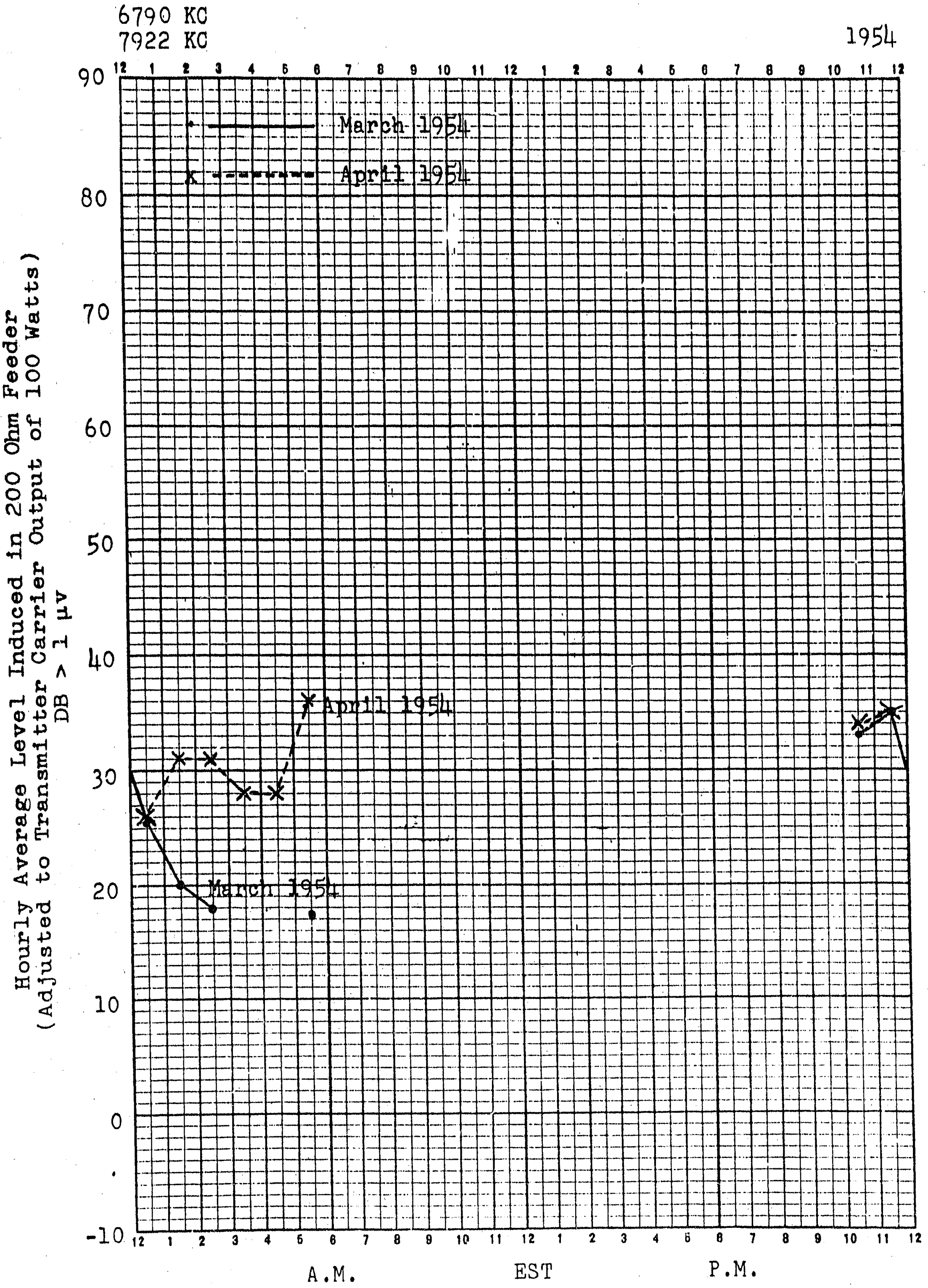


Figure AA32

MONTHLY MEDIAN SUPPRESSED CARRIER LEVELS
FROM KAHUKU, SSB TRANSMISSIONS
RECEIVED AT RIVERHEAD

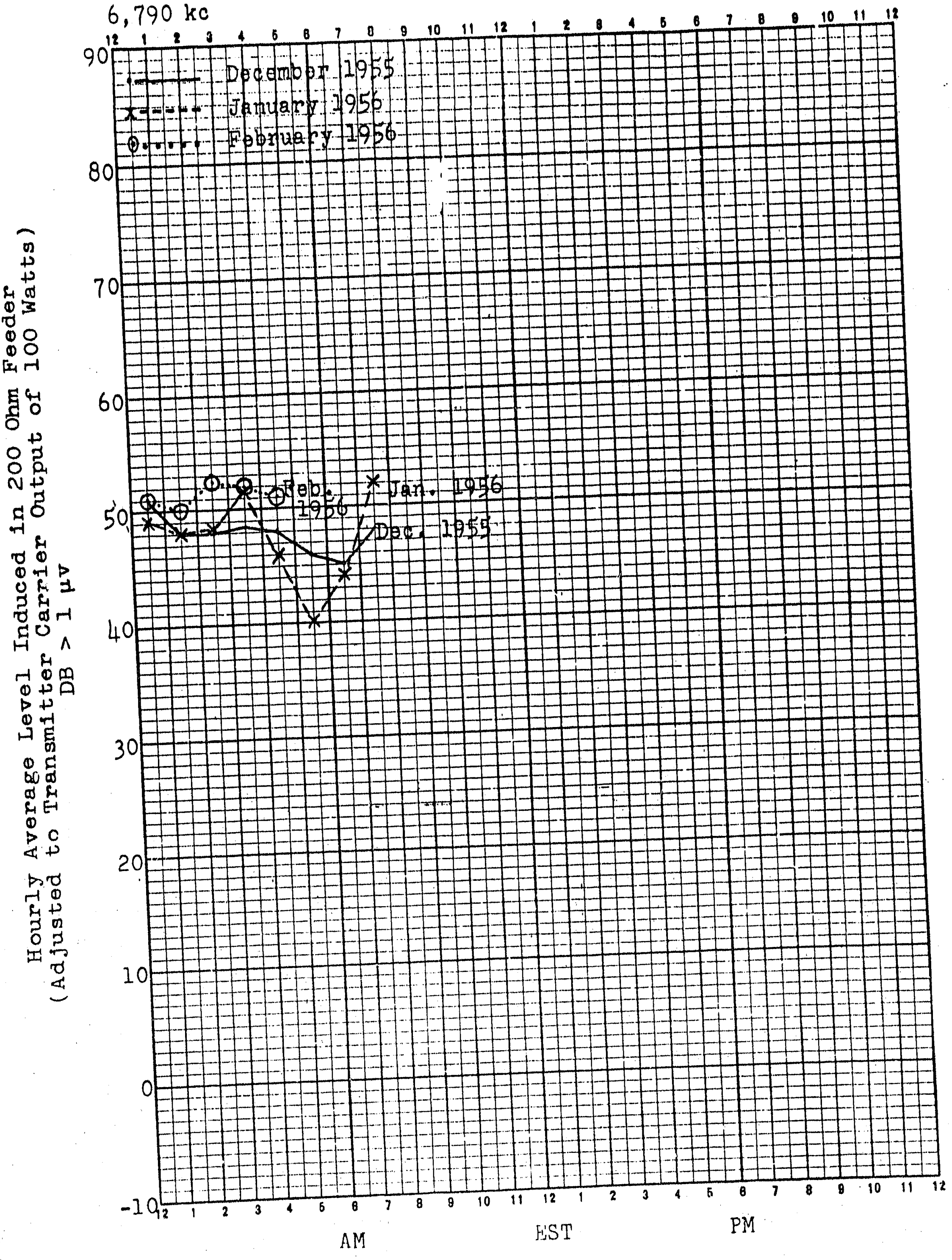


Figure AA

MONTHLY MEDIAN SUPPRESSED CARRIER LEVELS FROM KAHUKU'S SSB TRANSMISSIONS RECEIVED AT RIVERHEAD

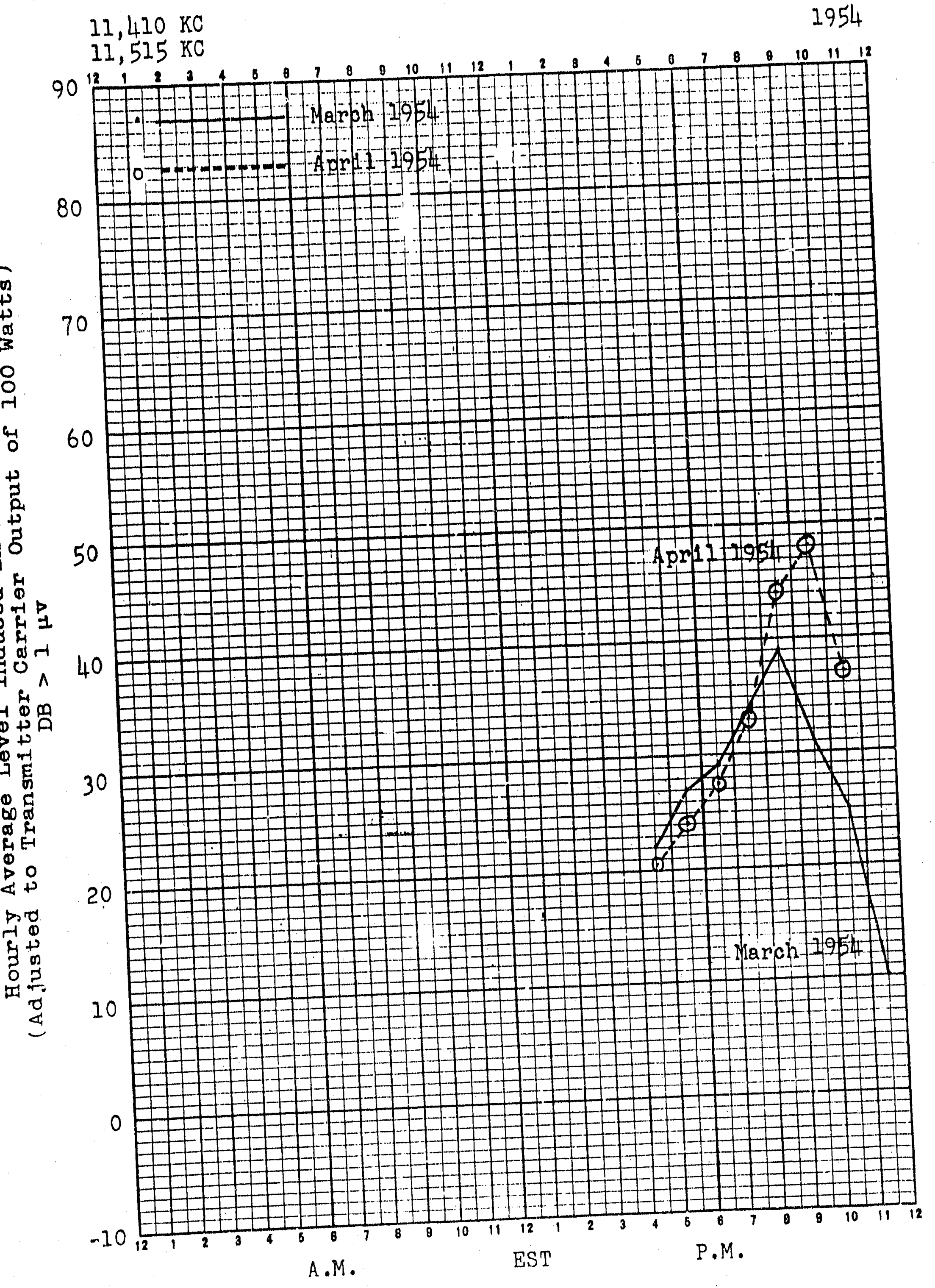


Figure AA34

MONTHLY MEDIAN SUPPRESSED CARRIER LEVELS FROM KAHUKU'S SSB TRANSMISSIONS RECEIVED AT RIVERHEAD

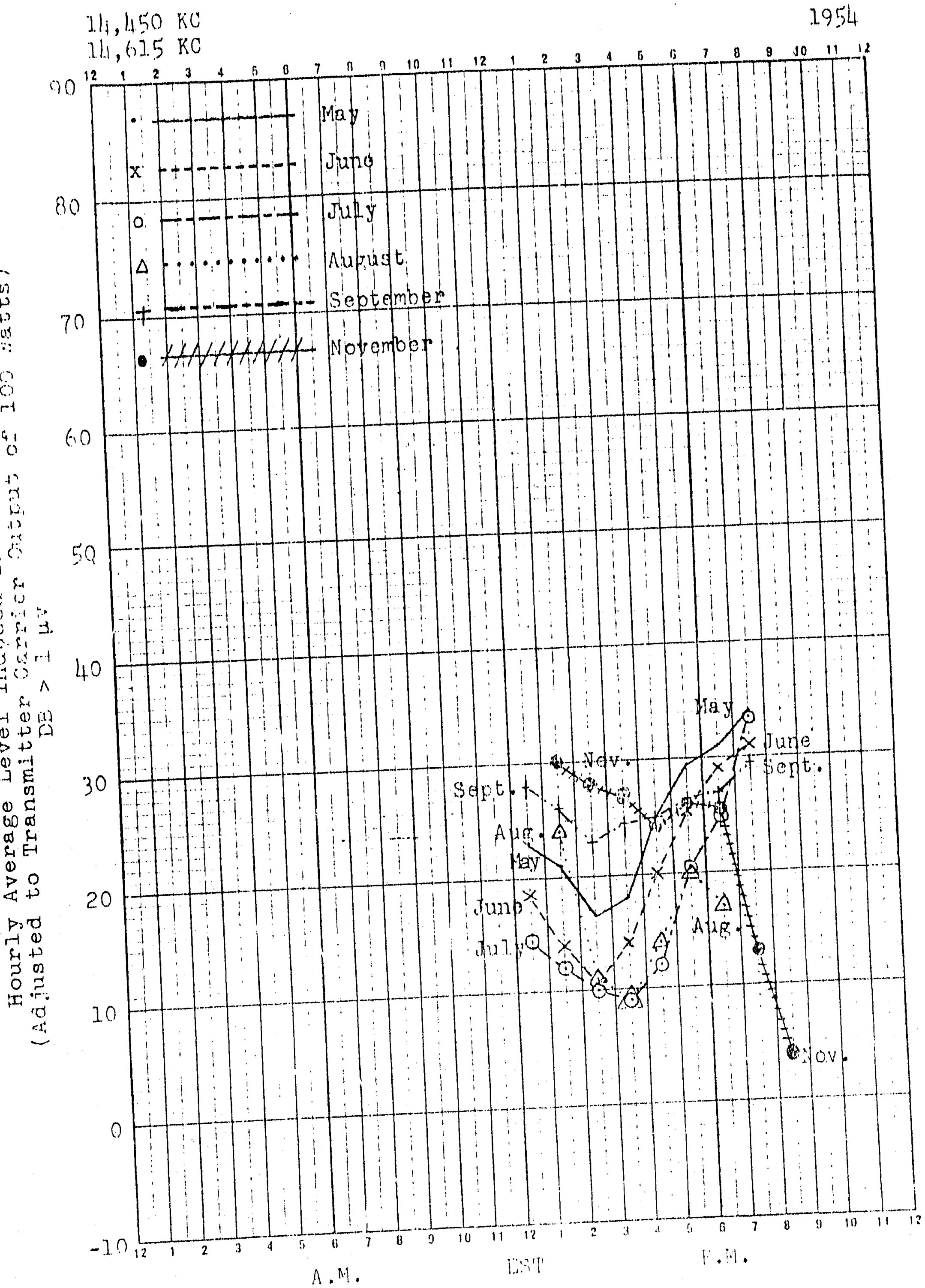


Figure AA3

MONTHLY MEDIAN SUPPRESSED CARRIER LEVELS
FROM KAHUKU, SSB TRANSMISSIONS
RECEIVED AT RIVERHEAD

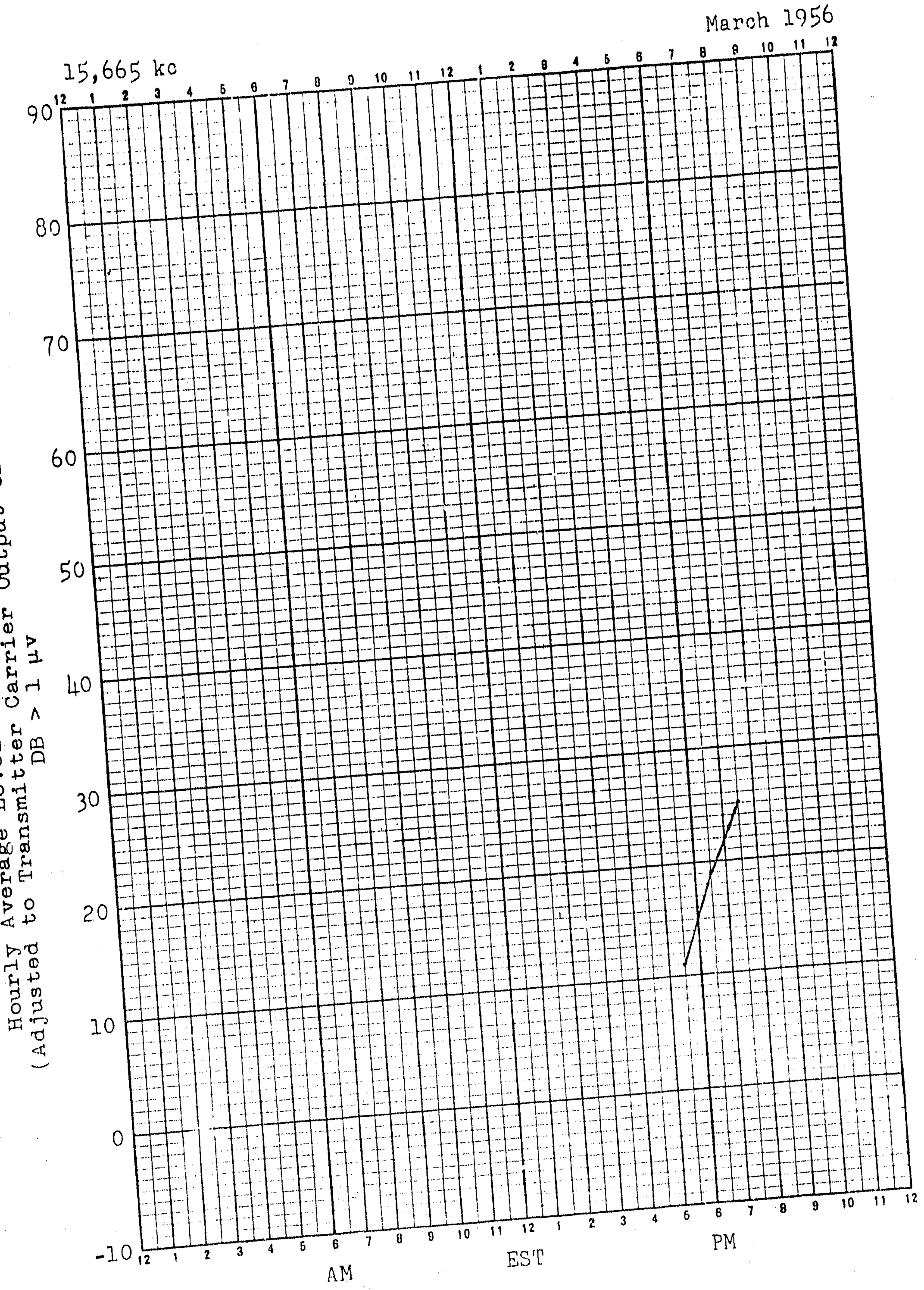


Figure AA3

MONTHLY MEDIAN SUPPRESSED CARRIER LEVELS FROM KAHUKU'S SSB TRANSMISSIONS RECEIVED AT RIVERHEAD

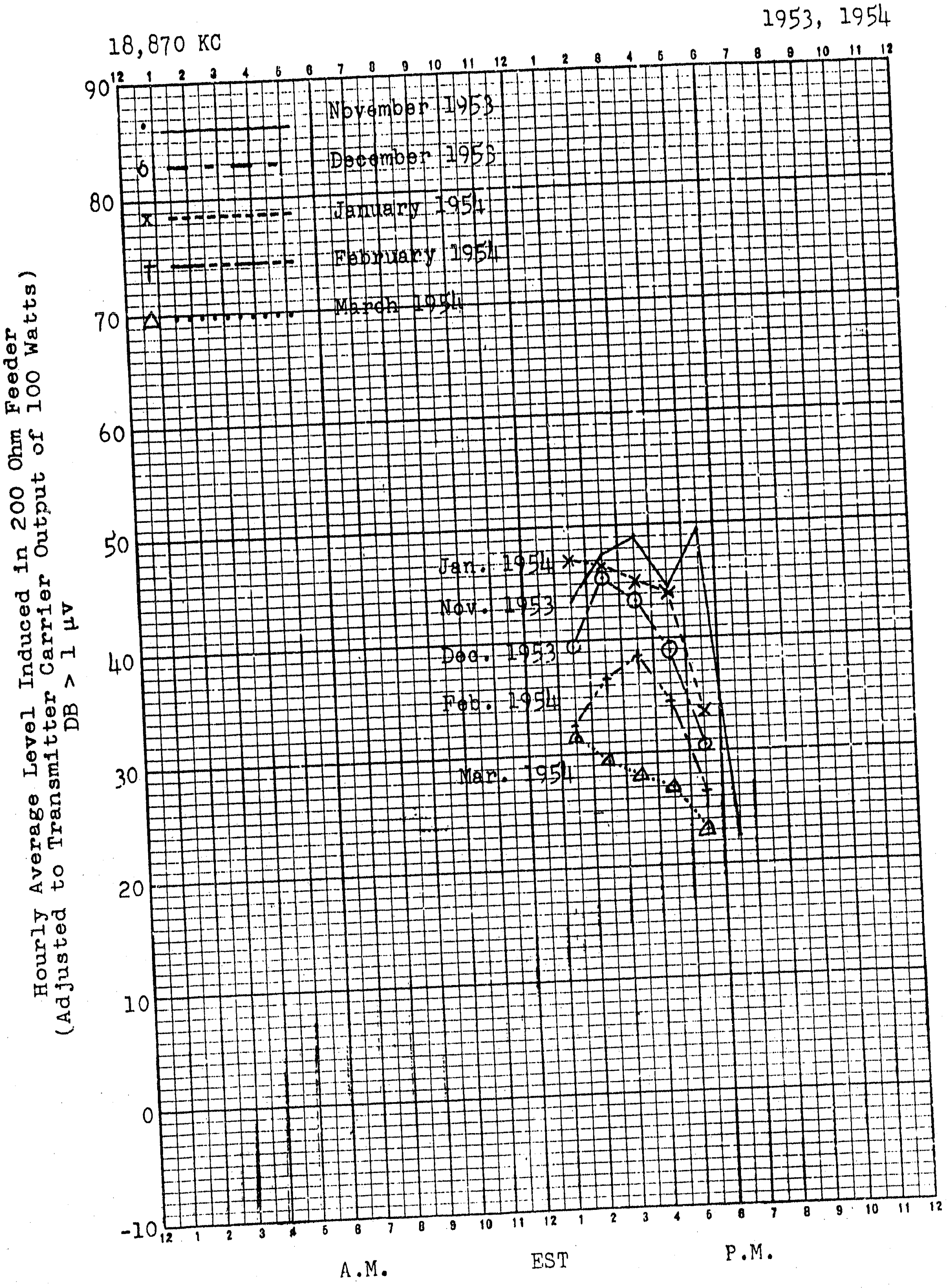


Figure AA3

MONTHLY MEDIAN SUPPRESSED CARRIER LEVELS FROM KAHUKU, SSB TRANSMISSIONS RECEIVED AT RIVERHEAD

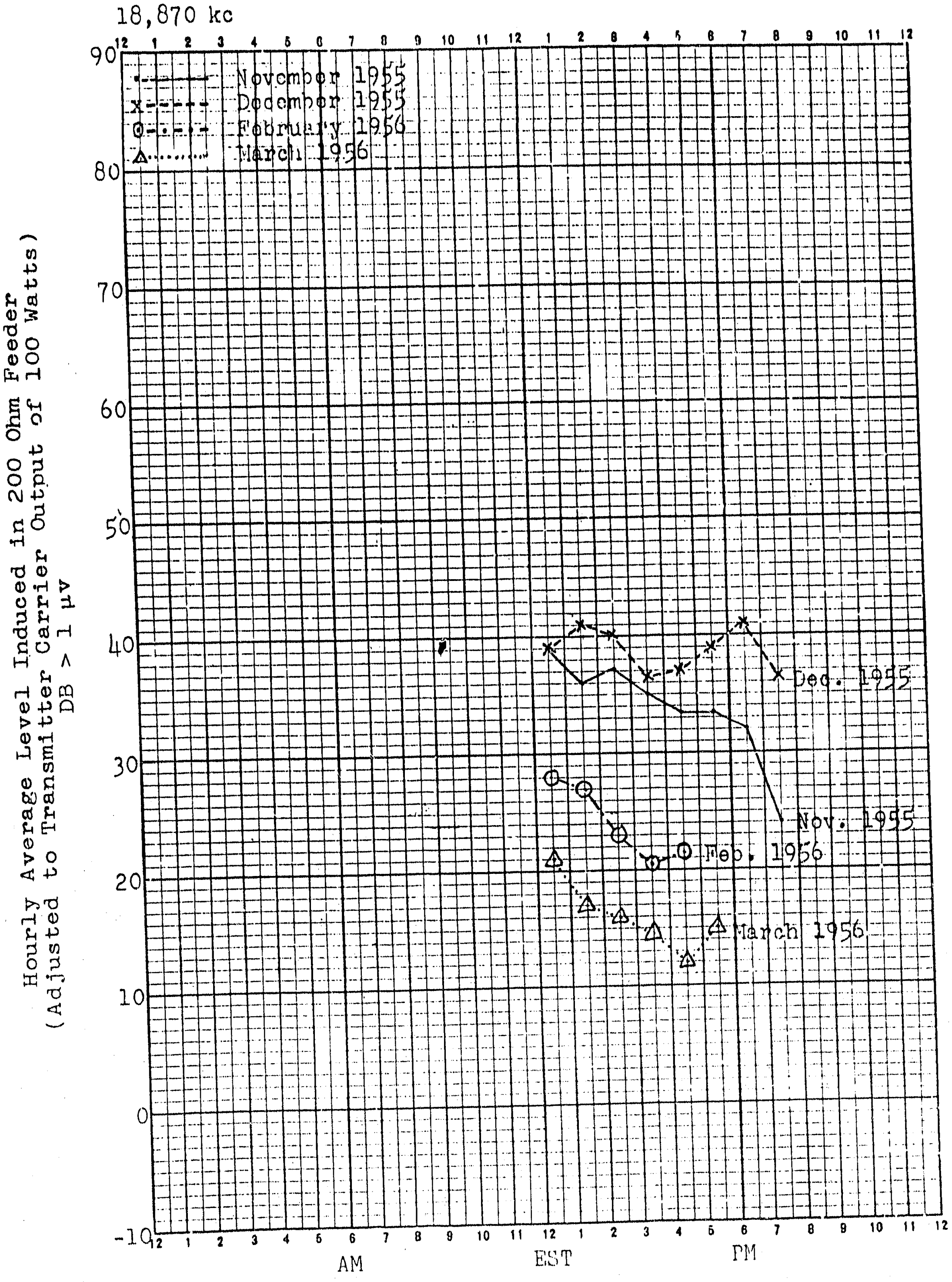


Figure AA38

MONTHLY MEDIAN SUPPRESSED CARRIER LEVELS
FROM KAHUKU, SSB TRANSMISSIONS
RECEIVED AT RIVERHEAD

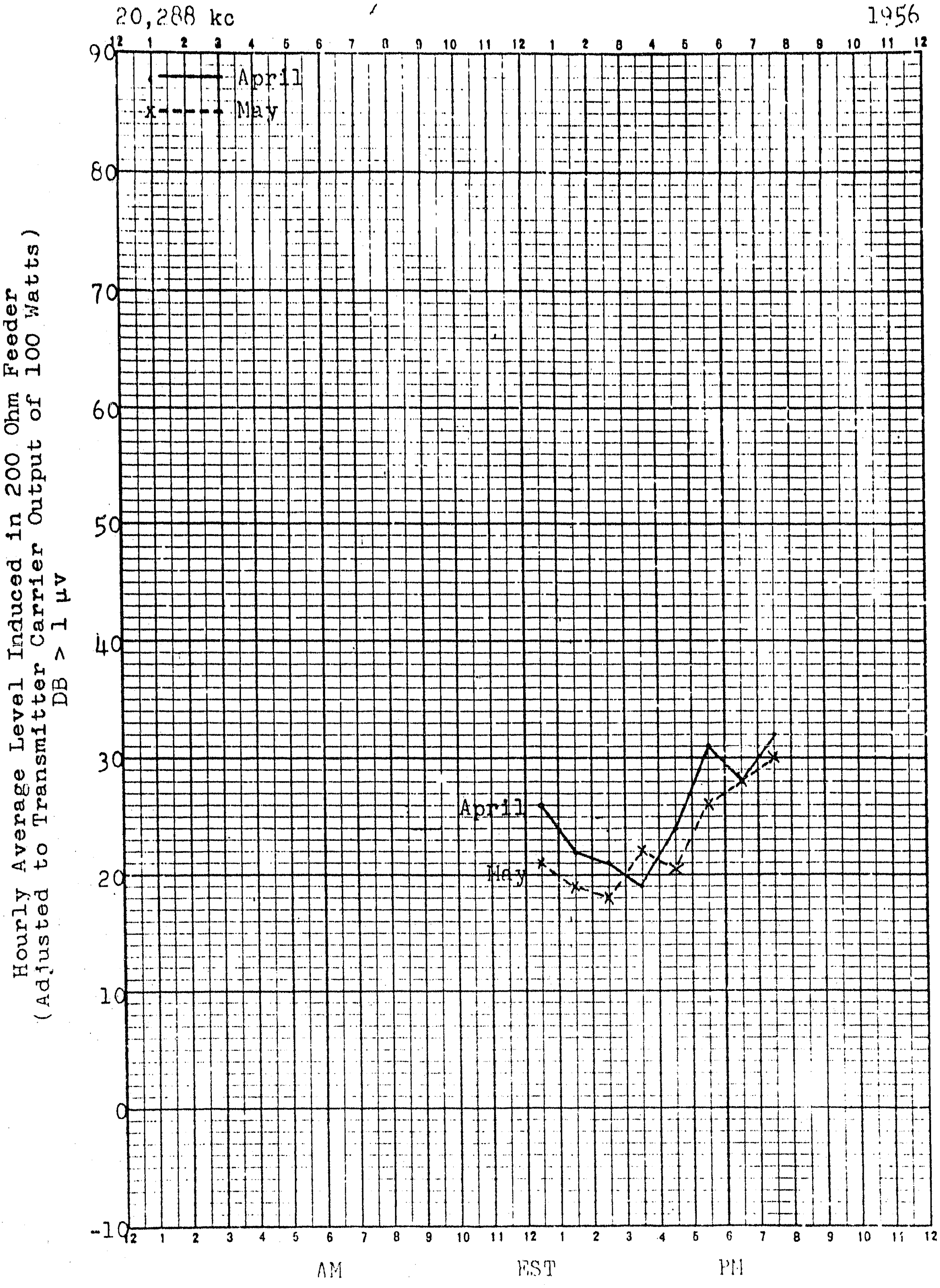


Figure AA39

MONTHLY MEDIAN SUPPRESSED CARRIER LEVELS FROM KAHUKU, SSB TRANSMISSIONS RECEIVED AT RIVERHEAD

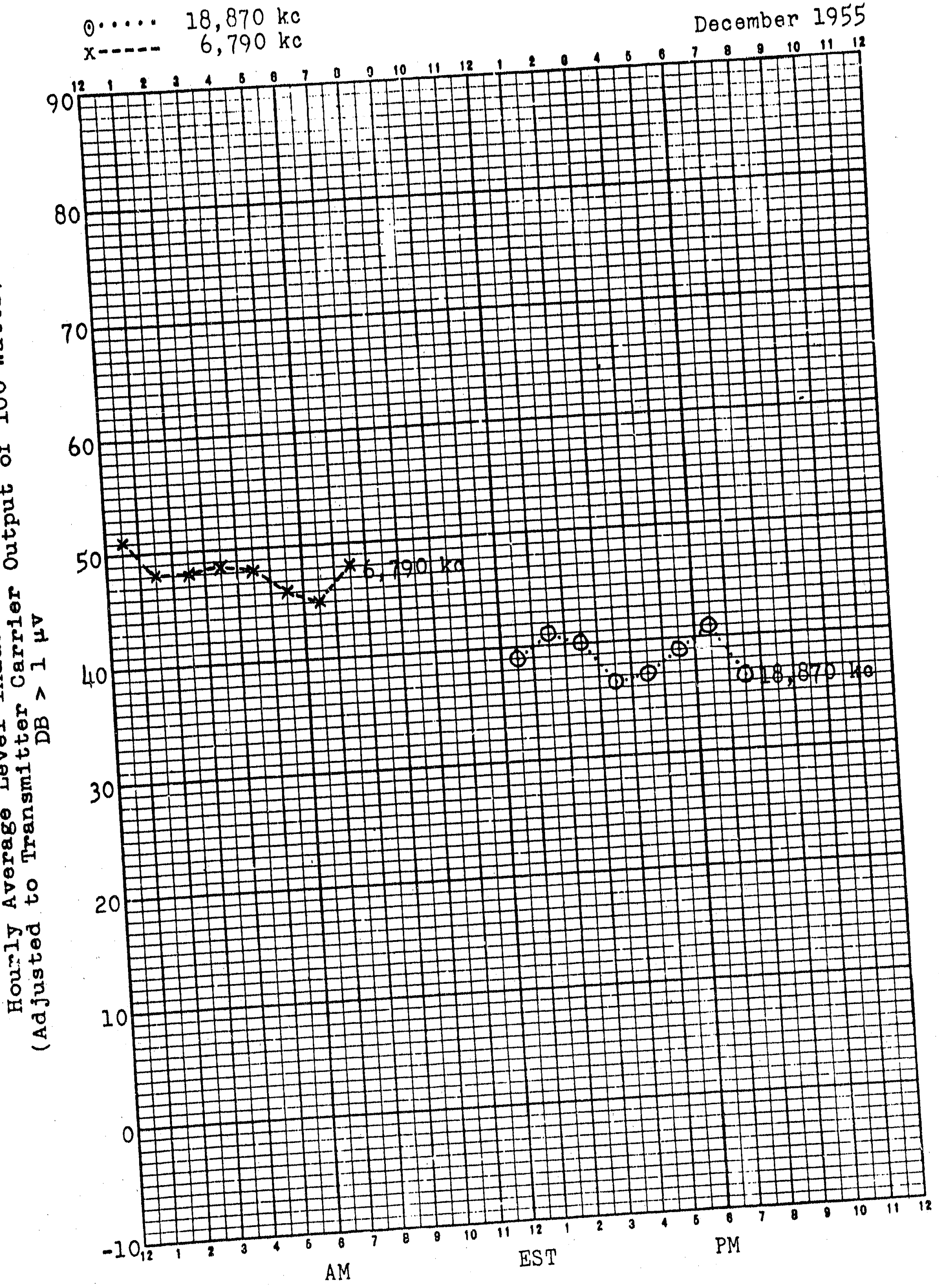


Figure AA40

MONTHLY MEDIAN SUPPRESSED CARRIER LEVELS
FROM KAHUKU, SSB TRANSMISSIONS
RECEIVED AT RIVERHEAD

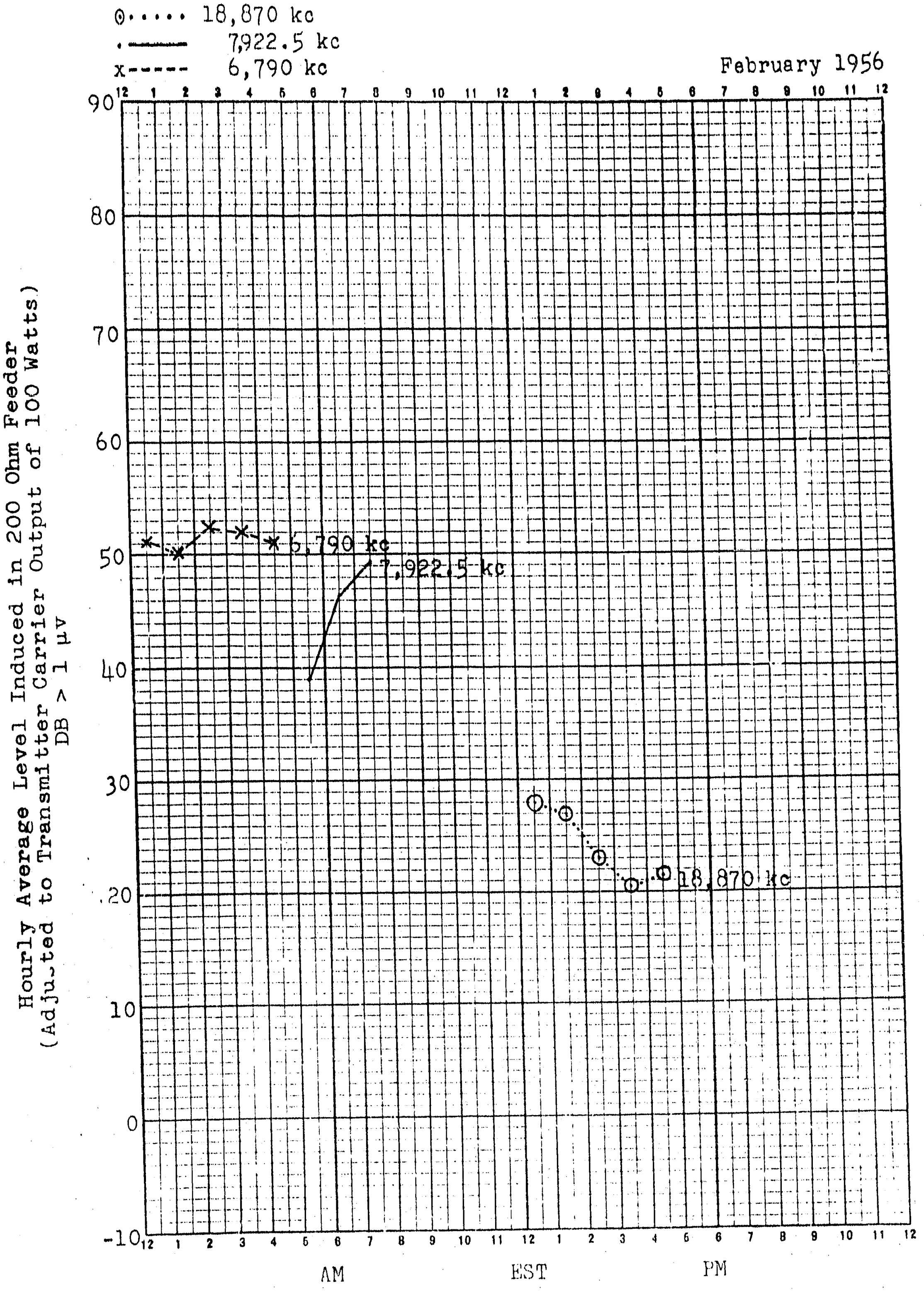


Figure AA41

MONTHLY MEDIAN SUPPRESSED CARRIER LEVELS FROM KAHUKU, SSB TRANSMISSIONS RECEIVED AT RIVERHEAD

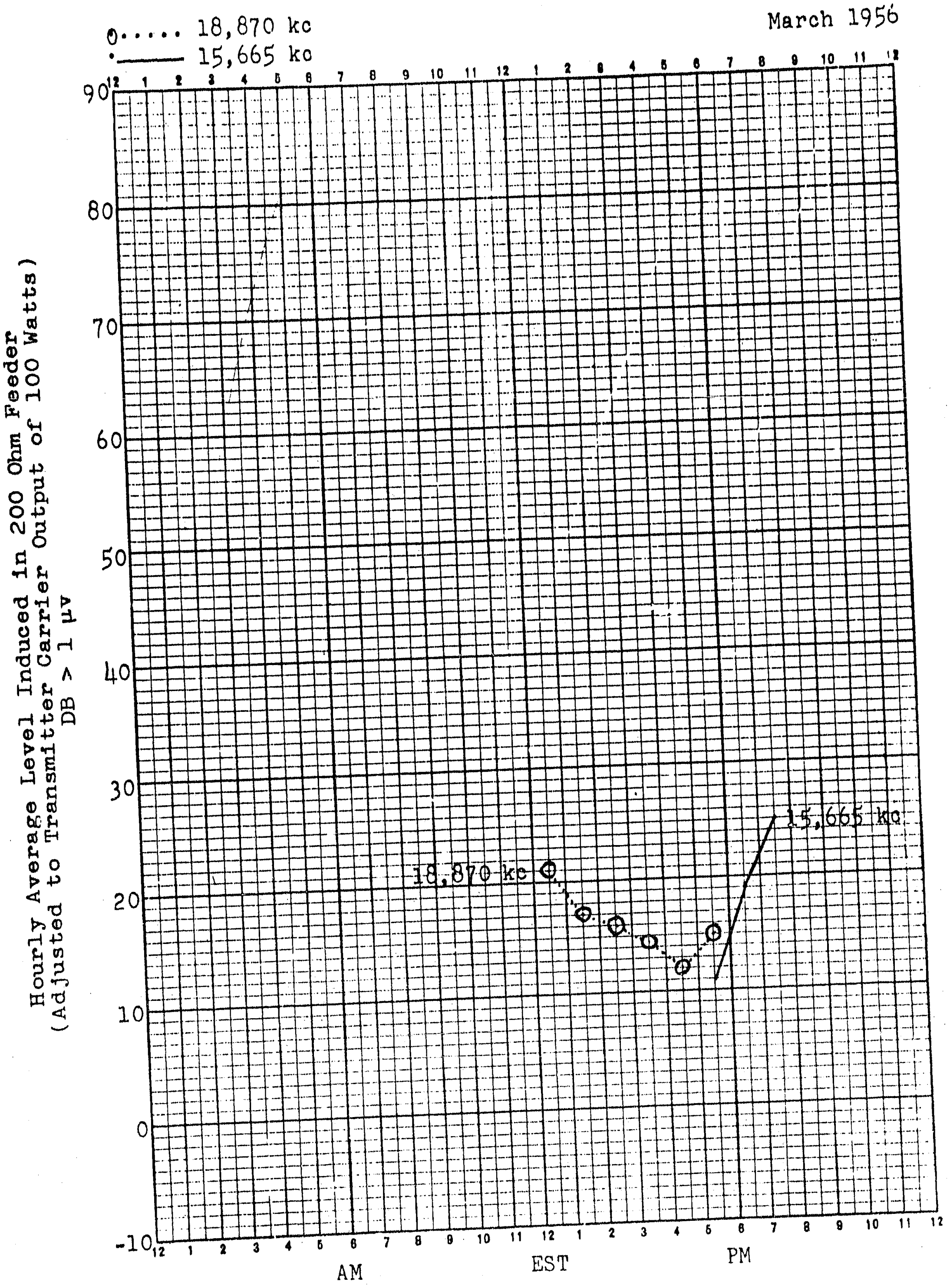


Figure AA42

ANNUAL VARIATIONS OF THE RECEIVER INPUT VOLTAGE AT 6790 KC & 7922 KC DURING ALL-DARK PATH COMPARED TO THE SMOOTHED SUNSPOT NUMBER

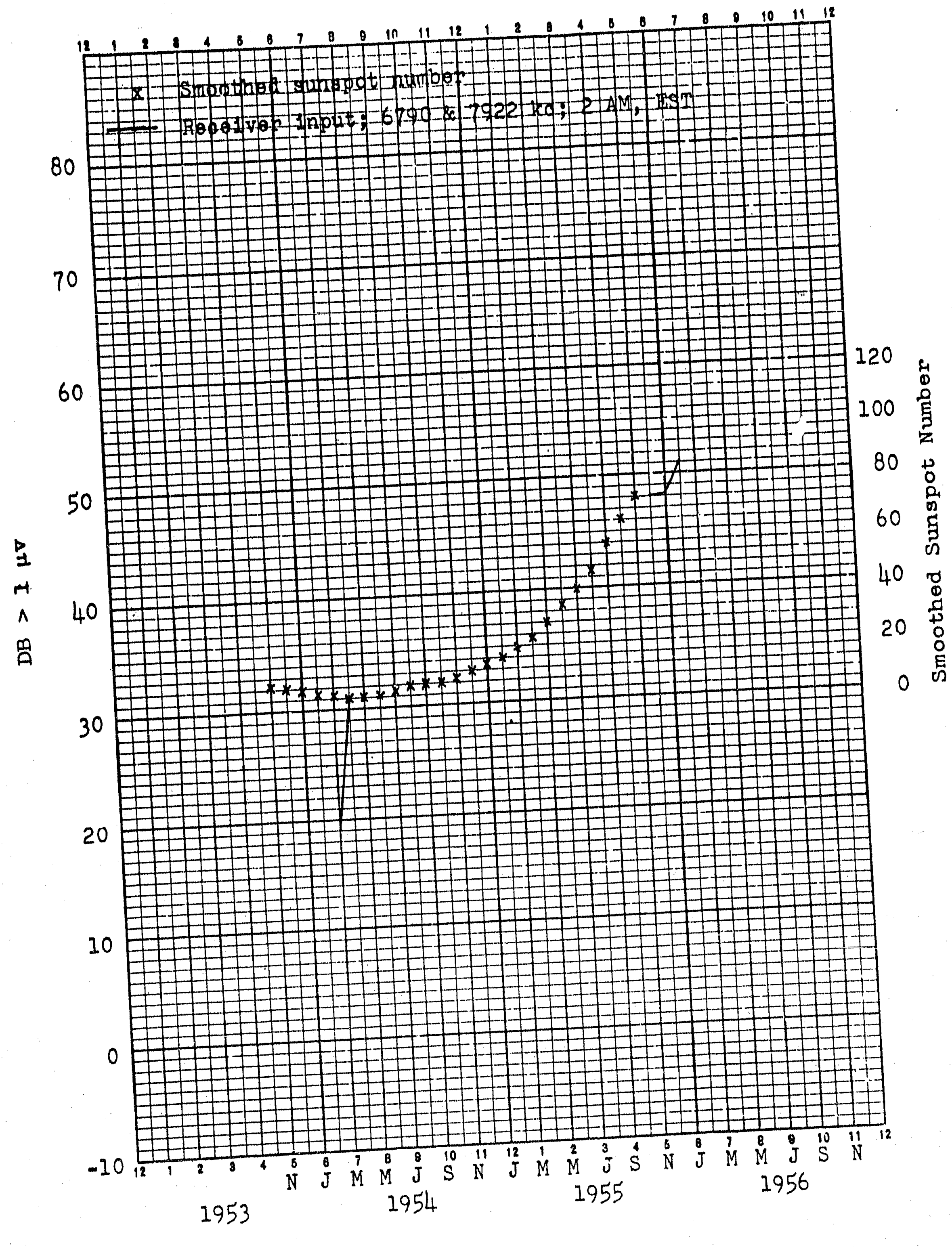


Figure AA43

ANNUAL VARIATIONS OF THE RECEIVER INPUT VOLTAGE AT 18,870 KC DURING ALL-DAYLIGHT PATH COMPARED TO THE SMOOTHED SUNSPOT NUMBER

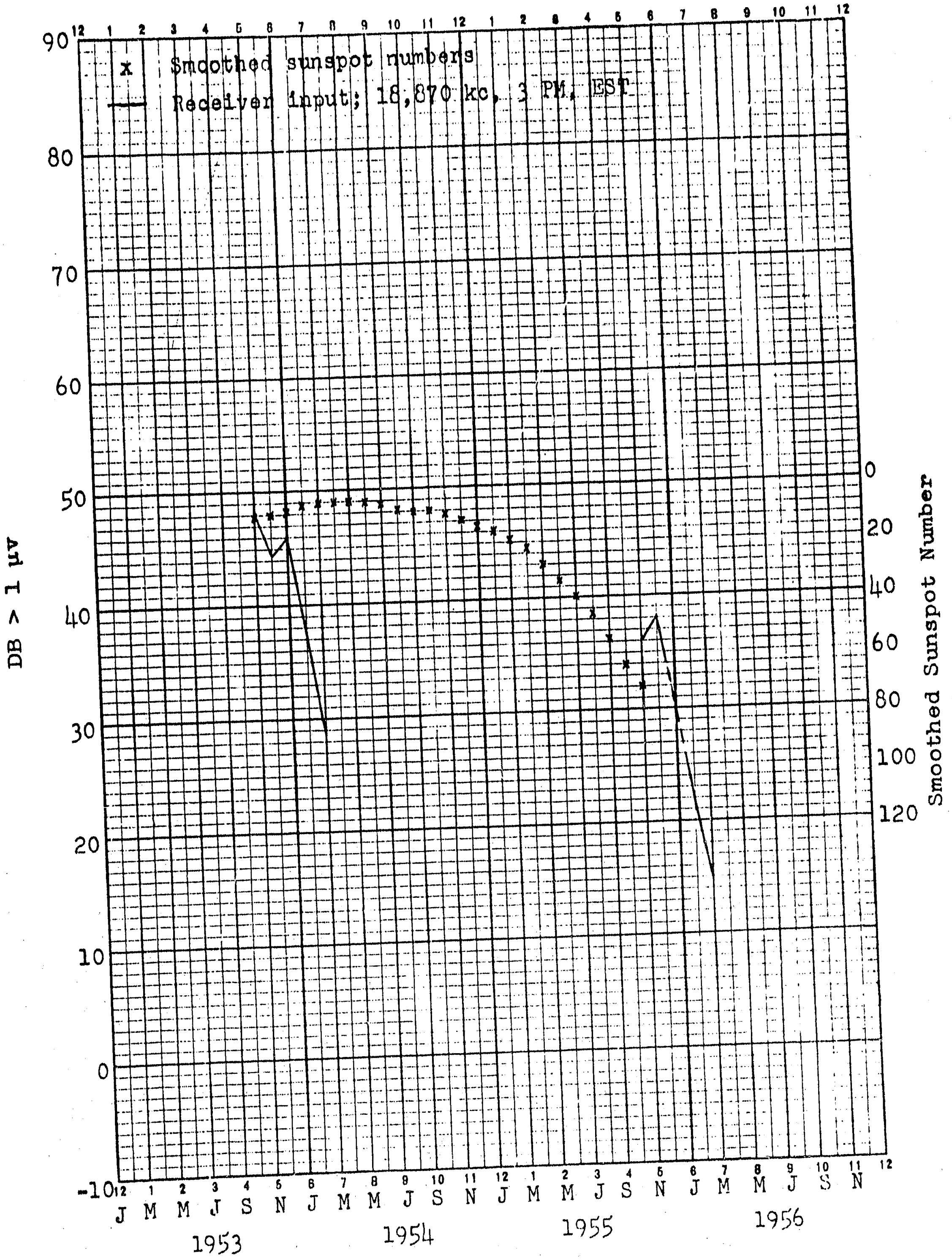


Figure AA44

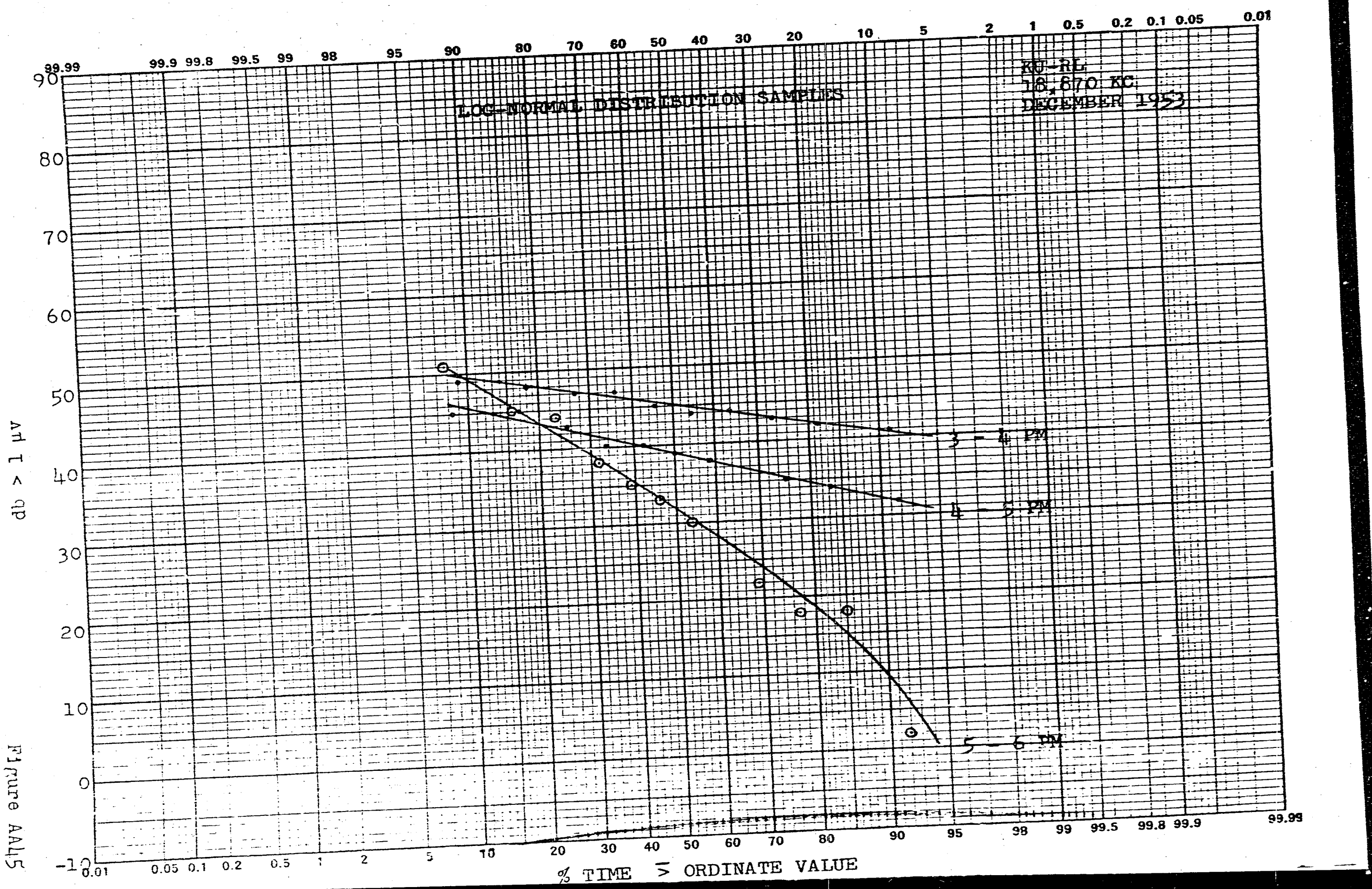

LOG-NORMAL DISTRIBUTION SAMPLES
KU-RL
18,670 KC
DECEMBER 1953
3 - 4 PM
4 - 5 PM
5 - 6 PM
db > 1 µv
90
80
70
60
50
40
30
20
10
0
-10
99.99
99.9
99.8
99.5
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0.5
0.2
0.1
0.05
0.01
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.5
99.8
99.9
99.99
% TIME > ORDINATE VALUE

Figure AA45

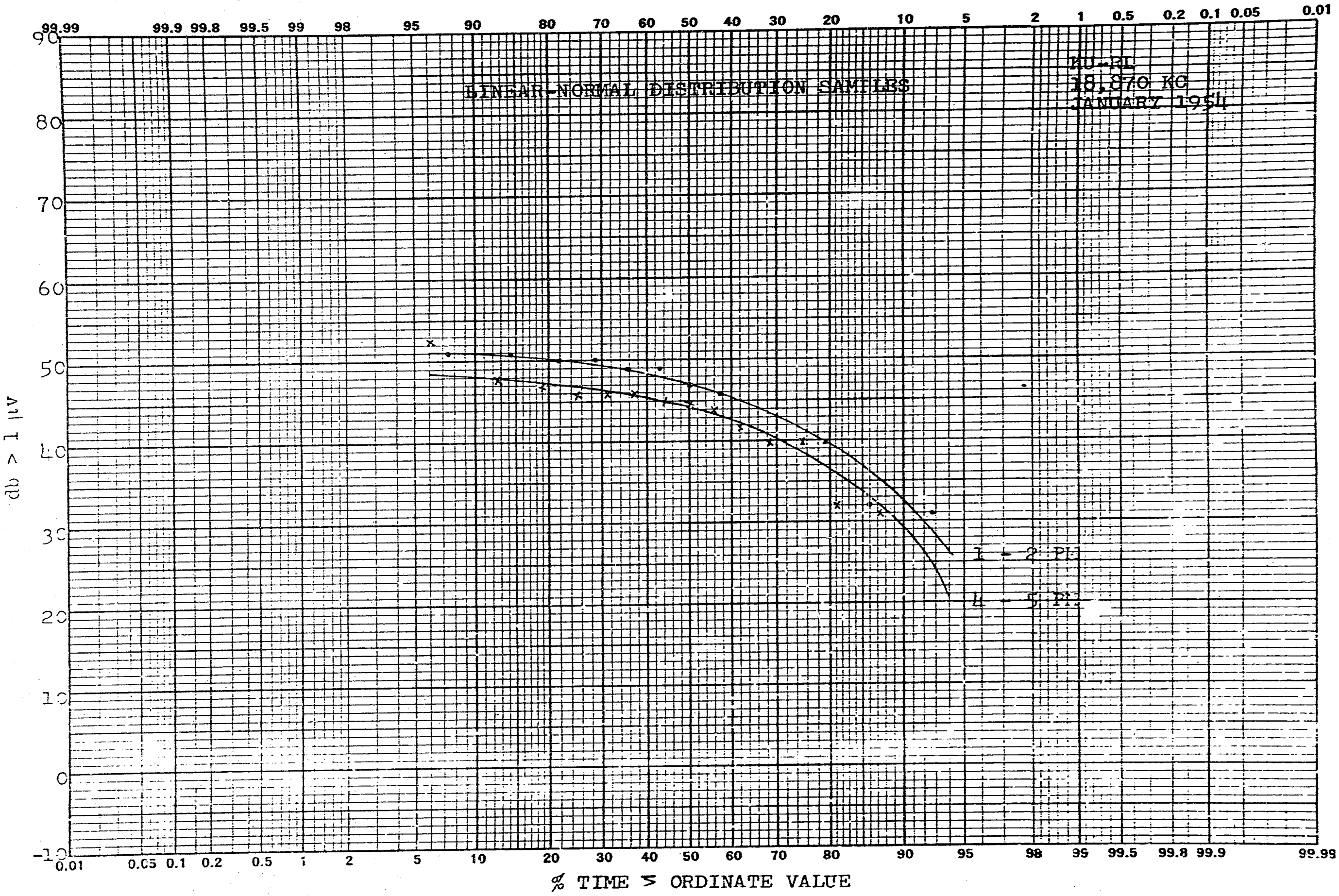

LINEAR-NORMAL DISTRIBUTION SAMPLES
KU-RL
18,870 KC
JANUARY 1954
1 - 2 PM
4 - 5 PM
db > 1 µv
90
80
70
60
50
40
30
20
10
0
-10
% TIME > ORDINATE VALUE
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.5
99.8
99.9
99.99
99.9
99.8
99.5
99
98
95
90
80
70
60
50
40
30
20
10
5
2
1
0.5
0.2
0.1
0.05
0.01

Figure AA46

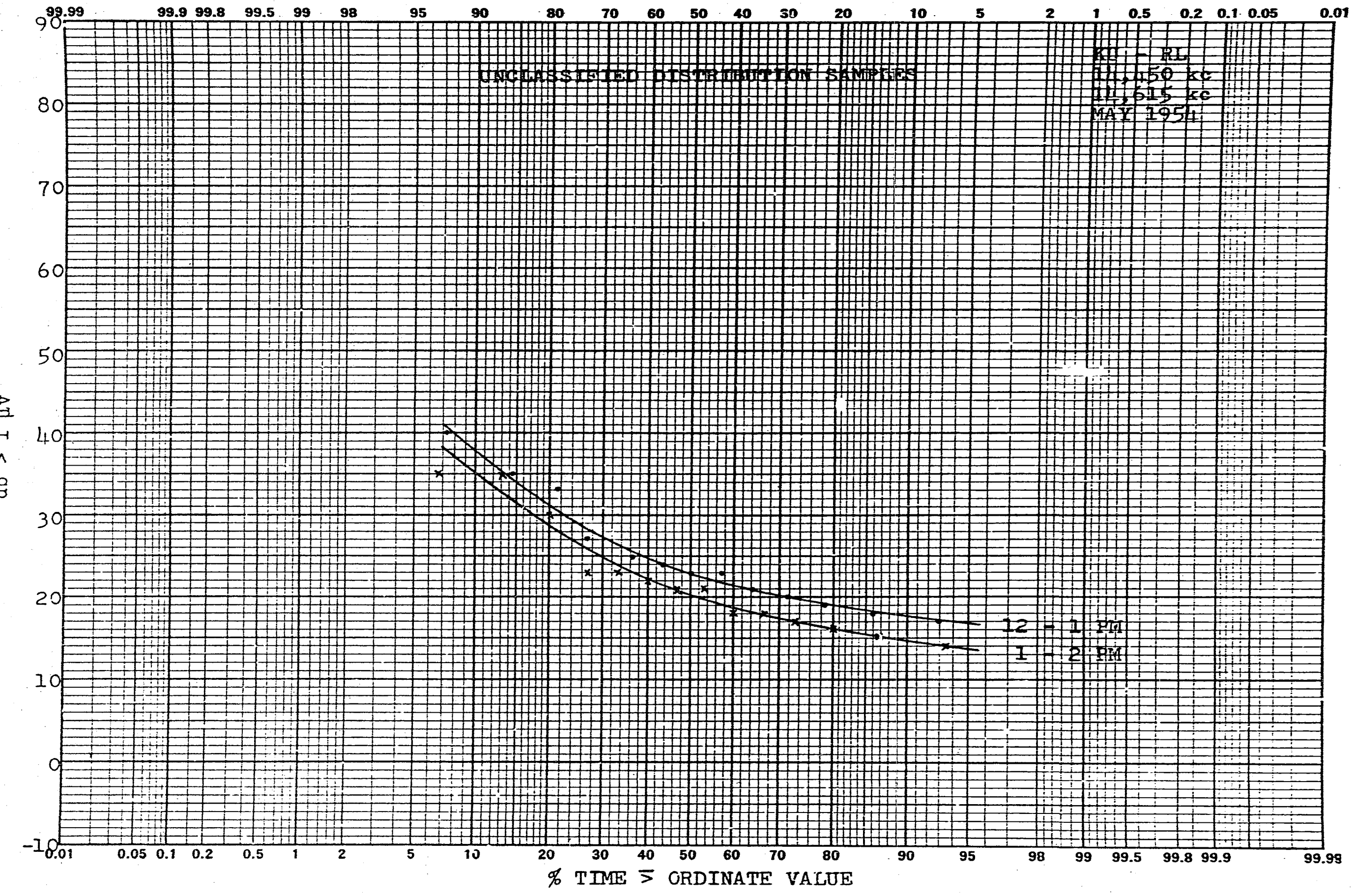
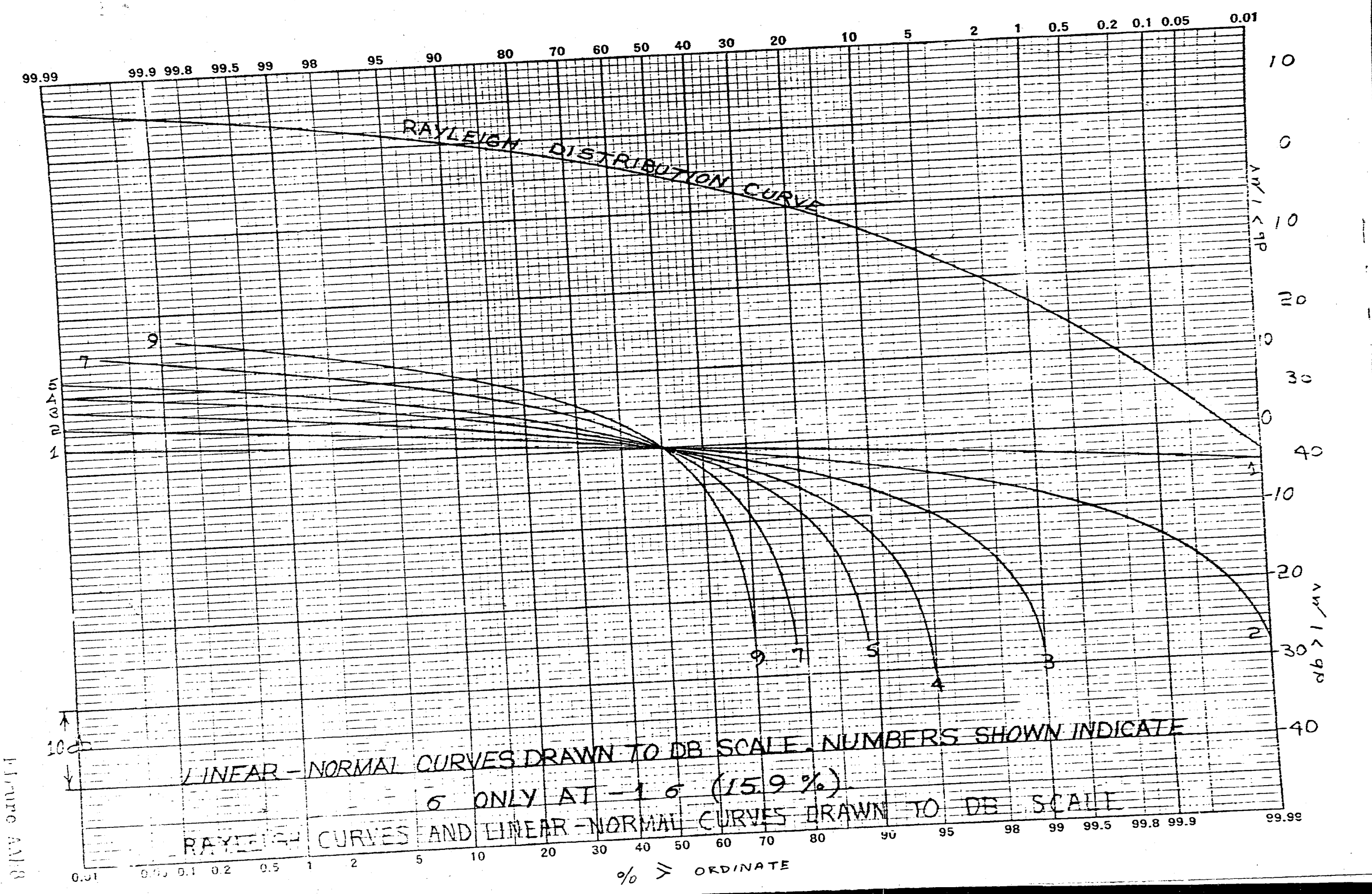

UNCLASSIFIED DISTRIBUTION SAMPLES
KU - RL
11,450 kc
11,615 kc
MAY 1954
12 - 1 PM
1 - 2 PM
db > 1 µv
% TIME ≥ ORDINATE VALUE
90
80
70
60
50
40
30
20
10
0
-10
0.01
0.05
0.1
0.2
0.5
1
2
5
10
20
30
40
50
60
70
80
90
95
98
99
99.5
99.8
99.9
99.99

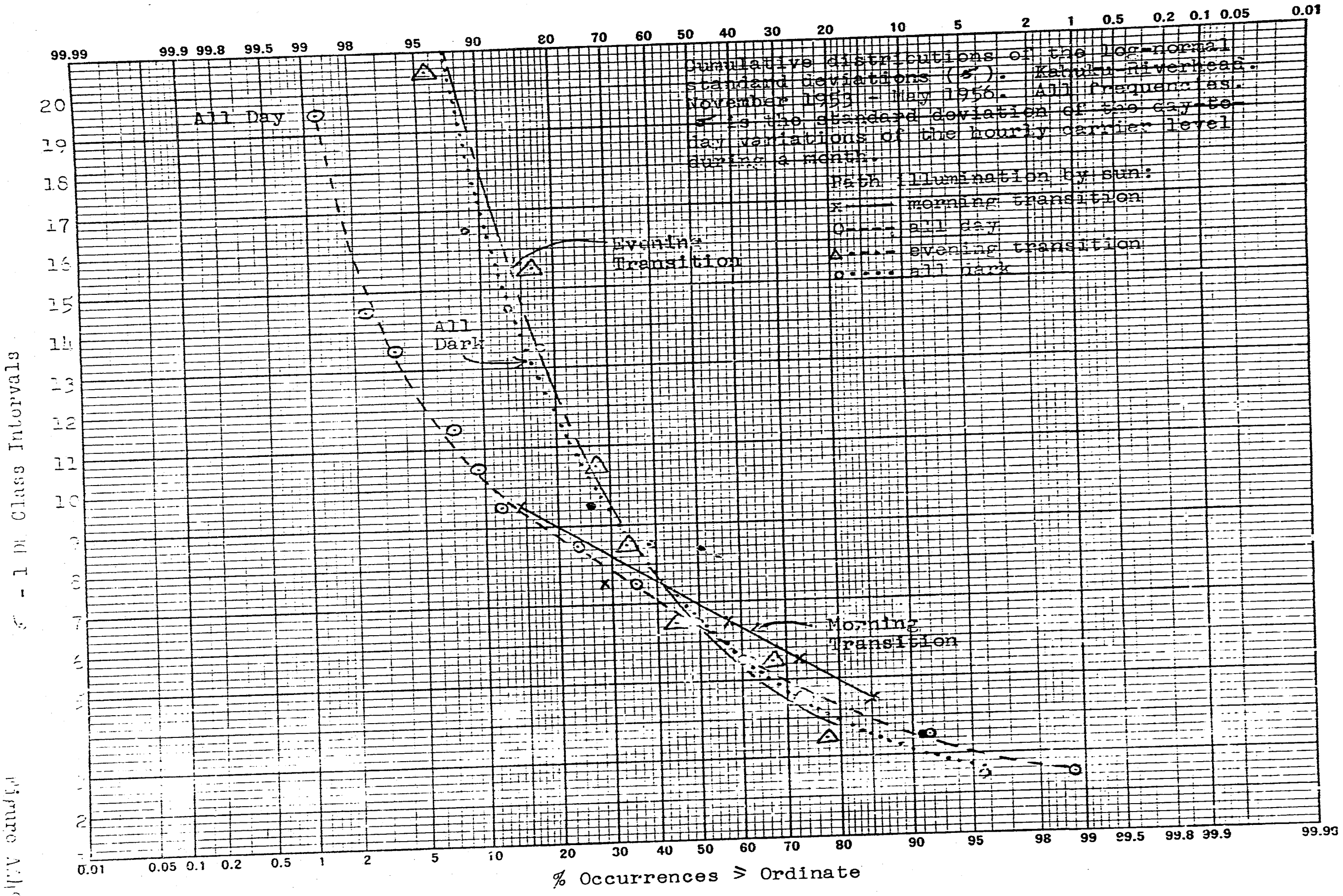
Figure AA47



LINEAR - NORMAL CURVES DRAWN TO DB SCALE. NUMBERS SHOWN INDICATE σ ONLY AT -1 σ (15.9 %).

RAYLEIGH CURVES AND LINEAR-NORMAL CURVES DRAWN TO DB SCALE

Figure A.1-8



Cumulative distributions of the log-normal standard deviations (σ). Kahuku-Riverhead. November 1953 - May 1956. All frequencies. σ is the standard deviation of the day-to-day variations of the hourly carrier level during a month.

Figure V.16

Appendix BB

DETAILS OF SIGNAL-TO-NOISE MEASUREMENTS

In the transmission of information over radio circuits, one of the most important factors leading to the reliability of the system is the ratio of the received signal energy and the energy of noise and static present when the signal is removed. This describes a ratio of "signal plus noise-to-noise" (S + N/N), which is commonly referred to as "signal-to-noise" (S/N). For large values, the difference between these ratios is small.

During these tests the audio output of the receiver was passed through an AN/FGC-29 receiving channel filter having a bandwidth of about 115 cps and thence to a calibrated amplifier with a high speed recording meter. The amplifier input was adjusted so that during a one-minute period the maximum reading resulting from signal plus noise peaks gave a peak reading of zero db. Since the inertia of the meter movement, while relatively low, could not permit the pointer to accurately follow the peak excursions of the signal and particularly the noise, a number of readings were made. Usually four such readings were taken during four consecutive one-minute periods. Following the last reading the modulation was removed from the sidebands leaving the radiated carrier power unchanged. By using carrier operated automatic gain control in the receiver, the receiver gain did not change between the signal and noise readings. The receiver audio output with the sideband energy off was reduced. The amplifier input pad was readjusted to bring the peak output of the receiver back up to zero db on the output meter during a one-minute period. Four consecutive "noise" readings were usually taken.

When these four readings in db were subtracted from the four readings obtained with the sideband energy radiated, four "signal plus noise-to-noise" (signal-to-noise or S/N) ratios in db were obtained. The recorded value of S/N was found by converting the db values to ratios, averaging these ratios, and converting the average ratio to db.

During a number of noise meter S/N measurements, simultaneous "peak-to-peak" readings were taken on an oscilloscope. These comparative measurements were made both on the Kahuku-Riverhead radio circuit and also in the laboratory. The procedure followed in determining the "peak-to-peak" S/N ratio was the same as that indicated above except that voltage ratios were read directly from the oscilloscope face instead of the db setting of the attenuator. Comparative "peak-to-peak" and "noise meter" measurements in the laboratory were made by injecting locally generated white noise with the signal. Figure BB1 is a block diagram of the circuit which was used.

Figure BB2 is a plot of the peak-to-peak S/N in db versus the noise meter reading in db based upon data taken in the laboratory. A similar plot is given in Figure BB3 for data taken on the Kahuku-Riverhead radio circuit. On both plots, the dotted line represents the calibration curve that was determined from the plotted points. It may be noted that the noise meter measurements made on the back-to-back circuit with white noise were approximately 2 db higher than the simultaneous peak-to-peak noise measurements.

The noise meter measurements made on the Kahuku-Riverhead circuit were approximately 3 db higher than the simultaneous peak-to-peak measurements for signal-to-noise ratios in the order of 10 db. The db difference between the two measuring methods increased with the signal-to-noise ratio so that the noise meter measurements at signal-to-noise ratios in the order of 50 db were about 7 db higher than the simultaneously-measured peak-to-peak signal-to-noise ratios.

BLOCK DIAGRAM OF NOISE MEASURING ARRANGEMENT

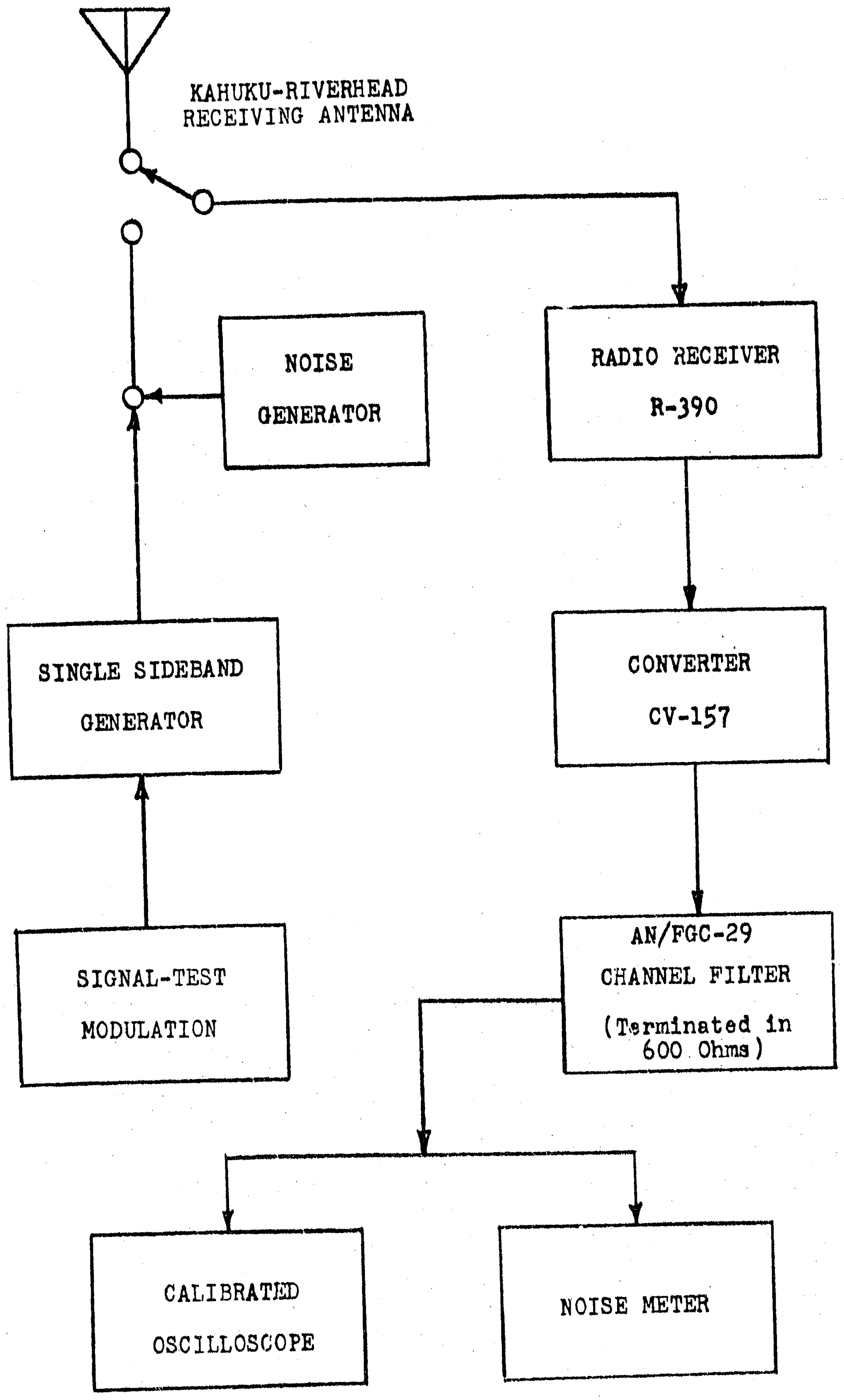


FIGURE BB1

Laboratory Comparison of Signal-to-Noise Measuring Methods: Peak-to-Peak Oscilloscope vs Noise Meter Values

Back-to-Back Test With Locally Injected Noise. Measurements Through 115~ Band Pass Filter.

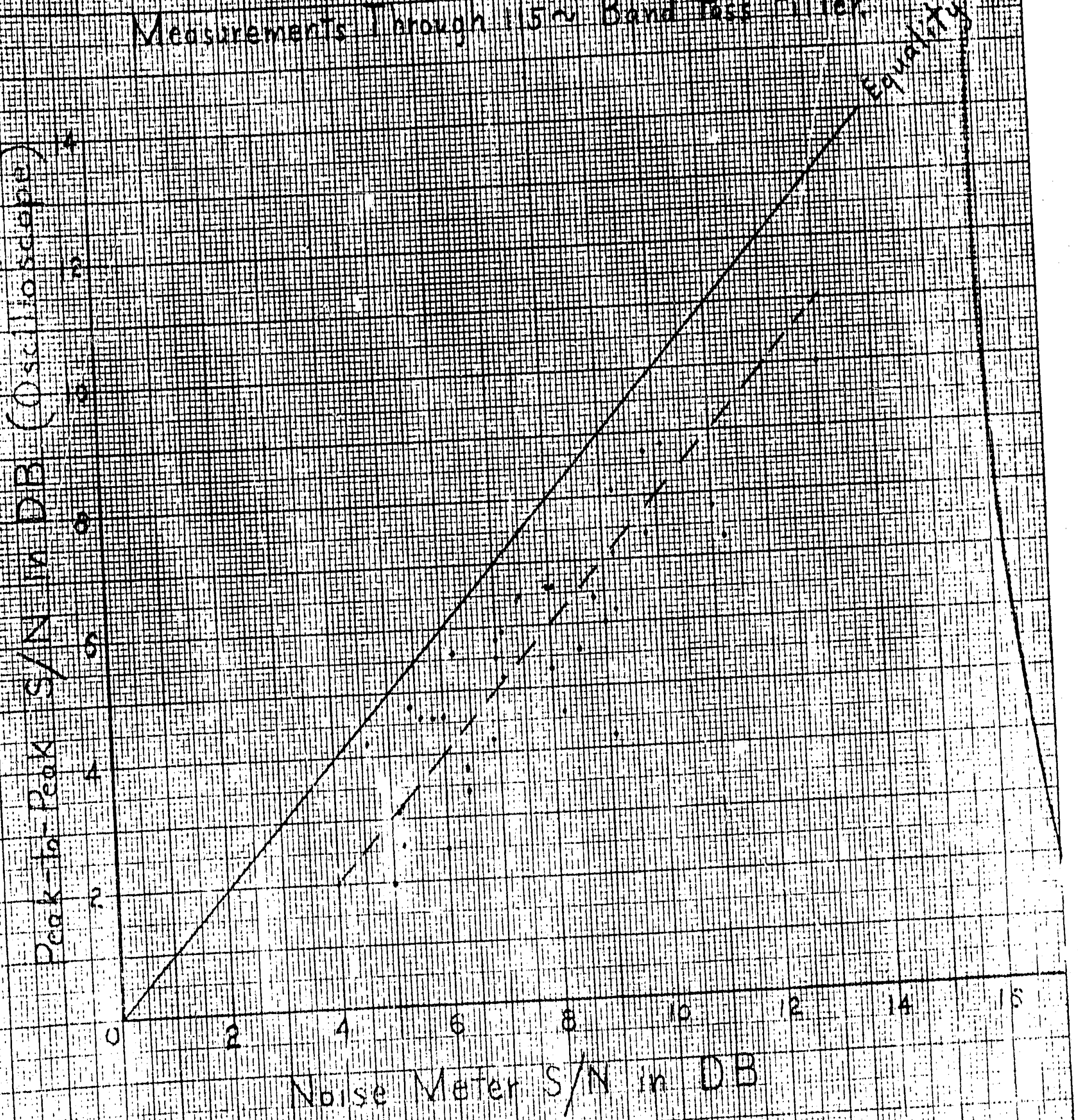


Fig BB2

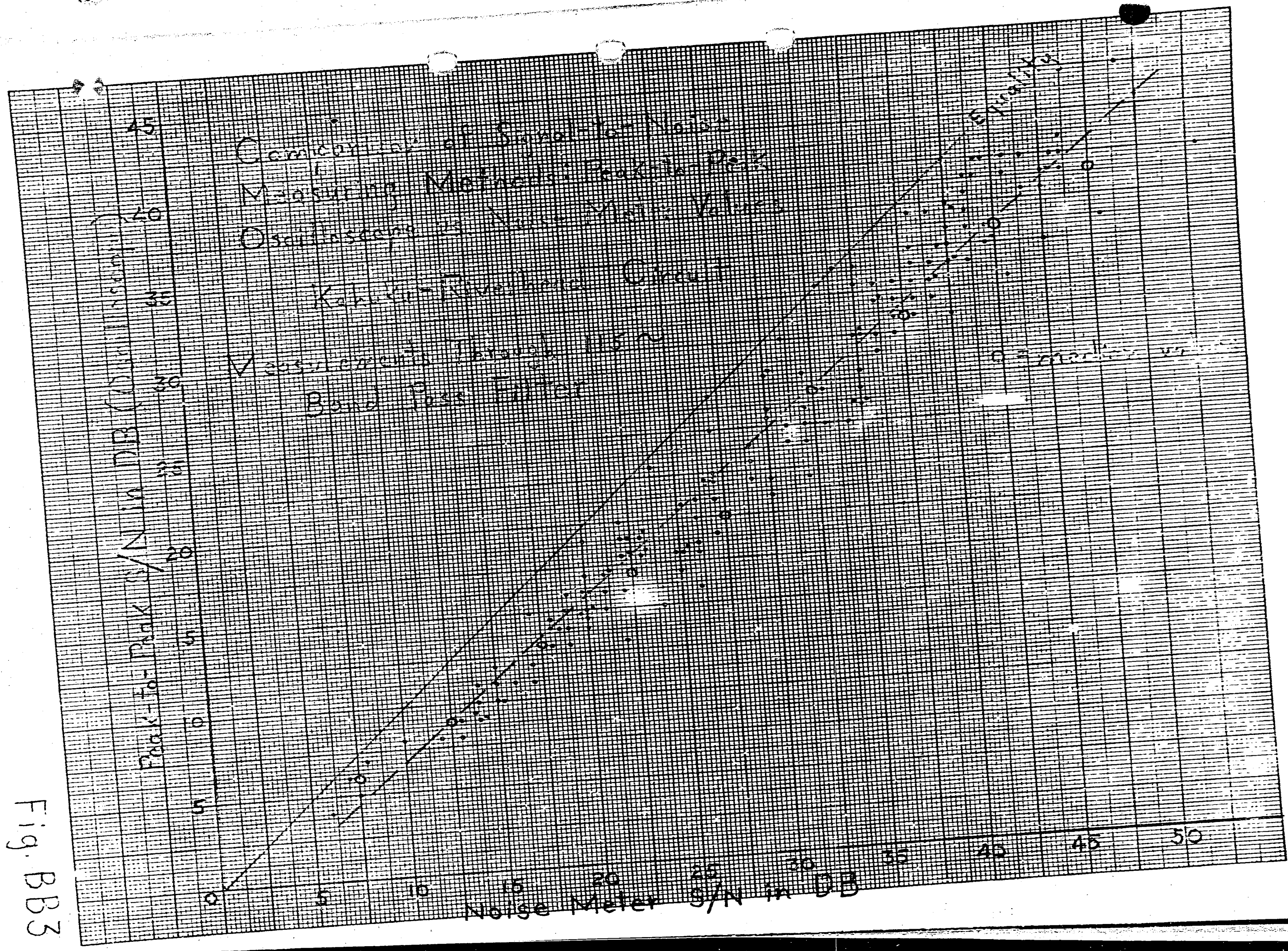

Comparison of Signal-to-Noise
Measuring Methods: Peak-to-Peak
Oscilloscope vs Noise Meter Values
Kahn-Rivelbeck Circuit
Measurements Through 115~
Band Pass Filter
Equality
o = median
Peak-to-Peak S/N in DB (Oscilloscope)
45
40
35
30
25
20
15
10
5
Noise Meter S/N in DB
5
10
15
20
25
30
35
40
45
50

Fig. BB3

Appendix CC

FREQUENCY STABILITY MEASUREMENTS ON THE WESTERN ELECTRIC D-152499 FREQUENCY STANDARD

Comparison of the Western Electric D-152499 Frequency Standard Against WWV

A breadboard frequency multiplier of the type shown in Figure CC1 was constructed to supply harmonics of the D-152499 100 kc Frequency Standard. As shown in Figure CC2, the 5 mc harmonic of the Standard was coupled into a receiver tuned to the 5 mc WWV standard frequency transmissions. The coupling of the local harmonic was adjusted to supply a signal at the input to the receiver at approximately the same level as the incoming WWV signal. The Frequency Standard was detuned slightly from 100 kc, and the resulting beat note between the 5 mc harmonic of the Standard and WWV was direct-coupled from the receiver second detector to a Sanborn chart recorder. In this manner, a recording of the beat signal versus time was obtained, a sample of which is shown in Figure CC3.

Short strips of the beat signal recording, each between one and two minutes in length, were taken at 15-minute intervals during portions of a two-day period. The average beat frequency during each recorded period was determined from the chart strips and plotted as a parts per million frequency difference between the 5 mc harmonic of the Standard and WWV. (Figure CC5) As indicated in Figure CC5, the maximum frequency difference between the 5 mc harmonic of the Standard and WWV did not exceed 0.272 parts per million. The minimum frequency difference was not less than

0.260 parts per million. This indicates an overall frequency variation between the Frequency Standard and WWV of 0.012 parts per million, and is based on measurements taken during portions of a two-day period.

The actual beat frequency between WWV and the Standard 5 mc harmonic was approximately 1-1/3 cps, which is a frequency offset of 0.266 parts per million from WWV. It was found by experiment that a beat signal of between one and two cps between the two 5 mc signals gave the best results for measuring purposes. A beat signal less than one cps was sometimes difficult to observe when examining the recorder charts because of the normal fading of the incoming WWV signal. Also, a great enough frequency offset had to be used to insure that the Standard harmonic never went through zero beat with respect to the WWV signal during the measuring periods since an ambiguous condition would have existed if this had occurred. On the other hand, it was desirable to set the Frequency Standard as close as practicable to its normal operating frequency.

During the signal-tests, the W. E. Frequency Standard at the Kahuku end of the circuit was adjusted by listening to the beat note between the 5 mc harmonic of the Standard and WWVH with a radio receiver. During periods when the incoming WWVH signal was stable, it was possible to detect beat notes with periods of seven seconds or less. During most of the signal-test program, the 5 mc harmonic of the Kahuku Frequency Standard was held to within 1/3 cps of WWVH. This is within 0.067 parts per million of the standard frequency. The WWVH signal as received at Kahuku was most stable during midday or midnight and, whenever possible, frequency measurements were made at this time. In the region of sunrise and sunset hours, it was almost impossible to obtain accurate frequency measurements because of severe disturbance in the received WWVH signal.

Frequency Variation Measurements Between Two Western Electric D-152499 Frequency Standards

A second frequency multiplier of the type shown in Figure CC1 was constructed and the circuit described in Figure CC6 was used to obtain chart recordings of the frequency variations between the two standards. The 100 mc harmonic from each standard was fed into a Hallicrafter S-27 radio receiver. The output frequency of one standard was kept at 100 kc, but the other standard was detuned slightly so that the beat signal between the two 100 mc harmonics produced an audio frequency in the vicinity of 40 cps. (It had been determined by experiment that the measuring arrangement of Figure CC6 operated best when the beat signal between the 100 mc harmonics of the standards was not less than 30 cps nor greater than 50 cps.

The beat signal present at the audio output of the receiver was fed through a low-pass filter to reduce the effects of unwanted audio voltages, and then into an RCA Type 306A Audio Frequency Meter. The meter was of the type that produced a dc output voltage proportional to frequency. The output of the audio frequency meter was direct-coupled through a low-pass filter to a Sanborn chart recorder. Since the Sanborn recorder is capable of responding to frequencies greater than 40 cps, the filter network was required to reduce the beat signal ripple components. A high impedance battery bias supply provided a bucking voltage to facilitate centering the trace on the chart recorder.

Figure CC4 is a copy of a portion of the recorder chart strip and the trace that was obtained. The calibration was accomplished by feeding audio signals of known frequency into the frequency meter. The chart revealed the presence of a periodic frequency variation between the standards, the variation having a period of about 3-1/3 minutes and a peak-to-peak swing of 1.2 cps which is a frequency variation of 0.012 parts per million. During a seven-hour period, the maximum variation in frequency between the two standards was less than 0.02 parts per million. It should be stated that during this test each standard was operated from its own regulated dc power supply; both standards were in the same room and were operated from the same ac power source.

No attempt was made to determine the cause of the periodic frequency variation between the two standards. Each Western Electric D-152499 Frequency Standard was subsequently compared against a third standard of a different type, and the same periodic frequency variation was present in both chart recordings. This appears to indicate that the periodic variation was present in both Western Electric standards. It has been suggested that the periodic frequency variation between the two standards might be a result of "hunting" in operation of the crystal oven heater circuit.

Frequency Multiplier 6/19/56 HE

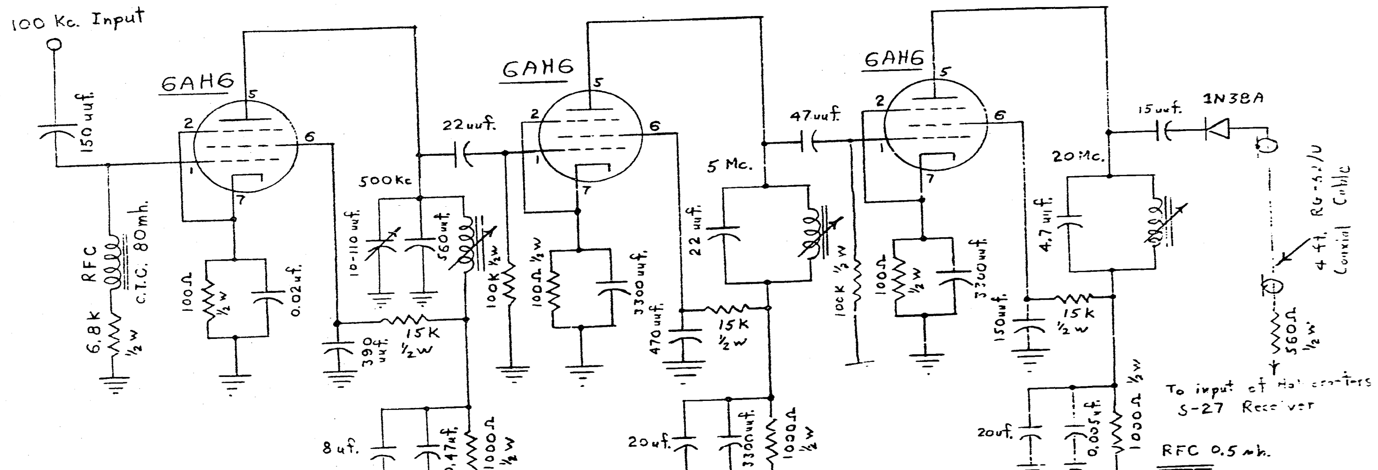


Fig. CC1

Block Drawing of Circuit Used to Compare WE Frequency Standard With WWV on Five Megacycles

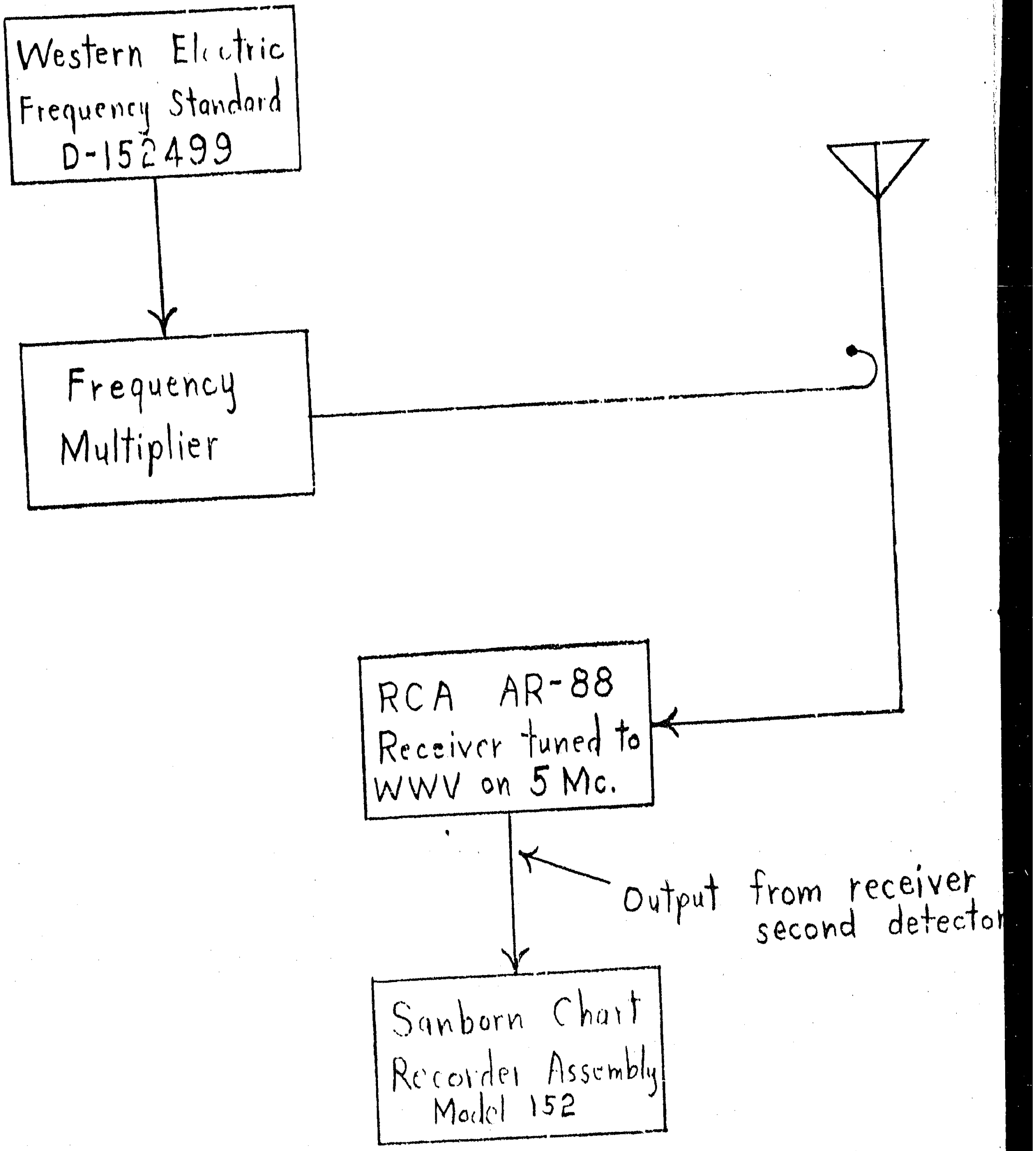


Fig. CC2

Fig. CC3

Sample Recorder Chart Strip of Beat Between 5 Mc. WWV and the Frequency Standard 5 Mc. Harmonic

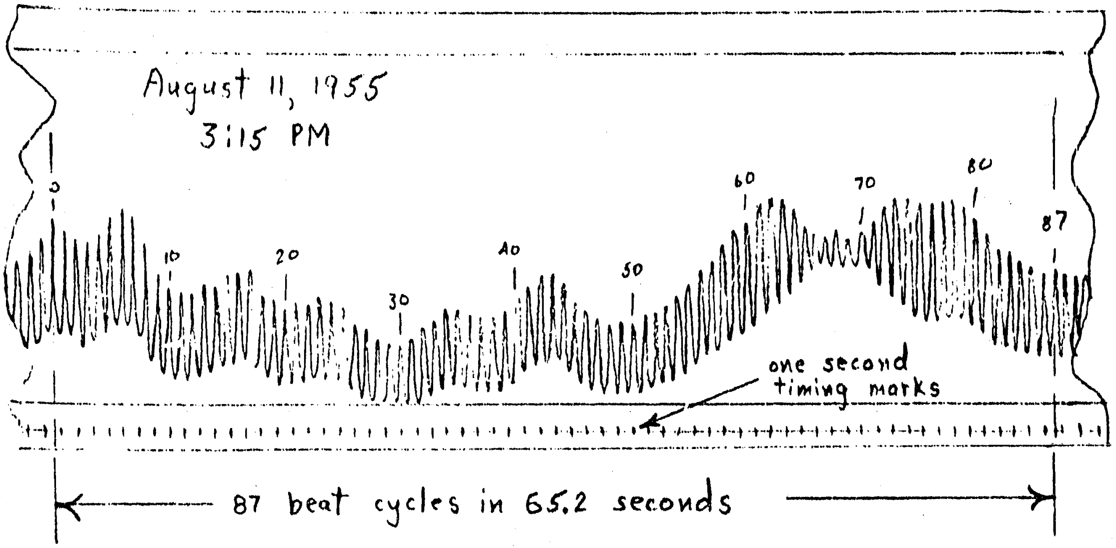
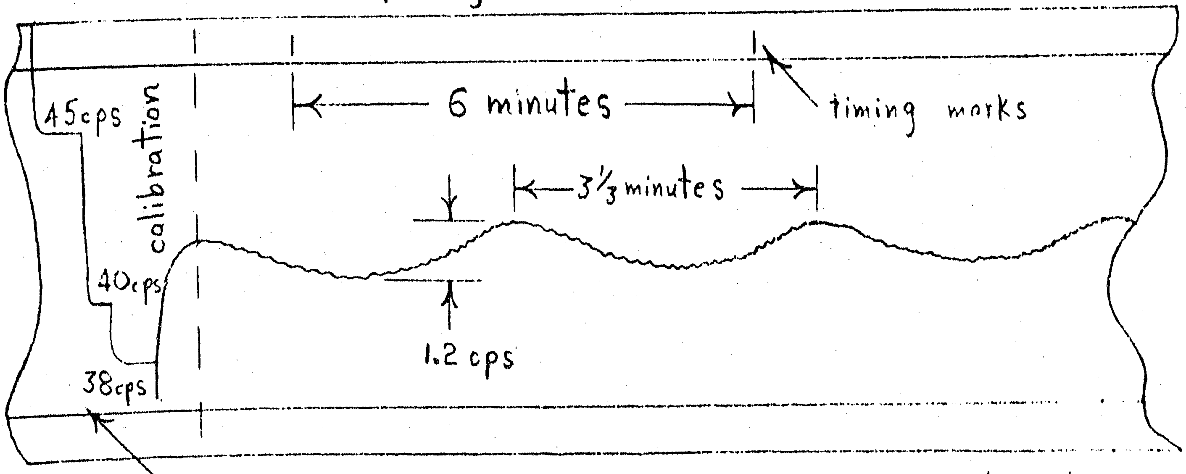


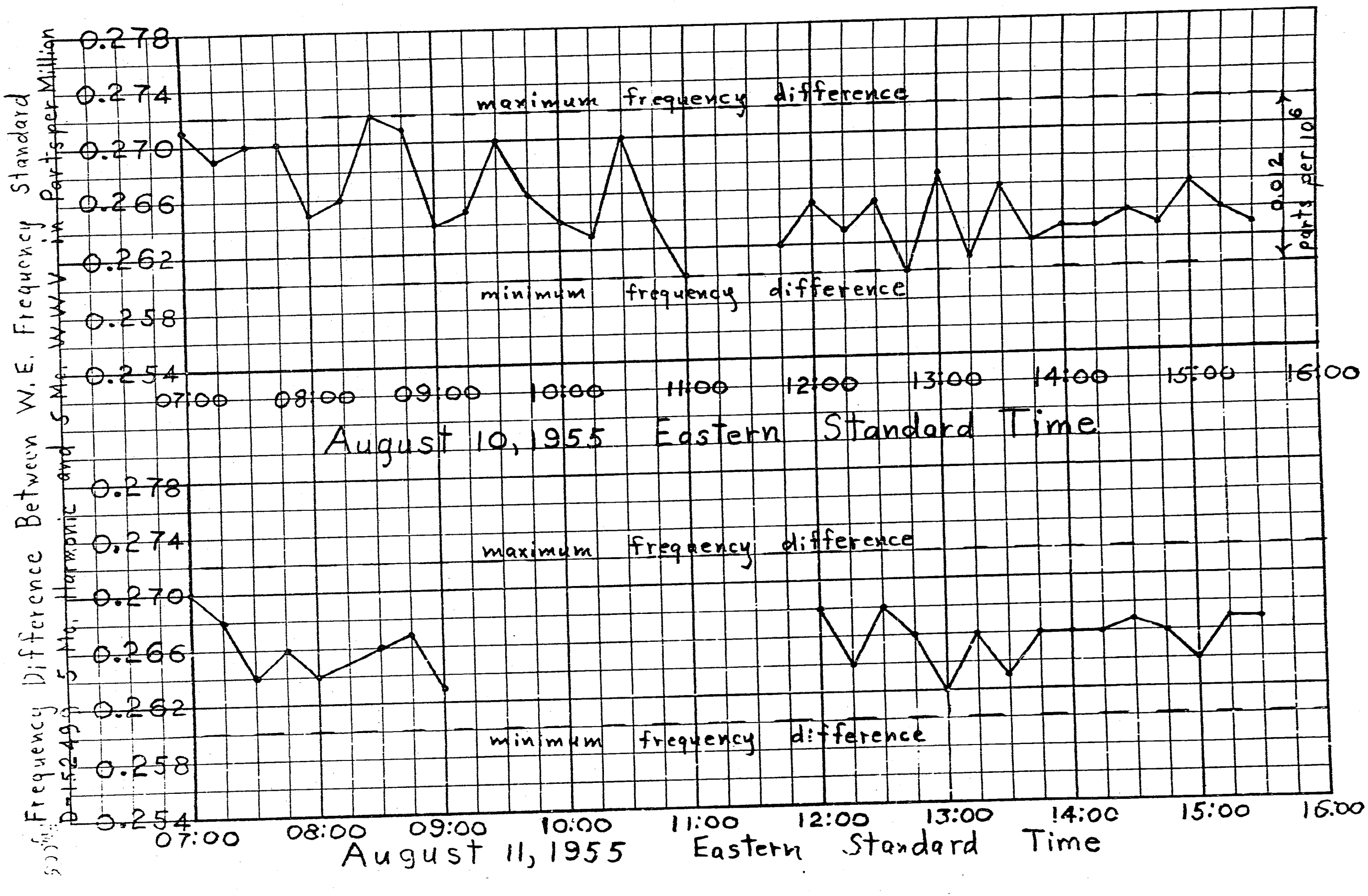
Fig. CC4

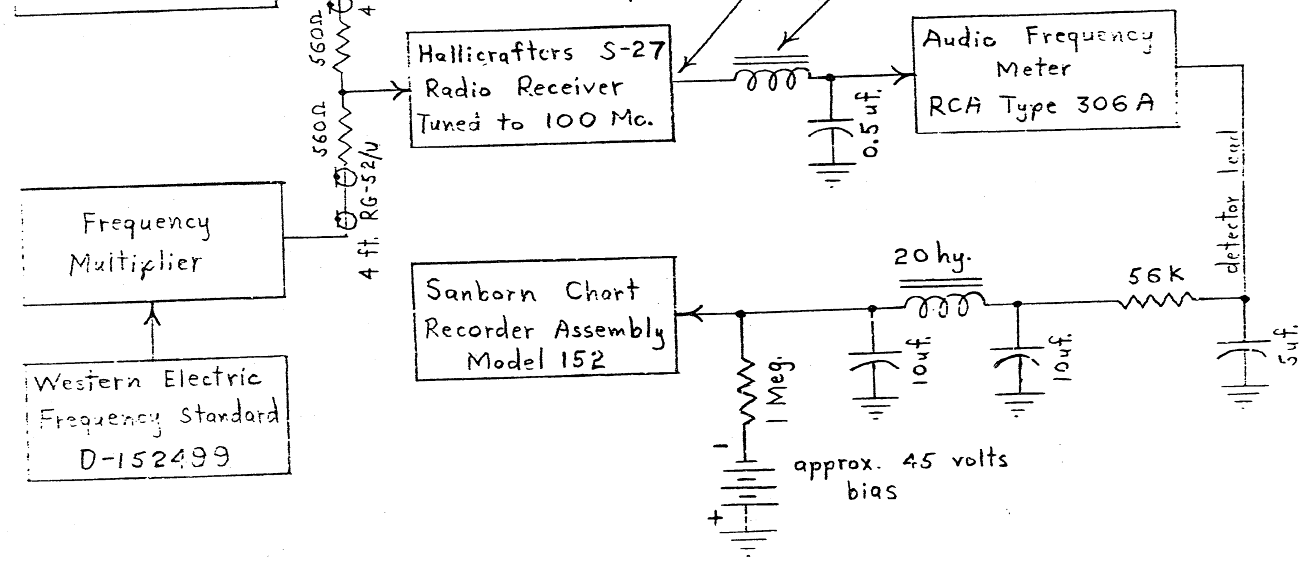
Sample Recorder Chart Strip of Beat Frequency Between 100 Mc. Harmonics of Two W.E. D-152499 Frequency Standards



The magnitude of the beat frequency in cycles is also equal to the difference in frequency in parts per hundred-million.

Fig's. CC3 and CC4


Frequency Difference Between W.E. Frequency Standard and 5 Mc. Harmonic of WWV in Parts per Million
D-15249 5
0.278
0.274
0.270
0.266
0.262
0.258
0.254
maximum frequency difference
minimum frequency difference
0.012 parts per 10^6
07:00
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
August 10, 1955 Eastern Standard Time
0.278
0.274
0.270
0.266
0.262
0.258
0.254
maximum frequency difference
minimum frequency difference
07:00
08:00
09:00
10:00
11:00
12:00
13:00
14:00
15:00
16:00
August 11, 1955 Eastern Standard Time



Block Drawing of Circuit Used to Measure Frequency Variations Between Two Western Electric D-152499 Frequency Standards

Fig. CC6