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1 August 1947

ANALYSIS OF CHANNEL INTERFERENCE
ON COMMUNICATION SYSTEMS
(225-to 400 Mc)

By
A. W. Walters

Report No. R-3059

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NAVAL RESEARCH LABORATORY
Washington, D. C.

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RADIO DIVISION II - COMMUNICATION SECTION

1 August 1947

ANALYSIS OF CHANNEL INTERFERENCE ON COMMUNICATION SYSTEMS (225 to 400 Mc)

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[redacted]

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NRL Problem S1331R-C

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[redacted]

ABSTRACT

This report constitutes a summary of the Laboratory analyses performed in connection with several combinations of VHF/UHF naval communication equipments in the frequency range 225 to 400 Mcs. The specific systems studied were combinations of:

Model TDZ Transmittersand Model RDZ Receivers
Model TDZ Transmitters and Model RDR Receivers
Model MAR Transmitters and Model RDZ Receivers
Model MAR Transmitters and Model RDR Receivers.

The primary purpose of the measurements was to determine the magnitude and location of interfering signals when employing 100 standard communication channels and one guard channel. A total of approximately 40,000 measurements were required to obtain the desired data. The analyses were augmented by additional data and information obtained from previous studies of the communication equipments involved.

Analysis of the results lead to the following general conclusions:

(a) Systems employing the RDR receiver in conjunction with either the TDZ or MAR transmitters exhibited the presence of approximately three times as many interference signals as systems using the RDZ receiver.

(b) In all systems studied the spurious response characteristic of the receivers accounted for the presence of 50 to 90 percent of the interference signals.

(c) The MAR transmitters generated a large number of interference signals which varied widely in location and magnitude.

(d) The TDZ transmitterswere responsible for only a small percentage of the total interference signals and these were essentially stable.

(e) Very few interference-free communication channels will be available in systems utilizing all four models of equipments (TDZ, MAR, RDZ, and RDR).

(f) The RDR and MAR equipments are not considered suitable for shipboard installation when several sets of equipments are required and interference-free operation is necessary.

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INTRODUCTION

1. Reference (1) requested the Naval Research Laboratory to perform systems analyses of 225-400 Mc. Communication equipments. References (6), (7), (8) and (9) describe system analyses performed on the following combinations of equipments:

(a) Model TDZ transmitters and Model RDZ receivers

(b) Model TDZ transmitters and Model RDR receivers

(c) Model MAR transmitters and Model RDZ receivers

(d) Model MAR transmitters and Model RDR receivers.

These equipment groups were operated on the 100 primary Navy Channels and one guard channel in this frequency range. One of the more important phases of the system analyses was the selection of interference free channels for a communication system, i.e. where a system is considered as a large number of communication nets. The purpose of this report is to correlate the results obtained from the systems evaluations with data and information secured from previous studies of these communication equipments so that a more complete system evaluation can be made. In addition, one method is presented for selecting interference free communication channels for a single shipboard installation containing TDZ, RDZ, MAR and RDR equipments.

2. In a communication system containing 101 frequency channels, possible interference on any receiver channel could result from one or more transmitter signals. Therefore, to adequately analyze a system employing TDZ, RDZ, MAR and RDR equipments, every receiver channel on the RDZ and RDR receiver must be checked for interference against both transmitters on 101 channels, necessitating a total of approximately 40,000 measurements. These measurements were conducted on systems employing the above equipments and the results are described in references (6), (7), (8), and (9). The measured data are shown on Plates 2, 3, 4, and 5.

3. In order to determine the primary causes of interference in a communications system each component of the system must be examined to ascertain its objectionable characteristics. The Model TDZ and MAR transmitters, and the Model RDZ and RDR receivers all employ frequency multiplication in order to obtain the desired output frequencies. Any equipment which produces its final output frequency or heterodyne frequency by multiplication of a basic crystal oscillator, will have in its output power components at

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frequencies which will include each and every harmonic of the basic frequency. The actual strength of these components will depend upon numerous factors, including the shielding integrity between stages, the operating condition of the various tubes, the adjustments of tuned circuits and the circuit elements. In transmitters, the magnitude of these components which are radiated will depend largely upon the electrical characteristics of the antenna system.

4. Individual studies were conducted on each of the equipments and it was found that the general analysis described in paragraph 2 was applicable to all equipments. These studies were performed prior to the system analyses and the pertinent results are reported in references (6), (7), (8), and (9). In general, these studies indicated that every receiver had many spurious response frequencies and that both transmitters had a large number of radio frequency outputs of considerable strength in addition to the desired output frequency. Therefore, in a system containing two or more equipments, i.e. at least one transmitter and one receiver, three potential sources of interference exist for each operating frequency. They are:

(a) One of the spurious response frequencies of a receiver coinciding with a transmitter operating frequency.

(b) One of the undesired radio frequency outputs of a transmitter coinciding with a receiver operating frequency.

(c) One of the spurious response frequencies of a receiver coinciding with an undesired radio frequency output of a transmitter.

The first two types of interference accounted for essentially all of the interference signals measured in the interference analyses. The occurrence of the last type was highly improbable because the level of this type of interference is below the sensitivity of the average system. For all practical considerations this third type of interference can be neglected, as it contributes only a very small percentage of the total interference signals, and all of these would be of very low amplitude.

5. If the average number and magnitude of the unwanted radio frequency outputs per channel for a transmitter and the average number and magnitude of spurious response frequencies per channel for a receiver are known for a given system, then a reasonable prediction can be made as to the total number and range of intensity of interference signals

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that will exist in this system. One criterion for an analysis of this type is that the interference signals have a random distribution over the frequency spectrum considered. This will be the case, to a reasonable degree, if in the system considered there is no fixed mathematical relation between the methods of frequency multiplication in the equipments and the methods utilized in selection of the channel frequencies. In the systems considered, with the exception of those including the MAR transmitter, these conditions were fulfilled. The MAR transmitter obtains its output power by multiplying the basic crystal oscillator frequency 54 times and subtracting a fixed frequency of 30.2 Mc. This transmitter may have in addition to the desired output frequency the following:

(a) All harmonics of the basic crystal oscillator frequency.

(b) All harmonics of the fixed frequency oscillator (10.066 Mc).

(c) All sum and difference frequencies of the above.

Therefore, some of these spurious output frequencies will follow an arithmetic progression. An arithmetic progression also exists in the channel spacing on the Navy communication channels in the 225-400 Mc. band which has a fundamental spacing of 800 kc. Thus, the potential interference may not be totally independent of channel spacing and the methods used for computing interference signals for other equipments, i.e. TDZ-RDZ and TDZ-RDR equipment may not give accurate results on systems containing the MAR equipments. In systems containing the TDZ, RDZ and RDR equipments the converse is true, in that an accurate estimate can be made. In reference (6) an analysis of this type was performed for a system containing TDZ and RDZ equipments and the results are repeated here as an example of how this was accomplished. Considering the average intensity of all receiver spurious response frequencies and transmitter unwanted radio frequency outputs, potential interference signals were found to be (12) twelve per operating receiver channel, so that for 100 primary channels, 1200 interference signals could exist. The mean effective bandwidth of the receiver is about 0.20 Mc. so that 100 operating channels occupy 100 x .20 or 20 Mc. Methods for determining the mean effective bandwidth are given in Appendix, part (a) of reference (6). The frequency band used for these tests were from about 230 Mc to 390 Mc or a total of 160 Mc. Therefore, interference signals observed on the 100 receiver channels for

[redacted]

the 100 transmitter channels would be 12.5% of 1200, or 150 interference signals. Considering the average number and level of the receiver spurious response frequencies, and the transmitter unwanted radio freuqency outputs, it can be concluded that about 75% of the instances of channel interference calculated were due to the spurious responce characteristic of the receiver. In the analysis described in reference (6), 151 instances of channel interference were observed for the system containing TDZ and RDZ equipments. This excellent agreement is probably more accidental than real; however, one would expect in systems comparable with the TDZ-RDZ or in the case of other TDZ-RDZ systems, a probable accuracy of 90% or greater.

6. In estimating the range of level of interference that would exist in a communication system containing TDZ and RDZ equipments, certain basic factors must be known. They are:

(a) The power output of the transmitter on the operating frequency.

(b) The power output of the transmitter on the unwanted radio frequencies.

(c) The sensitivity of the receiver on the operating frequency.

(d) The sensitivity of the receiver on frequencies where spurious response points occur.

(e) Attentuation between transmitting and receiving antennas for all frequencies considered.

With these basic factors known the magnitude of the strongest interference signal can be determined. In one case the maximum interference signal was observed when the transmitter operating frequency channel coincided with a strong spurious response in the receiver. For the TDZ-RDZ system this maximum signal was calculated to be approximately 50 db above the noise level of the receiver. Actual measurements as reported in reference (6) indicate that this figure is essentially correct.

RESULTS

7. Table 1 presents the essential information secured from the system analyses or from references (2), (3), (4),(5) and (10), on equipment characteristics for this composite interference analysis. Table 1, column one, indicates the

[redacted]

total number of interference signals produced if each and every transmitted signal interfered with all receiver channels. Column two shows the average number of transmitter spurious radio frequency outputs per channel which can be considered of sufficient strength to cause system interference, and the spurious response frequencies per channel for the receivers which are also likely to cause system interference. Potential interference signals for the RDZ receiver were averaged on three channels, while on the RDR receiver information was available on only a single channel. Insufficient information was available on the MAR transmitter to make any reasonable estimate of the potential number of interference signals per channel. Columns 3 and 4 indicate the total number of interference signals measured in each system and the range in level of these signals. Column 5 presents the number of receiver channels which were essentially free of system interference when transmitters were transmitting on all channels. Column 6 indicates the maximum range of interference caused by interference signals. Distances given are between transmiting and receiving antennas. Column 7 indicates the expected variation in the average intensity of interference signals for each system. Column 8 gives the mean effective bandwidth for both receivers. The mean effective bandwidth of a receiver is defined as a theoretical, flat-bottomed, vertical sided, selectivity curve (ideal I.F. amplifier curve) which could be substituted for normal I.F. selectivity curve and produce comparable results. One method for determining the mean effective bandwidth of a receiver is given in reference (6), Appendix, Part (a).

8. To determine the causes of interference in any communication system a careful examination must be conducted on all components utilized. Both the TDZ and MAR transmitters produced system interference when a receiver operating channel coincided with a transmitter unwanted radio frequency signal of sufficient strength to cause interference. These unwanted radio frequency outputs in the TDZ transmitter were essentially stable in character, that is, when specific interference measurements were repeated, similar results were obtained. This was not the case with the MAR transmitter. In addition to variations caused by slight equipment adjustments and temperature changes, considerable variations were noted in magnitude and location of interference signals when the position of the meter switch on the equipment was changed. This switch changes the position of a multi-meter in order to indicate the operating conditions of the various circuits in the equipment and if properly designed should have little or no effect on the

[redacted]

radio frequency outputs. The changes in magnitude and location of interference signals due to these causes make duplication or checking of results virtually impossible. Thus, one would expect that on any group of measurements utilizing the MAR transmitter the results would be more of an estimate rather than an accurate analysis. That is, the number, magnitude and the position of the various interference points for the MAR transmitter are not stable and an accurate analysis of the data is not practical.

9. The principal cause of interference signals in the VHF/UHF communication systems analyzed has been the spurious response characteristic of the receivers. This can be substantiated by observing column 2 of Table 1 and comparing the results obtained on TDZ, RDZ and RDR equipments. The RDR receiver, due to its spurious response characteristic alone, will produce approximately ten times as many interference signals as the TDZ transmitter when these equipments are operated together as a local system. By comparison, the RDZ receiver will produce about three times as many interference signals as the TDZ transmitter. An additional factor which seriously limits the usefulness of the RDR receiver in a communication system is its relatively broad I.F. selectivity curve. This receiver has a mean effective bandwidth of approximately 400 kc. So when one considers the present channel spacing of 800 kc, and the attenuation of a standard shipboard antenna system of from 30 to 40 db, it is fairly certain that in a great many cases adjacent channel transmitters will produce interference on the operating channel of this receiver. (Standard shipboard antenna installation refers to a system containing two MAR antennas collinear mounted with a center to center spacing of four feet or for a horizontal spacing of 20 feet.) This adjacent channel interference existed, as may be seen by observing Table 1, Plates 3 and 5. The mean effective bandwidth of the RDZ receiver is approximately 200 kc. A study of Plates 2 and 6 will show that the probability of observing adjacent channel interference was no greater than for any of the more remote channels. If the stability of the operating system could be improved such that the mean effective bandwidth of the receiver could be decreased, say for example, to one-half of its present value, then the average number of interference signals would be reduced to approximately one-half. In addition, this reduction in mean effective bandwidth of the receiver would produce the following results:

(a) The noise level in the receiver would be reduced, which would be observed as an increase in receiver sensitivity. This increased receiver sensitivity would effectively increase

[redacted]

the communication range of the system.

(b) The number of interference free channels on the receiver would be increased, which, in turn, would increase the number of interference free communication channels.

Other methods for system improvement could include improved filter circuits in the heterodyne oscillator system of the receivers and improved shielding and circuit design in the transmitters.

10. Plates 2, 3, 4, and 5 show complete results of all interference measurements in systems containing TDZ-RDZ, TDZ-RDR, MAR-RDZ and MAR-RDR equipments. These equipments were operated on the 100 Primary Navy Channels and the guard channel for the system analyses. The one exception was that the RDR receiver was operated on 98 channels, as three channels were blocked due to the local oscillator signal appearing at the intermediate frequency. To select interference free channels for a system containing all four of the above listed equipments, a careful examination must be made on Plates 2, 3, 4, and 5. The following procedure was used to select 7 communication channels which are essentially free of interference for all conditions of transmission. First, Plate 5 was examined and fifteen channels were selected as interference free for a system containing MAR-RDR equipments. These channels are 1, 5, 6, 15, 23, 29, 34, 38, 46, 51, 62, 71, 83, 91 and 96. Second, Plate 3 was examined to see which of these channels were also clear for a system containing TDZ-RDR equipments. Channels 1, 5, 6, 15, 23, 38, 51, 71, 83 and 96 were selected. In a system containing the RDR receiver and both of the transmitters the above channels could be utilized without inter-system interference. Now the problem is to see how many of these channels can also be used with the RDZ receivers. First, Plate 2 was observed and it was seen that channels 1, 5, 6, 23, 51, 71, 83, and 96 could be used. These channels were clear for the TDZ-RDZ combination of equipments. Second, Plate 4 was examined and it was found that channels 1, 5, 6, 23, 51, 83 and 96 could be used for the entire system. This indicates that on these seven channels all four equipments can be operated in a local system with essentially no interference on the receiver channels for all conditions of transmission. The methods utilized here are applicable when a small number of channels are to be selected. The more complicated problem of selecting the maximum number of interference free channels for a task force is beyond the scope of this report.

[redacted]

CONCLUSIONS

11. The experimental arrangements on which 40,000 measurements were made are equivalent to standard shipboard installations in which the receiving and transmitting antennas are collinear with a 4 foot spacing, or, for a horizontal spacing of about 20 feet. The specific data obtained during these measurements are valid only for the particular equipment on which the measurements were made. It can be concluded from the data derived from specific systems containing TDZ-RDZ, TDZ-RDR, MAR-RDZ and MAR-RDR equipment that:

(a) The TDZ-RDZ system contained the least number of interference signals and the greatest number of interference free channels.

(b) For the systems containing the RDZ receiver, the maximum interference level was approximately 50 db above the noise level of the receiver. For the RDR receiver this maximum level was about 90 db above the noise level.

(c) An interference signal level of 90 db, as observed in these analyses, can produce detectable interference when the transmitting antenna is spaced from the receiving antenna a distance corresponding to 25% of the communication range of the system; an interference signal of 50 db can produce undesirable interference when the transmitter to receiver antenna spacing is one mile, an interference signal of 30 db will not produce interference when the transmitter to receiver antenna spacing is greater than 600 feet. Thus, it is possible for a transmitter on one ship to produce interference in a receiver on a nearby ship.

(d) An interference signal of the order of 90 db in a local system will render that receiving channel unusable. An interference signal of 50 db will reduce the communication range to less than 10 per cent of its normal value and an interference signal of 10 db will reduce the communication range of a system to about 60% of its normal value.

(e) In all systems analyzed 50% to 90% of the interference signals were due to the spurious response characteristic of the receivers.

[redacted]

(f) On systems containing the RDR receiver 98 channels only are usable, as two of the primary channels and the guard channel are blocked by local oscillator signals appearing at the intermediate frequency.

12. The measured data obtained from the system analyses of TDZ-RDZ, TDZ-RDR, MAR-RDZ and MAR-RDR equipments are for given transmitter receiver combinations. Channel frequency tolerances due to set effects and crystal tolerances will in all probability affect the magnitude and channel number of some of the interference signals. All equipment and component tolerances can, for the sake of convenience, be considered as effectively increasing the mean effective bandwidth of the receiver in the system. Then it can be concluded that:

(a) The maximum number of interference signals that could be measured on a large number of transmitter-receiver systems is approximately 25% greater for systems containing the RDR receiver and 50% greater for the RDZ receiver, than the measured number of signals.

(b) The most probable number of interference signals that will exist for a large number of TDZ transmitter-receiver combinations is approximately 5% greater for systems using the RDR receiver and 10% greater for the RDZ, than the measured number of interference signals.

(c) The average variation in intensity of the measured interference signals in systems containing the RDR receiver will be approximately ± 3 db and in systems using the RDZ receiver approximately ± 5 db.

(d) In systems comparable with those containing TDZ-RDZ equipments, the probable variation from system to system in the total number of interference signals measured will be approximately 10%.

RECOMMENDATION

13. It is recommended that the use of MAR-RDR equipment be excluded from communication systems aboard ship where several sets of equipment are to be used and interference free communication is desired.

[redacted]

[redacted]

REFERENCES

1. BuShips Ltr., Sec. 911, Ser. 529, of 24 Oct. 1945 to NRL.

2. NRL Ltr. C-S67/L5(1215), Ser. C-1210-134/46 of 24 April 1946 to BuShips.

3. NRL Ltr. C-S67/L5(1210:ARR), Ser. C-1210-181/46 of 13 July 1946.

4. NRL Report, C-S67/43(356:LFB), Ser. C-350-257/45 of 17 August 1945 to BuShips.

5. NRL Ltr. C-S67/66(380:WAW), C-380-324/45 of 20 June 1945 to BuShips.

6. NRL Report R-2967 of 6 Dec. 1946 (TDZ-RDZ).

7. NRL Report R-3050 of 1 April 1947 (TDZ-RDR).

8. NRL Report R-3051 of 1 May 1947 (MAR-RDZ).

9. NRL Report R-3052 of 1 June 1947 (MAR-RDR).

10. NRL Report R-2667 of 23 Oct. 1945.

[redacted]

TABLE 1

Equipments included in a system	1 Possible number of interference signals in the system	2 Potential Interference signals produced per equipment on each channel Transmitters -	 Receivers	3 Number of interference signals measured on 101 channels	4 Range in level of interference signals in db	5 Interference free channels for the system listed
TDZ and RDZ	10,101	4-5, an average for three channels on the TDZ	12, an average for three channels	154	From one to 50 db above the noise level of the receiver	33
MAR and RDZ	10,101	sufficient information was not available for an accurate estimate on the MAR	RDZ	286		9
TDZ and RDR	9,800	TDZ as above	46 based on measurements on a single channel RDR	1184	From one to 90 db above the noise level of the receiver	None
MAR and RDR	9,800	MAR as above		1033		None

[redacted]

TABLE I (Cont.)

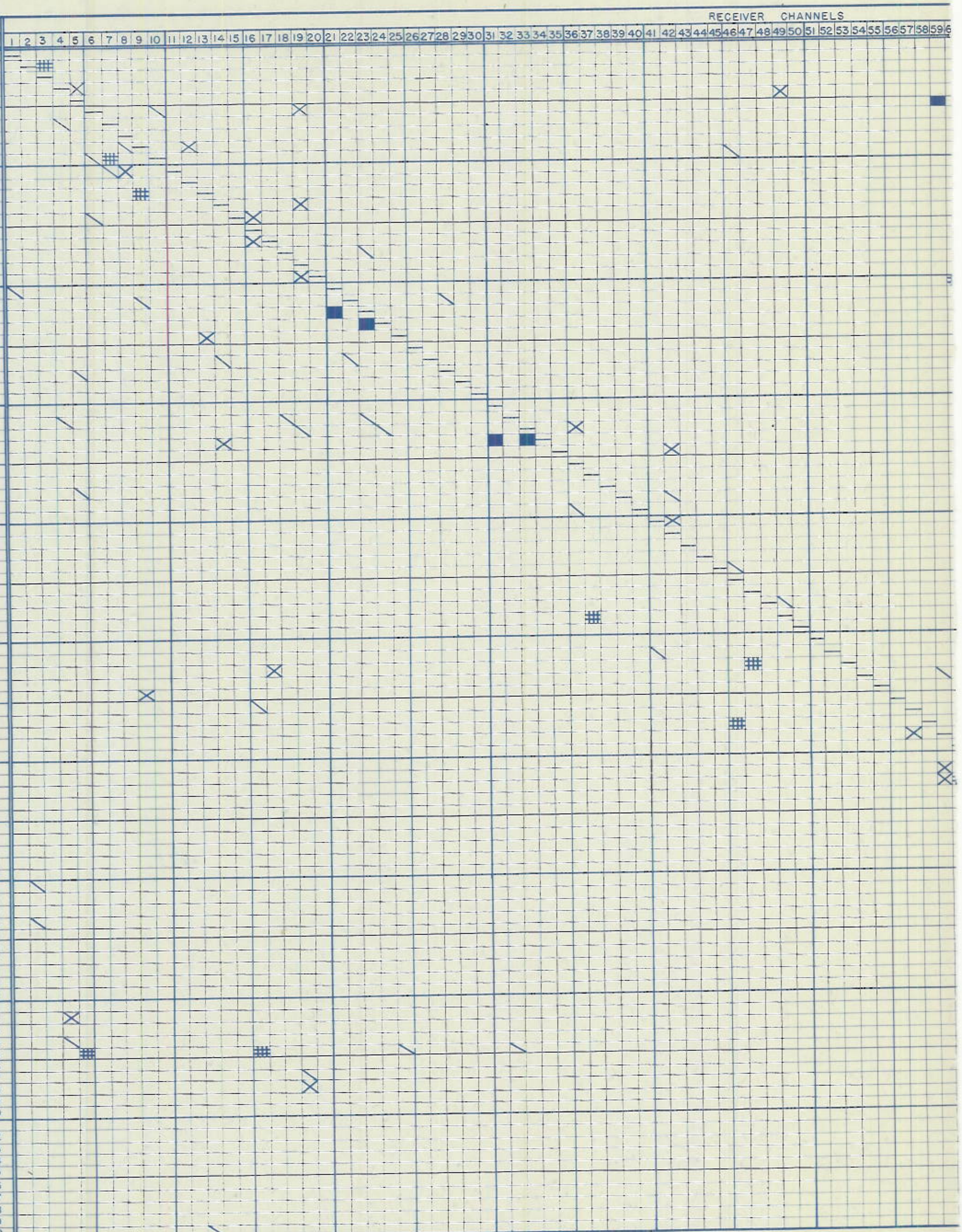
6 Maximum range of interference caused by interference signals	7 Variation in the average intensity of interference signals for the system	8 Mean Effective bandwidth of the receiver
One mile	± 5 db	200 kc
25% of the communication range of the system	± 3 db	400 kc

[redacted]

TDZ, RDZ, MAR AND RDR INSTALLATION

PLATE 1

TRANSMITTER FREQUENCY IN MCS	TRANSMITTER CHANNEL NUMBER
231.4	1
233.8	2
234.6	3
236.2	4
237.8	5
249.8	6
250.6	7
251.4	8
253.8	9
255.4	10
256.2	11
257.8	12
258.6	13
262.6	14
263.4	15
264.2	16
265.0	17
265.8	18
267.4	19
268.2	20
269.8	21
270.6	22
271.4	23
273.0	24
273.8	25
274.6	26
275.4	27
277.0	28
277.8	29
279.4	30
280.2	31
283.4	32
285.0	33
285.8	34
289.8	35
291.4	36
299.4	37
301.0	38
302.6	39
304.2	40
305.0	41
305.8	42
307.4	43
309.0	44
310.6	45
312.2	46
313.8	47
315.4	48
317.0	49
318.6	50
320.2	51
321.8	52
323.4	53
325.0	54
326.6	55
328.2	56
329.8	57
330.6	58
333.0	59
334.6	60
336.2	61
337.8	62
339.4	63
341.0	64
342.6	65
344.2	66
345.8	67
346.6	68
349.0	69
349.8	70
350.6	71
352.2	72
353.0	73
354.6	74
355.4	75
356.2	76
357.0	77
357.8	78
358.6	79
359.4	80
361.0	81
361.8	82
362.6	83
363.4	84
364.2	85
365.8	86
367.4	87
368.2	88
369.8	89
370.6	90
371.4	91
373.8	92
381.8	93
383.4	94
384.2	95
385.0	96
385.8	97
386.6	98
387.4	99
389.8	100



NOTE: FREQUENCY INDICATED BY TRANSMITTER CHANNEL IS THE SAME FOR CORRESPONDING RECEIVER CHANNEL.

[redacted]

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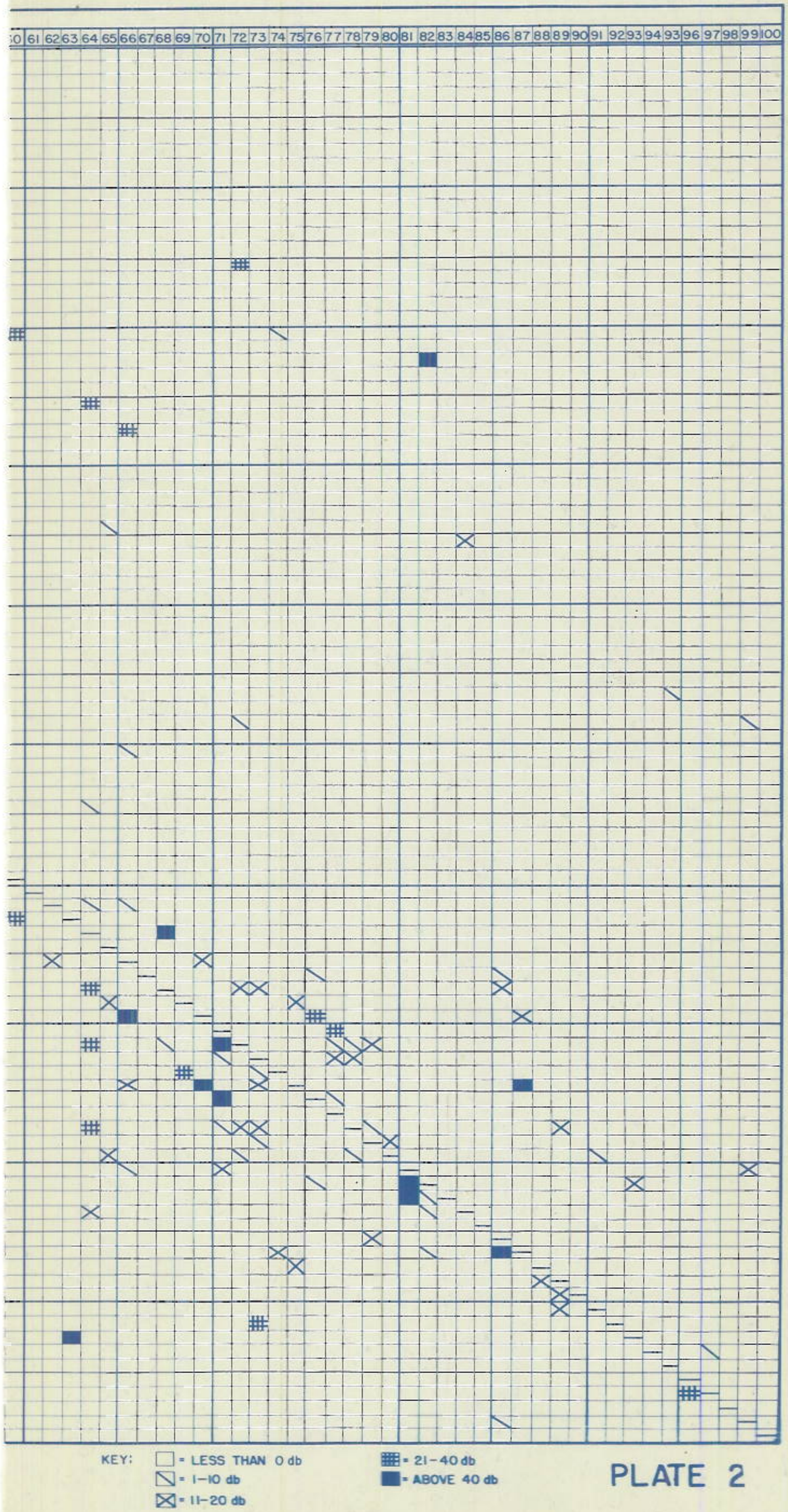
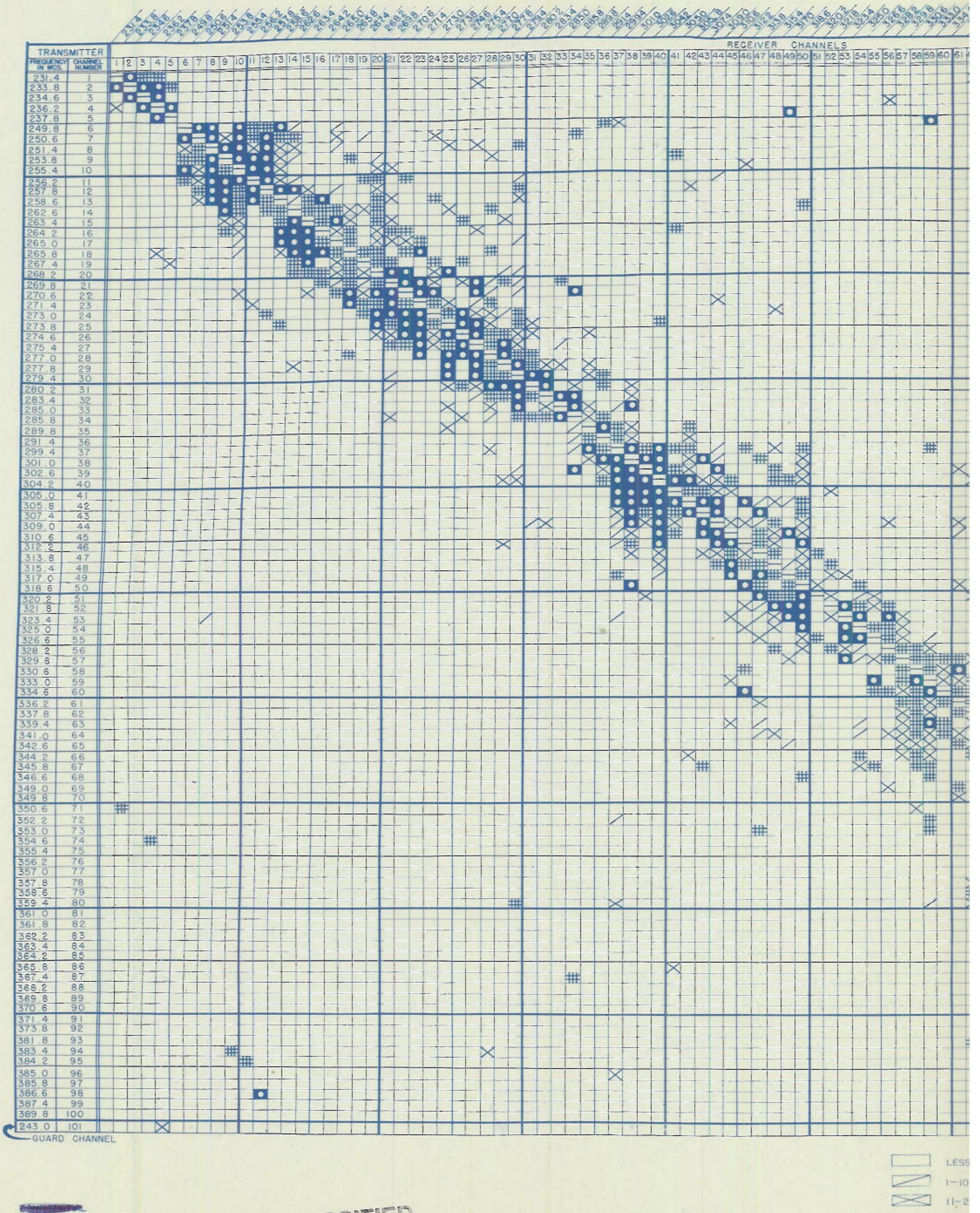


60 61 62 63 64 65 66 67 68 69 70 71 72 73 74 75 76 77 78 79 80 81 82 83 84 85 86 87 88 89 90 91 92 93 94 93 96 97 98 99 100
KEY:
= LESS THAN 0 db
= 1–10 db
= 11–20 db
= 21–40 db
= ABOVE 40 db

PLATE 2



[redacted]

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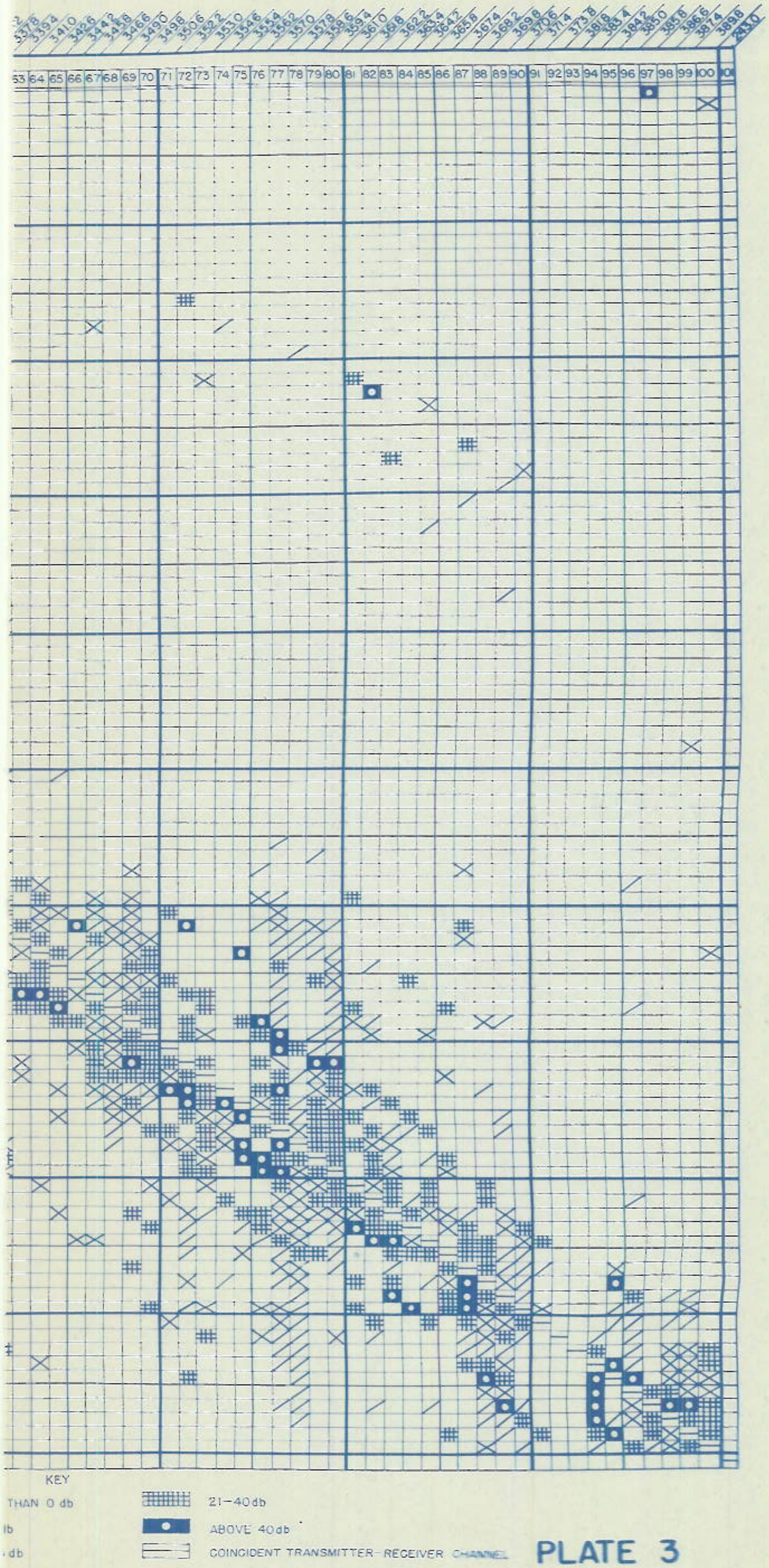
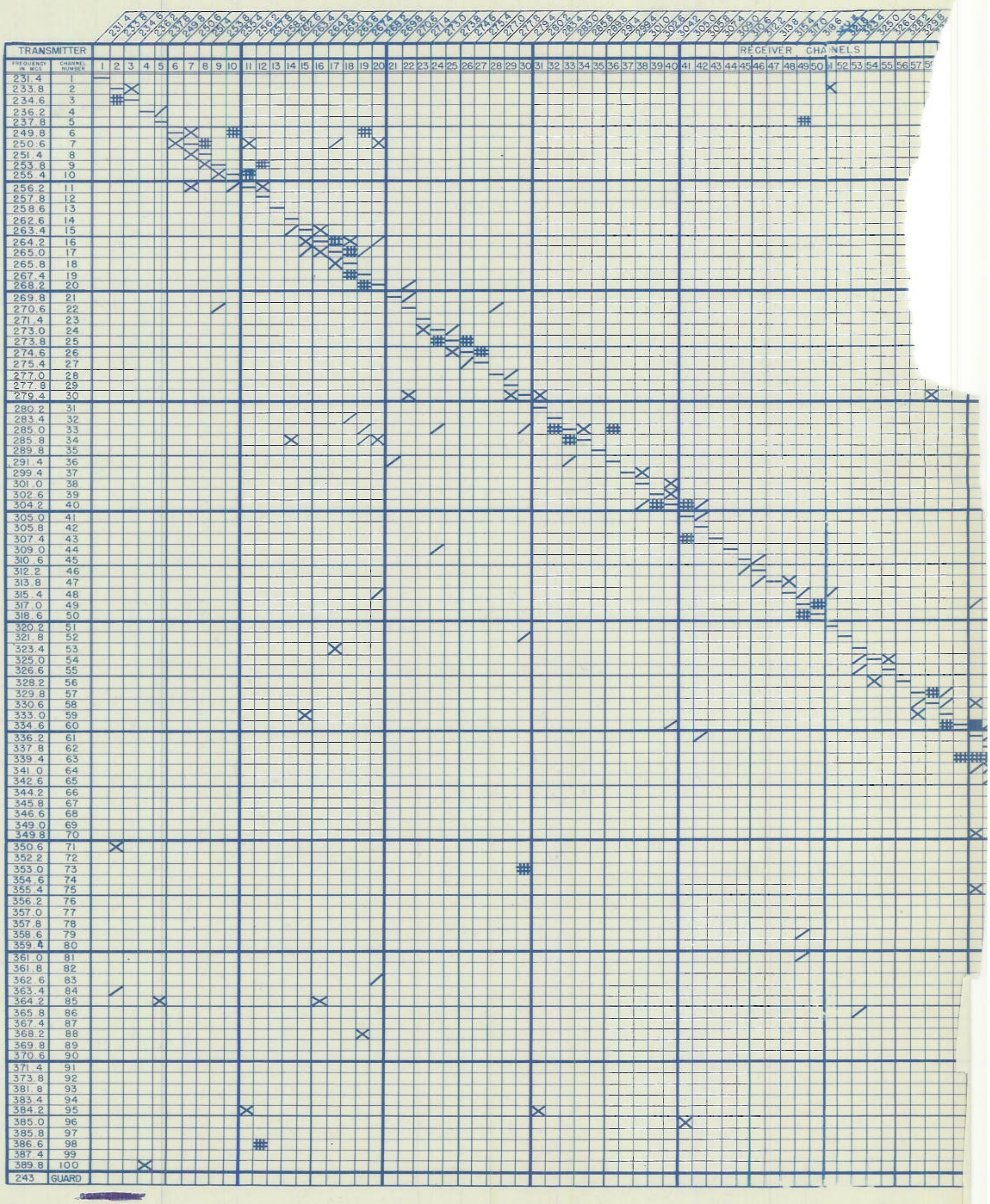
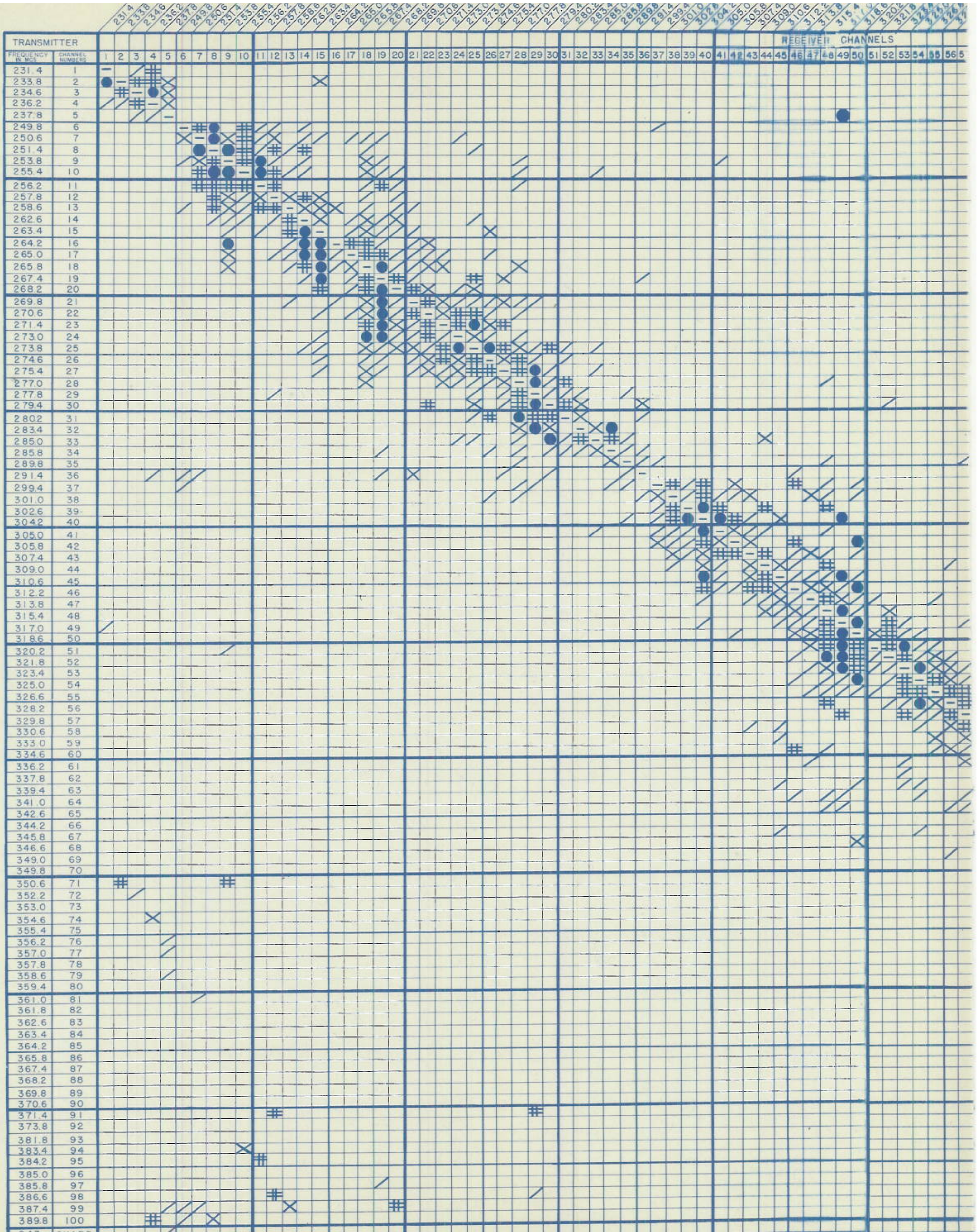
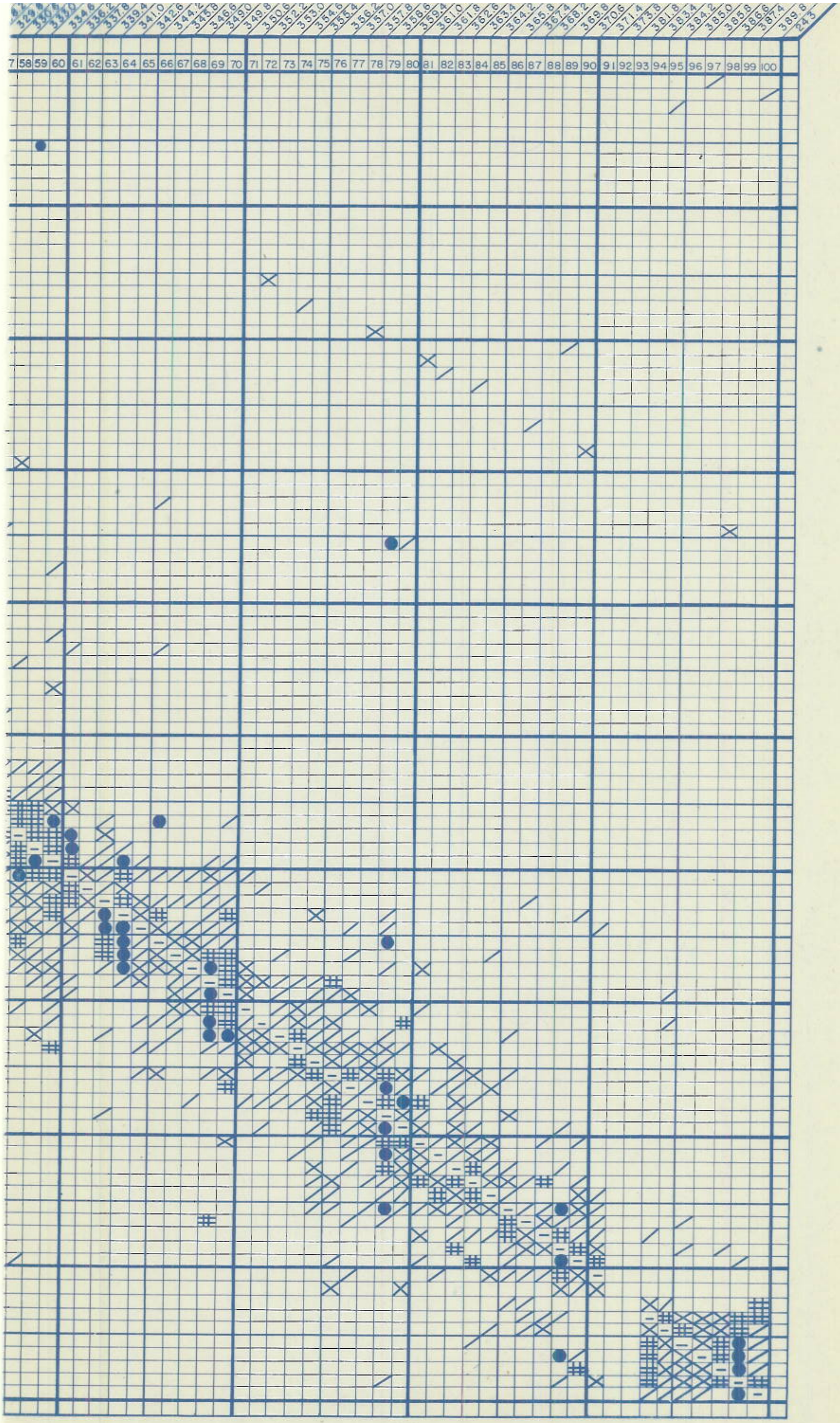

KEY
THAN 0 db
lb
db
21–40db
ABOVE 40db
COINCIDENT TRANSMITTER-RECEIVER CHANNEL

PLATE 3


TRANSMITTER
RECEIVER CHANNELS
FREQUENCY IN MCS
CHANNEL NUMBER
231.4 1
233.8 2
234.6 3
236.2 4
237.8 5
249.8 6
250.6 7
251.4 8
253.8 9
255.4 10
256.2 11
257.8 12
258.6 13
262.6 14
263.4 15
264.2 16
265.0 17
265.8 18
267.4 19
268.2 20
269.8 21
270.6 22
271.4 23
273.0 24
273.8 25
274.6 26
275.4 27
277.0 28
277.8 29
279.4 30
280.2 31
283.4 32
285.0 33
285.8 34
289.8 35
291.4 36
299.4 37
301.0 38
302.6 39
304.2 40
305.0 41
305.8 42
307.4 43
309.0 44
310.6 45
312.2 46
313.8 47
315.4 48
317.0 49
318.6 50
320.2 51
321.8 52
323.4 53
325.0 54
326.6 55
328.2 56
329.8 57
330.6 58
333.0 59
334.6 60
336.2 61
337.8 62
339.4 63
341.0 64
342.6 65
344.2 66
345.8 67
346.6 68
349.0 69
349.8 70
350.6 71
352.2 72
353.0 73
354.6 74
355.4 75
356.2 76
357.0 77
357.8 78
358.6 79
359.4 80
361.0 81
361.8 82
362.6 83
363.4 84
364.2 85
365.8 86
367.4 87
368.2 88
369.8 89
370.6 90
371.4 91
373.8 92
381.8 93
383.4 94
384.2 95
385.0 96
385.8 97
386.6 98
387.4 99
389.8 100
243 GUARD



NOTE: FREQUENCY INDICATED BY TRANSMITTER CHANNEL IS THE SAME FOR CORRESPONDING RECEIVER CHANNEL.



KEY

- LESS THAN 0 db
- 1-10 db
- 11-20 db
- 21-40 db
- ABOVE 40 db
- COINCIDENT TRANSMITTER-RECEIVER CHANNELS

PLATE 5

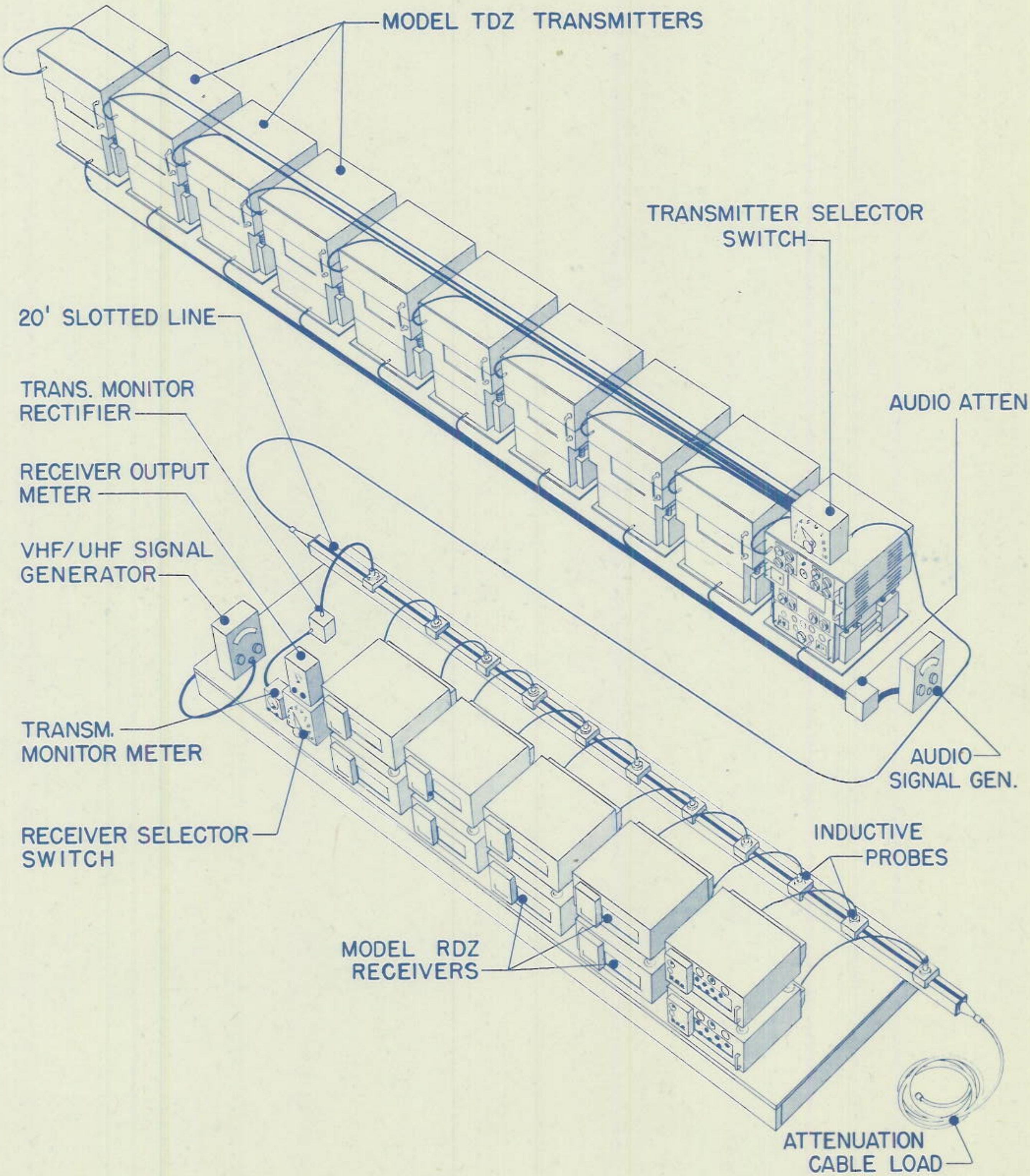
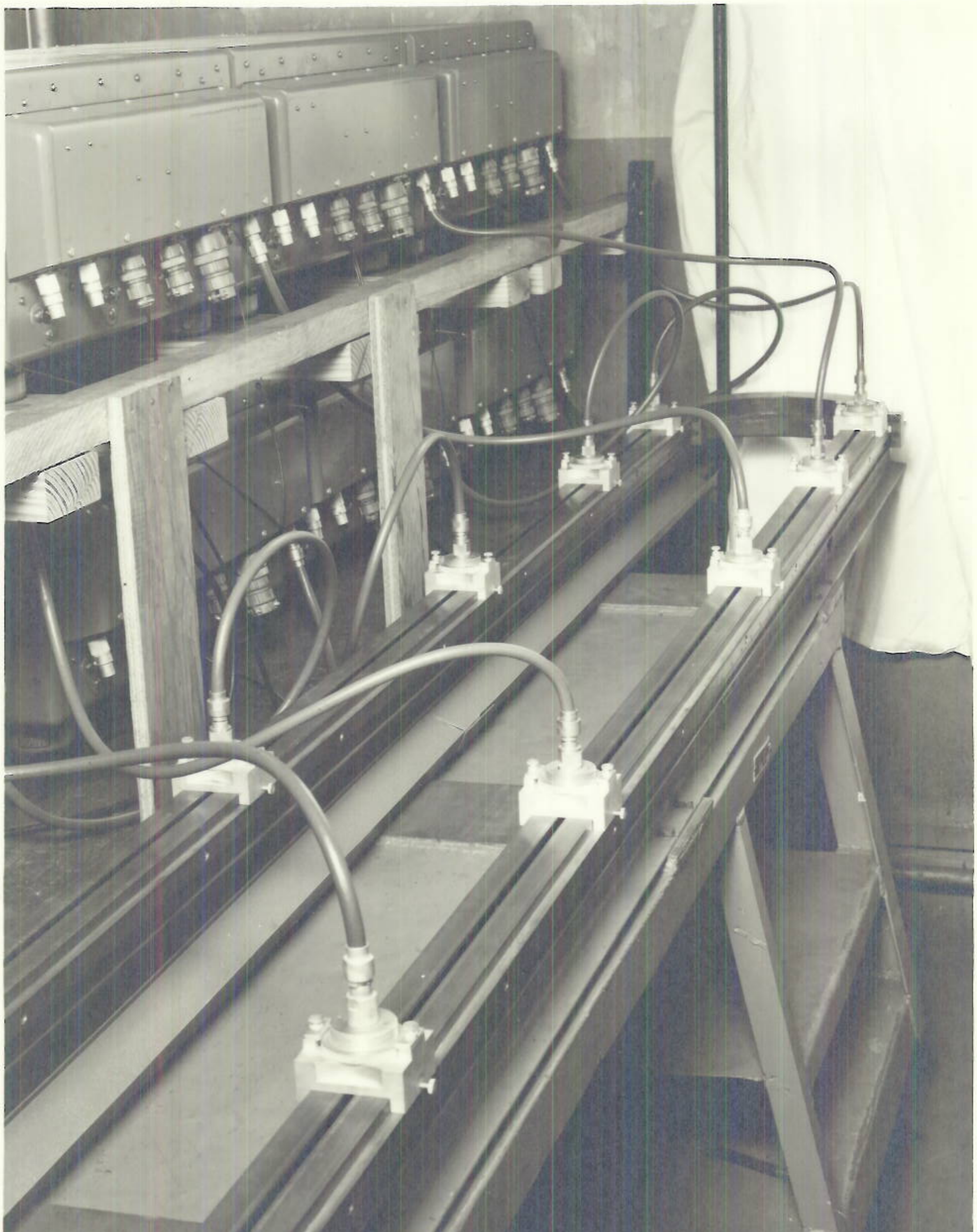


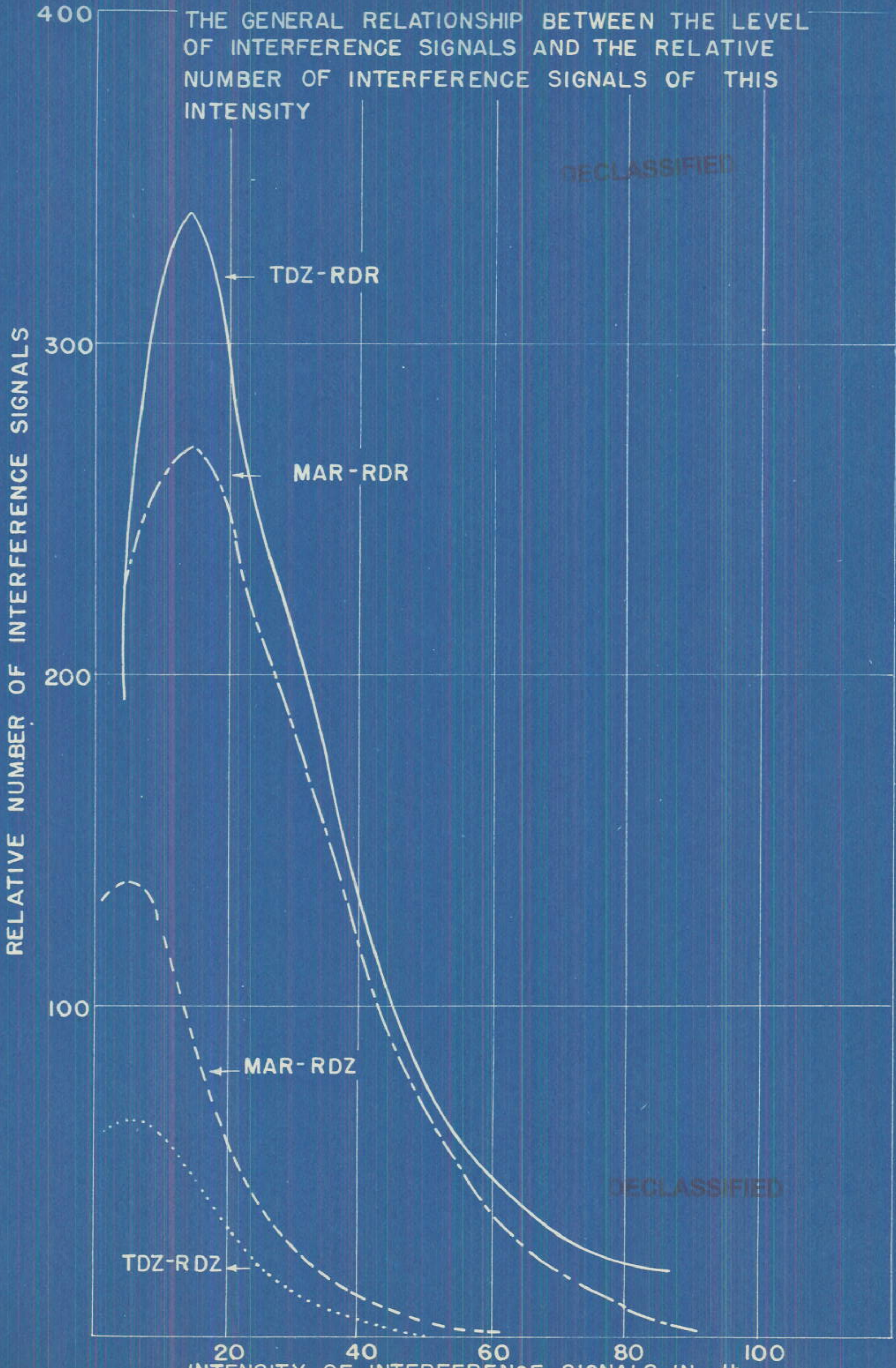
PLATE 6 . TDZ-RDZ INSTALLATION DIAGRAM



INDUCTIVE PROBES ON 20' SLOTTED LINE

DECLASSIFIED

THE GENERAL RELATIONSHIP BETWEEN THE LEVEL OF INTERFERENCE SIGNALS AND THE RELATIVE NUMBER OF INTERFERENCE SIGNALS OF THIS INTENSITY



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