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ELECTRONIC SPECIAL RESEARCH DIVISION
APPLICATION RESEARCH SECTION

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2 January 1946

DEVELOPMENT OF ELECTRONIC RECEIVING SWITCHES FOR THE 225 TO 390 MEGACYCLE FREQUENCY RANGE

FR-2715

BY

M. HEUSINKVELD

- Report R-2715 -

[redacted]

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Preliminary Pages ...a-d
Numbered Pages......11
Plates...............12
Distribution List....e

BuShips Problem S1004.2R-C

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NAVAL RESEARCH LABORATORY
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DEVELOPMENT OF ELECTRONIC RECEIVING SWITCHES FOR THE 225 TO 390 MEGACYCLE FREQUENCY RANGE

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ABSTRACT

On board Navy ships many antennas must be located in places where the resulting field intensity patterns do not give adequate coverage in all directions. A system has been devised using two antennas in parallel and switching the receiver alternately from one antenna to the other at a super-audible rate; this giving an averaging effect of the patterns from the two antennas.

This report describes the development of and results obtained from electronic switches for a receiving system, and it gives a discussion of the interfering harmonics produced. The frequency range covered was 225 to 390 megacycles and a switching rate of 20 kilocycles was used. The results obtained from the receiving switches were moderately good, switching of the order of 18 decibels being obtained with a maximum insertion loss of approximately $1\frac{1}{2}$ decibels.

The switching action was accomplished through the use of a vacuum tube across a resonant tank. The plate resistance of the tube, varying with the dc current through the tube, was used to control the r-f transmission through this tank.

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INTRODUCTION

1. This work was requested by the Bureau of Ships and authorized by reference 1.

2. On board Navy ships, due to the large numbers of antennas used it is necessary that some of the communication antennas be mounted in places where good coverage over 360 degrees in the horizontal plane is not possible. One possible method of improving the coverage of these antennas would be to use a pair of antennas with each receiver. Each antenna would be mounted in a position such that in the direction in which reception by one antenna is low, the reception by the other antenna is high. Such a case would occur if the two antennas were mounted on opposite sides of the ship. The receiver could then be switched from one antenna to the other at a super-audible rate, and the patterns of the two antennas would in effect be averaged thus giving more nearly uniform coverage.

3. In this project, the electronic switch for such a receiving antenna system was to be developed. The frequency range covered was to be from 225 to 390 megacycles. The switch system was to be so devised that the receiver could be electronically connected to either antenna alone or to both of them alternately at the super-audible rate.

4. The method used to produce the switching was essentially the same as that used in some TR systems in radar. A switching vacuum tube was used under the two operating conditions of conduction and non-conduction, r-f plate resistance being low during conduction and very high during non-conduction of the current through the tube. This tube was connected directly across the antenna transmission line, thereby alternately providing a low resistance short and an open circuit in parallel with the line, switching thus being obtained. Switching was at a 20 kilocycle frequency.

5. The plate resistance of most tubes is not low enough to provide a good short circuit across a 50-ohm line during conduction of the tube. Consequently, a resonant tank tuned by a parallel tuning stub was used to build up the voltage (See Figure 1, Plate 1). The tank was made approximately a half wave length long at mid-frequency with the switching tube located at the center or high impedance point. This location permitted maximum effectiveness in switching.

6. The switch as just described would, in one condition, transmit the r-f energy and, in the second, provided a short past which the energy could not flow. For alternate switching of two antennas two of these units were required, each keyed 180 degrees out of phase so that one switch would transmit energy during the time the other

would not. When one switch would be shorted out its input impedance would be very low; therefore quarter-wave length transmission lines were used between each switch and the common transmission line to the receiver to transform this low impedance into a high impedance. This high impedance, being in parallel with the other branch, would not have much effect on the transmission of the energy from the other switch to the receiver. This system is shown by Figure 2, Plate 1.

STATIC TESTS USING DIODES

7. All of the switches tried were of the same type as illustrated by Figure 1, Plate 1, no simpler nor more efficient method of transforming the voltage or of tuning the switch to resonance being devised.

8. A requirement for efficient switching was that the electron tube should have a low r-f plate resistance. For this reason the 6AL5 and the 559 diodes were tried. However the 559 gave better results due to the simpler r-f circuit arrangement obtainable with this tube. Photographs of a single switch using a 559 diode are given by Plates 2 and 3.

9. Results obtained from switches using 559 diodes with dc bias are given by Plates 4 and 5. It is seen that with a single switch insertion loss is of the order of one decibel, switching is some eighteen decibels, and maximum reflection is about ten percent on a fifty-ohm line. The switching is expressed as the ratio in decibels between the power transmitted through the switch in the two operating conditions. When the two switches were connected in parallel by the use of transmission lines a quarter-wavelength long at mid-frequency (See Figure 2, Plate 1), maximum insertion loss went up to 1.6 decibels and maximum reflection went up to 40 percent at the lower end of the frequency band. The variation of insertion loss and reflection was due to the fact that the quarter-wavelength transmission lines were not tuned over the frequency band. Plates 4 and 5 indicate that these sections of transmission lines were too short for optimum overall performance over the band.

STATIC TESTS USING TRIODES

10. Triodes were also tried as the variable impedances in the resonant tanks of the switches, the grids being by-passed to the plates such that the tubes functioned as diodes at the carrier frequency and as triodes at the keying frequency of 20 kilocycles. This permitted grid keying with its characteristic of low power requirement.

11. The triodes used were the 2C40 and the 2C43. The 2C43 gave the better results, these results being comparable to those obtained with the 559 diodes. Some of the results obtained from the switch using the 2C43 triode are given by Plate 6. This plate shows that the switching efficiency using triodes is equivalent to that obtained with diodes.

APPLICATION OF GAS TUBES

12. It was found by another investigator of electronic switches at this laboratory that the noise produced by gas tubes used as the switching tubes made them unacceptable for this application. (See reference 2).

COMPARISON OF SQUARE-WAVE KEYING

13. For purposes of analyzing the wave forms of the switched signals, the curve given on Plate 7 was obtained from a single switch using a 559 diode at a carrier frequency of 325 megacycles. This curve gives the r-f output voltage in percent of voltage which would be transmitted without the switch versus the dc voltage applied to the plate of the diode. It is seen that the range over which the variation is linear is not large, and that in order to reach the opposite conditions of good transmission and of good cut off of the signal transmitted through the switch it is necessary to operate along non-linear portions of this curve. If a keying signal of sinusoidal waveform is applied to the 559 diode and if this signal is of sufficient amplitude to swing the operating point of the diode between good transmission and good cutoff, the envelope of the switched signal will be far from sinusoidal. On the other hand, if square-wave keying be applied, the output r-f signal will still have a square-wave envelope.

14. The desirability of either form of switching over the other is open to question. The switching here is somewhat similar to amplitude modulation at a 20 kilocycle rate, and the number and amplitude of the various harmonics produced by the switching will be somewhat the same as those of the corresponding modulating wave in amplitude modulation. This is verified to a partial extent by the analysis given in Appendix 1. As in amplitude modulation, sine-wave switching will produce sidebands of the fundamental switching frequency. Square-wave switching will produce sidebands containing the fundamental and harmonics of the square-wave switching wave form. Additional sideband components are produced by interaction between the original carrier modulation and the switching frequency components as shown by the analysis.

15. Equation (8) in Appendix 1 gives the composite signal which would be present at the input to the receiver under the special case of single-frequency modulation and sine-wave switching. It is

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this signal which determines interference with adjacent communications signals. The frequency components given by equation (17) are produced by the method of demodulation used and are not undesirable except in possible distortion of the audible signal received.

16. For both sine-wave and square-wave switching, when the signals from the two antennas are unequal, the 20 kilocycle fundamental frequency will be present. This can be seen in Figures 16 and 19, Plate 11.

17. Square-wave switching gives a larger average signal since the switches are operating under optimum conditions over most of the cycle of the 20 kilocycle frequency. The decrease in signal due to sine-wave switching is shown by the dips in the oscillogram of Figure 12, Plate 10.

TESTS USING 20 KILOCYCLE KEYING

18. A keyer with good sine-wave and good square-wave outputs was used for keying the switches at 20 kilocycles. With the apparatus connected as is shown by Plate 8, the oscillograms of Plates 9 through 12 were obtained from the switches using the 559 diode.

19. The oscillograms given on Plates 9 and 10 were obtained by feeding a signal from an LAF-1 signal generator to the input points of the two switches in parallel, and by detecting the output with a crystal detector. This detected output was amplified and presented by a Type 241 DuMont cathode ray oscilloscope, this system being as indicated by the block diagram of Figure 3, Plate 8.

20. The oscillograms given in Plates 11 and 12 were obtained by using the switches as they would be used in actual operation. A Navy type XAZ transmitter was used to radiate a modulated signal and two receiving antennas were used, each connected to one of the switches, as shown by the block diagrams of Figure 4, Plate 8. All the oscillograms were taken at a carrier frequency of 325 megacycles.

21. Plate 9 shows the modulation envelopes obtained under various conditions of keying of the switches and of signal input. The difference between the sine-wave and the square-wave keying in switching envelopes is shown. The rounding-out of the pattern in the sine-wave keying indicates a smaller number and amplitude of high-frequency harmonics of the 20 kilocycle switching. In these oscillograms the envelopes obtained with the sine-wave keying were dependent upon the amplitude of the sine-wave keying voltage and upon the dc operating point of the 559 diodes. With the square-

wave keying the potentials of the plates of the diodes varied between seven volts positive and twelve negative. With the sine-wave keying, voltages were chosen to give the best-rounded switching waveforms while still giving fairly effective switching, the amplitude of the keying sine-wave being somewhat smaller than that used in the square-wave keying.

22. Plate 10 shows the demodulated 3333 cycle sine-wave signal used in modulating the LAF-1 signal generator. The frequency was chosen because it was a divisor of the 20 kilocycle switching and the two frequencies could be sunchronized to present stationary patterns on the oscilloscope.

23. With equal signal input to the two switches square-wave keying is seen to give a smooth demodulated sine wave, as shown by Figure 11, Plate 10, while the sine-wave keying gives dips in signal intensity at the change-over points from one switch to the other, as shown by Figure 12, Plate 10. These dips are not necessarily undesirable except in that they indicate harmonics of the 20 kilocycle note. It should be noted that the equal-signal-input conditions is a special case, and that under normal conditions of unequal signal i input, the harmonics from the square wave keying will be greater than those from the sine-wave keying.

24. Plate 11 gives the 20 kilocycle envelope obtained when the switches were actually operated with antennas receiving the 325 megacycle signal from the XAZ transmitter modulated internally with a 1000 cycle signal. The significance of the oscillograms is the same as that in Plate 9 discussed in paragraph 21.

25. Plate 12 shows the 1000 cycle demodulated signal from the carrier received from the XAZ transmitter. The non-sinusoidal shape of the pattern was the actual modulation signal of the transmitter and is not due to distortion in the switches.

26. There is some distortion in the oscillograms obtained when using the LAF-1 signal generator as the source of the 325 megacycle voltage because the crystal detector did not respond linearly at the low voltage levels received from the signal generator. In an oscillogram like Figure 7, Plate 9, for example, the switching as indicated by the oscillogram is more nearly complete than that actually obtained. Since the waveforms as given by Figure 15, Plate 10, for example, are very nearly sinusoidal even at low power levels, this distortion was probably not serious.

27. In order to determine the possible distortion of a voice-modulated received signal, a test was made on a single switch using a 559 diode, with 20 kilocycle square-wave switching. The XAZ transmitter was used to radiate the signal, this signal being received by a Navy

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type RDO receiver through the switch. Only one switch was used because this gave the greatest switching effect on the received signal, giving a degree of switching "s" as expressed in Appendix 1 of approximately 80 percent. The degree of modulation of the signal transmitted from the XAZ transmitter was not high, reaching approximately 60 percent at peak modulation. With this arrangement there was no noticeable change in fidelity of the audible signal from the RDO receiver when the 20 kilocycle switching action of the switch between the receiving antenna and the receiver was turned on and off.

28. No provision has been made in the keyer for a control to give transmission through one switch only. If it should be desired to receive the signal from one antenna only, the plate voltage on the diode in the switch in that line would have to be set beyond cutoff, and the plate voltage on the other diode would have to be set to produce normal plate current. Since only dc bias would be required, it would not be difficult to incorporate this feature in the keyer.

CONCLUSIONS

29. The receiver switches using the 559 diodes work moderately well and could be developed into a single tuning unit which could be used with existing Navy equipment. Other tubes, such as the 2C43 triode, might be used to give equal or better results.

30. Whenever the amplitude of the signals in the two antennas are unequal the switching frequency will be present in the receiver signal.

31. Switching of the order of 18 decibels was obtained with a maximum insertion loss of approximately $1\frac{1}{2}$ decibels.

ACKNOWLEDGEMENTS

32. Co-workers on this project were Sam K. Brown, Ens., USNR, and Henry F. Carlson, CRE, USN.

33. Mr. John H. Markell of this laboratory performed preliminary work on electronic switches under this project, including work on gas tubes. His work was of value in the development of the switches presented in this report

REFERENCES

1. BuShips ltr. Sec. 929 Serial 89 of 22 Jan. 1945 to NRL; Request for assignment of Problem S10042.

2. NRL Log Book 2232.

3. Communication Engineering, Everitt, Chapter XIII.

Original data recorded in NRL Log Book 5367

[redacted]

1. The sideband frequencies produced by switching the received signal in a sinusoidal waveform can be found by the following analysis:

2. Assume a carrier wave of frequency ω_c radians per second amplitude modulated by a signal of frequency ω_m radians per second. This modulated signal will have the form

$$e = E_o\,(1 + m \sin \omega_m t) \sin \omega_c t, \qquad (1)$$

or $$e = E_o \sin \omega_c t + 1/2 m E_o \cos (\omega_c - \omega_m)t - 1/2 m E_o \cos (\omega_c + \omega_m)t \qquad (2)$$

where m is the degree of modulation, expressed by

$$m = \frac{A\ max - A\ min}{A\ max + A\ min} \qquad (3)$$

where A is the amplitude of the modulation envelope.

3. Assuming the amplitude of the r-f signal to be low enough that the r-f impedance of the switch is practically constant over the r-f cycle at any operating point, each term can be analyzed independently. Each frequency component will have a modulation envelope due to the sinusoidal switching which will be exactly similar to that of amplitude modulation, except that the average amplitude of the frequency component considered will be decreased due to the switching.

4. Using a new average voltage amplitude E_1, the component of instantaneous switched r-f voltage will be, from (2)

$$\begin{aligned} e = {} & E_1\,(1 + s \sin \omega_s t) \sin \omega_c t \\ & + 1/2 m E_1\,(1 + s \sin \omega_s t) \cos (\omega_c - \omega_m)t \\ & - 1/2 m E_1\,(1 + s \sin \omega_s t) \cos (\omega_c + \omega_m)t \end{aligned} \qquad (4)$$

where the degree of switching "s" is expressed in a manner similar to the degree of modulation "m" of equation (3). This quantity "s" is not the "switching efficiency" discussed earlier in the report.

Simplifying,

$$\begin{aligned} e = {} & E_1 \left[\sin \omega_c t + s \sin \omega_s t \sin \omega_c t \right] \\ & + 1/2 m E_1 \left[\cos (\omega_c - \omega_m)t + s \sin \omega_s t \cos (\omega_c - \omega_m)t \right] \end{aligned}$$

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$$- 1/2mE_1 \left[\cos (\omega_c+\omega_m)t + s \sin \omega_s t \cos (\omega_c+\omega_m)t\right] \tag{5}$$

Using the trigonometric relations

$$\cos x \sin y = 1/2 \left[\sin (x+y) - \sin (x-y)\right] \tag{6}$$

$$\sin x \sin y = 1/2 \left[\cos (x-y) - \cos (x+y)\right] \tag{7}$$

the following expression for instantaneous voltage is obtained:

$$\begin{aligned} e = {} & E_1 \sin \omega_c t + 1/2\, sE_1 \cos (\omega_c - \omega_s)t - 1/2sE_1 \cos (\omega_c+\omega_s)t \\ & + 1/2mE_1 \cos (\omega_c - \omega_m)t + 1/4msE_1 \sin (\omega_c-\omega_m+\omega_s)t \\ & - 1/4msE_1 \sin (\omega_c-\omega_m-\omega_s)t - 1/2mE_1 \cos (\omega_c+\omega_m)t \\ & - 1/4msE_1 \sin (\omega_c+\omega_m+\omega_s)t + 1/4msE_1 \sin (\omega_c+\omega_m-\omega_s)t \end{aligned} \tag{8}$$

This expression gives, in addition to the usual sideband frequencies which would be produced by amplitude modulation by the frequencies ω_m and ω_s, four more frequency components involving the interaction between the three frequencies ω_c, ω_m and ω_s.

5. The low frequency signals which would be obtained from this signal when demodulated by a square-law detector can be found as follows (see reference 4):

$$C_1 i = e^2 \tag{9}$$

$$\begin{aligned} \frac{C_1 i}{E_1^2} = \Big[& \sin \omega_c t + 1/2\, s \cos (\omega_c - \omega_s)t - 1/2s \cos (\omega_c + \omega_s)t \\ & + 1/2m \cos (\omega_c - \omega_m)t - 1/2m \cos (\omega_c + \omega_m)t \\ & + 1/4\, ms \sin (\omega_c - \omega_m + \omega_s)t - 1/4ms \sin (\omega_c - \omega_m - \omega_s)t \\ & - 1/4\, ms \sin (\omega_c+\omega_m+\omega_s)t + 1/4ms \sin (\omega_c+\omega_m-\omega_s)t\Big]^2 \end{aligned} \tag{10}$$

Using the following trigonometric relations:

$$\sin^2 x = 1/2 \left[1 - \cos 2x\right] \tag{11}$$

$$\cos^2 x = 1/2 \left[1 + \cos 2x\right] \tag{12}$$

$$\sin x \sin y = 1/2 \left[\cos (x-y) - \cos (x+y)\right] \tag{13}$$

$$\cos x \cos y = 1/2 \left[\cos (x-y) + \cos (x+y)\right] \tag{14}$$

$$\sin x \cos y = 1/2 \left[\sin (x+y) + \sin (x-y)\right] \tag{15}$$

$$\cos x \sin y = 1/2 \left[\sin (x+y) - \sin (x-y)\right] \qquad (16)$$

and substituting into (10) it is seen that only the difference terms (x-y) will produce low frequency components, where x and y denote carrier and sideband frequencies. Each term if multiplied by itself will produce no audio-frequency terms so that only the cross-products of (8) need to be written out. Doing this and substituting in only the audio frequency components as given by (13), (14), (15) and (16), and grouping the terms, the following is obtained:

$$\begin{aligned} C_1 i = {} & (m + 1/2ms^2) \sin \omega_m t + (s + 1/2m^2 s) \sin \omega_s t \\ & + ms \cos (\omega_s - \omega_m)t - ms \cos (\omega_s + \omega_m)t \\ & - (1/4m^2 + 1/8m^2s^2) \cos 2\omega_m t - (1/4s^2 + 1/8m^2s^2) \cos 2\omega_s t \\ & + 1/4ms^2 \sin (2\omega_s - \omega_m)t - 1/4m^2 s \sin (\omega_s - 2\omega_m)t \\ & - 1/4ms^2 \sin (2\omega_s + \omega_m)t - 1/4\, m^2 s \sin (\omega_s + 2\omega_m)t \\ & + 1/16\, m^2 \cos (2\omega_s - 2\omega_m)t + 1/16m^2s^2 \cos (2\omega_s + 2\omega_m)t \qquad (17) \end{aligned}$$

These audio frequency components are tabulated below, along with these components which would be present if the carrier wave were simultaneously amplitude modulated by the frequencies : m and · s and subsequently demodulated by the square-law detector. The first column gives the audio frequency components, the second gives the relative amplitude of these components in the sinusoidal switching case, and the third column gives the relative amplitude of the components in the case in which the signal is amplitude modulated by the two frequencies : $_m$ and : $_s$.

Frequency Term	Amplitude	Amplitude
$\sin \omega_m t$	$m + 1/2ms^2$	m
$\sin \omega_s t$	$s + 1/2m^2 s$	s
$\cos (\omega_s - \omega_m)t$	ms	$1/2ms$
$\cos (\omega_s + \omega_m)t$	$-ms$	$-1/2ms$
$\cos 2\omega_m t$	$-1/4m^2 - 1/8m^2s^2$	$-1/4m^2$
$\cos 2\omega_s t$	$-1/4s^2 - 1/8m^2s^2$	$-1/4s^2$
$\sin (2\omega_s - \omega_m)t$	$1/4ms^2$	
$\sin (\omega_s - 2\omega_m)t$	$-1/4m^2 s$	
$\sin (2\omega_s + \omega_m)t$	$-1/4ms^2$	

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$\sin(\omega s + 2\omega m)t$	$-1/4m^2 s$
$\cos(2\omega s - 2\omega m)t$	$1/16m^2$
$\cos(2\omega s + 2\omega m)t$	$1/16m^2 s^2$

It is seen that the number of the undesired signals is increased by the switching.

6. Equation 8 gives the composite signal which would be present at the input to the receiver. It is this signal which determines interference with adjacent communication signals.

7. For square-wave switching it is logical to break the square modulation wave-form into its Fourier series in trigonometric functions, and to use this as a modulating band of frequencies in place of the single modulation frequency ωs of equation (3). This would create a much larger band of frequencies in equation (8) although the general form of the equation of the composite signal would not be changed.

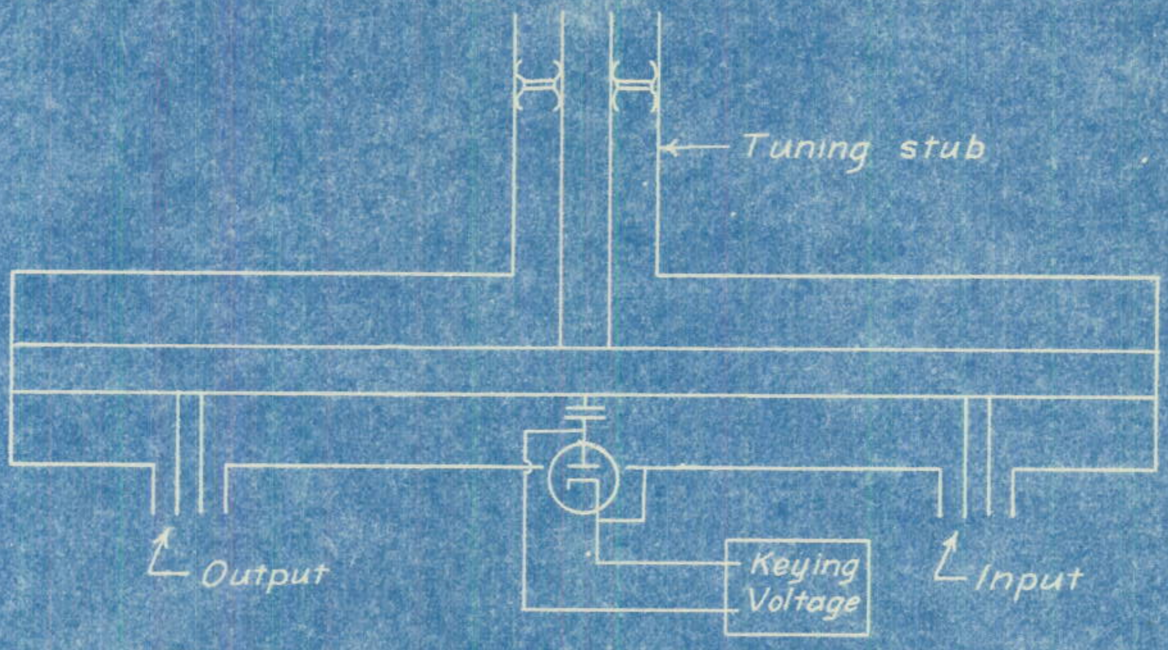

Fig. 1

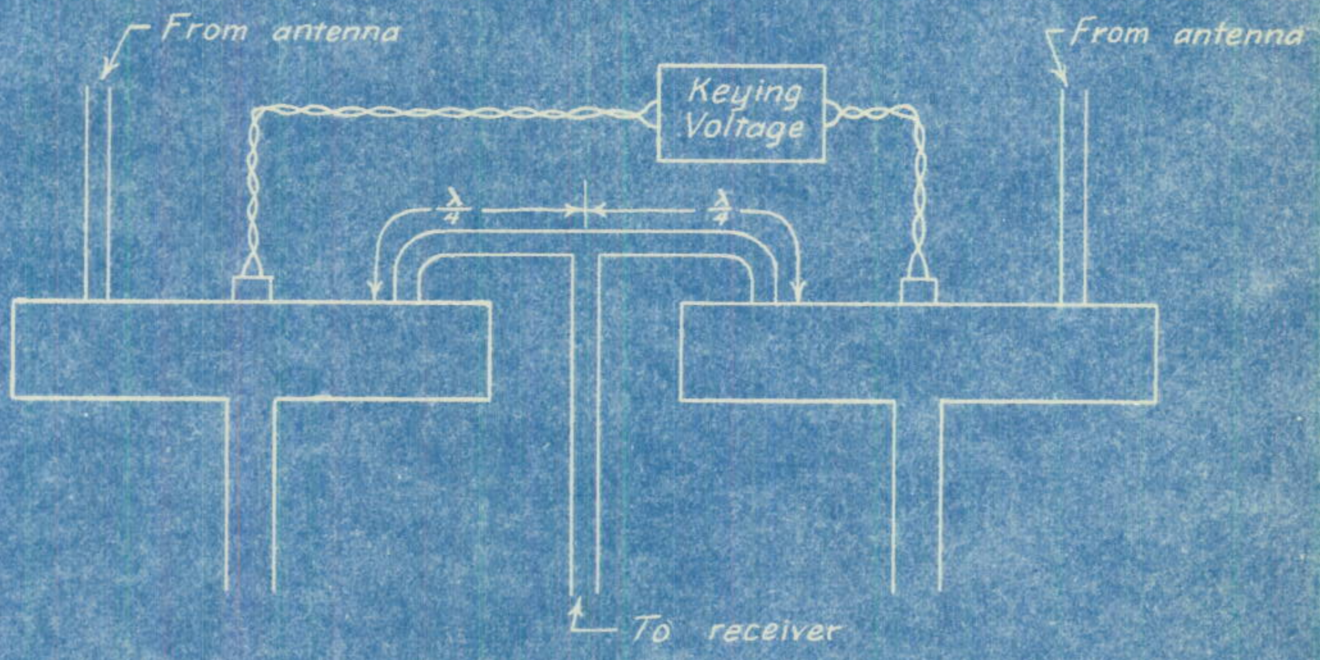

Fig. 2

SKETCHES SHOWING
METHOD OF OPERATION OF ELECTRONIC SWITCHES

PLATE 1

ELECTRONIC RECEIVING SWITCH USING 559 DIODE

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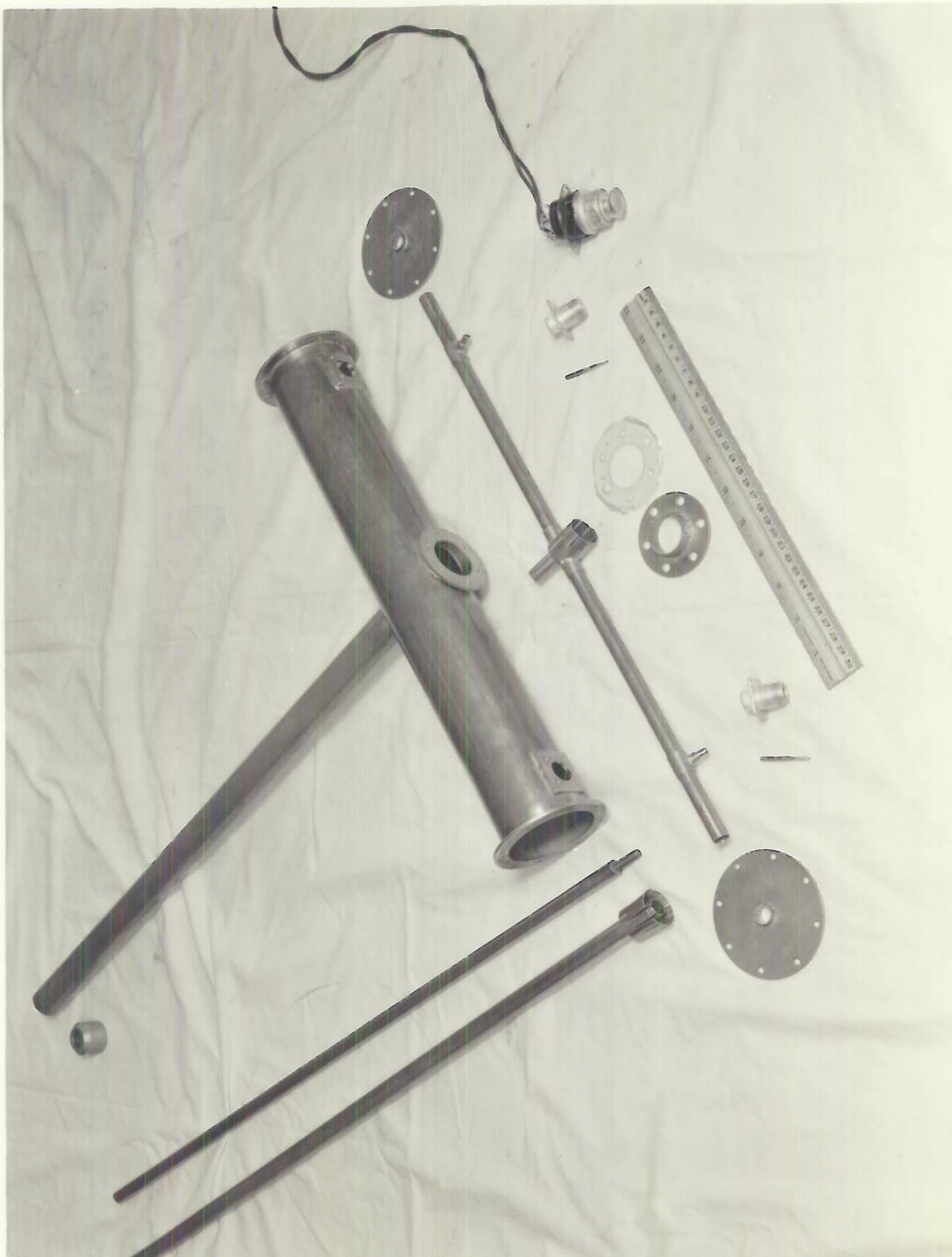
PLATE 2



DISASSEMBLED ELECTRONIC RECEIVING SWITCH USING 559 DIODE

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PLATE 3

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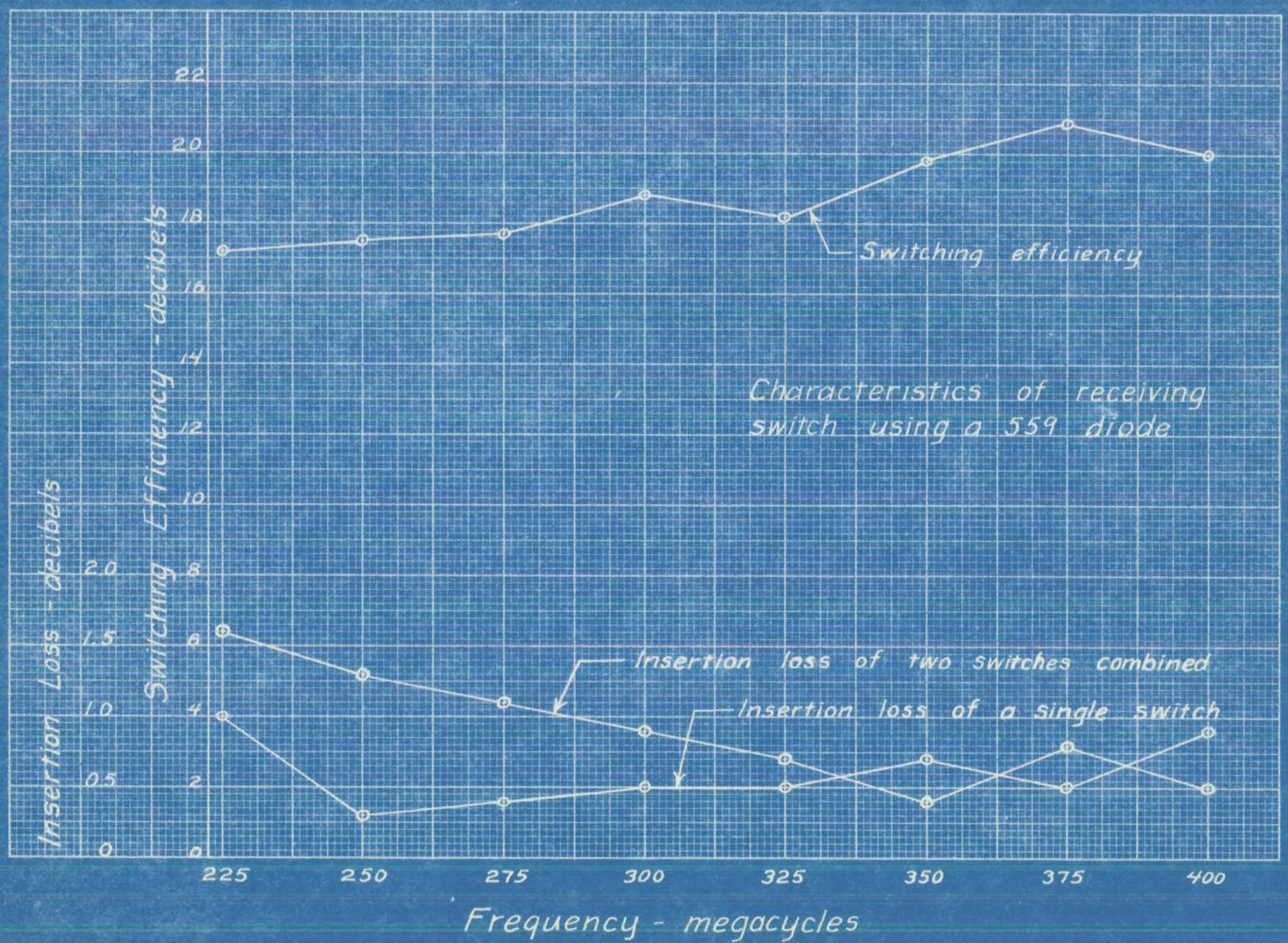


PLATE 4

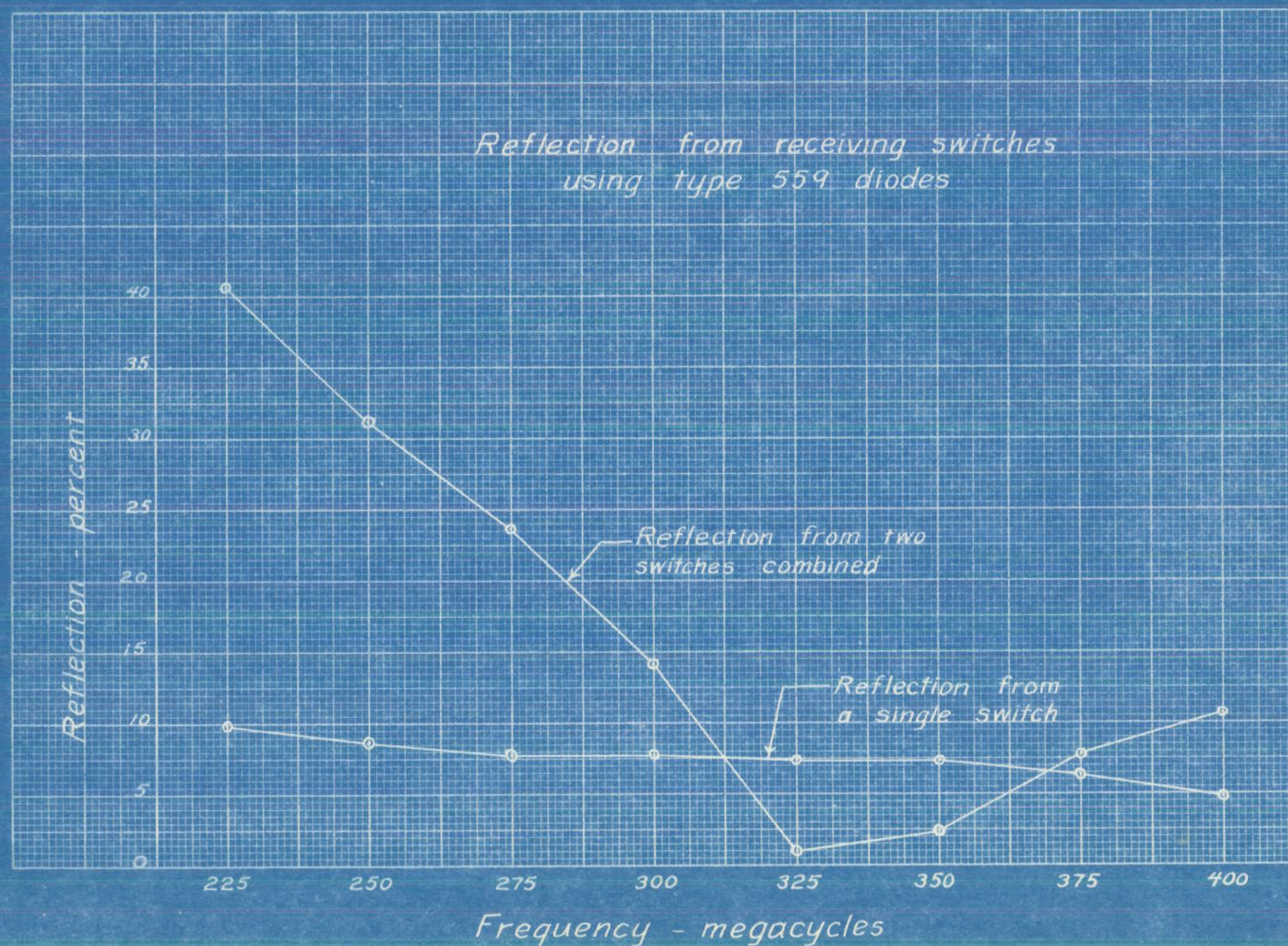
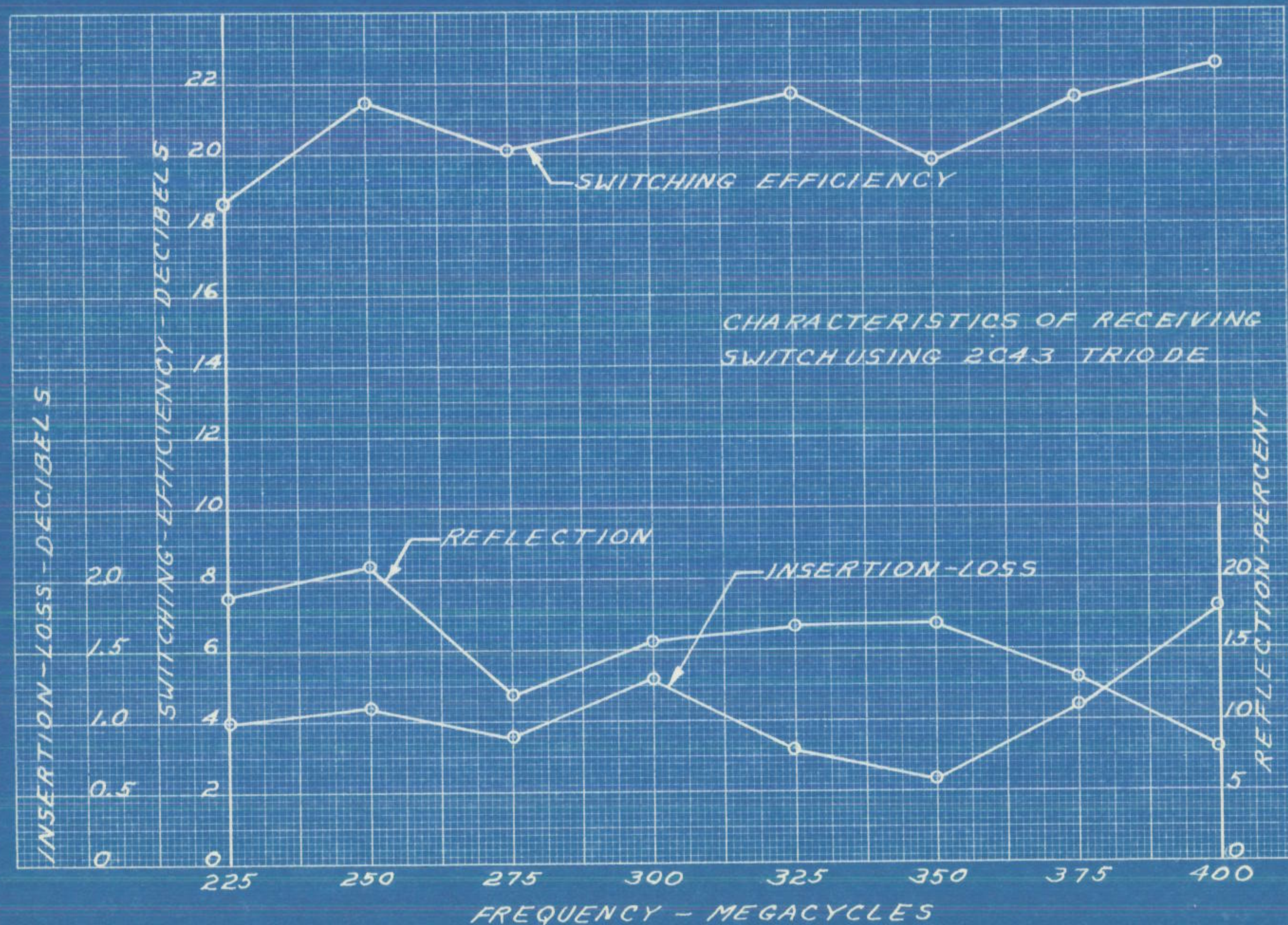

Reflection from receiving switches
using type 559 diodes
Reflection from two
switches combined
Reflection from
a single switch
Reflection - percent
40
35
30
25
20
15
10
5
0
225
250
275
300
325
350
375
400
Frequency - megacycles

PLATE 5


CHARACTERISTICS OF RECEIVING
SWITCH USING 2C43 TRIODE
SWITCHING EFFICIENCY
REFLECTION
INSERTION-LOSS
INSERTION-LOSS-DECIBELS
SWITCHING-EFFICIENCY-DECIBELS
REFLECTION-PERCENT
FREQUENCY - MEGACYCLES
225
250
275
300
325
350
375
400
22
20
18
16
14
12
10
8
6
4
2
0
2.0
1.5
1.0
0.5
0
20
15
10
5
0

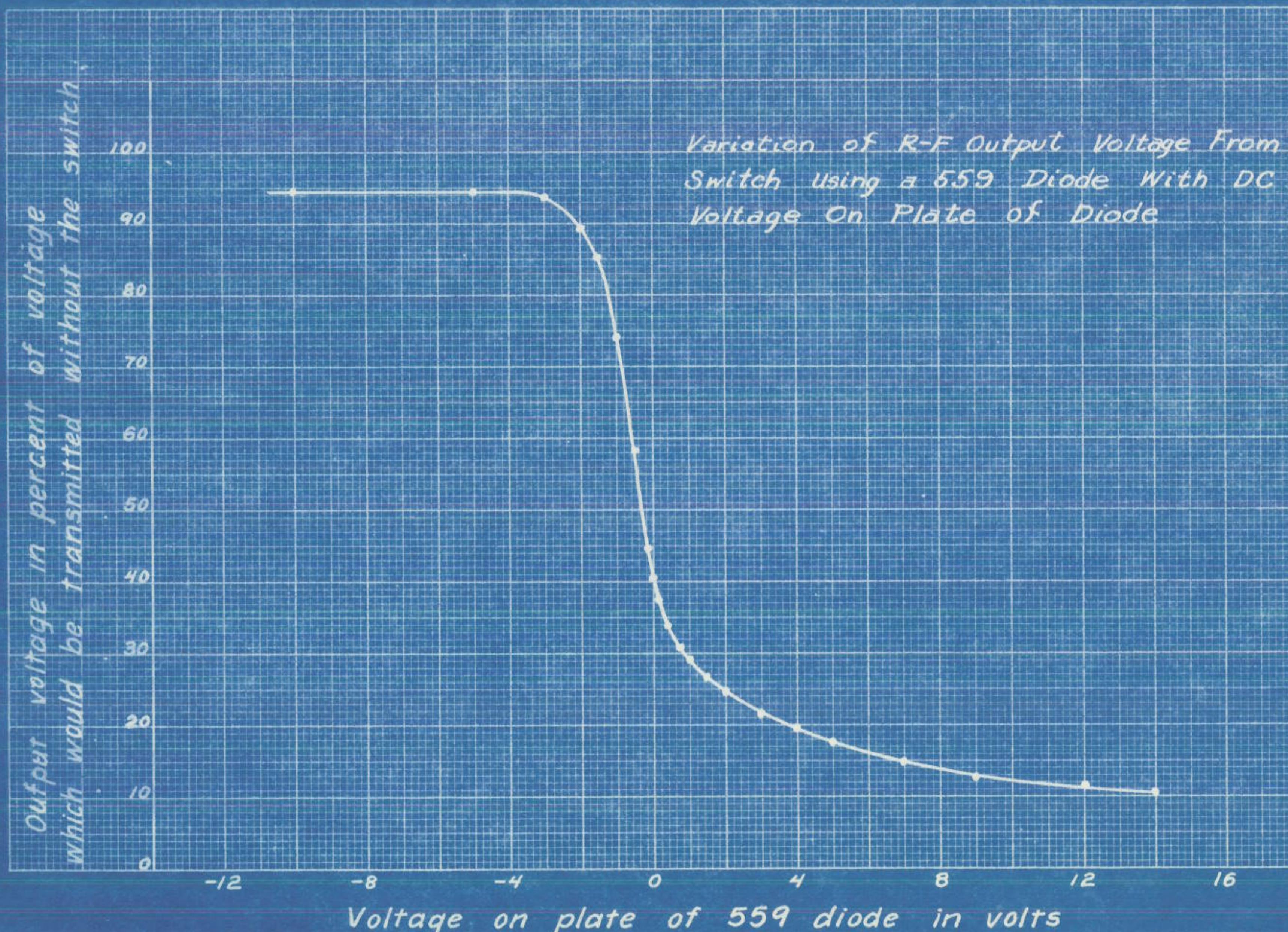
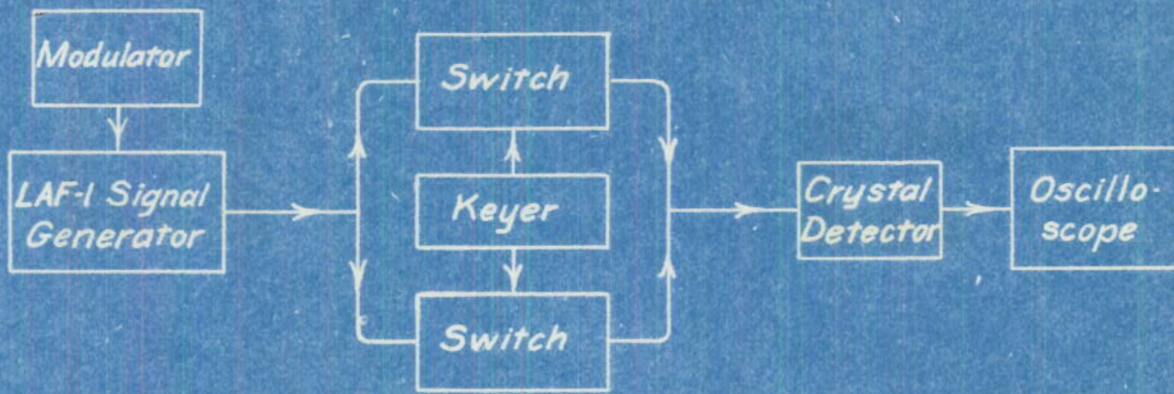
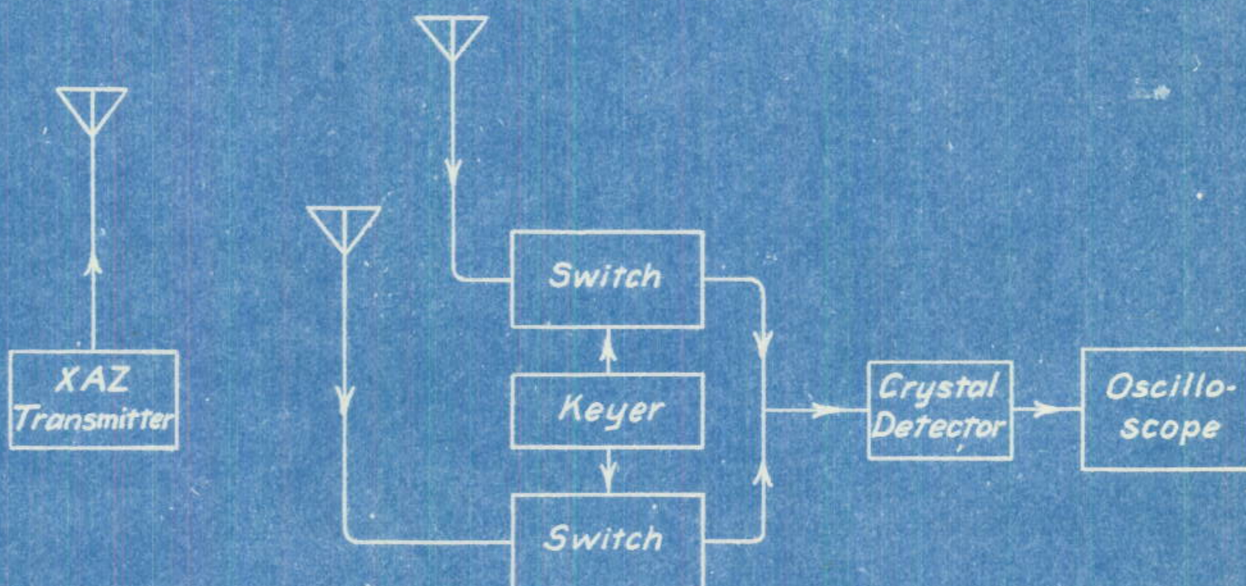

Variation of R-F Output Voltage From Switch Using a 559 Diode With DC Voltage On Plate of Diode
Output voltage in percent of voltage which would be transmitted without the switch
100
90
80
70
60
50
40
30
20
10
0
-12
-8
-4
0
4
8
12
16
Voltage on plate of 559 diode in volts

PLATE 7



Test Arrangement of Electronic Switch System with Signal from LAF-1 Signal Generator
Fig. 3



Test Arrangement of Electronic Switch System with Signal from XAZ Transmitter
Fig. 4

BLOCK DIAGRAMS SHOWING METHODS OF CONNECTING APPARATUS IN OBTAINING OSCILLOGRAMS

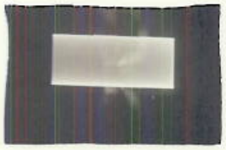


FIG. 5 EQUAL SIGNAL INPUT TO BOTH SWITCHES: SQUARE WAVE KEYING ON THE 559 DIODES.

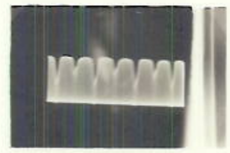


FIG. 9 INPUT TO ONE SWITCH ONLY: CARRIER SIGNAL 50 PERCENT MODULATED: SOUARE WAVE KEYING.

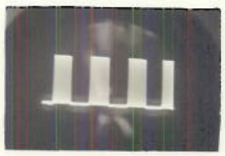


FIG. 7 INPUT TO ONE SWITCH ONLY: CARRIER SIGNAL 100 PERCENT MODULATED: SOUARE WAVE KEYING.

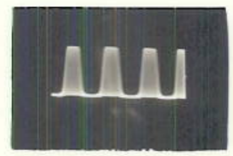


FIG. 8 INPUT TO ONE SWITCH ONLY: CARRIER SIGNAL 100 PERCENT MODULATED: SINE WAVE KEYING.

FIG. 6 EQUAL SIGNAL INPUT TO BOTH SWITCHES: SINE WAVE KEYING ON THE 559 DIODES.

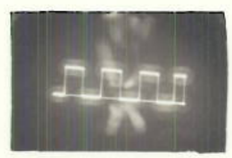


FIG. 10 INPUT TO ONE SWITCH ONLY: CARRIER SIGNAL UNMODULATED: SQUARE WAVE KEYING.

OSCILLOGRAMS SHOWING 20 KILOCYCLE SWITCHING ENVELOPES OF SIGNAL FROM LAF-1 SIGNAL GENERATOR, WITH RECEIVING SWITCHES USING 559 DIODES.

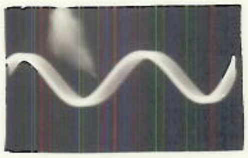


FIG. 11 EQUAL SIGNAL INPUT TO BOTH SWITCHES: SQUARE WAVE KEYING ON THE 559 DIODES.

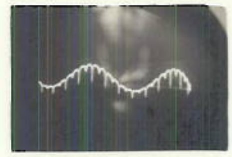


FIG. 12 EQUAL SIGNAL INPUT TO BOTH SWITCHES: SINE WAVE KEYING ON THE 559 DIODES.

FIG. 13 INPUT TO ONE SWITCH ONLY: CARRIER SIGNAL 50 PERCENT MODULATED: SQUARE WAVE KEYING.

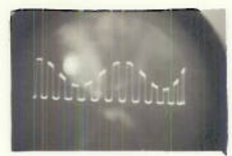


FIG. 14 INPUT TO ONE SWITCH ONLY: CARRIER SIGNAL 50 PERCENT MODULATED: SINE WAVE KEYING.

FIG. 15 UNEQUAL SIGNAL INPUT TO TWO SWITCHES: CARRIER SIGNAL 50 PERCENT MODULATED: SQUARE WAVE KEYING.

OSCILLOGRAMS SHOWING DEMODULATED SIGNAL FROM LAF-1 SIGNAL GENERATOR MODULATED AT 3333 CYCLES, WITH RECEIVING SWITCHES USING 559 DIODES.

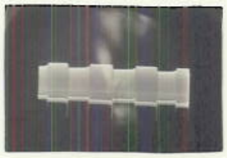


FIG. 16 SLIGHTLY UNEQUAL SIGNALS FROM THE TWO ANTENNAS: SQUARE WAVE KEYING ON THE 559 DIODES.

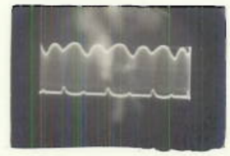


FIG. 17 EQUAL SIGNALS FROM THE TWO ANTENNAS: SINE WAVE KEYING ON THE 559 DIODES.

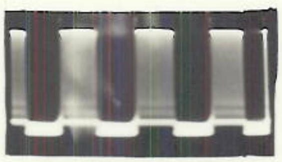


FIG. 18 SIGNAL FROM ONE ANTENNA ONLY: CARRIER 100 PERCENT MODULATED: SQUARE WAVE KEYING.

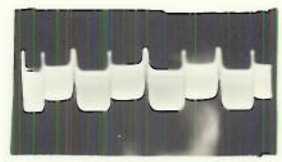


FIG. 19 UNEQUAL SIGNALS FROM THE TWO ANTENNAS: SINE WAVE KEYING.

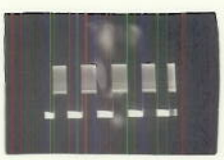


FIG. 20 SIGNAL FROM ONE ANTENNA ONLY: CARRIER 50 PERCENT MODULATED: SQUARE WAVE KEYING.

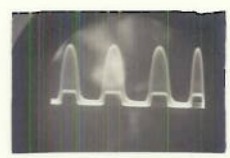


FIG. 21 SIGNAL FROM ONE ANTENNA ONLY: CARRIER 80 PERCENT MODULATED: SINE WAVE KEYING.

OSCILLOGRAMS SHOWING 20 KILOCYCLE SWITCHING ENVELOPES OF SIGNAL RECEIVED FROM XAZ TRANSMITTER BY ANTENNAS THROUGH RECEIVING SWITCHES USING 559 DIODES.

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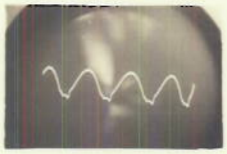

FIG. 22 EQUAL SIGNALS FROM THE TWO ANTENNAS: SQUARE WAVE KEYING ON THE 559 DIODES.

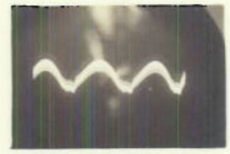

FIG. 23 EQUAL SIGNALS FROM THE TWO ANTENNAS: SINE WAVE KEYING ON THE 559 DIODES.

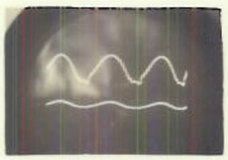

FIG. 24 SIGNAL FROM ONE ANTENNA ONLY: CARRIER 30 PERCENT MODULATED: SQUARE WAVE KEYING.

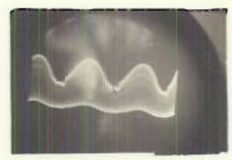

FIG. 25 SIGNAL FROM ONE ANTENNA ONLY: CARRIER 30 PERCENT MODULATED: SINE WAVE KEYING.

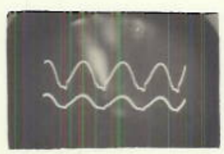

FIG. 26 UNEQUAL SIGNALS FROM THE TWO ANTENNAS: CARRIER 30 PERCENT MODULATED: SQUARE WAVE KEYING.

OSCILLOGRAMS SHOWING DEMODULATED SIGNAL FROM XAZ TRANSMITTER MODULATED AT 1000 CYCLES, RECEIVED FROM ANTENNAS THROUGH RECEIVING SWITCHES USING 559 DIODES.

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