



DECLASSIFIED NRL REPORT NO. R-3119



INTERIM REPORT ON
THE DEVELOPMENT OF
DRIVE UNITS AND CONTROL MECHANISM
FOR AIRBORNE AUTOMATIC SEARCH
AND JAM SYSTEM... AN/APQ-33 (XB)



FR-3119

DECLASSIFIED by NRL Contract

Declassification Team

Date: 14 DEC 2016

Reviewer's name: H. Do, H. Hanna

Declassification authority: NAVY DECLASS
GUIDE/NAVY DECLASS MANUAL, 11 DEC 2012
48 SERIES



DISTRIBUTION STATEMENT A APPLIES

Further distribution authorized by UNLIMITED only.

NAVAL RESEARCH LABORATORY

Washington, D.C.

DECLASSIFIED

DECLASSIFIED

**INTERIM REPORT ON
THE DEVELOPMENT OF
DRIVE UNITS AND CONTROL MECHANISM
FOR AIRBORNE AUTOMATIC SEARCH
AND JAM SYSTEM... AN/APQ-33 (XB)**

by

J. H. Markell

August 1947

Problem No. 39R06-25

Approved by:

L. A. Gebhard
Superintendent
Radio Division II

Commodore H. A. Schade, USN
Director
Naval Research Laboratory



NAVAL RESEARCH LABORATORY

Washington, D.C.

DECLASSIFIED

DECLASSIFIED

~~CONFIDENTIAL~~

DISTRIBUTION

BuShips	(10)
BuAer	
TD-4	(1)
CNO-Op-413-B2	(6)
ONR	
Boston	(1)
Code N482	(4)
USNEL	(2)
JRDB	
Library	(2)
Navy Secretary	(1)

DECLASSIFIED

~~CONFIDENTIAL~~

CONTENTS

	Page
Abstract	iv
INTRODUCTION	1
GENERAL CONSIDERATIONS AND LIMITATIONS	1
Tuning System	1
Image Rejection	2
Effects of Signal Amplitude and Pulse Characteristics	3
Pulse Discrimination	3
Look-Through	4
DETAILS OF PRESENT LABORATORY MODEL	5
Drive Unit	5
Control Unit	6
CONCLUSIONS	9
RECOMMENDATIONS	10
APPENDIX 1: THEORY OF DISCRIMINATOR ACTION ON PULSE SIGNALS	11
APPENDIX 2: THEORY OF BALANCER ACTION	15

~~CONFIDENTIAL~~

DECLASSIFIED

ABSTRACT

This report describes the present state of development of an automatic search and jam system designed primarily for use in carrier based aircraft for operation against fixed-frequency types of radar. It is the basis for future work on both airborne and shipboard models of systems to be used against varying-frequency radar, guided missiles, and proximity fuses.

The present system has the following features:

- (1) A search receiver is mechanically tuned over a pre-set frequency range in a given band at a rate of 35 mc/sec.
- (2) Interception of a pulse signal of width greater than 1/2 microsecond causes the search receiver to stop accurately on the signal.
- (3) When the receiver is locked on a signal, a jamming transmitter is mechanically tuned over the same pre-set frequency range at a rate of 35 mc/sec.
- (4) Reception of the transmitter signal on the receiver causes the transmitter to stop accurately on the signal and applies noise modulation to the transmitter.
- (5) After a period of time which is adjustable from 1/2 to 20 seconds, the transmitter is turned off for approximately 0.03 seconds, during which time look-through is obtained. Jamming will continue if a signal is still being received. The search receiver will sweep if the signal has disappeared.

General considerations and limitations of a system of this type are discussed, and recommendations are made for increased sweep rates, pulse-type discrimination, operation on pulses of shorter width, and effective jamming on look-through.

DECLASSIFIED

~~CONFIDENTIAL~~

DECLASSIFIED

AUTOMATIC SEARCH AND JAM SYSTEM

INTRODUCTION

The development of the Airborne Automatic Search and Jam System AN/APQ-33 (XB) was undertaken, at the request of BuShips.*† This report covers only the mechanism for automatic frequency scanning and the necessary control unit to tie in the functions of the receiver and transmitter so as to provide efficient and automatic jamming.

The present laboratory setup consists of an S-band search receiver (SPR-2), an S-band jamming transmitter (APT-10), two laboratory model mechanical drive units (one for receiver and one for transmitter), and a breadboard model control unit. The receiver sweeps until a signal is received. The receiver drive then stops and the transmitter sweeps until it reaches the frequency to which the receiver is tuned, whereupon the transmitter drive stops and modulation is applied. After an adjustable interval of time the transmitter is turned off and the receiver looks-through to determine whether the enemy signal is still on the air. If the signal is received, jamming continues; if no signal is received, the receiver starts sweeping.

GENERAL CONSIDERATIONS AND LIMITATIONS

TUNING SYSTEM

Present S-band equipment is tuned by mechanical variation of concentric lines and cavities that require considerable power to tune. Automatic control systems previously developed for lower frequencies had the advantage of being condenser tuned, so that power requirements were small and the inertia of rotating parts was not great. As an example of the power needed for S-band equipment, the APT-10 transmitter requires a 1/30 hp motor for a positive sweep rate of 35 mc/sec when the oscillator tube is hot, although 1/60 hp is sufficient when the tube is cold. In addition, the power required to sweep in one direction is fifty percent greater than that required to sweep in the other direction. For higher speed operation even more power is required, and motor size and weight increase beyond practical values. The APT-10 transmitter was not designed for high-speed operation, so mechanical redesign was necessary to eliminate dynamic unbalance.

Other mechanically tuned transmitters would present similar difficulties, and the mechanical power requirements are likely to increase as the transmitter power output is increased.

* BuShips Conf. Ltr. Ser. 08606 (913D-904) of 11 April 1946 to Dir. NRL: Airborne Automatic Search and Jam System, Development of

† NRL Ltr. C-A22-2, C1200-42/46 jmb to BuShips Code 913: Airborne Automatic Search and Jam System, Development of - Proposal from NRL

DECLASSIFIED

DECLASSIFIED

2

NAVAL RESEARCH LABORATORY

~~CONFIDENTIAL~~

The maximum sweep rate that can be obtained is limited by several other factors in addition to power requirements. Some of these factors are the maximum velocity at which it is safe to tune the equipment and the maximum acceleration and deceleration the system can stand without damage. Higher speeds require greater deceleration, which means larger gears and shafts are necessary, thereby increasing the weight and inertia of rotating parts. The problem of obtaining the required deceleration is thereby further complicated.

Another factor limiting the sweep rate is the accuracy of tuning required. For a given deceleration time, the acceptance bandwidth of the control system must be sufficiently large to initiate the stopping impulse at a point far enough from exact resonance that the transmitter or receiver will be stopped by the time it is within a reasonable distance of resonance. Since any mechanical stopping system will have variations in time required for different stops, the accuracy of stopping will be different each time, and becomes poorer at higher sweep speeds. Dynamic braking is more accurate in this respect, but gives too slow a deceleration rate. The use of a servo system to solve the accuracy problem was considered, but the power requirements for driving are so high that the vacuum tubes necessary to drive the servo motor reach the proportion of large transmitting tubes, with the accompanying large power supply. This system was therefore deemed impractical.

Partial tracking between transmitter and receiver was considered to reduce total sweep time. However, on neither the transmitter nor receiver is the tuning rate in megacycles per revolution a constant factor over any appreciable range. Therefore, if the two units were adjusted to track fairly well over a short range, one unit would tune faster than the other when the range of tuning was shifted slightly, and after a few cycles they would be hopelessly out of tune. To make this system work satisfactorily, a particular receiver and transmitter would have to be adjusted to give the same tracking over the entire range of operation.

For really high speed tuning rates, an electronic sweep is the desirable system. Until a means of electronically sweeping magnetrons is developed, however, it will be necessary to continue with mechanical systems.

IMAGE REJECTION

The S-band receivers available at present have no image rejection. At any point of the receiver, two different signals whose individual frequencies are separated by twice the f_i can be received. Thus when the receiver stops on a signal, the signal may be at either one of two frequencies. By limiting the sweep of the transmitter to a range equal to twice the f_i of the receiver, only one of these two signal frequencies can be covered by the jammer. Therefore, although the transmitter tunes to the frequency of the receiver, the signal to be jammed may not be on that frequency, and the chance of jamming is only 50 percent.

This effect can be illustrated by an example. Suppose a receiver with a 30 mc f_i is sweeping the range from 2970 to 3030 mc, so that its local oscillator is tuning from 2940 to 3000 mc. If a signal appears at 3000 mc, the local oscillator will stop at 2970 mc to give the 30-mc beat for the receiver f_i . The transmitter will tune to 3000 mc and stop on the signal, as is desired. Now suppose a signal appears at 2940 mc instead of 3000 mc. When the receiver oscillator is at 2970 mc, a 30-mc signal will be produced

DECLASSIFIED

to stop the receiver. The transmitter cannot tune to 2940 mc, but can tune to 3000 mc, producing a 30-mc signal to stop the transmitter. Thus the jammer will be on 3000 mc while the signal is on 2940 mc, out of range of the jammer.

When the sweep range is not limited to twice the f_c of the receiver, there are several possibilities. Suppose the transmitter and receiver are sweeping the range from 2900 to 3100 mc, so that the receiver oscillator is covering 2870 to 3070 mc. If a signal appears at 3000 mc, the receiver oscillator may stop at either 2970 or 3030 mc, depending upon which direction the receiver is sweeping. If the receiver oscillator stops at 3030 mc, then the jammer can stop at 3000 or 3060 mc. If the receiver oscillator stops at 2970 mc, then the jammer can stop at 2940 or 3000 mc. Thus of the four possibilities, only two are correct, and there is only a 50 percent chance of jamming.

From the two cases given, it can be seen that as long as the image problem is present, the system is only 50 percent effective. Since the control unit is being developed to work on signals down to the noise level of the receiver, the image signal would have to be below the noise level of the receiver.

One solution to the image problem might be to gang together two receivers whose local oscillators were separated by twice the f_c . If a signal were received on both receivers at the same time, the position of the signal would be fixed and the control unit could operate. The so-called image would appear at different points on each receiver, and the control unit would not operate.

EFFECTS OF SIGNAL AMPLITUDE AND PULSE CHARACTERISTICS

In previous control systems, the accuracy of stopping was some function of either signal amplitude or pulse characteristics. Systems using simple tuned circuit selectivity suffer from both effects, so that some type of discriminator circuit is required. Although amplitude variation effects were eliminated in the zero-beat type of discriminator of the Automat, † this type of discriminator is affected by changes in pulse width. A discriminator of the type used in f-m receivers seems to be more desirable, since its output is zero (for a-m signals) when the circuit is exactly on resonance. However, its output is also zero when there is no signal present. Therefore, it is desirable to have a system which indicates the presence of a signal but still preserves the discriminator characteristic of perfect balance at resonance. The same problem has arisen in employing tuning eyes for f-m receivers. One solution is offered by a British circuit, § but as it stands, this circuit does not work satisfactorily on pulse signals. Consequently, modification of this circuit was undertaken, and a description of the operation of the modified circuit is given in Appendix II.

PULSE DISCRIMINATION

It has been requested that acceptance or rejection of certain type pulse signals be

† NDRC Div. 15 Report No. 411-IB-75 of 11 April 1945: Preliminary Handbook of Maintenance Instructions for U600 Automat.

§ British Patent No. 554388

DECLASSIFIED

4

NAVAL RESEARCH LABORATORY

~~CONFIDENTIAL~~

incorporated in the control unit. This part of the problem has not yet been undertaken, but a preliminary survey indicates that the use of present pulse-discriminating systems would increase the size, weight, and number of tubes in the control unit by a factor of two or three. In addition, since several pulses must be received before pulse discrimination can be accomplished, the pulse relay will not be able to operate on the first pulse as it does now. This means that the time of deceleration of the receiver will be increased, so that the maximum possible sweep rate will be decreased.

LOOK-THROUGH

In order to determine whether or not a signal which is being jammed is still on, present look-through systems require that the jamming transmission be interrupted for a short interval of time. The time of interruption is a function of the operating time of any relays involved; the minimum non-jamming time is therefore limited. Also, the time interval of look-through should not be made less than the time between pulses, and this might be considerable with very low pulse rates.

Continuous look-through systems have been considered, but have been found unsatisfactory. In fact, if a really good continuous look-through system could be devised, it would also be a good anti-jam system. In general, for continuous look-through the receiver and transmitter must be extremely well shielded from each other, both on the individual units and on their respective antenna systems. Noise balancing, as tried in another jamming system, has not yet been found effective for automatic operation. In the development of the discriminator circuit, it was found to be quite difficult to balance properly all components of a pulse signal, and noise signals are much harder to balance than pulse signals. Continuous look-through would also require continuously susceptible circuits in the control unit, whereas with present systems, holding devices are necessary.

The advantages of continuous look-through over intermittent look-through are somewhat doubtful when the various ways in which the enemy could unlock the jammer are considered. With continuous look-through, a short signal interruption would unlock the receiver, and with present slow sweep rates, it might be some time before the receiver again reached that frequency. With intermittent look-through, the enemy radar would have to be interrupted at the same time as the occurrence of look-through. On the other hand, if the enemy merely shifted frequency, the continuous look-through system would immediately start hunting for the new frequency, whereas the intermittent look-through system would not start its operation until the look-through occurred. In either case, it is not difficult for the enemy to avoid being jammed for a period of time.

Any effective look-through system must operate faster than ordinary circuits involving relays. This would indicate that electronic relays would be desirable in place of mechanical relays, if a practical system could be developed. With a system of extremely short look-through it might be desirable to have several sample look-through's before the receiver is allowed to sweep in order that short signal interruptions do not cause loss of effectiveness of the jammer for an extended period.

DECLASSIFIED

DETAILS OF PRESENT LABORATORY MODEL

DRIVE UNIT

Four different drive units have been designed and completed. The first unit was a modification of one of the Automat drives. In it, a brake was added in addition to the clutch, and provision was made for gear changes to cover a wide variation of speeds. Since the SPR-2 receiver requires a shaft speed of only 20 rpm to give the same sweep rate as the APT-10 transmitter does when its shaft speed is 1000 rpm, a very wide range of speed adjustment is required. The clutch-brake arrangement in this unit consisted of the same magnetic clutch and clutch faces as in the Automat unit, but the axially movable part of the clutch (which will be referred to as piece M) was attached to the shaft by means of a spline instead of a collar and spring. On the opposite face of piece M was attached a brake face consisting of 120 radial V teeth. A magnetic brake with a similar set of teeth was mounted where it could attract piece M. Thus when the clutch was energized (brake de-energized) piece M would slide on the spline and engage with the clutch to drive a 150-rpm shaft. With the brake energized (clutch de-energized), piece M would slide back on the spline and engage with the brake to stop the 150-rpm shaft. There were two important faults with this unit, (1) the motor was much too small for the load, and (2) the interchangeable gears (held by set screws) became loose in operation.

In the second model, the power of the motor was increased ten times. In addition, all gears were pinned to the shafts. To facilitate speed changes, gear cartridges were used which could be interchanged by removing two screws. The second unit still did not have sufficient power for the transmitter, and in addition, the action of the clutch-brake arrangement was too sluggish for the high speeds of drive desired.

For the third model, the casting of the original Automat unit was dropped completely, and a more efficient arrangement was designed. Only a transmitter drive of the third model was constructed, since this was the more critical of the two drives. The interchangeable gear system was dropped in favor of higher efficiency, and the unit was designed for the particular transmitter. The motor size was not increased because no motor was available. A permanent magnet motor is used in this unit because field-coil motors of equivalent rating are several times larger and heavier. A manufacturer has not been located who makes permanent magnet motors with ratings of over 1/60 hp -- the size in use. By the improved design of the third unit, the shaft output was doubled over that of unit two, which indicated that half the power was lost in the gearing and bearing system of unit two.

The clutch-brake arrangement of model two was replaced by just a brake in model three, since the time required for piece M to slide back and forth on a rotating shaft was too great. In model three, a rotating cork disk is attached to the motor, and braking is accomplished at motor speed (6000-8000 rpm) by shoving another cork disk against it. The second cork disk can move axially but not angularly, and is pulled away from the rotating disk by a magnet in series with the motor. Magnetic operation is possible because of the steel backing on the second cork disk. When the motor circuit is broken, the magnet releases the second cork disk, and a spring pushes this disk against the rotating one. By using small clearances between the disks, an operating time of about 0.015 seconds can be obtained in spite of the fact that the motor is being stopped in addition to the transmitter

tuning mechanism. This type of brake is far superior to the type used in models one and two.

Model three is satisfactory for the present setup, except that a more powerful motor is desired. With the transmitter cold, the sweep rate in one direction is 30 mc/sec, and in the other direction is 40 mc/sec because of the drive power difference of the magnetron in the two directions. With the magnetron hot, the sweep rate decreases slightly, and if the magnetron has been operating for a long time the motor may not start. However, if the motor is started, it will continue running. This indicates that the magnetron adjustment tends to freeze when the magnetron becomes quite hot, so that a motor with high starting torque is needed.

Model four is identical with model three except that two additional gear pairs have been used to reduce the speed to that required to run the SPR-2 receiver.

CONTROL UNIT

The present control system is outlined in the block diagram of Figure 1. A detailed schematic drawing of the control circuit is shown in Figure 2.

A 30-mc signal from the receiver i.f. is used as the source for the control unit. To operate with receivers having a different i.f. a converter is required to provide a 30-mc signal.

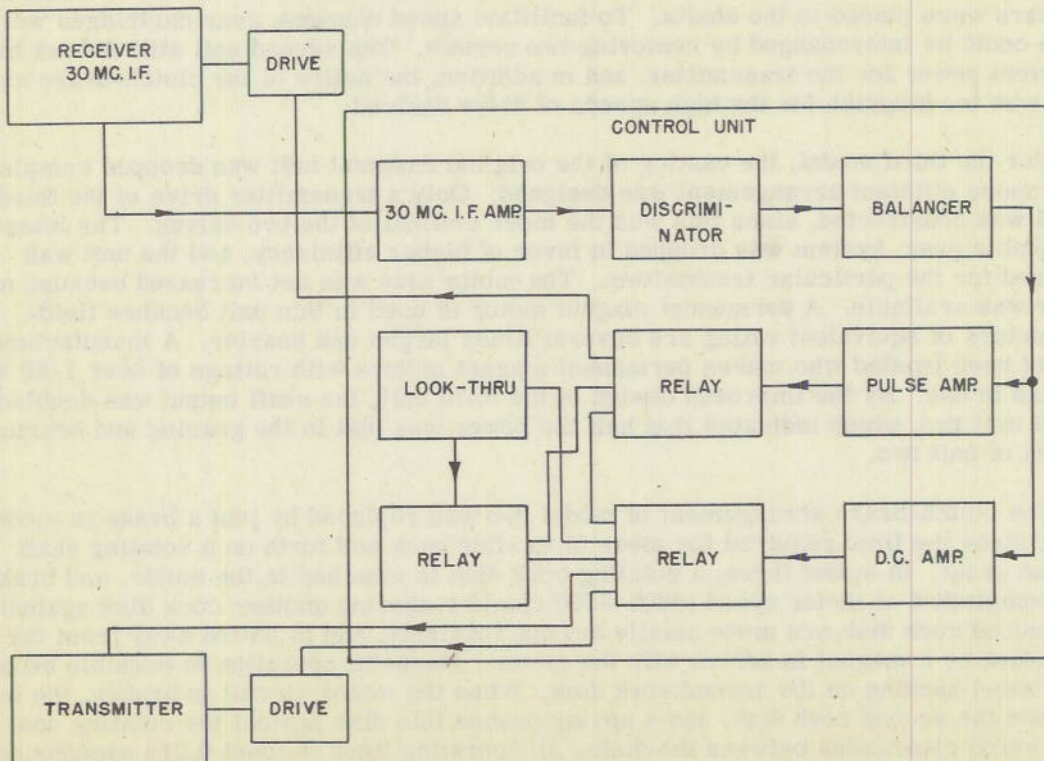
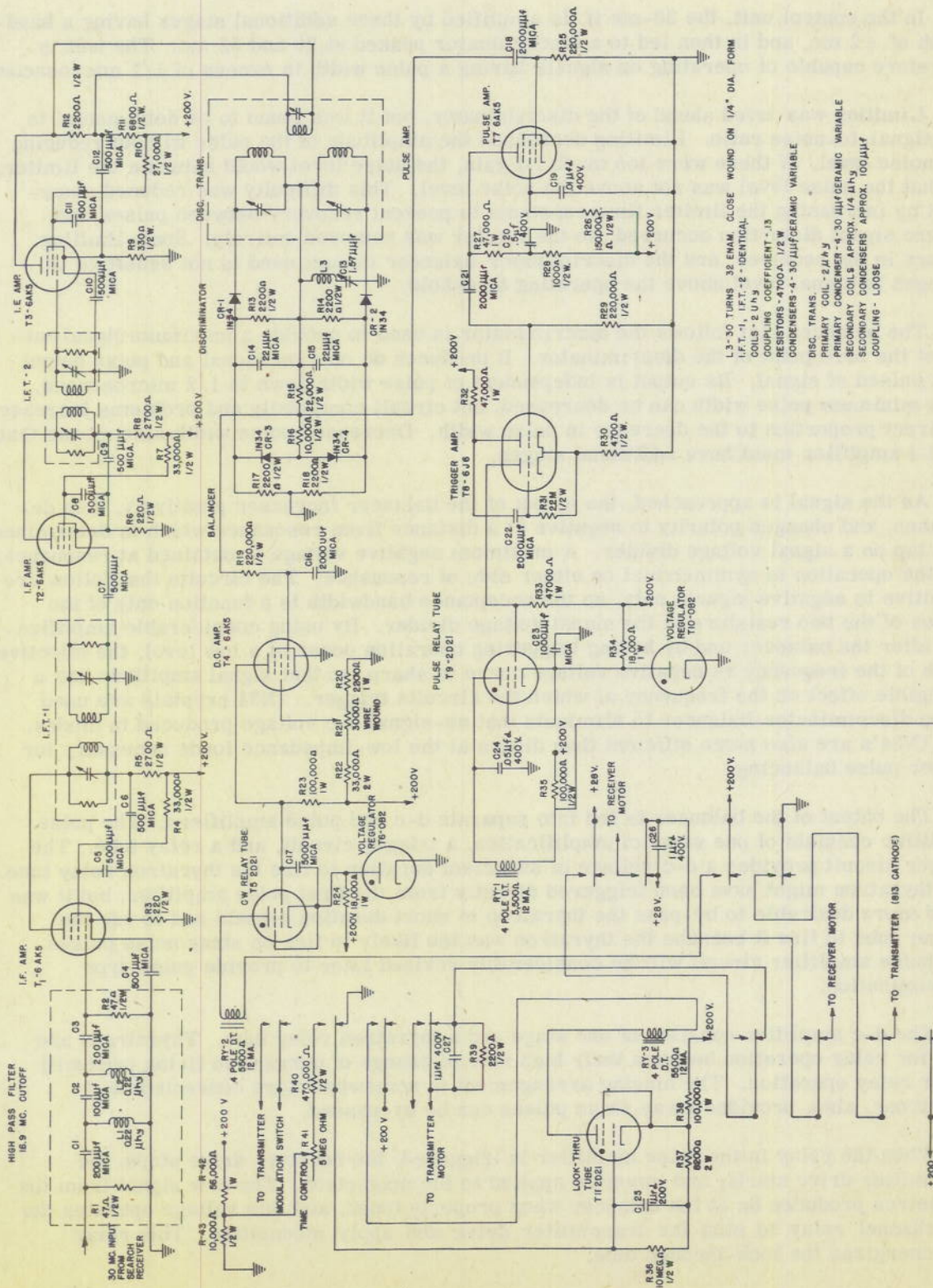


Fig. 1. Block Diagram of Complete System



L3-30 TURNS 32 ENAM. CLOSE WOUND ON 1/4" DIA. FORM
 I.F.T.-1, I.F.T.-2 - IDENTICAL
 COILS - 2 U.H.
 RESISTORS - 4700Ω 1/2W
 CONDENSERS - 4-30 μF CERAMIC VARIABLE
 DISC. TRANS.
 PRIMARY COIL - 2 μH
 SECONDARY COILS APPROX. 1/4 μH
 COUPLING - LOOSE

Fig. 2. Schematic Diagram of Control Unit

DECLASSIFIED

8

NAVAL RESEARCH LABORATORY

In the control unit, the 30-mc if. is amplified by three additional stages having a bandwidth of ± 2 mc, and is then fed to a discriminator peaked at 28 and 32 mc. The unit is therefore capable of operating on signals having a pulse width in excess of 1/2 microsecond.

Limiting was tried ahead of the discriminator, but it was found to be detrimental to the signal-to-noise ratio. Limiting decreased the amplitude of the pulse without reducing the noise level. If there were too much i-f gain, the noise level would saturate the limiter, so that the pulse level was not above the noise level. This difficulty was reduced somewhat by increasing the limiter time constants to prevent recovery between pulses, but severe signal distortion occurred, so the limiter was removed entirely. Some limiting occurs in the receiver, and the discriminator-balancer circuit used is not sensitive to changes in signal level above the operating threshold.

The balancer that follows the discriminator is used to provide a maximum signal output at the zero point of the discriminator. It produces dc on a cw signal and pulse output on a pulsed rf signal. Its output is independent of pulse width down to 1/2 microsecond. This minimum pulse width can be decreased, but circuit complexity and problems increase in direct proportion to the decrease in pulse width. Decreased pulse width also means that the i-f amplifier must have additional stages.

As the signal is approached, the output of the balancer increases positively, then decreases, and changes polarity to negative at a distance from resonance which is determined by a tap on a signal voltage divider. A maximum negative voltage is obtained at resonance, and the operation is symmetrical on either side of resonance. The circuits that follow are sensitive to negative signals only, so the acceptance bandwidth is a function only of the values of the two resistors in the signal voltage divider. By using considerable amplification after the balancer and by having triggering operation occur at a low level, the effective slope of the frequency vs negative voltage curve is sharp, so that signal amplitude has a negligible effect on the frequency at which the circuits trigger. 1N34 crystals are used in the discriminator-balancer to eliminate that no-signal d-c voltage produced in diodes. The 1N34's are also more efficient than diodes at the low-impedance loads necessary for proper pulse balancing.

The output of the balancer is fed into separate d-c and pulse amplifiers. The pulse amplifier consists of one stage of amplification, a trigger circuit, and a relay tube. The trigger circuit provides a d-c voltage of sufficient duration to fire the thyatron relay tube. The thyatron might have been triggered directly from the first pulse amplifier, but it was found more desirable to by-pass the thyatron to short duration signals and to use the trigger tube to fire it because the thyatron was too likely to fire on stray noise pulses. The pulse amplifier circuit will be considerably revised later to provide pulse-type discrimination.

The d-c amplifier consists of one stage and a thyatron relay tube. Thyatrons are used for relay operation because their high rate of change of current on firing produces faster relay operation. The biasing arrangement is somewhat more convenient with thyatrons, also, provided stray noise pulses can be by-passed.

When the relay in the pulse amplifier is triggered, the receiver drive stops, the transmitter drive starts, and power is applied to the magnetron. The c-w signal from the magnetron produces dc at the balancer when properly tuned, and this voltage operates the c-w channel relay to stop the transmitter drive and apply modulation. This relay also energizes the look-through tube.

DECLASSIFIED

The RC network in the grid of the look-through tube causes a delay in the firing of this thyatron. The time delay is adjustable from about 1/2 second to 20 seconds. This time can be increased if desired by changing circuit constants.

When the look-through relay is energized, the transmitter is shut off, and the plate circuit of the pulse channel relay tube is opened to extinguish that thyatron. The look-through relay also provides an additional break in both transmitter and receiver motor circuits to prevent creepage during look-through. When the pulse channel relay releases, it opens the plate circuit of the c-w channel relay tube to extinguish this thyatron. The release of the c-w channel relay breaks the look-through circuit, and the opening of the look-through relay returns the entire circuit to its no-signal condition. If a signal is still being received, the unit locks on and jams again. If the signal is absent, the receiver starts sweeping. The transmitter is off for about 0.03 seconds during this look-through operation. This complete cycle of look-through is necessary to prevent the pulse channel relay from closing on the pulse produced by breaking the transmitter circuit.

In an automatic system of this type, only the magnetron cavity is tuned in the transmitter. The line stretcher and voltage controls are not adjusted by the control unit, which means that the output-frequency characteristic of the magnetron may be poor, with little effectiveness at some frequencies. However, these additional controls follow no specific law of variation with frequency, so there is no practical way of adjusting them by the control unit.

CONCLUSIONS

The present control system for automatic search and jam satisfactorily performs the following functions:

- (a) Sweeps a search receiver over a given frequency band at a rate of 35 mc/sec, detects any pulse signal having a pulse width greater than 1/2 microsecond, and stops the receiver on the center of this signal.
- (b) Tunes a transmitter to the detected pulse signal and provides jamming operation.
- (c) Looks-through at intervals to determine whether or not to continue jamming.

This system is unsatisfactory for the following reasons:

- (a) There is no means of distinguishing between a signal and its image.
- (b) The sweep rate is less than desired.
- (c) Pulses of width less than 1/2 microsecond are not satisfactorily jammed.
- (d) There is no pulse discrimination between friendly and enemy signals.
- (e) Jamming is not effective during look-through periods.

It does not appear possible to obtain high sweep rates or effective jamming on look-through as long as mechanical drive units and mechanical relays are used. Operation on short pulse width and pulse discrimination may be obtained with further work. The image rejection problem may be solved if proper receivers become available.

The equipment should have the following qualifications:

- (a) The search receiver must have good image rejection and be single-dial tuned.

~~CONFIDENTIAL~~

- (b) The jamming transmitter must provide stable c-w and modulated signals over its frequency range, and must be completely single-dial tuned and controlled.
- (c) Both receiver and transmitter must be mechanically satisfactory for high tuning rates, and the tuning power required should be low.
- (d) A straight-line-frequency type of tuning is desirable for possible ganging of receiver and transmitter drives.

RECOMMENDATIONS

To accomplish the desired results, it is recommended that investigation and research be undertaken on

- (1) Electronic sweep systems. (This requires individual work for each particular receiver and transmitter.)
- (2) A discriminator-balancer circuit to provide operation on pulses shorter than 1/2 microsecond.
- (3) A pulse-discrimination system.
- (4) Look-through systems employing electronic relays and multiple sampling before unlock.

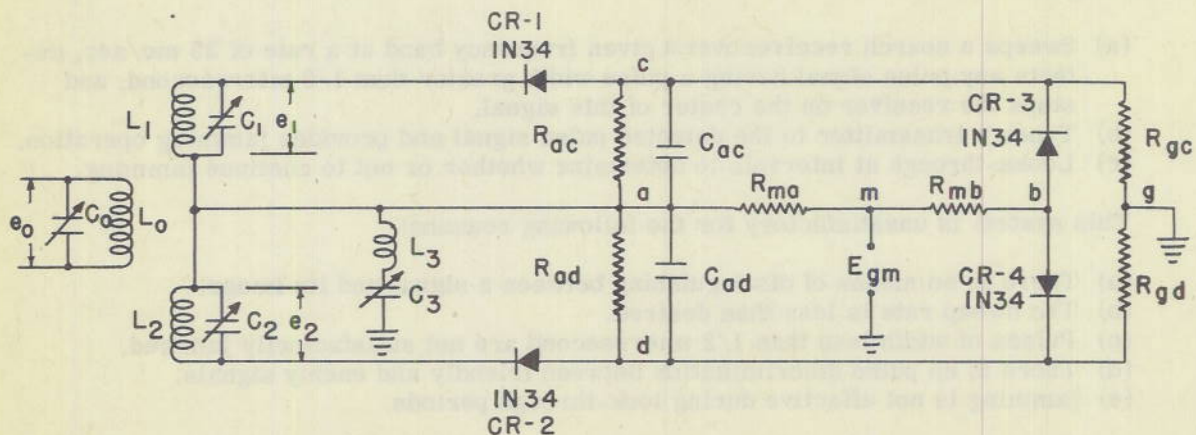


Fig. 3. Discriminator-Balancer Circuit

APPENDIX 1: THEORY OF DISCRIMINATOR ACTION ON PULSE SIGNALS

All notation is referred to the discriminator-balancer circuit shown in Figure 3. In addition, the following notation is used: f_0 is the parallel resonant frequency of the coil-condenser combination L_0C_0 , and is also the series resonant frequency of the coil-condenser combination L_3C_3 . f_1 is the parallel resonant frequency of the tuned circuit L_1C_1 , and f_2 is the parallel resonant frequency of the tuned circuit L_2C_2 . All constants are denoted by A's with various subscripts.

The Fourier expansion for a short square pulse is given by

$$\phi_p(t) = E_p \left(D + \sum_{k=1}^{\infty} \frac{2}{\pi k} \sin kD\pi \cos k \omega_p t \right) \quad k = 1, 2, 3, \dots,$$

where D is the duty cycle, $\omega_p = 2\pi \times$ pulse rate frequency, and E_p is the amplitude of the pulse signal.

Assume that the pulse is to modulate a continuous carrier voltage given by

$$\phi_c(t) = E_c \cos \omega_c t \text{ where } \omega_c = 2\pi \times \text{carrier frequency, and } E_c \text{ is the amplitude of the carrier signal.}$$

The portion of the modulated voltage that would be radiated becomes

$$\phi_m(t) = A_1 E_c \cos \omega_c t + A_2 E_c E_p \left[2D \cos \omega_c t + \sum_{k=1}^{\infty} \frac{2}{\pi k} \sin kD\pi \cos (\omega_c \pm k \omega_p) t \right]$$

For the manner in which pulse signals are usually generated, there is no continuous carrier, so that the terms $A_1 E_c \cos \omega_c t$ does not appear. Therefore, the radiated signal is actually given by

$$\phi_s(t) = A_3 \left[2D \cos \omega_c t + \sum_{k=1}^{\infty} \frac{2}{\pi k} \sin kD\pi \cos (\omega_c \pm k \omega_p) t \right].$$

This is the voltage e_0 applied to the discriminator, provided f_c is used to represent the i-f carrier frequency. It is assumed that the Q of the resonant circuit L_0C_0 has been sufficiently reduced by damping to prevent appreciable distortion of the signals $\phi_s(t)$.

For proper discriminator action

$$f_1 - f_0 = f_0 - f_2 \quad \text{or} \quad f_0 = \frac{f_1 + f_2}{2}$$

It is assumed that the discriminator characteristic is linear over the range in which we are interested, that is

$$e_1 = A_4 - A_5 (f_{sn} - f_1) \quad \text{and} \quad e_2 = A_4 - A_5 (f_2 - f_{sn}),$$

where f_{SN} is any frequency in the aggregate of frequencies in the pulsed signal (see Figure 4). For convenience, these values are rearranged as

$$e_1 = A_5 [A_6 - (f_{SN} - f_1)] \quad \text{and} \quad e_2 = A_5 [A_6 - (f_2 - f_{SN})] \quad \text{where } A_6 = A_4/A_5.$$

These expressions hold only for $A_6 > f_{SN} - f_1$ and $A_6 > f_2 - f_{SN}$. This will be true as long as $f_1 < f_{SN} < f_2$, as can be seen from the figure. It is also assumed that there is no phase shift in the linear range.

Then the peak values of the terms in the equation for $\phi_s(t)$ for the voltage e_1 applied to CR-1 are proportional to

$$A_5 2D [A_6 - (f_c - f_1)] \quad \text{for the term } 2D \cos \omega_c t, \quad \text{where } (f_{SN} = f_c);$$

$$\frac{2}{\pi} \frac{A_5}{k} [\sin kD\pi] [A_6 - (f_c - f_1 + k f_p)] \quad \text{for the terms } \frac{2}{\pi k} \sin kD\pi \cos (\omega_c + k \omega_p) t,$$

where $(f_{SN} = f_c + k f_p)$; and $\frac{2}{\pi} \frac{A_5}{k} [\sin kD\pi] [A_6 - (f_c - f_1 - k f_p)]$ for the terms

$$\frac{2}{\pi k} \sin kD\pi \cos (\omega_c - k \omega_p) t, \quad \text{where } (f_{SN} = f_c - k f_p).$$

Since all terms in $\phi_s(t)$ are cosine terms, all terms will be a maximum when $t = 0$. Furthermore, in the original Fourier expression, the peak value of the entire pulse is the sum of the values of the components at $t = 0$. Therefore, the peak value of the resultant voltage e_1 is the simple sum of the peak values of all the components.

$$|e_1| = A_7 \left\{ D [A_6 - (f_c - f_1)] + \sum_{k=1}^{\infty} \frac{1}{\pi k} [\sin kD\pi] [A_6 - (f_c - f_1 + k f_p)] \right.$$

$$\left. + \sum_{k=1}^{\infty} \frac{1}{\pi k} [\sin kD\pi] [A_6 - (f_c - f_1 - k f_p)] \right\}$$

$$|e_1| = A_7 \left\{ D [A_6 - (f_c - f_1)] + \sum_{k=1}^{\infty} \frac{2}{\pi k} [\sin kD\pi] [A_6 - (f_c - f_1)] \right\}$$

$$= A_7 [A_6 - (f_c - f_1)] \left[D + \frac{2}{\pi} \sum_{k=1}^{\infty} \frac{\sin kD\pi}{k} \right]$$

$$= A_7 [A_6 - (f_c - f_1)] \left\{ D + \frac{2}{\pi} \left[\frac{\pi}{2} (1-D) \right] \right\}$$

$$|e_1| = A_7 [A_6 - (f_c - f_1)]$$

Thus the peak value of e_1 is a function of carrier frequency and not of pulse characteristics, a fact which is extremely important.

A similar analysis for e_2 will give the result

$$|e_2| = A_7 [A_6 - (f_2 - f_c)].$$

It remains to consider the effect on pulse shape. For the demodulated pulse signal, the peak value of any component frequency in the Fourier analysis ($k f_p$) will be the sum of the peak values obtained from the two sidebands for that frequency. The relative amplitudes of the two sidebands are given by

$$[A_6 - (f_c - f_1 + k f_p)] \sin kD\pi \quad \text{and} \quad [A_6 - (f_c - f_1 - k f_p)] \sin kD\pi.$$

$$A_5 = \text{SLOPE OF } e_2 = -\text{SLOPE OF } e_1$$

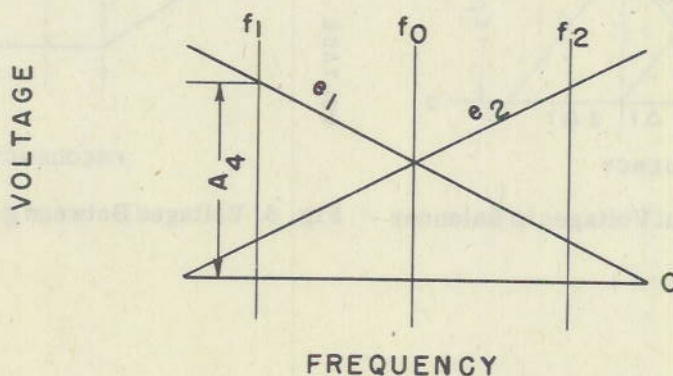


Fig. 4. Assumed Discriminator Characteristic

Adding these two sidebands gives,

$$|e_k| = 2 [A_6 - (f_c - f_1)] \sin kD\pi.$$

Thus the peak amplitude of any of the component frequencies in the pulse has the same relative value after demodulation as before being applied to the discriminator, so that no signal distortion occurs. This result, along with the result for peak amplitude of the entire pulse, leads to the fact that the output voltages of the discriminator (input voltages to the balancer) can be treated as simple pulse voltages for a pulse signal, or as d-c voltages for a c-w signal.

It must be realized that this analysis is based on a linear characteristic with zero phase shift for each half of the discriminator, a condition which does not exist with a single-tuned circuit. For long pulses the assumption is more valid than for short pulses, since the portion of the selectivity curve used is smaller. This is apparently one of the reasons why in actual practice better results are obtained on longer pulses. Use of complex filter circuits in place of a single tuned circuit would be preferable from this standpoint. In addition, an infinite sum was used in the series expansion, so that an infinitely long selectivity curve would be needed for exact analysis. Actually, the results are fairly good if the expansion is taken just to the first zero, $k = 1/D$.

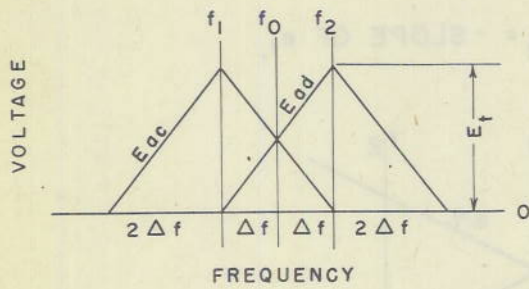


Fig. 5. Assumed Input Voltages to Balancer

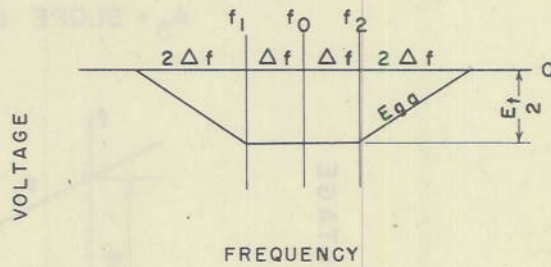


Fig. 6. Voltages Between g and a (Fig. 3)

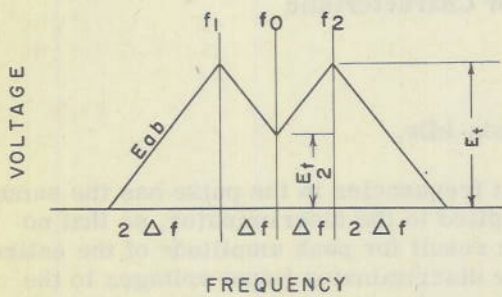


Fig. 7. Voltages Between a and b (Fig. 3)

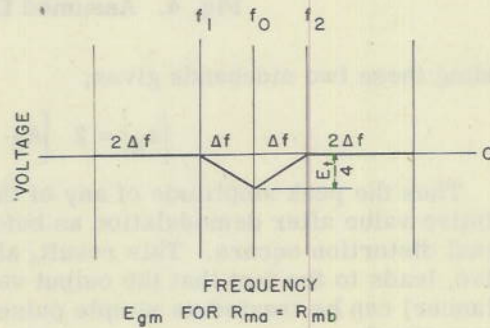


Fig. 8. Balancer Output Voltage for $R_{ma} = R_{mb}$

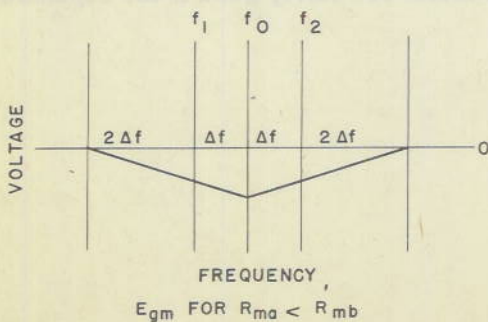


Fig. 9. Balancer Output Voltage for $R_{ma} < R_{mb}$

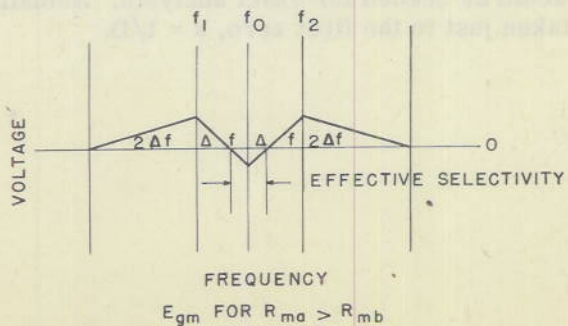


Fig. 10. Balancer Output Voltage for $R_{ma} > R_{mb}$

APPENDIX 2: THEORY OF BALANCER ACTION

The notation and circuit diagram are the same as given in Appendix 1. Voltages are designated with a double subscript, indicating polarity. The effects of C_{ac} and C_{ad} on a pulse signal are neglected, and $R_{ac} = R_{ad} = R_{gc} = R_{gd}$. It is assumed that the 1N34 crystals have zero impedance in the forward direction and infinite impedance in the reverse direction. For simplicity of drawing, it is further assumed that the voltage responses E_{ac} and E_{ad} as a function of frequency are linear in the manner shown in Figure 5. Analysis is based on a c-w signal for e_0 , so that the voltages E_{ac} and E_{ad} are pure dc. From the results obtained in Appendix 1, this analysis holds equally well for pulse signals under the assumptions made. Effects of variations from these assumptions are discussed at the end of the analysis.

The output voltage E_{gm} is determined by starting with the voltage

$$E_{cd} = E_{ca} + E_{ad} = E_{ad} - E_{ac}.$$

Since $R_{gc} = R_{gd}$,

$$E_{cg} = E_{cd}/2 = (E_{ad} - E_{ac})/2.$$

$$E_{ga} = E_{gc} + E_{ca} = -E_{cg} - E_{ac} = -(E_{ad} - E_{ac})/2 - E_{ac} = -(E_{ac} + E_{ad})/2.$$

E_{ga} is shown as a function of frequency in Figure 6.

If $E_{ac} > E_{ad}$, CR-3 conducts, so that $E_{ab} = E_{ac}$. If $E_{ad} > E_{ac}$, CR-4 conducts, so that $E_{ab} = E_{ad}$. This leads to the voltage-frequency curve for E_{ab} shown in Figure 7. Also, $E_{gm} + E_{ma} = E_{ga}$, so that $E_{gm} = E_{ga} - E_{ma}$.

$$\text{But, } E_{ma} = \frac{R_{ma}}{R_{ma} + R_{mb}} E_{ba} = -E_{ab} \frac{R_{ma}}{R_{ma} + R_{mb}}.$$

$$\text{Therefore, } E_{gm} = E_{ga} + E_{ab} \frac{R_{ma}}{R_{ma} + R_{mb}}.$$

The equation for E_{gm} gives rise to three possible cases, $R_{ma} = R_{mb}$, $R_{ma} > R_{mb}$, $R_{ma} < R_{mb}$.

$$\text{If } R_{ma} = R_{mb}, E_{gm} = E_{ga} + E_{ab}/2.$$

The addition of the curves for E_{ga} and $E_{ab}/2$ is shown in Figure 8.

DECLASSIFIED

16

NAVAL RESEARCH LABORATORY

~~CONFIDENTIAL~~

If $R_{ma} < R_{mb}$, then $\frac{R_{ma}}{R_{ma} + R_{mb}} < 1/2$, so that the effect of E_{ab} is decreased. This produces the curve of Figure 9.

If $R_{ma} > R_{mb}$, then $\frac{R_{ma}}{R_{ma} + R_{mb}} > 1/2$, so that the effect of E_{ab} is increased. The resultant curve is shown in Figure 10.

Figure 10 shows that if the pulse and d-c amplifiers respond only to negative signals, the effective selectivity may be increased by increasing the ratio R_{ma}/R_{mb} . The limit occurs when $R_{mb} = 0$, in which case the voltage never becomes negative. However, increased selectivity results in decreased signal level, which reaches zero when $R_{mb} = 0$.

The advantages of producing selectivity by this method are (1) that the same results are obtained regardless of pulse width, (2) the selectivity does not depend on signal amplitude to any great degree, and (3) the effective selectivity is independent of power supply and tube variations. A disadvantage is that the point (a) must be at r-f ground for stability, but should have high impedance to ground for all frequencies in the pulse.

The effects of non-linearity and phase shift in the tuned circuits are to produce curved lines instead of straight lines in Figures 4-10 and to round off the sharp points. Thus the actual selectivity curve may not be as sharp as is indicated. In addition, the change in amplitude and phase of components in the pulses does not give simple addition of voltages at all frequencies in the pulse. Therefore, the pulse voltage E_{gm} will not be square, but may have sharp spikes where there has been no voltage cancellation. These spikes do not necessarily follow any particular relation with frequency, so that they may trigger following circuits at undesirable times. It is therefore desirable to obtain as linear a circuit as is possible.

If C_{ac} and C_{ad} are too large compared with R_{ac} and R_{ad} , a similar effect will be obtained. However, C_{ac} and C_{ad} should have low impedance at the intermediate frequency.

The reverse impedance of the crystals is sufficiently high compared with the load, so that it may be neglected. The forward impedance causes a slight reduction in the voltage E_{ab} .

The most difficult problem in balancing is to keep the capacity low between point (a) and ground. This capacity is the most effective item in producing sharp spikes on the output pulse.

PRNC-2580-7-28-47-100

DECLASSIFIED