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FR-2508

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SHIP-SHORE RADIO DIVISION - SEARCH RADAR SECTION

4 April 1946

SOME FUNDAMENTALS OF A-J DESIGN
FOR RADAR RECEIVERS

By T. H. Chambers

- Report R-2508 -

* * *

Approved by:

R. C. Guthrie - Head, Search Radar Section

L. A. Gebhard - Superintendent,
Ship-Shore Radio Division

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

Preliminary Pages a-d
Numbered Pages 48
Plates 24

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ENCL. A TO NRL LTR. C-2040-1491/48 -a-

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ABSTRACT

This report discusses the philosophy of a-j receiver design at this laboratory. All discussions are of a very general qualitative nature with almost no mathematics being used. They are purposely made very general and qualitative since the purpose of this paper is distinctly not to form a basis for actual design, but rather to familiarize the engineer with the requirements which must be met in an a-j receiver and the general circuits used to meet them. Actual circuit details and component parts values are left to other authors.

The paper starts with a discussion of the requirements which must be met by the receiver. This is followed by a discussion of some of the protective circuits including a discussion of the reasons for choosing the particular circuits used at this laboratory.

The next parts of the paper then discuss the fundamentals of the operation of these circuits in general terms covering such subjects as,

- (a) Dejamming Action of Back-Bias Circuits
- (b) Pulse Transmission of Back-Bias Circuits
- (c) The Detector
- (d) Video Filters
- (e) The Echo By-Pass

Each of these subjects and the others covered, are discussed from the standpoint of importance and how they are affected by various system characteristics such as,

- (a) Bandwidth
- (b) Dynamic Range
- (c) Filter Q

and other such factors.

A part of the paper is then devoted to a discussion of the development of actual receivers, one for search equipments and one for fire control equipments. This part includes a section which discusses the general method of adjusting the fire control system for constant gain.

The last part of the paper gives an estimate of the value of the designs presented.

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1-2-5. Reference 5 is also of special interest. It describes the a-j receiver for the Mark 12 fire control system. This receiver is the first fire control receiver designed and produced which incorporates complete semi-automatic a-j protection.

1-3. Early Work

1-3-1. No discussion of the early work done on a-j receivers will be given here. References 4 and 6 cover this early work quite thoroughly.

2. GENERAL REQUIREMENTS

2-1. Prevention of Overload

2-1-1. Any dejamming system must, to be effective, prevent overload of the receiver with jamming signals much stronger than the echo signal present. This requirement is so well known that it needs no further discussion here except as regards the level to which the receiver must be protected.

2-1-2. No work which is conclusive enough to set a maximum absolute level or a maximum j/s ratio to which the receiver must be protected has as yet been done. In the absence of a definite maximum, it is advisable to put as much protection in a receiver as is practical. This amounts to protection against a maximum level of more than 100 mv and a j/s ratio of more than 80 db. When sufficient work has been done to set levels, they will probably be found to be lower than these.

2-2. Removal of Interference Patterns

2-2-1. Little need be said of the necessity of removing jamming components which cause interference patterns on the indicator screen. This is, after all, the primary purpose of an a-j receiver.

2-2-2. There are, however, certain jamming components, or types of jamming modulation, which cannot be dealt with without elaborate systems which are very difficult to operate. The present work has been based on the idea of developing a receiver which will be relatively simple to operate and relatively foolproof and in which a loss is accepted from these jamming components.

2-3. Constancy of Gain Versus Jamming Level

2-3-1. Although a variation in gain (as jamming level is varied) as high as 4 to 1 can be tolerated in an a-j receiver for search equipment, the gain of a receiver for fire control radar

must remain constant within a few percent. Consider Plate 1 -- it shows the right and left main lobes of a radar antenna for a fire control radar. The radar is at R and the target is at T. In this case the radar is shown on target and the pips are matched on the train scope. Now suppose that a jammer is placed at J. It will be noted that the jammer is on a different bearing from the target and since the crossover of the antenna is on the target bearing, the jamming level picked up by one lobe will be different from the jamming level picked up by the other lobe. If the receiver gain changes as the jamming level changes, it will change the height of one or both of the pips and, although the radar is on target, the pip heights will differ and show an off target indication. The operator will then move the radar off target to correct the difference in pip heights and thus will introduce an angle error. This angle error may be severe. In some cases as much as a 4° error has been measured.

2-3-2. It should be noted that this angle error occurs on off-target jamming only. In the case of on-target jamming, the jamming level will be the same on both lobes and, although the gain may be different from what it would be at any other jamming level, it will still be the same for both lobes and no angle error will be introduced.

2-3-3. It should also be noted that there is a maximum difference in the level of the jamming picked up by the two lobes for any given lobe pattern. Plate 2 shows the difference in db in the pick-up between the two lobes as a function of the bearing of the source relative to the bearing of the crossover of the lobes. This curve is for the Mark 12 and shows that in the worst condition the difference between the level picked up by the two lobes will be only about 20 db. Thus, gain must be essentially constant over a 20 db change in jam level. It must, however, be remembered that this 20 db range may appear anywhere between zero and the maximum level to be handled.

2-3-4. The degree of constancy of gain necessary can also be found from this curve. Examination of the curve shows that the slope at the crossover point, is about 1 db per degree for the one-way pattern or about 2 db per degree for radar use. This means that if the receiver gain changes 2 db between lobes as a result of the change in jam level it will be necessary to swing the antenna about 1° off target to introduce a 2 db difference (in the opposite direction) in echo levels so that the pip heights will be matched. Thus a 1° error has been introduced. It is obvious then, that to keep an accuracy of say, 15 minutes, we will have to limit the change in gain to 0.5 db or less in any 20 db change in jamming level. Working backwards this gives a permissible change in gain of 6% in the 20 db change in jamming level. By a similar process the necessary constancy of gain can be found for any system from a knowledge of the accuracy desired, the slope of the lobe ratio curve at the crossover, and the maximum lobe ratio.

2-3-5. The constancy of gain which can be obtained in a practical set-up will be discussed later but for the present suffice it to say that 6% is probably better than can be expected. If, however, the slope of the lobe ratio curve at the crossover point were to be made greater, it is immediately apparent that a greater change in gain could be tolerated without a loss in accuracy (providing, of course, that the maximum lobe ratio was not materially increased). To this end, every effort should be made to design the antenna for maximum slope at crossover without appreciable loss in sensitivity. Although no definite rule, applicable in all cases, can be laid down, it appears that a lobe spacing which places the crossover at about the 85% points on the lobes will generally give a good crossover slope (about 4 db per degree for two-way radar use) with only slight loss in radar range.

2-4. Constancy of Incremental Gain

2-4-1. The reset accuracy of a lobe switched system is a direct function of the incremental gain of the system. It is therefore immediately apparent that the incremental gain must be kept high and limiting must be avoided. Furthermore, since constant incremental gain is fundamental to a linear system, it must be maintained constant.

2-5. Wide True Dynamic Range

2-5-1. When the jamming encountered is modulated at frequencies above those which the back-bias system will follow, the true (not back-bias) range of linearity must be relied on for protection and thus becomes of importance. The back-bias will set the average bias to a value such that the positive peaks of the modulation envelope will drive just to zero bias. The negative peaks of the modulation will then be clipped. This clipping of the negative peaks of modulation reduces the amount of discrimination against jamming components necessary in the a-j video to approximately the true dynamic range of the i-f system. From this standpoint it would seem that a narrow dynamic range would be best. This is not, however, true. When the negative peaks of jamming are lost, any echo beat note energy superposed on them will be lost. This loss in echo energy can lead to rather serious losses in reset accuracy.

2-5-2. Thus the true dynamic range of the system must be a compromise between two factors. The dynamic range is discussed from the standpoint of protection of the video in section 4-3. It is discussed in relation to the system's pulse transmission characteristics in section 5-6.

2-6. Constancy of Gain vs. Jamming Frequency. The necessity for maintaining constancy of gain regardless of jamming frequency is not so evident as the necessity of maintaining constancy of gain regardless of jamming level. Nor can it be discussed completely

at this point. It is, however, an extremely important point to be considered and, although the discussion of it will be reserved for later (see Section 5-3), it must at least be named as one of the requirements of the system.

2-7. Clean Design

2-7-1. Perhaps it is redundant to mention clean design as a requirement of an a-j receiver. It should be a foregone conclusion that any equipment for fleet service will be of clean design. It has, unfortunately, been found that, in many cases marginal stability and freedom from regeneration are sacrificed to manufacturing convenience. It should be pointed out that marginal stability is absolutely essential in an a-j receiver. Unless the receiver is absolutely stable, the protective circuits cannot be of maximum value.

2-7-2. In many instances equipments have been built using insufficient by-passing, decoupling and shielding. The circuit of Plate 20 and the mechanical layout of Plate 24 show a suggested circuit and structure which have been found by this laboratory to be very stable.

3. PROTECTIVE CIRCUITS

3-1. The I-F System

3-1-1. There are several possible methods of protecting the i-f system of a receiver. Perhaps the most common of these are the use of side detectors or the use of one of the several forms of back-bias. The use of side detectors will not be considered in the present report but rather the discussion will be confined to the back-biased i-f system.

3-1-2. The two common forms of back-bias (amplified and non-amplified) have been given extensive comparative test at this laboratory. It has been found at the laboratory, that, for equipments using a pulse length of one microsecond or longer, the non-amplified back-bias is distinctly superior. As yet no work has been done on shorter pulse lengths.

3-1-3. The non-amplified back-bias is a degenerative circuit and thus is inherently stable, whereas the amplified system must employ some sort of feed-back path which almost always leads to regeneration and oscillation troubles. Furthermore, although shorter recovery times are claimed for amplified back-bias, experience at this laboratory has failed to substantiate this claim. Because of these considerations, and those discussed in part 10 of reference 4, non-amplified back-bias will be found in general to be the best choice of a method of protecting the i-f system of

a receiver.

3-1-4. Parts 4 and 5 of this paper will cover the fundamentals of the non-amplified back-biased i-f system as applied either to the receiver for the search equipment or to the receiver for the fire control equipment.

3-2. The Detector

3-2-1. Part 2 pointed out the requirements of linearity of gain for the i-f system. These requirements, quite obviously, apply equally well to the detector. The necessary linearity can be obtained in either the infinite impedance detector or the diode detector. Since the diode is simpler and since the loading which the diode places on the last i-f transformer is not detrimental (the transformer would otherwise have to be resistance loaded to obtain the necessary bandwidth) the diode is used almost exclusively. Part 6 will discuss briefly the operation of the diode detector.

3-3. The A-J Video System

3-3-1. Part 3 of this paper will discuss the use of video filters in the a-j video system. The FTC will be discussed for use both in the receiver for service in the search radar system and for the receiver for the fire control radar system. The high pass and the band pass filters will be discussed for use in the receiver for the fire control system.

3-3-2. Section 10-2 discusses the use of the echo rectifier both to improve pulse shape and to conserve the total of the pulse energy.

3-3-3. Part 9 covers two possible systems for the echo by-pass necessary when either a band-pass or a high-pass filter is used in the a-j video system. Each of these systems has its advantages and its disadvantages and no decision has as yet been made at this laboratory as to which is best.

4. DEJAMMING ACTION OF BACK-BIASING CIRCUITS

4-1. Static Conditions. The following paragraphs will discuss the action of a non-amplified back-biased i-f amplifier. For the purpose of this discussion the applied jamming is assumed to be c.w.

4-1-1. Plate 3 shows the basic circuit of a stage of non-amplified back-biased i.f. It will be noted that this single stage is perfectly straightforward except that the cathode bias resistor is unusually large and a bias is applied to the grid. The action of this high cathode resistor is as follows: When a jamming signal of several volts, say, for example, 5 volts RMS (such as a

strong jamming signal amplified by several precoding stages of the receiver) is applied to the grid of the i-f amplifier it will drive the stage into class C operation and cause more plate current to flow. This increase in plate current will increase the drop across the cathode resistor and thus increase the bias on the tube. If the value of the cathode resistor is correct, the increase in bias will be such that the grid is never driven positive. At the same time the echo signal energy, which in this case is much smaller than the jamming energy, will appear as a beat on the envelope of the jamming as shown in Plate 4. Since it appears as a beat, a portion of it (the portion on the positive side of the jamming envelope) will appear in the near zero-bias region of the tube's characteristic where g_m is high, and will be greatly amplified, while the remainder will be lost together with all the jamming energy which drives below cutoff. If the amplifier is correctly set up, as much as 97% of the jamming energy can be discarded in this manner with a loss in echo energy of only about 70%.

4-1-2. No attempt will be made here to analyse the operation of the circuit quantitatively in a rigorous fashion; however, some rough calculations of its performance would be of value to show, in general terms, how it operates.

4-1-3. Consider the case of a 6AC7 set up to handle a signal level of 5 volts RMS. The operating cycle of this tube may be found by substituting the known values in the following equation for the input signal:

$$E_{RMS}(In) = \frac{K_{class\ C} \times E_g(co)}{2.8} \quad (4-a)$$

Where,

$K_{class\ C}$ = class "C" factor

$E_g(co)$ = cut-off bias for the tube used under the operating conditions used.

Substituting in the known E_{RMS} and $E_g(co)$, and solving for $K_{class\ C}$

$$K_{class\ C} = \frac{2.8 \times 5}{3.5} = 4$$

Thus the class "C" factor for this mode of operation is 4. It should be noted that this figure is not rigorously accurate. It is, however, sufficiently accurate for practical purposes over the range of conditions under which a back-biased stage will operate. The class "C" factor is, in actuality, the duty factor of the class "C" stage, and to be rigorously accurate would have to be found by means of an integral.

4-1-4. Knowing the class "C" factor, it is now possible to calculate the jamming output level from the stage. This is done by means of the following equation,

$$E_{\text{RMS}}(\text{Out}) = \frac{I_{p(o)} \times R_L}{2.8 \times K_{\text{class C}}} \quad (4-b)$$

Where,

$I_{p(o)}$ = the zero bias plate current of the tube under the conditions used.

R_L = load resistance

For the 6AC7 the value of $I_{p(o)}$ will be 36 ma and the value of R_L in the particular stage under consideration is 1500 Ω . Hence,

$$E_{\text{RMS}}(\text{Out}) = \frac{36 \times 10^{-3} \times 1500}{2.8 \times 4} = 5 \text{ V}_{\text{RMS}}$$

Thus the output jamming level is 5 volts RMS or equal to the input jamming level. Hence the stage has a gain of unity, or 0 db, to the strong jamming signal.

4-1-5. In connection with these calculations, it should be pointed out that it was not a lucky accident that the gain to the jamming came out to be unity. This is a necessary condition for the successful use of a back-bias system and the stage is purposely adjusted to meet it. Consider now the method of adjustment. First examine equation (4-b). It is obvious that $I_{p(o)}$ will be fixed for a given tube type for a given condition of operation, but will vary for different tube types and different values of screen voltage. Also R_L will vary according to the coupling circuit used and $K_{\text{class C}}$ will vary in a manner yet to be determined. Consider next equation (4-a). The cut-off bias will be fixed for a given tube type operated under given conditions, but will vary for different tube types and different values of screen voltage. Again the class "C" factor will vary in a manner yet to be determined. From this discussion it is apparent that the values of all variables, with the exception of the class "C" factor, in both equations are fixed by other design considerations than the back-bias circuit, so if the input and output are to be made equal, it will have to be done by varying the class "C" factor.

4-1-6. Equating tentatively, the input and output voltages and solving for $K_{\text{class C}}$, we get,

$$\frac{K_{\text{class C}} \times E_g(\text{co})}{2.8} = \frac{I_{p(o)} \times R_L}{2.8 \times K_{\text{class C}}}$$

$$K_{\text{class c}} = \sqrt{\frac{I_{p(o)} \times R_L}{E_{g(co)}}} \quad (4-c)$$

If the class "C" factor can be made to meet this requirement then the condition for unity gain can be met.

4-1-7. Consider now what determines the class "C" factor and whether any of the other variables are dependent on it. Clearly R_L is not dependent on it, and since $I_{p(o)}$ and $E_{g(co)}$ depend only on the tube type and on E_p and E_{sc} , they are clearly independent of $K_{\text{class c}}$. Consider now what the class "C" factor does depend on. Remembering that it is in reality the operating angle of the class "C" amplifier, it will be remembered from radio fundamentals that it is a function of the d.c. bias applied to the grid provided that, regardless of the value of this bias, the peak of the r.f. envelope drives just zero-bias. Thus by adjusting the bias on the tube we can vary $K_{\text{class c}}$ to make the input and output voltages equal. This variation of the grid bias can be accomplished simply by varying the cathode resistor provided the screen and plate voltages are varied by an amount equal to the variation in the cathode voltage so that E_p and E_{sc} , and hence $I_{p(o)}$ and $E_{g(co)}$ do not vary.

4-1-8. The above discussion covers the first requirement of a successful back-bias system; namely, that the gain to a strong jamming signal be unity, and shows how it is met. Next, consider what happens to a weak echo riding on top of the jamming envelope. It will be remembered that the echo energy rides on top of the jamming energy and hence will be subject to the maximum gain of the amplifier (at almost the zero-bias G_m) when the tube is conducting, and to no gain when the tube is not conducting. Since, however, the pulse energy will be present over a number of cycles of jamming, it is most convenient to discuss pulse gain in terms of the average G_m of the tube. Clearly this average G_m will be approximately,

$$G_m(av) = \frac{G_m(o)}{K_{\text{class c}}} \quad (4-d)$$

Hence the gain to a pulse will be,

$$\text{Gain}_{\text{pulse}} = G_m(av) R_L \quad (4-e)$$

Or in the case of the 6AC7 stage under consideration where,

$$G_m(o) = 16,000 \text{ } \mu\text{mho}$$

$$R_L = 1500 \text{ ohms}$$

$$K_{\text{class c}} = 4$$

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$$\text{Gain}_{\text{pulse}} = \frac{16,000 \times 10^{-6}}{4} \times 1500 \approx 6$$

This is, of course, voltage gain. Converted to db it would be about 16 db.

4-1-9. It should be pointed out again that this analysis is not rigorous and the values given and calculated are only approximate. In actual amplifiers the pulse gain is found to be somewhat less than this. This results from the fact that the cathode condenser will generally, in order to secure the desired dynamic characteristics, be made small enough that it will have 10 or 20 ohms reactance at the i-f frequency. This reactance will reduce the stage gain 3 or 4 db.

4-1-10. An examination of equations (4-a) and (4-b) will show several interesting features of this amplifier stage. First, it is operating with the maximum jamming level applied that it can take without overload. If the jamming level is increased it will drive into the grid conduction region. Second, it is delivering the maximum output that it can, without overload, since its plate is swinging through its maximum permissible current swing; namely, from its zero-bias current to zero.

4-1-11. Another interesting feature of this amplifier can be seen from an examination of equations (4-c) and (4-d). It will be apparent from these equations that the gain is not inversely proportional to bandwidth as is the case with an ordinary amplifier. R_L will still vary inversely as the bandwidth, but in order to maintain unity gain to jamming $K_{\text{class c}}$ will be varied as the square root of R_L so that as R_L is reduced $K_{\text{class c}}$ will be reduced; and since $K_{\text{class c}}$ appears in the denominator of equation (4-d), the gain will actually vary inversely as the square root of the bandwidth. It should be noted that this does not mean that there is an increase in gain for wide bandwidths. It simply means that the loss in gain when back-bias is applied is less in wide band amplifiers. In actual amplifiers the gain appears to be 4 to 6 db per stage lower in the back-biased amplifier for a narrow bandwidth (.5 to 1 Mc), and to approach asymptotically the gain of the normal amplifier as bandwidth is increased.

4-1-12. Thus far this discussion has considered only the performance at high jamming level. As mentioned in paragraph 4-1-1, and shown in plate 4; as the jamming level applied to a given stage is reduced, the plate current of the tube drops (because it is operating class "C") thus reducing the bias and maintaining the positive side of the jamming envelope in the operating region. It is essential that this reduction in bias take place in a way such that the gain to a small pulse superposed on the jamming signal be constant regardless of jamming level. The meeting of this requirement is to be considered under the discussion of the pulse transmission characteristics of the system (see part 5) and will not be discussed here. It is sufficient to say

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that this requirement is met by adjusting the voltage applied to the grid.

4-1-13. Consider now a chain of seven stages such as discussed above, followed by a 6AG7 stage. This 6AG7 is set up in a somewhat similar manner except that it is not necessary to limit the gain to jamming to unity since it is not necessary to limit its output so that it will not overload the following stage (a diode detector follows it). It is only necessary to make certain that its bias, in the jammed condition is sufficient to prevent driving into the positive grid region. Its class "C" factor will then be,

$$K_{\text{class c}} = \frac{2.8 \times 5}{7} = 2$$

Its output will then be,

$$E_{\text{RMs (out)}} = \frac{70 \times 10^{-3} \times 1500}{2.8 \times 2} = 20 \text{ volts}$$

Gain to the pulse will be,

$$\text{Gain}_{\text{pulse}} = \frac{18,000 \times 10^{-6} \times 1500}{2} = 12$$

or 26 db,

Adding up all the gains we then have an amplifier whose calculated pulse gain is 138 db. When corrected for the degeneration in the cathode condensers this figure will be reduced to about 110 db. If, however, we apply jamming to this amplifier its action will be as follows. At very low jamming levels, say 10 uv, all stages will be operating class A and the jamming will be subjected to normal gain. This will build the jam level up to about 3 volts at the detector and about .2 volts at the grid of the last i-f stage. This is too low to cause any back-bias action and the amplifier will operate in perfectly normal fashion. As the input jam level is then increased the level at the grid of the last i-f stage will continue to rise till it reaches about 1 volt at which time this stage begins to bias back. As the input level continues to increase, this stage biases further back until, when the input level has reached about 250 uv the level at the grid of the last stage is about 5 volts and the stage is completely biased back. But by this time the next-to-the-last stage has about 1 volt on its grid and it is biasing back. Then, as the input level is further increased, this next-to-last stage continues biasing back, and reducing its gain to jamming (thus maintaining its 5 volt output to the grid of the last stage) until the input has reached about 1.5 mv at which time the input to its grid has reached 5 volts and it is completely biased-back and the preceding stage is biasing back. From a continuation of the above process, it is apparent that, as the level is further increased, the remaining

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stages will bias-back successively in order from last to first till the input level is 5 volts, at which time all stages will have maximum level applied to them and will be delivering maximum output. No stage will, however, be overloaded. This biasing back procedure is discussed in more detail in section 5-4, but the above discussion gives the general outline necessary for an understanding of the dynamic properties of the system to jamming having low frequency modulation.

4-2. Back-Bias Action at Low Modulation Frequencies The above section considered the action of the system only in the presence of c-w jamming. This section will consider what happens when modulated jamming is applied. Before starting on this subject it should be pointed out that, for the sake of simplicity, the effects that circuit characteristics discussed have on the pulse energy will not be treated here. They will be discussed in part 5.

4-2-1. If the applied jamming is modulated using a low modulation frequency, exactly the same thing will happen as happened in the c-w case, except that the cathode bias will vary according to the modulation envelope and will maintain the positive side of the envelope just below zero-bias. Plate 5 shows this graphically. It is immediately evident that the back-bias system is simply following the modulation envelope and that in so doing it is removing the modulation from the jamming signal. As stated before this holds only for low modulation-frequencies. The next section will discuss the action of the back-bias when subject to jamming having high modulation frequencies.

4-3. Back-Bias Action at High Modulation Frequencies

4-3-1. As described above, when the jamming modulation frequency is low, the back-bias will follow the modulation envelope and effectively remove the modulation from the jamming. However, as the modulation frequency is increased, the cathode condenser will come into effect to reduce the ability of the bias to follow the high frequency variation of the envelope. Thus, the back-bias will, as the modulation frequency increases, become progressively less effective at removing the modulation until finally it will reach a point at which it can no longer follow. Plate 6 shows this. In figure (a) the modulation frequency is low and the bias follows it easily; in (b) it is medium and the bias follows partially. At (c), however, it is high and the bias cannot follow at all.

4-3-2. When the back-bias can no longer follow the modulation envelope it will set the average bias on the i-f at a point such that the peaks of the modulation envelope will reach almost to zero bias. Plate 7 shows this. It will be noted that in figure (a) a modulation percentage of only about 20% has been used. In the case of this low percentage modulation, the entire positive side of the envelope remains above cutoff. If a higher

percentage modulation is used, the bias increases and maintains the peaks of the envelope just below zero-bias. Remembering that this stage is now operating class "C", it is evident that this will happen. As the percentage modulation increases the peaks will drive further and further into the zero-bias region and will draw more and more current. It is true that the negative peaks are more negative and draw less current, but the non-linearity of the tube causes the average current to increase, and thus, the bias to increase.

4-3-3. Plate 7 figure (c) shows the case for 100% modulation. It will be noted that all but the peaks of the modulation envelope are lost. Although this clipping effect gives rise to certain difficulties in the transmission of echo pulses, it does offer considerable protection to the video filter. Consider the characteristics necessary in the video filter. Assume for the moment that a strong jamming signal, modulated heavily at say 500 kc is encountered. This 500 kc modulation will not be substantially reduced by the back-bias following the envelope. It will, however, be reduced by clipping. Consider the amplifier discussed in section 4-1. The maximum output of the last stage was 56 volts peak to peak, thus it is obvious that the peaks of the modulation envelope applied to the detector cannot rise above 28 volts (28 volts positive and 28 volts negative). Assuming a 70% efficient detector then the peak-to-peak voltage of the detected modulation envelope which is applied to the video will be 20 volts. Since the echo signal level will normally be run at say 2 volts it then is obvious that the filter need have a rejection ratio of only 30 db to reduce the modulation components 10 db below the echo.

4-3-4. Consider now the effect of changing the true dynamic range of the i-f system. Since the minimum linear output of the system is definitely set by the minimum linear output of the detector, it is necessary, in order to increase the dynamic range of the system, to increase the maximum detector output and hence the maximum output of the i-f amplifier. This can easily be done by using a more powerful tube in the last i-f stage. Consider a tube which will deliver 40 volts RMS instead of 20 volts. It is obvious that the true linear range has been increased 6 db. But at the same time the peak-to-peak detector output voltage has been increased from 20 to 40 volts, so the filter will need a 36 db rejection ratio (instead of 30 db) if it is to reduce the jamming modulation 10 db below a 2 volt echo.

4-3-5. The above discussion leads immediately to the conclusion that the use of back-bias limits the rejection ratio necessary in the video filter to a value approximately equal to the true dynamic range of the i-f system. This would indicate that a narrow true dynamic range should be used in the receiver. This is true from the standpoint of video filter design but not from the standpoint of pulse transmission. The next part of this paper will discuss the pulse transmission characteristics of the system with section 5-6 covering the characteristics with respect to the

true dynamic range of the system.

5. PULSE TRANSMISSION OF BACK-BIAS CIRCUITS

5-1. Beat Note Transmission

5-1-1. In section 4-1 it was pointed out that, in the jammed condition, the pulse energy appears on the envelope of the jamming as a beat between the jamming carrier and the echo signal carrier. This beat note arises from the heterodyne action of the jamming carrier and the echo carrier and its origin needs no particular discussion here. Suffice it to say that this beat note arises from exactly the same action as takes place in a converter tube. Its frequency is the difference frequency between the jamming and echo carriers and, when the jamming level is substantially greater than the echo level, its amplitude is a function of the echo level only.

5-1-2. Plate 8 shows the beat note present on the envelope for several conditions of jamming substantially greater in level than the echo. Figure (a) shows the zero-beat case (where jamming and echo frequencies are equal). It will be noted that the echo appears as an approximately square pulse of energy on the envelope. In actuality this square pulse is simply a small portion of a sine wave representing any extremely small difference between the two frequencies. Obviously, since this is the case, this approximately square pulse can be either positive or negative with any amplitude up to maximum or down to zero, depending on the instantaneous relative phase of the two r-f signals. Figure (b) shows the case where the difference frequency is $\frac{1}{2}/T$. In this case $\frac{1}{2}$ cycle of sine wave; in random phase is superposed on the pulse. In figure (c) the difference frequency is $1/T$ and 1 cycle, again in random phase, appears.

5-1-3. The above condition holds only for cases where the jamming is substantially stronger than the echo signal so that conversion is efficient. It is now necessary to consider the condition of a weak jamming signal. It is obvious that a very weak jamming signal will have little or no effect on the echo. Plate 9 figure (a) shows this. When, however, the jamming level is equal to the echo level there will be partial conversion and part of the echo energy will appear as a beat note and part of it will appear as a pulse. Plate 9, figure (b) shows this condition. As the jamming level increases above this the conversion becomes complete. This condition is shown in Plate 9, figure (c) as well as in Plate 8.

5-1-4. In line with the restriction of this report to discussions of a qualitative nature, quantitative values of the conversion efficiency will not be presented. Reference 12 contains a very good quantitative discussion of this phenomenon. One point that should be discussed here is the apparent disagreement between

Fig. 7 of reference 12 and plate 9 of this report in the case of a J/S ratio of 0 db. Reference 12 shows a signal rising to equal amplitude on either side of the base line whereas plate 9 shows a decidedly greater positive component. The difference is quite simple, the negative peaks in figure 7 in reference 12 are very sharp and consist of extremely high frequency components which in general will not be passed by the video. Thus the actual video will have these negative excursions rounded and considerably reduced in amplitude. Figure 9 (b) of reference 12 gives actual values for the conversion efficiency.

5-1-5. It should be pointed out here that both plate 8 and plate 9 describe the performance of a system using very long cathode time constants. The next section will discuss the effects of a short cathode time constant.

5-2. Loss in the Zero-Beat Area

5-2-1. Consider first the case of zero-beat jamming. As described in section 5-1, when the jamming is at or near zero-beat the echo pulse energy will appear as a square pulse on the envelope. This pulse may be either positive or negative or zero depending on the relative r-f phase of the jamming and the echo pulse signal. (When they are in phase it will be positive; when out of phase, negative and when in quadrature phase, zero.) In any case it will be a square pulse such as shown in Plate 10 figure (a). Now consider what will happen if such a signal is applied to a back-biased stage having a short cathode time constant. As explained earlier, when the input level to a back-biased stage is changed, the cathode bias changes in such a way as to give a much smaller change in the output level. Thus, if back-biasing is instantaneous, this pulse of echo signal energy will be almost entirely removed. In any practical set-up, however, back-biasing action is delayed by a condenser across the cathode circuit so that back-bias will be applied slowly, in accordance with a condenser charging characteristic. Thus when a pulse is applied to a back-biased system, the output will rise sharply to full output for that particular pulse height and then drop off slowly as the back-bias builds up across the cathode condenser. Plate 10 shows this action for three different time constants.

5-2-2. It will be noted that as back-bias builds up, the later part of the pulse is reduced in amplitude and pulse energy is lost. Thus, there is a loss in pulse gain, and an attendant loss in echo signal sensitivity. As would be expected, this loss, the zero-beat loss, becomes greater as the time constant is made shorter the action being simply a differentiation of the envelope. Figure (a) shows practically no differentiation for a long time constant, figure (b) shows some differentiation for a medium time constant and figure (c) shows extreme differentiation for a very short time constant. It will be noted that as the time constant is shortened, more back-bias is built up during

the pulse time and more of the pulse energy is lost.

5-2-3. Another factor which must be considered in connection with the zero-beat loss is the recovery time. It will be noted in Plate 10 that, since a bias is built up on the cathode condenser during the pulse, there will be a residual bias on the tube when the pulse ends. This bias will either increase or decrease the carrier momentarily giving rise to the recovery time (often called "sailboats"), again in a manner typical of a differentiating circuit.

5-2-4. Consider now what will happen if the jamming is moved off-frequency. As explained in section 5-1 and shown in Plate 8: as the difference frequency of jammer and echo increases, the top of the pulse shows more and more of a sine wave appearance until eventually it contains several cycles of sine wave. Again the action is simply that of a differentiating circuit. At low beat frequencies, the back-bias is able to partially follow the pulse envelope and a substantial portion of the pulse energy is lost. However, as the beat frequency, and hence the rate of change of the envelope, increases, the back-bias becomes less and less able to follow, and the loss in pulse energy becomes less and less. Finally a point is reached where the back-bias is completely unable to follow the beat note on the envelope and no pulse energy is lost through back-bias action. Gain and sensitivity at this point will then be normal. Also, since, in this condition, no back-bias will be built up, there will be no recovery time. Plate 11 shows this action.

5-2-5. From the above discussion it is apparent what the character of the zero-beat loss area will be. The greatest loss will be at zero-beat. As the jamming is moved off zero-beat, in either direction, the loss will decrease, first slowly and then more rapidly, along a curve which is in actuality the pass characteristic of one or more differentiating circuits in series. Furthermore, both the depth and the width of this loss area will increase as the cathode time constant is shortened. Plate 12 shows a set of curves taken from an actual receiver. It will be noted that there are also present on these curves extra side-lobes of loss. These will be discussed in section 6-5 since they are a secondary characteristic which can be eliminate.

5-3. Constancy of Pulse Gain Versus Jammer Frequency In the preceding sections the fundamentals of the operation of a back-bias system have been discussed in general terms referring several places to constancy of gain. The following two sections will discuss the fundamentals of the operation of such a system from the standpoint of obtaining constant gain. No data on the setting up or adjusting of such a system will be given here. That will be reserved for a later section.

5-3-1. As pointed out in section 2-3, constancy of pulse gain is absolutely essential in a receiver for a lobe switched system. The question which first arises is the question of where to compensate the amplifier to have constant gain; in other words at what relative jammer and radar frequencies. Should it be compensated for zero-beat jamming or for off-frequency jamming, and if for off-frequency jamming, how far off-frequency? A study of the curves of Plate 12 very quickly gives the answer.

5-3-2. Assume for the moment that it is compensated for zero-beat jamming.. This of course means a rising gain characteristic, since pulse energy is lost as zero-beat jamming is applied. (This rising gain characteristic can be obtained with the non-amplified back-bias system.) Consider now what will happen if jamming slightly off-frequency is encountered. From the curves of Plate 12 it is seen that the jammed sensitivity (and therefore gain) in the case of off-frequency jamming is higher than in the case of zero-beat jamming, but the jammed gain for zero-beat jamming has been adjusted to be equal to the unjammed gain so the amplifier must have a rising gain characteristic for off-frequency jamming. Thus, if the system is compensated for zero-beat jamming, it will be flat at only this one jammer frequency and it will be necessary to, at all times, have the radar transmitter accurately tuned to zero-beat with the jammer. (This would probably not be possible because of frequency modulation and drift of the jammer.)

5-3-3. It is immediately obvious that an extension of the above discussion can be used to show that if the amplifier is compensated to be flat for any one frequency in the zero-beat loss area, it will be flat only for that one frequency. At any frequency nearer to zero-beat it will have a drooping characteristic and at any frequency further from zero-beat it will have a rising characteristic. Such a system would be extremely difficult to operate because of the necessary precise adjustment of the relative jammer and radar transmitter frequencies.

5-3-4. Consider now the possibility of compensating the system to be flat immediately beyond the knee of the sensitivity (or gain) versus frequency characteristic curve where it enters the flat portion. By the above reasoning it can be shown that the receiver will be flat for all frequencies further from zero-beat (assuming the side-lobes of loss have been eliminated) and will have a drooping characteristic for all frequencies closer to zero-beat. Thus it will be possible to operate at this frequency or any frequency further from zero-beat. Furthermore, tuning will be quite simple. When jamming is encountered, it will only be necessary to rock the transmitter frequency (most modern radars are made tunable over a sufficient range to permit any tuning that will be necessary in the use of a receiver of this type) and if echo height changes the jammer is in the zero-beat loss area and the transmitter frequency should be moved in the direction of increasing echo height until the

echo stops increasing. The zero-beat area is thus moved over so that the jammer is now out on the flat portion of the curve and compensation is flat. If, however, the pulse height does not change as the transmitter is rocked, it will mean that the jammer is sufficiently far off-frequency to start with and the transmitter need not be retuned.

5-3-5. There are several factors which, though they are discussed elsewhere, should be mentioned here. The receiver bandwidth must be made sufficiently broad to allow for the transmitter tuning necessary. Also the side lobes present on the curves of Plate 12 must be eliminated. These side lobes will be discussed in section 7-1 of this report.

5-3-6. Before going on to the method of compensating the amplifier, it might be well to discuss one other point. From the above discussion it is evident that a radar system equipped with a receiver such as this cannot be operated through zero-beat jamming and the question immediately arises as to whether the inclusion of such an a-j receiver is of any value. The value will, of course, depend on the amount the transmitter must be moved off-frequency. As discussed earlier, the width of the zero-beat loss area can be varied simply by varying the cathode time constants. Experience has shown that a total width of this loss area of about 2.5 Mc is a good compromise. This will allow the radar to operate 1.25 Mc from the jammer. Experience has shown that in most cases a jammed radar can be moved this much in frequency without its movement being spotted by the operator of the jammer. Thus, he will not know that his jamming was effective, nor will he know that the radar has been moved to a point where it is no longer effective and that he must move his jammer. If no a-j receiver were included it would be necessary to move the system 4 or 5 Mc (involving retuning the receiver as well as the transmitter). This movement would be spotted immediately by the enemy.

5-4. Constancy of Pulse Gain Versus Jamming Level

5-4-1. The major portion of the discussion so far has been confined to the action of the back-bias circuits in the jammed condition with relatively little said about the unjammed condition. The problem now is to examine the gain throughout the entire range of jamming levels from zero to the maximum that the stage will handle.

5-4-2. Consider first, again, the jammed condition. Assume again that the stage must be able to handle 14 volts peak to peak of jamming. As pointed out earlier, in the jammed condition, the positive side of the envelope should be in the near zero-bias region of the tubes characteristic so that the beat note on the positive side of the envelope will be greatly amplified. If this is to be true, the bias will have to be about 8 volts. Assume now that the voltage applied to the grid is zero. The average

cathode current of the tube will be about 6 ma. so a cathode resistor of about 1200 ohms will be needed. Under these conditions the tube will have a peak plate current of about 36 ma and a G_m (o) of about 16,000 at the peaks of the jamming carrier where the echo energy is concentrated and an echo signal gain (see section 4-1) of 6.

5-4-3. Consider now what happens when jamming is removed. The plate current will drop down to about 3 ma with a bias of about 4 volts. This will give a G_m of about 3000. Now since:

$$\text{Gain} = G_m R_L = 3000 \times 10^{-6} \times 1500 = 4.5$$

the gain will be down to 4.5 in the unjammed condition. What happens between these two points will not be discussed here except to say that it rises and then drops again giving a curve such as Plate 13, curve (a).

5-4-4. Suppose now that a bias of about 5 volts positive is applied to the grid. A cathode voltage of about 13 volts will now be required in the jammed condition and an average current of about 6 ma will require a cathode resistor of about 2200 ohms to give a 36 ma peak plate current and a peak g_m of 16,000. With this value cathode resistor the unjammed plate current will drop to about 4 ma, (cathode drop will be about 8.8 volts for an actual bias of 3.5 volts) thus g_m will be about 4000 and gain will be equal to the jammed gain. Curve (b) of Plate 13 shows this.

5-4-5. Going to a still higher grid bias and cathode resistor will give a still higher initial gain and give a drooping gain characteristic as is shown by curve (c) of Plate 13.

5-4-6. It should be pointed out before going further that the figures given above are not exact figures. They simply are used as an illustration because they represent approximately what a 6AG7 will do in a non-amplified back-biased amplifier.

5-4-7. Consider now what will happen when we cascade 7 such stages and the 6AG7 discussed in section 4-1, all set up for equal jammed and unjammed gains. As the jamming level rises it will first start to bias back the last i-f stage since the jamming level is strongest at its grid. As this stage biases back its gain will first rise and then fall. However, by the time it begins to fall, the next to the last stage will have started to bias back and will have a rising gain characteristic to compensate for the drooping of the last stage. The same thing will hold for every other stage and the stage ahead of it; that is, as its gain is decreasing the stage ahead of it will be increasing. Thus the overall characteristic will first rise slightly, then remain flat until the jam level has reached a strength sufficient to complete the biasing back of the first stage. Gain will then drop off.

5-4-8. Suppose now that the last stage is readjusted to have a characteristic such as that shown by curve (c) of Plate 13. This stage will then have no initial rise and the initial rise of the overall gain characteristic will be eliminated thus making the characteristic essentially flat for all jam levels up to the point where the first stage begins to overload. Plate 14 shows the gain curves for all stages and the composite curve showing overall gain.

5-4-9. Up to this point the discussion has presupposed an adjustable bias applied to the grid. This requires extra parts and its elimination would be well worth while. It has been found in all amplifiers tested at this laboratory that this bias can be eliminated. Suppose that a somewhat smaller resistor is put in the cathode circuit than was calculated earlier. It is immediately clear that this will increase the unjammed gain. At the same time, it will reduce the back-bias developed and make the echo peaks drive very slightly into the grid current region. This will, of course, mean that, in the jammed condition, some of the signal energy will be dissipated in grid current and gain will be reduced. Thus it is possible to equalize the jammed and the unjammed gain for the stage without using a bias on the grid. It should be mentioned that this method of equalizing the gains reduces the obtainable stage gain. The reduction in gain, however, amounts to only one or two db and is thus not sufficient to nullify the advantages obtained in eliminating the bias.

5-5. The Gain Control

5-5-1. Thus far, nothing has been said about the method of controlling the gain of a back-biased i-f stage. Unfortunately, it is not possible to apply a gain control to such a stage without destroying the constancy of gain. Control of screen voltage cannot be used because it limits dynamic range. A variable cathode resistor cannot, of course, be used because the cathode resistors must be adjusted to the correct value as outlined above. Again as explained above, the application of a bias to the grid affects unjammed gain much more than jammed gain, so that if this method is used the amplifier can be made to have a flat characteristic for only one gain control setting. Another possibility which has to be considered is the use of an attenuator. If, however, an attenuator is used between back-biased stages, it will reduce the maximum level applied to the stage immediately following it and this stage will then operate, in the fully jammed condition, at an intermediate point on its gain curve, where its gain is higher than in the unjammed condition. Thus, the constancy of gain will be destroyed. If, on the other hand, the attenuator is put ahead of the first back-biased stage, the high gain following it may make it affect signal-to-noise ratio.

5-5-2. From the above discussion it is obvious that the gain control will have to be some sort of compromise. Fortunately the application of negative grid bias to the grids of the first two back-biased stages, and simultaneously to one pre-i-f stage is quite satisfactory if the amplifier is set up to have a flat gain versus jam level characteristic when the gain control is set at maximum gain. Consider what will happen as gain is reduced. As pointed out above, the gain control bias will affect the unjammed gain more than the jammed gain. But, the two stages affected are the first two, and since the gain ahead of them, as well as in them, is being reduced, the jamming level applied to them is reduced enough that they will not bias back. Thus, although the amplifier's constancy of gain is partially destroyed, it can, by correctly setting up the gain control, be made to have constant gain for any jam level up to 100 mv applied to the receiver's antenna input terminals.

5-5-3. In order that the second stage of the amplifier does not bias back, it is necessary to limit the i-f voltage applied to its grid to about 1 volt. Since there will normally be about 50 db gain ahead of this stage, it will be necessary to reduce the gain of the pre-i.f. and first stage about 30 db before applying gain control to this second stage if it is to be safe up to 100 mv at the antenna terminals. Similarly, the gain of the pre-i.f. must be reduced about 15 db before gain control voltage is applied to the first stage. Thus, if the gain control voltage to the first back-biased stage is delayed until the pre-i-f gain has been reduced 15 db, and gain control voltage to the second is delayed until the gain of the pre-i.f. and first stage has been reduced 30 db, the amplifier may be made to have constant pulse gain regardless of any jam level up to 100 mv at the antenna terminals and regardless of gain control setting.

5-6. Dynamic Characteristics Section 4-3 discussed the true dynamic range of the amplifier as it affects performance against jamming. This section will discuss the effects of the true dynamic range on the echo pulse transmission characteristics of the system.

5-6-1. As pointed out in section 4-3, when jamming, modulated heavily at a high frequency, is applied to a back-biased i-f amplifier, the back-bias will set the bias to a value such that the positive peaks of the modulation envelope will drive just about to zero bias. The negative peaks of the modulation envelope will then drive below cutoff and will be clipped. If then an echo is riding on the upper portion of the modulation envelope it will come through the system while if it falls in a trough in the envelope it will be lost (see Plate 15). Since there is ordinarily no relation between the phase of the jamming modulation and the time the echo returns, the echo will assume positions at random on the envelope of the modulation when any number of pulses are considered. Then, averaging over this number of pulses, some will fall on or near peaks of the envelope and will be passed and some will fall in the troughs of the envelope and will be lost.

5-6-2. Consider now what will happen if some of these echoes are lost. First, it is obvious that a loss in minimum visible signal will result since each pulse lost represents a loss in signal energy. The second effect encountered will be an effective reduction in pulse repetition frequency. If, for example, the true dynamic range is such that one-half of the modulation envelope is clipped off, one-half of the echoes will be lost and the effective repetition rate will be one-half the actual repetition rate. This effect can be serious in a fire control system (such as the Mark 12) where the actual repetition rate is low (480). In this case, there is originally only a very small number of pulses per lobe (4 in the Mark 12) and the loss of many of these can lead to serious errors. Furthermore, the fact that there are only a small number of pulses per lobe, and there are very few repetitions of a given lobe during the persistence period of the eye (2 in the Mark 12) means that the total number of pulses in a given lobe that will be seen by the operator at a given time (thus those on the screen plus those seen due to persistence of vision -- 8 in the Mark 12) will be so small as to not give a good statistical average. In this case the echo will flicker badly and will cause operator confusion and loss in reset accuracy. It should be pointed out that this loss is in reset accuracy only and is not a positive or negative error introduced.

5-6-3. From the above discussion it is apparent that not only should the true dynamic range be kept wide but that the repetition rate should be made high. The maximum system repetition rate is of course a function of the maximum range desired and cannot be increased at will. In any event, it should be made as high as possible.

5-6-4. The maximum true dynamic range which can be used is of course dependent on the maximum modulation percentage likely to be encountered. The tendency at present in modulated jammers is to use as high a percentage modulation as is possible; even overmodulation in many cases. Since the dynamic range of such a signal is from zero to its maximum level, and thus the receiver will have to handle signals from its own equivalent noise level to the maximum the jammer delivers at the receiver's antenna, it is obvious that the greatest true dynamic range that can be had will be the best from this standpoint.

5-6-5. The question now arises as to how to secure the desired wide dynamic range. In any system the minimum point of the linear range will be set by the minimum linear output of the detector. Thus it is the maximum output which must be changed to get the desired range. This maximum is determined by the capabilities of the last i-f stage. In general it will be found that it will be the actual value of the grid bias on this last stage that will determine the dynamic range of the stage; not the plate dissipation.

5-6-6. Assume that the minimum level for linear detection is .2 volts and that a dynamic range of 45 db is wanted. This will mean a maximum detector output of about 40 volts. If the

detector load resistance is 2000 ohms a current of 20 ma will be necessary. If then the detector coupling transformer is a unity gain transformer and the detector is 70% efficient, the last i-f stage will have to deliver 60 volts zero to peak or 120 volts peak to peak at 20 ma. As far as the plate circuit is concerned a 6AG7 is capable of delivering considerably more power output. However, consider the grid circuit. The stage gain will be about 24 db. This will mean that, to deliver a linear voltage swing in the plate circuit of 120 volts, the grid will have to swing 8 volts. The tube will, however, cut off at about 8 volts negative, so, although the plate circuit could deliver considerably more, the dynamic range will be limited to about 45 db.

5-6-7. It must be understood that the above discussion holds only for a back-biased amplifier. In an ordinary amplifier, where the cathode resistor is low, and the tube will not bias back, the grid may, if the grid circuit resistance is low, be driven positive for a more complete utilization of the power output capabilities of the tube. In fact, amplifiers have been constructed for use in Navy equipment in which the last three stages use type 6AG7 tubes purposely so that the grids may be run positive with a resultant wide dynamic range.

5-6-8. Another interesting possibility in securing wide dynamic range is the use of transmitting type tubes in the last i-f stage. An amplifier has been built at this laboratory in which the early stages are ordinary back-biased amplifiers with the last two stages being Class AB amplifiers designed to take the maximum level to which they will be subjected, without overload so that no back-bias is needed. One such system employed six stages of back-biased 6AK5 followed by a 6AG7 operated at about 8 volts bias. The output of the 6AK5's was a maximum of 15 volts peak-to-peak so the 6AG7 could not be overloaded. The 6AG7 then drove an 832-A operated in Class B with 30 volts bias. Since the 6AG7 had a gain of about 4, the maximum level that could be applied to the 832-A was about 60 volts peak-to-peak, so this stage could not be overloaded. The output of the 832-A was rectified by a standard diode. This amplifier had a true dynamic range of about 60 db, and at the same time the back-bias action made it able to cope with jamming levels up to about 5 volts RMS at the input to the first i-f stage (equivalent to well above 100 mv at the antenna terminals).

5-6-9. Unfortunately, an amplifier, such as described above, cannot be made use of at the present time. As explained in section 2-5, the dynamic range must be a compromise between what is desired for pulse transmission, and what can be used without requiring that the a-j video do the impossible. This being the case, probably the best compromise is the 6AG7 set up to give a true dynamic range of about 45 db.

6. THE DETECTOR

Very little need be said about the detector for the a-j receiver that has not already been said many times in other papers on the subject. It is simply a good linear diode with a low minimum linear level and capable of handling the maximum output of the last i-f stage. For the sake of completeness, however, the following sections will discuss several phases of detector design.

6-1. The Minimum Linear Output

6-1-1. As pointed out earlier, the minimum end of the true dynamic range of the receiver is set by the minimum linear output of the detector. Thus, in order to get the necessary dynamic range without excessively high power output from the last i-f stage, a detector tube which is linear to a very low level should be chosen. The 6AL5 is probably the best tube available. It is linear some 10 or 12 db lower than other diodes and at the same time it has short leads and low capacities which make it very good for high frequency systems.

6-2. The Maximum Linear Output

6-2-1. Also of importance in the design of the detector is the maximum output level. It must, of course, be considered from the standpoint of detector peak current and plate dissipation rating. Again, as pointed out earlier, the maximum detector output is determined by the desired true dynamic range and once it has been set, the maximum output will have been set. It will then be necessary to make certain that this maximum output will not overload the detector.

6-3. Choice of Operating Echo Level

6-3-1. The last characteristic of the detector that must be considered is the normal operating echo level. This level must be well up into the linear range of detection so that as the echoes rise and fall in pip matching, there is no danger of dropping down into a non-linear region. At the same time, it must be enough below the maximum limit of linearity to eliminate any possibility of limiting.

6-3-2. In setting up the normal operating levels in a system with a 45 db true dynamic range it has been found satisfactory to set the normal noise level (for high gain) at about 10 db above the minimum linear level and to set the normal echo level (for a .7 saturation pip on the scope) at about 20 db above the minimum linear level. Using a 6AL5 detector this would give approximately the following levels. The minimum linear level would be about .2 volts; the noise level (at high gain) would be about .6 volt, the normal echo level would be about 2 volts and the maximum output would be about 40 volts. (Note that this does not mean that the indicator would have to handle echoes of 40 volt level. It is

only jamming components, which are to be removed by the filters and on top of which the echo rides, that drive to this amplitude.)

6-4. The J/S Detector

6-4-1. In certain types of a-j receivers it is necessary to use what is known as an echo by-pass. This echo by-pass is part of the a-j video system and will be described later. For the moment, it is sufficient to say that, this video by-pass requires, for its proper operation, a voltage which is proportional to the J/S ratio of the signal being studied. It is the purpose of the J/S detector to supply this voltage.

6-4-2. The J/S detector is simply a half wave diode connected to the same transformer as the normal video detector. It may be connected either to the same point on the coil or tapped higher up as shown in plate 20. Its output is fed through a filter which serves to remove video frequency components above about 5 Kc and then to the video by-pass circuit where it is used.

6-4-3. Consider now the operation of this circuit. It will rectify all the i-f output and give an output, essentially d-c in character, which is proportional to the i-f energy integrated over about 200 micro-sec. consider now what this i-f energy is. Is it pulse energy or is it jamming energy? Remembering that jamming is on continuously, or at least, almost continuously, and that even a relatively long block of echoes will have a duration of only 20 to 40 micro-seconds, it is evident that the major portion of the energy received during the 200 micro-second integration interval was jamming energy, and thus the voltage developed is a measure of the approximate average jam level. However, in a fire control radar, when an echo is being pip-matched on, it will be in the notch and gain will be set so that it will give a deflection of .6 or .7 saturation. This is true of any echo being studied, and, since the video gain has been set to give a normal detected echo level of 2 volts for a pip height of .7 saturation, we can therefore say that the level of any echo being studied will be 2 volts at the detector. Thus since S is constant, the simple measure of J given by the J/S detector is in actuality a measure of J/S.

6-4-4. Accuracy of Measurement of J/S It is obvious from the above discussion that the measure of J/S given by the J/S detector will not be accurate. It depends on too many variables for that. First, the operator may set the pip height anywhere from about .5 to .9 saturation. This allows an error of 2 to 3 db in either direction. Second, video gain may change even though all precautions have been taken to keep it constant and third, an echo block will make a measurable difference in the d-c output of the J/S detector even though its duty cycle is very short.

Because of these factors, the accuracy of measurement by the J/S detector probably will not be better than 3 or 4 db but fortunately, 3 or 4 db accuracy is sufficient for the echo by-pass where this d-c voltage is needed (see section 9-2).

7. THE A-J VIDEO-GENERAL

7-1. Bandwidth

7-1-1. Ordinarily the bandwidth of the video system of a receiver is made equal to, or slightly greater than, one-half the i-f bandwidth at the 3 db down points. Such a bandwidth is not sufficient in an a-j receiver. Consider what will happen if such is the case. Assume a receiver with an i-f bandwidth of 2 Mc and a video, flat to 1.5 mc and then dropping off to zero at 2.5 Mc. Conditions such as these are not unusual in an ordinary receiver.

7-1-2. Assume now that a jamming signal about 2.5 Mc off frequency and strong enough to give a J/S ratio at the antenna of 60 db is encountered. The shape of the i-f pass of the receiver has not been specified, but it is likely that it will be down only 40 or 50 db at the frequency of the jamming signal. Thus the jamming signal will arrive at the detector at a J/S of between 10 and 20 db. This jamming level is sufficient to give good conversion of the echo energy to a beat note. But this beat note will be a 2.5 Mc beat note and since the video will not pass 2.5 Mc. the echo will be lost. This loss of the echo out beyond the normal i-f pass band is called a side lobe loss, the term being borrowed from antenna terminology. Plate 12 shows such side lobes of loss displaced about 2.5 Mc on either side of the zero-beat loss area.

7-1-3. In a receiver for use with a fire-control radar these side lobes must be eliminated. From an extension of the above discussion, it is clear that that can be done simply by a correct adjustment of i-f and video pass characteristics. The video bandwidth must be equal to $1/2$ the i-f bandwidth at some point much further down than the 3 db point ordinarily used as the point at which bandwidth is measured. Suppose that it is necessary to protect the receiver against a J/S ratio of 80 db. If this 80 db signal is to be reduced to the point where it will not convert echo energy to a beat note it, will have to be reduced to where its J/S at the detector is -10 db or lower. Thus it will have to be reduced about 90 db if no loss is to be taken. Obviously then, the video bandwidth must be equal to one-half the i-f bandwidth at the 90 db down points to protect the receiver to a J/S ratio of 80 db.

7-1-4. In actual design work it is more convenient and better to use a slightly different rule. Only a very slight loss will be taken if the "db-down" point used is equal to (instead of 10 db greater than) the J/S ratio for which the receiver is to be protected. Furthermore, some mistuning must be allowed for. Thus the rule actually used for computing video bandwidth is to make the video bandwidth equal to .7 or .8 the i-f bandwidth measured

as far down in db as the J/S ratio, again in db, to which the receiver is to be protected.

7-1-5. From the above discussion it is apparent that the shape of the skirts of the i-f pass characteristic is extremely important in an a-j receiver. Although the bandwidth of the i-f at the 60 or 80 db down points will have almost no effect on pulse shape, it has a very pronounced effect on the required video bandwidth. Thus the skirts of the i-f pass should be made to drop off steeply outside the useful pass band. In general it will be found that the best i-f characteristic will result if double tuned circuits are used with slightly less than critical coupling. Less than critical coupling should be used so that tuning is simply a matter of peaking all circuits and can be done without special equipment. For the same reason traps should not be used to reduce the skirts. They would very soon, from one cause or another, become mis-aligned and do more harm than good. Also, the practice of using an i-f amplifier composed of several stages unnecessarily broad with only one or two stages narrowed to determine the bandwidth is very costly in video bandwidth.

7-1-6. The question now arises as to how far through the video amplifier the bandwidth must be maintained this wide. Since this beat note pulse is, in actuality, simply a second i-f, it may be rectified to give a square pulse requiring a bandwidth of only $1/T$. In a fire control system this rectifier, commonly called the echo rectifier, will generally be a good full wave rectifier following the video filter or filters. In a search receiver, where requirements are not so strict, it is common practice to simply operate the first video stage at zero-bias and allow the diode action of the zero-bias grid and the cathode to do the rectifying.

7-2. Desired Protection

7-2-1. As pointed out in the introduction there are certain types of jamming which, while they can be worked through, require equipment so complex and difficult to operate that it is not practical for fleet use. All the work done at this laboratory has been based on the idea of developing a receiver which is simple to operate and does not attempt to work through such jamming. This attitude seems to be a well justified one in the light of experience in the recent war.

7-2-2. Getting more to the point, it is obvious that any system must protect against c-w and low modulation frequencies, including modulation at lobing rate or repetition rate. In general, the back-bias system will remove all such modulation for all levels except those immediately around a J/S ratio of 0 db. The remaining base-line bounce can then be removed by means of the video filter.

7-2-3. It would also be desirable to protect the video against fairly high modulation frequencies. Probably the best

protection that can be obtained in a simple receiver will be up to between .5 and 1.0 Mc.

7-2-4. It is also desirable to protect the receiver against barrage jamming. The most common type of barrage jamming is the spaced jammer type in which a number of jammers are operated at frequencies from 2 to 5 Mc apart.

7-2-5. Although it will not in general be possible to eliminate noise jamming, the receiver should be designed to provide as much protection as is possible against noise without undue complexity. (A considerable amount of protection can be provided by a receiver of straight-forward design. The amount of this protection is shown graphically by the curves of references 3 and 5.)

7-3. Normal Video. While on the subject of the general requirements of the video system, it might be well to mention the normal video system.

7-3-1. Any a-j receiver should, of course, operate satisfactorily with no jamming present. The unjammed condition is simply one end of the range of jam levels which must be contended with. It is, however, best to put in a supplementary channel to use in normal operation when no jamming is encountered. The a-j channel will be cluttered up with filters, F T C's, echo rectifier and other such things which, while they are necessary to dejamming action, make it harder to get a "clean" presentation in normal operation and thus may reduce range resolution.

7-3-2. This normal video channel should be switchable from the range operators position by means of a single switch. One method found convenient at this laboratory for switching such a channel is by permanently connecting both normal and a-j channels to the detector output, and then after the signal has passed through each channel it is mixed again in the plate circuits of two pentode tubes. Either channel may then be inactivated by removing the plate and screen voltages from its tubes. Another possible method of switching from one channel to the other, is of course to use a relay switching the video signal itself. In any case, strict attention must be paid to the capacity added to the video circuits by the switching means. It must not be sufficiently high to adversely affect the video bandwidth.

8. VIDEO FILTERS

This part will discuss the various filters commonly used in a-j receivers, from the standpoint of protection afforded, and general theory of application.

8-1. The Fast Time Constant

8-1-1. Probably the most common video filter used in a-j receivers today is the FTC. It is, without question, the

simplest a-j measure which can be incorporated in a receiver and, while it is more effective when used with a back-biased i-f, it is still of considerable value in a receiver with no other protection.

8-1-2. The FTC should always be an LR circuit (rather than an RC circuit) and should be used with dc restoration. Unfortunately papers have been published stating that an FTC introduces a loss of the order of 1 db to an unjammed echo. Actually losses as high as 3 or 4 db has been measured using an RC fast time constant; however, if an LR circuit is used there will be no loss in unjammed sensitivity and there will be an improvement in filtering action against jamming. More information on the use of the FTC is given in reference (11).

8-1-3. The protection offered by the FTC is most striking against the lower modulation frequencies, of the order of 10% of the receiver bandwidth and less. It gives this protection without introducing any loss in unjammed performance and without necessitating off-frequency operation of the jammer. The FTC is in reality a high pass filter of very low Q. The next section will discuss what is commonly called a high pass filter and will compare the two for use in an a-j receiver.

8-2. The High Pass Filter

8-2-1. The high pass filter is probably the most useful filter for the fire control a-j receivers and although it is not generally used by this laboratory in general service search equipment, it has been used by other laboratories in search gear. In general it consists of two or three sections, either M-derived or lattice structure. When it is used in search equipment where zero-beat operation is expected it must be made low Q to avoid sailboats, but when used in fire control equipment, where the jamming will always be off-frequency it may be made high Q.

8-2-2. Basically, there are two ways in which a high pass filter may be operated. One of these (rather infrequently used) is to operate it in the same manner as the FTC. In this use, filter cut-off is set below 1/T and the normal pulse will pass through with very little loss. In this case, the filter must be made low Q to avoid sailboats, and its action is little more than that of a very good FTC. It is in this manner that it is used in search equipment.

8-2-3. The other method of using the high pass filter consists essentially of using the video system as a second i-f. In this case the filter cut-off is set at a frequency between .5 and 2.0 Mcs and the radar operated off the jammer frequency so that the beat-note pulse will pass through the filter as a second i-f. The necessity of operating off-frequency does not work any extra hardships on the system since, as explained earlier, the jamming must be off-frequency for the i-f to function properly. This method of

operation is probably more common than the other. In it, the high pass filter will have high Q and sharp cut-off and will give satisfactory protection against jamming modulation frequencies up almost to its cut-off frequency. Protection will not be complete since the limited dynamic range of the i-f system will clip the modulation envelope and there-by introduce harmonics. These harmonics will, however, appear as sharp spikes on the indicator and will not interfere seriously with pulse readability.

8-2-4. The high pass filter will also give some protection against noise jamming. Although a very wide spectrum is advertised for many noise jammers, most of the energy is concentrated in the lower frequencies and will be removed. Furthermore, the jamming energy which does pass will be of very fine structure and the relatively broad pulse (the pulse is not narrowed by the filter since it is actually a second i-f which passes through the filter, and this second i-f is later rectified to give the pulse) will be easily seen in the fine noise structure.

8-3. The Band Pass Filter

8-3-1. The band pass filter is of use primarily against barrage jamming using the spaced jammer techniques. Operation of the band pass filter is the same as the second method of operating the high pass filter, thus using the high filter cut-off frequency and the off-frequency operation. The band pass filter then operates in exactly the same manner as the high pass filter except that frequencies above the high cut-off limit of the filters are rejected.

8-3-2. The rejection of these high frequencies is useful in removing the inter-jammer beat-note when spaced jammer barrage jamming is used. Suppose that two jammers, set 3 Mc apart, are encountered. They will give a 3 Mc beat note in the receiver. This beat-note would of course pass through the high pass filter, but, if a band-pass filter, passing from, for example, 1.0 to 2.0 Mc. is used, the 3.0 Mc beat note will be rejected. Thus the band-pass filter offers the same protection against low frequency modulation as the high pass filter with the addition of protection against spaced jammer barrage jamming. This added protection, is not, however, bought without cost. The use of the band pass filter limits the usable off-frequency spacing to the pass band of the filter. Such limitation is highly undesirable and when only one filter can be included, the high pass filter should be used.

8-3-3. The band pass filter has one other characteristic which makes it less desirable than the high pass filter. It's ringing characteristics are much worse, and if the same pulse fidelity is to be had, its Q, and thus the protection it affords, must be made considerably less.

8-4. The Q of the Filters Although the Q has been mentioned briefly above, it should be discussed in a little more detail.

8-4-1. In general it will be found that, in a system designed for operation at zero-beat, the Q of the filters must be made very low if ringing, with its highly objectionable sailboats, is to be avoided. Methods of ringing cancellation (covered in some detail in reference 10 and to be discussed briefly in the next section of this paper) have been developed and used in a-j receiver video filters but have not proven too successful. Attempts also have been made to damp out this ringing by means of diode loads, but these diodes simply terminate the filter with a non-linear impedance and destroy its filtering action. To be safe, therefore, the filters must be designed using very low Q's. This, of course, restricts the amount of protection afforded.

8-4-2. In the case of systems designed for off-frequency operation, the Q that can be used is almost unlimited. Any Q that can be built into a practical filter can be used without serious ringing or recovery time. Filters have been built in the laboratory and tested using Q's of the order of 300 and have proven entirely satisfactory. Using such Q's, a filter can easily be built with a cut-off frequency of 1 Mc and giving complete protection below about 800 kc. This filter can then be operated with beat note pulses of 1.5 Mc with almost no pulse distortion.

8-5. Ringing Cancellation

8-5-1. Several systems of ringing cancellation have been developed and tested at this laboratory for use in video filters for a-j receivers. The simplest, and perhaps most useful of these is simply a design formula for setting the cut-off frequency of the filter. Suppose that a square pulse is applied to a high pass filter whose cut-off frequency is $1/T$. The ringing frequency or frequencies of this filter will be approximately equal to the cut-off frequency. Now consider the leading edge of the pulse. It will shock the filter into oscillation at its ringing frequency. This oscillation would ordinarily persist for some time; however, consider the action of the trailing edge of the pulse. It is simply a step similar to the leading edge but of opposite polarity. Now since the ringing frequency is approximately $1/T$, the oscillation from the leading edge will have completed one cycle when the oscillation from the trailing edge will start. But this oscillation from the trailing edge is in opposite phase, so it will simply cancel out the oscillation from the leading edge. The action is shown graphically in plate 16.

8-5-2. From the above discussion it is immediately apparent that the ringing cancellation will be quite critical of pulse length. This, unfortunately, limits its usefulness considerably in the field of radar.

8-5-3. Several other systems for cancelling ringing have been developed and are described in reference 10. These systems in general use delay lines or other filter sections in a cancellation scheme and, like the above described system, are too sensitive to pulse length to find extensive use in radar.

8-6. Loss at Low J/S Ratios

8-6-1. It has been pointed out earlier that both the high-pass filter and the band-pass filter operate the video system as a second i-f amplifier and do not pass pulse frequency components. Suppose now, that off-target jamming is encountered on a bearing such that the filter is necessary on one lobe but that the J/S ratio is low, say 5 db, on the other lobe. From the discussion, given earlier, of the conversion of pulse energy to a beat note it is evident that only part of the pulse energy in this second lobe will be converted to a beat note. Since however, the filter will pass only the beat note, the unconverted part of the pulse energy will be lost. This, of course, means a lowering of the effective gain of the system and a consequent introduction of a bearing error.

8-6-2. The above described loss of pulse energy and attendant lowering of effective gain is an inherent characteristic of this method of operating the filter and cannot be corrected in the filter channel. Its effect can, however, be eliminated by the use of an echo by-pass channel. The next part of this paper will discuss this echo by-pass channel.

9. THE ECHO BY-PASS

9-1. The Compensating Characteristic

9-1-1. As pointed out in the last section, at low J/S ratios the conversion of the echo energy to beat note energy is inefficient, and since the filter passes only the beat note, energy is lost and effective gain is reduced. Consider for the moment the characteristic of this loss. Section 5-1 discussed the conversion of the pulse to a beat note. At J/S ratios below minus 10 db, there is almost no conversion, the conversion efficiency then rises to about 50% at 0 db and continues on up to almost complete conversion at 12 db J/S ratio. Plate 17 figure (a) shows this conversion efficiency graphically. The efficiency of conversion is, however, just a measure of the per cent of the signal converted to a beat note. Then, since the filter passes all the beat note energy, and almost none of the pulse energy, this same characteristic will describe the performance of the filter as a function of J/S ratio,

9-1-2. The question now arises as to what characteristic must be introduced into the system to compensate for this filter characteristic. The obvious answer is to by-pass some of the echo around the filter, the amount by-passed being equal to the

difference between the curve of plate 17 figure (a) and a constant gain curve. Plate 17 figure (b) shows then the filter characteristic and the necessary compensating characteristic.

9-1-3. The question now arises as to how to obtain such a characteristic. The obvious answer is simply to put an amplifier in parallel with the filter (with delay compensation means) and vary the gain in accordance with the desired characteristic. Such a system will be discussed in the next section.

9-2. The Sloping Cut-Off Echo By-Pass

9-2-1. The sloping cut-off echo by-pass consists of five main parts. The first of these is the by-pass control tube. This tube is a high Gm pentode amplifier, made highly degenerative to stabilize its normal gain. The video signal is applied to its grid and taken off its plate. It is this tube whose gain is varied to control the amount of echo by-passed. The second main part is the by-pass cut-off tube. It is this tube which, acting as a d-c amplifier, feeds bias to the grid of the control tube and actually controls its gain. The control signal for the cut-off tube comes from the third main part. This third main part is the J/S detector in combination with a delay bias which prevents any action by the cut-off tube until a J/S ratio of -5 db is reached. The fourth main part is simply a delay line whose only purpose is to delay the by-passed signal by an amount equal to the amount the filter delays the signal passing through it, so that the signals will arrive at the point where they are recombined simultaneously.

9-2-2. The fifth main part of the by-pass channel is very important and deserves some discussion. It is a fast time constant video coupling with d-c reinsertion. When J/S ratio is low, say 5 db, the echo by-pass channel will, of course, be passing signal. But, not only will it be passing signal, it will be passing jamming components as well since it passes frequencies in the stop-band of the filter. The FTC is put in to give as much protection as is possible against the passage of these jamming components. It has been found in practice, that this FTC, together with the reduction in gain of the control tube, will give sufficient protection at all J/S ratios.

9-2-3. There is one other point which must be discussed in connection with this type of echo by-pass. That is the question of the correct matching of the two curves. It will be clear from the above discussion that the matching of the two curves depends directly on the accuracy of the output of the J/S detector. As pointed out earlier, the output cannot be relied on to better than 3 or 4 db. Plate 19 figure (a) shows the characteristics with the by-pass curve shifted as it would be by such an error. It will be noted that this introduces an error in the constancy of gain of about 15%. Such an error would introduce a rather serious bearing error, but fortunately, would be encountered only extremely rarely since it requires a coincidence of the worst jammer bearing with a

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particular jamming level.

9-3. The Filter Type Echo By-Pass

9-3-1. In an effort to get around the possible error in the constancy of gain curve resulting from the inaccuracy of the J/S detector when sloping cut-off by-pass is used, the filter type by-pass was developed. In structure the filter type by-pass differs very little from the sloping cut-off by-pass. The method of operation is, however, quite different.

9-3-2. The only structural difference in the filter type by-pass is that the equalizing delay is replaced by a low pass filter whose cut-off is approximately equal to the cut-off of the filter in the filter channel, and the delay applied to the cut-off tube is increased to delay cut-off till a J/S ratio of more than 15 db is reached.

9-3-3. Operation of the filter type by-pass is as follows. At low J/S ratios the filter channel and the by-pass channel act simply as a single wide band channel, the low frequencies, below the common cut-off, going through the filter channel. Thus, at J/S ratios up to 15 db all the pulse energy is passed by one channel or the other. Above this 15 db J/S ratio, the by-pass channel is cut-off as quickly as possible. But, as pointed out earlier, by this time all the pulse energy is in beat note form and thus, it is passing through the filter channel and the by-pass is not needed.

9-3-4. Although the filter type by-pass does not suffer from loss of accuracy in the way the sloping cut-off by-pass does, it does have one bad feature. As pointed out earlier, the sloping cut-off by-pass begins to cut-off at a J/S ratio of about -5 db and cut-off is complete by the time J/S has reached about 12 db. On the other hand the filter type by-pass does not start to cut-off until J/S is up to about 15 db, or if all error from inaccuracy of the J/S detector is to be eliminated, even later. Thus the problem of protecting the by-pass channel is much more difficult. Indeed complete protection cannot be achieved. The loss in protection is shown in Plate 19 figure (b).

9-4. Comparison of the Two By-Pass Systems

9-4-1. The difficulties encountered in both by-pass systems have been described above and are shown graphically in plate 19. As yet no definite decision has been made as to which system is preferable. Probably, if the error in the J/S detector can be limited to plus or minus 3 db, the sloping cut-off type by-pass will be best. If, however, this accuracy cannot be maintained, the filter type by-pass will probably be best even though protection must be sacrificed.

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9-5. Equalizing of Gains

9-5-1. Up to the present time nothing has been said about what is in the filter channel. That is the subject of the next part of this paper. It should, however, be pointed out here that the gains of the by-pass and filter channels must be made absolutely equal. If they are not, the constancy of gain of the system will not be maintained.

9-5-2. The methods of maintaining gain constant and equal will be discussed in the next part in connection with the filter channel and will not be gone into here. Suffice it to say that the major portion of the job is the judicious use of degeneration.

10. THE FILTER CHANNEL

10-1. The Filter Circuit

10-1-1. The most important point to be considered in connection with the input circuits to the filter is the introduction of harmonics. In general, the filter should be connected directly to the detector. If a coupling tube is used, it will almost always, even though it is a cathode follower, be unable to cope with the detector output levels and will limit; thus introducing harmonics which will pass through the filter. It is true that the back-bias system introduces harmonics, but there is no need to make a bad situation worse.

10-1-2. The output of the filter will in general feed into a single stage amplifier which in turn feeds the echo rectifier. This amplifier is necessary since the input to the echo rectifier is a pulse transformer and is not a satisfactory load for the filter. The amplifier should be a high transconductance pentode, made highly degenerative to stabilize gain.

10-2. The Echo Rectifier

10-2-1. An echo rectifier is needed for two reasons. The first and more important of these is to salvage all the pulse energy. As pointed out earlier, the pulse energy coming out of the filter is in the form of a doublesided beat note. The indicator, however, uses a single sided pulse. If, then, the beat note were simply clipped to remove the part below the base line and applied to the indicator, one-half the pulse energy would be lost in the clipping process and the effective pulse gain would be reduced to one-half (in power gain). Thus it is necessary to use either a full wave or a bridge type rectifier to salvage all the energy on both sides of the double sided pulse and put it in the form of a single sided pulse.

10-2-2. This leads directly to the second need for the echo rectifier. It is necessary as a pulse shaping means. The pulse, as pointed out above is double sided and must be rectified to give a single sided pulse such as is needed by the indicator.

10-2-3. While it is not of importance, it is interesting to note and perhaps worth mentioning here that the necessary salvage of pulse energy could be accomplished in another way. Suppose that a half wave echo rectifier were used and the power gain of the filter channel was then exactly doubled. One-half of the pulse energy would then be lost but would be made up for by the increase in gain. This method of operation is made possible by the fact that only the beat note components are handled by the filter channel; thus the normal pulse components would pass through the by-pass channel and would be subject only to normal gain. Such a system is not used in practice since the half-wave rectifier will not give nearly as good a pulse shape as the full wave rectifier.

10-2-4. The echo rectifier structure consists of a pulse transformer followed by a full-wave diode rectifier. This full wave rectifier may be either a single 6AL5 used with a split secondary transformer, or it may be a pair of 6AL5's used in a bridge circuit. In any event a pulse transformer should be used to secure the double ended output, rather than a phase inverter tube, since it will eliminate one source of possible gain variation.

10-3. Mixing the By-Pass and Filter Channel Outputs

10-3-1. There are several possible methods of mixing the outputs of the two channels. One of these, the use of mixer tubes, has been mentioned earlier. Another possibility is the use of a resistance network. In any case care must be taken to see that gains are maintained correct.

10-4. Stabilizing the Gains

10-4-1. As mentioned in section 9-5 the gains of the filter channel and of the by-pass channel must be equal. To implement this all tubes should be eliminated from these channels except where they are absolutely essential and they ~~they~~ should be made highly degenerative and of very low gain. The gain through either channel should not exceed 2 under any circumstances.

10-4-2. It is also very important that the voltages for the by-pass cut-off tube be regulated. If they are not, a very severe shift in the point of cut-off, as a result of voltage changes, may destroy the accuracy of the system.

11. GENERAL DESIGN OF THE AJ RECEIVER

11-1. General Requirements

11-1-1. At first glance it would seem that the major requirement of an a-j receiver for search equipment is that it gives the maximum possible protection against jamming. This is not, however, the case. The major requirement is ease of operation and dependability. To be effective in service, a receiver must be operable by fleet operators who have not had the engineering training of laboratory personnel and who often must work under adverse conditions. Furthermore, the equipment must be dependable so that it can be relied on to operate under these adverse conditions.

11-1-2. Second to the requirements of operability and dependability comes the performance against jamming. It must be recognized that complete protection against jamming can never be built into a receiver. There are certain types of jamming, especially noise, which cannot be completely removed by the receiver and which must be dealt with by other means. These other means include such things as system frequency dispersal, MTI (for use against passive jamming), etc. These measures are beyond the scope of this paper and are described in general terms in reference 15 so they will not be discussed here. It should, however, be pointed out that they do limit the usefulness of an a-j receiver and at the same time make it possible to sacrifice performance to operability and dependability.

11-1-3. As a result of the above considerations the practice adopted at this laboratory has been to design receivers using straight forward circuits which are stable and, where possible, free of critical adjustments and independent of tube characteristics. The remainder of this part will cover, in general terms the two types of receivers generally used at this laboratory, and recommended for use in fleet radars; one for search equipments and one for fire control equipments.

11-2. The AJ Receiver for Search Equipments

11-2-1. Part 2 of this paper covered the requirements of an a-j receiver quite thoroughly from the standpoint of fire control equipments. The requirements of a receiver for search equipments are the same except that they are less severe. The permissible variation in gain with jam level is about 4 to 1 instead of a few percent, the incremental gain need not be maintained constant, and the side lobes may be 5 db or more instead of a few per cent.

11-2-2. The i-f system used in a receiver for search equipment will be the same as is used in fire control equipment except that the cathode resistors need not be adjusted to quite as close tolerance since the constancy of gain requirement is not as severe. The method of setting the cathode time constant will be somewhat different. In the case of a receiver for a fire control equipment operation in the zero-beat area is not contemplated

so the cathode time constant is made long enough to keep the zero-beat loss area narrow. However, in the case of the receiver for search equipment, operation in the zero-beat area is possible so a shorter time constant is used to obtain greater protection. The cathode time constants are thus arbitrarily set to make the width of the zero-beat area at high jam level, and at the $\frac{1}{2}$ loss point (measured in db) approximately equal to B (the receiver's bandwidth at the $\frac{1}{2}$ power points). Plate 20 shows the i-f circuit of a fire control a-j receiver. The i-f circuit of an a-j receiver for a search equipment will be the same as this except for the parts values.

11-2-3. The gain control also deserves mention. In the fire control receiver the gain control voltage must be delayed on the later stages if the constancy of gain requirements are to be met. However, in the case of the receiver for search equipment, the less stringent constancy of gain requirements makes it possible to apply the gain control simultaneously to 2 or more of the earlier stages.

11-2-4. The detector in the a-j receiver for search equipment will be the same as the video detector in the receiver for fire control equipment (as shown in plate 20). Its polarity may be either positive or negative as necessary for the video system used. In a receiver for search equipment the video by-pass circuit is not used so no J/S detector is needed.

11-2-5. The video system used in a receiver for search equipments is made much simpler than in fire control equipments. The complete video system will consist of a fast time constant detector to video coupling using, preferably, an LR fast time constant with d-c reinjection. This will be followed by a single amplifier tube and an output stage. The standard output levels for a receiver for search equipment are 5 volts peak negative into a 75 ohm line and 50 to 100 volts positive into a high impedance "A" scope. Plate 21 shows the detector and video circuit of a typical receiver for a search equipment. The detector is $\frac{1}{2}$ a 6AL5 delivering positive video to an LR fast time constant. The other half of the 6AL5 is used as d-c reinserter. The video then goes to a 6AC7 video amplifier of straight forward design. The output of this tube goes to a 6AG7. The low impedance output is taken off the cathode of this 6AG7 and the high impedance output off the plate.

11-3. The A-J Receiver for Fire Control Equipments

11-3-1. The general requirements of the receiver for fire control equipments are as laid down in part 2 of this paper and need no further discussion here.

11-3-2. Parts 3 to 10 discuss the protective circuits and the way they operate in general terms without discussing any specific circuits. Plates 20, 22 and 23 show some representative circuits. Plate 20 shows the circuit of the i-f and detector system. Plate 22 shows one video system using the sloping cut-off video by-pass while plate 23 shows a video system using the filter type of video by-pass. In the light of the discussions of parts 3 to 9 no discussion of these circuits will be necessary. It would, however, probably be of value to discuss the method used in setting up the i-f amplifier for constant gain.

11-3-3. The receiver is first put into operation using cathode resistors approximately equal to the load resistor on the previous stage. If both primary and secondary of the coupling transformer are loaded with resistance, the cathode resistor will be approximately equal to the equivalent single resistor load. A strong cw jamming signal is then applied together with a simulated echo signal. The jamming is then tuned off-frequency from the echo signal till the height of the echo pip stops increasing. This will set the jammer at the edge of the zero-beat loss area.

11-3-4. It should be noted that during this adjustment, the video is taken off the video detector output and fed directly to an ordinary "A" scope. The a-j video is not used. Thus the pulse, in the jammed condition, will appear as a double-sided beat-note pulse. When the height of this pulse is referred to, the height from the base line to one side is meant.

11-3-5. Returning to the actual adjustment procedure; the cathode resistor of the last stage is first adjusted for maximum gain. The next to the last stage is then adjusted and so forth on back through the earliest stage to which back-bias is applied. This gives a first approximation to the optimum back-bias action. It is only a first approximation since the adjustment of each stage affects the adjustment of the following stage. However, by repeating the adjustment of the complete system several times, the final adjustment may quickly be reached.

11-3-6. When this point is reached it will be necessary to adjust the unjammed gain of all stages to equal the jammed gain. This will be done in either of two ways depending on whether bias is applied to the grid or not. If bias is applied to the grid the adjustment procedure will be as follows. First apply a strong cw jamming signal tuned, as before, to the knee of the pip height versus jamming frequency curve. Then reduce the jam level slowly till the bias being developed on the cathode of the first back-biased stage is one or two tenths of a volt above the unjammed level. The bias on the grid is then adjusted to give the same gain as when the stage was biased back. This procedure is then repeated for each succeeding stage in order till the last stage has been adjusted. If no bias is applied to the grid, a similar procedure is used, the only difference being that the

cathode resistor must be adjusted to compensate the unjammed (as well as the jammed) gain. Thus it will be necessary during the adjustment of each stage, to check back and forth between the jammed and the unjammed gains. This will give a close approximation to the final constant gain characteristic. Both these adjustments may be repeated several times, if found necessary.

11-3-7. The next step in the adjustment of the system will be to center the operating point of the last tube in the center of its true linear range. This is done by applying a strong jamming signal (tuned off-frequency as before) and increasing the simulated echo signal till limiting is noted on one side or the other of the double sided pulse. If limiting is noted first on the positive side, the cathode resistor is too small and should be increased. Conversely, if limiting is noted first on the negative side, the resistor is too large and should be reduced. When the adjustment is correct, limiting will occur simultaneously on both sides. In most cases, the amount of adjustment necessary, will be very small and can be made without seriously affecting the constancy of gain.

11-3-8. The final adjustment of the constancy of gain must then be made while running the constancy of gain curves. No specific directions can be given at this point except to say that each stage will control the shape of the curve over a very short range, and if any irregularity occurs in the curve it can be traced to the stage causing it and corrected. A rise in the curve will indicate the unjammed gain of the stage which is biasing-back as the rise occurs is too low. A drop in the curve will indicate that the unjammed gain of the stage is too high. It should be noted that, assuming the setting-up of the system for optimum jammed operation has been correctly made, all corrections to the constancy of gain curve will be made by varying the unjammed gain.

11-3-9. There are several points which should be mentioned in connection with this adjustment procedure. When any measurements or adjustments are made on a jammed stage, a check should be made to make certain that the preceding stage is delivering, to the stage being adjusted, its maximum output. This can best be ascertained by measuring the cathode bias voltage being developed by this preceding stage. Under the jammed condition, when the adjustment is being made, the cathode bias being developed by this preceding stage should be at least 50% greater than in the unjammed condition. A second point of interest is that, when the final adjustment is reached the cathode resistors of all similar stages, driven in the same manner should be equal. It should also be pointed out that the whole adjustment is quite non-critical and no special selection of resistors is necessary. The standard 10% tolerance resistors are satisfactory. Furthermore, the adjustment is sufficiently non-critical that it need be done only on the pre-production prototype, and then if production tolerances are met on other

parts of the circuit, the same resistance values will hold for production equipments.

11-3-10. Adjustment of the video by-pass for constant gain is quite straight forward. The gain of the by-pass channel is first adjusted to match the unjammed pip height to the jammed pip height. The delay bias applied to the by-pass control tube is then adjusted to set the start of the cut-off at the correct point. Then if the by-pass is of the sloping cut-off type, the gain of the by-pass control tube is adjusted to match the slope of the cut-off to the filter characteristic.

12. TESTING OF THE A/J RECEIVER

The methods of testing a-j receivers differs so widely among different laboratories, and reports on these test methods are so lacking, that engineers developing equipments for manufacture often find themselves at a loss to know how to test their equipments. To rectify this situation, a standard test procedure for type acceptance tests of the a-j properties of a receiver has been developed at this laboratory and reported in reference 3.

12-1. Type Acceptance Tests

Nothing need be said here of the type acceptance tests. They are covered quite thoroughly in reference 3.

12-2. Developmental Testing

Reference 3 was written to cover type acceptance testing. However, several of the tests which it discusses can very profitably be used in developmental testing.

12-2-1. Loss in Sensitivity in the Presence of cw Jamming. This test will help in setting the back-bias time constants and the relative i-f and video bandwidths in receivers for search equipments. It is described in part 5 of reference 3.

12-2-2. Gain Versus Jamming Level. This test will help in setting the cathode resistors in the back-biased i-f of a receiver for search equipments. It is discussed in part 9 of reference 3.

12-2-3. Constancy of Gain Versus Jamming Frequency. This test will help in setting the back-bias time constants and relative i-f and video bandwidths in receivers for fire control equipments. This test is covered by part 14 of reference 3.

12-2-4. Constancy of Gain Versus Jamming Level. This test is necessary to make the final adjustment of the cathode resistors for constant gain. It is described in part 13 of reference 3.

12-2-5. Incremental Gain. This test is useful in checking the true dynamic range of the system and in checking the centering of the operating point of the last i-f stage. It is discussed part 15 of reference 3.

13. OVERALL PERFORMANCE

Fleet reports on the performance of the systems discussed in this report are not yet available in sufficient quantity to evaluate their performance in service. However, earlier designs, quite similar in character, have received many very good reports, and a few bad ones, traceable, mainly, to complexity of controls and the lack of that "ease of operation" so strongly recommended by this report. On the basis of these fleet reports and laboratory and field tests, this part will attempt to give some evaluation of the general designs presented in part 11.

13-1. Dejamming Capabilities

13-1-1. The i-f system of either the search or the fire control receiver will be capable of handling jam levels of the order of 100 MV at the antenna and J/S ratios of the order of 80 to 100 db.

13-1-2. Either system will perform with little or no loss against cw jamming or modulated cw jamming with the modulation frequencies below 20 to 50 kc. The search receiver will offer some protection above these modulation frequencies but not as much as the fire control receiver which will give good protection against modulation frequencies up to 600 or 700 kc.

13-1-3. The search receiver will give some protection against noise jamming and the fire control receiver will reduce the efficiency of most noise jammers greatly. The curves of references 3 and 5 show graphically the protection obtained.

13-2. Operation

13-2-1. Throughout the work on a-j receivers at this laboratory the need for simplicity of operation has been heavily stressed. The resulting receivers described above are extremely simple to operate. In the case of the receiver for search equipment the only control is the FTC on-off switch. In the receiver for fire control the only controls are the a.j. - normal switch and the transmitter tuning.

13-3. Normal Performance

13-3-1. In either of the receivers, the unjammed, normal performance is unaffected by the a-j circuits. Furthermore, the unjammed performance, when set for a-j is very nearly as good as when set for unjammed reception.

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13-4. Bearing Errors

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13-4-1. In the case of the receiver for fire control equipment bearing errors introduced by the receiver are kept to a minimum. Although no figure can be set for the probable maximum error without knowing the slope of the antenna lobe ratio curve at the crossover point, it can be said that with a slope that can be obtained in a practical antenna, the bearing errors should be less than 15 minutes.

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REFERENCES

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1. BuShips ltr S-S67/36(485J) Serial No. 2184 to NRL dated 18 March 1942 assigning problem X4-28S (S45R-S).
2. BuShips ltr S-S67-5(920-Di) S-920-06808 to NRL dated 27 Dec. 1943 requesting establishment of problem S578R-S.
3. NRL Report R-2456 dated 3 Jan. 1946 "Standard Test Procedures for A-J Receivers".
4. NRL Report R-2392 dated 1 Nov. 1944 "Investigation of Anti-Jam Receivers for Search Radar".
5. NRL Report R-2507 dated 1 Nov. 1945 "Development of the Mark 12 A-J Receiver".
6. NRL Report R-2156 dated 31 June 1943 "Anti-Jam Receivers".
7. NRL Report RA 3A 220A dated 1 Dec. 1944 "A Study of the System Vulnerability of the Radar Mark 12 to Electronic Jamming".
8. NRL Report RA 3A 217A dated 30 Oct. 1944 "A Study of the Vulnerability of the Radars Mark 3 and Mark 4 to Enemy Electronic Countermeasures.
9. NRL ltr S-S67(398/LFG) Serial No. 4628 to BuOrd dated 14 March 1945 reporting on problem O-88T-C.
10. NRL Report R-2535 dated 21 May 1945 "A-J Video Filters for the Radar Mark 12 Receiver".
11. Report No. HB-1 of A-J Practices Panel titled "Fundamentals of Radar Anti-Jamming".
12. Paper No. B-3 of A-J Practices Panel titled "Video Bandwidth Considerations".
13. Paper No. B-7 of A-J Practices Panel titled "Stability Margin".
14. Radiation Laboratory Report No. 708 dated 22 June 1945 and titled "Synthetic Radar Echoes in the Presence of Jamming".
15. Joint Communications Board Countermeasures Committee Report No. JX/CM 70 titled "Anti-Jamming for New Radars".

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GLOSSARY OF TERMS

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1. Antenna Crossover - The point at which the pickup on the two lobes of an opposed pair in a lobe switched system are equal - thus the on-target point.
2. Beat Frequency - The heterodyne frequency resulting from the heterodyning of the jamming signal and the echo signal.
3. Beat Frequency Pulse - A pulse consisting of several cycles of beat frequency sine wave instead of a single sided square pulse.
4. Class "C" Factor - The duty factor of a class "C" amplifier stage.
5. Clutter - A form of interference or jamming resulting from the reflection of radar pulse energy from extraneous targets, such as nearby land, waves or clouds.
6. Difference Frequency - A frequency equal to the difference between the radar frequency and the jammer frequency, thus the frequency of the beat between them.
7. Differentiating Action - The frequency selective action of a circuit whereby the low frequencies are not passed.
8. Dynamic Range - Ordinarily defined as the range of signal levels over which the receiver is linear. In the case of an a-j receiver there are, however, two possible interpretations:
 - (a) Back-Bias Dynamic Range - The range of jamming levels over which the gain to a small echo pulse remains constant.
 - (b) True Dynamic Range - The range of echo pulse levels over which the echo pulse gain remains constant.
9. Fast Time Constant - Short time constant video coupling circuit.
10. J/S Detector - An extra detector, fed from the last i-f stage, whose output is an approximate measure of the j/s ratio.
11. Jamming - There are two types of jamming commonly considered:
 - (a) Active (or Electronic) Jamming - Jamming by means of relatively large amounts of power generated and radiated at the radar frequency.
 - (b) Passive Jamming - Jamming by means of reflected energy from such things as window, rope, etc.

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GLOSSARY OF TERMS (Cont'd)

This category also includes deceptive methods. In the present report the term jamming refers exclusively to electronic jamming.

12. Lobe Ratio - The ratio of the pickup on two opposed lobes of a lobe switched system at any given angle between the energy source and the crossover bearing.
13. Marginal Stability - A measure of the freedom from oscillation and regeneration of a radar receiver.
14. Maximum Lobe Ratio - The lobe ratio when the bearing of the source is set so as to maximize the lobe ratio.
15. Off-Frequency Jamming - Electronic jamming of which the carrier frequency is several hundred kilocycles removed from the radar frequency but still close enough to affect performance.
16. On-Frequency Jamming - Electronic jamming of which the carrier frequency is within a few kilocycles of the radar frequency.
17. Railings - A type of electronic jamming consisting of a series of pulses with dead spots between them. These pulses are generally of very short length and with very short spacing between them and recur at a definite rate.
18. Range of Linearity - The range of echo signal pulse levels over which incremental gain is constant. The same as true dynamic range.
19. Sailboats - Triangular shaped pulses following an echo pip on an indicator. These sailboats are the result of bad recovery characteristics and in some cases exceed the echo pip in both amplitude and duration.
20. Side Lobes of Loss - A term, borrowed from antenna terminology, used to describe the peaks of loss which appear on the curves of loss plotted against frequency and are displaced several megacycles from the zero-beat peak.
21. Video Bypass - A circuit, used in a-j receivers for fire control systems, designed to bypass a sufficient amount of echo energy around the video filter at low j/s ratios to compensate for the loss at these low j/s ratios inherent in the use of a high cut-off filter in an a-j receiver.
22. Zero-Beat Jamming - Electronic jamming at the same frequency as, or within a few kc of the radar frequency.

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GLOSSARY OF TERMS (Cont'd)

23. Zero-Beat Loss Area - The portion of the curve of loss plotted against jamming frequency which includes the peak of loss and the sloping sides of this peak out as far as the first minimum of loss.

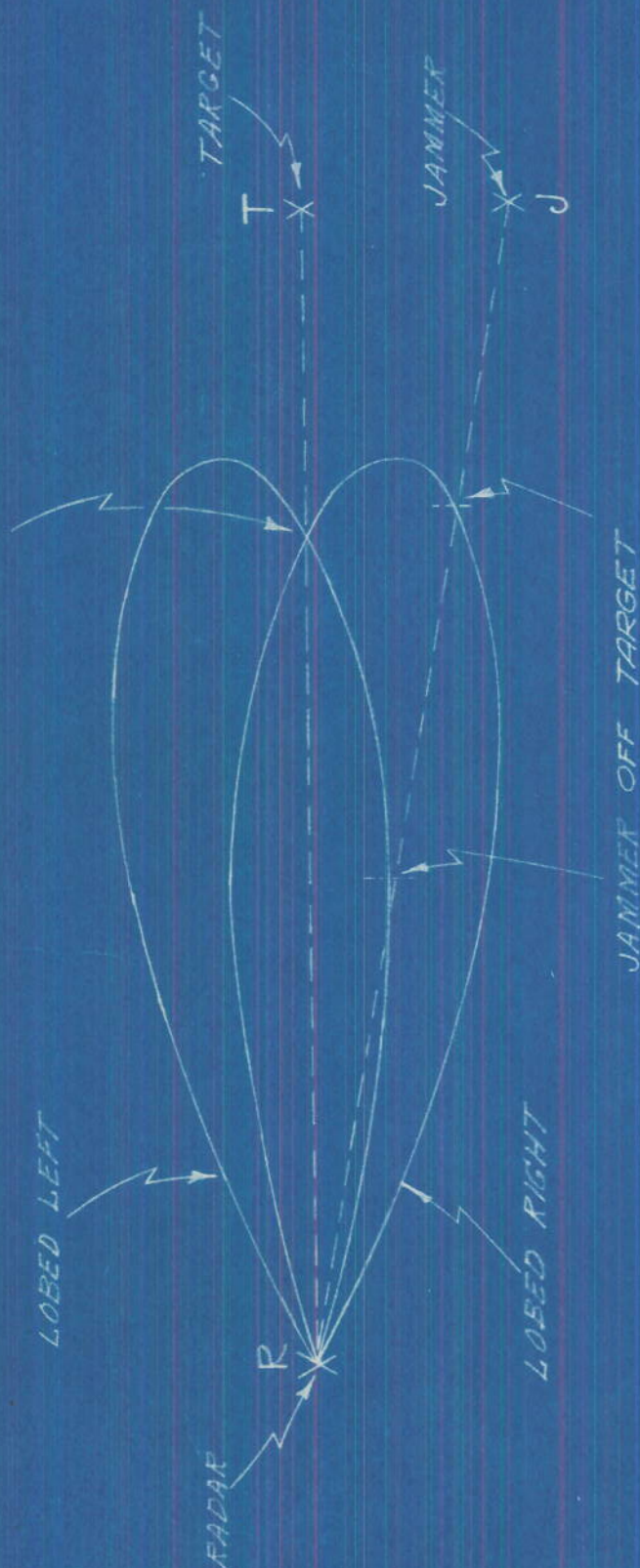
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GLOSSARY OF SYMBOLS

1. B - The i-f bandwidth to the $\frac{1}{2}$ -power points.
2. BFO - Beat Frequency oscillator.
3. FTC - Abbreviation for fast time constant.
4. J/MVS - The ratio of any specific jamming level to the level of the minimum detectable signal in the unjammed condition. Given in db and used in the following equation for j/s:
$$j/s \text{ (db)} = j/mvs \text{ (db)} - \text{Loss (db)}.$$
5. J/S - The ratio generally given in db, of the jamming level to the minimum detectable signal when jammed by a signal of that level.
6. K Class c - Class "C" factor.
7. MVS - The minimum detectable signal in the unjammed condition.
8. R - The pulse repetition rate of the system with which the receiver is to be used.
9. S - Minimum detectable echo pulse signal for any given jammed condition.

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RADAR ON TARGET
ECHO LEVELS EQUAL ON BOTH LOBES



JAM LEVEL UNEQUAL ON TWO LOBES

ANTENNA PICKUP LEVELS ON A
LOBE SWITCHED RADAR

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R-250B

PLATE 1

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KEUFFEL & ESSER CO., N. Y. NO. 250-11.
18 x 40 to five 1/4 inch, 3th lines screened.
Engraving 7 x 30 in.
MADE IN U. S. A.

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LOBE RATIOS MARK 12
HORIZONTAL LOBES
945 MCS.

40°

30°

20°

10°

0°

350°

340°

330°

320°

ON TARGET
CROSSOVER

RIGHT LOBE
-DA-
LEFT LOBE

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RELATIVE BEARING OF SIGNAL SOURCE

PLATE 2

R-2508

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STRONG
JAMMING

MEDIUM
JAMMING

UNJAMMED

ZERO
BIAS

PORTION OF ECHO ENERGY AMPLIFIED

DEVELOPED
CATHODE
BIAS VOLTAGE

CUT-OFF

ECHO

JAMMING
ENERGY LOST

PORTION OF ECHO ENERGY LOST

ENVELOPE OF JAMMING SIGNAL

JAMMING
ENERGY LOST

BACK - BIASING

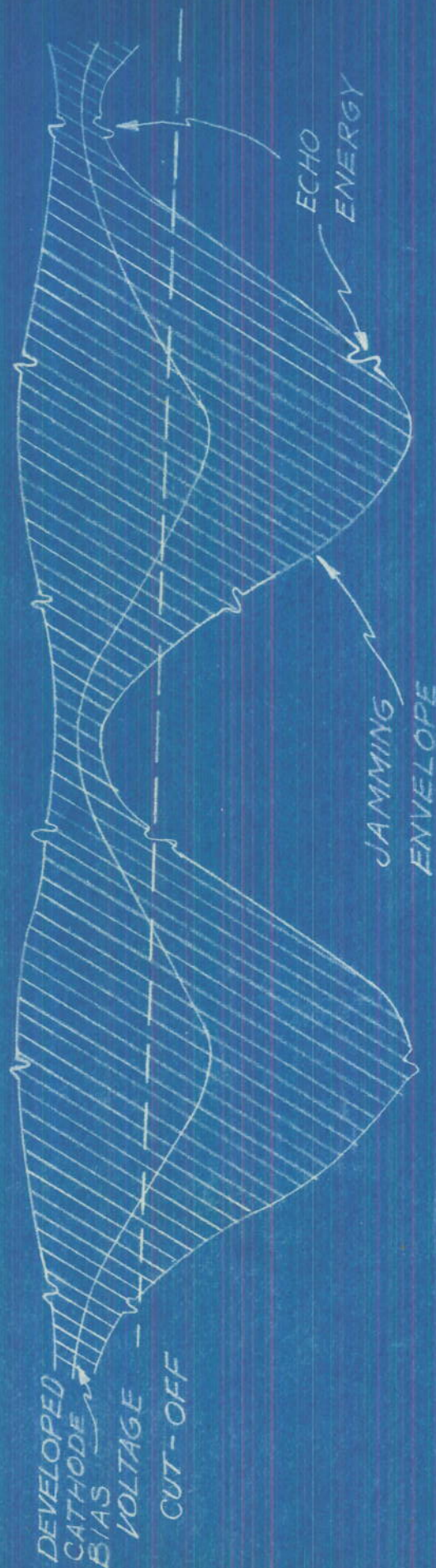
ACTION

AGAINST CW

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CONFIDENTIAL

ZERO
BIAS



R-2508

DECLASSIFIED

PLATE 5

BACK-BIAS ACTION AGAINST
LOW FREQUENCY MODULATED CW

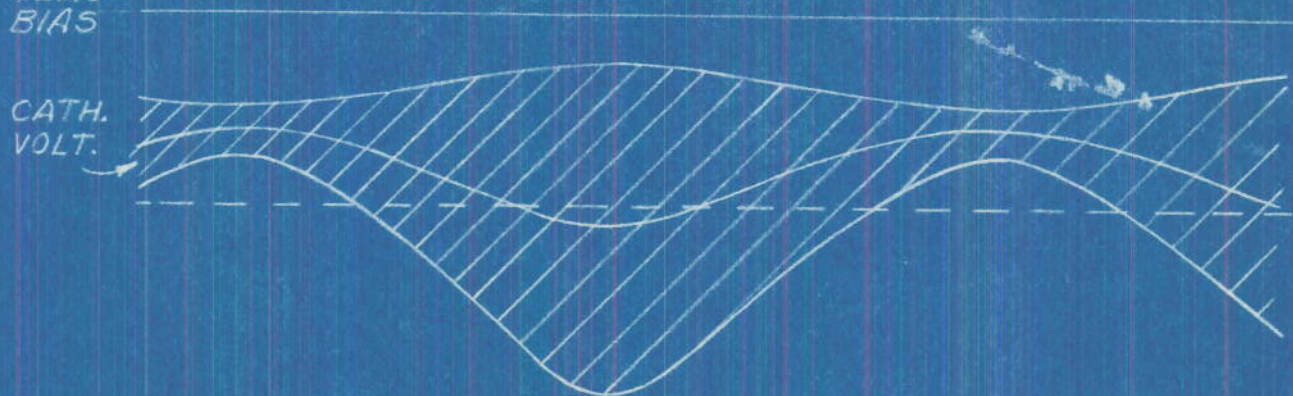
DECLASSIFIED

DECLASSIFIED

ZERO
BIAS

FIG. A - LOW

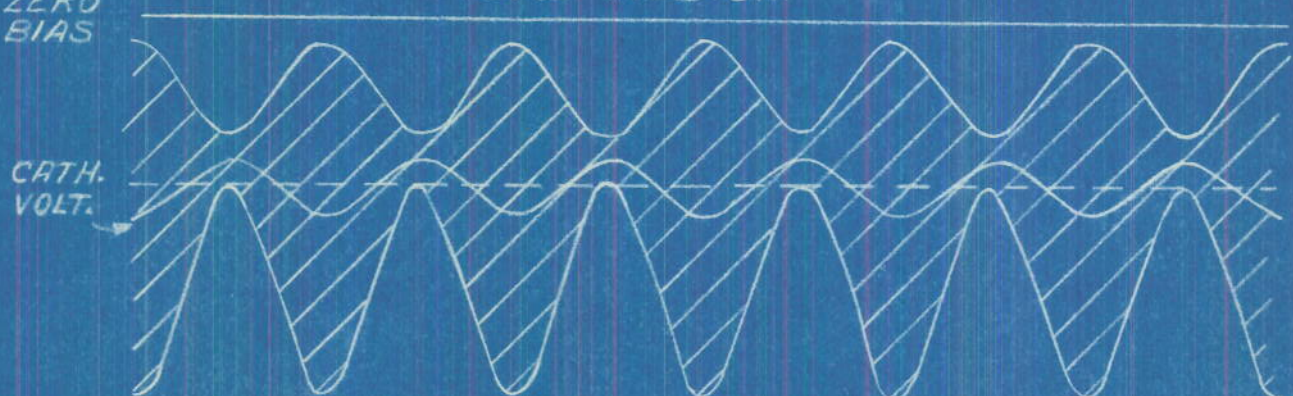
CATH.
VOLT.



ZERO
BIAS

FIG. B - MEDIUM

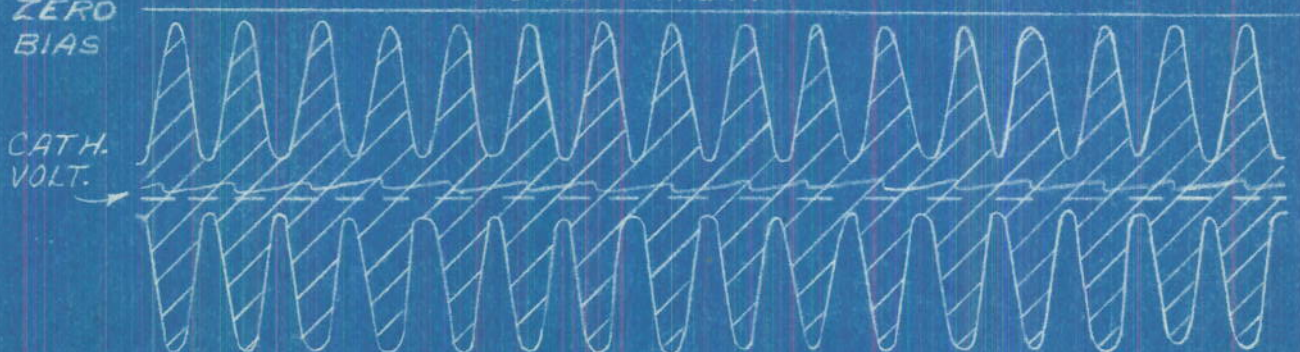
CATH.
VOLT.



ZERO
BIAS

FIG. C - HIGH

CATH.
VOLT.



BACK-BIAS ACTION
AT DIFFERENT MODULATION
FREQUENCIES

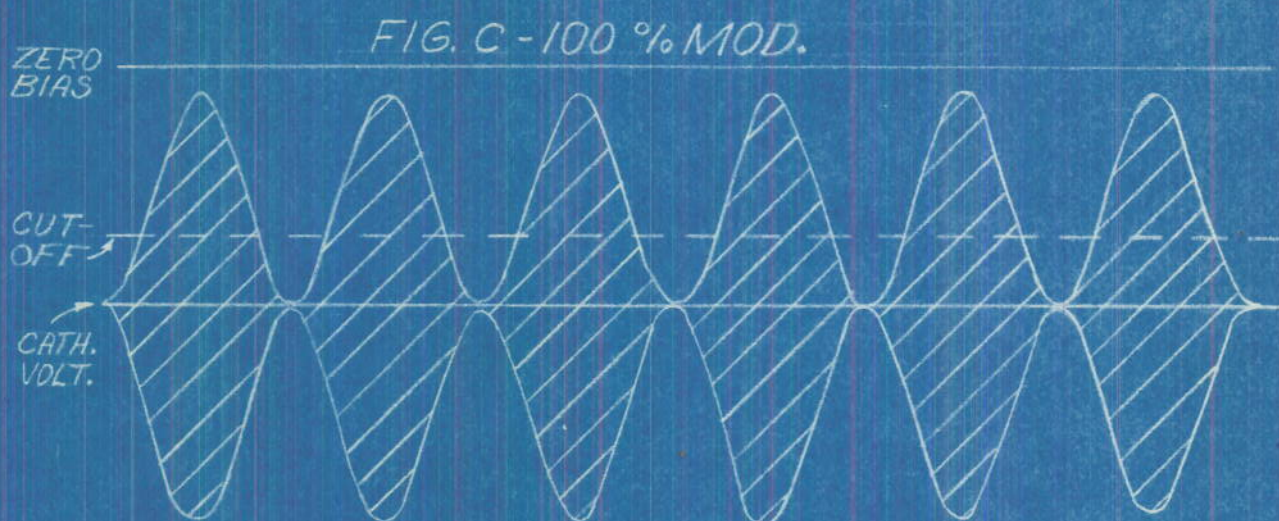
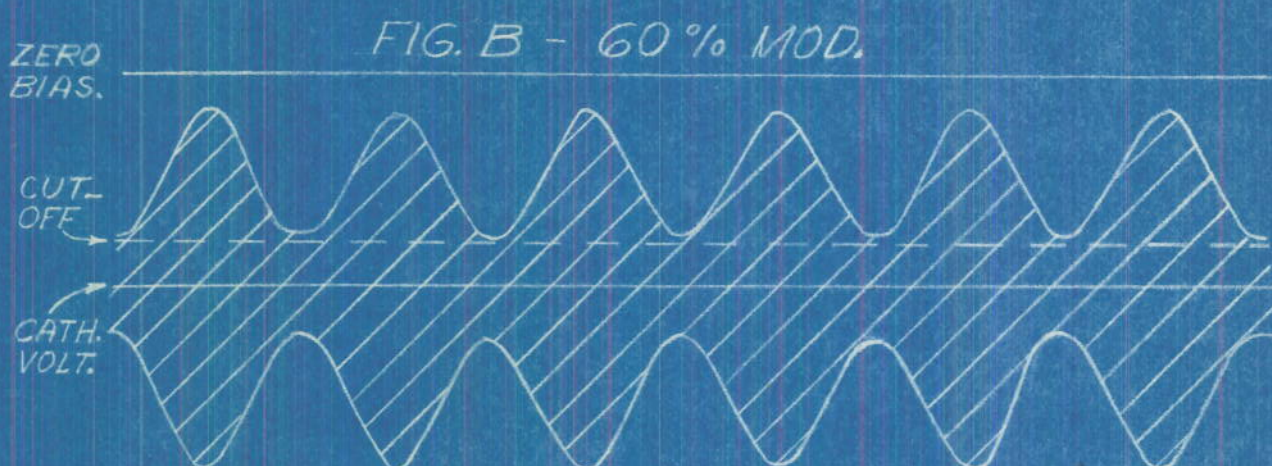
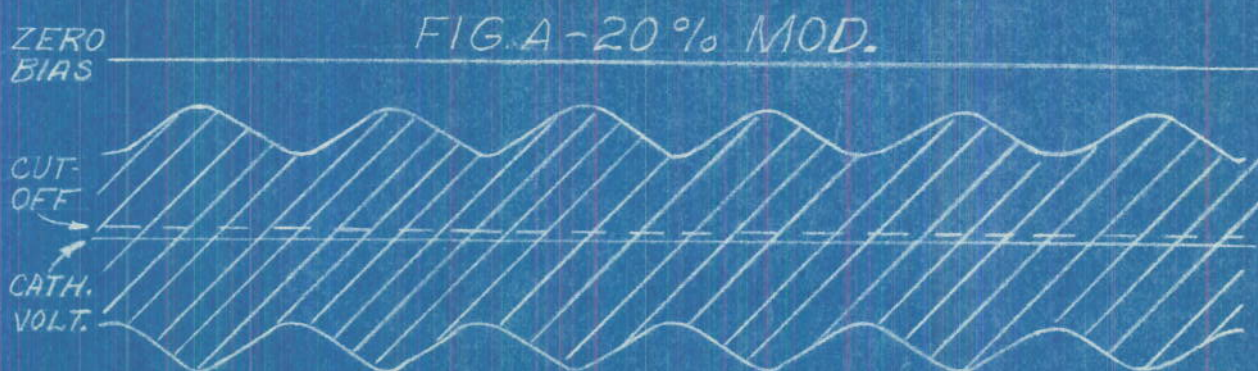
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PLATE 6

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BACK-BIAS ACTION
AT HIGH MODULATION
FREQUENCY

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PLATE 7

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$$\Delta F = 0$$

$$\frac{1}{S} = 15 \text{ db}$$



$$\Delta F = \frac{1}{2T}$$

$$\frac{1}{S} = 15 \text{ db}$$



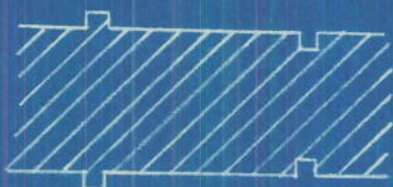
$$\Delta F = \frac{1}{T}$$

$$\frac{1}{S} = 15 \text{ db}$$



$$\Delta F = 0$$

$$\frac{1}{S} = 30 \text{ db}$$



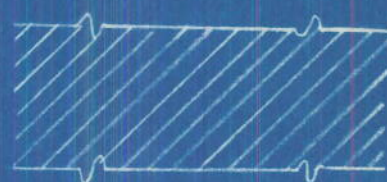
$$\Delta F = \frac{1}{2T}$$

$$\frac{1}{S} = 30 \text{ db}$$



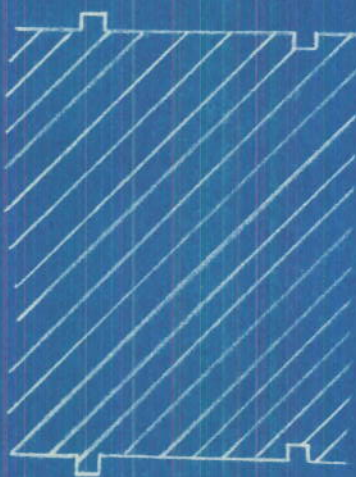
$$\Delta F = \frac{1}{T}$$

$$\frac{1}{S} = 60 \text{ db}$$



$$\Delta F = 0$$

$$\frac{1}{S} = 60 \text{ db}$$



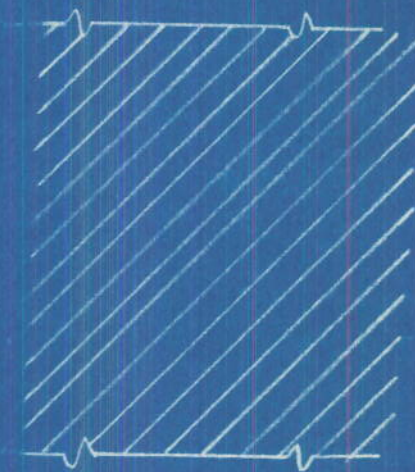
$$\Delta F = \frac{1}{2T}$$

$$\frac{1}{S} = 60 \text{ db}$$



$$\Delta F = \frac{1}{T}$$

$$\frac{1}{S} = 60 \text{ db}$$



JAMMING ENVELOPE SHOWING
BEAT NOTE ECHOS

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LONG CATHODE TIME CONSTANT

T = PULSE LENGTH

ΔF = DIF. IN RAD. & JAM. FREQ.

PLATE 8

R-2508

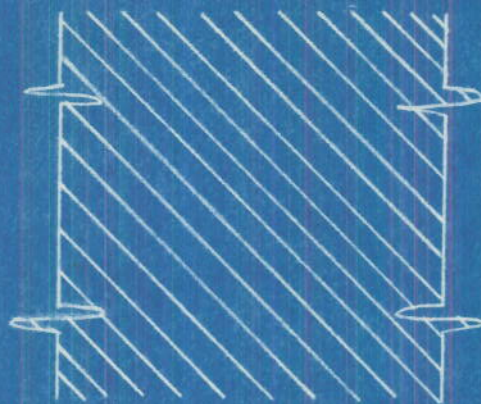
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$J/S = -5 \text{ Db}$

$J/S = 0 \text{ Db}$

$J/S = 20 \text{ Db}$

IF ENVELOPE



DETECTED OUTPUT



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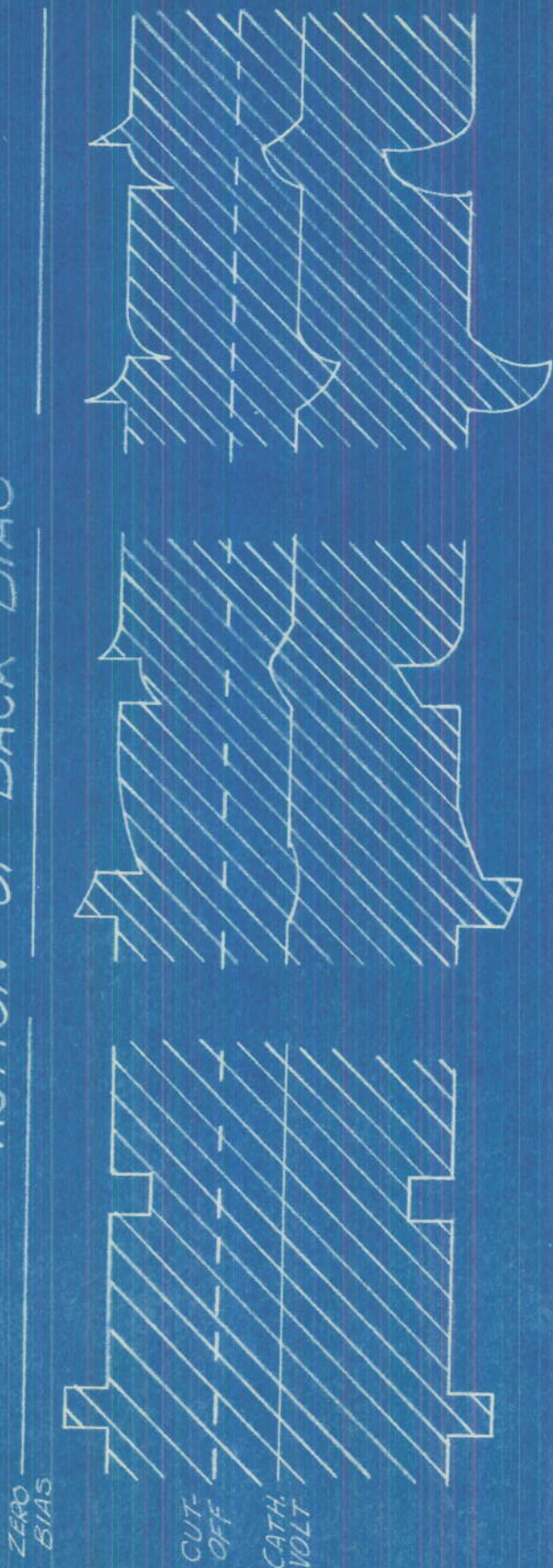
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BEAT NOTE PULSES
AT LOW J/S RATIOS

LONG CATHODE TIME CONSTANT

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LONG TC MEDIUM TC SHORT TC
ACTION OF BACK-BIAS



DETECTED OUTPUT



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EFFECT OF CATHODE
TIME CONSTANT ON ZERO-BEAT
PERFORMANCE

R-2508

PLATE 10

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$$\Delta F = 0 \quad \Delta F = \frac{1}{4T} \quad \Delta F = \frac{1}{2T} \quad \Delta F = \frac{1}{T} \quad \Delta F = \frac{2}{T}$$

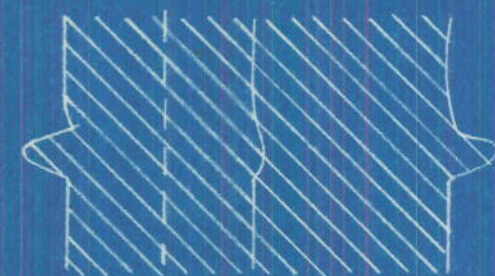
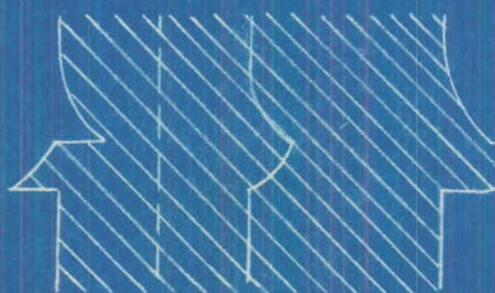
BACK-BIASING ACTION

ZERO
BIAS



CUT
OFF

CATH.
VOLT



DETECTED OUTPUT



ENERGY LOST



NO ENERGY LOSS

NO SAIL BOAT

EFFECT OF OFF-FREQUENCY
OPERATION ON PULSE TRANSMISSION

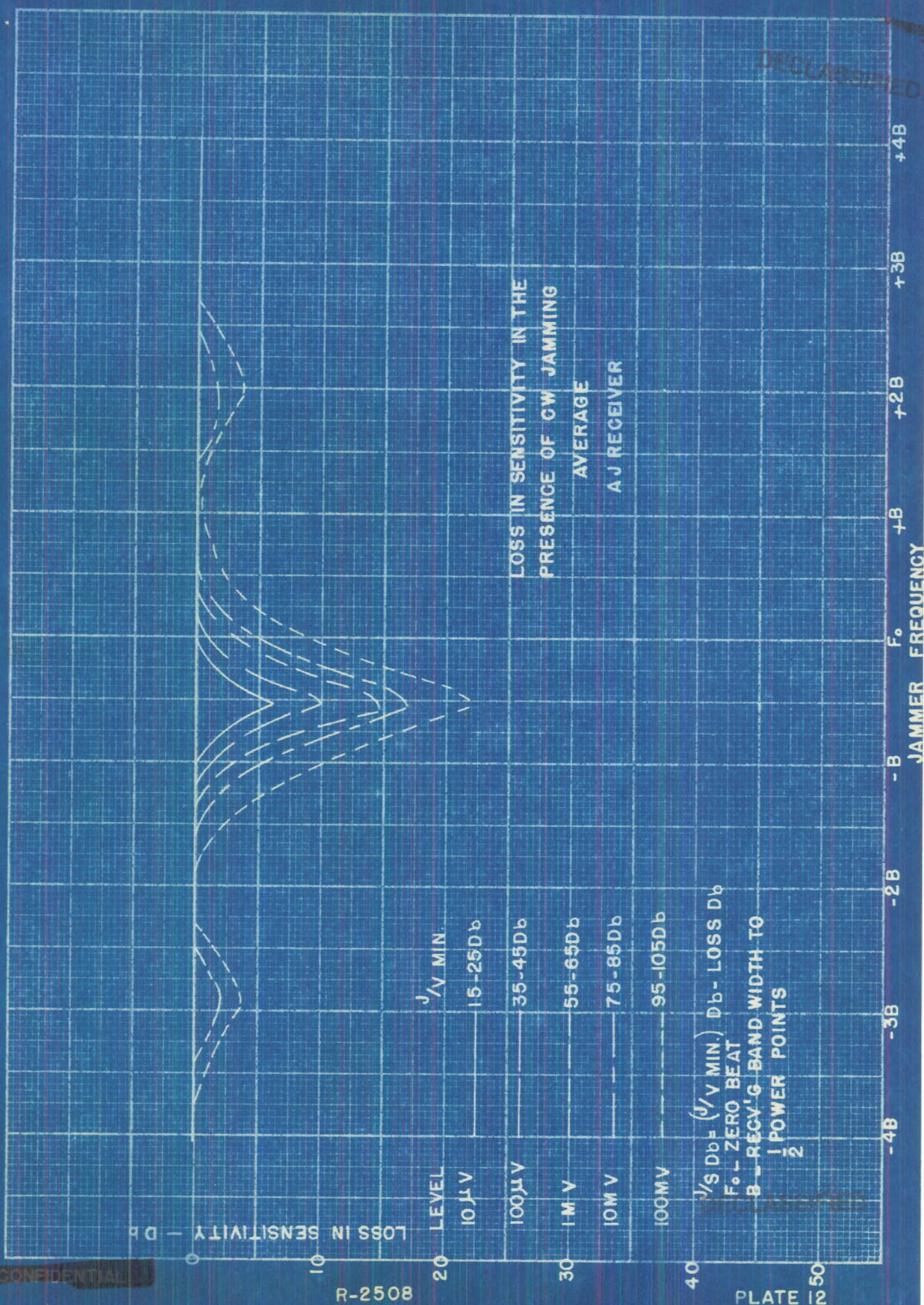
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DECLASSIFIED

R-2508

PLATE II

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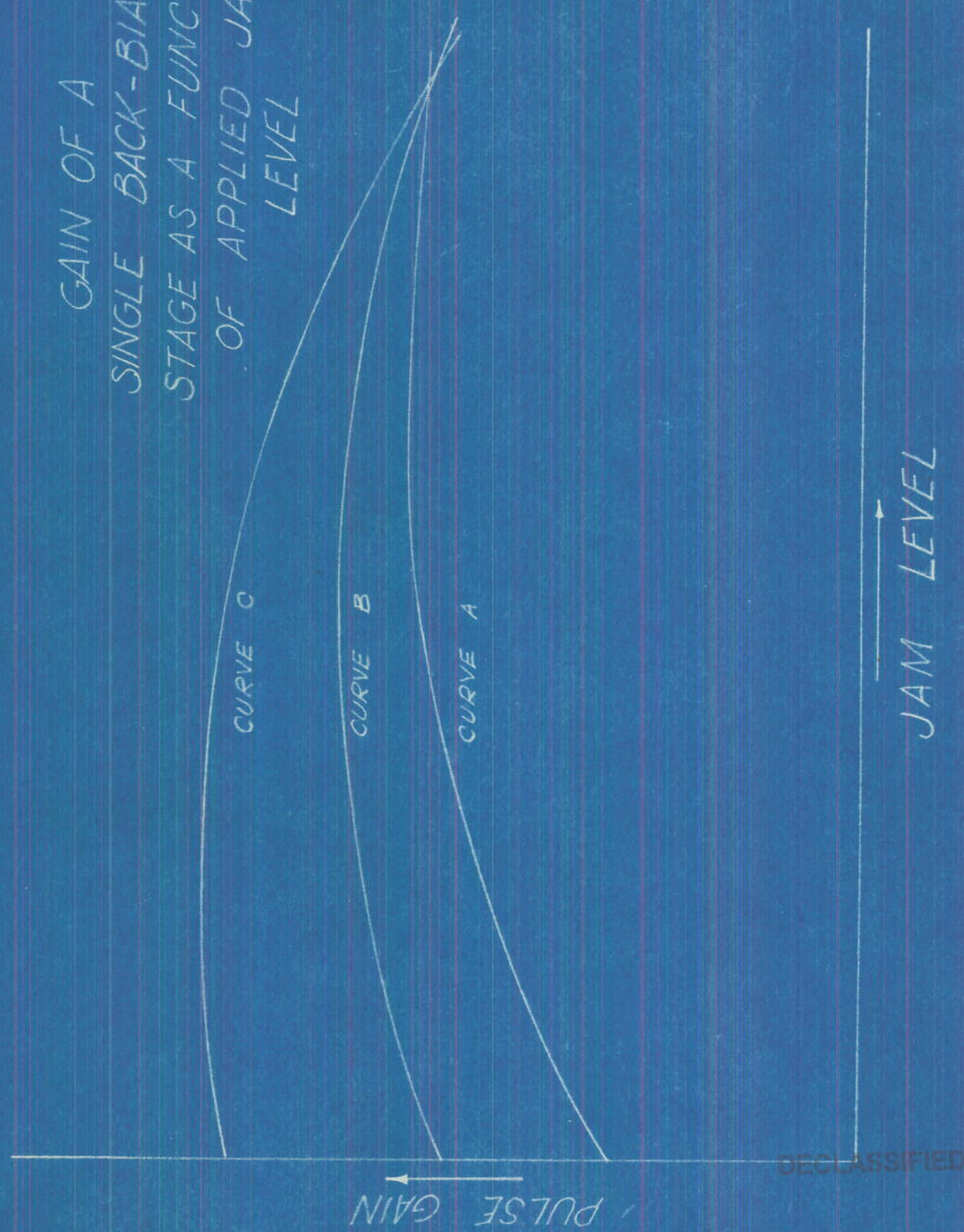


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R-2508

PLATE 12

GAIN OF A SINGLE BACK-BIASED STAGE AS A FUNCTION OF APPLIED JAM LEVEL



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PLATE 13

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COMPOSITE GAIN CURVE FOR EIGHT STAGES

GAIN CURVE FOR AN
INDIVIDUAL STAGE DURING
BIASING - BACK INTERVAL



NORMAL GAIN, EITHER
UNJAMMED OR FULLY JAMMED
AND BIASED - BACK COMPLETELY

JAM LEVEL

COMPOSITE GAIN
CURVE FOR AN EIGHT STAGE
BACK - BIASED AMPLIFIER

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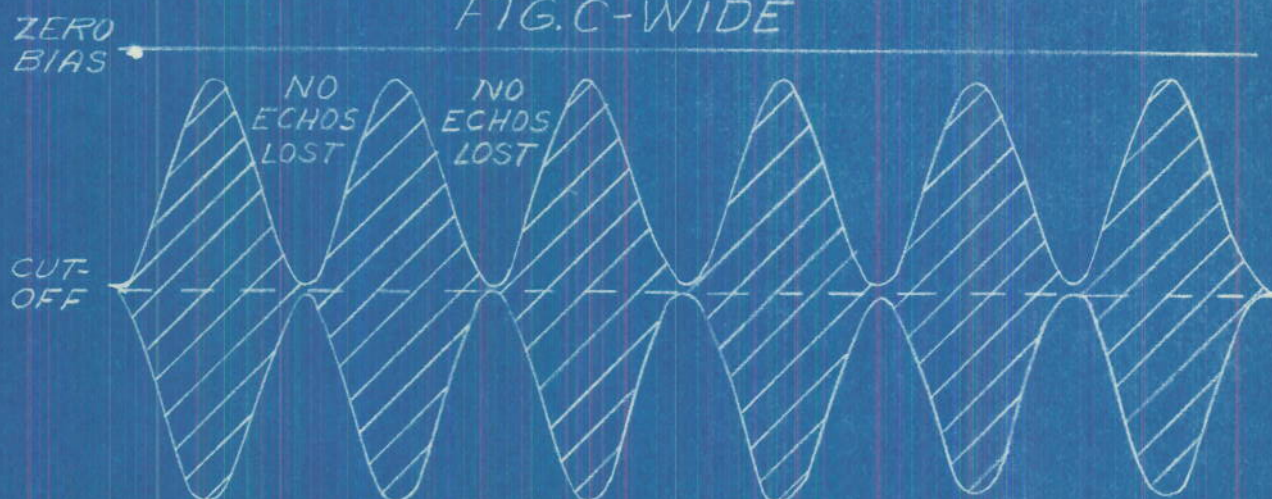
FIG. A - NARROW



FIG. B - MEDIUM



FIG. C - WIDE



EFFECT OF TRUE DYNAMIC RANGE
ON PERFORMANCE AGAINST HIGH
MODULATION FREQUENCY

DECLASSIFIED

RINGING CANCELATION

DECLASSIFIED

PULSE



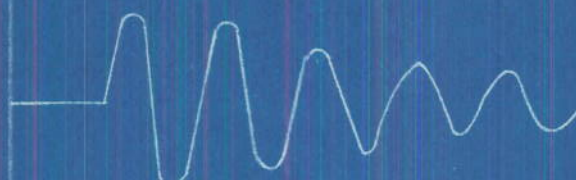
PULSE LEADING
EDGE



PULSE TRAILING
EDGE



RINGING FROM
LEADING EDGE



RINGING FROM
TRAILING EDGE



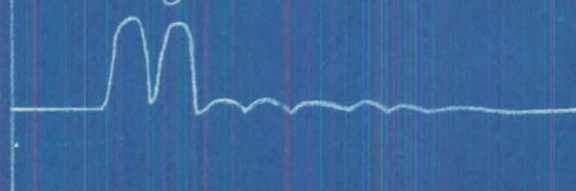
ADDITION OF
TWO RINGINGS



FINAL OUTPUT
PULSE



OUTPUT OF
ECHO RECTIFIER



DECLASSIFIED

FIGURE A

CONVERSION EFFICIENCY OR HIGH
PASS FILTER RESPONSE

DECLASSIFIED

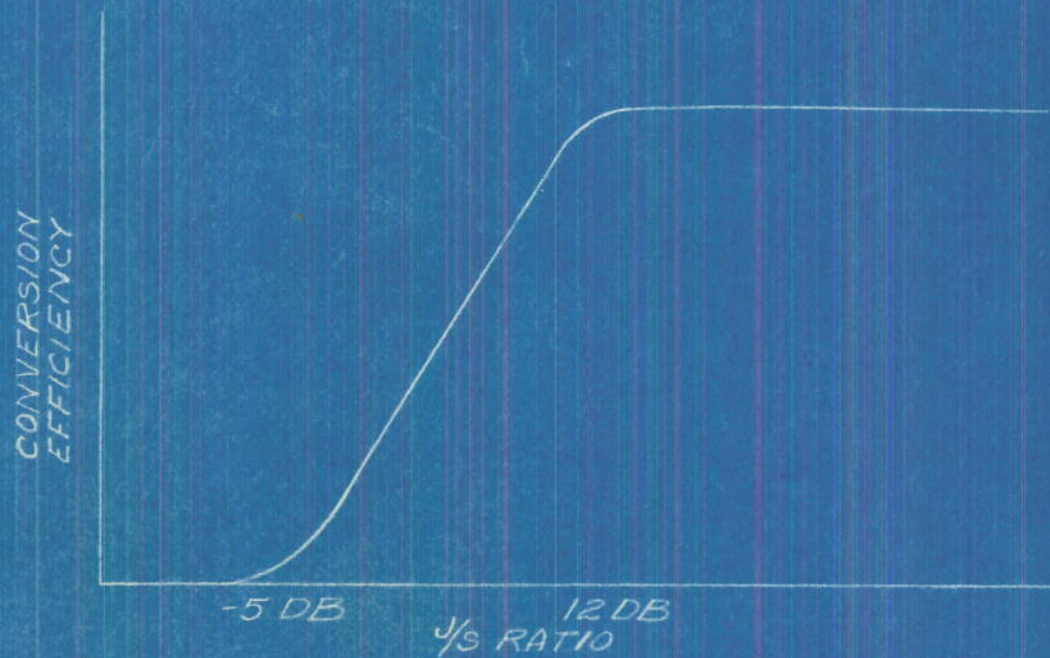
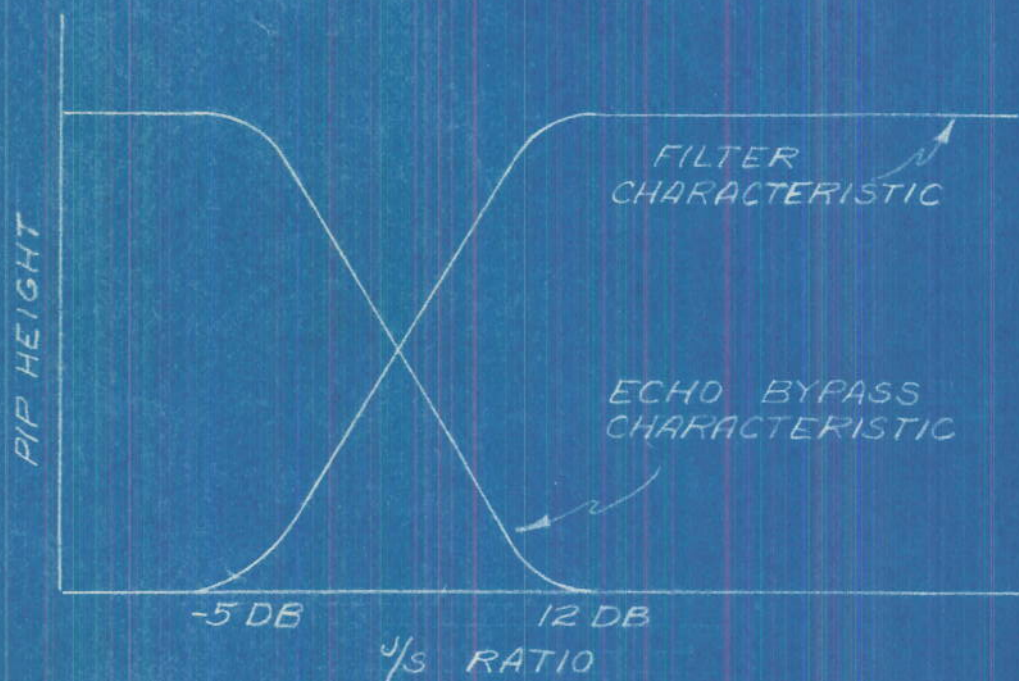


FIGURE B

ECHO BYPASS CHARACTERISTIC



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FIGURE A
ECHO ENERGY DISTRIBUTION

DECLASSIFIED

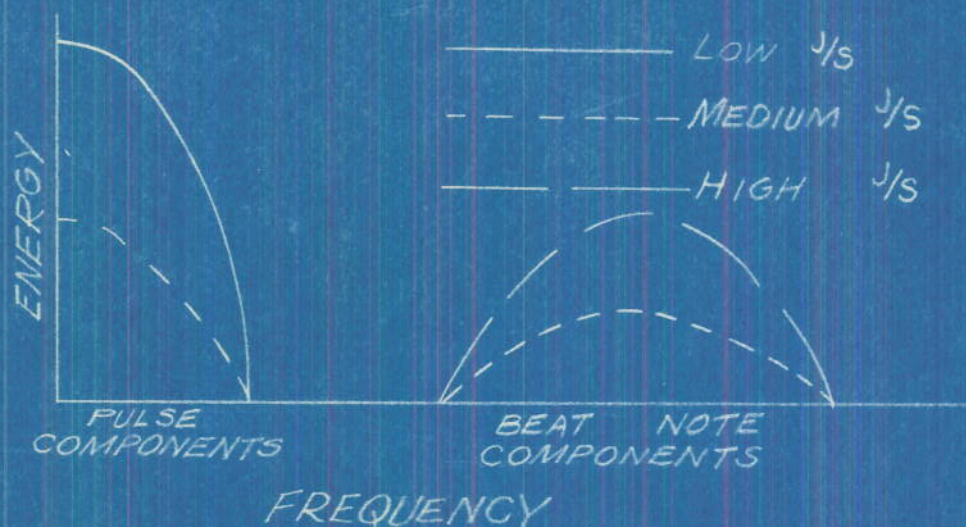


FIGURE B
FILTER FREQUENCY RESPONSE

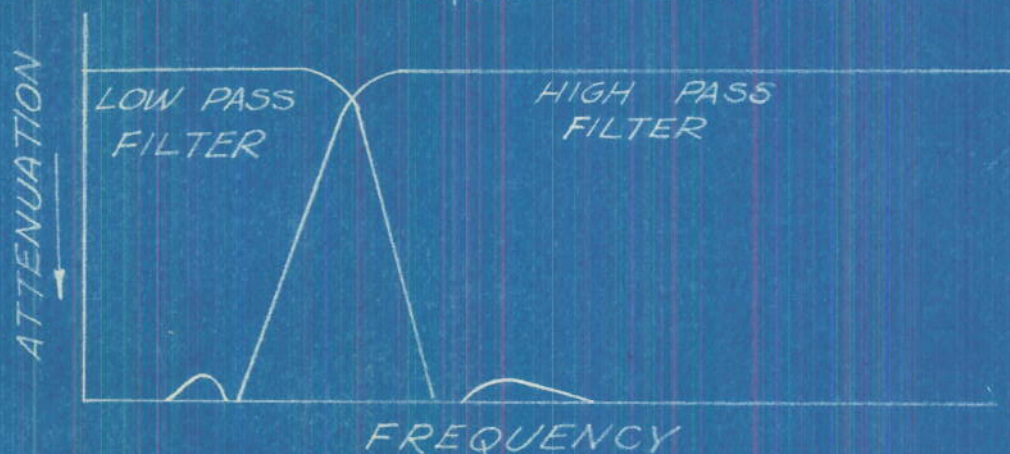
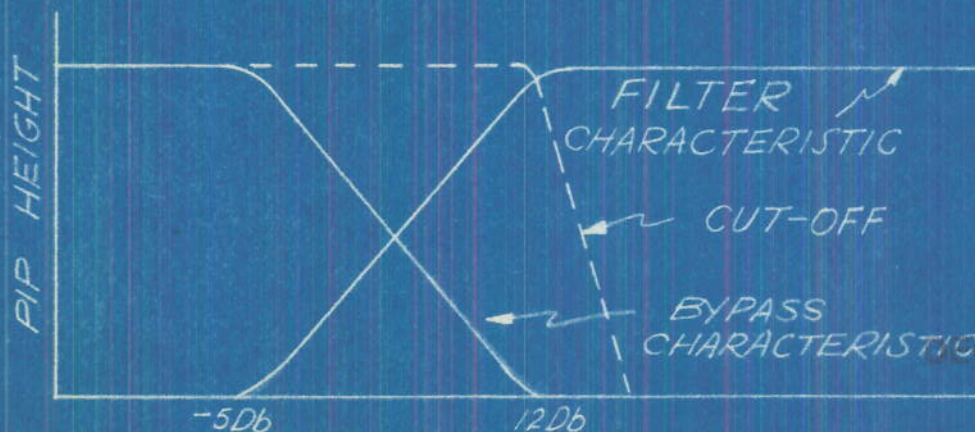


FIGURE C
BYPASS CHARACTERISTIC



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PLATE 18

DEFECTS OF ECHO BYPASS SYSTEMS

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FIGURE A SLOPING CUT-OFF BYPASS

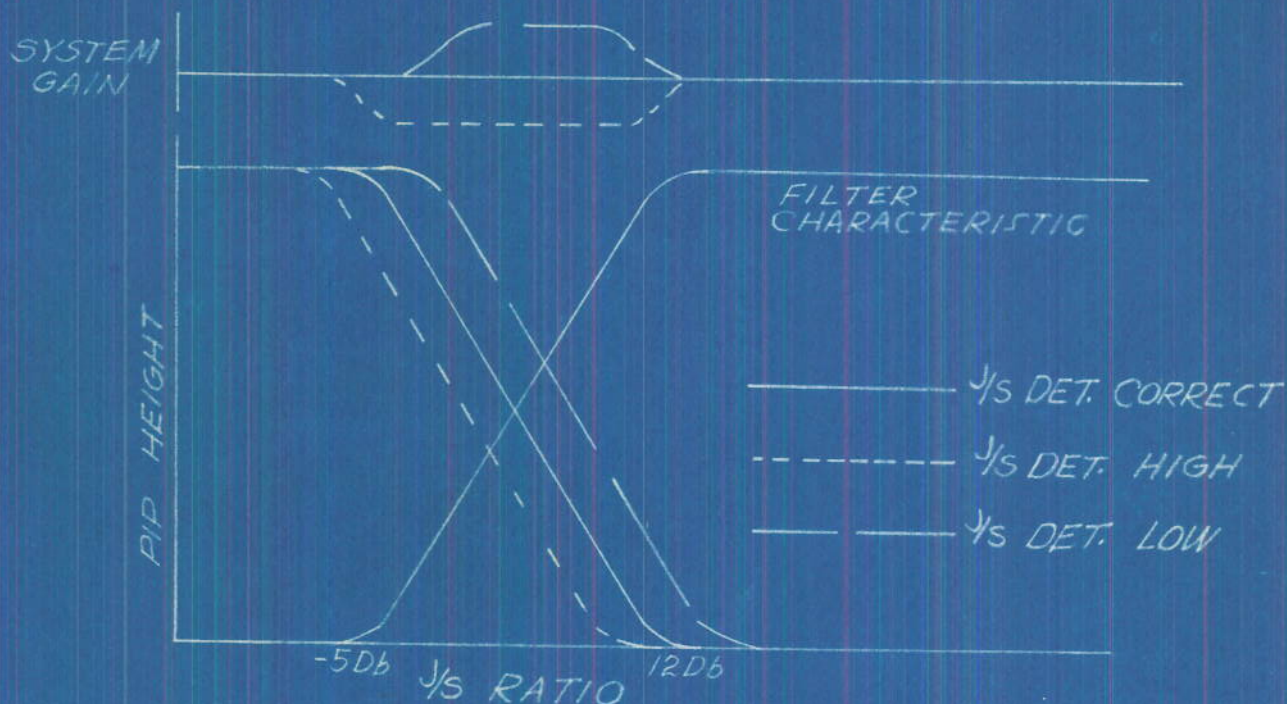
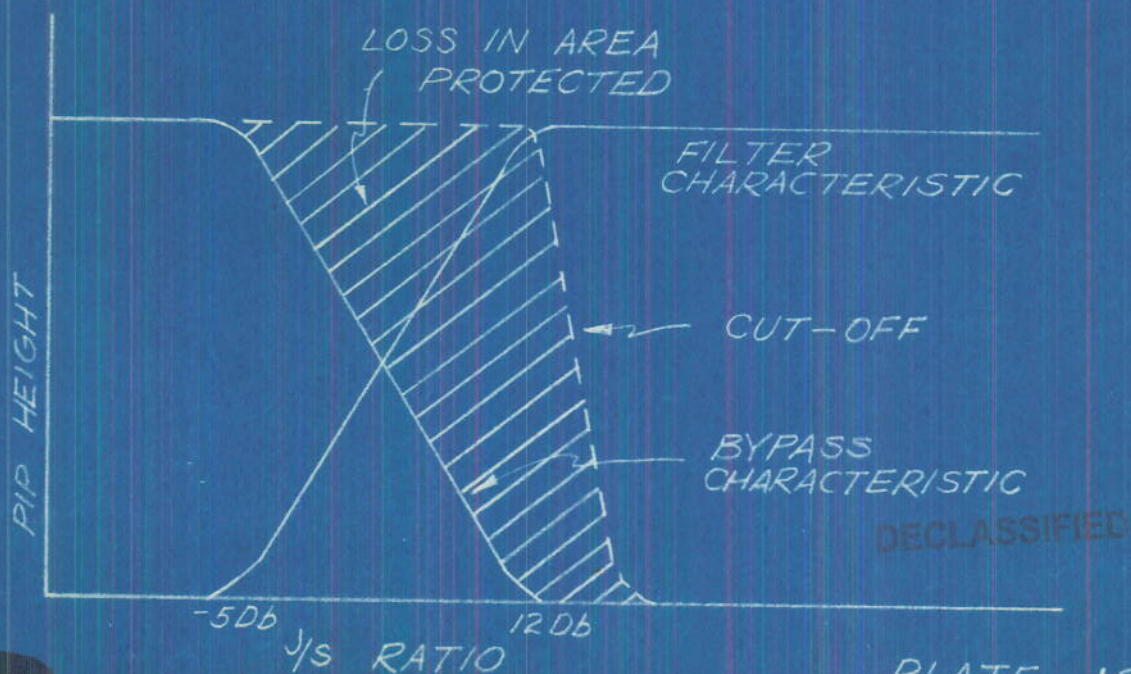
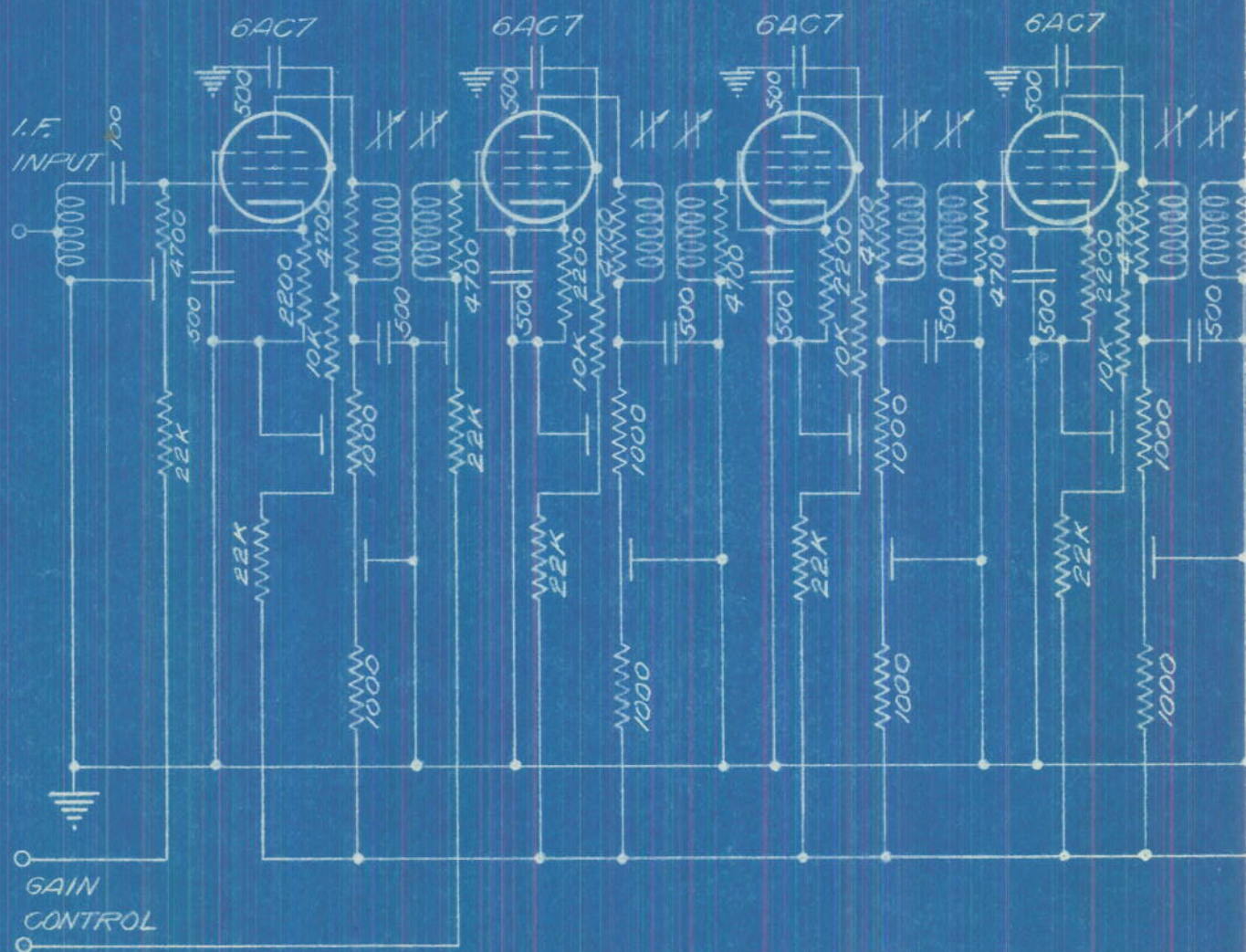


FIGURE B FILTER TYPE BYPASS

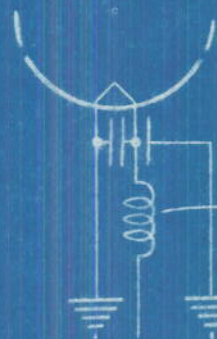


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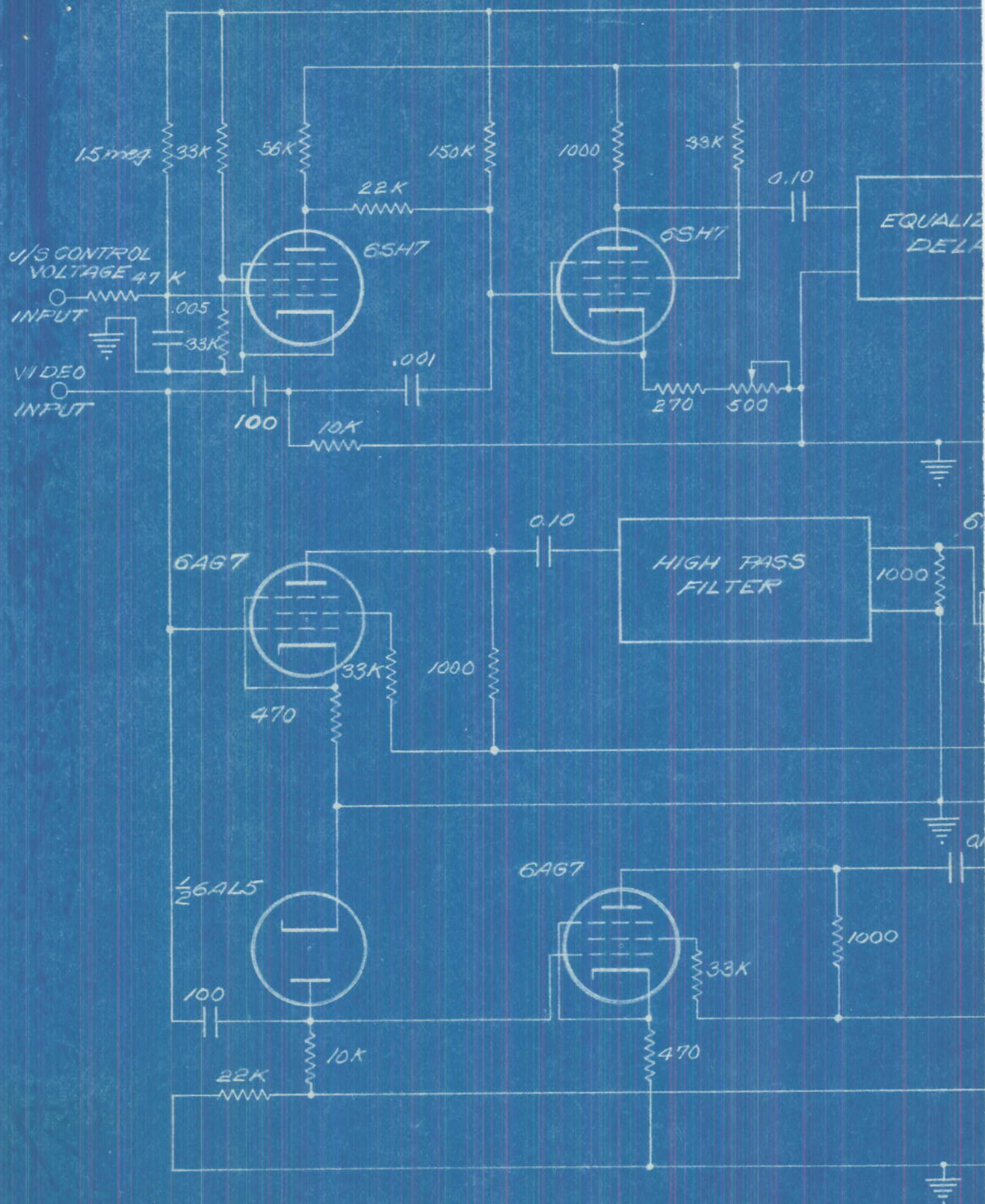


ALL CONDENSOR INDICATED
THUS; 1500 μ mf FEEDTHROUGH



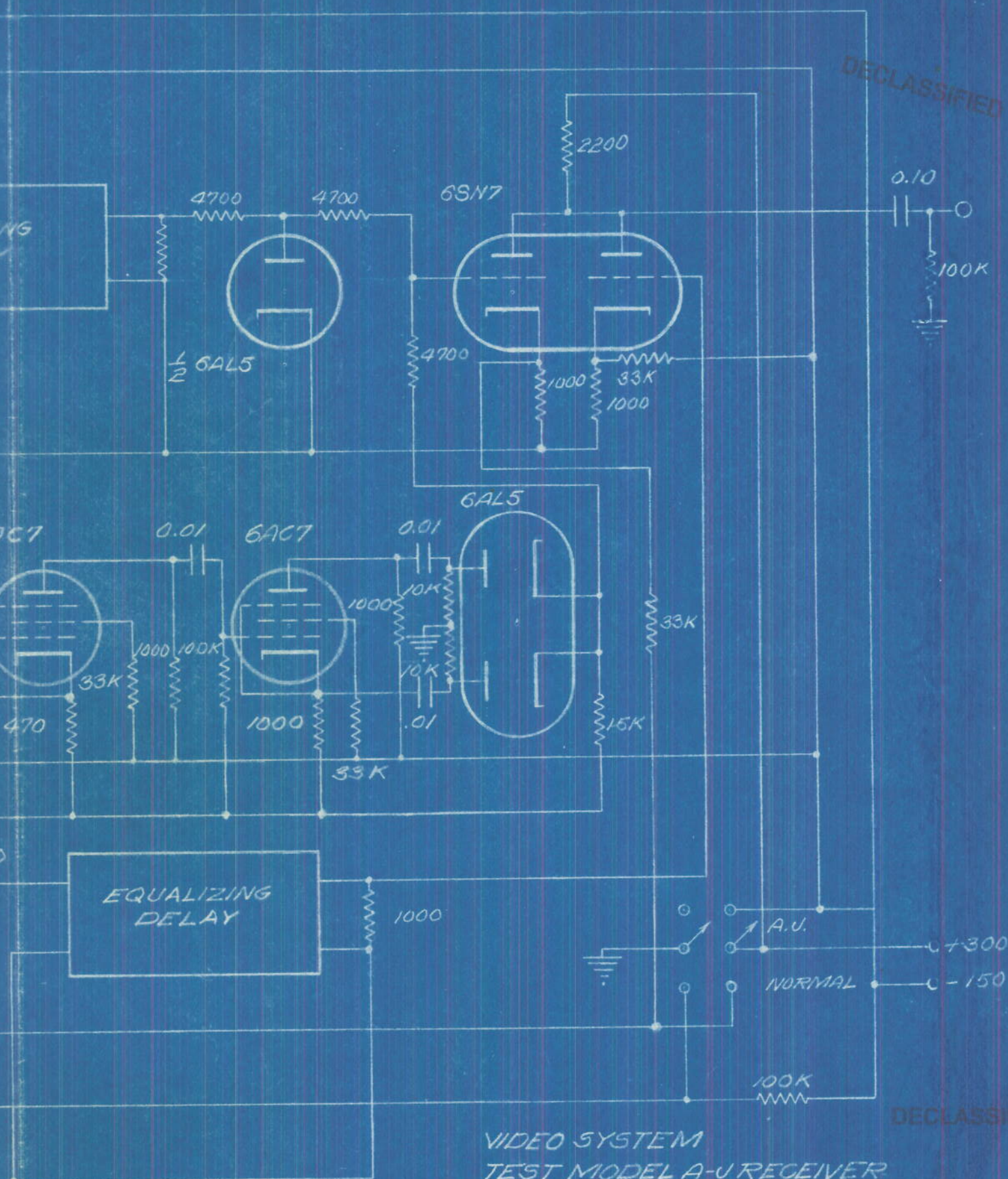
SELF RESONANT
CHOKE—60m

ALL HEATERS



[Redacted] L

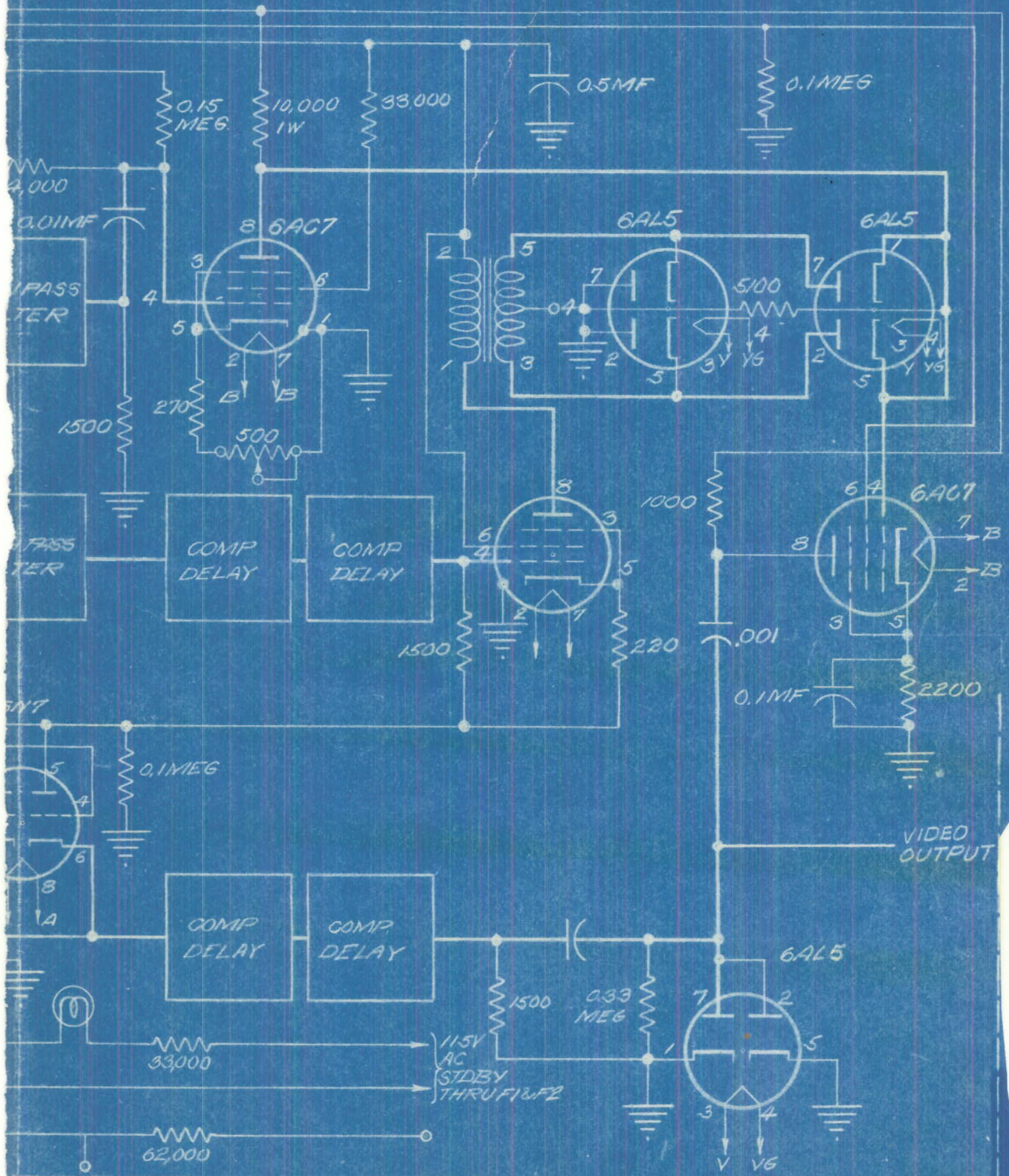
DECLASSIFIED



DECLASSIFIED

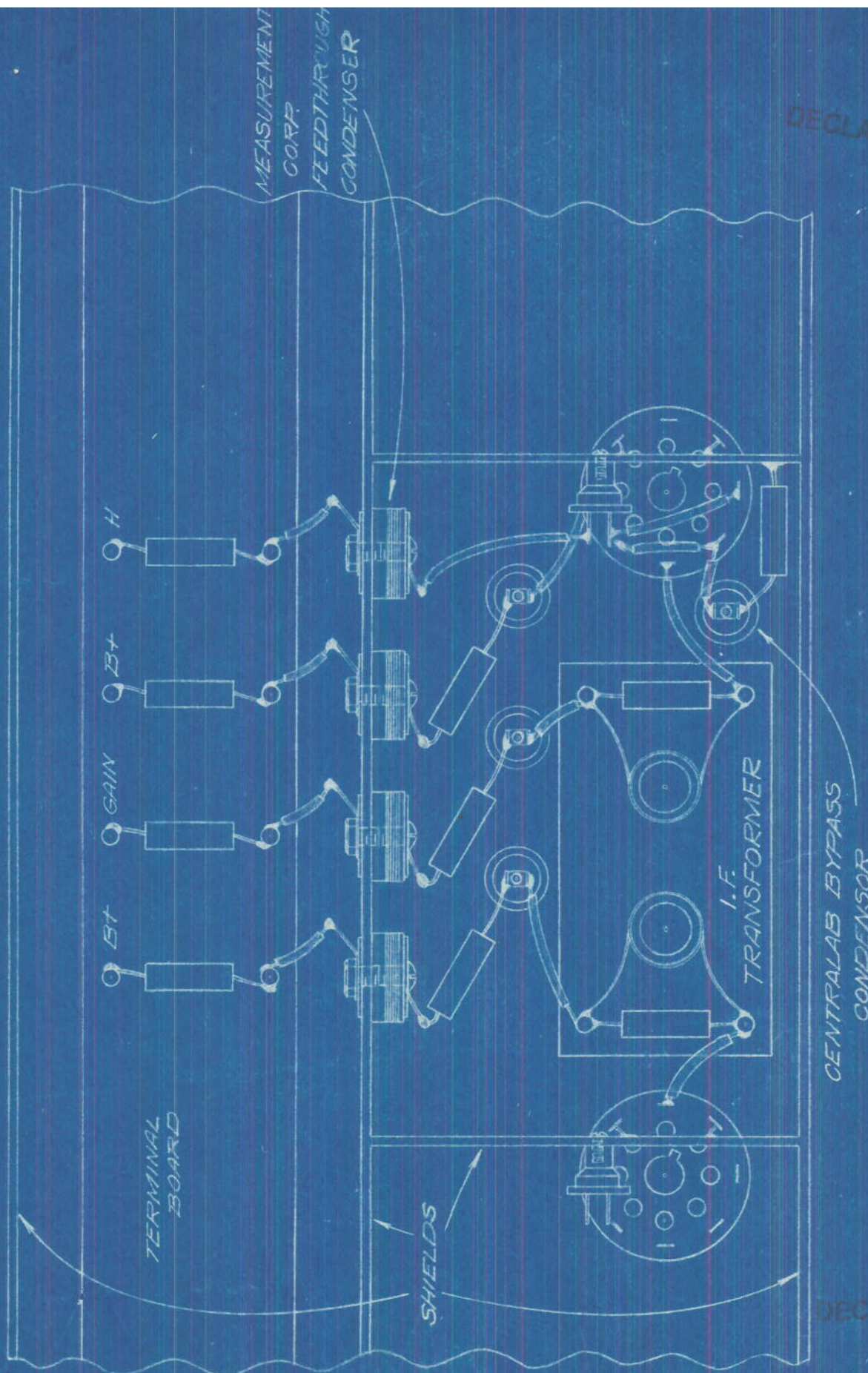
VIDEO SYSTEM
TEST MODEL A-U RECEIVER
FOR MARK 12

VIDEO AU CIRCUIT



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I.F. STAGE LAYOUT
TEST MODEL AU RECEIVER
FOR MARK 12



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PLATE 24