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A CIRCUIT FOR IMPROVING THE ADJACENT-CHANNEL REJECTION OF AN IFF RECEIVER

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A CIRCUIT FOR IMPROVING THE ADJACENT-CHANNEL REJECTION OF AN IFF RECEIVER

D. W. Lynch

7 December 1949

Approved by:

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DEPARTMENT OF THE NAVY OFFICE OF NAVAL RESEARCH

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CONTENTS

ABSTRACT

A "discriminating" second detector has been developed which can be used to reduce the frequency range over which a receiver will respond to pulse-modulated signals. This provides a means for improving the off-channel rejection of a receiver for pulse-modulated signals. The operation of this circuit is discussed and some experimental results are presented.

PROBLEM STATUS

This is an interim report on this phase of the IFF development program. Work is continuing.

AUTHORIZATION

NRL Problem RO3-06R, (BuShips Problem S1234X-S.)
NR 503-060

A CIRCUIT FOR IMPROVING THE ADJACENT-CHANNEL REJECTION OF AN IFF RECEIVER

INTRODUCTION

The present day IFF systems as well as proposed future IFF systems are, in general, pulse-modulated multi-channel systems with each system being allocated a certain frequency band in which to operate. Since the allocated band is limited, it is not only desirable, but may be necessary, to use it in an efficient manner. Therefore, wasted or unused space between channels which is necessary to obtain the required amount of adjacent-channel rejection is undesirable and should be reduced to a minimum.

The adjacent channel spacing, and thus the total number of channels of a given width that can be placed in the allotted band, is partially determined by the amount of adjacent-channel rejection that can be obtained at the receiver. In a pulse-modulated IFF system employing rectangular pulses of short duration (in the order of 1 microsecond), the adjacent-channel rejection problem becomes serious, the difficulty arising as a result of the wide frequency-spectrum of the transmitted signal. Since the usual methods of improving the ordinary (cw) selectivity of a receiver are not effective in this case, special circuits or techniques are required.

The purpose of this report is to describe one special method of improving the adjacent or off-channel rejection of an IFF receiver for pulse-modulated signals. A discriminating second detector has been developed which reduces the frequency range over which a receiver will respond to such signals, thereby providing off-channel rejection. A discussion of the operation of this circuit and some experimental results which have been obtained are presented.

PROBLEM DISCUSSION

The frequency spectrum of an r-f or i-f pulse, such as the one illustrated in Figure 1, in which T is large compared to $\frac{1}{f_0}$, has the familiar $\frac{\sin x}{x}$ amplitude distribution shown in Figure 2. As a result of this frequency spread, a conventional band-pass receiver will appear to have much less off-channel rejection to pulsed signals than it does to ordinary c-w signals. This effect is illustrated in Figure 3 which shows the response curves of an i-f strip as measured with a c-w signal and with a pulsed signal. The i-f strip used in these tests was one of the stagger-tuned strips used in the receivers of the AN/CPX-3 and AN/CPX-4 equipments of the Mark V IFF system. A simplified schematic diagram of the strip is shown in Figure 4.

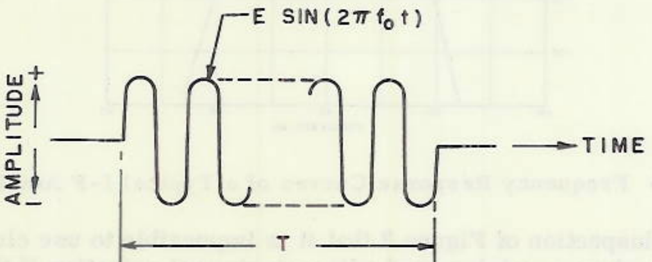


Fig. 1 Idealized R-F or I-F Pulse

The pulsed signal used for testing the amplifier consisted of single pulses of 1 microsecond duration with a recurrence rate of 400 per second. The effective rise and decay times of the pulse were approximately 0.1 microsecond or 10% of the duration of the pulse. The pulse shape at the output of the detector was, of course, dependent upon the spacing between the center frequency of the strip and the frequency of the signal. In this case, as well as in all other pulse measurements discussed in this report, the peak of the detected pulse was taken as a measure of the output since this is, in general, a good measure of output for IFF applications.

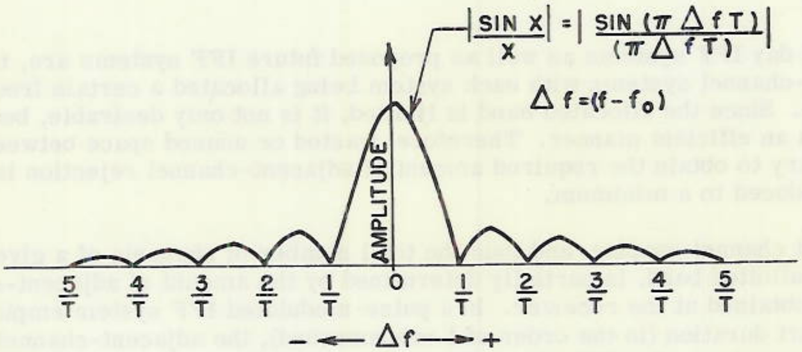


Fig. 2 Amplitude Distribution of the Frequency Spectrum of the Pulse in Figure 1.

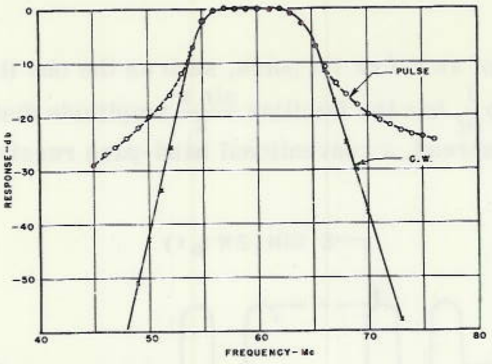
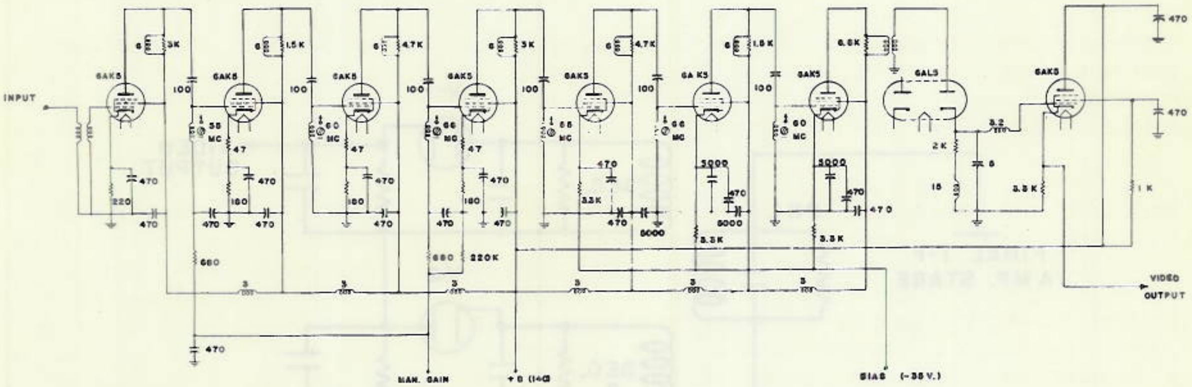


Fig. 3 Frequency Response Curves of a Typical I-F Amplifier

It is evident upon inspection of Figure 3 that it is impossible to use closely spaced channels in a pulse-modulated system requiring good adjacent-channel rejection if the receiver is of the conventional type. Thus to avoid large unused or wasted portions of the frequency band between channels, it is necessary to make some change in the system or in the receiver. It should be noted again that this apparent defect is not primarily a fault of the receiver, but is a consequence of the nature of the transmitted signal.

The effect illustrated in Figure 3 and discussed in the preceding paragraphs has been known and understood for many years. In recent years, however, the increased number of applications of pulse systems, along with the fact that the ever increasing use of radio in general makes it necessary to use the frequency bands efficiently, has caused a rising interest in the problem. The work described in the following pages, although of a general nature and applicable to other than IFF systems, was initiated as a direct consequence of the measurements made on an experimental IFF receiver.[1]



ALL RESISTANCE VALUES ARE EXPRESSED IN OHMS.
ALL CAPACITANCE VALUES ARE EXPRESSED IN MICRO-MICROFARADS.
ALL INDUCTANCE VALUES ARE EXPRESSED IN MICRO-HENRIES.

Fig. 4 I-F Amplifier Schematic

POSSIBLE SOLUTIONS

There are two obvious paths to be followed in attempting to improve the effective adjacent channel rejection in a pulse system. The first, and undoubtedly the most obvious and direct attack, is to attempt to control the frequency spectrum of the transmitted signal so as to limit it to a narrow band. The second, and somewhat indirect attack, is to attempt to provide the receiver with a means of discriminating against the sidebands of off-frequency signals.

The methods involving the control of the transmitted-frequency-spectrum will not be considered except to note that, in general, the complexities of the commonly known methods outweigh any advantages realized.[2] The solution involving the receiver, which on first thought might appear to be more difficult than the other, can be accomplished through the use of special circuits.

HISTORICAL NOTE CONCERNING PAST WORK

Before discussing the newly developed circuit for improving off-channel rejection in pulse-modulated systems, it is of interest to see what circuits, if any, have already been devised for this purpose. A search of the previous work on this problem revealed only one circuit which had been used with any appreciable success. This circuit, commonly known as the "Ferris discriminator,"[3] was first used to improve the off-channel rejection in distance measuring equipment.

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[1] Easton, R. L., Furlow, W. M., Lynch, D. W., Rhodes, L. T., and Ruhlig, A. J. "An Experimental Omni-Channel Receiver for an IFF System," NRL Report R-3432, March 16, 1949 (Secret).

[2] See for example, "Crystal Control at 1000 Mc for Aerial Navigation," Federal Telecommunication Laboratories, Inc., Tech. Memo. No. 359, March 1949, p. 6.

[3] Ibid.

The Ferris discriminator is an a-m second detector which discriminates against signals in the passband which are sidebands of pulses with center frequencies outside the passband.[4] One arrangement of the basic circuit is shown in Figure 5. Secondary 1 is adjusted to have a bandwidth approximately equal to the resulting bandwidth desired. Secondary 2, the primary, and all preceding selective circuits are adjusted to have a resultant bandwidth somewhat wider than the desired bandwidth. The couplings between each secondary and the primary are adjusted so that the peak output of secondary 1 is of the order of twice the peak output of secondary 2. As a result of these adjustments and considering the polarity resulting from the method of connecting the secondaries, the c-w response curves of the circuit would appear something like the curves sketched in Figure 6.

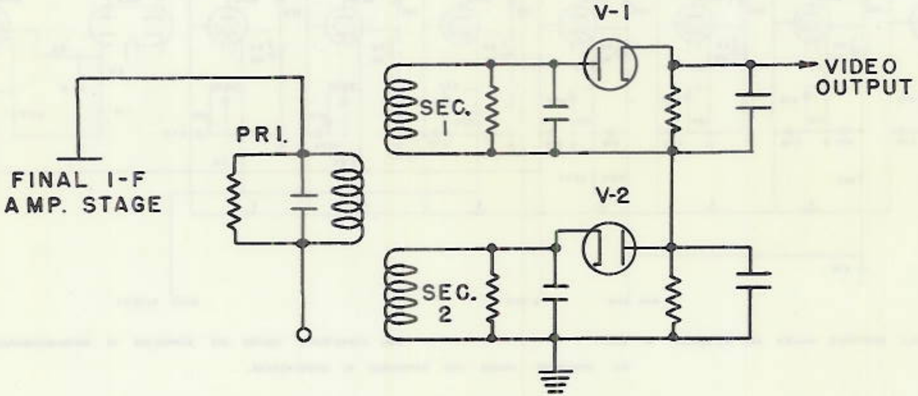

Fig. 5 Ferris Discriminator

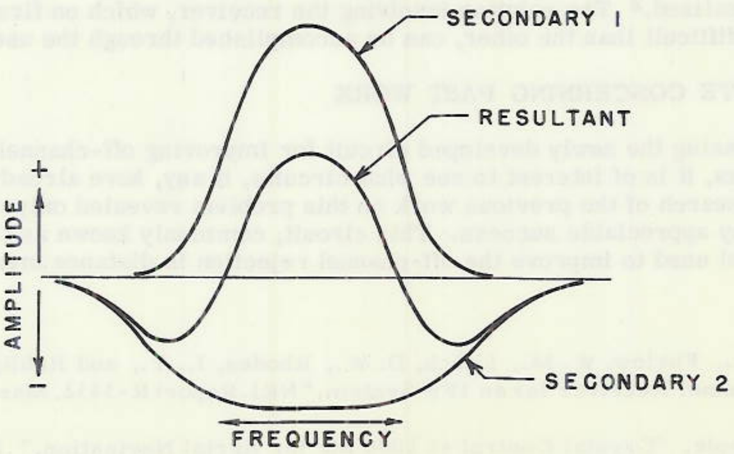

Fig. 6 C-W Curves of the Ferris Discriminator

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[4] "Center frequency" is used here in reference to the frequency corresponding to the maximum amplitude present in the frequency spectrum of the signal.

The operation of the Ferris circuit on pulsed signals is similar to its operation on c.w. By proper choice of relative bandwidths and couplings, the circuits can be made to give a resultant positive output pulse if the center frequency of the pulse is within the passband of secondary 1 and a negative output if the center frequency is outside the passband of secondary 1. This simply means that, if the center frequency of the pulse is in the passband of secondary 1, the amplitude of the pulse resulting from the portion of the spectrum of the pulse falling in the passband of secondary 1 is greater than the amplitude of the pulse resulting from the portion of the spectrum falling in secondary 2. Similarly, if the center frequency of the pulse is outside the passband of secondary 1, the amplitude of the pulse resulting from the portion of the spectrum falling in the passband of secondary 1 is less than the pulse resulting from the portion of the spectrum falling in the passband of secondary 2. As a result, if only positive outputs are accepted, the Ferris discriminator will provide essentially infinite off-channel rejection to pulsed signals as well as to c-w signals.

Experimentally, it was found that the bandwidth of secondary 2 must be two to three times as wide as that of secondary 1 to obtain good off-channel rejection of pulsed signals. This, of course, requires that the i-f amplifier and any r-f selective networks have a bandwidth at least twice as wide as the resultant bandwidth desired. Thus,the use of the Ferris discriminator has two disadvantages, the loss in gain in the passband due to partial cancellation in the detector circuits, and the effective loss in bandwidth with the accompanying deterioration of the noise figure and gain of the receiver. In view of these disadvantages, other possible circuits were investigated and, as a result, the circuit to be described was developed.

CIRCUIT DESCRIPTION

The circuit which was developed to provide increased off-channel rejection to pulsed signals with less loss in gain and bandwidth than the Ferris discriminator is also a discriminating second detector.[5] The circuit is designed so that it distinguishes between the signals in the i-f passband resulting from i-f pulses with center frequencies in the passband and those resulting from i-f pulses with center frequencies outside the passband. The principle underlying the operation of the circuit is based on the fact that the frequency spectrum of an i-f pulse is symmetrical about, and has a maximum at, the center frequency of the pulse. This will become clear as the operation of the circuit is discussed in more detail.

A simplified schematic diagram of the basic discriminating detector circuit is shown in Figure 7. The primary is tuned to the center of the i-f passband and is adjusted to have a bandwidth equal to that of the i-f amplifier preceding it. Secondary 1 is also tuned to the center of the i-f passband but has a bandwidth somewhat less than that of the primary. Secondary 2 is tuned so that its center frequency falls just below the passband of secondary 1 and is designed to have a bandwidth less than that of secondary 1. Secondary number 3 is adjusted in a similar manner, only it is tuned to the high side of the passband of secondary 1.

The transformer, consisting of the primary and three secondaries, is designed to minimize the coupling between secondaries. The couplings between the primary and the various secondaries are adjusted for optimum results. For most practical pulse widths and bandwidths, secondary 1 is coupled more closely to the primary than either 2 or 3; 2 and 3 have approximately equal coupling to the primary.

The output of secondary 1 is detected by V-1 and appears across the filter R-1, C-1. The outputs of 2 and 3 are detected by V-2 and V-3, which share a common filter R-2, C-2. The filters are connected in series as illustrated in Figure 7, so that the resulting video output is the algebraic sum of the voltages appearing across the separate filters.

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[5] This circuit will be referred to throughout this report as the "discriminating detector" to distinguish it from the Ferris discriminator.

The operation of the circuit is easily understood if the c-w case is considered first. A frequency-modulated c-w signal was fed into an amplifier similar to the one shown in Figure 4, in which the second detector had been replaced with the type just described. The waveforms appearing in the detector circuit were observed on an oscilloscope in the conventional manner. The positive output appearing across R-1, C-1, is shown in Figure 8. Figure 8a shows the main

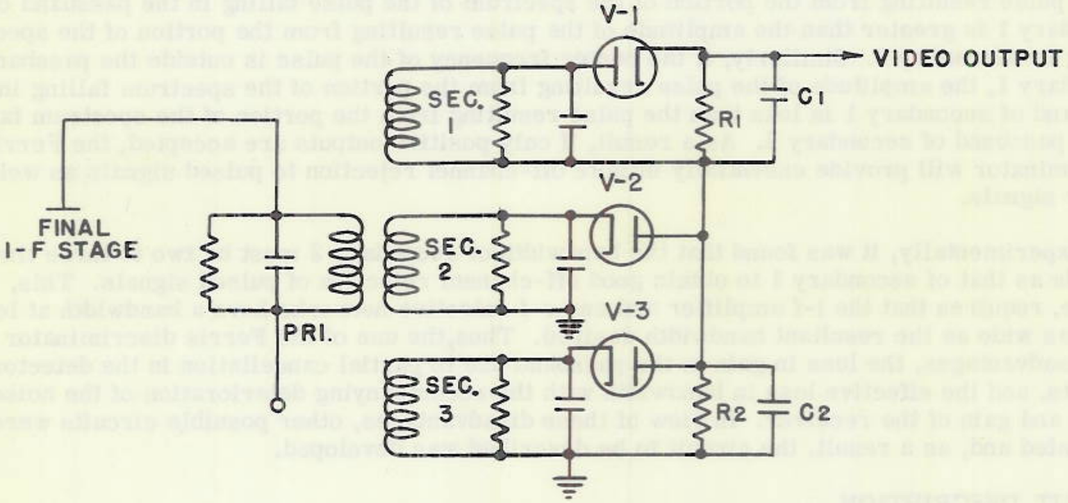

Fig. 7 Schematic Diagram of the Discriminating Detector

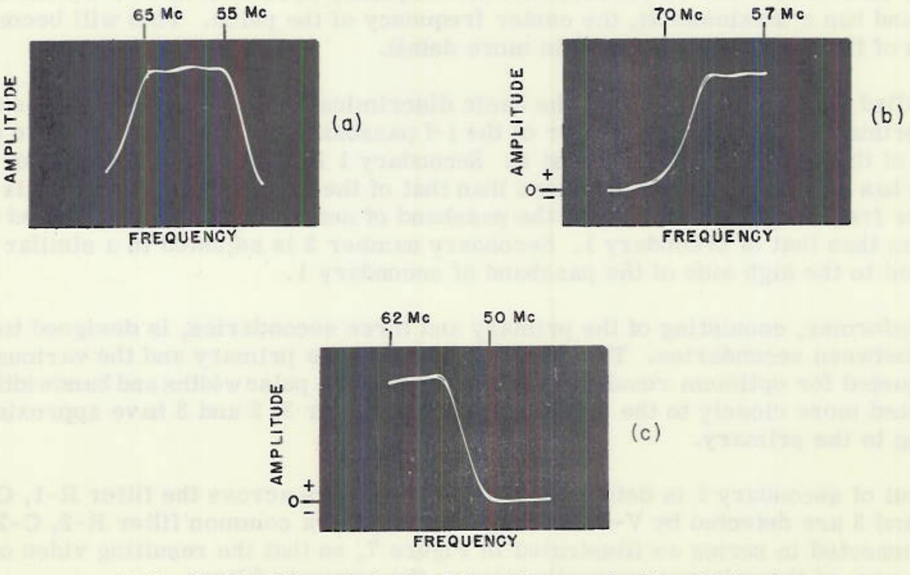

Fig. 8 Positive Output of the Discriminating Detector

portion of the response curve, while, in 8b and 8c, the frequency of the signal has been shifted to show the complete high and low frequency skirts of the response curve with the base line or zero level plainly visible. In a similar manner, Figure 9 shows the characteristic double-peaked negative output appearing across R-2, C-2. The resulting output of the circuit, which is simply the algebraic sum of the outputs shown in Figures 8 and 9, is shown in Figure 10. Thus for frequencies within the passband the output is positive, for frequencies just outside the passband the output is negative, and for frequencies still further from the passband the output is zero. Obviously, in any practical application where the negative output is detrimental, a unilateral or clipping circuit could be incorporated in the video circuits following the detector to eliminate the undesired portion of the output.

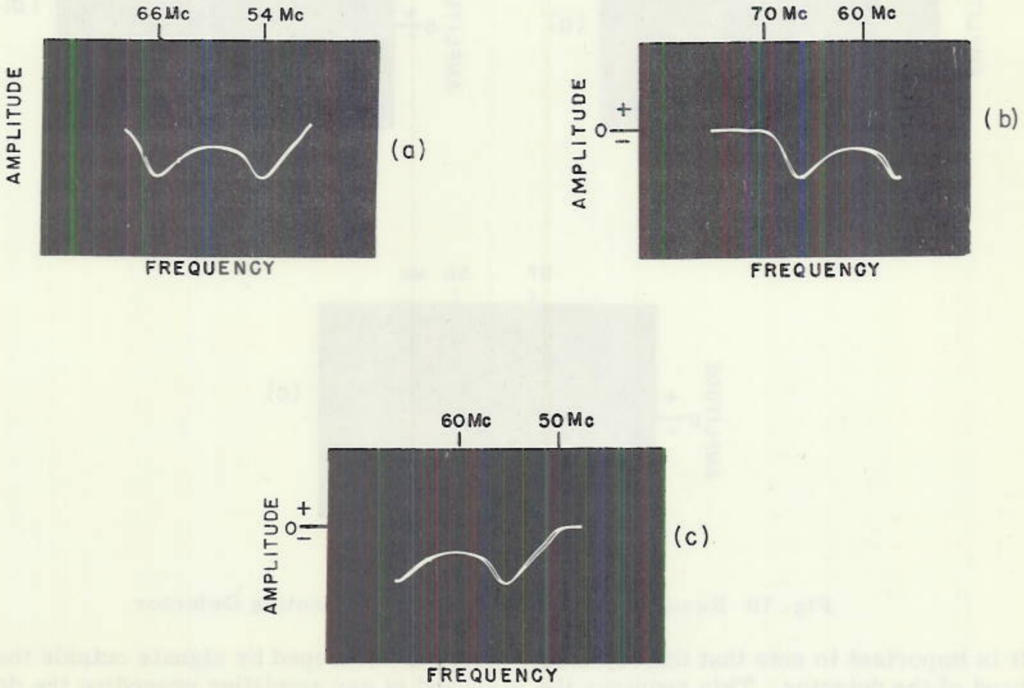

Fig. 9 Negative Output of the Discriminating Detector

The operation of the circuit with pulsed signals is similar to the c-w operation, being complicated only by the broad frequency-spectrum of the pulsed signal. When the center frequency of a received pulse falls within the resultant passband of the detector, the rejecting voltage (the voltage appearing across R-2, C-2) is small and the operation of the circuit is essentially the same as that of a conventional detector. However, when the center frequency of a received pulse is either above or below the passband of the detector, the rejecting voltage is increased and the voltage appearing across R-1, C-1, is reduced. With the proper selection of circuit parameters, the resulting output will be approximately the same as a conventional detector for signals with center frequencies in the passband and will be essentially zero or negative for signals with center frequencies outside the passband. Again, as in the c-w case, for any application in which the negative output is detrimental, it can be clipped, thereby leaving only the positive output for signals in the passband and zero output for all signals outside the passband.

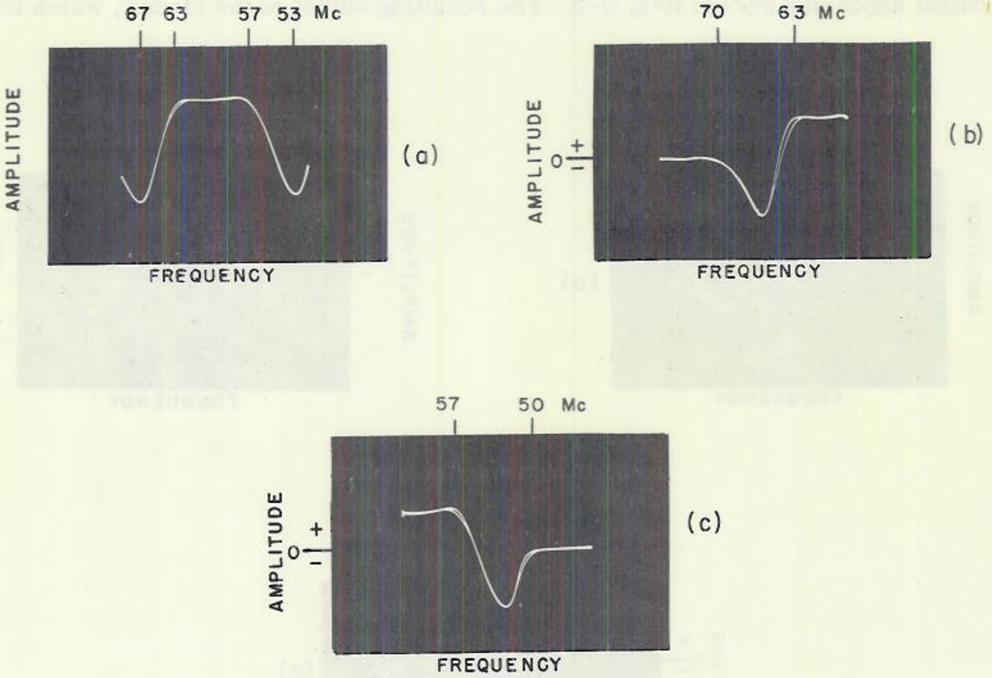

Fig. 10 Resultant Output of the Discriminating Detector

It is important to note that the rejecting voltage is developed by signals outside the resultant passband of the detector. This requires the passband of any amplifier preceding the detector to be somewhat wider than the resultant passband, or, stated in another way, the use of this type of detector is accompanied by a loss in overall bandwidth in the detector circuits. This effect will be apparent in some of the experimental results to follow.

EXPERIMENTAL RESULTS

Some experimental results obtained with the discriminating detector have already been presented in Figures 8, 9, and 10. These results which were used in describing the operation of the circuit apply primarily to c-w operation. Since the circuit was originated as a means of improving the adjacent-channel rejection of pulse-modulated signals, the results obtained with pulsed signals will be of more significance here. However, since it is conceivable that the circuit might be useful in certain c-w applications, a comparison of the c-w response to that obtained with a conventional detector may be of interest.

The c-w response of the circuit shown in Figure 4 was measured, and a second set of measurements made after replacing the detector with a discriminating type. The results of these measurements are shown in Figure 11, in which the dotted curve represents the response of the conventional detector, and the solid curve represents the response of the discriminating detector. The measurements were obtained by selecting a convenient output level and measuring the signal level required to maintain this output level at the various frequencies.

The fundamental effect of the discriminating detector on the c-w response curve, as evidenced by Figure 11, is the marked increase in the slope of the skirts of the curve. This is, of course, accompanied by a reduction in bandwidth which would tend to produce the same results. It should be evident, however, that this effect in itself would account for only a small portion of the difference in the slopes of the skirts of the two curves.

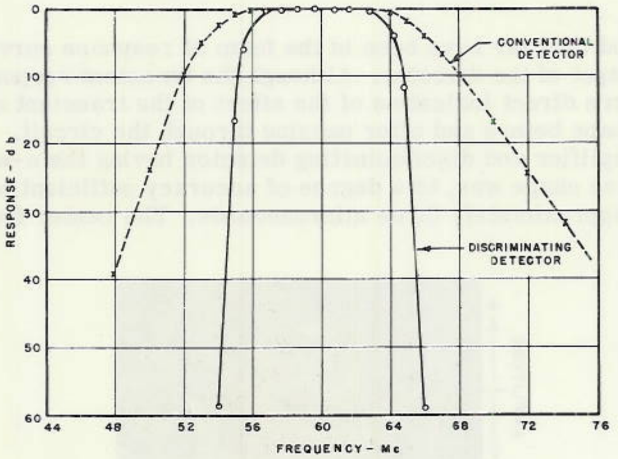

Fig. 11 C-W Response Curves

It is to be noted that, although it is not apparent in Figure 11 because the curves are normalized response curves, there was a loss in overall gain of approximately 3 db in going from the conventional detector to the discriminating circuit.

In a manner similar to that used in the c-w case, the response curves of the amplifier with the two different detectors were measured with pulse-modulated signals. These results are shown in Figure 12, where again the dotted curve corresponds to the conventional circuit and the solid curve corresponds to the discriminating detector. The pulse duration used in obtaining the data of Figure 12 was approximately one microsecond. The pulse response of the discriminating detector was also checked with a pulse duration of three microseconds and found to be essentially the same as that for one microsecond.

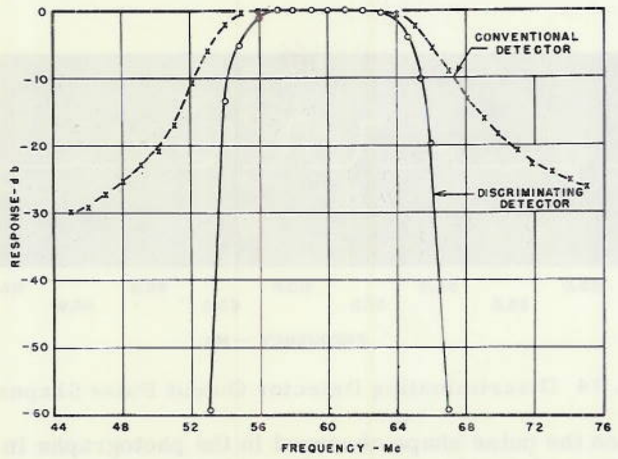

Fig. 12 Pulse Response Curves

Again, as in the c-w case, the principal difference between the response curves obtained with the different detectors is in the slope of the curves in the off-channel regions. This effect is even more pronounced in the pulse case than it was in the c-w case. The reduction in bandwidth and overall gain is approximately the same for pulse modulated signals as was observed for c-w signals.

The results presented thus far have been in the form of response curves based on the peak amplitude of the pulse output of the detector. Although the transient response of the circuit will affect these curves, a more direct indication of the effect of the transient response is obtained by observing the pulse shape before and after passing through the circuit. A pulse-modulated signal was fed into an amplifier and discriminating detector having the c-w response shown in Figure 13. The input pulse shape was, to a degree of accuracy sufficient for this test, rectangular with a duration of approximately three microseconds. The center frequency of the pulse was varied and the detector output observed. These results are presented in panoramic form in the photographs of Figure 14. It is to be noted that for frequencies just outside the passband the output is actually negative. This is the output that, for some applications, might require clipping.

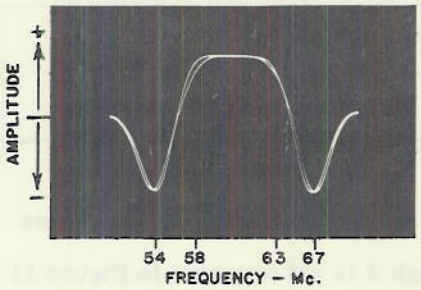

Fig. 13 C-W Response of the Amplifier and Detector Used to Observe the Pulse Shapes of Figure 14

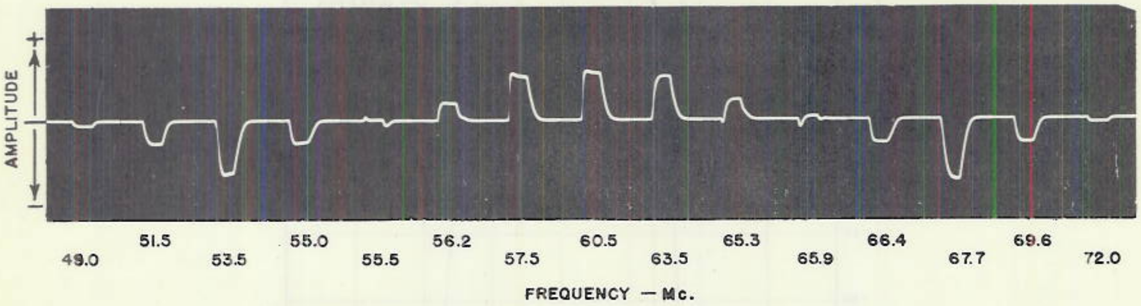

Fig. 14 Discriminating Detector Output Pulse Shapes

The principal effect on the pulse shape observed in the photographs in Figure 14 is the integration effect on the leading and trailing edges. This effect was in part due to the values of the components used in the detector circuit filters, R-1, C-1, and R-2, C-2. More recent measurements made with different values for these elements resulted in this effect's being reduced but not completely eliminated.

It was observed experimentally that there is some relationship among the time constants of the two filter circuits of the discriminating detector that must be satisfied for optimum performance of the circuit. This relationship was found, as might be expected from a study of Figure 7, to be that the charging as well as the discharging rates of the two filter circuits should be approximately equal. When this relationship was violated, it was observed that the pulse shape was distorted for signals in the passband and/or a positive spike corresponding to the leading or trailing edge of the pulse appeared in the output for signal frequencies adjacent to the passband.

In addition to the experimental results already discussed, a series of measurements were made to determine the effect of adjacent-channel or off-channel interference. It was found that this type of interference was, in effect, instantaneous; i.e., for interference to occur, the desired signal and the interfering signal pulses must be overlapping in time, with the interference taking place only during the overlap.

The amount of interference caused by simultaneous signals was measured for an amplifier and discriminating detector adjusted to produce a response curve similar to that of Figure 13. Signals from two sources, one with a frequency corresponding to the center frequency of the passband and the other with a frequency outside the passband, were fed into the amplifier.[6] A convenient output level was selected and the signal strength required to maintain this output in the presence of the interfering signal was measured for various levels and frequencies of the interfering signal. The results of these measurements are shown in the family of curves of Figure 15. It will be noticed that interference did not occur when the frequency difference between the two signals was 4 Mc. This is explained by the fact that this spacing put the interfering signal at the zero gain point between the passband and the rejection region of the response curve. Maximum interference occured when the frequency difference was approximately 6 Mc.

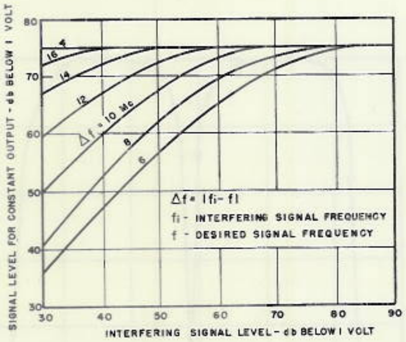

Fig. 15 Simultaneous Signal Interference

Another series of measurements was made to determine the maximum interference at different signal levels caused by an interfering signal of approximately the same strength as the desired signal. The output without intereference was noted at each signal level, and the increase in signal required to maintain this output in the presence of an interfering signal at the frequency of maximum interference and a level equal to the original signal-level was measured. The resulting curve is shown in Figure 16. It was found that the frequency of interfering signal that caused maximum interference was essentially independent of signal level. In addition, it was observed that, for the particular adjustment of the circuit used in this test, the interference was approximately the same for interfering signal frequencies above and below that of the desired signal.

---

[6] It was found that simultaneous signals, the frequencies of which were both in the passband of the detector, simply added.

It is most important to note that the results of Figures 15 and 16 are not unique for the discriminating detector but are simply the results obtained with one particular adjustment of the circuit. With different coupling coefficients, Q's, etc., results widely different from those of Figures 15 and 16 can be obtained.

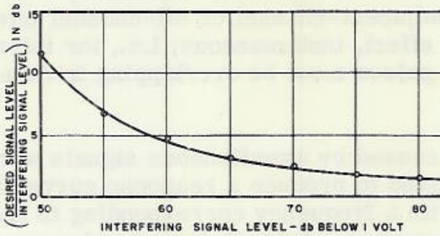

Fig. 16 Maximum Interference Curve

Finally, as a typical example of the results that can be achieved with the discriminating detector, the i-f response of an experimental IFF receiver in which the circuit was used is shown in Figure 17. The receiver required two i-f channels, each approximately 8 Mc wide at the 6 db points, and spaced approximately 10 Mc between center frequencies. In addition, it was necessary to have at least 30-db attenuation at the crossover point between channels. Since the signals to be received were pulse-modulated with pulses of 1 microsecond duration, it was impossible to achieve these results with a conventional i-f strip and detector. The results shown in Figure 17 were obtained by using two i-f strips similar to the one shown in Figure 4, except that the conventional detectors were replaced with discriminating detectors. The strips ahead of the detectors each had a c-w bandwidth of about 10 Mc. This was reduced to an overall pulsed-signal bandwidth of 8 Mc by the loss in bandwidth required in the detector.

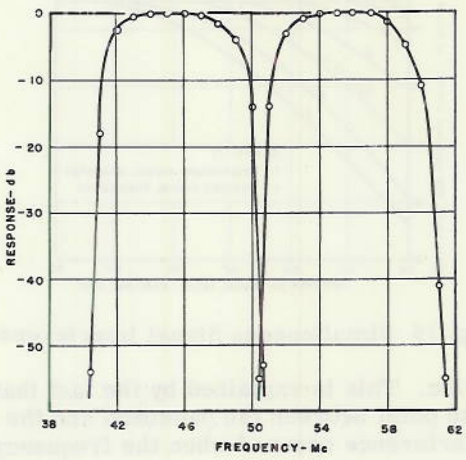

Fig. 17 Pulse Response of Two-Channel I-F Amplifier

CONCLUSIONS

The experimental results just discussed show that the discriminating detector provides a means for increasing the off-channel rejection of a receiver for systems employing pulse-modulated signals with the possible exception of systems wherein there would be simultaneous signals on adjacent channels. In the latter case, the exact specifications of the system would have to be known in order to determine the effect of adjacent-channel interference and thus determine if the circuit could successfully be used in the system.

The price that must be paid for the increase in rejection is, in addition to the physical components and complications of the detector circuit, a loss in gain in the detector and an increase in the required bandwidth of the circuits preceding the detector. The loss in gain is, as a rule, not too serious since it occurs at a high-level point in the circuit and does not materially affect the noise figure of the receiver and, if necessary, can be overcome with additional amplification. The increased bandwidth required in the circuits preceding the detector may be serious, since, in addition to requiring more components to obtain a given gain, there is the corresponding deterioration in noise figure of the receiver. In this respect, however, the results obtained with the discriminating detector are better than those that have been obtained at these bandwidths and pulse widths with a Ferris discriminator. As a result, the discriminating detector appears to be the better method for increasing the off-channel rejection of IFF receivers in systems employing channel widths and pulse widths comparable to those used in the tests described.

PROPOSED FUTURE WORK

The present plans for future work on the problem of adjacent-channel rejection in IFF receivers include an investigation of additional applications of the Ferris discriminator and the discriminating detector with special emphasis on narrow channel widths. In addition, a study is planned to determine if a multi-channel i-f amplifier with good off-channel rejection on each channel can be obtained by using a single wide-band amplifier and several narrow-band detectors staggered across the band of the amplifier.

* * *