type. Several cw magnetrons are now being constructed for noise-measurement investigations.

Regarding the rectifiers indicated, it is interesting to note that the hydrogen-filled rectifier indicated no emission, which is perhaps attributable to hydride formation.

CONCLUSIONS

In conclusion, let us summarize the essential features and properties of the L cathode. It consists essentially of barium oxide contained behind a wall of porous tungsten. During the operation of the cathode, the barium oxide is reduced gradually, and free barium resulting from this reduction escapes through the pores and forms on the surface a monatomic layer of barium bound to the surface of the tungsten by oxygen. Hence the work function of the tungsten is reduced from 4.5 to 1.8 volts.

The essential advantages of the L cathode are its capacity to produce high-thermionic emission, combined with long life. The life of an L cathode is dependent entirely upon the temperature of operation and the amount of barium oxide available in the dispenser. It is particularly suited for application in microwave tubes since it can be machined to exact tolerances.

ACKNOWLEDGMENT

Some of the discussion has been taken from the paper of H. J. Lemmens, M. J. Jansen, and R. Loosjes, *Philips Tech. Rev.*, vol. 11, pp. 341–350; June 1950, as well as from private communications with R. Loosjes.

The author wishes to express his gratitude to O. S. Duffendack, F. K. du Pré, and E. S. Rittner, for their interest and their many valuable suggestions.

The Theory of Amplitude-Modulation Rejection in the Ratio Detector

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Summary—**The procedure for a complete mathematical analysis of the AM-rejecting properties of the ratio detector is presented. The operation with 100-per cent efficient diodes is first treated, and it is shown that in this case compensating resistors which reduce the effective efficiency of the diodes must be used to obtain optimum AM rejection. The operation with practical diodes is then treated and design charts for optimum AM rejection are presented. From the theory, the effect of variations in ratio-detector transformer parameters upon the AM-rejection properties is predicted. Unbalanced effects and the manner in which they can be made to cancel each other mutually are briefly described. It is pointed out that the degree of apparent limiting action within the ratio-detector circuit is incidental and unrelated to its AM-rejection properties, and thus represents an inadequate design basis for the ratio detector.**

I. INTRODUCTION

IN ORDER to obtain the full benefits of FM reception, an FM receiver should include an FM-detector system which is insensitive to amplitude modulation. A few years ago a new FM detector, called the "ratio detector," which did not require the use of a limiter, was introduced in receivers being marketed. Since then this detector has been rather widely use in FM receivers and in the sound ends of television receivers. However, in spite of wide usage, the design of the ratio detector is still almost entirely empirical. Several papers have been presented giving a general story on the operating characteristics of this device, but an accurate mathematical analysis has not been presented and the AM-rejection properties have not been adequately explained. The purpose of this paper is to outline a procedure for a complete mathematical analysis of the AM-rejection properties of the ratio detector, giving the results of the complete analysis in the form of graphs to be used for designing ratio-detector circuits. Since a description of the general operating characteristics has been given in the literature,[1] it will not be repeated here.

The complete mathematical analysis of the AM-rejection properties of the ratio detector is lengthy and involved. Presentation of all steps is therefore beyond the scope of this treatment.[2] Instead, the procedure followed will be outlined and the essential background material presented. The complete analysis produces results which are in agreement with experiment. These results will be presented.

II. THE RATIO DETECTOR AND ITS EQUIVALENT CIRCUIT

The mathematical analysis of the ratio detector is simplified through the use of an equivalent circuit. The development of this equivalent circuit from a ratio detector, using either a phase-variation discriminator transformer or a side-tuned transformer, is shown in Fig. 1. The rf circuit components to the left of terminals

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[1] B. D. Loughlin, "Performance characteristics of FM detector systems," *Tele-Tech*, vol. 7, p. 33; January, 1948.

[2] The complete mathematical analysis is given in the Hazeltine Electronics Report #7096.

1, 2, and 3 (Figs. 1(a) and 1(b)) can, with complete generality, be represented by two generators (either current or voltage) and three impedances (connected either as a Y or Δ). For convenience, the form using two current generators and a delta connection of impedance is used here, giving the equivalent rf circuit shown in Fig. 1(c).

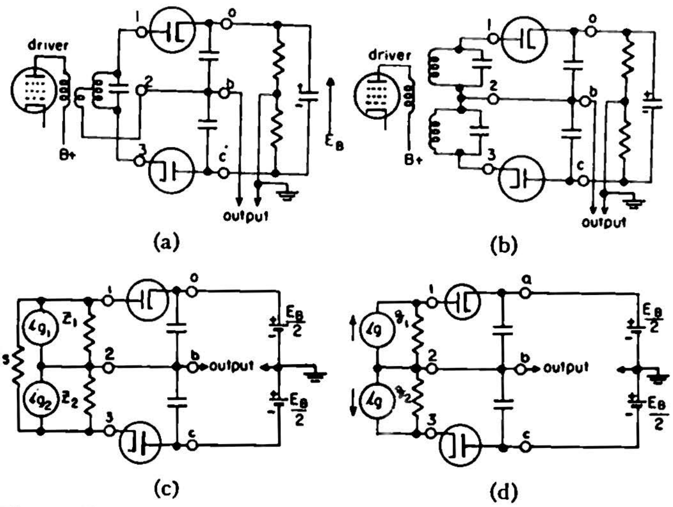

Fig. 1—Development of equivalent circuit for ratio detector. (a) Phase variation. (b) Side-tuned. (c) Equivalent. (d) Approximate.

To further develop the equivalent circuit, the dc circuit components to the right of terminals a, b, and c can be simplified. For a study of dynamic (audio-frequency) AM-rejection properties, this combination of two resistors and a large condenser can be replaced by a center-tapped battery since the large condenser holds the voltage between terminals a and c constant, as far as dynamic variations are concerned. However, the magnitude of this battery voltage is determined by the average operating level.[3] This gives the equivalent circuit as shown in Fig. 1(c).

From the equivalent circuit it is seen that the ratio detector consists fundamentally of two diode rectifier circuits whose dc output terminals are connected in series across a battery. Thus, the circuit as viewed from the dc side is much like two dc generators connected in series across a battery, and the net dc output voltage between terminal b and the ground is thus a function of the regulation characteristics of the dc generators. However, the equivalent dc-generator regulation characteristics are, in general, nonlinear and thus not too easy to handle.

Some further simplifications in the equivalent circuit can be made. For the well-balanced case, it can be shown that the two current generators (i_{g1} and i_{g2}) are identical in amplitude. Also, the shunt impedance Z_3 can be effectively eliminated by paralleling half of it with Z_1 and the other half with Z_2. This latter simplification can be shown to involve no approximation in regard to finding the conditions for optimum AM rejection. The approximate circuit of Fig. 1(d) is now obtained.

By comparing Fig. 1(d) with the side-tuned circuit of Fig. 1(b), it can be seen that z_1 and z_2 are of the nature of side-tuned resonant circuits. This equivalent circuit (with side-tuned resonant circuits) applies even for the phase-variation transformer, as will be apparent when it is realized that the rf circuits to the left-hand side of terminals 1, 2, and 3 in Figs. 1(a) and 1(b) produce substantially similar voltage variations with frequency.

By considering these impedances z_1 and z_2 to consist of parallel conductances (g) and susceptances (b_1 and b_2), the equivalent circuit of Fig. 2 is obtained. In the usual balanced case, the conductances (g) are equal and are relatively independent of frequency near the center frequency of the detector, while the susceptances b_1 and b_2 are opposite in sign and equal in magnitude at center frequency, but vary oppositely in magnitude with frequency. That is

$$\begin{aligned} b_1 &= +\,(b + \Delta b) \\ b_2 &= -\,(b - \Delta b), \end{aligned} \tag{1}$$

where b is the magnitude of the susceptance at center frequency and Δb is the variation with frequency.

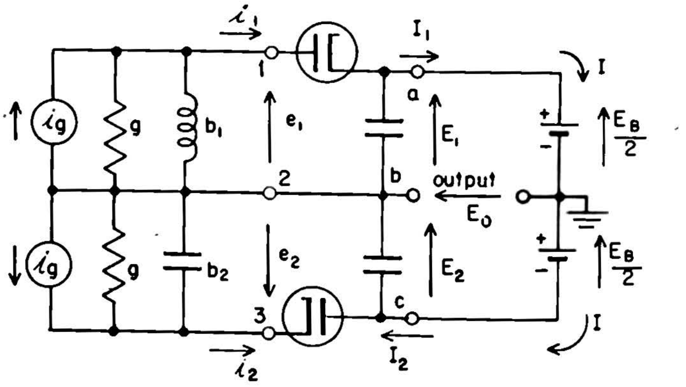

Fig. 2—Ratio-detector equivalent circuit.

It should be noted at this point that the impedance of the ratio-detector transformer at harmonic frequencies is rather low compared to the fundamental frequency impedance. Thus as a first-order approximation, the ac voltages are sinusoidal in shape. When ac voltages (e's) and currents (i's) are mentioned, it will be understood that these e's and i's refer to the peak values of the fundamental frequency ac components of voltage or current. This ignoring of the harmonic currents and voltages is permissible for a first-order approximation; however, the presence of harmonic currents when the harmonic impedance is not zero does result in some reactive effects. These reactive effects will be discussed later under "unbalanced effects."

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[3] This difference between static and dynamic operating characteristics of the ratio detector has been explained in the literature. See footnote reference 1, Figs. 10 and 11.

III. OPERATION WITH 100-PER CENT EFFICIENT DIODES

A. *Detector Output Voltage*

It is useful to study the performance of the ratio-detector circuit with ideal 100-per cent efficient diodes before proceeding to the practical case involving inefficient diodes.

On the dc side of the equivalent circuit of Fig. 2 there are two apparent relations, namely,

$$I_1 = I_2 = I \qquad (2)$$

$$E_B = E_1 + E_2. \qquad (3)$$

However, to determine the division of E_B between E_1 and E_2, further relations involving the regulation characteristics are required. These regulation characteristics are obtained from writing the mesh equations involving the ac side of the circuit, namely,

$$ge_1 + jb_1e_1 + i_1 = i_g = ge_2 + jb_2e_2 + i_2, \qquad (4)$$

where e_1 and e_2 are the fundamental frequency ac voltages across the two input circuits and i_1 and i_2 are the fundamental frequency ac components of the diode input currents (as marked in Fig. 2). The above equation can be simplified if i_1 and i_2 are in phase with e_1 and e_2, respectively, that is, if the input loading due to the diodes is purely resistive. This is true as a first-order approximation, and will be assumed in the present part of the analysis. Actually, in a practical case reactive components of i_1 and i_2 can result from incomplete by-passing of the diode output circuit, from insufficient stored energy in the input tank circuits, and from a change in diode capacitance with efficiency. These reactive effects will be treated in a later section.

As a next step, the ac equation can be written in terms of an equality of magnitudes instead of a complex equation if it is remembered that e_1 and i_1 (also e_2 and i_2) are in phase.

$$(ge_1 + i_1)^2 + b_1^2e_1^2 = (ge_2 + i_2)^2 + b_2^2e_2^2 = i_g^2. \qquad (5)$$

Now this is an equation of magnitudes, and the ac voltages and currents can be replaced by their absolute magnitudes, that is, e_1 can be replaced by $|e_1|$, and so on. These absolute magnitudes can be related to the dc voltages and currents by the well-known relations for a 100-per cent efficient diode, namely, that the dc voltage equals the peak of the applied ac voltage and that the fundamental frequency ac component of the input current is twice the dc current.[4]

$$|e| = E; \qquad |i| = 2I. \qquad (6)$$

The following equation results:

$$(gE_1 + 2I)^2 + b_1^2E_1^2 = (gE_2 + 2I)^2 + b_2^2E_2^2 \doteq |i_g|^2. \qquad (7)$$

This equation gives the interrelation between the dc voltages and currents and the ac circuit impedances, and can be manipulated to derive the output dc voltage E_0. The algebraic steps required involve the substitution of (1) for b_1 and b_2 and the substitution of

$$\frac{E_B}{2} - E_0 \text{ for } E_1 \text{ and } \frac{E_B}{2} + E_0 \text{ for } E_2.$$

In addition, it is assumed that consideration is limited to conditions near center frequency, that is, $\Delta b^2 \ll b^2$ and $E_0^2 \ll (E_B/2)^2$. The resulting relation for E_0 is

$$E_0 = \frac{E_B}{2}\frac{\Delta b}{b}\frac{q^2}{\left[(1+q^2) + \dfrac{4I}{gE_B}\right]}, \qquad (8)$$

where $q = b/g$ and $\Delta b/b$ represents the detuning of the applied signal from center frequency.

Now the important thing to note is that the above relation states that the output voltage E_0 *decreases* when the dc current I is *increased.* It is relatively simple to show that I increases as the input current $|i_g|$ is increased. To show this, I versus $|i_g|$ can be found *at center frequency* from (7);

$$4I = \sqrt{4|i_g|^2 - b^2E_B^2} - gE_B, \quad [I > 0]. \qquad (9)$$

Now since I increases with i_g, the output voltage E_0 must decrease with a dynamic increase in input signal level i_g. This is illustrated by Fig. 3, where E_0 is plotted versus $|i_g|$ for some assumed values of circuit constants.

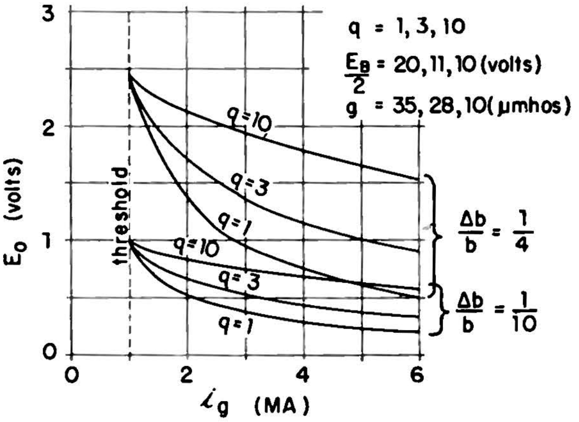

Fig. 3—Output of ratio detector with ideal diodes.

The above leads to the rather important conclusion that a ratio detector with *100-per cent efficient* diodes does not reject amplitude modulation, but instead is *over-compensated* so that a dynamic increase in signal amplitude always results in a reduction of output voltage. From (8) it can also be seen that circuit constants *cannot* be selected to give complete AM rejection. This characteristic should be contrasted with the limiting characteristic of a diode limiter, in which case a 100-per cent efficient diode can give perfect limiting.

It can be seen that as i_g is increased $I = 0$ until i_g exceeds $(E_B/2)\sqrt{g^2+b^2}$, that is, until the open-circuit ac voltages exceed the back bias of the battery voltage. This level may be thought of as the dynamic threshold above which the ratio detector operates and below which the diodes are cut off. This threshold is a dynamic threshold since in an actual ratio detector using a

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[4] Fundamental property of a short pulse.

long time-constant load the effective battery voltage E_B changes with the average input signal level and the diodes cannot be cut off on a long time basis. Above this threshold the diode current I increases as the input signal level i_g is increased.

B. AM-Reduction Factor

In order to talk about AM rejection in quantitative terms, the quantity "AM-reduction factor," which has been used by workers in the ratio-detector field, is introduced here. This term is equal to the per cent variation of the output signal divided by the per cent amplitude modulation of the input signal producing this output variation; in the other words, calling the AM-reduction factor equal to R,

$$R = \frac{\dfrac{dE_0}{E_0}}{\dfrac{d|i_g|}{|i_g|}}. \tag{10}$$

It is apparent from the definition of AM-reduction factor that perfect AM rejection corresponds to $R=0$. Also, it is apparent that an ideal balanced discriminator with linear diode detectors gives $R=1$.

As a matter of mathematical convenience it has been found easiest to evaluate this AM-reduction factor in two parts, namely,

$$R = R_1R_2 = \frac{\dfrac{dE_0}{E_0}}{\dfrac{dI}{I}} \; \frac{\dfrac{dI}{I}}{\dfrac{d|i_g|}{|i_g|}}. \tag{11}$$

As center frequency is approached, R_1 approaches a 0/0 form, and thus needs to be effectively evaluated just slightly off center frequency. However, R_2 can be evaluated at center frequency. Thus R_1 is obtained by differentiation of (8), which gives E_0 versus I *slightly off* center frequency while R_2 is obtained by differentiation of (9), giving I versus $|i_g|$ *at* center frequency. By this procedure the over-all AM-reduction factor can be obtained as

$$R = R_1R_2 = -\frac{(D+1)^2+q^2}{(D+1)(D+1+q^2)}, \tag{12}$$

where D is defined as the ratio of input conductance g_d of the diode to the conductance g of the circuit. From (6) therefore

$$D = \frac{g_d}{g} = \frac{\dfrac{|i|}{|e|}}{g} = \frac{4I}{gE_B}.$$

It can be seen that R is a negative number (implying the opposite polarity effect previously mentioned) with a magnitude less than unity but always greater than 0 (implying imperfect AM rejection). The relation for R is shown by the curves given in Fig. 4.

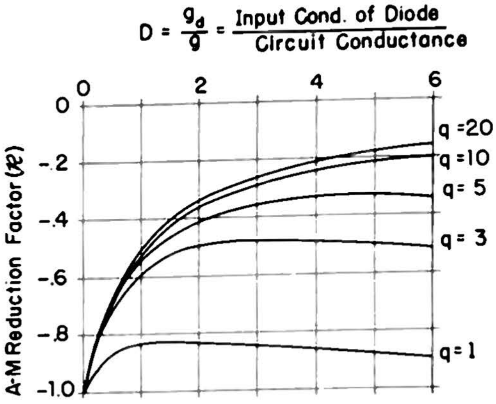
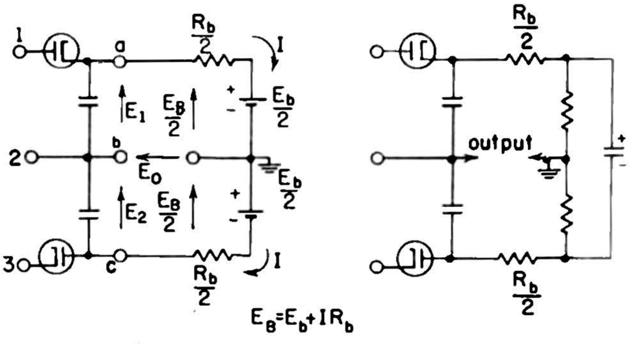


Fig. 4—AM-reduction factor of ratio detector with ideal diodes.

C. Compensating Resistors

In the above-described arrangement with 100-per cent efficient diodes a dynamic increase in signal level produced a reduction in output voltage E_0. If the effective "battery" voltage were to increase as the input signal level increases, the previously mentioned decrease in output voltage could be compensated to give an output that is independent of signal-level variations (over a certain range). This can be accomplished by including compensating resistors in series with the battery, as shown in Fig. 5. The effect of these compensating resistors is illustrated in Fig. 6, where the output voltage is plotted versus the input signal current for several values of compensating resistors and certain of the assumed circuit values of Fig. 3.



(a) (b)

Fig. 5—Ratio detector-load circuit with compensating resistors. (a) Equivalent. (b) Actual.

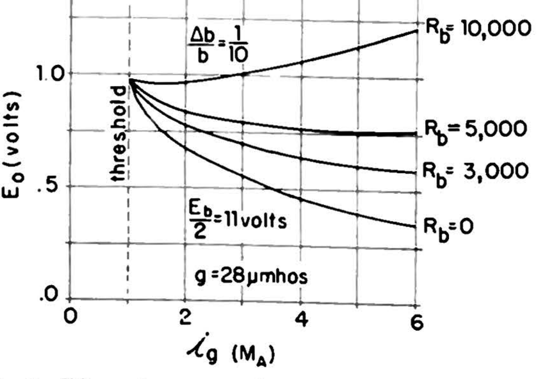


Fig. 6—Effect of compensating resistors in ratio detector with ideal diodes.

The AM-reduction factor for this case, using compensating resistors, can be solved by a similar procedure to that used before. To evaluate R_1, (8) is again differentiated; but this time E_B is not independent of I (instead $dE_B/dI = R_b$). Differentiating and collecting terms R_1 can be written as

$$R_1 = \frac{IR_b}{E_B}\left(\frac{2D + 1 + q^2}{D + 1 + q^2}\right) - \frac{D}{D + 1 + q^2}. \tag{13}$$

From (13) R_1 is seen to be a difference of two terms, and under certain conditions these two terms can be made to cancel giving R_1 equal to zero. When R_1 is zero, the over-all AM-reduction factor R is also zero (actually, $R_2 > 1$). Thus the conditions for perfect AM rejection are obtained by setting $R_1 = 0$. This is obtained when

$$\frac{IR_b}{E_B} = \alpha = \frac{D}{2D + 1 + q^2}. \tag{14}$$

This (14) specifies the fraction of the total load or battery voltage [$\alpha = IR_b/E_B$] that must be unstabilized in order to obtain perfect AM rejection with 100-per cent efficient diodes.

IV. OPERATION WITH PRACTICAL DIODES

To get an approximate picture of the effect of using practical diodes, the inefficiencies in the diodes might be thought of as being approximately equivalent to a series resistor inserted in the output circuit of each diode, with the diodes being thought of as having 100-per cent efficiency. Upon insertion of these "inefficiency resistors" the circuit appears like that using compensating resistors, such as shown in Fig. 5. Again, as the input signal level is increased, the effective battery voltage increases. This increased effective battery voltage tends to increase the output voltage E_0 and compensate for the drop in output obtained with high-efficiency diodes. Thus it can be seen that an *appropriate amount of inefficiency* can just cancel the tendency toward over-compensation obtained with 100-per cent efficient diodes, giving perfect AM rejection.

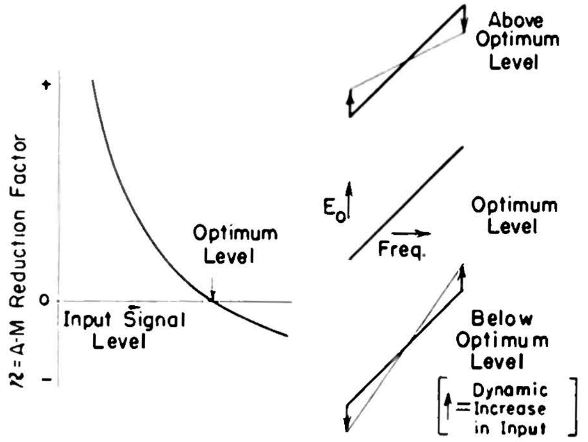


Fig. 7—AM-reduction factor versus signal level for a practical ratio detector.

From the above reasoning it would be expected that for a given circuit arrangement there is a particular diode efficiency that would give optimum AM rejection. This means that a particular operating level will give optimum AM rejection since practical diodes have an efficiency that varies with operating level. Operation at a higher than optimum signal level (i.e., at greater than optimum efficiency) will result in an over-compensation effect (approaching that of the 100-per cent efficient diode case), giving a negative AM-reduction factor. On the other hand, operation at lower signal levels will result in a positive AM-reduction factor, that is, it will result in an output signal having an in-phase AM effect. Such a variation of the AM-rejection properties is obtained with a practical ratio detector and is illustrated in Fig. 7.[5]

The AM-rejection properties of the practical ratio detector might be calculated using the above approximation of a compensating resistor in place of diode inefficiencies. However, following this procedure, significant errors are obtained in the calculated level for optimum AM rejection compared to practical operation. The reason for this is that with practical diodes which follow closely the three-halves power law (after correcting for "initial or contact" potential error) the effective value of compensating resistor is a nonlinear element being a function of the instantaneous load current I. The use of an equivalent inefficiency resistor is adequate for most diode circuit analysis, but in the ratio detector the nonlinear nature of the diode is important since significant changes in efficiency occur with dynamic changes in input signal level. This is true because the diode works into a load of approximately constant voltage instead of constant resistance. As a practical matter, in order to obtain results that even approximately agree with experimental data, it has been necessary to consider the diode as a three-halves power nonlinear element.

The interrelation between the ac and dc circuits of a three-halves power diode detector can be found using an approximate solution developed by Wheeler and described in an unpublished Hazeltine report. This solution is based on the assumption that the top part of the applied sine-wave voltage, which causes diode conduction, can be represented by a parabola. The following relation is obtained:

$$|i| = \frac{5 + \gamma}{3} I, \tag{15}$$

where γ is the efficiency, that is,

$$E = \gamma |e|.$$

The output voltage E_0 for the practical ratio detector can now be calculated. Equation (5) is applicable since it specifies the interrelation between the magnitudes of the various ac voltages. Then the relations for the practical diode are substituted in (5), giving

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[5] When a ratio detector is operated at a very low signal level, the diode detectors become square-law detectors, the AM-rejection property disappears, and the AM-reduction factor will approach 2.

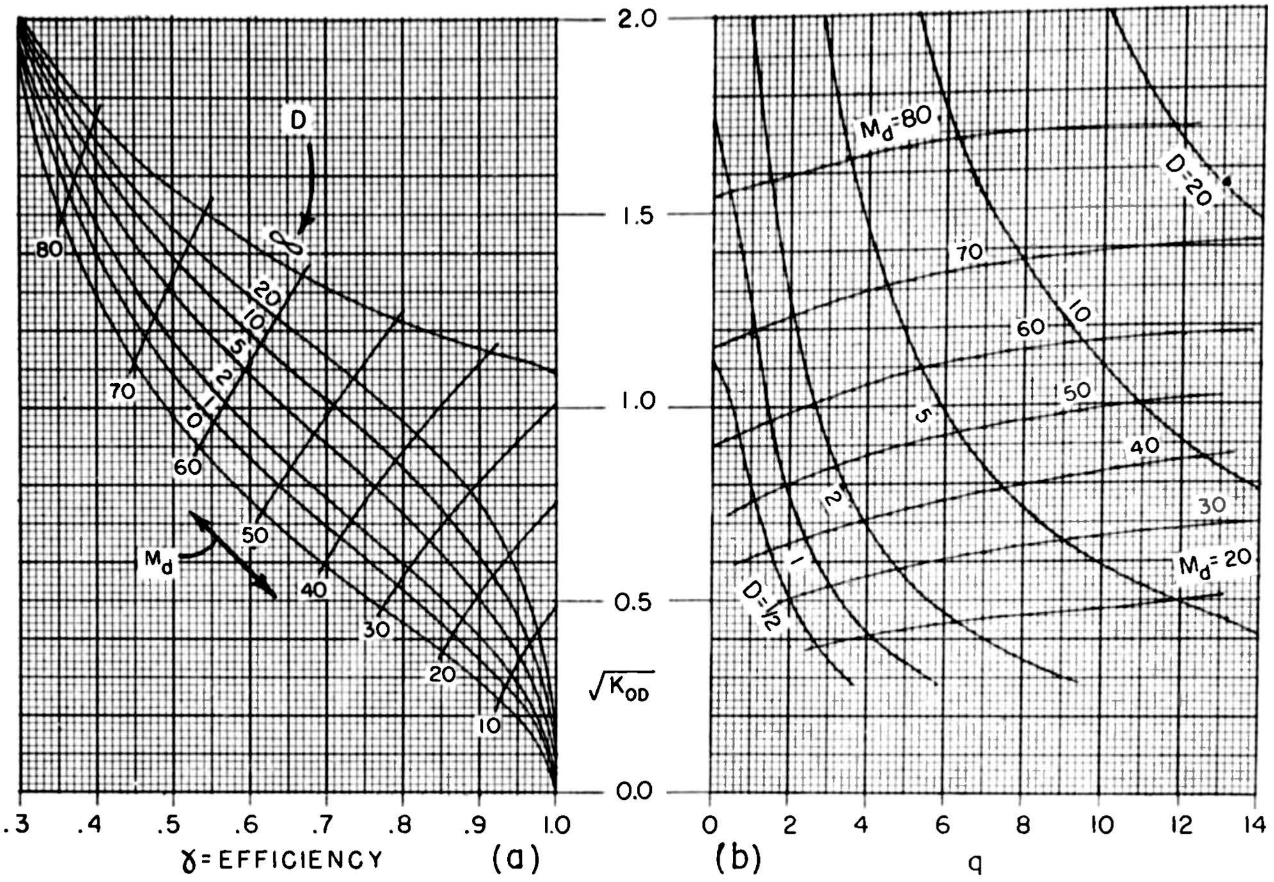

Fig. 8—Conditions for optimum AM rejection in a practical ratio detector.

$$\left(g\frac{E_1}{\gamma_1}+\frac{5+\gamma_1}{3}I\right)^2+b_1^2\frac{E_1^2}{\gamma_1^2}$$

$$=\left(g\frac{E_2}{\gamma_2}+\frac{5+\gamma_2}{3}I\right)^2+b_2^2\frac{E_2^2}{\gamma_2^2}\cdot \qquad (16)$$

The relation finally obtained for the output voltage, after lengthy but straightforward algebra, is

$$E_0=\frac{E_B^3b\Delta b(3+\gamma)}{8g^2E_B^2\gamma(1+q^2)+32gE_BI\gamma^2+16I^2\gamma^3(1-\gamma)}, \qquad (17)$$

where γ is the value of diode efficiency *at* center frequency when $\gamma_1=\gamma_2$.

While (17) again indicates that E_0 varies inversely with I, the circuit constants can be adjusted to make E_0 independent of I over a certain range because the efficiency γ varies inversely with the diode current I. Thus, circuit parameters in a practical ratio detector can be adjusted to give perfect AM rejection *at some specific diode efficiency.*

By further straightforward algebraic operations, (17) can be used to find the conditions for optimum AM rejection in a practical ratio detector. The results have been plotted as a series of graphs shown in Fig. 8. In these graphs, the quantity M_d is the per cent downward amplitude modulation which can be handled by the ratio detector before the diodes cut off and the ratio detector ceases to function. The quantity D is the ratio of the diode input conductance to the circuit conductance, that is,

$$D=\frac{g_d}{g}=\frac{\frac{i}{e}}{g}=\frac{(5+\gamma)}{3}\times\frac{2I\gamma}{gE_B}.$$

The quantity $\sqrt{K_{OD}}$ is merely a transfer constant used when going between the two graphs.

One important distinctive feature of the ratio detector that is quite apparent from the curves of Fig. 8 is that optimum AM rejection with a *specified downward AM capability* can only be obtained over a *narrow range* of diode efficiency. This limited region of permissible interrelations between circuit constants and diode efficiency is bounded by the curves for $D=0$ and $D=\infty$ (that is, 0 and infinite diode input loading). Of course, this limitation in permissible diode efficiency only applies when compensating resistors are *not* used. It is possible to operate with higher diode efficiencies than those indicated in Fig. 8(a) by the inclusion of compensating resistors (as has been explained with reference to 100-per cent efficient diodes). It appears that *optimum* AM rejection could *not* be obtained by use of *less efficient* diodes than indicated by Fig. 8(a) nor by use of *higher values* of *compensating resistors* than those indicated in (14). Thus, by reference to (14) and Figs. 8(a) and 8(b) the complete range of possible operating conditions are given for optimum AM rejection in the ratio detector.

V. PRACTICAL USE OF MATHEMATICAL ANALYSIS

A. Calculation of Design

Equations have been developed giving the interrelations between D, q, the circuit parameters, and the peak spacing of the FM-detector characteristics of the ratio detector.[6] Using these relations and the graphs of Fig. 8 it is possible to develop a reasonably rational design procedure for the ratio detector which gives answers that agree adequately with empirically obtained design data. Of course, the exact steps to be followed depend upon the known limitations placed upon the design, and the details of the design procedure are beyond the scope of the present paper.

B. Adjustment of Existing Ratio Detector

Frequently the engineer is faced with the problem of adjusting an existing empirically designed device which does not perform in the desired optimum manner either because of incorrect construction or because of stray effects. From the mathematical analysis, a general knowledge of the effect of various adjustments can be obtained so that an existing ratio detector can be adjusted empirically for optimum AM rejection.

Going back to the curves of Fig. 4, it is seen that for 100-per cent efficient diodes an increase in $q (q = b/g)$ reduces the magnitude of the negative AM-reduction factor. This means that in the practical case a higher diode efficiency (or higher operating level) is required for optimum AM rejection as q is increased. It can be shown that the *optimum* AM-rejection point is moved in the direction of a *higher diode efficiency* or a *higher operating level* by making the following adjustments (since these adjustments increase q):

For the phase-variation transformer

1. Increasing the primary to secondary coupling.
2. Decreasing the tertiary turns.
3. Increasing the secondary Q.
4. Decreasing the primary Q.
5. Increasing the secondary inductance.
6. Decreasing the primary inductance.

For the side-tuned transformer

1. Increasing the fractional detuning of each side-tuned circuit.
2. Increasing the Q of each side-tuned circuit.

The above effects of the variations in circuit parameters upon the AM-rejection properties have been substantiated by a considerable volume of experimental observations on both types of ratio detectors.

VI. UNBALANCED EFFECTS

So far unbalanced effects in the ratio-detector circuit have been ignored, that is, all effects discussed have resulted in a perfect balance of both the dc and AM output at center frequency. However, apparent unbalance in the ratio detector should be carefully considered since it may severely reduce the over-all AM-rejection properties of the device.

In the ratio detector the diodes may draw a reactive current, or *appear* to draw a reactive current, which varies with dynamic changes in the input signal level. If this is true, there will appear to be a dynamic shift in center frequency of the detector characteristic (that is, a detuning of the transformer) as illustrated in Fig. 9. This results in an audible output due to amplitude modulation even when the applied signal is at center frequency and is not frequency modulated. This unbalanced effect will result in a dynamic crossover, or *dynamic* (AM) *balance* point, which is *not* at center frequency even though the *dc balance* may be at center frequency. These reactive effects are severe in a ratio-detector circuit and must be carefully controlled.

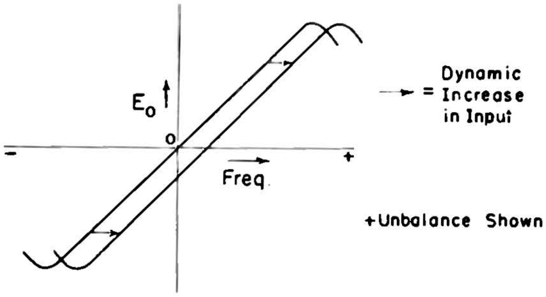

Fig. 9—Effect of apparent frequency shift in a ratio detector.

There are at least three causes for changes in apparent reactive diode currents with dynamic changes in applied signal level. These causes are: first, a change in diode input capacity with change in diode conduction, which produces a positive unbalance; second, insufficient stored energy in the tuned circuits feeding the diodes, which produces a negative unbalance; and third, insufficient by-passing across the detector load, which also produces a negative unbalance. In a practical ratio-detector design these unbalanced effects are made to cancel each other at the desired operating level, generally by adjusting the capacity of diode-load bypass condensers.

In certain designs it may be found that the negative unbalanced effect due to insufficient stored energy exceeds the positive unbalance due to diode capacity change so that even very large by-pass capacities do not give cancellation of dynamic unbalanced effects. This results in a practical limitation upon the *minimum* ratio-detector transformer *capacity* that can be used with a particular type diode at a particular frequency.

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[6] The complete interrelations, together with a sample calculated design, are given in the Hazeltine Electronics Report #7096.

This empirical data on tank capacity in conjunction with empirical data on practical Q's for coils generally gives a starting basis for a ratio-detector transformer design. The remaining circuit constant interrelations can then be determined by the requirements for optimum "balanced" AM rejection.

VII. Inadequacy of Simplified Analysis for Designing a Ratio Detector

The mathematical analysis presented above is certainly rather involved, and might lead one to look for a simplified analysis of the AM-rejection properties of the ratio detector. One type of simplified analysis, which has been considered by a number of engineers, is based upon the fact that if the ac voltages between the various terminals of a ratio-detector transformer are observed on an oscilloscope some apparent limiting action will be seen. It can be demonstrated that the degree of this limiting action is incidental and unrelated to the AM-rejection properties of the ratio detector, and thus provides an inadequate design basis which can result in substantial errors.

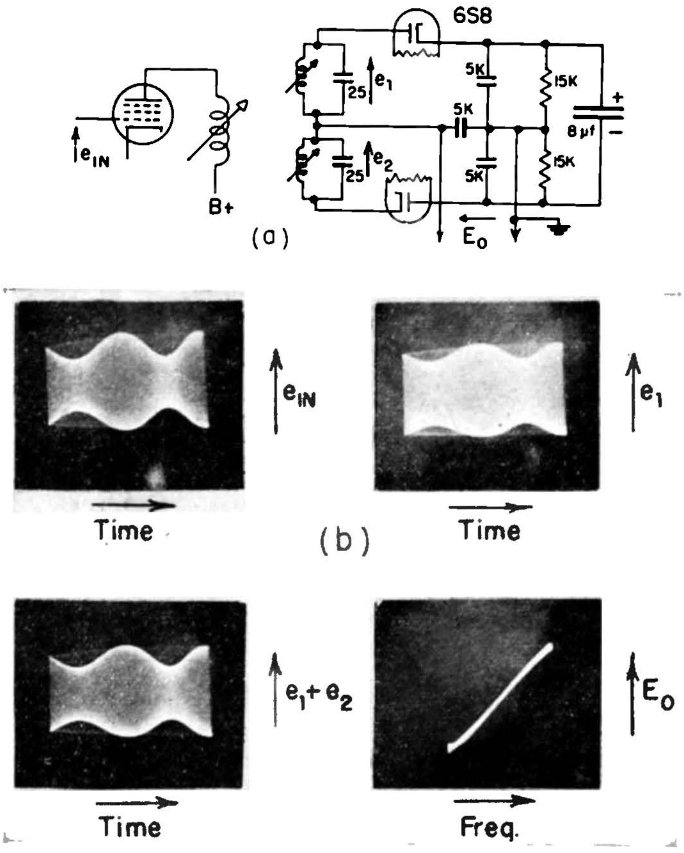

Fig. 10 (a) and (b)—Ratio detector with low-efficiency diodes.

An analysis of the ratio detector using a phase-variation transformer will show that an apparent perfect limiting action can occur across the ***secondary*** winding and that this ***might*** actually occur at a signal level which is close to that giving optimum AM rejection for a ***particular design*** of ratio detector. However, if the phase-variation transformer is replaced by an ***equivalent*** side-tuned transformer, this apparent perfect limiting action ***may*** or ***may not*** be obtained across the terminals 1–3 of Fig. 1(b) (equivalent to secondary of phase-variation transformer), ***depending upon*** the relative ***direction of winding*** of the two side-tuned circuit coils. While the direction of winding will substantially change the apparent limiting action, it will have no effect upon the ability to obtain optimum AM ***rejection*** in the ratio detector since reversing the ***phase*** of the two input-current generators of Fig. 2 does ***not*** affect the conditions for optimum AM rejection.

To illustrate the point that this simplified analysis is inadequate and that the apparent limiting on the ac side of a ratio detector is completely incidental and unrelated to the AM-rejection properties, a side-tuned circuit ratio detector with low-efficiency diodes was constructed. As shown by Fig. 10, this device had optimum AM rejection as a ratio detector but very small limiting of amplitude modulation on the ac side.

The oscillogram of E_0 versus frequency was taken with simultaneous AM (30 per cent) and FM (±75 kc), the AM and FM being nonsynchronous, and shows that the ratio detector has relatively good AM rejection.[7]

VIII. Conclusions

A ratio detector using 100-per cent efficient diodes has been shown to be overcompensated, and compensating resistors or inefficient diodes must then be used to obtain optimum AM rejection. In a practical ratio detector the detector transformer parameters must be correctly designed with respect to the diode efficiency in order to obtain optimum AM rejection at a desired operating level. In addition, it has been shown that the degree of apparent limiting action within the ratio detector is incidental and unrelated to the AM-rejection properties of the ratio detector, and does not provide an adequate design basis.

IX. Acknowledgment

Due credit must be given to N. P. Salz for his assistance in the mathematical analysis presented and to M. Aron for his assistance in collecting the "volumes" of experimental data to substantiate the theory presented.

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[7] However, this design using a 6S8 is not suggested for a *production* design of ratio detector because of the large variation in characteristics of various 6S8's.