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A MODULATOR FOR NOISE WAVEFORMS OF HIGH JAMMING EFFECTIVENESS



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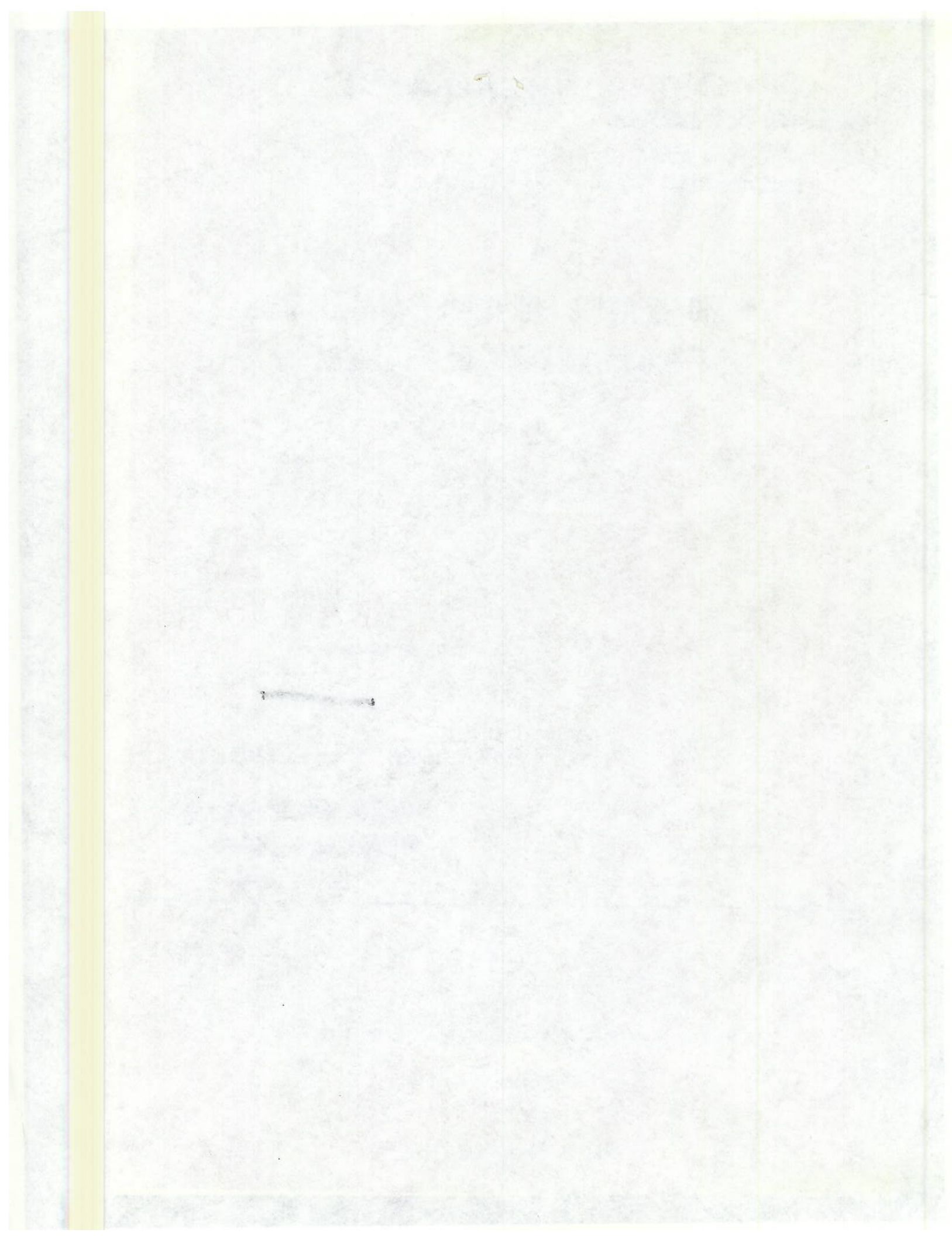
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A MODULATOR FOR NOISE WAVEFORMS OF HIGH JAMMING EFFECTIVENESS

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22 September 1947



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ABSTRACT

A circuit is described for producing noise modulation for use with radio countermeasure jamming transmitters. The noise produced by this circuit, though substantially unclipped, possesses a dissymmetry which aids in reducing the amount of relatively useless carrier power. Data is presented to show that jamming by unclipped noise is superior to that of clipped noise on a per-watt-of-modulator-plate-dissipation basis. A figure of merit for efficiency of modulator tubes is derived and values are given for several commercial types. Noise studies are to be made to determine the effect on jamming effectiveness of changes undergone by the modulator output waveform in the process of modulation.

PROBLEM STATUS

This is an interim report on this problem; work is continuing.

AUTHORIZATION

BuShips conf. Ltr. C-A221 (920-Db) C-920-7489, 14 August 1945
to NRL

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A MODULATOR FOR NOISE WAVEFORMS OF HIGH JAMMING EFFECTIVENESS

INTRODUCTION

Unsymmetrical noise is a desirable type of modulation for use in jamming pulsed radar signals because of the reduction of relatively useless carrier power resulting from its use. In the past, dissymmetry has been obtained by limiting the amplitude of the noise peaks severely on either positive or negative swing and less severely or not at all on the swing of opposite polarity. The X-MBT transmitting equipment utilizes this type of waveform. Recent studies, however, have shown that the screening effect of noise is diminished by such clipping. Hence, a type of noise that is unsymmetrical and yet substantially unclipped will possess the two advantages of low carrier power and good screening. An investigation was made of methods for producing this type of unclipped noise. Particular emphasis was placed on the question of practicability of unclipped noise from the standpoint of the modulator since the difficulty of producing such modulation at high power has been a great factor in preventing its adoption generally.

This report covers the results obtained at an interim stage of the problem and does not include the effect of the changes that might be undergone by the modulator output waveform in the process of modulating the RF wave. The assumption is made that the envelope is a faithful reproduction of the modulator output. Investigations are being continued to determine the effects of parameters in the transmitter circuits on modulation effectiveness.

EFFECTIVENESS OF VARIOUS NOISE TYPES

It is generally agreed that random unclipped noise is the most desirable form of modulation for use in jamming enemy radar transmitters but certain characteristics of this noise have raised a question as to its practicability. Unclipped noise, because of its high peak to RMS voltage ratio cannot be amplified as efficiently as clipped noise and, when used to modulate a carrier, results in a low percentage of sideband power. (Theoretically the peak to RMS ratio of unclipped random noise is infinite, but the term will be used here to denote noise such as is obtained at the output of gas tubes where the peak to RMS ratio is roughly 4.) On the other hand, more effective jamming is produced by a given sideband power of unclipped noise, than by the same sideband power of clipped noise. NRL Report R-2870 * presents the results of tests made on various types of noise and the conclusion is reached that unclipped noise is so superior to clipped noise of the same bandwidth in its masking qualities as to more than outweigh its poor sideband-to-carrier power ratio. One type of modulation,

* Watson, K. M., "The Radar Jamming Effectiveness of Various Types of Noise Signals," NRL Report R-2870, 13 June 1945.

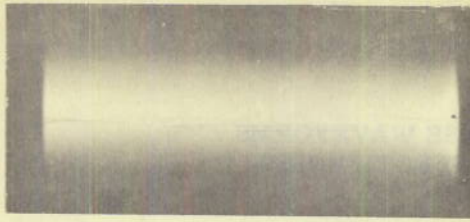


Figure 1a - Symmetrical
noise unclipped

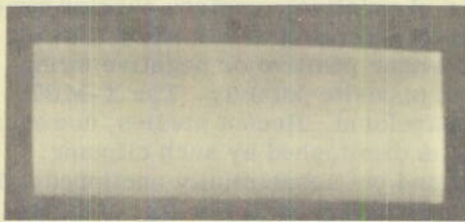


Figure 1b - Symmetrical
noise moderately clipped

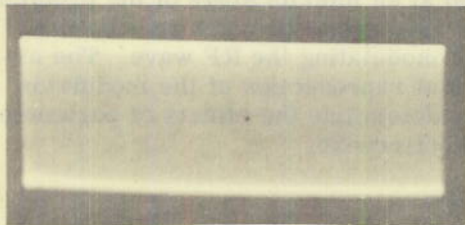


Figure 1c - Symmetrical
noise severely clipped

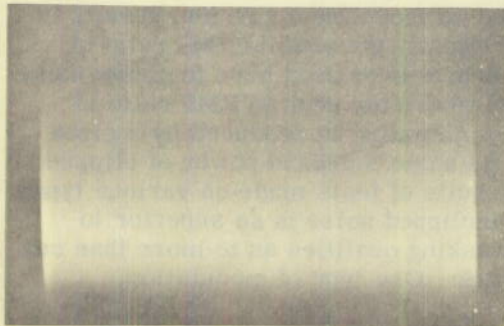


Figure 2 - Unclipped unsym-
metrical noise.

"Detected Receiver Noise", was found to be superior even to ordinary unclipped noise, for it possessed the desirable characteristic of being unsymmetrical as well as unclipped, an aid to decreasing the proportion of relatively useless carrier power. In Figures 1 and 2 are shown oscilloscope photographs of these various types of noise.

It has been argued in the past that the scrambling effect resulting from severe limiting of the bandwidth of clipped noise such as might take place in an IF amplifier will make it substantially random and hence as satisfactory for screening as ordinary unclipped noise. Although this is true, it should be realized that the development of wideband IF amplifiers for present-day radar has proceeded at a much faster pace than the development of wideband noise jammers and the safest assumption that can be made is that the entire noise bandwidth is accepted by the receiver. For these reasons it was decided that an investigation of methods for producing Detected Receiver Noise at sufficient power to modulate a transmitter would be valuable.

PRODUCTION OF DETECTED RECEIVER NOISE

Detected Receiver Noise can be produced at low power by amplifying a band of noise in an RF amplifier and detecting it as in conventional receiver circuits. When an attempt is made to produce it at high power by amplifying it in a Class B amplifier, a serious difficulty arises. It is found that coupling chokes and wideband transformers scramble the noise to such an extent that most of the dissymmetry is lost and ordinary symmetrical noise remains. At first it was believed that the noted scrambling effect resulted from the removal of the very low-frequency components in the noise. This was true in part, but most of the scrambling was traced to the transient effects of inductive elements. Thus, when Detected

Receiver Noise was passed through a low pass filter consisting of resistive and capacitive elements, the noise retained most of its dissymmetry, but when passed through a low pass filter having exactly the same attenuation characteristic but composed of resistive and inductive elements, the noise became completely symmetrical.

It was finally decided that a practical system would be one in which the noise is amplified in its symmetrical form up to the load and is converted from symmetrical to unsymmetrical noise in a final operation. This is the system eventually adopted. The device for converting the symmetrical noise to unsymmetrical noise is shown in Figure 3 and consists simply of a half-wave rectifier shunted by a resistance. This shunting resistance permits some current to flow through the load in a direction opposite to the normal conduction of the rectifier. When the resistance of the rectifier tube is low compared to the load, the shunting resistance may be made equal to the load resistance for a dissymmetry ratio of two to one between positive and negative peaks which is the value for Detected Receiver Noise. In general the shunting resistance by itself is insufficient for wideband noise applications because of the effects of rectifier and load capacities.

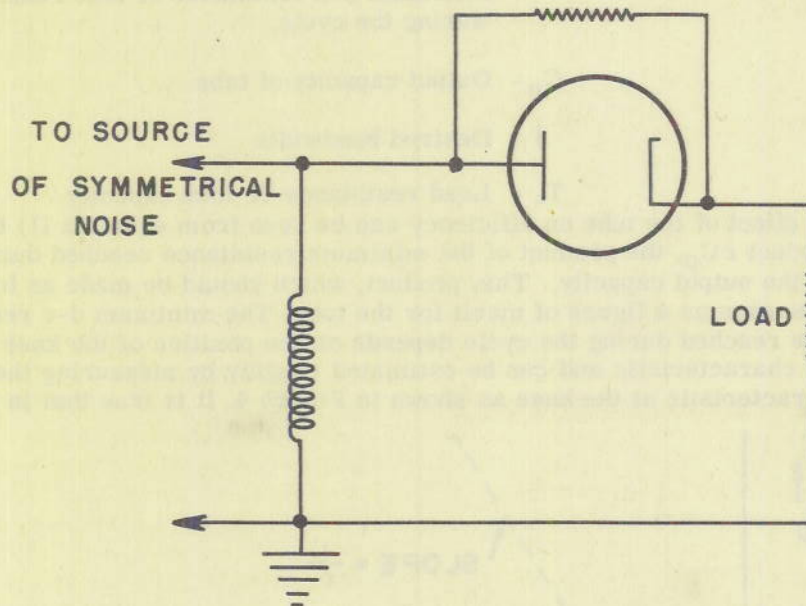


Figure 3 - Circuit for converting symmetrical noise to unsymmetrical noise

In such cases a compensating reactance must be added and the rectifier shunt becomes an impedance rather than a pure resistance. A question naturally arises as to whether the noise so produced is really the equivalent of Detected Receiver Noise. It is exactly the same in appearance, for it has the same degree of dissymmetry and is unclipped on both positive and negative peaks. Furthermore, tests show no measurable difference in the screening ratios of the two types.

If the system just described is used, it is seen that the problem of producing unsymmetrical unclipped noise efficiently resolves itself into that of producing symmetrical unclipped noise efficiently. This leads to a consideration of the factors affecting the efficiency of amplifiers in general. For purposes of analysis it would be convenient to have an equation that expresses in simple form the effect on plate efficiency of such things as the waveform being amplified, the constants of the tube being used, and the bandwidth desired. The following equation for a Class B amplifier, derived in the Appendix, assumes a symmetrical waveform.

$$\text{Eff.} = \frac{2}{K^2 D} \left(\frac{1}{1 + \frac{1}{\frac{2rC_p}{\Delta} - T_L}} \right) \quad (1)$$

Where $K = \frac{\text{Peak to peak of full waveform}}{\text{RMS of full waveform}}$

$D = \frac{\text{Average of half waveform}}{\text{Peak to peak of half waveform}}$

$r = \text{Minimum d-c resistance of tube reached during the cycle.}$

$C_p = \text{Output capacity of tube}$

$\Delta = \text{Desired bandwidth}$

$T_L = \text{Load resistance X load capacity}$

The effect of the tube on efficiency can be seen from equation (1) to depend on the product rC_p , the product of the minimum resistance reached during the cycle and the output capacity. This product, which should be made as low as possible, serves as a figure of merit for the tube. The minimum d-c resistance that can be reached during the cycle depends on the position of the knee of the tube plate characteristic and can be estimated roughly by measuring the slope of the characteristic at the knee as shown in Figure 4. It is true that in actual

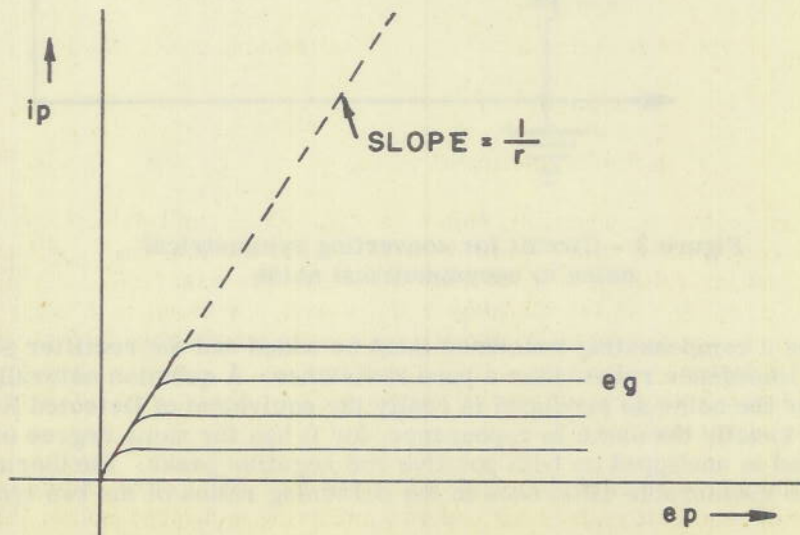


Figure 4 - Measurement of minimum d-c resistance from tube plate characteristics

operation, considerations of distortion may prohibit operating to this minimum resistance, but the slope shown serves nevertheless as a means of determining the relative merits of tubes. The figure of merit, rC_p , of several common tube types is listed below for typical operating conditions.

Tube Type	Ohms (r)	mmf (Cp)	Ohms x mmf (r C _p)
813	208	14	2912
829	125	7	875
807	250	7	1750
4-250	150	4.5	675
828	210	14.5	3050

It should not be concluded that the figure of merit by itself is sufficient to determine the choice of tube. It merely determines the plate efficiency that can be obtained and does not consider the driving power required. When two tubes of approximately the same plate dissipation have figures of merit that differ only slightly, the choice will probably go to the one having the larger transconductance. It is interesting to note that paralleling tubes to obtain a larger plate dissipation does not change the figure of merit for efficiency.

It is seen from equation (1) that the theoretical maximum efficiency is obtained when the minimum tube resistance, r , is zero. In this case equation (1) reduces to:

$$\text{Eff} = \frac{2}{K^2 D} \quad (2)$$

For random noise the peak-to-peak/RMS ratio, K , is approximately 7.5 and the duty cycle, D , of the half-wave rectified noise is 0.2. For a pulse waveform with vertical sides the product $K^2 D$ is 2 for 50-percent duty cycle. For a sine wave K is $2\sqrt{2}$ and D is $1/\pi$. Using equation (2) the following results are obtained:

Type of Waveform	Theoretical max. efficiency Class B
Sine wave	78.5%
50% Pulse	100%
Random unclipped noise	18.0%

From the plot of equation (2), shown in Figure 5 it can be seen why clipped noise can be amplified so much more efficiently than random noise. Clipped noise has a smaller value of K than random noise, the exact value depending on the degree of clipping. As the clipping is increased, the value of K approaches 2, the value of D approaches 0.5, and the efficiency approaches 100-percent. The curve of Efficiency vs K for noise, shown in Figure 6, was plotted by using the data of Figure 5 with experimental values of D vs K obtained by clipping random noise at various levels.

From the above results it can be concluded that great care should be taken in the choice of modulator tubes for use in amplifying unclipped noise. Tubes

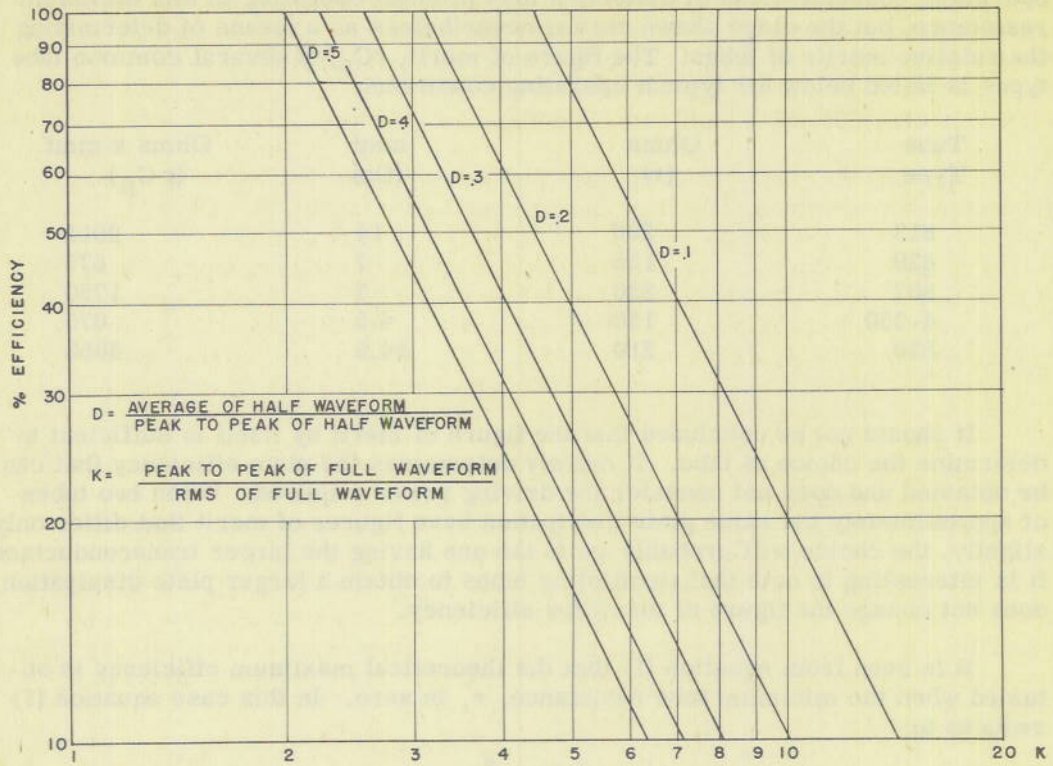


Figure 5 - Theoretical maximum efficiency of a Class B amplifier as a function of waveform

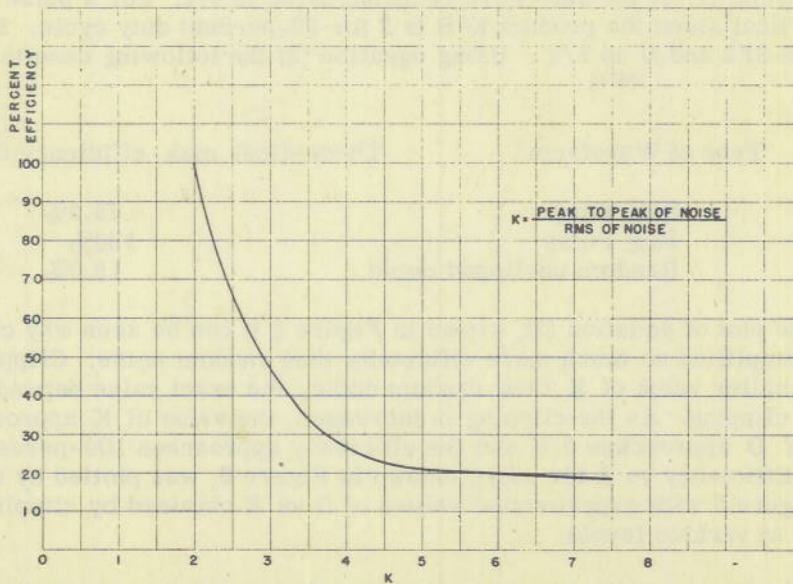


Figure 6 - Theoretical maximum plate efficiency for Class B amplifier as a function of the noise clipping

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with good figures of merit are particularly important where wideband random noise is to be amplified, for the efficiency in such cases changes rapidly with a change in the figure of merit as can be seen from equation (1).

PRACTICABILITY OF UNCLIPPED NOISE

Since the efficiency of amplifiers for unclipped random noise is quite low, a question sometimes arises that can be stated as follows:

"Granted that unclipped noise is the most desirable type of modulation to use on the basis of the total RF power required to jam a given pulse, is it not impractical from the modulator standpoint? Consider, for example, a modulator operating at its rated plate dissipation and producing the minimum clipped noise power required to jam a given pulse. Suppose now that the same amplifier is used for unclipped noise instead. Since unclipped noise is produced at much lower efficiency than clipped noise, the power output of the amplifier under the new condition is much less. Will not the resultant noise, in spite of its high quality, be of insufficient power to jam the same pulse?"

The answer to the above question can be found by comparing the screening effectiveness of a given type of noise with the efficiency with which it can be produced. For this purpose it was necessary to make measurements of the jamming effectiveness of noise having various degrees of clipping as shown in Figure 7.

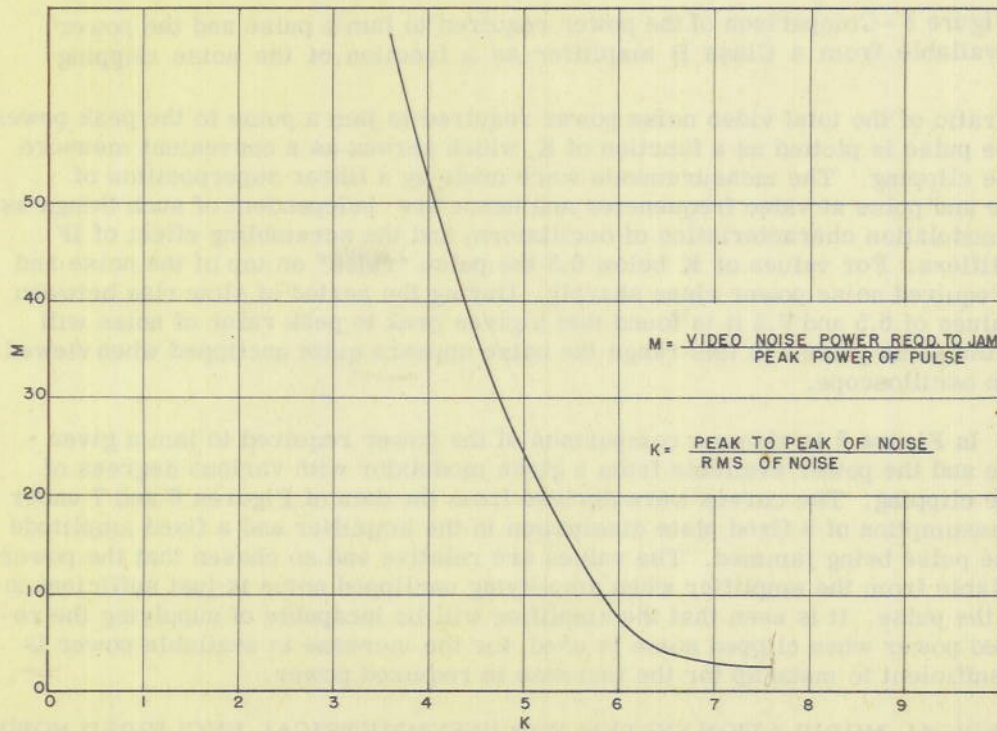


Figure 7 - Effectiveness of jamming as a function of the noise clipping

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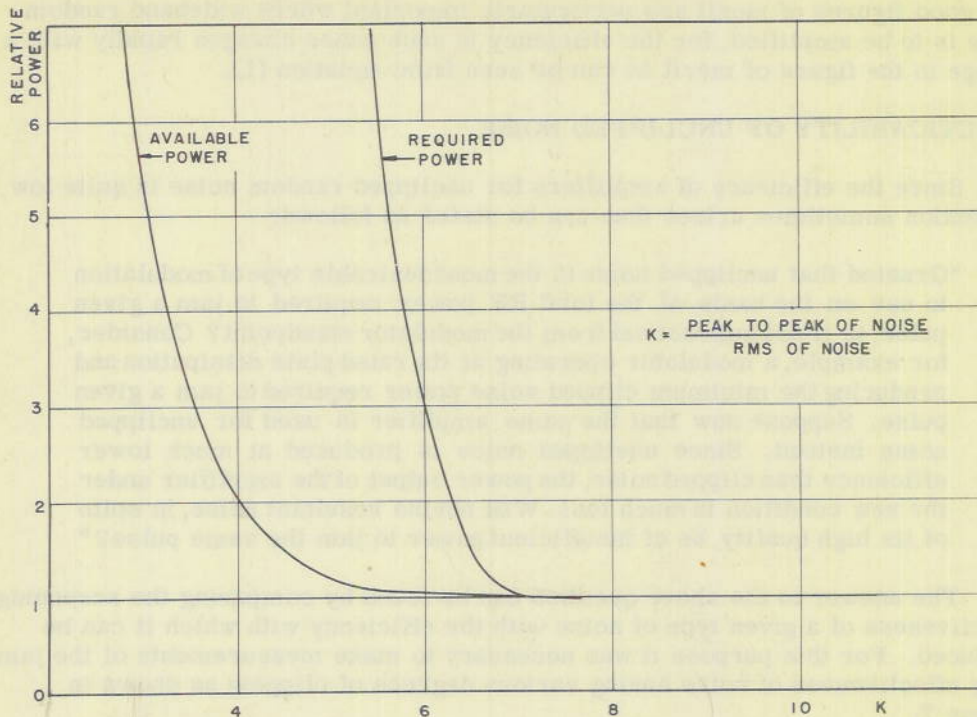


Figure 8 - Comparison of the power required to jam a pulse and the power available from a Class B amplifier as a function of the noise clipping

The ratio of the total video noise power required to jam a pulse to the peak power of the pulse is plotted as a function of K, which serves as a convenient measure of the clipping. The measurements were made by a linear superposition of noise and pulse at video frequencies and hence are independent of such things as the modulation characteristics of oscillators, and the scrambling effect of IF amplifiers. For values of K below 6.5 the pulse "rides" on top of the noise and the required noise power rises sharply. During the period of slow rise between K-values of 6.5 and 7.5 it is found that a given peak to peak value of noise will jam the same pulse. In this range the noise appears quite unclipped when viewed on an oscilloscope.

In Figure 8 is shown a comparison of the power required to jam a given pulse and the power available from a given modulator with various degrees of noise clipping. The curves were derived from the data of Figures 6 and 7 under the assumption of a fixed plate dissipation in the amplifier and a fixed amplitude in the pulse being jammed. The values are relative and so chosen that the power available from the amplifier when amplifying unclipped noise is just sufficient to jam the pulse. It is seen that the amplifier will be incapable of supplying the required power when clipped noise is used, for the increase in available power is not sufficient to make up for the increase in required power.

A TYPICAL MODULATION SYSTEM FOR UNSYMMETRICAL UNCLIPPED NOISE

Although unclipped noise is highly desirable for modulating jamming transmitters, its effectiveness is improved appreciably by making it unsymmetrical

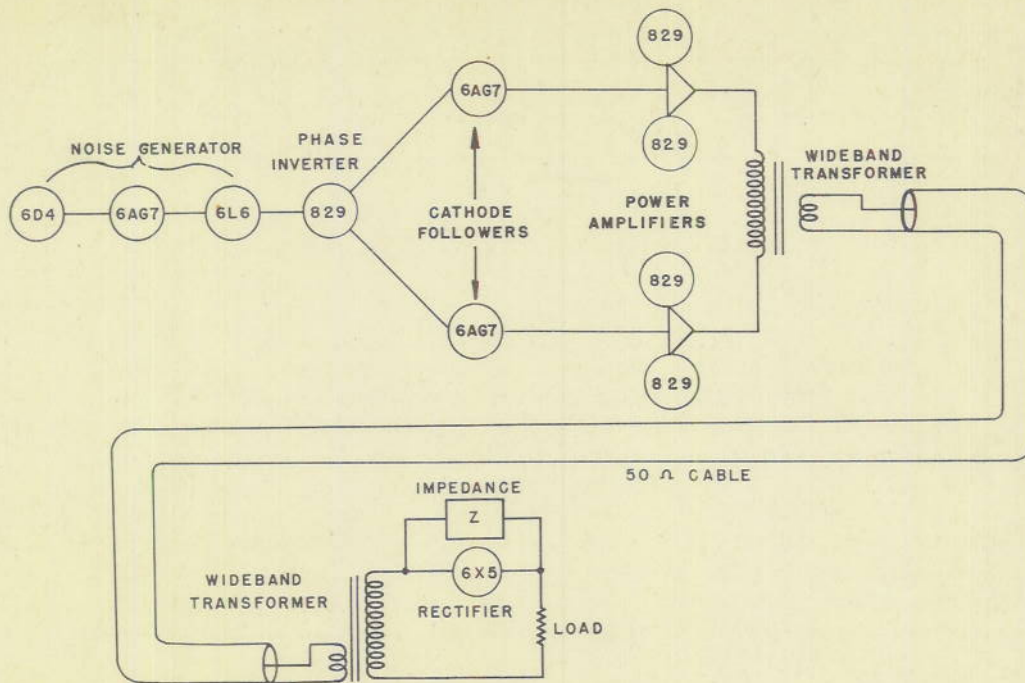


Figure 9 - Modulation system using unsymmetrical unclipped noise

as well as unclipped, with the circuit of Figure 3 previously described. This improvement results from the carrier power reduction of about 50 percent that can be obtained by its use. A typical modulation system for unsymmetrical unclipped noise is shown in Figure 9.

Noise from the generator is applied to the 829 as a phase inverter. Type 6AG7's as cathode followers are biased near cut off and driven in the positive direction to serve as low impedance drivers for the four type 829 tubes in Class B. The wideband video transformer at the modulator matches it to the 50 ohm cable and the second transformer matches the cable to the 6X5 half-wave rectifier circuit. The rectifier shunt impedance is adjusted for flat frequency response and a ratio of two to one between positive and negative peaks. When used with wideband transformers having an efficiency of 70 percent each, the circuit shown produces 450 volts peak to peak of unsymmetrical unclipped noise across an impedance of 500 ohms. The spectrum is flat within 3 db between 100 KC and 5 MC.

CONCLUSIONS

Symmetrical unclipped noise, which has been found to give better jamming on a per-watt-of-RF-output-power basis than clipped noise, also gives better jamming on a per-watt-of-modulator-plate-dissipation basis than clipped noise. Unsymmetrical unclipped noise, which results in a carrier power reduction of 50 percent over symmetrical unclipped noise, can be produced from symmetrical unclipped noise by means of a rectifier shunted by an impedance.

The product of minimum d-c resistance and output capacity of a modulator tube, which should be kept as low as possible, serves as a figure of merit for plate efficiency.

APPENDIX

DERIVATION OF CLASS B EFFICIENCY EQUATION

When a sine wave is amplified in a Class B amplifier, the efficiency is given by the following relation, assuming linear operation: *

$$E_{ff} = \frac{\pi}{4} \left(1 - \frac{E_{min}}{E_{bb}} \right) \quad (1)$$

Where E_{min} is the minimum plate voltage reached during the cycle and E_{bb} is the supply voltage. Since the minimum plate voltage reached during the cycle is equal to the supply voltage minus the maximum voltage drop in the load impedance, the above equation may be rewritten as follows:

$$E_{ff} = \frac{\pi}{4} \left(\frac{I_{max} R}{E_{bb}} \right) \quad (2)$$

Where I_{max} is the peak current reached during the cycle and R is the load impedance seen by each tube.

The waveform of the current in each tube is that of a half-wave rectified sine wave with I_{max} as its peak value and an average i_o equal to $1/\pi$ (I_{max}). The factor $1/\pi$ relating peak and average values is valid only for the sine waveform and will be denoted by the constant D for the general case. Thus, for any waveform:

$$i_o = DI_{max}$$

For a pulse waveform, the quantity D is also equal to the duty cycle of the pulse. Hence the "duty cycle" of a half-wave rectified sine wave is $1/\pi$.

In addition to the duty cycle, D , of the half wave rectified waveform, another quantity affecting efficiency is the peak-to-peak/RMS ratio of the complete waveform as it appears at the load. For a sine wave the peak-to-peak/RMS ratio is $2\sqrt{2}$.

The general quantity for any waveform will be denoted by K :

$$K = \frac{\text{Peak-to-peak value of waveform}}{\text{RMS value of waveform}}$$

Now since a given value of I_{max} determines the peak-to-peak current in the load, it also determines the RMS current in the load according to the value of K , and hence the output power. A given value of I_{max} , as has been seen, also determines the average current taken by each tube according to the value of D and hence the

* Terman, F. E., "Radio Engineering" McGraw - Hill, p. 311, 1937.

input power. Thus, the efficiency will be inversely proportional to D and the square of K. The equation of efficiency for a general waveform can be obtained from that of a sine wave by a conversion factor as follows:

$$\begin{aligned} \text{Efficiency for general waveform} &= \frac{\text{Efficiency for sine wave}}{\frac{K^2 D \text{ for sine wave}}{K^2 D \text{ for waveform}}} \\ &= \frac{\pi}{4} \frac{(I_{\max} R)}{E_{bb}} \times \frac{(2\sqrt{2})^2 (1/\pi)}{K^2 D} \\ &= \frac{2}{K^2 D} \frac{(I_{\max} R)}{E_{bb}} \end{aligned}$$

Let r be the minimum d-c resistance of the tube reached during the cycle.

Then:

$$I_{\max} = \frac{E_{bb}}{r + R} \quad \text{and}$$

$$\text{Eff.} = \frac{2}{K^2 D} \left(\frac{1}{1 + \frac{r}{R}} \right) \quad (3)$$

Assuming an ideal output transformer with a turns ratio of 2N to 1, the total capacity at the plate of each tube is $2 C_p + C_L/N^2$, where C_p is the output capacity of one tube and C_L is the load capacity. The resistance R seen by each tube is $N^2 R_L$ where R_L is the load. Assuming that tubes having relatively high plate resistances such as tetrodes or pentodes are to be used, the bandwidth obtained is determined solely by the total capacity at the plate of each tube and the resistance seen by each tube looking into the transformer. The following relation then exists:

$$\Delta R \left(2 C_p + \frac{C_L}{N^2} \right) = 1.$$

Where Δ is the desired bandwidth in radians per second. After substituting the relation $T_L = R_L C_L$

$$R = \frac{\frac{1}{\Delta} - T_L}{2 C_p} \quad (4)$$

Substitution of (4) into (3) yields

$$\text{Efficiency} = \frac{2}{K^2 D} \left(\frac{1}{1 + 2r C_p \left(\frac{1}{\Delta} - T_L \right)} \right)$$