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APPLICATION NOTE
ON
INFLUENCE OF CIRCUIT CONSTANTS ON RECEIVER OUTPUT NOISE

The effect of circuit constants on the noise output of a radio receiver is discussed in this bulletin.

It is well known that extraneous noise in the output of a radio receiver may be caused in several different ways. A few of these are:

(1) Atmospheric static
(2) Power supply noise
(3) Man-made static
(4) Poor connections
(5) Defective or poor quality parts

There are, however, other noise sources which persistently remain after the above sources have been eliminated. These become evident as a steady hissing sound when the receiver sensitivity is high. When an attempt is made to eliminate these sources of noise, it is found that a certain minimum remains which approaches the value predicted theoretically as due to thermal agitation and "shot" effect.

Thermal-agitation noise is supposed to be due to the random movements of electrons within a conductor. It has no particular frequency, but consists of a series of pulses.

Shot-effect noise is produced by the emission of electrons. Electricity is not an infinitely fine grained fluid, but consists of discrete particles, that is, electrons. From the theory of emission it can be predicted that a certain noise current is present in the electron current. This noise current consists of a series of pulses similar to the thermal-agitation effect.

On a purely theoretical basis, relations have been derived for calculating both the thermal-agitation voltage and the shot-effect voltage. Measurements show agreement between calculated and measured values.

The theoretical relation for thermal agitation is:

$$\bar{e}^2 = 5.49 \text{ X } 10^{-23} \, TZ \, df$$

$$\bar{e} = 7.4 \text{ X } 10^{-12} \, T^{\frac{1}{2}} \, df^{\frac{1}{2}} \, Z^{\frac{1}{2}}$$

where, $\bar{e}^2$ = the mean square thermal-agitation voltage
T = the absolute temperature of the conductor = (273 + °C)
Z = the resistance of the conductor or the resonant impedance of a tuned circuit
df = the frequency band width factor

The theoretical relation for shot effect (without space charge) is:

$$\bar{E}^2 = 3.18 \text{ X } 10^{-19} \, I \, Z^2 \, df$$

$$\bar{E} = 5.63 \text{ X } 10^{-10} \, I^{\frac{1}{2}} \, Z \, df$$

where, $\bar{E}^2$ = the mean square shot voltage
I = the electron current
Z = the resonance impedance of the tuned circuit
df = the frequency band width factor

At normal filament voltage, a vacuum tube has sufficient space charge so that the shot voltage is reduced to about one-half of the value obtained without space charge.

From these formulae, assuming a temperature of 27°C, a band width factor of 10000 and a plate current of 4 milliamperes, the theoretical values for the thermal-agitation voltage and the shot voltage are as follows:

Load Impedance Z Ohms	Shot Voltage Without Space Charge $\bar{E}$ Volts RMS	Shot Voltage With Space Charge $\bar{E}/2$ Volts RMS	Thermal-Agitation $\bar{e}$ Volts RMS
1000	3.56×10^{-6}	2.19×10^{-6}	0.40×10^{-6}
2000	7.12	3.56	0.57
5000	17.8	8.90	0.90
10000	35.6	17.80	1.28
20000	71.2	35.6	1.81
30000	107.	53.6	2.21
40000	143.	71.6	2.55
50000	178.	89.0	2.85
75000	267.	133.6	3.50
100000	356.	178.0	4.04
150000	535.	268.	4.94
200000	713.	356.	5.71
500000	1780.	890.	9.03

Fig. 1 shows a block diagram representing a receiver. Assume a standard signal applied to the receiver input. When the signal voltage is increased from zero, the a-f output volts increase first as the square of the input voltage, then linearly with input voltage. This is true for diodes as well as other types of detectors. The range of square-law increase will depend on the type of detector. For a diode operated with a large input signal, the square-law range may be entirely negligible. In more modern receivers there is sufficient a-f gain between the diode detector and the tube so that the output will be according to the square law at the 50-milliwatt output level. In general, we may say then, that at the initial noise level, a detector will follow the square law.

Frequently, a receiver has no noticeable noise until a carrier is tuned in. Fig. 2 shows how the noise-output voltage and the a-f output voltage increase as the carrier voltage is increased.

In the square-law range, the noise-output volts increase linearly while the a-f output increases according to the square law. In the linear range the noise-output volts are constant, while the a-f output volts increase linearly.

The laws of increase of noise and a-f voltage are different. As the signal is increased, both carrier volts and sideband volts increase proportionately. The noise-input volts existing independent of signal appear as a constant sideband voltage. In both instances the output is proportional to the product of the carrier voltage and the sideband voltage.

As the detection becomes linear the output is no longer proportional to the product of the voltages, but is directly proportional to the smaller of the two voltages and is independent of the magnitude of the larger voltage. Since the carrier is the larger voltage, increasing it does not increase the noise-output voltage. The increase in a-f output voltage results because the sideband voltage is increased.

It is interesting to note that the ratio of noise-output volts to a-f volts varies inversely as the signal-input voltage throughout the square law and linear range of operation.

It is evident that as the signal is increased, the noise will become a negligible factor and that as the signal is decreased the noise will eventually become greater than the a-f output. This latter condition may occur at an inaudible level.

The noise voltage usually originates either in the grid circuit or in the plate circuit of the first tube. Under conditions of very low gain in these circuits, the second tube may also contribute to the noise.

Since the noise is a series of pulses, it excites the associated circuits in the frequency range to which they respond. It is amplified by the succeeding stages provided they are in tune with the initial circuit either directly or through the medium of a frequency converter. For example, if the noise originates as a band of radio frequencies, it is changed by the converter just as any other signal is changed to the corresponding band of intermediate frequencies. Thus, the noise voltage appears at the detector input and also in the a-f output, although it may be inaudible until sufficient carrier voltage is supplied at the detector input.

Effect of Circuit Constants

Refer to Fig. 1 and suppose the input to the first tube is short-circuited so that only plate-circuit noise is amplified.

Then, by adjusting Gain II the noise-voltage input to the detector may be made any value either large or small.

Changing the plate-load impedance Z_2 has the same effect as changing Gain II. Both noise and signal are changed in the same ratio.

Cutting the frequency band width either in the i-f or a-f stages gives a satisfactory apparent reduction in noise, since the ear is most sensitive to high frequencies. Of course, the higher a-f components of the signal are reduced.

If the noise-volts input to the detector is low enough so that the detector becomes linear before the noise voltage reaches the audible level (approx. 0.1 volt across 4,000 ohms), no amount of increase in signal will produce audible noise. This is evident by referring to the curves of Fig. 2.

In the theoretical tabulation, the shot voltage appears large relative to the thermal-agitation voltage. From Fig. 1, it is evident that when the gain in the first tube is large, the plate-circuit noise voltage will be negligible in comparison with the grid-circuit noise voltage. For example, the tabulation shows for 75,000 ohms resonant impedance that the shot voltage is 133.6 microvolts and the thermal-agitation voltage, 3.5 microvolts. Assume the thermal-agitation voltage appears in the grid circuit and the shot voltage in the plate circuit. If the tube gain is 70, the plate-circuit noise is equivalent to less than 2 microvolts in the grid circuit. In this case, the 3.5 microvolts of thermal agitation in the input circuit will cause more of the noise in the output.

When Gain I is large, the signal is increased with respect to the noise at the first grid.

Choice of Tube and Operating Voltages

Theory shows that the shot voltage increases in proportion to the square root of the plate current of a tube.

The variation of plate-circuit noise voltage with plate current is found to change in proportion to the square root of the plate current and to be almost independent of the plate, screen and grid voltage, and of whether or not the tube has oscillator-input voltage on it.

High gain in the first tube gives low output noise for any receiver sensitivity. For example, in a superheterodyne receiver, a first detector tube gives less gain for the same plate current than an amplifier tube. Hence, for a given sensitivity, a set which uses a first detector in the first tube position will have more noise than a similar set which uses an amplifier.

When gain is controlled in the first tube, the gain decreases faster than the square root of the plate current. That is, noise and gain are both decreased, but the gain is decreased more than the noise is decreased. It would be advantageous then, as regards noise, to secure this decrease in gain in the succeeding stages.

If the first tube can be operated at a fixed bias with small signal input, the lowest noise will be obtained by choosing a tube with high gain and low plate current, and by operating this tube at the highest value of plate current permissible. Operating with high plate current increases the gain more than it increases the noise. It is assumed that the plate resistance is not reduced enough to effect the results.

Similarly, if two or more tubes are put in parallel and the plate resistance remains high enough to be negligible, the gain will be increased n times, where n equals the number of tubes in parallel. The plate current is increased n times, also, and the noise is increased by the square root of n. The noise, for the same overall sensitivity, is thus reduced by a factor of one over the square root of n.

RCA Radiotron Cunningham RADIO TUBES

DIAGRAMMATIC REPRESENTATION OF TYPICAL RADIO RECEIVER

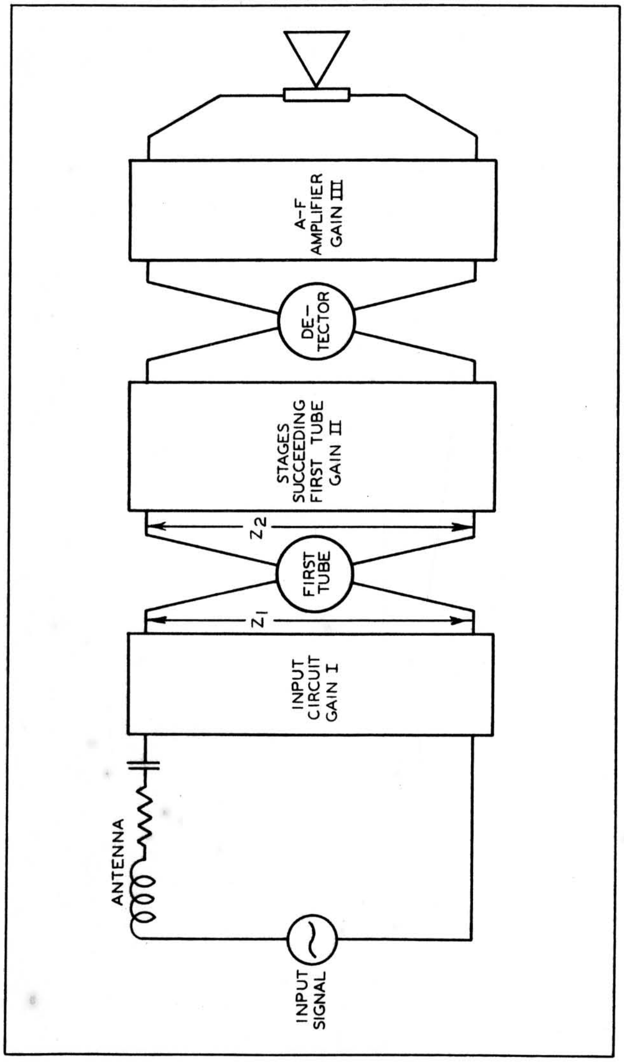

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FIG. 1

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RCA Radiotron Cunningham RADIO TUBES

RELATIVE NOISE OUTPUT & A-F OUTPUT VS. CARRIER INPUT VOLTS FOR TYPICAL RADIO RECEIVER

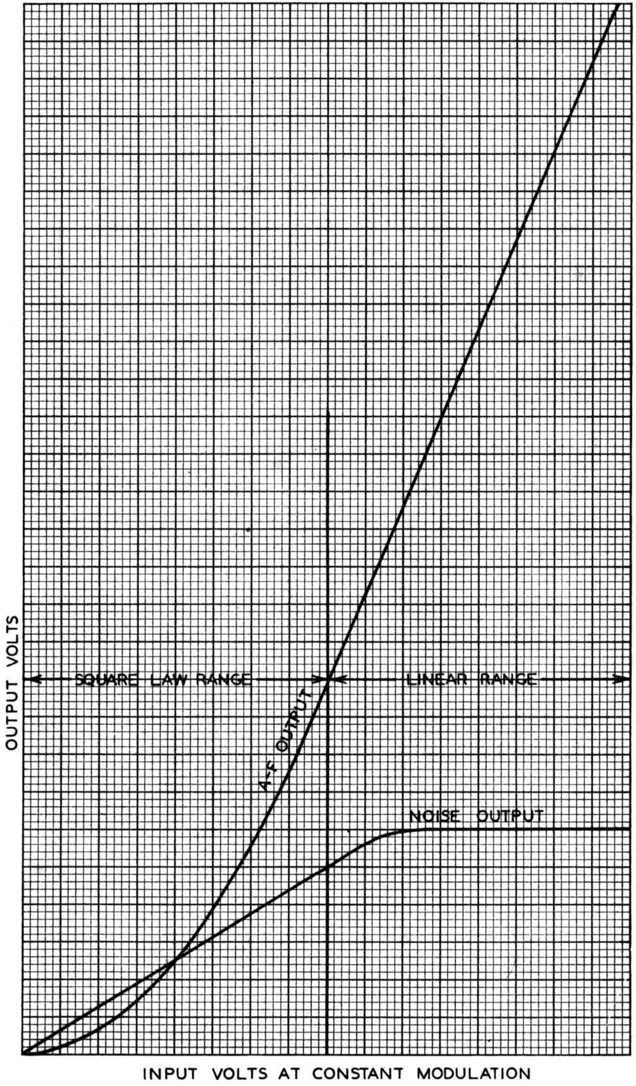

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FIG. 2

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