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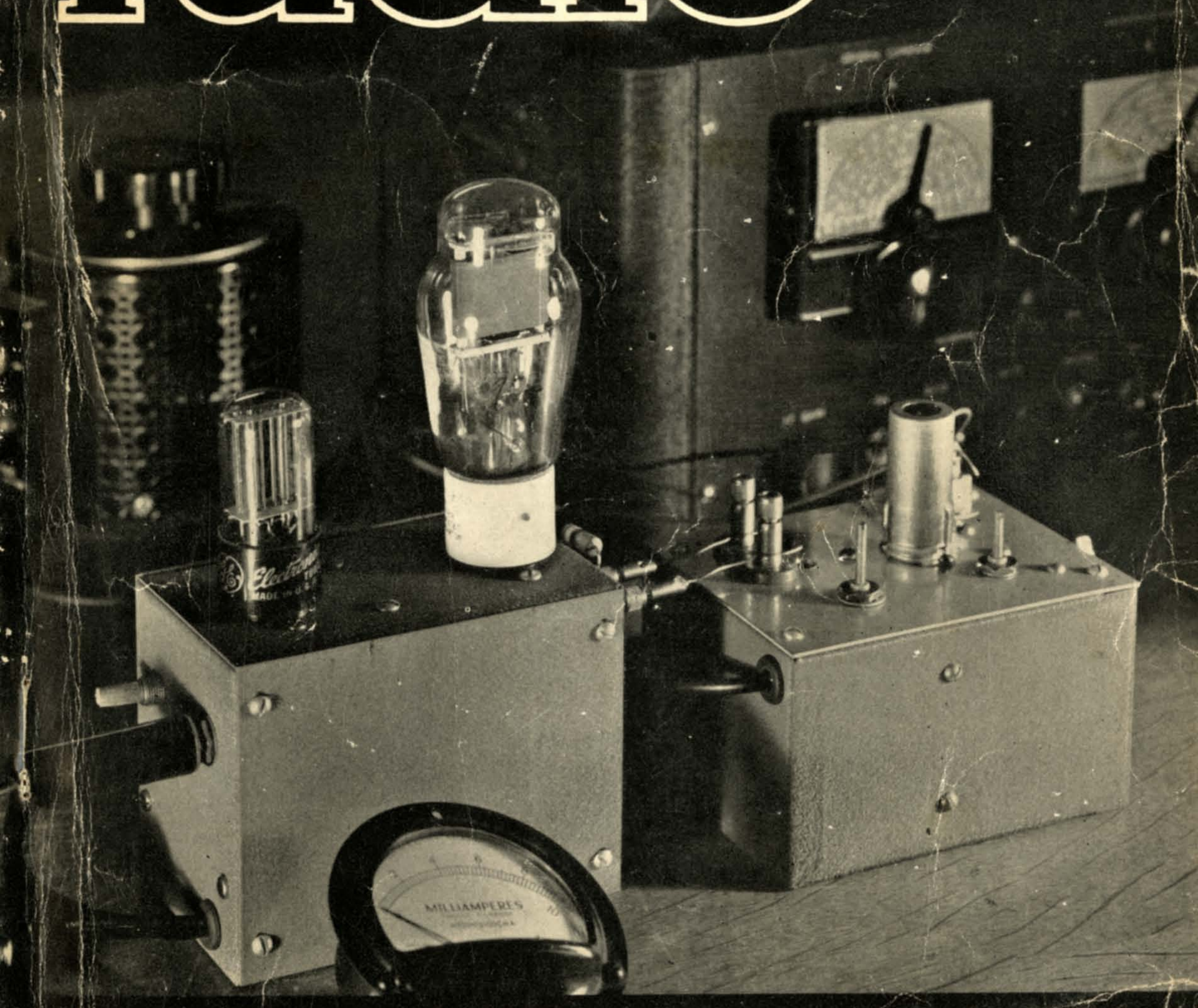

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How Sensitive Is Your Receiver?

The Diode Noise Generator for Testing Receiver Sensitivity

BY BYRON GOODMAN,* W1DX

> **OUR COVER**
>
> **this month shows how simple it is to get the cold dope on a receiver or preselector with the "noise generator" described on these pages. Unlike the spark-coil or neon-sign type of noise generator familiar to all amateurs, this one gives a kind and gentle sort of noise that tells how closely your receiver approaches the ideal noise-free set. All it takes is an old tube, a few simple parts, and a milliammeter.**

Building a converter, preamplifier or even a receiver is a simple job compared with checking its sensitivity. Most amateurs use a no more complicated system than to compare their finished product with someone else's that is presumed to work well. Most hams can tell by the "feel" if a receiver or converter is sensitive at frequencies up to 15 Mc., but above that it is easy to be fooled. Switching two units back and forth on the same antenna is another expedient, but it isn't the most convenient method and it often leads to inconclusive results when the difference is slight. Even if a high-priced signal generator were standard equipment in every ham shack, one would find it difficult to measure the ultimate worth of the receiver or converter, because sensitivity measurements are not easy to make even with a good c.w. or modulated generator.

Receiver Noise

Before describing a new and simple means for checking receivers, let's review briefly the hows and whys of receiver sensitivity. On frequencies where outside noise is the limiting factor to weak-signal reception, as on the broadcast band and up to 20 or 30 Mc. (depending on location and time), sensitivity is generally defined as the input required to give a specified output. However, this is only a measure of the *gain* of the receiver and isn't what the amateur means by sensitivity. He is thinking of "signal-to-noise ratio," and this is an equine of another hue. At the higher frequencies, where atmospheric and other noise can be quite small, the noise generated by the tubes and circuits in the receiver becomes the limiting factor to weak-signal reception. If the stage gain in the front end of the receiver is high, only the noise generated by the first stage is important, because it is amplified by the tube and then masks the noise generated in the following stages. If the gain of the first tube isn't high enough to build up the first-stage noise to a level that will mask subsequent noise, then the first two stages must be considered, and so on. If the gain of the first stage is reduced for gain-control purposes, it is apparent that the signal-to-noise ratio can suffer, because the noise in the system is now contributed by the first *and* second stages. For this reason, it is advisable to run the first tube of a receiver "wide open" for best weak-signal reception. The first two or three stages might be run at full gain all of the time if it were not for the overloading

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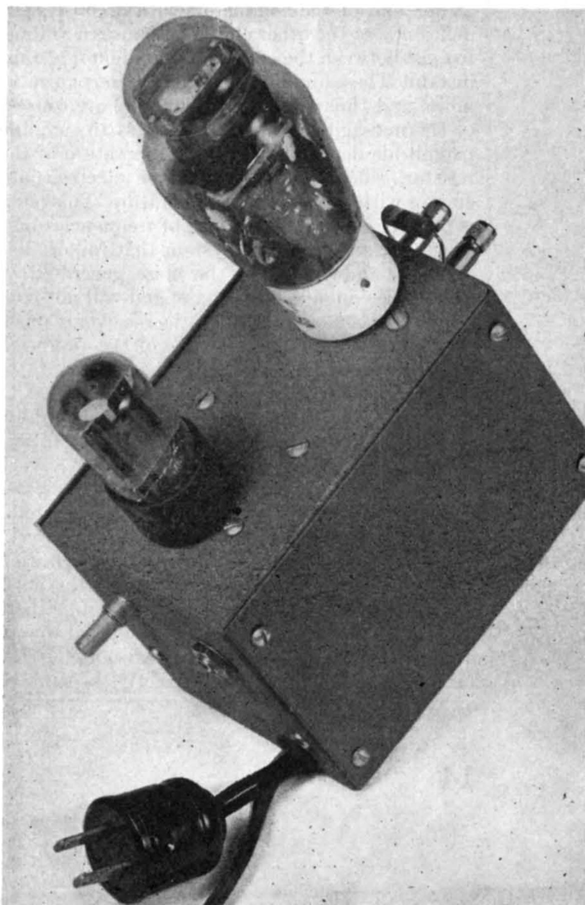


A diode noise generator for amateur use. The ceramic-based tube is a diode-connected 801A, and the noise output is taken from the two terminals just beyond the tube. The other tube is a 117Z6 used as a source of d.c. voltage. The d.c. milliammeter used for measuring diode current is plugged into the 'phone jack. The potentiometer shaft is left over from an earlier design.

ACKNOWLEDGMENT

• The new techniques discussed in this article are the result of intensive work at many wartime research laboratories, both in this country and in the British Empire. The practical diode noise generator was developed at the M.I.T. Radiation Laboratory, mainly by E. J. Schremp and C. P. Gadsen. Further details of these developments can be found in the Radiation Laboratory series of books now being published by the McGraw-Hill Book Co. The author wishes to express his thanks to Yardley Beers, W2AWH, ex-W3AWH, formerly of the Radiation Laboratory, for much of the information contained in this article.

and cross-modulation by strong signals that might take place.

Sources of Noise

Before discussing circuits, we must consider the types of noise that can occur in a receiver. These divide into two groups: the Johnson, or "thermal-agitation," noise, and the "shot" noise.

At any temperature above absolute zero, the conductor electrons in metals are in random motion. At any instant, and quite by chance, more than the average number of electrons are present at one end of the conductor, with a consequent deficiency at the other end. This causes a voltage to exist between the ends of the conductor at that instant. These random voltages we recognize as noise, and thus all ohmic conductors are sources of thermal-agitation noise. Needless to say, the magnitude depends upon the temperature of the resistor, since the motion of the electrons increases with the absolute temperature. This noise is produced over a wide range of frequencies but, of course, any receiving system that follows has a finite bandwidth, and the noise generated at frequencies outside of the passband will not contribute to the noise output of the receiver. Consequently, the equivalent noise voltage produced by the resistor increases with the bandwidth of the receiver (more exactly, it is proportional to the square root of the bandwidth[1]). Incidentally, the people who have developed the theory of this effect use the word "bandwidth" with a very special definition, but for all practical purposes it is the same as the bandwidth at the "half-power," or 3-db., points.

There is one special form of thermal-agitation noise that deserves special mention — the noise generated by the antenna. Yes, even though there is no static or ignition noise being picked up, an antenna is still a source of thermal noise. It has been shown that this noise is exactly the same as would be generated by a resistor equal to the radiation resistance of the antenna, at a temperature equal to the temperature of the antenna.[2] The practical result of this antenna thermal-agitation noise is that even if one could build a "perfect" receiver with no sources of noise within it, he would still have noise generated by the antenna. This antenna noise sets the ultimate limit upon the weakest possible signal we can hope to detect. It is not possible to build a "perfect" receiver, but it is possible to calculate what its noise level would be. Also, we can measure the noise level of a practical receiver and compare it with this "perfect" receiver. Expressed in proper mathematical language, this ratio is called the "noise figure" or "noise factor" of a receiver, and is an indication of the merit of the receiver.

In our discussion of thermal-agitation noise, we were very careful to use the word "ohmic" when speaking of resistors. Actually not all resistors are "ohmic." Some are what might be called "electronic," such as those produced by vacuum tubes, and are not sources of thermal-agitation noise. For example, the very low input resistance of a grounded-grid amplifier is such a resistance. This resistance is caused by feed-back — the plate current is caused to flow through the input circuit. In general, the feed-back will have little effect on the signal-to-noise ratio, since signal and noise are affected more or less in the same way by the feed-back.

While vacuum tubes are not sources of thermal noise, they are sources of the other type of noise, the "shot" noise. This effect is caused by the random way in which the electrons leave the cathode, and thus the plate current contains random variations. If grid current flows, it also generates noise in the same way.

As a matter of fact, this "shot" noise can be applied to our advantage. Under certain conditions, it is easy to calculate just how much noise is produced by a diode. The gadget to be described later operates on just such a principle. It is connected to the input of the receiver and adjusted to cause the noise power output of the receiver to double.

In multigrid tubes there is an additional type of noise known as "partition" noise. The cathode current, which already contains the ordinary shot effect, must divide between the plate and the screen grid, and the fraction of the current that goes to the plate fluctuates in time, causing larger variations in the plate current than would be produced in comparable triodes. Thus, theoretically triodes are far superior to multigrid tubes, from the standpoint of inherent noise. However,

[1] See Appendix.

[2] This effect has been put to practical use at microwaves, where it is possible to build antennas of high directivity. The "noise temperature" of the antenna is then controlled by some object placed along the path of maximum gain. It is possible to detect a lighted cigarette at a few feet by means of the noise at a 1 cm. wavelength.

as anyone knows, triodes cannot ordinarily be used as r.f. amplifiers without neutralization, which is often impractical or at least very inconvenient. In contrast to triodes, tubes which have relatively-high screen-to-plate-current ratios are unusually bad from a noise standpoint. Tubes like the 6SA7, 6K8 and 6L7, designed for converter use, fall in this category.

The ability of a tube to produce shot (and partition) noise is expressed as an "equivalent noise resistance." This is a hypothetical resistance whose Johnson noise at room temperature would cause the same fluctuation in the plate current of an otherwise noise-free tube as the actual shot effect. If the reader does not care to bother with definitions, he can think of this quantity as a number that expresses the relative noisiness of a tube. The lower the value is, the better the tube is. Table I gives the calculated equivalent noise resistances of most of the common receiving tubes. Note that the triodes have lower values than pentodes, as would be expected from the previous discussion. It will also be seen that there is a tendency for the higher-transconductance tubes to have the lower equivalent noise resistances. When triodes and pentodes are used as converter tubes, the conversion transconductance is usually less than the transconductance of the same tube used as an amplifier by a factor of about 3 or 4. The equivalent noise resistance increases by approximately the same amount. The figures for the converter tubes are quite high, and the moral is obvious: in a superheterodyne with no r.f. stages, multigrid converter tubes should be avoided. The inferiority of converter tubes is caused by the large partition noise, since the screen current generally runs several times higher than the plate current.

While the equivalent noise resistance gives a general idea of the relative merits of the various tubes, it doesn't tell the whole story. In the first place, at high frequencies transit-time effects give rise to additional noise, particularly in tubes not designed for these frequencies. In the second place, a more efficient input circuit can be designed when the input capacity is low. Partly because of its high input capacity, the 6AC7 is not quite as good as the table would indicate. In the third place, grid current may give rise to additional shot noise. Laboratory measurements have indicated that most tubes give slightly worse results than predicted, while the 6AK5, when employed as a triode and as a pentode, gives results that are more closely in agreement with the theoretical.

Hey, wait a minute! Don't go rushing off to slap a triode-connected 6AK5 into the input of your receiver and expect to have the best possible receiver — there is a lot more to the story. In the first place, the table indicates only what is theoretically possible in the way of performance — it doesn't come about automatically. The associated circuits and the operating voltages of the tube determine how close one can come to the theoretical figure.

A most important consideration is the fact that the adjustment of the input circuit which gives the best signal-to-noise ratio is not the same one that gives the loudest signal. For this reason, special apparatus (such as the noise generator to be described) is very desirable for obtaining the optimum adjustment. Simply adjusting for the loudest signal isn't the whole story, and generally results in something less than best performance. The antenna is, of course, the source of the signal and some thermal-agitation noise. In a perfect receiver there would be no other source of noise. In a well-designed practical receiver there are other sources but they make relatively small contributions. Adjusting the input circuit will affect signal and noise in different ways, because some of the noise is generated in the first tube and its associated circuits; therefore if one varies the adjustment away from the one that gives the loudest signal in the correct direction, it is to be

TABLE I

Equivalent Noise Resistances of Receiving Tubes

Tube	G_m (*µmhos*)	$R_{eq.}$ (*ohms*)	C_{input} (*µµfd.*)
	Triode Amplifiers		
1LE3	855	2920	
3A5	1800	1390	0.9
6AC7	11,250	220	11.0
6AK5	6670	385	4.0
6C4	2200	1140	1.8
6F4	5800	430	2.0
6J4	12,000	210	2.8
6J5	2600	960	3.4
6J6	5300	470	2.2
6SC7	1325	1840	2.2
6SL7	1600	1560	3.2
6SN7	2600	960	2.4
7F8	5650	440	2.8
9002	2200	1140	1.2
	Sharp Cut-Off Pentodes		
1L4	1025	4300	3.6
1LN5	800	3450	3.4
6AC7	9000	720	11.0
6AG5	5000	1640	6.5
6AJ5	2750	2650	4.1
6AK5	5000	1880	4.0
6AS6	3500	4170	4.0
6SH7	4900	2850	8.5
6SJ7	1650	5840	6.0
9001	1400	6600	3.6
	Remote Cut-Off Pentodes		
1T4	750	20,000	3.5
6AB7	5000	2440	8.0
6SG7	4700	4000	8.5
6SK7	2000	10,500	6.0
9003	1800	13,000	3.4
	Converter Tubes		
1LC6	270	160,000	9.0
1R5	250	160 000	7.0
6SA7	450	250,000	9.5

expected that, for a while, the signal will decrease less rapidly than the noise. If the input circuit involves a transformer, the optimum occurs at somewhat tighter coupling than the loudest signal or, if a single coil with an antenna tap is used, the tap will be closer to the grid end than with the loudest signal.[3] Under these conditions the input circuit will have poor selectivity. Thus if the receiver first stage is designed for optimum signal-to-noise ratio it cannot contribute much to the selectivity, and if high selectivity is desired it will have to be obtained in following stages.

You will recall that the receiver noise power is proportional to the bandwidth, and too often this fact isn't appreciated. In practically all receivers the bandwidth of the receiver is determined by the i.f.- and audio-amplifier characteristics, since the r.f. stages are incapable of any high-order selectivity. Assuming uniform noise over the portion of the spectrum where one is listening, the noise appearing in the output will be proportional to the bandwidth of the receiver, but the amount of signal is constant for any bandwidth in excess of that necessary to pass the signal with good fidelity. It is readily apparent, therefore, that the bandwidth of a receiver should be only enough to pass the signal, and that any greater bandwidth will result in a poorer signal-to-noise ratio.

Noise Figure

We have already described the noise figure of a receiver as a quantity that expresses the relative merit of a receiver as compared with a "perfect" receiver of the same bandwidth. This quantity may be expressed as a power ratio, but more commonly it is given in decibels. The smaller the number, the better the receiver is. In general, it is more difficult to obtain good noise figures at high frequencies than at low. With the best techniques now available, figures as low as 12 db. are obtained at centimeter wavelengths, 6 db. at 60 Mc., and 2 to 3 db. at 30 Mc. A perfect receiver would have a noise figure of 0 db.

This concept is particularly useful because it allows us to compare various receivers of different bandwidths. Receivers A and B might both have the same noise figure and the same gain. However, A might be only 10 kc. wide, since it is intended for telephony reception, while Receiver B, designed for radar work, might be 2 Mc. wide. Because of its greater bandwidth, Receiver B would have a larger equivalent noise power, but the fact that their noise figures were equal would indicate that in their respective applications they were equally good. If both had noise figures of 2 db., it would be apparent that little further improvement could be obtained by input-circuit refinements.

[3] These statements do not apply to grounded-grid amplifiers.

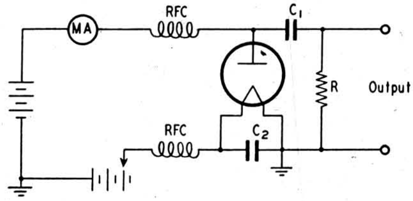


Fig. 1 — **The basic circuit of the diode noise generator for measuring receiver sensitivity. By controlling the filament temperature of the diode, the d.c. current through the diode is a direct measure of the noise power developed across *R*.**

Measurement of Noise Figure

The measurement of noise figure consists of first measuring the equivalent noise power of the receiver and then dividing this by the equivalent noise power of a perfect receiver. To measure the noise of the receiver, a noise generator having an internal impedance equal to that of the antenna is connected to the input. Some sort of device that indicates power is connected to the output. This power-reading device is read with the generator turned off. The generator is then turned on and its output increased until the receiver power output is doubled. Then the power of the generator (more exactly what is called its "available" power — see Appendix) is determined. This is equal to the equivalent "available" noise power of the receiver.

A Noise Generator

While noise figure can be measured with a c.w. generator, it is quite difficult. Noise figures of 3 to 20 db. correspond roughly to equivalent noise powers of 10^{-16} and 5×10^{-15} watts respectively in good communications receivers with 10-kc. wide i.f. amplifiers. Power can be measured directly only down to about 10^{-6} watts, and hence an attenuator must be used that is accurate over a range of 100 db. The exact determination of the "noise bandwidth" is a nuisance. And, lastly, some devices which might be used to measure output power in the receiver do not respond to noise and c.w. in the same way. On the other hand, noise figure becomes a simple thing to measure with a "noise generator," the war-born development mentioned earlier. Perhaps it would be better to say that it becomes easy to *compare* performance with a noise generator, since comparative checks will tell in an instant when an improvement in performance has been made in the unit under test. It is difficult to be sure that one's absolute measurements are exact, and great care must be taken with the construction and use of the generator, although the results obtained with the generator to be described have been quite reasonable and probably less than 2 or 3 db. in error from the absolute value. In any event, when the generator is used at one frequency under fixed conditions, the errors in measurement should all be the same, so the comparative checks will be quite good.

A simplified diagram of the noise generator is shown in Fig. 1. A diode is operated in a "temperature-saturated" condition, which means that the anode voltage is high enough so that the diode current is determined by the filament temperature alone. A diode of this type acts as a constant-current generator of noise because of the fluctuations in the number of electrons leaving the cathode (commonly called the "shot" effect). The chokes *RFC* prevent the r.f. components of this noise from flowing back through the batteries, and so they flow through *R*. The condenser C_1 prevents a short-circuit of the power supply. The resistor *R* represents the generator impedance, and should be a value equal to the input impedance of the receiver being tested. When the noise generator is connected to the input of the receiver, the temperature of the diode filament is adjusted until the noise output power of the receiver doubles. The noise figure of the receiver expressed as a ratio is then given by [4]

$$F = 20IR \qquad (1)$$

where I = diode d.c. current in amperes
R = resistance of generator (*R* in Fig. 1)

Since the quantities *I* and *R* are readily known, the simplicity of the system is obvious.

Expressed in db., *F* is 10 times the common logarithm of the value given by the equation.

Unfortunately, not all diodes are suitable as noise generators, since the diode should have a pure tungsten or thoriated-tungsten filament. Oxide-coated filaments introduce error because of "flicker" effect; i.e., shifting of the active spots on the cathode, which introduces additional noise not covered by the above relation. One of the best diodes for the purpose is a British tube, the CV172, and the Western Electric 708-A, the Eimac 15E (not the 15R), and the 801A, all seem to be good generators. The time-honored '01A will do in a pinch, if you have one around, but the 801A is in surplus and is the one we finally used. The 801A passes more current and hence can be used over a wider range, but both the 801A and '01A gave the same results.

The noise generator is shown in the photographs, and the actual circuit is given in Fig. 2. The output is brought out to two terminals that also take the resistor R_1 (which represents the generator impedance) so that different values can be used without diving into the unit itself. The choke, RFC_1, should be wound to resonate at the operating frequency with the diode and socket capacities, although the generator can be used for comparison purposes at other frequencies without changing the choke. A voltage-doubling rectifier circuit, using a 117Z6, furnishes enough anode voltage to saturate the tube. The filament is fed through a 6.3-volt transformer (full voltage is not needed, nor would the anode supply stand the drain), and the primary of the filament transformer is connected to P_2. In our tests we controlled this voltage with a Variac, but there is no reason why one of the many 10- and 25-watt rheostats in surplus wouldn't do the job just as well. All that is needed is smooth control of the filament voltage. The plate meter plugs in at J_1 — a 0–10 milliammeter will do the trick. Because the meter jack is at plate potential, it must be carefully insulated from the case.

The generator was built in a 3 × 4 × 5-inch box, and a small shield separates the r.f. portion from the power supply. The photographs show how the unit was assembled, and undoubtedly many variations will work as well. It is important to pay attention to the r.f. portion of things — everything to the right of the dotted line in Fig. 2 — and these leads should be kept as short as possible. To obtain absolute results it is necessary to resonate the choke RFC_1 with the tube and socket capacities — this was done with a grid-dip meter — but for comparison work we see no reason why one need be fussy. Getting absolute results allows one to compare his results with other amateurs, but we believe the usefulness of

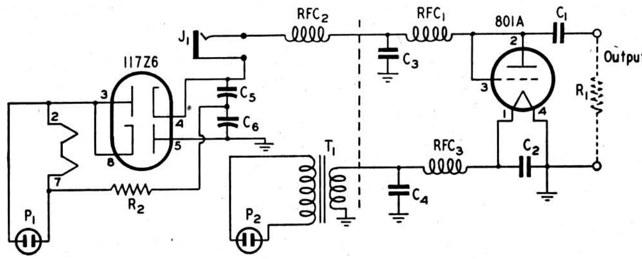


Fig. 2 — A practical circuit for a diode noise generator. The filament temperature is controlled by a Variac or rheostat in series with the a.c. to P_2.

C_1, C_2, C_3, C_4 — 0.001-μfd. mica.
C_5, C_6 — 16-μfd. electrolytic, 150 volts.
R_1 — Generator impedance. See text.
R_2 — 1000 ohms, 2-watt composition.
J_1 — Open-circuit meter jack, insulated rom case.
P_1, P_2 — Male plugs, 115-volt line.
RFC_1 — Resonates with tube capacity to signal frequency. For 29 Mc.: 30 turns No. 24 d.s.c. close-wound on ¼-inch diam. form.
RFC_2 — 2.5-mh. r.f. choke.
RFC_3 — 38 turns No. 22 d.c.c. close-wound on ¼-inch diam. form. RFC_1 and RFC_3 are wound on ¼-inch diam. carbon resistors. Any value above 10,000 ohms is satisfactory.
T_1 — 6.3-volt filament transformer.

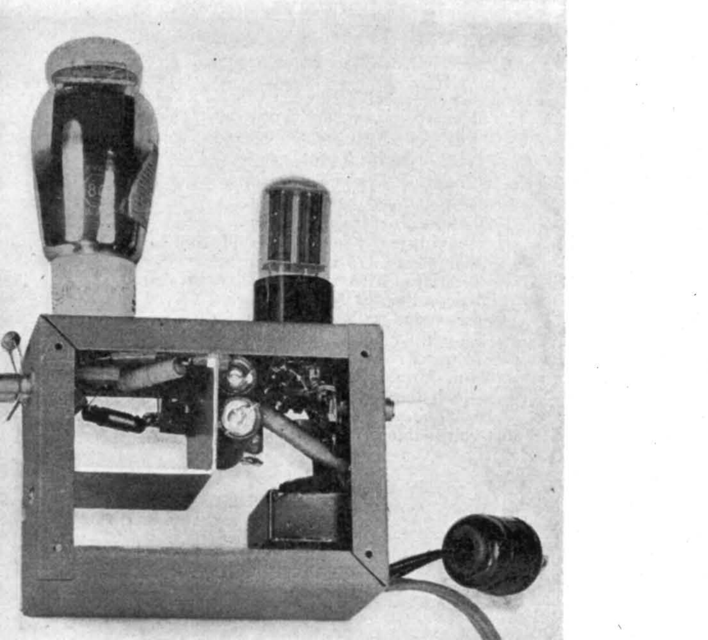
[4] See Appendix.

this gadget to the amateur lies primarily in its simplicity and the fact that it tells you at once when you have made an improvement in your receiver front end.

Using the generator is easy. If you are feeding your receiver with a flat line (300-ohm Twin-Lead or 50- or 75-ohm cable), connect a *non-inductive* resistor of this value at R_1 and use short leads to connect the generator to the antenna posts of your receiver. Connect an a.c. voltmeter across the output transformer of your receiver and run up the receiver audio gain until the receiver noise indicates some convenient voltage as read by the a.c. voltmeter. With the diode noise generator turned on, slowly increase the filament voltage of the 801A until the receiver output voltage increases 3 db. (41 per cent). Read the diode current and that's your reference. You can substitute it in the equation $F = 20IR$ if you have confidence in the noise generator, but we won't guarantee it will be exact. However, you do have a reference from which to work. If you want to see how much of an improvement your preselector gives, connect the noise generator to the preselector and make the same test. If you get a lower diode current with the preselector, the preselector is better than the receiver at that value of line impedance. The tests should be made with the receiver a.v.c. and b.f.o. switched off, and the r.f. gain control should be advanced as far as possible without overloading the receiver with noise. (You can check the latter by increasing the output of the noise generator well above the point that gives a 3-db. increase in receiver output. If the output is still going up fast, it is reasonably safe to assume that the overload point has not been reached.) And if you want to see whether having the input stage peaked at resonance is important, make a measurement with the input stage tuned "on the nose" and one with it detuned. Unless the antenna input circuit is very closely coupled (so that the tuning will have little effect) you will be amazed!

A Cathode-Coupled Preamplifier

The noise generator has been used on 28 Mc. with several of the receivers around the lab and on two preamplifiers. One of these preamplifiers was the popular "R9-er" which uses a 6AK5 in a broadband amplifier, and the other was a cathode-coupled 6J6 that will be described later. The R9-er showed quite a bit of improvement at 28 Mc. over the receivers (with the single exception of one using a 6AK5 r.f. stage), although a new converter using a 6AK5 r.f. stage and a 6AK5 mixer showed comparable performance. The variations in receiver performance became obvious when using the noise generator. By using different values of resistors at R_1 (Fig. 2), it was possible to see how the performance of the receivers varied with different input impedances, and the value of having the input impedance adjustable, as in the R9-er, became quite apparent. For example, the "hot" receiver with the 6AK5 input stage showed a noise figure of 6 db. with 300 ohms and 9.5 db. with 70 ohms, while the R9-er gave a value of 6 db. with either value of resistor. The receiver in question has no antenna trimmer brought out to the panel, and its incorporation might have helped the situation. However, this receiver was still better than others using regular metal tubes of the 6K7 variety, since their noise figures ran between 12 and 16 db. At several points during the development of the cathode-coupled preamplifier it showed inferior performance compared with the R9-er, although the difference wasn't apparent when listening to signals on the air. It was finally possible to get slightly better performance from the 6J6 job than the R9-er, although the difference was only 1 db. (as indicated by the noise generator). This is not to be interpreted as a boost for the 6J6 over the 6AK5, but only to show the usefulness of the noise generator. If we had spent as much time on the R9-er as on the 6J6 job, *it* might have turned out the better! We want only to stress



This view of the noise generator shows how the r.f. portion is shielded and filtered. The r.f. choke in the foreground is the filament choke — the resonant plate choke is in the rear.

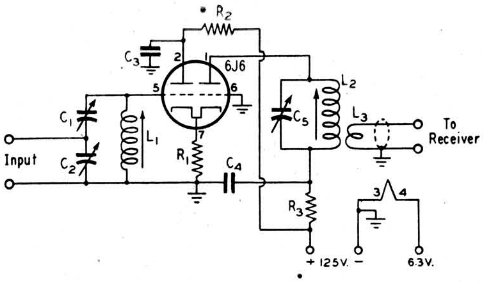


Fig. 3 — Circuit diagram of the cathode-coupled preamplifier.

C_1, C_2 — 3- to 30-μμfd. mica trimmer (National M-30).
C_3, C_4 — 0.001-μfd. mica, smallest size.
C_5 — 35-μμfd. midget variable (Millen 20035).
R_1 — 470 ohms, ½-watt carbon.
R_2, R_3 — 1500 ohms, ½-watt carbon.
L_1 — 28 Mc.: 17 turns No. 22 d.c.c., close-wound.
14 Mc.: 34 turns No. 30 d.c.c., close-wound.
L_2 — 28 Mc.: 10 turns No. 18 enam., space-wound to fill form.
14 Mc.: 20 turns No. 22 d.c.c., close-wound.
L_3 — 3 turns No. 18 flexible hook-up wire close-wound over ground end of L_2.
Coils wound on National XR-50 forms.

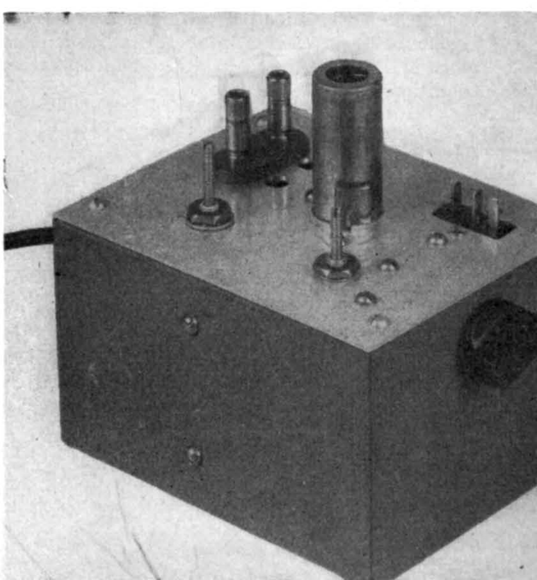
that the noise generator is a handy tool for the fellow trying to improve his receiver performance at 14, 28 and 50 Mc. At higher frequencies, the inductance of the leads in the 801A would probably enter into the picture too much, and no hope for absolute results could be held, although a comparison could still be made.

Pictures of the preamplifier are shown on these pages, and the circuit diagram is given in Fig. 3. The antenna is coupled in through a reactive network, C_1C_2. The plate of the input section of the 6J6 is grounded for r.f. through C_3, and the signal is developed across R_1. The second half of the 6J6 acts as a grounded-grid amplifier, with the signal coupled in through R_1. The plate circuit, L_2C_5, is tuned to the signal, and the condenser shaft of C_5 is brought out to a knob. Thus this condenser is the only tuning adjustment required, once the other constants have been set properly. The input circuit, $C_1C_2L_1$, is broadbanded because it is relatively low-C and is loaded down by the antenna, but the output circuit tunes and hence gives some image rejection. The improvement in image rejection at 28 Mc. is not great, however, and the merit of the preamplifier lies in its improved reception of weak signals. On 14 Mc., the image rejection is slightly better.

The construction of the unit is apparent from the photographs, and no lengthy description is required. With the single exception of the interstage shield, all of the components are mounted on the 4 × 5-inch piece of aluminum used to replace one side of the can. This makes it an easy matter to work on the gadget, since all of the construction work can be done with the chassis removed from the box. The two condensers, C_1 and C_2, are supported by No. 12 tinned wire soldered to the input terminals (a National FWH assembly) and a lug on a small National GS-10 stand-off insulator. This turns out to be a more rugged assembly than we expected, and nothing to be ashamed of mechanically. The output tuning condenser, C_5, is mounted on a small aluminum bracket. All r.f.-circuit grounds are brought to a single lug under one of the 6J6 socket mounting screws. The power leads are brought out through a Jones P-303-AB miniature plug, and the lip of the case must be cut out slightly to clear one bracket of this plug. The output cable, a length of RG-58/U, is secured to a small tie-point which also serves as a tie-point for the ends of L_3. The outer conductor of the cable is grounded by the tie-point mounting bracket.

The interstage shield is fastened to one side of the case only, and it is juggled into place after the chassis is fastened down. The interstage shield has a notch to clear the r.f.-circuit ground lug, and another notch holds the output cable in place. A small hole is necessary to pass the lead from L_1 to the grid of the tube. This grid lead must be connected after the shield is in place, but it is the only connection that can't be made beforehand. The grounded grid lead, from Pin 6, runs across the socket to the socket center shield, and then to Pin 3 and ground.

A cathode-coupled 6J6 preamplifier. The knob at the front tunes the output — the input tuning is fixed-tuned. Note the two holes just in front of the antenna binding posts, for ready access to the input coupling condensers.



The permeability-tuned coils and the adjustable input condensers make adjusting the preamplifier a fairly easy job. Connecting the amplifier to the receiver, C_5 is set at about half-scale and the core of L_2 adjusted for resonance, as indicated by a slight increase in noise in the receiver. Then different ratios of C_1 and C_2 are tried, resonating the circuit with the slug in L_1, until best results are obtained. If C_1 is small compared with C_2, the loading on the input circuit will be light, and if it is too light the amplifier will oscillate. This is remedied by increasing the capacity of C_1 (or decreasing that of C_2) and reresonating L_1. If the receiving antenna uses a tuned line, some combinations may occur where proper loading cannot be obtained, in which case it may be necessary to resort to an external tuned circuit link-coupled to the input of the preamplifier. With a reasonably "flat" line, no difficulty should be encountered.

With the diode noise generator, adjustment of the gadget is quite simple. The correct resistor (corresponding to your line impedance) is connected at R_1 in Fig. 2, and the noise generator is connected as described earlier. The input circuit of the preamplifier is then adjusted for the center of the band, and the performance across the band can be checked by making the same measurement at several frequencies. If the noise figure drops off at the edges, slightly tighter input coupling should clean it up. It will be found that loose coupling to the antenna, which makes for a regenerative condition in the preamplifier, will often give a good noise figure, although the input circuit is too sharply tuned to operate across the band without retuning. Here, however, may be the answer to the success hams have had in years gone by with regenerative preselectors using inductive antenna coupling. It has been found that the best noise figure generally obtains when the antenna coupling to the first tube is slightly *more* than optimum (which is why it isn't worth while at high frequencies to try to obtain much selectivity in the antenna circuit). In a regenerative preselector, the negative resistance introduced in the grid circuit rapidly changes the Q of the circuit as the regeneration is increased. Raising the Q increases the effective coupling, and so the regenerative preselector probably adjusts itself more or less automatically to a good operating condition.

In radar work, noise figures at 30 Mc. of less than 3 db. have been obtained with careful techniques. Since amateur antennas vary so widely, it is practically impossible to describe a universal unit that will work at optimum for everyone. However, with a noise generator to check whether or not an improvement has been made, and with the knowledge that "flat" lines can be made to behave more readily than tuned ones, we feel that the few hints given in this story will enable a serious worker to devise and develop his equipment to the point where the maximum performance is obtained with the tubes that are available. The input coupling circuit used in the preamplifier just described is a simple one that will meet a number of conditions, but inductively-coupled circuits, with provision for tuning both primary and secondary, and for changing the coupling, will probably give slightly better results. Higher-Q coils should also give improved performance, since the only desirable resistance ahead of the first grid is that furnished by the antenna itself.

Appendix

Proof of Equation 1

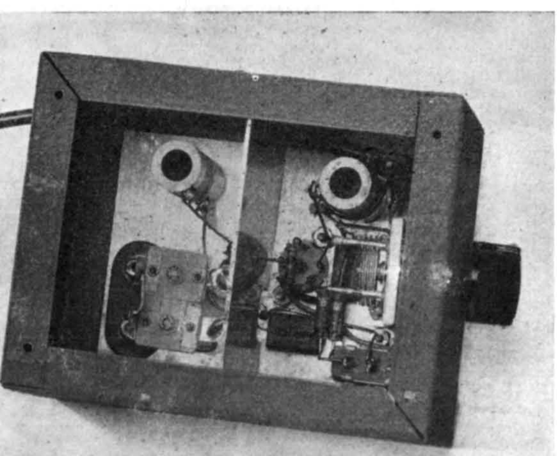
Electrical generators are generally represented as a source of voltage e in series with an internal resistance R. As far as the outside world is concerned, they may also be represented as a constant-current generator, i, in parallel with R, where $e = Ri$. A third way of describing a generator is in terms of its so-called available power and its internal resistance R. The available power W is the maximum power that the generator can supply to an external load, which happens to occur when the external load resistance is equal to R. When this condition is fulfilled, the voltage across the load is $\frac{1}{2}e$. The power dissipated within it is this voltage squared divided by R. Consequently,

$$W = \frac{e^2}{4R} \qquad (2)$$

Also since $e = Ri$,

$$W = \frac{Ri^2}{4} \qquad (3)$$

In noise theory, sources of noise and signal are generally described in terms of their available powers.

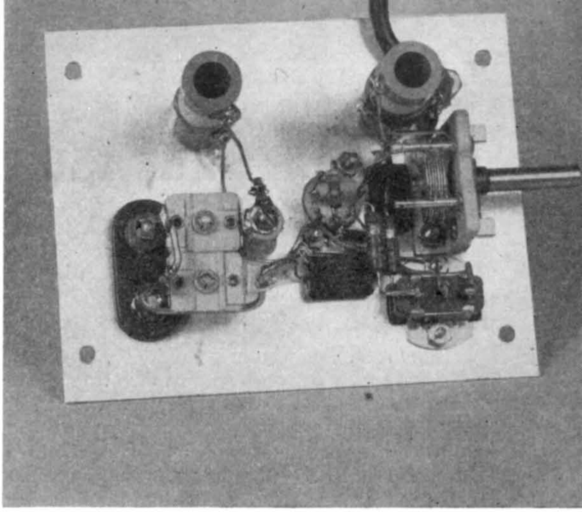


A view of the underside of the preamplifier, showing the shield partition through which the grid lead passes.

◆

The preamplifier chassis can be removed from its case after cutting the grid lead and removing the shield. The coils shown are for 14 Mc. — coil dimensions for 14 and 28 Mc. are given in Fig. 3.

◆



Now we are in a position to give more rigorous definition of noise figure. If we had a "perfect" receiver, there would be sources of noise within it, and the only source of noise would be the thermal-agitation noise of the antenna which has an available power N_1. With a practical receiver we have additional sources of noise. To get the same noise output from a perfect receiver of the same gain and bandwidth as the actual receiver we would have to place at the input a noise source having an available power N_2 (which is larger than N_1). The noise figure F is then defined by

$$F = \frac{N_2}{N_1} \qquad (4)$$

We shall now evaluate N_1 and N_2.

The theory of thermal-agitation noise shows that e, the r.m.s. equivalent noise voltage in series with a conductor of resistance R is given by

$$e^2 = 4kTR\Delta f, \qquad (5)$$

wherein k = Boltzmann's constant,
T = absolute temperature,
and Δf = noise bandwidth of receiver.

If we substitute the value of e from Equation 5 into Equation 2, we see that a conductor has an available noise power of

$$W = kT\Delta f, \qquad (6)$$

a factor of $4R$ having canceled out, and thus the available noise power is independent of R. It is useful to remember that at approximately room temperature (exactly 292° absolute) $kT\Delta f$ equals 4×10^{-15} watts per Mc. bandwidth.

Since the available noise power at the input of the perfect receiver is that due to the thermal agitation in the antenna,

$$N_1 = kT\Delta f. \qquad (7)$$

When we connect the diode noise generator and adjust it to cause the noise output power of the receiver to double, its available power must equal N_2. The shot noise in a temperature-limited diode can be represented as a current-generator i connected from cathode to plate, where i has an r.m.s. value given by

$$i^2 = 2\epsilon I\Delta f, \qquad (8)$$

wherein ϵ = charge of electron (which is equal to 1.6×10^{-19} coulombs), and I = the d.c. plate current.

When a resistance R equal to the radiation resistance of the antenna is connected in parallel with the diode, the combination has an available power given by substituting the value of i from Equation 8 into Equation 3. If I represents the particular value of the d.c. plate current which causes the output to double,

$$N_2 = \frac{\epsilon IR\Delta F.}{2} \qquad (9)$$

When N_1 from Equation 7 and N_2 from Equation 9 are substituted into Equation 4,

$$F = \frac{\epsilon}{2kT} IR, \qquad (10)$$

the bandwidth Δf having conveniently canceled out. At room temperature the constant factor $\epsilon/2kT$ is very nearly equal to 20, if I is expressed in amperes and R is expressed in ohms. Therefore,

$$F = 20\,IR. \qquad (1)$$

Strays

It is with heavy heart that we list the late Samuel C. Hitchon, VE4AE, in Silent Keys this month. Mr. Hitchon, a prominent amateur since the early '30s, was accidentally electrocuted on June 22nd. When discovered in his shack, the victim was holding a grounded microphone stand in his right hand and the station transmitter had been pulled from its shelf. It is believed that Mr. Hitchon's left hand came in contact with an exposed plate coil while he was tuning the rig.

Switch to safety!