A Calibrated Noise Source for Amateur Radio

Calibrated and stable noise sources are expensive —but not this one! Here's a reliable unit *you can build* at a quite reasonable cost.

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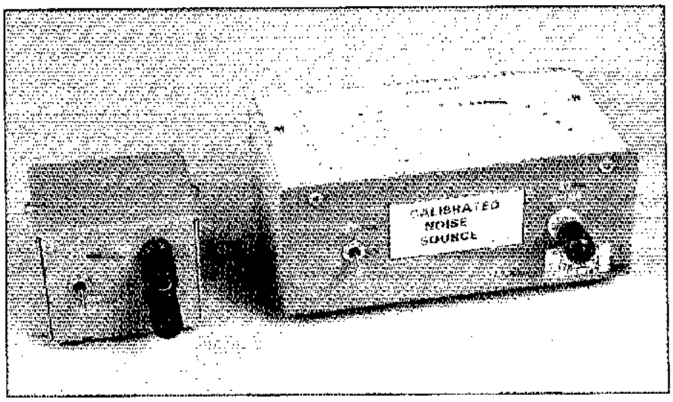

WØIYH's calibrated noise sources. The smaller 1 MHz to 2.5 GHz unit is to the left of the 0.5 to 500 MHz noise source.

Most hams know about the noise sources included in RF bridges that are used to measure impedances and adjust antenna tuners. A somewhat different device—an *accurately calibrated and stable* noise source—is also useful. If you combine a broadband RF noise source of known power output and known output impedance with a true-RMS voltmeter, you have an excellent instrument for making interesting and revealing measurements on a variety of circuits hams commonly use. (Later on, I'll identify some examples.) The true-RMS voltmeter can be an RF voltmeter, a spectrum analyzer, or an AF voltmeter[1] at the output of a linear receiver.

Calibrated noise generators and noise-figure meters are available at medium to *astronomical* prices. Here, I'll describe a *low-cost* approach you can use with reasonable confidence for many amateur applications where accuracy to tenths of a decibel is not needed, but where precision (repeatability) and comparative measurements are much more important. PC boards are available for this project.[2]

Semiconductor Noise Diodes

Any Zener[3] diode can be used as a source of noise. If, however, the source is to be calibrated and used for reliable measurements, avalanche diodes specially designed for this purpose are preferable by far. A good noise diode generates its noise through a carefully controlled *bulk avalanche*[4] mechanism, which exists *throughout* the PN junction, not merely at the junction surfaces where unstable and unreliable surface effects due to local breakdown and impurity effects predominate. A true noise diode has a very low *flicker noise* (1/f) effect and tends to create a uniform level of truly *Gaussian noise*[5] over a wide band. In order to maximize its bandwidth, the diode also has very low junction capacitance and lead inductance.

For this project, I used the NOISE/COM NC302L diode. It's in a glass, axial-leaded DO-35 package and rated for use from 10 Hz to 3 GHz, if appropriate construction methods are followed. Prior to sale, the diodes are factory-aged for 168 hours and are well stabilized. NOISE/COM[6] has kindly agreed to make these diodes available to amateur experimenters for the special price of $10 each, as compared to the usual low-quantity price of about $25.

Noise-Source Design

The noise source presents two kinds of available output power. One is the thermal noise (–174 dBm/Hz at room temperature) when the diode is turned off; call this N_{OFF}. The other is the sum of this same thermal noise and an "excess" noise, N_E, which is created by the diode when turned on; call this N_{ON} (equivalent to $N_{OFF} + N_E$). For accurate measurements, the output impedance of the test apparatus must be the same whether it is on or off, so that the device under test (DUT) always sees the same generator impedance. In Amateur Radio work, this impedance is usually 50 Ω, resistive. The circuit design must guarantee this condition.

For maximum frequency coverage, a PC-board layout and coax connector suitable for use at microwaves are needed. For lower-frequency usage, a less-stringent approach can be employed. Two noise sources are presented here. One is for the 0.5 to 500 MHz region and uses conventional components that many amateurs already have. The other is for the 1 MHz to 2.5 GHz range; it uses chip components and an SMA connector.

Circuit Diagram and Construction

Figures 1A and 1B are the simple schematics of the two noise sources. In series with the diode is a 46.4-Ω resistor, which, when combined with the dynamic resistance of the diode in the avalanche noise-generator mode (about 4 Ω), totals about 50 Ω. When the applied voltage polarity is reversed, the diode is forward conducting and its dynamic resistance is still about 4 Ω, but the avalanche noise is now turned off. As a result, the noise-source output impedance is always about 50 Ω. The 5-dB pad reduces the effect of any small impedance differences, so that the output impedance is nearly constant from the *on* to the *off* condition and the SWR is less than 2:1.

We must consider the noise situation of the noise diode when it is forward conducting. The resistance of the forward-biased PN junction is a *dynamic* resistance. This dynamic resistance is *not* a source of thermal noise, since it is not an actual physical resistance, such as in a resistor or lossy network. However, the 0.6-V forward drop across the PN junction does produce a shot-noise effect. The mathematics of this shot noise shows that the noise power associated with this effect is only about 50% of the thermal noise power that would be available from a physical resistor having the same value as the dynamic resistance. Therefore, the forward-biased junction does *not* add excess noise to the system.[7] There is a 1/f noise effect associated with this shot noise in the NC302L diode, but its corner frequency is at about 100 kHz and of no importance at higher frequencies. Also, the small amount of bulk resistance contributes a little thermal noise.

In order to maximize the unit's flatness and frequency response bandwidth, noise-source construction methods should aim for

[1]Notes appear on page 40.

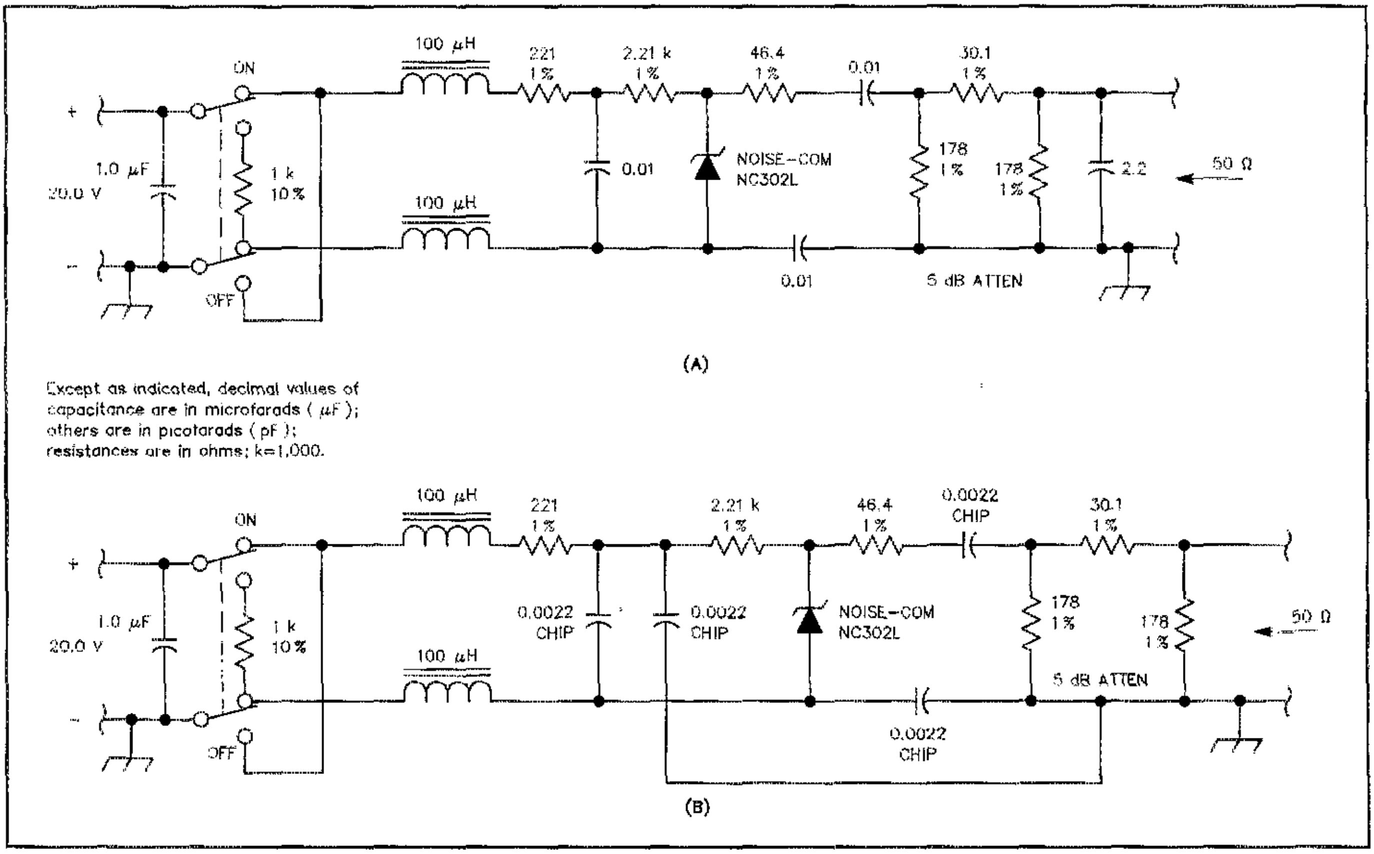

Figure 1—Schematics of the two noise sources. At A, the 0.5 to 500 MHz unit. Resistors are ⅛-W, 1%-tolerance metal-film units. The 1 MHz to 2.5 GHz unit at B uses 1% tolerance, 0.1-W chip resistors and chip capacitors.

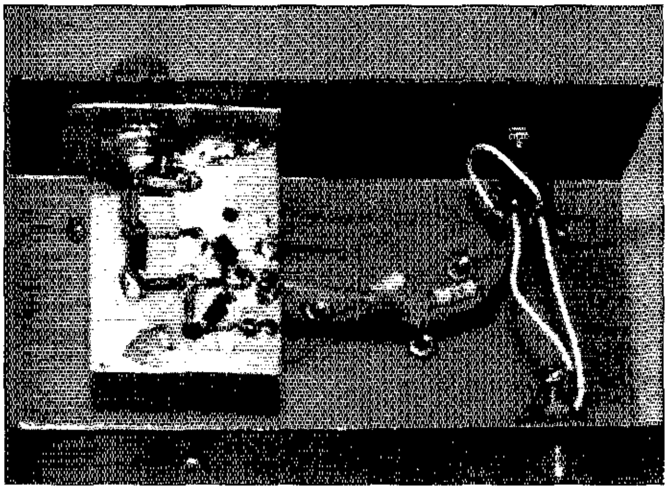

Figure 2—An inside view of the 0.5 to 500 MHz noise source.

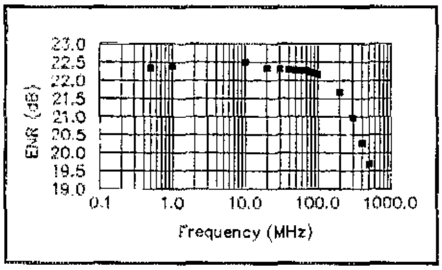

Figure 3—Sample calibration chart of excess noise ratio (ENR) versus frequency for the 0.5 to 500 MHz noise source.

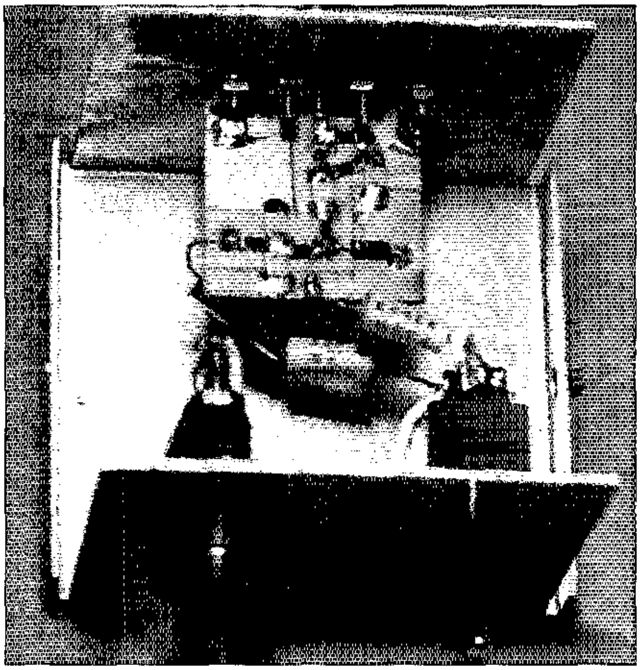

Figure 4—View of the inside of the 1 MHz to 2.5 GHz noise source.

RF circuit lead lengths as close to zero as possible, and minimum inductance in the ground path and the coupling capacitors. The power-supply voltage must be clean, well bypassed and set accurately. Figure 2 shows my 0.5 to 500 MHz unit. This construction method satisfies quite well the electrical requirements I wanted for this model. At 500 MHz, the return loss with respect to 50 Ω at the output jack decreased to 10 dB and I didn't try to extend the calibration beyond that frequency. A calibration chart (Figure 3) is attached to the unit's top for easy reference. Figure 4 shows the

Frequency (MHz)	0.5 to 500 MHz Unit		1.0 to 2500 MHz Unit	
	ENR (dB)	SWR	NR (dB)	SWR
0.5	22.33	1.03		
1	22.38	1.03	21.38	1.03
10	22.45	1.04	21.46	1.03
20	22.35	1.06		
30	22.32	1.06		
40	22.32	1.09		
50	22.30	1.11		
60	22.29	1.12		
70	22.25	1.15		
80	22.22	1.17		
90	22.20	1.20		
100	22.15	1.23	21.80	1.07
200	21.65	1.42		
300	20.96	1.62		
400	20.25	1.70		
500	19.60	1.90	20.71	1.44
1000			20.12	1.86
1500			20.00	2.06
2000			20.70	2.14
2500			21.51	1.88

Figure 5—NOISE/COM calibration for both of my noise sources. The data is, of course, not universal; it varies from unit to unit.

inside of the 1 MHz to 2.5 GHz noise source.

Calibrating the Noise Source

If the construction is solid, the calibration should last for a long time. There are two ways to calibrate the noise source. *If the unit has been carefully constructed and its correct operation verified,* NOISE/COM will calibrate home-built units over the desired frequency range for $25 plus return shipping charges. Note that one factory-calibrated unit can be used as a reference for many home-calibrated units. Figure 5 shows the NOISE/COM calibration data for both models of *my* noise sources, including SWR data. The noise data is strictly valid only at room temperature, so it's necessary to avoid extreme temperature environments.

The second calibration method requires a signal generator with known output levels at the various desired calibration frequencies. One approach is to build a tunable weak-signal oscillator[8] that can be compared to some accessible high-quality signal generator, using a sensitive receiver as a detector. The level of the signal source in dBm is needed.

Access to a multistage attenuator[9] is also desirable. If you build the attenuator, use the nearest 1% values of metal-film resistors so that systematic errors are minimized. A total attenuation of 25 dB in 0.1-dB steps is desirable. Attenuator construction must be appropriate for use at the intended frequency range. In some cases, a high-frequency correction chart may be needed.

With the calibrated signal source and the attenuator feeding your receiver in an SSB or CW mode, use the techniques discussed in the referent of Note 1 to determine the excess noise (N_E) of the noise source and the noise bandwidth (B_N) of the receiver.

Excess Noise Ratio

A few words about excess noise ratio (ENR) are needed. It is defined as the ratio of excess noise to thermal noise. That is,

$$ENR = \frac{N_{ON} - N_{OFF}}{N_{OFF}} = \frac{N_E}{N_{OFF}} \quad \text{(Eq 1)}$$

When the noise source is turned on, its output is $N_{OFF} + N_E$. The ratio of N_{ON} to N_{OFF} is then

$$\frac{N_{ON}}{N_{OFF}} = \frac{N_{OFF} + N_E}{N_{OFF}} = 1 + \frac{N_E}{N_{OFF}}$$
$$= 1 + ENR \quad \text{(Eq 2)}$$

Therefore, ENR is a measure of how much the noise increases, and the noise generator can be calibrated in terms of its ENR.

Normalizing ENR to a 1-Hz bandwidth and converting to decibels, this is

$$ENR\ (dB) = 174\ (dBm/Hz) + \frac{N_E\ (dBm)}{B_N\ (Hz)} \quad \text{(Eq 3)}$$

Prepare a calibration chart and attach it to the top of the unit (see Figure 3). If you decide to have the unit factory calibrated, first perform the calibration procedure so you're fairly sure everything is working properly. Remember, a factory calibrated unit can be used as a reference for other home calibrated units, once you've worked out the calibration-transfer procedure according to your lab capabilities. This requires some careful thinking and proper techniques. If you have any doubts, a NOISE/COM calibration is the best choice.

Noise-Figure Measurement

The thermal noise power available from the attenuator remains constant for any value of attenuator setting. But the excess noise, and therefore the ENR (in dB) due to the noise diode, is equal to the calibration point of the source minus the setting (in dB) of the attenuator.

The noise-figure measurement of a device under test (DUT) uses the Y method and the setup in Figure 6. If the DUT has a noise-generator input and a true-RMS noise-measuring instrument at the output, then the total output noise (including the contribution of the measuring instrument) with the noise generator turned off is

$$N_{OFF(TOT)} = kTB_N\, F_{TOT}\, G_{DUT}\, G_{NMI} \quad \text{(Eq 4)}$$

where kTB_N is thermal noise, G_{DUT} is the gain of the DUT, G_{NMI} is the gain of the noise-measuring instrument and F_{TOT} the noise factor of the combination of the DUT and the noise-measuring instrument. When the noise generator is turned on, the output noise is

$$N_{ON(TOT)} = kTB_N\, F_{TOT}\, G_{DUT}\, G_{NMI} + (ENR)kTB_N\, G_{DUT}\, G_{NMI} \quad \text{(Eq 5)}$$

where the last term is the contribution of excess noise by the noise generator. Note that none of these values is in dB or dBm.

If we divide Eq 5 by Eq 4 and say that the ratio

$N_{ON(TOT)} \div N_{OFF(TOT)} = Y$,

then

$$\frac{N_{ON(TOT)}}{N_{OFF(TOT)}} = Y = \frac{F_{TOT} + ENR}{F_{TOT}}$$
$$= 1 = + \frac{ENR}{F_{TOT}} \quad \text{(Eq 6)}$$

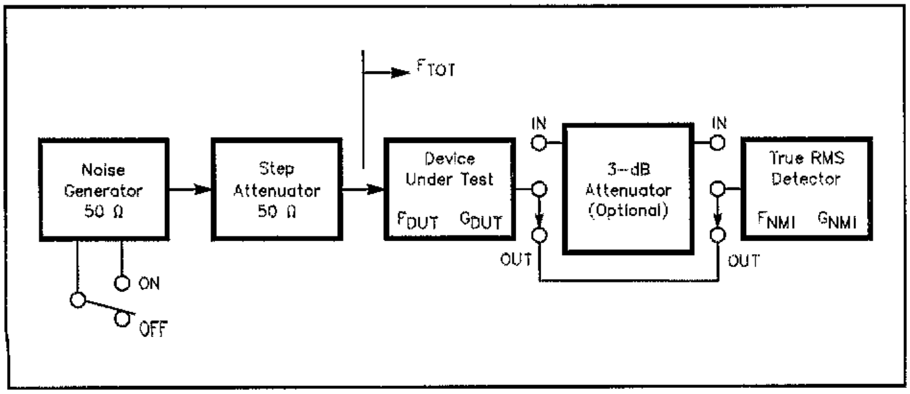

Figure 6—Setup for measuring the noise figure of a device under test (DUT).

Note that kTB_N, G_{DUT} and G_{NMI} disappear, so that these quantities need not be known to measure noise factor. If we solve Eq 6 for F_{TOT}, we get the noise factor

$$F_{TOT} = \frac{ENR}{Y - 1} \qquad \text{(Eq 7)}$$

If the noise output doubles (increases by 3 dB) when we turn on the noise source, then Y = 2, and the noise factor is numerically equal to the excess noise ratio (ENR). If the attenuator steps are not fine enough, or if the attenuator is not reliable over the entire frequency range, use Eq 7 to get a better answer. (It's much simpler to use a good fine-step attenuator.) The value of F_{TOT} is that of the DUT in cascade with the noise-measuring instrument. To find F_{DUT}, we must know the noise factor F_{NMI} of the noise-measuring instrument and G_{DUT} and then use the Friis formula, unless G_{DUT} is very large (as it would be if the DUT were a high-gain receiver [see Note 1]).

$$F_{DUT} = F_{TOT} - \frac{F_{NMI}}{G_{DUT}} \qquad \text{(Eq 8)}$$

The validity of Eq 8 (if we need to use it) requires that the noise bandwidth of the noise-measuring instrument be less than the noise bandwidth of the DUT (see the referent of Note 1). Verify this before proceeding.

There's another advantage to using the power-doubling method. If the 3-dB attenuator of Figure 6 is used to maintain a constant noise level into the following stages and the RMS meter, this means that the noise factor, using the calibration scale and the input attenuator (without using Eq 7), is

$$F_{DUT} = ENR + \frac{1}{G_{DUT}} \qquad \text{(Eq 9)}$$

If G_{DUT} is large, then the last term can be neglected. If G_{DUT} is small, we need to know its value. However, we do not need to know the noise factor F_{NMI} of the circuitry after the DUT, as we did in the previous discussion.

The 3-dB attenuator method also removes all restrictions regarding the type of noise-measuring instrument, since the meter reading is now used only as a reference point. This last statement applies only when two noise (or two signal generator) inputs are being compared.

Frequency Response Measurements

The noise generator, in conjunction with a spectrum analyzer, is an excellent tool for measuring the frequency response of a DUT, if the noise source is much stronger than the internal noise of the DUT and that of the spectrum analyzer. Many spectrum analyzers are not equipped with tracking generators, which can be quite expensive for an amateur's budget.

The spectrum analyzer needs to be calibrated for a noise input, if accurate amplitude measurements are needed, because it responds differently to noise signals than to sine-wave signals. The envelope detection of noise, combined with the logarithmic amplification of the spectrum analyzer, creates an error of about 2.5 dB for a noise signal (the noise is that much greater than the instrument indicates). Also, the noise bandwidth of the IF filter is different from its resolution bandwidth. Some modern spectrum analyzers have internal DSP algorithms that make the corrections so that external noise sources and also carrier-to-noise ratios, normalized to some noise bandwidth like 1.0 Hz, can be measured with fair accuracy if the input noise is a few decibels above thermal. One example is my Tektronix Model 2712. If only relative response readings are needed, then these corrections are not needed.

Also, the noise source itself can be used to establish an accurate reference level (in dBm) on the screen. An accurate, absolute measurement with the DUT in place will then be this reference level (in dBm), plus the increment in decibels produced by the DUT.

The noise-generator output can be viewed as a collection of sine waves separated by, say, 1 Hz. Each separated frequency "bin" has its own Gaussian amplitude and random phase with respect to all the others. So the DUT is simultaneously looking at a collection, or "ensemble," of input signals. As the spectrum analyzer frequency sweeps, it looks simultaneously at all of the DUT frequencies that fall within the spectrum analyzer's IF noise bandwidth. The spectrum display is thus the "convolution" of the IF filter frequency response and the DUT frequency response. If the DUT is a narrow filter, a very narrow resolution and a slow sweep are needed in the spectrum analyzer. In addition, the analyzer's video, or post-detection, filter has a narrow bandwidth and also requires some settling time to get an accurate reading. So, some experience and judgment are required to use a spectrum analyzer this way.

Using Your Station Receiver

Your station receiver can also be used as a spectrum analyzer. Place a variable attenuator between the DUT and the receiver. As you tune your receiver, in a narrow CW mode, adjust the attenuator for a constant reference level receiver output. The attenuator values are inversely related to the frequency response.

A calibrated noise source with an adjustable attenuator that can be easily switched into a receiver antenna jack is an excellent tool for measuring antenna noise level or incoming weak signal level (in dBm), or for establishing correct receiver operation.

The noise source can also be combined with a locally generated data-mode waveform of a known dBm value to get an approximate check on modem performance or to make adjustments that might assure correct operation of the system. The rigorous evaluation of system performance requires special equipment and techniques that may be unavailable at most amateur stations. Or, you could evaluate the intelligibility improvement of your SSB transmitter's speech processor in a noise background.

Summary

The calibrated, flat-spectrum noise generator described in this article is quite a useful instrument for amateur experimenters. Its simplicity and low cost make it especially attractive. Getting a good calibration is the main challenge, but once it is achieved, the calibration lasts a long time—if the right diode is used. The ENR of the units described here is in the range of 20 dB. You may want to use a high-quality, external, 10-dB attenuator barrel to get into the range of 10-dB ENR. If you send the unit to NOISE/COM, send the attenuator also and ask that it be included in the calibration. That attenuator then "belongs" to your noise source and should be so tagged. If the attenuator is of high quality, the output SWR will also be improved. Ask for calibrations with and without the attenuator, if you like. NOISE/COM suggests periodic recalibration, at your discretion.

Acknowledgments

I appreciate the review and suggestions, and also the collaboration with respect to diode purchase and calibration service, of Gary Simonyan and Bent Hessen-Schmidt at NOISE/COM.

Notes

[1]W. Sabin, "Measuring SSB/CW Receiver Sensitivity," *QST*, Oct 1992, pp 30-34. See also Technical Correspondence, *QST*, Apr 1993, pp 73-75.

[2]PC boards are available from FAR Circuits, 18N640 Field Ct, Dundee, IL 60118-9269; price, $3.50 plus $1.50 shipping. A PC-board template package is available free from the ARRL. Address your request for the SABIN NOISE SOURCE TEMPLATE to: Technical Department Secretary, ARRL, 225 Main St, Newington, CT 06111. Please enclose a business-size SASE.

[3]The term *Zener diode* is commonly used to denote a diode that takes advantage of avalanche effect, even though the Zener effect and the avalanche effect are not exactly the same thing at the device-physics level.

[4]The term *bulk avalanche* refers to the avalanche multiplication effect in a PN junction. A carrier (electron or hole) with sufficient energy collides with atoms and causes more carriers to be knocked loose. This effect "avalanches" and it occurs throughout the volume of the PN junction. This mechanism is responsible for the high-quality noise generation in a true noise diode.

[5]*Gaussian noise* refers to the instantaneous values that the noise voltage has. These values conform to the Gaussian probability density function of statistics.

[6]NOISE/COM Co, East 49 Midland Ave, Paramus, NJ 07652. Contact Gary Simonyan at 201-261-8797.

[7]Motchenbacher and Fitchen, *Low Noise Electronic Design*, (New York: Wiley & Sons, 1973), p 22.

[8]W. Hayward and D. DeMaw, *Solid State Design for the Radio Amateur*, (Newington: ARRL, 1986).

[9]*The ARRL Handbook for Radio Amateurs*, (Newington: ARRL, 1994), pp 25-37 to 25-39.

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