Noise Measurement and Generation

Quality weak-signal reception requires a low-noise system. Here's how to calculate and measure the noise performance of your *system.*

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As anyone who has listened to a receiver suspects, everything in the universe generates noise. In communications, the goal is to maximize the desired signal in relation to the undesired noise we hear. To accomplish this goal, it would be helpful to understand where noise originates, how much our own receiver adds to the noise we hear, and how to minimize it.

It's difficult to improve something unless we can measure it. Measurement of noise in receivers does not seem to be clearly understood by many amateurs, so I will attempt to explain the concepts and clarify the techniques, and to describe the standard "measure of merit" for receiver noise performance: *noise figure*. Most important, I will describe how to build your own noise generator for noise-figure measurements.

A number of equations are included, but only a few are needed to perform noise-figure measurements. The rest are included as an aid to understanding, with, I hope, enough explanatory text for everyone.

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Noise

The most pervasive source of noise is thermal noise, which arises from the motion of thermally agitated free electrons in a conductor. Since everything in the universe is at some temperature above absolute zero, every conductor must generate noise.

Every resistor (and all conductors have resistance) generates an rms noise voltage:

$$e = \sqrt{4kTRB} \qquad \text{Eq 1}$$

where R is the resistance, T is the absolute temperature in kelvins (K), B is the bandwidth in hertz, and k is Boltzmann's constant, 1.38×10^{-23} joules/K.

Converting to power, $P=e^2/R$, and adjusting for the Gaussian distribution of noise voltage, the noise power generated by the resistor, in watts, is:

$$P_n = kTB \qquad \text{Eq 2}$$

which is independent of the resistance. Thus, all resistors at the same temperature generate the same noise power. The noise is white noise, meaning that the power density does not vary with frequency, but always has a power density of kT watts/Hz. The noise power is directly proportional to

absolute temperature T, since k is a constant. At the nominal ambient temperature of 290 K, we can calculate this power; converted to dBm, we get the familiar –174 dBm/Hz. Just multiply by the bandwidth in hertz to get the available noise power at ambient temperature. The choice of 290 K for ambient might seem a bit cool, since the equivalent 17° C or 62° F would be a rather cool room temperature, but 290 K makes all the calculations come out to even numbers.

The *instantaneous* noise voltage has a Gaussian probability distribution around the rms value. The Gaussian distribution has no limit on the peak amplitude, so at any instant the noise voltage may have any value from $-\infty$ to $+\infty$. For design purposes, we can use a value that will not be exceeded more than 0.01% of the time. This voltage is four times the rms value, or 12 dB higher, so our system must be able to handle peak powers 12 dB higher than the average noise power if we are to measure noise without errors.[1]

Signal-to-Noise Ratio

Now that we know the noise power in a given bandwidth, we can easily calculate how much signal is required to achieve a desired signal-to-noise ratio (S/N). For SSB, perhaps 10 dB of S/N is required for good communication; the ambient thermal noise in a 2.5-kHz bandwidth is –140 dBm, calculated as follows:

$$P_n = kTB = 1.38\times10^{-23}\times290\times2500 = 1.0\times10^{-17}\,\text{W}$$

$$P_{dbm} = 10\log(P_n\times1000) = -140\,\text{dBm}$$

(The factor of 1000 converts watts to milliwatts.) The signal power must be 10 dB greater than the noise power, so a minimum signal level of –130 dBm is required for a 10 dB S/N. This represents the noise and signal power levels at the antenna. We are then faced with the task of amplifying the signal without degrading the signal-to-noise ratio.

Noise Temperature

Any amplifier will add additional noise. The input noise N_i per unit bandwidth, kT_g, is amplified by gain G to produce an output noise of kT_gG. The additional noise added by the amplifier, kT_n is added to the input noise to produce a total noise output power N_o:

$$N_o = kT_gG + kT_n \qquad \text{Eq 3}$$

To simplify future calculations, we pretend that the amplifier is noise-free but has an additional noise-generating resistor of temperature T_e at the input, so that all sources of noise are inputs to the amplifier. Then the output noise is:

$$N_o = kG(T_g + T_e) \qquad \text{Eq 4}$$

and T_e is the *noise temperature* of the excess noise contributed by the amplifier. The noise added by an amplifier is then kGT_e, which is the fictitious noise generator at the input amplified by the amplifier gain.

Cascaded Amplifiers

If several amplifiers are cascaded, the output noise N_o of each becomes the input noise T_g to the next amplifier. We can create a large equation for the total. After removing the original input noise term, we are left with the added noise:

$$N_{added} = (kT_{e1}G_1G_2\ldots G_N) + (kT_{e2}G_2\ldots G_N) + \ldots + (kT_{eN}G_N) \qquad \text{Eq 5}$$

[1]Notes appear on page 12.

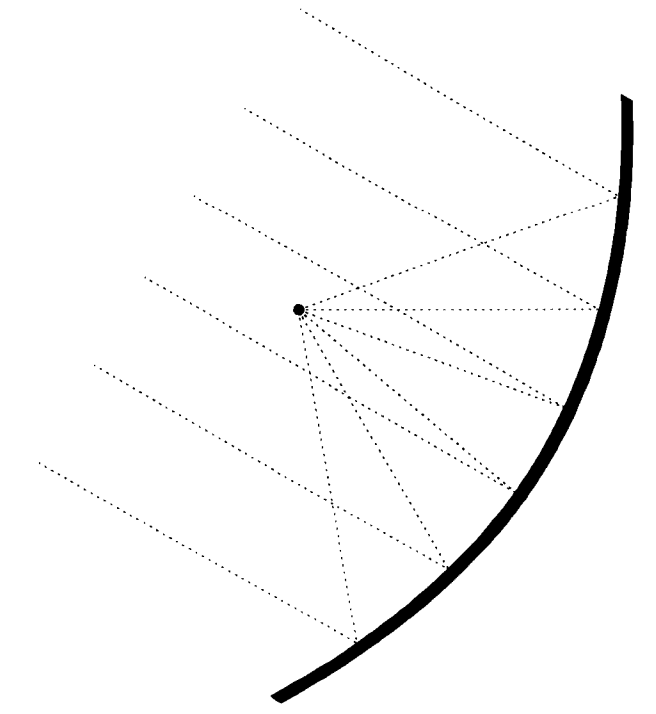

Fig 1—A parabolic dish antenna aimed at a satellite.

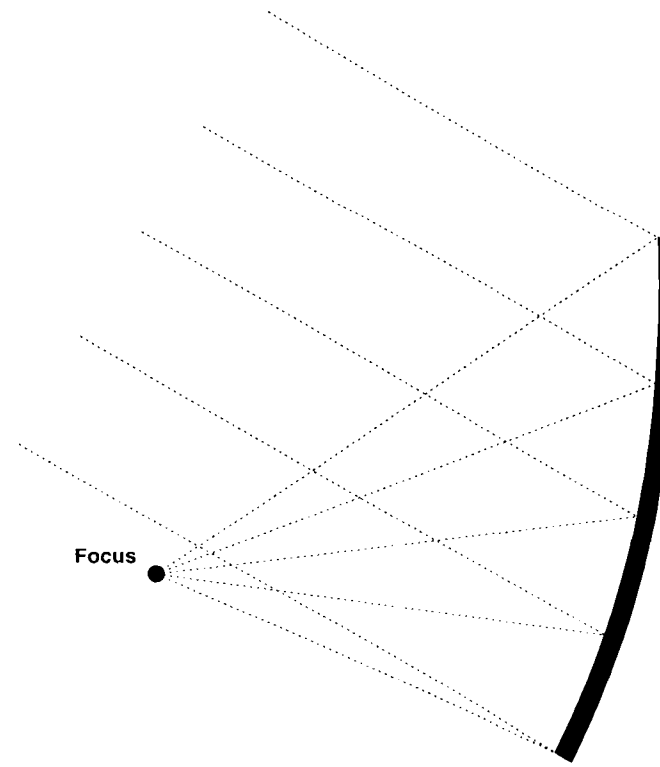

Fig 2—An offset-fed parabolic dish antenna aimed at a satellite.