Site noise vs. system noise figure

By Harold Kinley, C.E.T.

No matter how good the noise figure of *individual* components of a receiving system may be, it is the overall system *noise* figure that represents the bottom line in describing how well a receiving system will perform in the real world. To a large degree it is the ambient site noise in which the receiving antenna is placed that determines the overall system noise figure. In this column we will look at several receiving systems for a conventional narrowband FM (±5kHz deviation) system and compare the performance in high-, medium- and low-noise environments.

Antenna noise figure

Sometimes you will see the term *antenna noise temperature* used to describe the level of ambient site noise in which the antenna is placed. I prefer to use the term *antenna noise figure*. Figure 1 below shows a simple open-circuit resistor. Thermal noise voltage will appear across the resistor. The level of the noise voltage will depend on the resistance, temperature and bandwidth. The formula for noise voltage is(V_N):

$$V_N = \sqrt{4RkTB}$$

For 50W systems this can be reduced to

$$V_N = 14.14\sqrt{kTB}$$

where
k = Boltzmann's constant, or 1.38×10^{-23}
T = temperature in degrees Kelvin (K) and
B = bandwidth in hertz.

Generally, 290°Kelvin, or about 62°F, is considered to be earth's temperature. The noise voltage appearing across the 50Ω resistor shown in Figure 1 is 0.1096μV at 290°K in a 15kHz bandwidth.

The equivalent noise input of a receiver can be determined by the following formula: $N_R = 10\log(N_B) + N_F - 174$ where N_R = equivalent receiver input noise in dBm, N_B = noise bandwidth in hertz and N_F = receiver noise figure in decibels. If the receiver noise figure is 0dB and the noise bandwidth is 15,000Hz, then the equivalent noise input to the receiver is −132.24dBm or 0.0546μV rounded to 0.055μV.

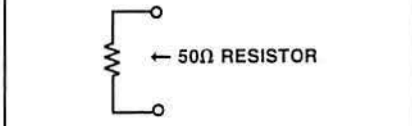

Figure 1. The open circuit thermal noise voltage across the 50Ω resistor is 0.1096mV

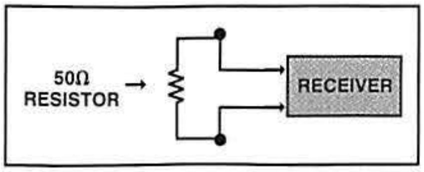

Figure 2. When the resistor is connected to the input of the receiver, the noise voltage from the resistor is reduced by one-half to 0.055μV, and the receiver with a noise figure of 0dB will have an equivalent noise input voltage of 0.055μV. This results in a total noise voltage of 0.0778μV at the receiver input.

Now, refer back to the 50Ω open-circuit resistor. It had a noise voltage of 0.1096μV across the terminals. If we connect this resistor to a 50Ω receiver with a 0dB noise figure (with the equivalent of 0.055μV noise voltage input), what happens? (See Figure 2 above.) Because the resistor is terminated in 50Ω (receiver input impedance), the noise voltage across the resistor will divide in half to produce 0.055μV of noise voltage across the receiver input. Now the resistor is contributing 0.055μV of noise, and the input noise at the receiver is 0.055μV. Because the two noise voltages are non-coherent, the total or resultant noise voltage at the input to the receiver is found from the *root-sum-square* (RSS) of the two voltages.

Thus, the resultant noise voltage at the input to the receiver is:

$$N = \sqrt{N_R^{\,2} + N_{Rx}^{\,2}}$$
$$= \sqrt{0.055^2 + 0.055^2}$$
$$= \sqrt{0.00605}$$
$$= 0.0778\mu V$$

Thus, with the 50Ω resistor connected to the receiver input, the noise voltage has increased from 0.055μV to 0.0778μV, representing an increase of 3dB. The noise figure has increased by 3dB with the connection of the resistor to the receiver, or simply, the resistor has a noise figure of 3dB. If we substitute an antenna for the resistor the antenna will have the same effect on noise figure; that is, assuming that the antenna is placed in an environment where site noise is negligible. It would be hard to find such a place in the real world. The main point is to show that an antenna will exhibit a noise figure of 3dB at a minimum. Normally, the equivalent antenna noise figure will be *much higher* than 3dB.

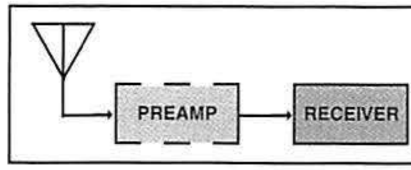

Figure 3. The basic receiving system is composed of the antenna, the preamplifier, transmission lines and the receiver.

System noise figure

Now, we will examine several examples of receiving systems to compare the effects of site noise with various amounts of line loss and with or without a tower-top preamplifier. Figure 3 above is our basic receiving system. The preamplifier (the dashed line) may or may not be in line for a particular series of data.

The receiver used in this table represents a sensitivity of approximately 0.25μV for a noise figure of 9dB. The first four lines of the table are for antennas with the best possible noise figure (3dB) representing a site with the lowest possible noise. Notice that the line loss affects the overall system noise figure almost on a decibel for decibel basis.

Lines 5–9 illustrate what happens when the antenna is at a site with moderate noise represented by a 10dB antenna noise figure. Notice that on line 5, for a 0dB line loss, the system noise figure is 12.3dB. On line 7, the line loss is increased to 4dB but only increases the system noise figure by slightly more than 2dB.

Lines 9–11 show some comparisons at a site where the site noise is high represented by a 20dB antenna noise figure. The overall system noise figure with a

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Table 1. How site noise affects line loss and the use of a tower-top amplifier.

Line	N_{ANT} (dB)	PREAMP	L_{LOSS} (dB)	N_{RX} (dB)	N_{SYS} (dB)
1	3	NO	0	9	9.5
2	3	NO	1.5	9	10.9
3	3	NO	3.0	9	12.3
4	3	NO	6	9	15.1
5	10	NO	0	9	12.3
6	10	NO	2	9	13.3
7	10	NO	4	9	14.6
8	10	NO	6	9	16.1
9	20	NO	0	9	20.3
10	20	NO	3	9	20.6
11	20	NO	6	9	21.2
12	3	NO	0	9	9.5
13	3	YES	0	9	4.2
14	3	YES	3	9	4.6
15	3	YES	6	9	5.3
16	10	NO	0	9	12.3
17	10	YES	0	9	10.3
18	10	YES	3	9	10.4
19	10	NO	3	9	14.0
20	20	NO	0	9	20.3
21	20	NO	3	9	20.6
22	20	YES	3	9	20.0

line loss of 0dB is 20.3dB (line 9). The overall system noise figure for 6dB line loss only increases by 0.9dB. Thus, with high site noise, the line loss is less significant than where site noise is low.

Lines 12–15 illustrate the effect of a tower-top preamplifier at a site where the ambient noise level is at an absolute minimum. On line 12, no preamplifier is used, and the overall system noise figure is 9.5dB for a line loss of 0dB. On line 13, a preamplifier is used (line loss still 0dB), and the system noise figure is reduced to 4.2dB. This represents an improvement of 5.3dB in the system noise figure—a significant improvement. On line 14, the line loss is increased to 3dB and with the preamplifier in place, the system noise figure only increases by 0.4dB. Thus, the preamplifier does an excellent job in improving the system performance in the presence of low site noise. Even with a 6dB line loss (line 15), the system noise figure is only 5.3dB.

Lines 16–19 show how a preamplifier affects system performance in moderate site noise levels. With a 10dB antenna noise figure and 0dB line loss, the system noise figure is 12.3dB without the preamplifier. With the preamplifier in line, the system noise figure is improved by only 2dB (line 17). If the line loss is increased by 3dB (line 18), the system noise figure only increases by 0.1dB.

Lines 20–22 show how system performance is affected by a preamplifier in a high site noise environment. On line 20, the preamplifier is not in line, and with 0dB line loss, the system noise figure is 20.3dB. If the line loss is increased to 3dB and still no preamplifier is in line, the system noise figure is 20.6dB. Line loss has little effect. On line 22, the preamplifier is inserted in line, and with 3dB line loss the system noise figure is 20.0dB. This represents an improvement of only 0.6dB compared to line 21, where the preamplifier was not in line. From this, it is obvious that a preamplifier is of little value at communication sites where the ambient noise level is quite high.

It is also apparent that in high ambient site noise, small line losses have little effect on the overall system performance. This would include insertion losses of cavity

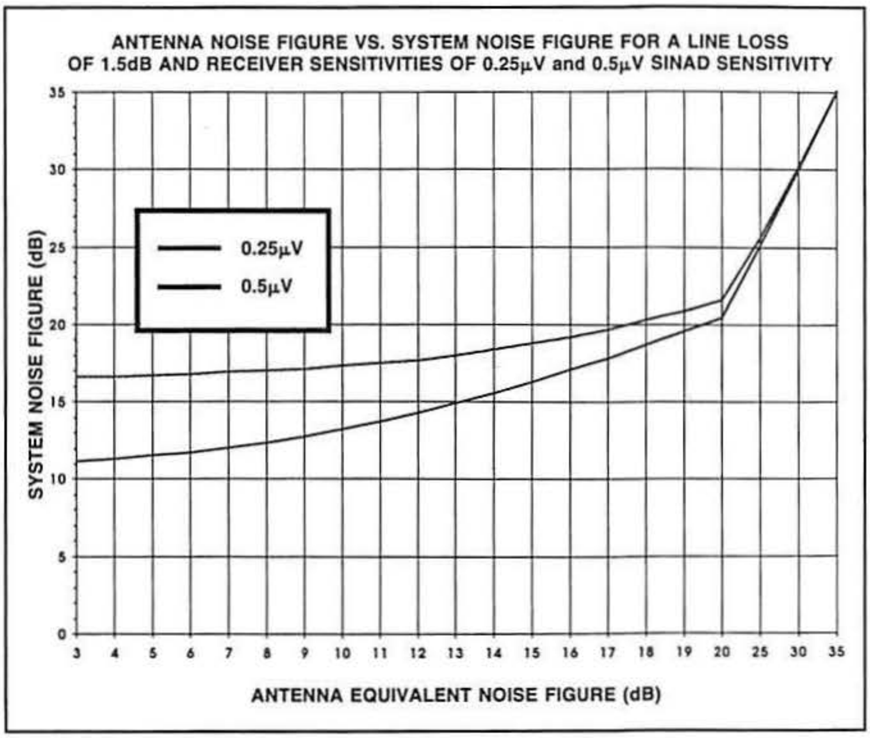

Figure 4. Plot of a receiver with a sensitivity of 0.25mV (red), compared to the plot of a receiver with a sensitivity of 0.5µV (blue).

filters and other insertion losses as well.

The isotee test

Suppose you perform an on-site test with the isotee to discover just how much site noise is degrading your receiving system. Suppose that you measure a degradation of 20dB with the antenna connected vs. the dummy load. Study the graph in Figure 4 above. This graph is for a receive system with a line loss of 1.5dB. The blue graph represents a receiver with a 12dB SINAD sensitivity of 0.5µV, and the red graph represents a receiver with a 12dB SINAD sensitivity of 0.25µV.

Now, if our isotee measurement were to indicate a degradation of 20dB with the antenna connected, the system noise figure would have been degraded by 20dB. Add the 20dB to the point of the vertical scale where the red graph intersects. Thus, 20dB plus 11dB = 31dB. Move up to 31dB on the vertical scale and over to the red graph and down to the horizontal scale, and we find the antenna has an equivalent noise figure of 31dB. If the external noise is reduced by 20dB so that the equivalent antenna noise figure is 11dB, then the overall system noise figure will increase less than 3dB. Move down the horizontal scale from 31dB to 11dB, up to the red graph and over to the vertical scale to about 13.5dB for the new system noise figure. Suppression of the noise much below this level will yield little improvement.

Summary

Remember, site noise from several sources adds as the *root-sum-square* for non-coherent noise voltages. If a certain transmitter is degrading your system, it will do no good to suppress that source of noise much below the noise level of the general noise floor at the site. To be sure you are attacking the problem at the correct transmitter, observe the difference in noise degradation with the suspect transmitter up and down.

When the equivalent antenna noise figure is high, suppressing the noise level by approximately 6dB *plus* the amount of degradation will yield about the best improvement.

Further suppression will be of little benefit.

Until next time—*stay tuned!*

References

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Ott, Henry W., *Noise Reduction Techniques in Electronic Systems*, 2nd ed., John Wiley & Sons, 1988.