External Noise, Antenna Efficiency, Cable Loss and Receiver Sensitivity

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Background

When designing any radio receiving system, engineers and technicians tend to avoid any antennas or transmission lines that may introduce loss or inefficiencies. The worry is that the receiver sensitivity will be lowered and signal-to-noise (S/N) will be diminished. Dealing with these issues are critical at VHF (30 to 300 MHz) and above, however their impact on system performance is greatly reduced in the HF (3 to 30 MHz) frequency band.

Noise Types

To understand the sensitivity issue, we need to have a fundamental understanding of two types of noise that you need to account for in a RADAR or communications receive system.

1. *Internal Noise*

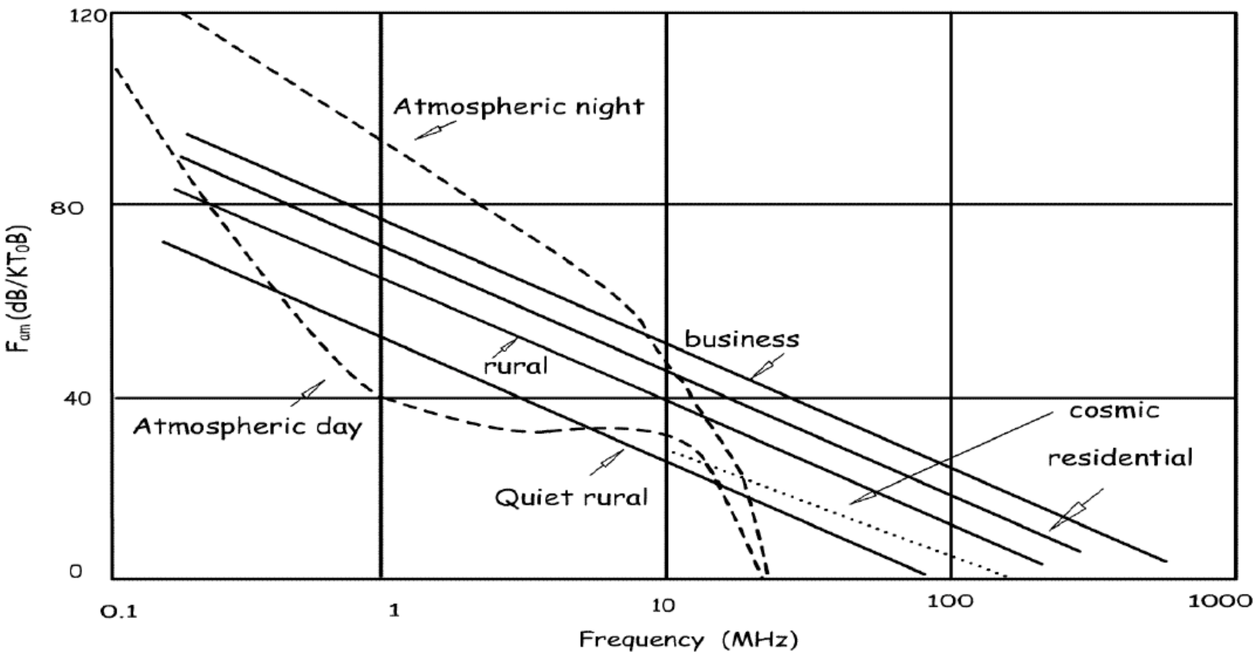
This is the noise wholly created within the receiver and is sometimes referred to as self-generated noise or a receiver's Noise Figure (NF). This noise level is limited on the low end by thermal noise introduced in the first RF amplifier or preamp. At room temperature you can never have noise level lower than -174 dBm/Hz. There are exotic applications like super cooling that reduce this level, but at a high price tag. Commonly adding to the thermal noise is the loss in the input filter or preselector. The simplest way to measure NF of a receiver is to terminate the input into a matched resistive load and look at the noise power level relative to a calibrated sine wave.

2. *External noise*

This is any signal source that is introduced into the receiver from the antenna that is not part of the usable signal spectrum. These undesirable noise sources can come from: (a) radio stations and other man-made emitters; (b) lightning strikes and other atmospheric events including solar flares; (c) galactic or cosmic noise. The sum of these noise contributions can vary significantly though there is considerably more noise power as you go lower in frequency. The plot (figure 1) graphs these noise sources. The solid lines represent the average total noise power for four different geographic areas from quite rural to business or industrial. It seems reasonable to expect that the contribution of man-made noise is higher in industrial locations and lower in less populated rural areas.

Predicting the Effect of Noise

We can use the plot to estimate what the external level would be if a receiver is tuned to 12 MHz using an ideal (isotropic) antenna and lossless cable. Using the graph we find that the noise power level for a rural location would be at a level of 40 dB. That means that the noise power from these different external sources listed above will be 40 above the level of thermal noise previously defined to be -174 dBm/Hz or 0 on the left vertical scale of the plot.



Plot of External Noise Power Variability and Frequency (figure 1)

To contrast, noise in the VHF band can be examined. We tune to a communications band at 150 MHz with the same isotropic antenna and lossless cable. From the plot, the intersection for a rural location will be at about 3 dB above thermal noise. Also it should be noted on the graph that once you are above 500 MHz, there are few or any external noise sources.

Relationships between S/N, Efficiency, Loss and Internal Noise

At any location there is a maximum possible S/N for any possible polarization and direction. When referring to maximum signal to noise, the noise is always the external noise power at the antenna. The preservation of this S/N is the goal of system designer who must understand and quantify both losses in the transmission line (cable) and mismatch loses or inefficiencies. In a practice as in these examples, antenna loss and antenna efficiency are treated as the same.

The relationship between noise types and losses are shown below.

$$\text{Noise}_{\text{external}} + \text{Antenna}_{\text{loss}} + \text{Cable}_{\text{loss}} > \text{Noise}_{\text{internal}}$$

In this relationship, system sensitivity is preserved as long as the external noise and the losses are above the level of internal noise.

To apply this to the communications system at 150 MHz we use the rural external power level we previously estimated at 3 dB above thermal noise or -171 dBm/Hz. For this case we will use an antenna efficiency of +2 dB. This will likely be higher if directional gain is used. Cable losses will be set at -5 dB and internal noise or NF will be at 3 dB or -171 dBm/Hz.

$$-171\ \text{dBm} + (2\ \text{dB}) + (-\ 5\ \text{dB}) = -174\ \text{dBm}$$

In this example the cable loss of 5 dB is too much and will result in the lowering of realized S/N by 3 dB.

To apply this relationship to an HF RADAR system operating at 12 MHz we use the rural external power level we previously got of 40 dB. This will set the typical external noise power to a level of -134 dBm/Hz. In this case we will give an antenna efficiency of -20 dB since loopsticks and short monopoles are not very efficient. Loss in the cable again will be set at -5 dB and internal noise or NF will be at 10 dB or -164 dBm/Hz.

$$-134\ \text{dBm} + (-20\ \text{dB}) + (-\ 5\ \text{dB}) = -159\ \text{dBm}$$

The results show that the external noise power is at a level 5 dB above the receiver internal noise power. In this example there will be no degradation of S/N even if we decided we needed to allow the cable losses to climb to 8 dB.

A Graphical Approach

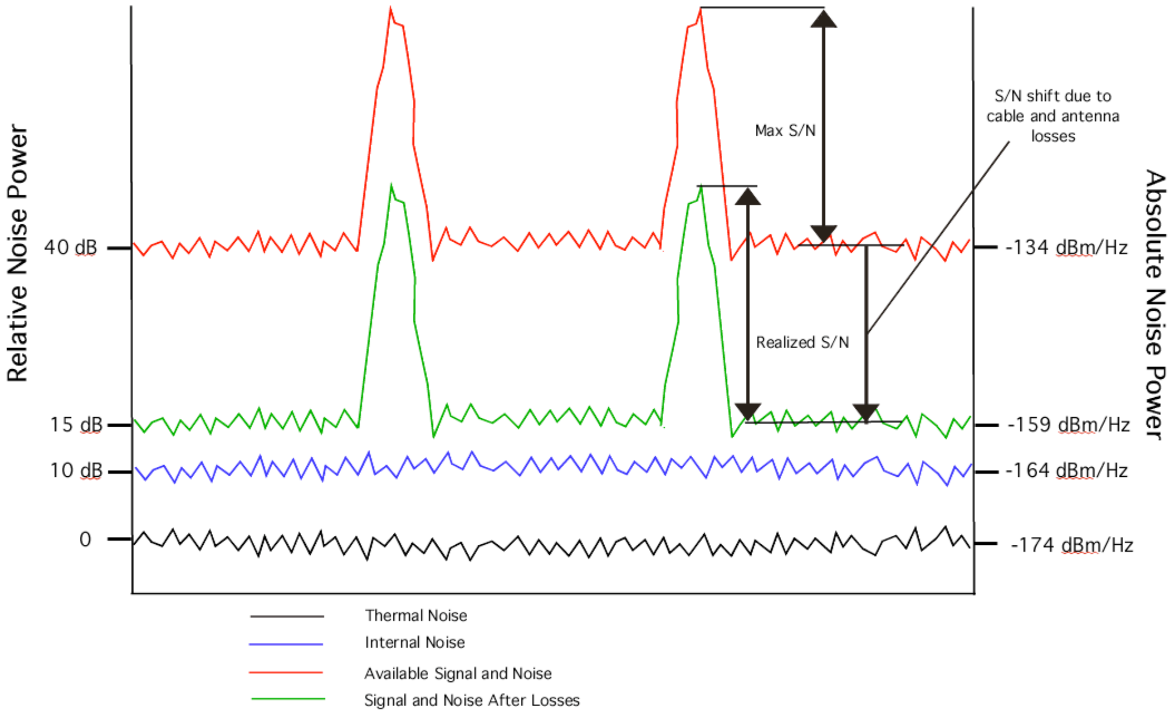
For those who don’t want to worry about the details of antenna and cable losses, the graph in figure 2 may be a helpful and intuitive tool. It shows the spectral relationship between the various signals and noise levels:

Black Line - At the bottom of the graph is the level of thermal noise. This is the rock-bottom minimum noise level of a optimized receiver.

Blue Line - This the noise level or Noise Figure of a typical SeaSonde receiver of 10 dB or 10 dB higher than thermal noise.

Red Line - Represents the signal and the external noise levels common in the middle of the HF RADAR band. This could be referred to as the maximum S/N or the highest signal and noise available at the receive antenna. The external noise level used is the 40 dB level that we obtained from figure 1.

Green Line - This is the signal and noise line which represents the degradation or downward shift of both signal and noise as the result of cable and antenna antenna losses. It is important that after this shift the external noise in the green plot be above the level of the blue plot. If it does ,maximum S/N will be realized.



Spectral Graph of various Noise and Signal Relationships (figure 2)

Conclusions

External noise power is significantly higher at frequencies below 50 MHz and increases tremendously in the lower HF spectral region. Operators at VHF and UHF (.3 to 3 GHz) also need to be aware of external noise, however it is much less of a consideration. Although the contribution of external noise is never desirable, a system designer can optimize the receive antenna and transmission line specifications to economize and simplify without loss of S/N hence sensitivity.