Propagation
WorldRadio August and September 2005
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More on Noise

The April 2005 column discussed the impact of noise on propagation. This column takes a deeper look at noise itself. We'll look at the three important issues that are under the umbrella of 'noise': receiver sensitivity (internal noise), external noise, and quality of service. Then we'll work through two examples. Let's start with receiver sensitivity. I should mention that I'm going to throw out many numbers in this month's column – so be forewarned.

Receiver sensitivity

Our receivers are not perfect – they have internally generated noise (produced by the movement of electrons in any substance that has a temperature above absolute zero) that limits our ability to hear. One measure of the sensitivity of a receiver is called its minimum discernible signal (MDS), or noise floor. It's the level of an RF signal that increases the no-signal audio output by 3dB. In other words, the RF signal level generates the same audio output power as the internally generated receiver noise.

The ARRL measures MDS in their product reviews. For example, in the product review of the Ten-Tec OMNI VI Plus in the November 1997 QST (I picked an OMNI VI Plus because it's the rig at my main station), the MDS on 3.5MHz when using the 500Hz IF filter is -135dBm (this will vary a bit from unit to unit). What does this mean? It says a signal level of -135dBm increases the no-signal audio output by 3dB when using the 500Hz filter. Does the MDS change with different filter bandwidths? Yes, it does, by 10 times the log of the ratio of the bandwidths (we use 10 time the log since we're dealing with noise *powers*). A 3KHz filter for SSB lets in more noise, so one would expect the MDS in SSB to be worse by 10 times the log of 3KHz/500Hz = 7.8dB. Thus the MDS would be -127.2dBm with a 3KHz IF filter. In other words, with the wider SSB filter, you can't hear down as far.

An interesting question to ask is "How does the OMNI VI's MDS compare to the lowest theoretical noise power?" The lowest theoretical noise power is k (Boltzmann's constant = 1.38×10^{-23}) times the temperature in degrees Kelvin times the bandwidth in Hz. Here's where a calculator really comes in handy. At room temperature ($25^{o}C = 298^{o}K$) in a 1Hz bandwidth, the lowest theoretical noise power is -174dBm. If an OMNI VI had a 1Hz filter, the MDS would be better than the -135dBm value by 10 times the log of 500Hz/1Hz = 27dB (it's better because the 1Hz filter lets in less noise). This works out to an MDS of -162dBm in a 1Hz bandwidth. Note that it's 12dB away from being 'perfect' – which is the -174dBm theoretical limit (this 12dB difference is the noise figure of the OMNI VI). This brings up another interesting question: "Is there any reason to make the OMNI VI's MDS better to allow it to hear signals closer to the theoretical limit?" We'll answer that question in the next section.

External noise

So far we've discussed a receiver and its internal noise. Now let's hook it up to an antenna to see what external noise does to our ability to hear.

Since external noise has a great impact on propagation, it has been studied extensively. One excellent reference on noise is Recommendation ITU-R P.372-7 (the old CCIR Report 322), which is appropriately titled Radio Noise. You can purchase this 75 page document on the ITU (International Telecommunications Union) website (**http://www.itu.int**) for 36 Swiss Francs.

There are three sources of external noise that can impact our HF operations: man-made noise, galactic noise, and atmospheric noise due to lightning discharges. Let's look at man-made and galactic noise first.

The ITU document includes a plot of man-made noise and galactic noise versus frequency, and this is reproduced in Figure 1 (it's Figure 10 in the ITU document). All noise powers are monthly median values and were measured with short vertical monopole antennas. And as indicated in the vertical axis legend, they're in a 1Hz bandwidth.

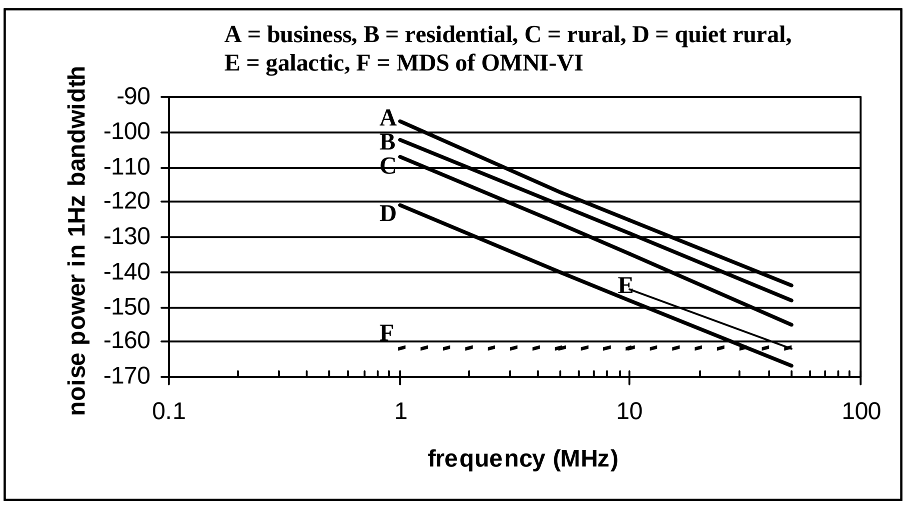

Figure 1 – Man-made noise and galactic noise versus frequency

There are several important pieces of information with respect to HF operation in Figure 1. First, the environment you live in determines how man-made noise will impact your QTH. Ideally, you would like to be in the quiet rural (D) environment. Second, as you go lower in frequency, the noise increases. So if you're a low band aficionado, noise is critical. Third, unless you live in a quiet rural environment and are an aficionado of the higher HF bands, galactic noise (the E curve) is probably not a big issue (galactic noise generally doesn't go below 10MHz as it doesn't get through the ionosphere). And fourth, if you have an OMNI VI with its extrapolated MDS of -162dBm in a 1Hz bandwidth (the dashed F curve, which assumes the MDS is constant for all the ham bands – a pretty fair assumption), man-made noise limits your ability to hear. Thus making the OMNI VI's MDS better won't help (here's where trading sensitivity for strong signal performance is very important).

Now let's address atmospheric noise due to lightning discharges – better known as QRN. What this represents is the constant drizzle of noise propagating into your QTH from lightning discharges worldwide (it is estimated that there are two thousand thunderstorms occurring worldwide at any given moment). The ITU document has worldwide maps of monthly median atmospheric noise in 4-hour time periods for the four seasons - for a total of 24 maps. Each map gives the noise (in dB above -174dBm) at 1MHz, along with two other plots that allow you to calculate the noise at other frequencies and to show how the noise varies statistically.

For my QTH in a winter month in the 4PM to 8PM local time period (2100 – 0100 UTC), the noise versus frequency is roughly halfway between the rural C curve and the quiet rural D curve in Figure 1 up to about 10MHz – above which it drops off significantly (due to the energy spectrum of a lightning discharge). As would be expected, the atmospheric noise propagating into my QTH is greatest during the summer months (lots of thunderstorms). And since it's mostly a low frequency phenomenon, it's greatest when my QTH is in full darkness (atmospheric noise propagates just like our signals).

Now we have information about our receiver sensitivity and estimates of the external noise at our QTH. But before we go through the examples, we need to quickly cover one other issue.

Quality of service

Just because a signal is at the noise floor of our system doesn't mean we can copy it well. We need to know what's commonly called the quality of service. This is the signal-to-noise ratio for a given intelligibility requirement (or bit error rate with a digital waveform), and it's dependent on the waveform. For example, for 90% intelligibility with suppressed carrier SSB, the signal-to-noise ratio relative to noise in a 1Hz bandwidth needs to be at least 48dB for an operator-to-operator link (from Table 4 in the Ionospheric Communications Enhanced Profile Analysis and Circuit Prediction Program User's Manual that comes with downloading VOACAP – see the January 2001 column). Using the '10 times the log of the ratio of the bandwidths' equation, this translates to a 13dB signal-to-noise ratio in a typical 3KHz SSB bandwidth.

An Example on a Low Band

Now we have everything we need. Let's work through an example on 75m SSB, using my OMNI VI, my QTH (quiet rural), and my quarter-wave vertical for receiving. We'll use a quiet rural environment in a winter month between 4PM and 8PM.

As a refresher, my OMNI VI on 75m has an extrapolated MDS of -162dBm in a 1Hz bandwidth. The man-made noise from Figure 1 for a quiet rural environment is -137dBm in a 1Hz bandwidth. The atmospheric noise (again from Figure 1 and from the earlier comment about atmospheric noise at my QTH being between the rural curve and the quiet rural curve) is -128dBm in a 1Hz bandwidth. The first observation is that my ability to hear is limited by atmospheric noise at -128dBm/Hz.

What signal level is required for 90% intelligibility for SSB? The signal level needs to be 48dB above the limiting noise in a 1Hz bandwidth, which works out to -128dBm plus 48dB = -80dBm. Assuming S9 is 50 microvolts and an S-unit is 5dB (see Table 1), the signal level from the station I'm trying to hear needs to be just under S8 for 90% intelligibility.

Reading	Power in dBm
S9 (50uv)	-73
S8	-78
S7	-83
S6	-88
S5	-93
S4	-98
S3	-103
S2	-108
S1	-113
S∅	-118

Table 1 – Theoretical S-meter readings versus power

A second observation is that 90% intelligibility is essentially a conversational QSO. For a DX QSO, in which you only need to hear his call and your call and your signal report (theoretically, of course!), a lower intelligibility might be entirely satisfactory – which means a lower signal-to-noise ratio, resulting in a lower required signal level. If we arbitrarily pick 70% intelligibility, the signal-to-noise ratio decreases by about 8dB. Thus the signal level now required is right around S6.

What if it's an especially quiet night with respect to QRN – in other words, atmospheric noise is non-existent and I'm limited by man-made noise at -137dBm/Hz? Then the other station would have to put a signal level of -89dBm (-137dBm plus 48dB, which is about S6) into my QTH for 90% intelligibility. For the 70% intelligibility scenario, the signal level would need to be just above S4.

An Example on a High Band

Now let's do an example on 15m SSB. The man-made noise in a quiet rural environment is -157dBm in a 1Hz bandwidth. The atmospheric noise is many dB below the man-made noise level. Thus on 15m, my ability to hear is limited only by man-made noise (unless the thunderstorm is really close!). Note that the -157dBm value is only 5dB above the extrapolated -162dBm OMNI VI MDS in a 1Hz bandwidth. My ability to hear is getting close to the limiting performance of the OMNI VI.

For 90% intelligibility, the signal level would have to be -109dBm. That's about an S2 signal. For 70% intelligibility, the signal level would have to be -117dBm. That's about an S∅ signal. This indicates that on the higher frequencies it's possible to have a QSO without moving the S-meter.

<u>Determining Your Receiver's MDS</u>

The easiest way to determine your receiver's MDS is to dig out a product review on your rig. An alternative way is to actually measure it. I've successfully done this with several receivers using a homebrew crystal oscillator, a homebrew step attenuator, and a DVM. If you do it this way, make sure your crystal oscillator, step attenuator, and interconnecting coax cables are well shielded (to prevent leakage from messing up your reading) and are calibrated (to assure accurate results).

<u>Determining Your Man-Made Noise Environment</u>

With the data in Figure 1, you should be able to work backwards to determine your man-made noise environment. For example, the noise on 80m on my full-size quarter-wave vertical on a QRN-free winter night in a 500Hz bandwidth is just under S3. That puts it at -105dBm per my OMNI VI calibration table, and translates to about -132dBm in a 1Hz bandwidth. This performance is very close to the quiet rural D curve in Figure 1.

<u>Summary</u>

This month's column covered the basics of noise. The two most important concepts to understand are that *noise is a function of bandwidth* and *noise limits our ability to hear*.

There are a couple issues that I didn't address here, and they could result in 'your mileage may vary.' One issue is that you may have one troublesome noise source that dominates your incoming noise: a near-by power line (been there, done that), a neighbor's electric blanket for their cat (also been there, done that), etc. Until it gets fixed, the data in Figure 1 may be useless. Another issue is that our filters do not have brick wall responses – this introduces a bit of error when using the '10 times the log of the ratio of the bandwidths' equation. And I didn't talk at all about directive antenna (for example, Beverages for the lower bands and Yagis for the higher bands) – assuming noise comes in from all directions, they can help due to their directivity. Likewise, I've ignored the benefits of DSP (which is extremely helpful on my OMNI VI).

Finally, a caveat about the data in Table 1 – from the receivers I've measured, most hold well to 5dB per S-unit down to the S3 or so level. Below that they're more on the order of a couple dB per S-unit. Thus it's best to calibrate your receiver's S-meter (as I have done with my OMNI VI) before using it for purposes such as we've discussed in this month's column.