

## **Attacking intermod in the EME station**

By K0CQ

There are multiple contributors to intermod in the EME receiver. All come from strong signals in the area that are made stronger by very high antenna gains especially when at the horizon. Most of these contributors can be helped to reduce intermod.

Intermod comes from overdriven RF and mixer stages. That can come from excess RF gain, insufficient selectivity, and from reciprocal mixing from the phase noise of the various oscillators. Often increased RF selectivity can reduce the signal strengths of the unwanted signal though that's hard to achieve at 2.3 or 2.4 GHz. Cleaner local oscillator phase noise can reduce reciprocal mixing. Reciprocal mixing is a bit insidious, in that it raises the background noise without necessarily showing any modulation good for identifying the source.

Setting front end gain. Typical ham procedures involve turning up the front end gain (when adjustable) until the receiver noise rises 10 dB or noise shows on the S-meter. Sometimes the added gain is in added stages. Mixers can be had that will have low intermod with half a watt of signal, of course they require 2 or 3 watts local oscillator power. But the problem is overdriven mixers and RF stages, not only in the converter or transverter, but in the IF receiver. Setting the front end gain for a significant rise in speaker noise or showing on the S-meter in my experience is way too much gain and every dB you can drop the RF gain you can drop intermod products by three or 5 dB or more depending on the intermod order.

Way back, in North Texas long about 1965 I was on 2m (not EME) with a nuvistor converter into a new Collins 75S-3B. Once I got the converter working well (decent NF) I did have intermod problems with W5WXV who lived about 16 miles away running high power (650 watts) to a quad array of Telrex yagis, adequate power and antenna to hold a nightly sked with Quincy Illinois on CW. But when he was looking north and I was looking south (pair of Hygain 14 element IIRC) I found his signal some 23 times in the lower 200 kHz of the band (he was on 144.085 in the days before the CW subband rule).

With manual NF measuring apparatus on my work bench (and that Collins receiver spent much of its first year or two on the bench up on edge so I could easily access circuits), I found that I could reduce the converter gain with attenuation between the converter and the receiver and reduce the gain in the receiver once I reduced the second mixer noise. I changed the 2<sup>nd</sup> mixer from the pentode of a 6AU8A to an Amperex 6688 or 7788, going from a Gm of 4000, to a Gm of 50,000 which meant a whole lot better noise performance. Then I was able to move the second mixer grid to a tap on the broad IF coil to cut signal even more. As a stand alone receiver it's a little deaf, but with the selected attenuator and the 2m converter it was still sensitive (same system NF as with excess gain) and AI's signals were cut to three. Pegging the S-meter on .085 and two other places at the noise level.

The key to the adjustments was in measuring the SYSTEM NF, not just that of the converter. And with the typical 2+/- kHz IF bandwidth of SSB or CW receivers, there is no handy automatic NF meter to make the test. So even today or especially today such a measurement has to be done manually. Actually there are two schemes possible, I used NF but also measuring MDS is practical today. The scheme is measure NF or MDS with all the gain you have, then starting at the IF receiver introduce attenuation or cut out RF stages until the NF or MDS rises, then take out a dB of attenuation to preserve the NF or MDS. Work towards the antenna at each separable stage and likely this will work best with single stage preamps so the excess gain can be controlled.

## Manual NF measurement

When measuring receiver sensitivity with noise one depends on the noise source being at least having good amplitude stability with time and a small variation of noise level over a wide bandwidth. One injects noise at a known level and looks at the change in receiver output with AGC off. Then once computes the NF from the known noise level and that change. Since the noise source bandwidth is much greater than the receiver IF and audio bandwidth, NF measurements are independent of receiver bandwidth. This fundamental is used in the automatic NF meter with a 4 MHz bandwidth for much easier measuring because with the wide bandwidth noise power shows little time variation. EMEers use the GR IF to measure sun noise for the same reason, a couple MHz bandwidth makes for a much steadier meter. But the IF receiver usually has no broadband IF taps for that happy result. So we hang an audio meter (perhaps VTVM like an HP400E) on the speaker wires and watch the meter bounce. One can modify the meter by increasing the filter (and integrating capacitor) across the meter movement. Other wise, I've spent hours turning noise source on and off and trying to decide the average noise for each condition and the difference between them. I think that an analog true RMS meter like a Keithley that I have that uses a 4 MHz bandwidth amplifier to heat a resistor and then displays voltage as a function of that heat sensed by a thermocouple will do better. Its possible that some computer audio noise analysis function exists or could be created to do a long integration time true RMS. I'll have to think about that further.

In the ault days of 5722 diode noise generators (considered inaccurate above 400 MHz though R&S offered one rated as flat to 1200 MHz with the same tube) we simple adjusted the filament voltage to set the noise diode plate current and all references said the noise ENR is proportional to the DC plate current. Then when the output noise power was doubled, the noise source ENR was the NF of the system. With fixed level noise sources we have to use the Y factor and a formula. Y is the ratio of noise with noise source on to noise with noise source off and the formula is  $NF = ENR(dB) - 10 * \log_{10}(Y - 1)$  and at one time AIL gave out a NF computing slide rule that would handle either scheme. This computation presumes that the system gain is the same for noise source on or noise source off.

Most modern solid state noise sources have much better bandwidth, but are not adjustable for amplitude other than by tacking on external attenuators. Indeed the solid state sources are not all that well predictable for noise power, but with regulated current have decent long term amplitude stability.

It was asked in a recent EME newsletter, whether 5 dB and 15 dB ENR noise sources are an adequate selection. Typically the precision of the measurement of fractional dB NF is bad done with a 15 dB ENR source, or if it is comparing one device to another or one test setup to another produces random results with more than a dB error, sometimes showing a negative NF. Changes in gain caused by changes in SWR of the noise source also introduces similar sized errors in the computation. Fortunately the 5 dB noise source is essentially the 15 dB noise source with a built in precision 10 dB attenuator which cuts the noise level while it reduces impedance changes immensely.

RecentlyI did some spread sheet calculations of the Y factor and and worked out why the strong NF source is poor with the fine EME preamp. If the actual NF is 0.5 dB, and the noise source is 0.5 dB (not commercially available), the Y factor is 2, or 3 dB. If the actual NF is 0.5 dB, and the noise source is 5 dB, the Y factor is 3.82 or 5.82 dB, and if the ENR is 15 dB, Y is 29.18, or 14.65 dB. For the 0.5 dB ENR source, the DUT is supplying  $\frac{1}{2}$  the noise power when the source is on. For the 5 dB ENR source the DUT is supplying 26.7% of the noise power, and for the 15 dB ENR source the DUT is supplying only 3.8% of the noise power. So the noise swings with the loud noise source are much greater than the

contribution of the DUT and large changes in the DUT NF essentially aren't detectable. Did I say that measuring noise level to a few percent was a pain, difficult and all that? It is. And measuring MDS is different in that the signal is a carrier and that makes the absolute measurement dependent on the true integrated system IF and audio bandwidth. We still have the noise level to measure with no signal, exactly the same as measuring NF, but the signal tends to make the measurement of signal plus noise a little easier.

Noise, especially narrow band noise tends to be filled with spikes that drive the standard meters batty because they are peak reading calibrated in RMS, whether Simpson 260, or HP400E. Noise power is actually a more steady value, so I'm thinking the true RMS meter like my Keithley should do better. I haven't yet tried it but I intend to. It might even be that a moving vane AC voltmeter despised by all because of its lack of damping may work better than the peak reading calibrated in RMS meter. At least with a distorted 60 Hz waveform those two meters agreed on the current in the circuit last time I was looking.

How to make a 0.5 dB ENR source.? Add 4.50 dB attenuation to a 5 dB source. Or try the hot and cold resistor method described by Ben Lowe in QST, Sept. 1976. With the modern LNA so touchy about mismatch for low NF, the biggest source of error with hot and cold resistors is getting the resistors to have the same return loss at both temperatures. I have noticed some 0.02% resistors in the Mouser catalog, surface mount with a 5 PPM temperature coefficient. Perhaps they would be close enough in value while hot and cold.

Measuring MDS requires a frequency stable signal generator that is well shielded. That leaves out the HP608 family, though the E and F are getting close. They still leak signal and don't have enough internal attenuator to get down to -150 dBm or so needed to be below the threshold of the EME receiver with CW passband. For VHF and UHF, the HP8640B works well. For any band one can make a crystal marker with a common crystal oscillator in an IC case or even a 3x5mm smt case and generate harmonics out through 10 GHz. That's not hard. What is important is to build it in a completely shielded box with internal power (battery), then mount that in a second shielded box where only the coax connector connects the two shields. Use a teflon rod to operate the power switch. Don't use BNC connectors, the bayonet doesn't hold the ground connection well and they will leak inconsistently. TNC, SMA, or N are fine. For many bands that assembly can put out a milliwatt so the external attenuation accounts for the output level in dBm. For VHF and UHF a fixed attenuator and a couple HP 355 family switch attenuators work well, and for our relative measurement returning to the same value they can work higher in frequency. Even a gang of individual SMA or N connected attenuators work well, just they are slower to change. The output attenuator of the 608 family could be extracted to make a very useful stand along wide range attenuator.

Standard MDS schemes vary the signal to make the S+N precisely 3 dB over the noise with no signal. That's handy with a generator fancy enough to have a reliably controlled variable output and a DC controlled PIN diode switch attenuates nicely with a lower DC drive. I haven't put much thought to it, but it seems to me that the EXACT SAME Y factor can be used with a generator adjustable on steps to detect the effects of tuning or attenuation.

#### LNA input selectivity

The antenna to LNA matching circuit is the most important circuit in the EME station. It sets the NF of nearly all LNA, the circuit loss is greater than the NF of the devices used these days. So for LNA measuring contests, the simplest circuit which has quite low loss is almost always used. A series

variable and a shunt inductor that also serves to supply bias to the device gate. Unfortunately this has a broad bandwidth (which makes for easy adjustment) and with the stage adjusted for best NF is often resonant some where above the signal frequency. One preamp I had for 2m, that input circuit was resonant about 200 MHz, which emphasized the channel 13 signal from 20 miles away. It should be possible to improve on the selectivity of the LNA input section without introducing additional losses, by going multiply tuned using low loss components. Surface mount inductors need not apply. Chunks of coax can make lower loss inductors, the fatter the better.

After the LNA, there could be a helical resonator filter or two to limit the bandwidth to less than 1 MHz (at least at VHF/UHF and maybe 10 or 20 MHz at 2.3 GHz) to reject out of pass band signals to reduce their intermod and reciprocal mixing effects.

If the LNA input and output bandpass filtering gets the pass band below 4 MHz, the automatic NF meter will show low gain and higher HF because its expecting its 4 MHz IF bandwidth to set the bandwidth and doesn't see the noise power it expects through the narrow DUT. There is no practical way to correct for that. But the LNA optimized with the automatic NF meter will be optimum on the antenna, it just won't win any LNA NF contests. The effect has different amounts of change depending on whether the selectivity is before the LNA active device or after.

I've left out sun noise, moon noise, or quiet sky vs earth noise as a measuring tool because they can be affected by the intermod. Without intermod they are valid test methods.

Anyway for optimizing (reducing) the gain, absolute NF or MDS measurements are not necessary, just so long as the added attenuation and filters don't change the NF or MDS at the frequency of interest, the process is successful.

So gather up those assorted attenuators and start sticking in while measuring NF or MDS and watch the intermod go away. Bits of small diameter coax also make excellent attenuators though the attenuation varies with frequency, they are easily customized for attenuation, and tend to be reliable and inexpensive.

73, Jerry, K0CQ