Phase Noise and MDS

Paul Wade W1GHZ 2009
w1ghz@arrl.net

There has been a lot of noise about phase noise recently, but very little data. We know that older FM rigs with synthesizers sounded terrible on an SSB receiver, but worked fine for FM. It is also generally understood that an LO with phase noise will add noise to signals in the presence of other very strong signals. But what really counts is the effect of phase noise on weak signals – and no one has worked this out mathematically.

The NEWS Group (www.newsvhf.com) does MDS (minimum discernable signal) testing on 10 GHz at the annual July picnic. I thought this would be a good opportunity to do some direct comparisons, but I wasn't getting my stuff together in time. Then Steve, N2CEI, called with an offer – he would send some equipment if I would test it. He sent a 10 GHz converter (receive half of a transverter) with two external LO sources: the older MICRO-LO crystal-multiplier source and the new A-32 synthesized source, both at 1136 MHz.

The two LO sources had less than 1 dB difference in output power, so I hooked them up with a coax relay to allow quick switching. They were close to the same frequency, perhaps 15 KHz apart, so that tuning was required when switching. A little tuning is ideal for MDS tests – if you can't find the signal, it is NOT discernable.

I had no idea what to expect, except that I've heard that some good operators are using a synthesized LO with good results. I certainly hoped that there would be no difference, so then I could change all my rigs to synthesized sources, lock all my LO sources to GPS and be right on frequency.

MDS Results

For the NEWS MDS testing, a transmitted signal is reduced in power by one dB at a time. Each listener indicates the level at which he can no longer hear the signal – the MDS is the previous level, 1 dB higher. This is the weakest signal you can detect, probably several dB less than needed to copy CW.

The transmitter is several hundred feet from the receive locations – far enough that leakage from the equipment will not be heard. Attempts to do MDS testing with just attenuators are usually foiled by generator leakage. We also eliminate the possibility of IF leakage by using oddball LO and IF frequencies to generate 10.368 GHz.

I connected the new 10 GHz receiver, with a nominal 1.5 dB NF, to a 24" offset dish. The IF rig was a Yaesu FT-817. At each power level, I switched back and forth between the two LO sources, detecting the signal by ear only, using decent headphones. I'm pretty good at finding very weak signals by ear – the nice waterfall displays are not easily transported to mountaintops, so I still dig them out with headphones. The MDS was comparable to similar systems, so performance was pretty good. The MDS with the crystal LO source was 2 dB better than with the synthesized source.

One further note: at the start of the MDS run, with the signal perhaps 45 dB out of the noise, the synthesized source had multiple responses several KHz apart on each side of the carrier, with level decreasing with distance from the carrier. The crystal source only had a pure CW note.

Further Tests

The following week, I discussed the results with Steve. He suggested that the internal oscillator he had provided in the A-32 source provided an inadequate drive level at 10 MHz, resulting in higher phase noise. I looked at it with my spectrum analyzer, an old HP 141T, and saw close-in noise only about 28 dB down. I then swapped out the internal oscillator for a good TCXO providing +13 dBm at 10 MHz – the noise was reduced to about 50 dB down. A second A-32 of an earlier vintage produced comparable results.

I then set up my own MDS range (since I provide the equipment anyway) and repeated the test. Results were the same: the crystal source was 2 dB better than the synthesized source. The multiple responses to strong signals were still present with the synthesized source.

IF Transceiver

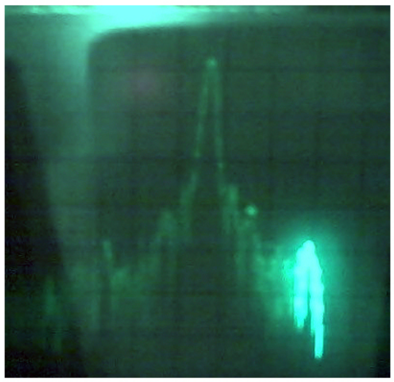
I also did experiments with the IF rig. Dale, AF1T, uses an IC-202, and he usually does better at MDS than most of us with more modern rigs. The IC-202 is known to have particularly good phase noise, since it uses a VCXO for tuning. So I dug out my old IC-202S for the second MDS test. The MDS using the IC-202s with either source was 2 dB worse than the FT-817 with SSB filter.

Another experiment was IF bandwidth. My FT-817 has the optional CW filter, which seems to help when copying very weak CW signals, if they are stable enough. The MDS with the CW filter was about 1 dB better than with the SSB filter.

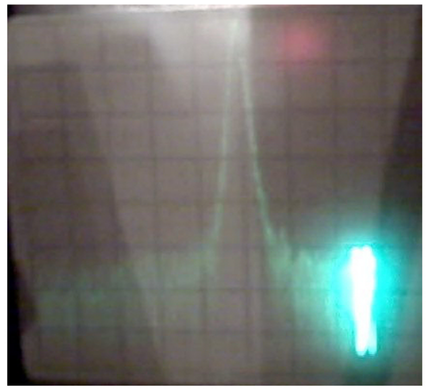
Phase noise plots

Actual phase noise data might help understand what is happening. Greg, WA1VUG, has been kind enough to bring nice Rohde & Schwarz (www.rohde-schwarz.com) test equipment to the Eastern VHF/UHF Conference, so I have some data. However, these are not the same local oscillators used for MDS testing, and not at the same frequency, so we are probably comparing apples and oranges and maybe bananas. But they are included here for what they are worth. There are also phase noise plots of the A-32 on the Down East Microwave (www.downeastmicrowave.com) web site at both 1136 and 10224 MHz.

First are the two spectrum analyzer plots of the A-32 source at 1136 MHz in Figure 1, with the internal 10 MHz oscillator at about +4 dBm, and with an external 10 MHz TCXO at about +13 dBm. Vertical scale is 10 dB/division and horizontal is 2 KHz/division, with a 300 Hz IF filter. The traces are faint because the storage function no longer works on my old HP 141T. Both of these violate my rule for oscillators: if you can see anything other than carrier on a spectrum analyzer, it's not good enough.

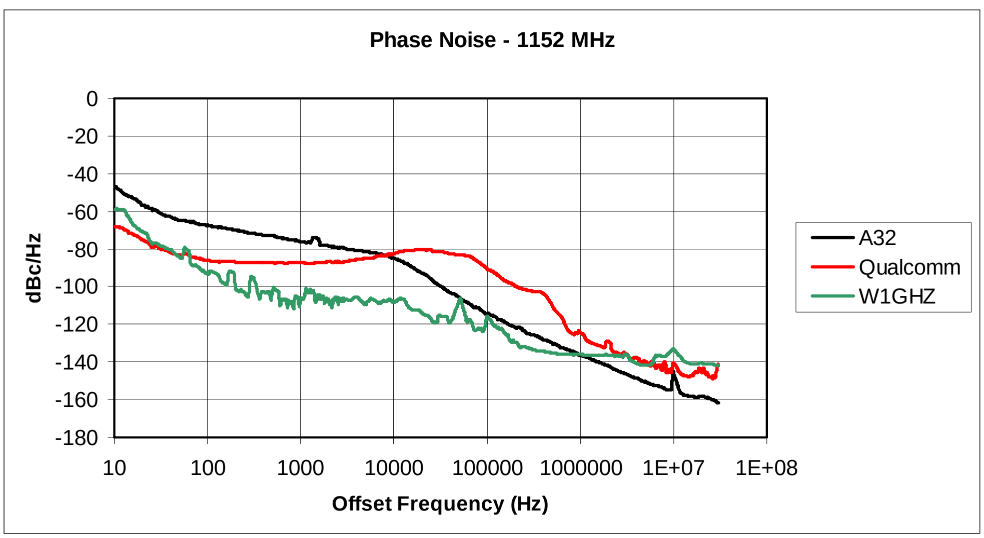


Internal Oscillator



External Oscillator

The other plots are measured with an R&S FSUP phase noise tester and signal analyzer. Figure 2 shows three different oscillators at 1152 MHz: a different A-32 unit at 1152.022 MHz, referenced to the 10 MHz TCXO, a Qualcomm synthesizer board (rectangular version) at 1152 MHz, and the 1152 MHz LO board from my "Simple Multiband Rover Transverter," which multiplies up from an 64 MHz computer oscillator.



Discussion

The MDS testing is somewhat subjective, but didn't know the answer beforehand, and I heard a consistent 2 dB difference. I don't know whether this would make any difference in copying a very weak CW signal.

How important is 2 dB? A final step in our NEWS MDS tests is to move the frequency slightly, less than 10 KHz, then increase the level in 1 dB steps to see when folks can actually find the signal. For most operators, this is 2 to 5 dB higher than the MDS with decreasing levels on the starting frequency. In other words, knowing the frequency is typically worth 2 to 5 dB. Therefore, if both stations are frequency-locked to GPS or rubidium standards so they are likely to be on the same frequency, the synthesized source is probably just as good as a crystal that is not right on frequency (i.e., all crystals).

The narrow IF filter also made a slight improvement, so frequency accuracy good enough to use the narrow filter would be an advantage. Note that the improvement was only 1 dB even though the difference in bandwidth is roughly 7 dB. Al, K2UYH, has been telling us for years that the human ear can be trained to be a very good filter. I guess my ears provide about 6 dB of filtering. I'll bet some of the EME operators can do even better.

Are these sources good enough for mountaintop operation in New England? There may be strong-signal problems – signals from nearby sites are frequently more than 45 dB above the noise, even with the dish pointed in another direction, and are typically only separated by perhaps 20 KHz. But I have seen good results with synthesized LO sources – W1FKF uses one and hears very well. Operating side-by-side, he often hears better than I do.

In other areas with no strong signals, knowing what frequency the weak ones might be on is a distinct advantage.

An alternative would be to use the synthesized source as a frequency reference marker and a crystal source for the LO. Some of us have been doing this with older, dirty synthesizers – the distinctive note differentiates the marker from a birdie.

At other frequencies, results may be different. We know that phase noise increases with multiplication – see the phase noise plots on the Down East Microwave website. What we don't know yet is whether the lower phase noise on lower bands will affect MDS, or whether the effect will be worse at higher bands

Summary

More testing is needed before we reach any conclusions. Synthesizers have been getting better, and I think more improvement is possible. Other choices, like the REFLOCK units, also need to be evaluated.

The MDS testing, while subjective, gives a realistic comparison so what most weak signal operators care about, hearing weak signals. It's not that hard to set up a test range, so give it a try when improving your equipment. At least you will be confident that it's an improvement.

Update – Phase Noise and MDS (Sept 2009)

I've been thinking about a new 10 GHz transverter. After talking to Steve, N2CEI, again, I decided to try one with the A32 synthesizer for the local oscillator and see how it works in the field. Of course, I have my old transverter as backup, on a smaller dish with 24 GHz and the dual-band feed.

Steve promised to have a transverter to me in time for the September weekend of the 10 GHz contest – it arrived about 10 days before. I usually figure three weeks to put a system together properly. However, I ended up with some extra time. My 6 and 2 meter antennas were bent up by the ice storm last December, and we planned to finish the repairs on Saturday morning before the September VHF Contest started at 2 PM. But it rained all day Saturday, so I was off the air and worked on the transverter. The antenna repairs were completed Sunday so I was on the air about 4 PM.

My plan was to integrate the DEMI transverter with two of the eight-watt amplifiers in parallel for some decent power, and to use my new "Even More Fool-Resistant Sequencer" for switching. The amplifiers work fine in parallel, but the transverter doesn't provide enough drive for two, so the pair only put out about 11 watts – not enough to justify the extra 25 watts of DC (2 amps at 12 volts for each amplifier) in a portable station.

Anyway, metalwork takes time, and the sequencer took a little debugging, so I finished up the transverter Thursday night as I was loading the truck for the September weekend on Block Island. As a result, I didn't have time to get the GPS-locked oscillator included, just the 10 MHz TCXO used for the MDS tests.

The TCXO was very stable during tests, but much less stable in the field. I had the worst of both worlds – synthesizer phase noise without accurate frequency control. A few contacts took longer or needed retries as a result, but I did pretty well anyway.

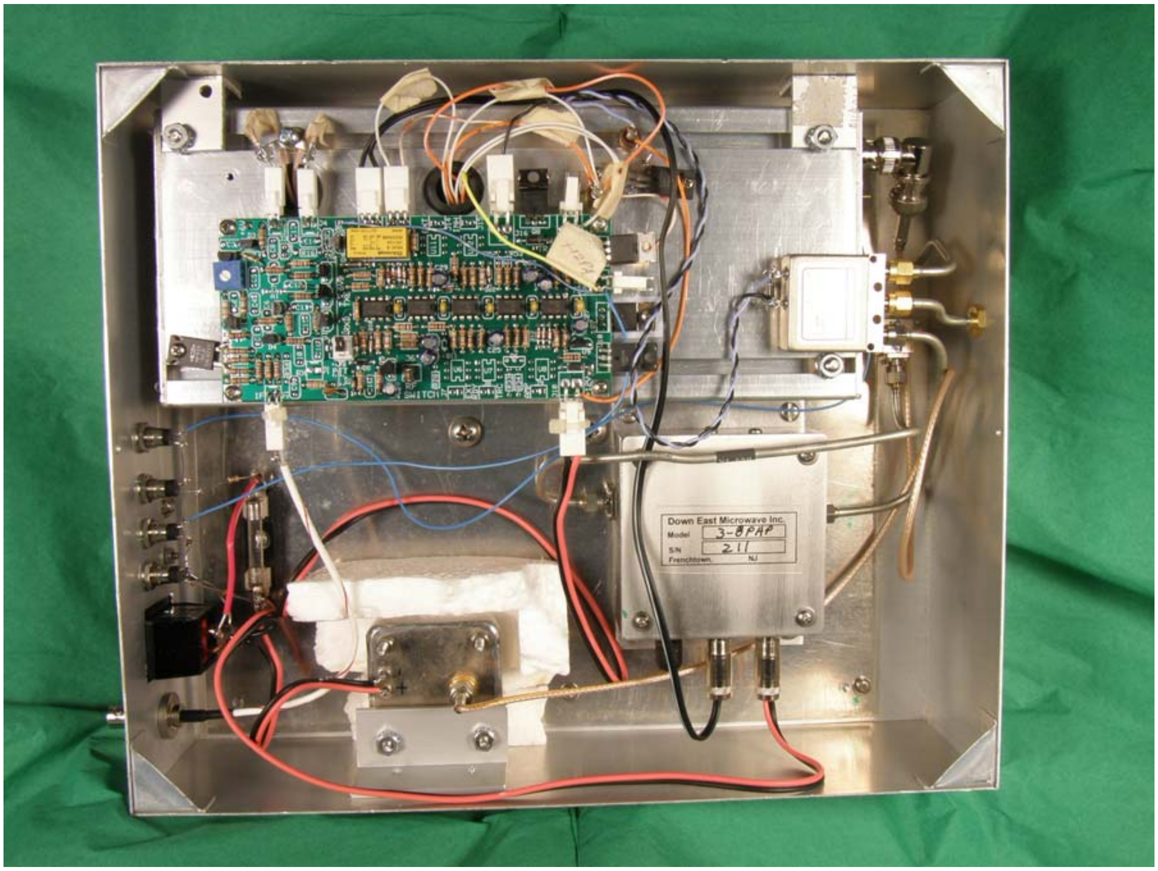
GOOD – I was hearing better than the other two guys on Block Island, one with an identical dish. Made several very weak contacts that they couldn't pull out.

BAD – definite phase noise, especially for each other, making spotting difficult. At times, AF1T, 80 km away, caused spurs near our frequency (we try to stay ~30 KHz apart). Enough birdies to make tuning for stations an adventure.

TBD – when we started out Saturday, my frequency seemed to be significantly off and drifting, slowly settling down. Sometime in the afternoon, I tripped over the power cord and dislodged it. When it came back up, my frequency was closer and drifting less.

Conclusion so far – with the GPS lock, it should make contacts much easier with stations that have good frequency control. The other half will still take lots of tuning.

P.S. – conditions got really good Sunday night, after all the roving stations had gone home. We worked a few DX home stations, then tore down. Early Monday morning, my phone rang – K1MAP in North Carolina was hearing beacons near us. We quickly set up again and worked him twice, two new grids at 800 km.



New 10 GHz Transverter with "Even More Fool-resistant Sequencer"