Introduction to SLAARC Presentation by Rob Sherwood NC0B

On April 11 our monthly SLAARC meeting will host a presentation by Rob Sherwood NC0B on Transmitter Spectral Purity. Rob is a world class expert on ham radio equipment performance. He is probably most famous for testing receiver performance and publishing "The List" for nearly four decades. Historically - if you wanted to know how a new radio would stack up – you checked Sherwood Engineering to find out. Rob has been reporting his latest findings for many years at the Dayton Hamvention and has recently retired and increased his availability for presentations to radio clubs. We are very fortunate to have a renowned expert of his caliber agree to do a Zoom presentation for our club!

Two years ago at our Field Day operations at Jim Atchison Park in Lyon Township we experienced some difficulties due to multiple transceivers operating in close proximity to each other. We have had some discussions about this commonly occurring problem and it turns out to be from our transceivers – both receivers and transmitters, not being "ideal". Rob is probably the best person on this planet to tell us about this, explain what is going on and provide real data on the real amateur equipment involved.

The rest of this introduction will provide background in preparation for Rob's presentation. If you are a grizzled Old Timer – like some of us who got their first ticket back in the 1960's, you can stop reading this right now because you've been there already and are probably familiar with all these concepts – since you lived through the entire era when they were being worked out by our Amateur Community.. But, if you are a more recently licensed Ham – the radios you likely have been using are already so good, you might not even be aware of the issues involved – and could likely benefit from the rest of this introduction.

In Rob's presentation you are going to hear a lot of terms that may not be familiar to you on a regular day-to-day basis! Like – dynamic range, minimum discernable signal (MDS), reciprocal mixing, and phase noise, etc. etc. Attached you will find some background on these items written by Rob himself - but perhaps a little more basic understanding might help before you delve into that detail.

An "ideal" receiver, which – by the way - does not exist, would faithfully reproduce at audio frequencies, exactly what is entering the antenna at the radio frequency it is tuned to and provide NOTHING beyond the bandwidth selected under ANY conditions. It turns out that in some ordinary operating conditions "real" receivers can do this pretty well, all the way down to the natural noise created by the physics of our atmosphere and interstellar space! BUT, as soon as conditions arise where there are perhaps weak signals tuned in and very strong signals (both natural and man-made) nearby in frequency, things often do not go as planned. Sometimes even signals far from the desired receive frequency can disrupt what is intended to be received. This is just one measure of receiver quality termed "dynamic range." There are several other measures of receiver quality as well – explained in Rob's notes.

An "ideal" transmitter, which also does not exist, would reproduce ONLY at the radio frequency it is tuned to, EXACTLY what is put into it at audio frequency, with the selected bandwidth. Or, if not modulated

– would only produce a pure sinusoidal continuous wave note (CW) interrupted only for keying purposes without generating any key clicks on adjacent frequencies. Some modern transmitters do a pretty good job at this. Some however do not, and produce all sorts of energy at frequencies far removed from the transmit frequency. Think for a minute what this means in a practical sense. Even if you have an "ideal" receiver, you might not be able to hear what is on the frequency you are tuned to because a "real" transmitter somewhere else is generating unwanted energy ON YOUR frequency. This is a measure of transmitter quality – the unwanted energy it generates beyond its intended transmit frequency. Rob will delve into the details of how and why this happens and how it is measured.

Here are Rob' notes:

Terms Explained for the Sherwood Table of Receiver Performance

Left to right starting with noise floor:

Noise floor measures how weak a signal one can hear. Practically it is only of significance on the higher HF bands due to the higher level of band noise on the low bands. This assumes you are listening on your transmit antenna. If you are using a Beverage or a low gain loop, then it could be an issue on any band.

The noise floor is measured with a 500 Hz CW filter bandwidth, assuming the radio has a CW filter. There is a note on the measurement if the radio only had an SSB bandwidth. Older radios (Drake, Collins) had no switchable preamp. Compare them to a modern radio with Preamp ON or Preamp #1 ON. A noise floor of -135 dBm is more than adequate on 15 meters in a quiet rural location. A lower noise floor (-138 dBm) might be useful on 10 meters in a quiet location. Serious 6 meter DXers often use an external low-noise preamp to get the noise floor down to -140 dBm or a few dBm lower. If you are in the city, hardly any of this matters due to all the local noise. (On 15 – 6 meters, hardline would be important to reduce the feedline loss to make the best use of the noise floor.)

Noise floor is quoted in dBm (power). Consider it a similar measurement to Sensitivity on SSB, which I quote in microvolts (uV). Noise floor is a 3 dB S+N/N ratio, usually measured at 500 Hz bandwidth. Sensitivity is a 10 dB S+N/N ratio, usually measured with a 2.4 kHz bandwidth for SSB. Due to the wider bandwidth on SSB, the signal vs. the noise sounds about the same by ear.

AGC threshold:

The threshold is the signal level below which the receiver gain is running wide open. Again this is mainly of significance on 20 meters and up, since the S meter often reads up scale on noise on the lower bands. If the band noise reads up scale several S units on band noise, a signal is never going to be below the AGC threshold. Some newer radios let you set the AGC threshold, though it may not "memorized" by band, which would be helpful. For modern radios with a switchable preamp, I prefer a threshold of 2.5 uV with the Preamp OFF and 1 uV with the Preamp ON.

Blocking:

Blocking occurs when the radio is just beginning to overload from a signal outside the passband. It is usually about 30 dB above the Dynamic Range of the radio (to be described below). If a radio has a good dynamic range, then it will have a good blocking number. 130 dB is a good number. With direct sampling radios, blocking is technically not the correct term. An A to D converter has an absolute overload point, unlike a 1 or 3 dB gain compression point. Note: Instantaneous overload from many strong signals may cause the overload indicator flicker, but may not have an audible side effect.

Sensitivity:

This figure of merit has been around since at least the 1940s. I quote it in uV, as mentioned above. To measure it, a signal generator is fed into the radio, and the output at the speaker is read on an RMS volt meter. The generator level is adjusted so the difference from when the signal is tuned in vs. when the signal is out of the passband equals 10 dB. In other words, the signal is 10 dB stronger than the receiver noise. Likewise, when one measures noise floor in CW mode, when the signal is tuned in it goes up 3 dB.

Phase Noise:

Old radios (Collins, Drake, Hammarlund, National) used a VFO or PTO and crystal oscillators to tune the bands. Any noise in the local oscillator (LO) chain was minimal. When synthesized radios came along in the 70s, the LO had noise on it. It is caused by phase jitter in the circuit, and puts significant noise sidebands on the LO. This can mix with a strong signal outside the passband of the radio and put noise on top of the weak signal you are trying to copy.

This is a significant problem in some cases: You have a neighboring ham close by, during Field Day when there are multiple transmitters at the same site, and certainly in a multi-multi contest station. You would like the number to be better that 130 dBc / Hz at 10 kHz. A non-synthesized radio, such as a Drake or Collins, has so little local oscillator noise the measurements were made closer-in between 2 and 5 kHz.

Note: Very few legacy synthesized superhet radios have low phase noise, though most direct sampling radios have low phase noise. The ARRL has clearly emphasized low phase noise (RMDR) since 2013. (RMDR = Reciprocal Mixing Dynamic Range) To convert my LO Noise (dBc/Hz) column data to RMDR subtract 27 dB for a 500-Hz bandwidth.

Front End Selectivity:

This is less of an issue today as almost every radio has a half-octave filter in the front end. The R-390A had the best mechanical front end (preselector) ever made, with the Drake and Collins somewhat behind. The R-390A preselector tracked the tuning knob, while you had to peak the Drake and Collins by hand. A small number of superhet radios today have a preselector that follows the main tuning dial.

Note: Direct sampling radios are more prone to overload from very strong signals within a given band since they have no roofing filter as in down-conversion radios. Some direct sampling radios have a tracking preselector that helps to some extent in environments like Field Day or having another ham near your QTH.

Filter Ultimate:

In the old days filter leakage was an issue. Either the filter didn't have many poles, or there was leakage around the filter (filter blow-by). 70 dB was a typical number. As radios improved, it became common to have dual conversion, with a crystal filter at 5 to 10 MHz, and then another filter at 455 kHz. Even if each filter only provided 70 dB attenuation, by the time the out-of-passband signal was attenuated twice, then filter leakage was a non-issue. 2X 70 dB = 140 dB.

Then along came synthesized radios with phase noise. Now the problem became the close-in phase noise limiting the rejection of the filter. Instead of hearing signal leakage on the edge of the filter, one hears noise from the LO, called reciprocal mixing.

I measure filter ultimate a few filter bandwidths away from the passband. On CW that would be a couple kHz, and on SSB that would be 4 to 6 kHz. Most of the legacy synthesized superhet radios near the top of the list are phase noise limited. Most of the older radios near the bottom of the list are leakage limited, if one makes a generalization.

Note: New direct sampling radios generally have both excellent phase noise and filter rejection. On SSB transmitted splatter from a station a few kHz away is typically the reception limit, not filter performance.

Dynamic Range:

Now we get to the nitty gritty. I started testing radios in 1976 because the ARRL rated the Drake R-4C very good, but in a CW contest it was terrible. The radio overloaded in a CW pile-up, so I decided to figure out what was wrong with their testing. In 1975 the League had started testing for noise floor and dynamic range, new terms for most amateurs. Spurious Free Dynamic Range measures how the radio can handle strong undesired signals at the same time as a weak desired signal, without overload. When a radio overloads, it starts generating spurious signals on its own.

Dynamic range is defined as the level in dB when two strong test signals make distortion in the radio equal to the noise floor. The radio thus can handle that range of signals before the strong signals just start to overload the radio.

The League originally only tested the dynamic range at 20-kHz test spacing, which was reasonable at the time. But as multi-conversion radios became the norm, this test was inadequate. The Drake example was a case in point. When the two test signals are 20 kHz apart, the overload distortion products are 20 kHz each side of the pair of test signals. In other words, they League was testing as if the QRM was always going to be 20 and 40 kHz away! In reality the QRM is likely going to be close by.

In 1977 I published an article in "ham radio magazine" discussing this subject. I tested the offending R-4C at 2 kHz in addition to 20 kHz. In that case the 20-kHz dynamic range was over 80 dB, but the 2-kHz dynamic range was less than 60 dB.

The roofing filter of the R-4C is 8-kHz wide, and in a CW contest, there were many signals inside that 8-kHz filter, overloading the radio. I installed a 600 Hz roofing filter in the R-4C, and the problem went away. When testing the Sherwood modified R-4C at 2 kHz, the dynamic range was over 80 dB, just like it was with the 20-kHz test.

Most radios in the 70s and 80s had gone to up-conversion for two reasons. This got rid of the necessity of a preselector, and it allowed general coverage without a dead spot equal to the first IF frequency. In the up-conversion radio, the first IF was always above 10 meters, and often above 6 meters. All first IF filters were at least 15 kHz wide, and there was the problem. The Drake 8-kHz first IF was bad enough, and now almost all the radios for 20+ years had a first IF what was at least 15-kHz wide. Almost all of them had a close-in dynamic range around 70 dB. That was barely adequate for SSB and inadequate for CW.

For more than 40 years I have been testing radios, and I decided to sort the table on my website by close-in dynamic range at 2-kHz spacing. This was the "acid test" for CW contest / DX pile up operation.

In 2003 the Ten-Tec Orion came along, and it went back to a 9 MHz first IF (instead of 40 to 70 MHz), and offered a narrow CW roofing filter, like I had added to the Drake. It was the first commercial rig to be better than the Sherwood roofing filter modified R-4C. Later the Elecraft K3 came to market, and now Yaesu and Kenwood have what is now called "down-conversion" radios with a low frequency first IF.

What do you need in the way of close-in dynamic range? You want a number of at least 70 dB for SSB, and at least 80 dB for CW. A 10 dB safety factor would be nice, so that means you would prefer 80 dB for SSB and 90 dB for CW. Now there are approximately 20 radios that meet that specification.

Note: Several transceivers have multiple listening on my website. In some cases, like the K3 which has been available for over 10 years, the performance has improved over that decade. There are several "second samples" of radios tested over the past 1 to 5 years. Direct sampling radios have more variation from sample to sample than legacy superhet radios.

Rob Sherwood

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