A Discussion of Measurement Accuracy and Sample Variation.

Several observant hams have asked some questions about apparent conflicts between the multiple-parameter performance table that has been on the Sherwood website for many years and the dynamic range chart presented at the Dayton Hamvention in 2004. This presents a good time to discuss an issue that has yet to be addressed by either the ARRL or myself. Please note that the multiple-parameter performance table has been updated several times in 2004, with dates of the testing noted. From here on in this discussion, the long-form table will be referred to as the "Table", while the chart from Dayton, which shows only dynamic range, will be referred to as the "Chart".

Question: Why has the Chart been updated?

Answer: As mentioned during my Dayton presentation, I was puzzled by the fact that the Elecraft K2 fell off as much as it did from wide-spaced third-order dynamic range (DR3) to narrow spaced dynamic range (DR3), since it is a single conversion radio. (The Drake TR-4, for example, does not fall off significantly from 20 to 2 kHz.) I had purchased an 1100+ serial number K2 from a fellow ham to be able to use and evaluate the product. All I had was a single sample of the K2, and an older one at that. The other strange data point was the Yaesu FT-1000 Mk V Field, which had 2 kHz DR3 much lower than all the other FT-1000x series.

Elecraft contacted me during the summer to see if we could resolve the differences between their data and my measurements. In September of 2004 I tested a factory-built unit, with performance numbers taken by both labs on the same sample. The Table now has both the older K2 and the newer K2 listed. The Chart has only the new data.

International Radio wished me to test their new FT-1000 series roofing filter, so I was sent Inrad's radio, and it was measured with specific attention to dynamic range. Also Inrad had data taken by the ARRL on a different FT-1000 model with their roofing filter, and the data was compared to mine. The Inrad Mk V Field radio was not "well behaved" in respect to dynamic range numbers. By this I mean that the IMD measured on the low side of the test signals compared to the high side of the test signals was significantly divergent. Generally this is not the case. Inrad averaged my data (high side and low side) for all measured signal spacings, and compared that data set to the ARRL data, and it matched within 2 dB.

The new data on the K2 and the Mk V Field fit what one would expect from past measurement experience better than the data I initially had. Thus I chose to update and re-order the chart, and "fix" the two anomalies that had been pointed out during the Dayton forum. The Mk V Field now closely falls in with all the other FT-1000 series radios in respect to 2 kHz DR3.

Data in the Table vs. data in the Chart:

The Chart for the Dayton presentation was produced because you could not possibly read the Table with all its numbers on a screen in the contest forum. The Chart has an average of the IC-781 data from three radios, thus it does not match any of the specific three samples. Some of the Chart radios were only tested for 20 and 2 kHz dynamic range made during a whirlwind period of testing during March of 2004, brought in just to flesh out the chart. The Table had not been updated for many years, and suddenly I needed a lot of data in a hurry. In the case of the Omni VI+, I had two samples, and for some reason one was used for the table and another for the chart. I did not even notice this until it was pointed out by another ham!

The over all purpose of the Chart was to show how a large number of up conversion radios perform, compared to a few classic tube radios, and finally how the Orion and the IC-7800 stacked up as the new kids on the block. Consider the expansive Table more significant when comparing the many parameters of a radio. The Chart was only one slide out of a long Power Point presentation on dynamic range in general. In particular, the Chart showed the progress made by Ten-Tec with a modern design 27 years after I introduced narrow roofing filters to the R-4C in 1977.

Sample variation and absolute accuracy:

The table on the web has had sample data on three different IC-781s for a considerable time. Initially the purpose of testing three different 781s was to see if the pin-diode mod improved dynamic range performance. The data did not confirm any improvement, plus it was interesting to note the data scatter among the three samples. Discussions with Michael Tracey of the ARRL have revealed that hams are at times making rig purchase decisions on the basis of minor differences in a single parameter. Differences between two radios of a few dB in any parameter is within measurement error and sample variation. A measurement as easy to make as noise floor can vary 1 dB depending whether the radio has been on for an hour or all day.

Take my 781 data scatter example on three different rigs. At 20 kHz the DR3 varies from 94 to 98, and the close-in DR3 varies from 72 to 78. Similarly, data taken by the Ten-Tec lab and my lab, or now the Elecraft lab and my lab on the same radio sample has shown good correlation with measurements in agreement within the 1 to 3 dB range, depending on the parameter.

At some point the League will be publishing a paper on their measurement accuracy. For instance, now the League publishes dynamic range (DR3) data to 0.1 dB resolution, which is very questionable in my opinion. Measuring intermod at the noise floor is a difficult to make measurement. Just because a piece of test equipment may resolve a number to a fraction of a dB in this case, does not mean the accuracy is that good.

When measuring noise floor and dynamic range, an RMS analog meter is bouncing around approximately + / - 1 dB, while the lab tech is trying to decide where the actual 3 dB peak in signal exists. Also, hysteresis effects have been noted by both myself and Ten-Tec when measuring dynamic range. One can sometimes see differences in IMD whether one is approaching the measurement point with weaker test signals going up in level or with stronger test signals going down in level. In the Ten-Tec Orion case, this may be due to intermod being produced in the 9 MHz roofing crystal filter, and thus the very high close-in dynamic range of this radio may be limited by the roofing filter itself.

In my experience, DR3 at 20 kHz and 5 kHz is one of the more variable numbers from sample to sample. This is because modest variations in the bandwidth of the up conversion roofing filter drastically affects the 20 or 5 kHz measurement. If one up conversion filter is 12 kHz wide, while another is 15 kHz wide, the wider filter will pass more of the test tones than the narrower one, making the measurements differ solely because of the up conversion filter bandwidth variation.

Once the test signals are totally inside the wide roofing filter, however, the IMD is determined by IF gain and mixer overload, rather than the roofing filter. Look at the amazingly consistent close-in data throughout the FT-1000x line.

Blocking:

Blocking is not a subject I get very excited about. The numbers are drastically higher than the dynamic range values, and thus rarely does blocking become the limit in performance with real on-the-air operation. Additionally, due to the change to fully synthesized radios over the past 20 years, phase noise if often more of a limit than desense blocking. Decades ago I used an S5 signal as the weak signal reference when doing a blocking test, as specified by the League at the time. I leave the AGC on for all my measurements, since this is generally how hams operate radios. As time went by, I noticed that when performing a blocking test, the S meter would often go down as the radio started to block, thus covering up the onset of blocking. Thus at some point I reduced the level of the reference signal to one that was just barely moving the S meter, thus taking the AGC out of the equation.

When trying to resolve measurement differences with Elecraft, I found that I got different numbers whether or not the AGC was off or on. IF the AGC was on, the S meter actually went up as I approached the blocking point, something I had never seen before. The League and Elecraft now turn the AGC off to make blocking measurements. With the AGC off on the K2, the blocking value was 11 dB higher on that specific radio.

The League vs. Sherwood Engineering:

There are some areas where the League and I disagree on how one should make measurements. Neither is right or wrong, I suppose, but here are my thoughts on the areas of disagreement.

Most any radio allows the operator to turn off the AGC. In the height of battle during a contest, I doubt many operators choose to run a radio with the AGC off, and be forced to fiddle with the RF gain all the time. So I think all measurements should be done with the AGC on. In the case of the K2, the blocking number is better with the AGC off, but is this meaningful?

Third-order intercept (IP3) is a number that gets a lot of press, especially in the last few years in advertisements for modern transceivers. It is a theoretical number that one cannot measure directly. You calculate the number after measuring two other parameters. Icom has made a lot out of the fact that the wide-spaced IP3 of the IC-7800 is in excess of +40 dBm. They don't say anything about the fact that the close-in performance of the radio is phase noise limited or IMD limited around 80 dB. The number calculated for IP3 can vary significantly depending on how one makes the measurements.

The League defined dynamic range in the 1970s by measuring the noise floor of the radio, and then noting when the third-order intermod product equaled the noise floor. Back then this was only measured at 20 kHz spacing, pre the problems associated with up conversion radios. For some reason, the League measures IP3 with the IMD product placed at S5, a significantly stronger signal than the noise floor. Their argument is, in the real world, the atmospheric noise coming in on the antenna is stronger than the noise floor of the radio, thus one should measure IP3 at S5. Well the same thing could be said about measuring the dynamic range of a radio. Maybe we should measure the intermod product at S5 instead of the noise floor. S5, however, varies widely from one model to another, and seems like a "fuzzy" standard. If something other than the noise floor is to be used, an absolute value like 1 uV or 5 uVs would seem preferable. The problem is the numbers are higher when we measure at S5 compared to the noise floor. In the case of IP3, the number I calculate for the IC-7800 is only +30 dBm when referencing the IMD to the noise floor, but using the S5 method, it is in excess of +40 dBm. What we appear to have here is number inflation!

Phase noise:

Noise in local oscillators did not use to be much of an issue. PTOs and VFOs were relatively clean, and crystal oscillators for band selection were very clean. I don't believe the League even measured noise when the concepts of noise floor and dynamic range were introduced in the 1970s.

When radios became synthesized, all this changed. The first radio I ever tested that was not phase noise limited at 20 kHz was the JRC NRD-515. Earlier synthesized sets were pretty horrible. Most synthesized radio / transceivers had a common pattern of the phase noise improving as one gets further and further off frequency. Thus close-in phase noise is usually much worse than wide-spaced. Likewise, most up conversion radios have a much worse close-in dynamic range than wide spaced, usually 20 to 30 dB worse.

The most complete information on phase noise would be a graph vs. frequency from 1 kHz to 100 kHz. That is hard to put in a table, plus it is very time consuming to produce. Most of my table data is listed at 10 kHz. Some of the classic tube radios had data closer in since it is hard to even measure the noise in a non-synthesized set.

The anomaly in the phase noise world presently is the Orion. It has very good close-in phase noise, but it degrades significantly at 50 to 60 kHz. Because the Orion divides down an LO produced in the VHF region, its phase noise varies from band to band, depending on the divide by N number. In the theoretical world, each time one divides by 2, the phase noise should improve by 6 dB. In the real world the improvement is not that much, as noticed by some fine HP signal generators that use this principal. In the case of the Orion, the radio is best on 160 and 80 meters (which have a common divide by N), and it degrades by approximately 3 dB on each successive higher octave band. Thus 40 meters is 3 dB worse, 20 m. is 6 dB worse, and 10 m. is 9 dB worse than 80 or 160.

A funny thing happened when the League tested the Orion over a year ago. They said the rig had the quietest synthesizer ever tested. In the same report, however, they noted in a table that the dynamic range at 50 kHz spacing was phase noise limited. So in reality, the Orion did not have the quietest synthesizer ever tested, it was just different. It's maximum noise occurred at wide spacing, not close-in spacing.

Also interestingly enough, the dynamic range of the Orion was listed as better with the preamp on than with the preamp off by about 2 dB. Of course this is impossible, and showed some kind of measurement error that slipped through the cracks.

Phase noise vs. IMD limited data:

Presently both the League and Sherwood lists DR3 dynamic range data as either IMD limited or phase-noise limited. Noise from the synthesizer may raise its ugly head before the IMD pops out of the noise floor. Both Michael Tracy (of the League) and I feel that all things being equal, we would rather have a radio IMD limited than phase noise limited. All it takes is one strong signal nearby to cause phase-noise reciprocal mixing to degrade reception. In the IMD case, it takes at least two signals to cause extraneous intermod products. Presently the League has a steering group trying to resolve and improve measurement issues. (I am a member of this group.) Possibly the League will develop a way to better distinguish between phase-noise limited and IMD limited radios.

Have things improved?

The question asked at the beginning of my Dayton presentation was whether radios have improved in the past few years, let alone 30 years. In most respects, the answer is a resounding "yes". We have more features than one could dream about in the 1960s and 70s. Stability, frequency readout, no-tune transmitters, etc. The list goes on and on. The interesting thing is in the area of dynamic range, except for the Orion, little has changed. Look at the data for the two Collins 75S-3B / 75S-3C data points. They show a 100 kHz DR3 of 90 dB on 20 meters, a 20 kHz DR3 between 85 and 88 dB, and a 2 kHz DR3 between 72 and 74 dB! These close-in dynamic range numbers are better than any stock FT-1000 series transceiver tested. Due to the preselector on the S-Line, the 100 kHz wide-spaced DR3 on 80 meters would be even higher than 90 dB!

Wide spaced vs. close-in dynamic range.

If I had to pick a radio on one performance number, what would it be? Close-in dynamic range, particularly if I am a CW operator. Radios fall apart in a CW pileup if the DR3 is only 70 dB. On SSB it is not quite as critical. Tom Rauch, W8JI, has published some articles recently in WorldRadio on radio performance, test data numbers and advertising hype which are an interesting read.

One area that is in dispute is the significance of wide-spaced dynamic range. Some hams in Europe feel that a radio has to have an IP3 of +30 dBm to function on 40 meters with all the broadcast interference. The aforementioned S-Line has an IP3 of only –10 dBm. Do they fall apart on 40 meters? At least in the US, I don't think so. The EU argument is we will see an elevated noise floor due to overload by the integration of all those BC signals. In my experience, and W8JI's, strong signals cause discrete IMD products, not just wideband noise. Tom has yet to see a radio fold up solely due to strong signals 20 to 50 kHz away compared to close-in QRM. This issue has not yet been resolved.

Final comments:

Don't get obsessed with minor variations of a few dB. Luckily most radios are not stressed most of the time we operate them. The worst stress is a CW pileup. You also have to like operational aspects of a radio, not just its numbers. As a ham, you will be sitting in front of a radio for hours each week over a period of years, thus ergonomics, ease of use, and listening fatigue should be taken into consideration. Personally I like big radios with big knobs, except mobile when small is good!

Comments are always appreciated.

73, Rob Sherwood, NC0B