Transceiver Test Reports – what do the numbers mean?

Part 1 - the Receiver tests, by Andrew Barron ZL3DW, Sept12

Every time one of the major ham radio manufacturers comes out with a new transceiver model many hams are eager to read the reviews on the Sherwood Engineering web site or in the QST, CQ, or Radcom magazines. We very are keen to know how the new toy rates, what new features are included and to get an idea of the value for money. The specifications and pictures are very interesting but they are not the complete story, we need to look at features like the bands available, transmit power, ergonomics, fan noise, dimensions, 2nd receiver, DSP, spectrum scope, build quality and most importantly the price before making a major purchasing decision or adding the new transceiver to the 'lotto list'. But this article deals with the test results that are presented in those technical reviews. What do they mean, why are they important, and how do you interpret them? I have worked in the telecommunications industry for nearly 40 years and I don't know what all of the numbers mean, so this is a learning exercise for me as well.

The ARRL reviews include a handy "key measurements summary" which shows what the lab considers to be the most important test results on sliding red to green scales. Generally the green end represents the best results obtained from any equipment tested to date. Bear this in mind when looking at reviews of older equipment. What was a good result, and shown in green in 1985 may be distinctly mediocre today. Check out http://www.sherweng.com/table.html and http://www.remeeus.eu/hamradio/pa1hr/productreview.htm for benchmarking tests of many ham transceivers. It is very interesting to see that the cost of the transceiver is not necessarily linked to excellent receiver performance. The very expensive FTDX9000 and IC7800 are beaten on receive performance by the FTDX5000, Elecraft K3, and Kenwood TS590S. But of course those expensive transceivers have many other features such as higher power on transmit and dual receivers. It is also interesting that relatively cheap, software designed receivers (SDR) also offer world class receiver performance.

Most of the emphasis in the lab testing is placed on the receiver performance. This is partly because transmitter parameters are pretty well defined and so long as your transmission is relatively clean and the audio is acceptable there is little perceptible difference in the signal received across the world between a 100W signal from a brand new elite transceiver and a 100W signal from an old boat anchor transceiver. I know some purists spend a lot on hi-fi microphones, filters and equalisers, and you can tell the difference but the gains are more related to how natural your signal sounds and having a chirp free CW signal than making it through a pile up for a DXPedition or working a multiplier in a contest. On the other hand good receiver performance makes a big difference. A quiet receiver with great noise filters will really help when you are on the rag chewers or counties net on 80m, selectivity is important if you are an avid contester trying to pull out a weak multiplier operating 500Hz from a Russian mega station and what happens to the signal you are listening to when your next door neighbour opens up with 1 kW on the same band?

Deciding which of the measurements is the most important factor when comparing receivers depends a lot on how you plan to use your receiver. For hearing weak signals at or near the receiver's noise floor, receiver noise is typically the limiting factor. For the reception of stronger signals under crowded band conditions like a contest, two tone third order dynamic range is the most important number. To assess a receiver's ability to perform well in the presence of a single, strong off-channel signal for example a ham operating in the same suburb, blocking gain compression dynamic range is the dominant factor. These three basic requirements are called receiver sensitivity, receiver selectivity and receiver intermodulation performance.

Let's look at the receiver measurements and work out why they are important. Next issue we will tackle the transmitter tests.

RECEIVER SENSITIVITY is the ability to listen to weak signals, preferably without undue background noise. **Minimum discernible signal** (MDS) is a measurement of the sensitivity of the receiver. It is usually measured using a spectrum analyser by increasing a test signal on the receiver frequency until it is 3dB above the noise floor of the receiver. The noise you hear in a receiver that is not connected to an antenna is proportional to the bandwidth of the receiver. So for instance reducing the bandwidth from 500Hz to 50Hz reduces the noise power by 10dB (a 10 times reduction in power). Where possible the ARRL MDS test is carried out with a 500Hz bandwidth setting. Of course when you connect the antenna you hear atmospheric noise and other signals in addition to the noise generated within the receiver. Another common measurement of receiver sensitivity is 'signal to noise ratio' (or for FM receivers SINAD). **Signal to noise is the ratio**, expressed in dB, of the level of (signal plus noise) with a signal present to the level of (noise) with no signal present. It is measured by increasing the signal into the receiver until the receiver audio output increases by 10dB (10dB S+N/N) so it is normally around 10dB higher than the MDS, which for an HF receiver should be around -120 to -130dBm in a 500hz bandwidth. SINAD is the ratio of (signal + noise + distortion) to (noise + distortion) and for a VHF or UHF receiver is typically around 12dB for an input to the receiver of 0.25uV (-119dBm).

RECEIVER SELECTIVITY is the ability to listen to the signal you want to without interference from stronger signals on nearby frequencies. **Reciprocal mixing dynamic range** (RMDR) is usually measured with a test signal at either 2kHz or at 20kHz away from the receive frequency. Reciprocal mixing is noise generated in a superheterodyne receiver when noise from the local oscillator (LO) mixes with strong adjacent signals. All local oscillators generate some noise on each sideband and some LOs produce more noise than others. This sideband noise mixes with the strong adjacent off-channel signal and generates noise at the output of the mixer. The generated noise can degrade a receiver's sensitivity and is most notable when a strong signal is just outside the IF pass-band. RMDR is a 'ham next door test', it measures how large an interfering signal which is offset 2kHz (or 20kHz) from your receive frequency needs to be to make your received signal to noise ratio degrade by 3dB. An RMDR of 100dB is good and 140dB is excellent. Direct sampling software designed receivers with no local oscillator are immune to this kind of distortion and so score very high on this test. Often a single adjacent interfering signal has more effect on the wanted receive signal than two strong signals 20 and 40kHz away (20kHz spacing) or 2 and 4kHz away (2kHz spacing) as measured in the IMD 3rd order tests, so in many cases RMDR is the primary limiting behaviour in a receiver's performance.

Dynamic range is the difference between the weakest signal that a receiver can hear and the strongest signal a receiver can simultaneously accommodate without degradation of the weak signal performance. There are two key dynamic range tests; blocking dynamic range and third order intermodulation distortion.

Blocking dynamic range (BDR) which is also known as blocking gain compression (BGC) or just 'blocking', measures a condition in which a weak signal is blocked or suppressed by a stronger signal on a nearby frequency. Like RMDR it is measured by injecting an interfering signal at a 2kHz or

20kHz offset and is another 'ham next door' test. The test shows when a receiver's sensitivity begins to drop in the presence of strong nearby signals, this is known as 'desense'. The amount of signal that is injected is increased until the wanted signal decreases by 1dB. BDR is usually better in receivers using a single conversion to IF than in multiple conversion receivers. With the pre-amp off, a result of 100dB is good and a result higher than 120dB is excellent. Unless the station you want to work is extremely weak, turning off the pre-amp and adding attenuation to the input can improve the situation by eliminating the desensitisation. This is the reason that transceivers have that ATT button that you never use.

A blocking result that is shown as 'noise limited' in the test report means that the measurement was unable to be measured due to a high noise floor in the receiver. The noise floor may rise when the offending signal is injected, which is the condition measured by RMDR. In situations where the blocking is 'noise limited', the ARRL test lab takes a 1dB increase in noise floor to be equivalent to a desense of 1dB and reports that as the blocking data for the review. Noise limiting is usually worse on the 2kHz measurement than the 20kHz measurement which is an indicator that the receiver local oscillator has a high level of phase noise, affecting close in receiver performance, and masking the measurements. 70s and 80s receivers with phase locked loop technology often had very noisy oscillators compared to older VFOs and the new DDS synthesisers. In most cases the local oscillator is used for both receive and transmit, so a noisy local oscillator, as well as affecting the dynamic range measurements and limiting the noise floor of the receiver, will also add broadband noise to your transmit signal.

INTERMODULATION PERFORMANCE (IMD). Intermodulation is false signals generated inside the receiver by the mixing of strong signals within the receiver bandwidth. IMD dynamic range is the difference between the receiver's noise floor and the level of unwanted signals that cause an undesired signal to appear right on the receive signal. The process of mixing causes the worst IMD product (2A-B) to appear at a frequency spacing equal to the difference in frequency between the two interfering signals. For example if your receiver was tuned to 14,020kHz and the interfering signals were on 14,040kHz and 14,060kHz (20kHz spacing test), then the second harmonic of the lower frequency 2x 14,040 = 28,080 mixed with the upper frequency 14,060 causes an unwanted signal right on the wanted frequency of 14,020kHz. Because it is 2x one frequency (2^{nd} order) and 1x the other frequency (1^{st} order) the test is known as a 3^{rd} order intermodulation dynamic range test.

The **2 tone, 3^{rd} order IMD dynamic range** measurement, tests how the receiver performs in the presence of multiple strong nearby signals. It is tested with two tones, either 20kHz or 2kHz apart, (some labs use 5kHz spacing). With the pre-amp off IMD numbers greater than 90dB are considered very good.

The two 3^{rd} order IMD tests (2kHz and 20kHz) are the key numbers for anyone wanting to work in contest conditions where you can expect many other signals close to your receive frequency.

3^{rd} order intercept (IP3) is another 2 tone test and is related to the IMD test. It also shows how well the receiver performs in the presence of multiple strong nearby signals and gives a good overall indication of how well a receiver performs when receiving a strong signal in the presence of other strong signals. At 20kHz an IP3 with pre-amp off of +15dBm is OK and above +30dBm is excellent. At 2kHz an IP3 of above +25dBm is excellent. This explanation is a difficult one so feel free to skip ahead. In a good receiver, with the AGC turned off or disabled, the audio output level should increase linearly as the input signal increases. A 3dB in input signal should give a 3dB increase in audio output. But the audio signal created by the 3rd order IMD intermodulation signal is caused by non linerarities in the receiver and it increases at around three times the rate of the input signals. If you plot the audio output level of the wanted signal with increasing input level and also plot the audio output level of the unwanted IMD signal with increasing 2 tone interfering signals the two lines on the chart will cross. The point where they cross is the 3rd order intercept point and the measurement is the input level of the wanted signal in dBm at that crossing point. In a real receiver the AGC acts to reduce the audio level and at high levels the receiver will suffer from blocking gain compression and desense so in the real world you can never reach the intercept point but it can still be plotted by extending the data points gathered at low signal levels before the AGC becomes active.

The ARRL also checks **2nd order intercept (IP2)**. This is similar to the 3rd order test except neither of the offending frequencies being mixed is a second harmonic. It is a straight A-B test. For example it can act as a check to see if shortwave stations around 6,000kHz and 8,020kHz create interference 'birdies' on the 20m band, 6000+8020 = 14,020kHz. An IP2 with pre-amp off of +55dBm is OK and above +70dBm is excellent. The rate of change for a 2nd order signal is twice that of the wanted signal, so again, if both are plotted on the same chart an intercept point can be estimated.

The last important receiver tests are **IF rejection** and image rejection. As if the effects of unwanted nearby signals like those contest stations or the ham next door weren't enough of a problem there is also the issue of problems caused by interfering signals that affect frequencies that are intentionally generated within the receiver. The first IF of many HF ham transceivers is higher than maximum receive frequency for example 45Mhz. A strong interfering signal on the 45Mhz IF frequency could possibly be heard within the receivers pass-band. In the IF rejection test a signal on the IF frequency is input to the receiver via the antenna connector. It is increased until a signal appears at the receivers output that is equal to the receiver's noise floor. This input level in dBm is the IF rejection in dB. The test is normally done with the receiver tuned to a range of different frequencies, for example the Icom 7600 was tested at 14 and 50MHz. IF rejection over 70dB is good and over 100dB is very good.

Another problem where external signals might affect frequencies within the receiver is **image rejection**. One of the characteristics of mixers is that they create a number of frequencies at their output, these include the receive frequency the local oscillator frequency, the sum and difference frequencies and products generated by harmonics of the input signals. Good IF filters and a sensible choice of IF frequency attenuate the effects of most of the unwanted frequencies but some combinations of RF frequencies can produce images in the mixer that are within the IF pass-band. Testing for image rejection is the same as for IF rejection, except the input signal is on the image frequency. Because image frequencies are usually far removed from the tuned receiver frequency image rejection is usually excellent, being 80dB or more. Image rejection over 100dB is very good. On VHF and UHF bands particularly with dual band hand held receivers which have extremely broad front end filtering the image rejection is often very poor.

OK, you can have a rest for two months now. Part two will discuss the transmitter tests.

References: Internet sources, ARRL test reports and QST August 2004.

Part 2 - the Transmitter tests, by Andrew Barron ZL3DW, Sept12

Last issue we took an in depth view of the receiver tests that are included in the new transceiver reviews that feature on the Sherwood Engineering web site or in the QST, CQ, or Radcom magazines. I hope it was a useful guide to understanding what the tests are for, provided a high level view how they are carried out, and explained why the results matter in the real world. The receiver tests are important when you want to work weak signals, or on a crowded band, or when a neighbouring ham is operating on the same band (or sometimes on a different band). This month we will take a look at the transmitter tests.

While the receiver tests were all about how well you can hear a wanted signal in the presence of unwanted signals or noise, the transmitter tests are more concerned about making sure that the transceiver works as advertised and making sure that the transmit signal sounds good and does not interfere with other band users, or worst case, services operating on non amateur band frequencies. Clearly operating outside of the conditions of your licence can cause all kinds of grief ranging from a visit from the licensing authority, to upset neighbours suffering TV interference, or a grumpy ham down the road demanding to know why you are filling 20m with horrible splatter. So an understanding of the transmitter tests can also give you an understanding of the problems that can occur with a poor or faulty transmitter.

The first transmitter test is **output power**. It is measured at various frequencies, usually on each available mode CW,AM,SSB,FM,RTTY,PSK and it is really just a check to show that the metering works OK and that the transceiver is producing at least the power specified by the manufacturer. Where the transmit power is adjustable the report usually also includes the minimum power output which is useful information for QRP operators. If there is a transverter output that level would also be included in the report. If the maximum power was low on any particular band this would be noted.

Spectral purity is a set of measurements to show clean your transmitted signal spectrum is. In other words it includes a range of tests to show if your transmitter is putting out signals on unintended frequencies, or splatter is causing a wider than intended transmission. In SSB mode there are tests to check whether there are unwanted sideband signals and how good the suppression of the carrier frequency is. In some respects the keying waveform check also fits into this group of tests, the oscilloscope trace can tell you a lot about how your CW signal sounds. For example are there any keying clicks and is the first 'dit' shortened or malformed?

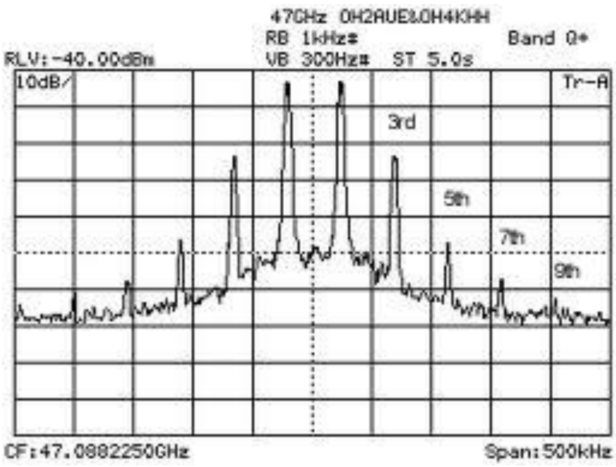
The test report includes a check on the **harmonic and spurious signal suppression**. The transmitter is keyed at full power and the transmit spectrum is checked for offending signals. Generally the worst spurious signal is the second harmonic which is 2x the transmit frequency, followed by the third harmonic which is 3x the transmit frequency. Other spurious signals could include leakage from the transmit local oscillator and out of band mixer products. The transmitter output stage in your transceiver is followed by a low pass filter designed to reduce the level of the harmonic signals. Transmitters or linear amplifiers which have two power amplifier devices arranged in a 'push – pull' configuration generally have very good harmonic suppression as push-pull amplifiers only output the fundamental frequency and the third harmonic. A good transmitter or linear amplifier should have at least 50dBc of harmonic suppression, which means that the highest harmonic or spurious signal is at least 50dB less than the transmit carrier signal. Interference from harmonics of our transmitters is one of the reasons that the international ham band allocations are harmonically related; 160m, 80m, 40m, 20m 10m. The harmonics of our transmissions fall into the next band up. Another reason for having harmonically related bands is ease of multi-band antenna construction.

One of the advantages of single sideband transmission is that all of the transmitted power is in the upper, or below 10MHz, lower sideband. The other sideband and the carrier are suppressed by filters and the design of the modulator in the transceiver. This means that the SSB transmission takes up less RF spectrum than an equivalent AM transmission and none of the power is wasted in sending the carrier frequency, so stations can operate close together without interference. The **carrier and unwanted sideband suppression test** is done by feeding an audio tone into the microphone jack and adjusting the level until the transceiver is operating at its rated power output. The level of the carrier frequency and unwanted sideband is measured relative to the wanted sideband signal and should be 'down' at least 45dB -50dB.

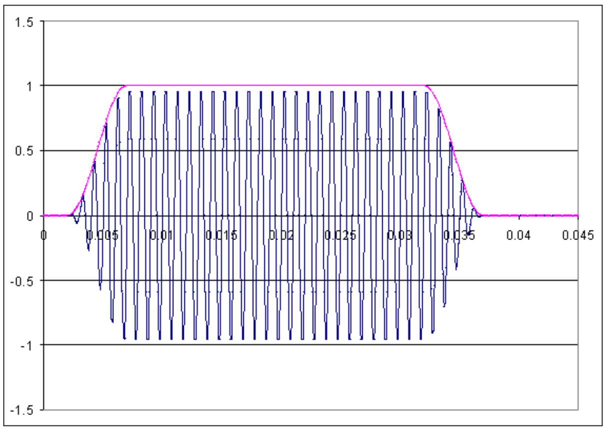
To quote QST and the Sherwood web site which has the same text; "*Transmit two-tone intermodulation distortion, or **two-tone IMD**, is a measure of spurious output close to the desired audio of a transmitter being operated in SSB mode. This spurious output is often created in the audio stages of a transceiver, but any amplification stage can contribute. If you have ever heard someone causing 'splatter', the noisy audio that extends beyond a normal 3 kHz nominal SSB bandwidth, then you have heard the effects of transmit IMD. Frequencies close to the transmit signal are affected the most, but depending on the amount of IMD, large portions of the band can suffer from one poor transmitter.*" This kind of IMD splatter can be caused by overdriving the audio stages of your transmitter, for example turning the mic gain all the way up, or having too much speech processor gain, causing audio signal clipping.

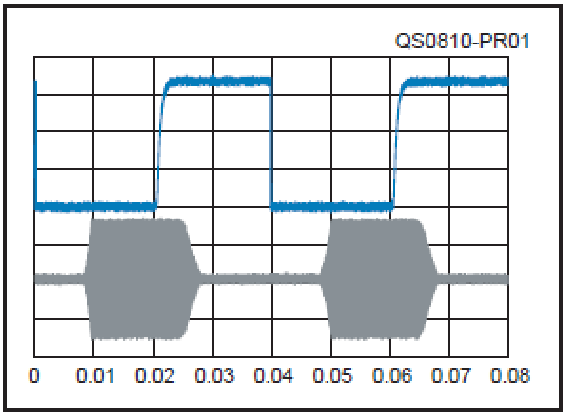
The traditional method of measuring IMD is to feed the transmitter's audio input with two clean audio frequencies, not harmonically related, and observing the transmitter's output signal with a spectrum analyser. If the transmitter was perfect, only two RF signals would be seen, corresponding to the two input tones shifted to RF by the SSB modulation process. If the transmitter (and any linear amplifiers as well) is not perfect, new frequency components will be generated and will appear in the output signal, as additional sideband tones at multiples of the audio tone frequency spacing. The level of the signals generated by IMD are compared with the PEP power of the transmitter which is 6dB above the RF level with a single modulation tone.

ARRL records the 3rd, 5th, 7th and 9th order IMD and includes the 3rd and 9th order results on the key measurements summary (see spectrum picture). The results are worst case intermodulation products relative to the PEP power of the transmitter. A 3rd order IMD result of -28dB is typical and less than -30dB is very good, a 9th order IMD result of less than -50dB is good and less than -60dB is excellent.



I included the **CW keying waveform** check in the spectral purity tests because spikes, distortion and fast rise times can cause IMD issues. But the main reason the waveform is included in the ARRL test is because the shape of the CW signal can have a big influence on how your CW signal sounds at the receiver. In the ARRL test a string of 'dits' is sent at 60wpm and the RF output waveform of the first two dits is captured using a storage oscilloscope. The 3rd and subsequent dits are not usually shown because they are normally the same as the 2nd dit. The delay after the keying signal shows how fast the transceiver switches to transmit in QSK mode. Is the first dit shortened or not there at all? The waveform also shows if there are any odd spikes and indicates the keying delay which is the time between when the Morse key is pressed and the time the RF appears. You will note when you see a picture of the keying wave form or 'keying envelope' that there is a rise time and fall time of around 8mS - 5mS, in other words the rising and falling edges of the CW signal are not sharp like a square wave. This shaping of the CW signal is done with RC filters, or DSP these days, to limit the RF bandwidth of the transmitted signal. Too fast a rise time causes a wide signal that sounds 'hard' or 'clicky' due to the high frequency audio components inherent in a square wave. As with all digital modes, the speed of the CW transmission also affects the bandwidth.





The **transmit turn around tests** are done in SSB and FM modes, they measure the time it takes the transceiver to go from receive to transmit and the time it takes to go from transmit to receive, (from the time the PTT is released until there is 50% of the normal audio output with an S9 signal on the input). In FM mode the receive to transmit time is important for packet and repeater operation. It should be less than 150mS. Long delays on either Tx->Rx or Rx->Tx can also lead to 'doubling' and confusion in either SSB or FM mode. The transmit to receive time is important for digital operation in SSB mode and needs to be less than 35mS.

The last test is **composite transmitted noise**. In the discussion on receiver dynamic range I mentioned that noisy local oscillators sometimes mask the dynamic range measurement, this is referred to as a 'noise limited' result. In most transceivers the same local oscillator is used for the transmitter and the noise from the local oscillator will be mixed up to the transmit frequency and amplified in the PA stages. Phase locked loop 'synthesised' oscillators are prone to high levels of phase noise. The noise usually affects both the amplitude and the frequency of the transmit LO. The amplitude variation is unimportant but the frequency variation causes phase noise on the SSB sidebands. A single modulation tone with phase noise will show as a widening of the signal shown on a spectrum analyser. This test result is normally shown as a spectrum analyser plot starting just to one side of the large tone or carrier signal, so that the display can be expanded to show the effect of the noise. A typical caption reads; "*Worst-case tested spectral display of the FT-847 transmitter output during composite-noise testing on HF. Power output is 100 W at 3.5 MHz. The carrier, off the left edge of the plot, is not shown. This plot shows composite transmitted noise 2 to 22 kHz from the carrier*".

The technical tests are just a part of the overall review and the amount they bias your decision around a possible purchase or selection of the all-important ‘lotto’ transceiver is very dependent on the type of ham radio station you operate. For casual or mobile use a small transceiver with medium performance and VHF / UHF in addition to HF bands at a reasonable cost might suit you best. An avid contester or DXer will pay a premium for excellent receiver performance. Others may value CW performance or remote Internet access. Some may like the features of SDR transceivers which offer a radically different way to operate and great receiver performance at a reasonable price or they may prefer a more conventional transceiver. It is apparent that some of the best performing radios, especially with regards to receiver performance, are not necessarily the most expensive on the market. But factors such as; brand loyalty, ergonomics, multiple receivers, higher power output, faster DSP and band-scopes may justify the additional cost. In the end it is up to you.

Hopefully these two articles have shed some light on the technical tests performed as part of the transceiver reviews, the basics of how the measurements are made, and the reasons they are included.

73 de Andrew ZL3DW

References: Internet sources, ARRL test reports and QST August 2004.