Performance testing of Software Defined Radios

By Andrew Barron ZL3DW

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Do SDRs perform better than conventional Superhet architecture radios? There is no clear answer to this question because there is a wide variance in the performance in both conventional and SDR radios. Some of it is related to the price you pay, the particular SDR or conventional radio's internal architecture or how recent the transceiver (or receiver) is. Some of the recent offerings for the major equipment suppliers have much better performance statistics than radios released ten years ago. In the real world SDRs offer a different way to operate and as long as the signals in the pass-band are a few dB under the clipping level the SDR gives excellent results.

Based on the numbers in QST lab tests, SDR receivers often do not out-perform conventional superhet receivers. If you compare transceivers at a similar price point the conventional radio is likely to beat the SDR in terms of receiver performance. The transmitter performance could go either way.

A big problem is that many of the tests traditionally used to compare radios on league tables like the Sherwood Engineering list, and in Radcom and QST reports are not very relevant to SDRs because of the fundamental difference in technology. For example the Sherwood Engineering list is sorted on the 'close in' (2kHz spacing) 2 tone IMD (intermodulation distortion) performance test. This is because that test indicates how well a receiver would perform when the band is busy such as during a contest. The problem in using this approach when comparing SDR receivers with traditional superhetrodyne receivers is that the causes and effects of receive IMD is completely different in SDR receivers. SDR receivers often look very good on the 2 tone IMD at 2kHz spacing test and score quite high on the Sherwood list and in reviews, but the results are not really comparable.

When we are making a decision about which transceiver to buy, or which to add to our 'Lottery list', we want to make an informed decision so we check out the online reviews, advertisements and technical reviews. A big part of most reviews deal with the functional aspects, what features are included, ergonomics, and how well they work on air. These are very important issues and in many cases they should be the major factors in deciding whether the rig is right for you. After all you want a radio that suits the way you operate. Another very important thing for many of us, me included, is the balance of what you get versus the cost for the unit, "how much bang for your buck".

Some of the reviews such as the ones published in ARRL's QST magazine and RSGB's Radcom include test results from their lab testing. Other great resources are the test results published on the Sherwood Engineering web site and test reports done by Adam Farson VA7OJ / AB4OJ.

I see many comments online stating that the test results mean nothing and that the only way to evaluate a radio is by using it on air. I disagree. The tests are designed to simulate conditions found in real world situations, like a contest weekend, rag chewing on 80m, or another ham in the same street operating a little further up the band. **The advantage with these lab results is that they are repeatable and they offer an unbiased comparison between radios**. You just need to know how to read the numbers and work out which tests are the most important considering the way you want to operate. For example contesters might want different performance than those that need to work weak signals on 160m. CW operators may be more interested in some measurements than SSB operators. **You also need to understand that SDRs are fundamentally different and that different tests need to be applied to them**.

The trouble with on air evaluations and many of the videos that show different radios side by side is that often the author or video producer does not comment about which radio they believe is better and why. Even when comments are made, like "*it's much better (or worse) than my old transceiver made by XYZ*", it is a subjective view. Another ham may think differently. I'm not saying there is no place for the subjective reviews and videos, I love them, they are great for seeing how the radios look and work and for finding radios with a history of poor performance or reliability. But you must agree that many online comments are often a bit biased by the "*I just paid a lotta cash for this so it is the best radio I ever owned*" syndrome. Also there is a lot of brand loyalty which is fine, but it causes a tendency for people to run down radios that use a new technology, or are not made in a particular country, or are not made by their favourite manufacturer. I am sick of hearing why "ham X" (Insert callsign of your choice) would never even consider buying an SDR and prefers to stick with his C,E,D, Y,K,I,T,x,y, or z brand radio. He has probably never used an SDR and frankly I don't care if he never does.

The only problem with the lab test results is working out which ones are important to you and how to compare them to the results for other radios. It is all very well saying a radio has an MDS of -136dBm, but is that good? Is it better than other radios? What is it anyway?

The ARRL reports in QST magazine address this very well by putting the most important parameters in a nice panel with pictures of sliders like those level controls that are used on audio mixers and old fashioned tape recorders. The closer the slider pointers are to the right (green) side the better the transceiver or receiver's performance. I like this approach a lot because it gives an instant appreciation of how good the radio is compared to the 'best in class.' However there is a small issue with 'the goal posts moving'. The performance level at right side of each of the sliders represents the best result obtained by the lab for any receiver or transmitter tested to date. This means that a 1990s QST review might show sliders all well over to the right side, but that does not mean that the radio would compare well against today's transceivers.

Until recently I was completely unaware that **many of the traditional tests, particularly on receiver performance are not valid for Software Defined Radios**. Adam Farson VA7OJ/AB4OJ has done a lot of work on testing conventional and SDR radios and has explained the issues. He has also introduced a new Noise Power Ratio test which I believe is a really good performance indicator for radios with wide band front ends like SDR receivers.

- Receiver MDS – basic sensitivity – is essentially the same test in SDRs
- Receiver dynamic range – is affected by different the technology of SDR receivers, especially the number of bits the ADC uses
- 3rd order IMD dynamic range – IMD performance is completely different in an SDR, the practice of quoting 2kHz DR3 measured when IMD products are equal to the MDS level is not applicable to SDR receivers
- 3rd order intercept point (never measured directly anyway) can't be measured or calculated for an SDR receiver
- RMDR can be measured although the cause of RMDR is different in an SDR
- Noise Power Ratio can be measured in either type and is a very good test of SDRs because they are wideband receivers
- Blocking dynamic range – SDRs don't suffer from blocking de-sensitivity. BDR can be measured but does not mean much as you just record the clipping level.
- IF rejection – is not relevant to DDC SDRs since they don't have an IF. QSD SDR receivers do have an IF but it is most often 0Hz.
- Image rejection – is not relevant to DDC SDRs since they don't have mixers, but you can test image rejection in QSD type SDRs which as a direct conversion receiver are prone to image signals

- All of the transmitter tests; RF carrier and unwanted sideband suppression, 2 tone IMD (intermodulation distortion), transmitter harmonics, and composite noise, are just as important in SDR transmitters as in conventional ones.

RECEIVER TESTS

Most reviews and reports include a lot of receiver tests. This is because most transceivers do a pretty good job on transmit and small differences in transmitter performance do not make a big impact in the real world. On the other hand good receiver performance can dramatically affect your enjoyment of the hobby.

2 tone 3rd order Intermodulation Distortion.

In a superhetrodyne receiver the non-linear process of mixing causes intermodulation distortion (IMD) products. Large signals near the receive frequency can cause interference on your receive frequency. This is a big problem in contest situations when you want to hear weak signals operating near to stronger stations.

The worst IMD product "2A-B" appears at a 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 mixed with the upper frequency causes an unwanted signal right on your operating frequency of 14,020kHz.

2nd harmonic [2x 14,040kHz = 28,080kHz] mixed with the other tone [28,080-14060=14,020kHz]

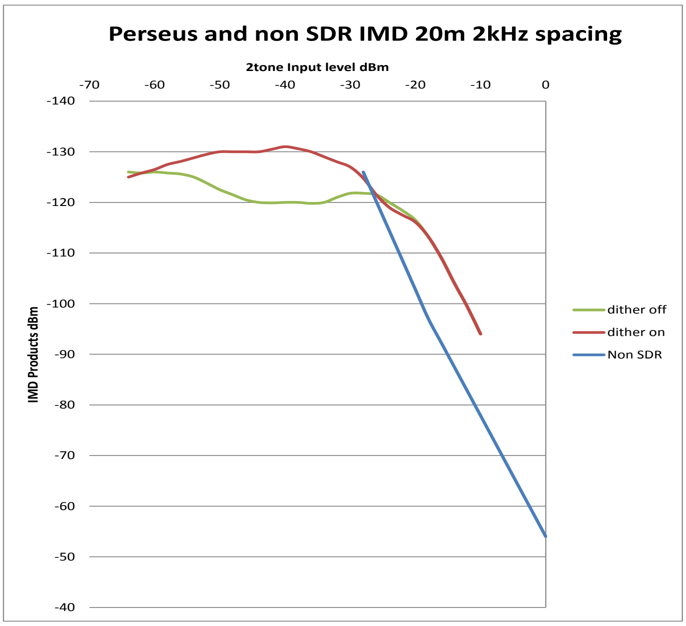
Because it is 2x one frequency (2nd order) minus 1x the other frequency (1st order) the test is known as a 3rd order intermodulation test (3rd order IMD).

The radio is tested by injecting two tones, either 2kHz or 20kHz apart, (some labs use 5kHz spacing) and measuring the intermodulation product on the receiver frequency. As the two tone input signal is increased, the 3rd order IMD products increase at close to three times the rate of the input signals.

If you plot both the input level and the IMD level on a chart and extend the lines they cross at a point which is recorded as the 3rd order intercept point (IP3). AGC action and limiting in the receiver prevents the IP3 level actually being reached.

The 3rd order dynamic range (DR3) is measured at a point where the IMD (intermodulation distortion) level is equal to the MDS (minimum discernible signal) level. In other words you can just hear (or see on a scope) the interference. At that point the [DR3 = Pi (input level) – IMD]. As the input signal of the offending tones is increased the 3rd order dynamic range (DR3) reduces linearly.

An SDR using direct digital down conversion (DDC) has no mixers so it is not affected by the same kind of intermodulation distortion. But it does have an analog to digital converter and that introduces some intermodulation products. The more bits that the ADC uses the better the maximum possible IMD performance becomes. Unlike the superhetrodyne receiver, the IMD does not get worse at around three times the rate that the tone signals are increased. It is not a linear relationship at all. In fact the large tone signals within the receiver bandwidth can actually improve the IMD performance on the wanted frequency. This effect is used to advantage in SDRs when a 'dither' signal is deliberately added and later removed in order to improve IMD performance.



This chart shows the completely different 3rd order IMD performance of a typical SDR and a typical conventional superhetrodyne receiver.

As you can see from the chart IMD generated in the SDR receiver is radically different from the linear response shown for the conventional superhet receiver. In the SDR receiver, as the level of the offending tone signals (x axis) are increased the IMD products (y axis) remain roughly the same (they may increase or decrease a few dB depending on whether dither is in use). When the offending tone (two tone test signal) level gets close to the receiver clipping level the IMD levels start to degrade and when the receiver clipping level which is the maximum signal that the ADC can process is reached, the IMD increases catastrophically.

What all this means is that unless the offending signals are very large, i.e. near the clipping level of the SDR receiver, the signals near your receive frequency will not adversely affect the signal you are listening to, in fact they may actually improve it.

This is completely unlike the result from the superhet receiver and it makes the traditional measurement useless for SDR receivers. The test is still relevant but a plot of the IMD performance or IMD dynamic range is required rather than just a single measurement taken when the IMD level is equal to the MDS level. In an SDR the IMD may be equal to the MDS level at more than one input level creating two radically different DR3 figures.

DR3 (2 tone 3rd order Intermodulation Dynamic Range)

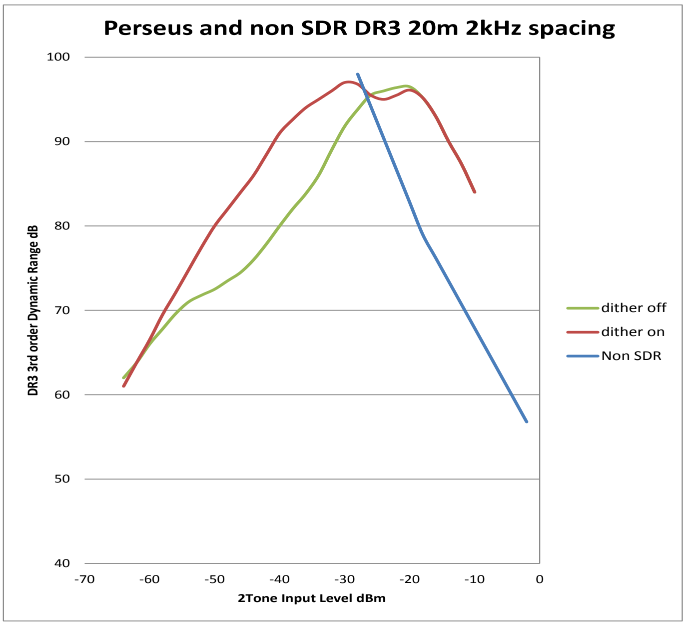
This is the king of receiver tests for non SDR receivers, but as discussed above it is a less useful measurement of SDR receivers. The test measures how the receiver performs in the presence of two or more strong signals near your receive frequency. **The DR3 result gives a good indication of how well a receiver will work in a contest situation where there are many big signals on the band.** It is another way of recording the 2 tone 3rd order IMD.

In a non SDR receiver DR3 is usually worse at a close 2kHz spacing than at a wide 20kHz spacing. In an SDR it is usually the same at any spacing. This makes SDRs look good on tables ranked using narrow spaced IMD dynamic range.

3rd order Intermodulation 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. In conventional receivers with the pre-amp off DR3 numbers greater than 90dB at the 2kHz spacing are considered very good. In a superhet the best DR3 (2 tone 3rd order Intermodulation Dynamic Range) occurs when the interfering tone signals are large enough to just see (or hear) the intermodulation on the receiver i.e. IMD level = MDS level. As the level of the offending tones is increased above that point the DR3 degrades linearly. This does not occur in an SDR receiver.

Direct sampling SDR receivers don't have any mixers so they don't have this kind of distortion. But the ADC process causes some IMD products so you can still do the test and present the result on a chart. Poor DR3 in an SDR is an indication of front end non-linearity usually occurring in a preamp or filter stage before the ADC. Likewise degraded NPR (noise power ratio) on one band indicates passive IMD in the RF filter for that band. A good SDR using a 16bit ADC can achieve a DR3 with a peak performance level above 100dB. SDRs using 14 bit or 8 bit sampling cannot achieve that level of DR3 performance because of the limitations of the analog to digital conversion.

DR3 (3rd order IMDR) should be read in association with RMDR. The usual case is that DR3 is worse than RMDR at the same offset, indicating that front end linearity is the dominant impairment rather than clock phase noise.



This chart shows the completely different 3rd order dynamic range performance of a typical SDR and a typical conventional superhetrodyne receiver.

If we use the [DR3 = Pi (input level) – IMD] calculation for The 3rd order dynamic range we find that unlike a superhet receiver, the dynamic range of the SDR (y axis) increases as the level of the offending tones (x axis) is increased. Dynamic range peaks and then roll off starts as the input tone level gets near the clipping level of the receiver. When the clipping level is reached the dynamic range collapses.

Leif Åsbrink, SM5BSZ recommends recording the DR3 at the peak point of the IMD curve.

"The standard procedure for measuring the two-tone, intermodulation-free dynamic range, used for example at the ARRL Lab, is to gradually increase the test signal until the third order intermodulation signal equals the noise floor. While adequate for conventional analog receivers, although sometimes technically extremely difficult (on really good receivers), this procedure does not give a valid result for a digital radio like the SDR-14. Therefore, a different procedure should be adopted. It would give identical results as the old procedure on analog receivers but it would give a true figure of merit for

digital radios. Rather than measuring what level is required for getting IM3 equal to the noise floor, one should measure the largest difference (in dB) between the test tones and the intermodulation product. It will be close to saturation of the A/D converter on the SDR-14, while it will be at the noise floor for an analog receiver. Obviously the digital radio might need an RF amplifier to lift the external noise floor to the IM3 level observed in the test."

Leif Åsbrink, SM5BSZ in QEX Nov/Dec 2006.

Note that the highest point of the blue line is the MDS point for the superhetrodyne receiver, it occurs very close to the same input tone level as the peak of the dynamic range for this particular SDR receiver with dither turned off. The SDR maintains this dynamic range as the input level increases a further 10-15dB while the dynamic range of the superhet reduces. When the input tones reach around 7dB below the clipping level (i.e.-15dBm) the SDR dynamic range rolls off and at clipping (-8dBm) it crashes.

"As the input power increases above MDS the IMD dynamic range (DR3) increases until the "sweet spot" (≈ -10 dBFS) is reached, then begins to decrease rapidly. Thus, if we specify DR3 at MDS, this is essentially meaningless as the IMD behaviour is opposite to that of a superhet.

IP3 cannot be defined or stated, as the transfer function and 3rd order line diverge rather than converging as they do in a conventional receiver.

In a direct-sampling SDR, DR3 at any given P_i level is equal to P_i minus the power level of the IM3 product. (This can be conveniently measured on the spectrum scope if the scope's amplitude calibration is accurate, which it usually is.) One can actually see the amplitude of the IM3 products drop as the test tone level increases. ***To the operator, this means that strong out-of-band signals are considerably less likely to throw IM products into the passband than in a superhet and in fact the stronger these signals are, the less troublesome they will be****. Add to this the effect of "external dither" caused by the multitude of out-of-band signals and the receiver's IMD behaviour becomes quite unpredictable as it is a function of instantaneous band conditions.*

For all the above reasons, I do not think DR3 at MDS is a valid way to compare a direct-sampler to a superhet. I favour the NPR test as a benchmark for direct-sampling SDR evaluation. The closer the measured NPR is to the maximum theoretical value for the ADC in use (given the same noise-loading bandwidth for the theoretical calculation and the test) the better the receiver will perform. The only limit is that imposed by the ENOB of the ADC.

Ultimately, the operator (especially the contester working a crowded band) will be the final judge of a direct-sampler's suitability for serious amateur HF operation"

Adam Farson VA7OJ/AB4OJ

RMDR (Reciprocal Mixing Dynamic Range)

RMDR tests how well a receiver copes with a single large signal just outside the pass band you are listening to. I call it **a 'ham next door test'; it demonstrates how well your receiver copes when the ham down the street transmits near your operating frequency.** In a conventional receiver reciprocal mixing noise is caused 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 so it is usually worse the closer the offending signal is to your receiver frequency. This is why it is usually reported at a close offset of 2kHz (or 5kHz) and at a wider offset like 20kHz.

In a direct sampling SDR receiver reciprocal mixing noise is caused when phase noise from the ADC (analog to digital converter) mixes with the offending signal, so RMDR is an indicator of the ADC clocks spectral purity. This is why phase noise is usually included in SDR specification sheets. In an SDR the RMDR is usually independent of the offset from the receiver frequency and is normally pretty much the same at 2kHz, 5kHz and 20kHz. An RMDR of 100dB is very good and 120dB is excellent.

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.

RMDR should be read in association with DR3 (2 tone 3rd order Intermodulation Dynamic Range). In cases where the RMDR is worse than DR3 at the same offset, then phase noise is the dominant impairment rather than front end linearity.

MDS (Minimum Discernible Signal)

MDS is a measurement of how sensitive the receiver is. It represents the weakest signal you can hear. **You need it to be good if you want to hear very weak signals on a quiet band, for example when sunspots are poor or the band is closing**. If the band is noisy the noise level coming in the antenna port will often be higher than the MDS so sensitivity is not as relevant.

In the test a signal is input to the receiver and the MDS is the input signal level when it shows as 3dB above the receiver noise floor. The MDS is better if the bandwidth of the receiver is reduced because a narrow bandwidth allows less noise in. So it is usually measured using a typical CW bandwidth of 500Hz and using a typical SSB bandwidth of 2.4kHz. It is normally checked on several bands as well. In most SDR receivers especially direct sampling (digital down conversion DDC) receivers you would expect the same performance on all bands. When you compare results relating to different radios, check that no attenuators or preamplifiers are in use. Most SDR receivers have an MDS better than -125dBm in 500Hz bandwidth and better than -115dBm in 2.4kHz bandwidth. Excellent receivers can achieve an MDS better than -130dBm in 500Hz bandwidth and better than -120dBm in 2.4kHz bandwidth. SDRs with 8bit analog to digital conversion (ADC) will probably not be able to achieve that level of performance because of limited dynamic range.

If you don't have a signal generator you can estimate the MDS by looking at your SDR spectrum display with the receiver input terminated using a 50 Ohm load. You will see the receivers 'noise floor' as the flat jiggly line across the spectrum display and there is normally a dBm scale on the display axis. The MDS is nominally 3dB above the noise floor. When you connect an antenna the noise level displayed will probably rise due to noise being received, but if you look at online videos you commonly see a noise floor better than 120dB even with the antenna connected. Note that adding front end attenuation will make the noise floor look better, a good marketing trick.

Dynamic Range

The dynamic range of SDR receivers is not commonly measured because it is pretty much determined by the receiver design. It is the difference between the noise floor and the largest signal that the receiver can manage without clipping. Standard non SDR receivers typically don't have a particularly good dynamic range. They extend the range by using AGC (automatic gain control) which reduces the receiver gain (sensitivity) when large signals are detected so that clipping does not occur. In the SDR receiver the maximum dynamic range achievable is mostly determined by the number of bits that the analog to digital converter (ADC) uses to sample the RF waveform. The more bits that are used, the more individual voltage levels can be described and therefore the wider the range of signal levels that can be converted into numbers. This is an important limitation in SDRs like the RTL TV dongles which use an 8bit ADC. SDR receivers using 16 bit or better ADCs typically have a dynamic range greater than 90dB so no AGC is required. Some SDRs do include front end filters to eliminate really big signals from broadcast stations etc. because big signals reduce the dynamic range of an SDR receiver. Actually the AGC action of big signals within the pass band of a superhet receiver desensitises the receiver to weak signals, so you could say that big signals reduce the dynamic range of a superhet receiver as well.

Some SDR receivers do use a type of AGC, really automatic audio level control, to reduce the audio level output on strong signals, otherwise you get blasted every time you tune across a strong station. The control marked 'AGC-T' AGC Threshold on PowerSDR works like a kind of RF gain control which limits the maximum output from the receiver on strong signals.

One very important factor affecting the dynamic range of SDR receivers is that the clipping level reduces in proportion to the number of large signals being received. The ADC has limited 'head room.' If many large signals are present the clipping level goes down, reducing the dynamic range. For this reason it is good to have band pass filters or a tracking pre-selector filter in the front end before the ADC.

This effect can be tested using a 'worst case', wideband noise signal as per the NPR test below and comparing the clipping level with the wideband input signal vs the clipping level with a single tone. In one test done on the FlexRadio 6700, the clipping level with a single tone was greater than +13dBm but with the noise source it was around -2dBm. This represents a best case to worst case reduction in dynamic range of more than 15 dB, but since this receiver has more than 140dB of dynamic range this is not a big problem. It would be more significant on an SDR like a RTL dongle which has a limited dynamic range due to its 8 bit ADC and no front end filtering. You would not expect to see a reduction in dynamic range of 15dB in the real world because the loading of signals would never get anywhere near the loading that a white noise signal at clipping level presents, that much noise is equivalent to 1200 S9 +30dB SSB signals side by side. This effect is not a fault with the receiver just a result of the Analog to Digital conversion process.

NPR Noise power Ratio

Adam Farson has introduced this new test of SDR receiver performance. As far as I know no other labs are doing it. The test can be done in any receiver and with different roofing filters, but it is particularly useful with DDC SDRs since they sample a very wide bandwidth and can be affected by signals both within and outside the ham bands.

The NPR test makes me all nostalgic because I used to do NPR 'white noise' testing on analog microwave radio equipment. It was used to simulate a fully loaded 'baseband', of telephone signals and then test how much crosstalk (intermodulation) fell into a quiet voice channel.

The idea of the NPR test is that you load up the wideband SDR receiver with lots of signals. This is simulated by connecting a 2, 4 or 8MHZ wide, band limited, 'white' noise source to the receiver input. You push the noise level up until the receiver is very slightly under the clipping level. Then you cut a slot in the noise exactly 3kHz wide using a very good band stop filter and measure the amount of noise caused by intermodulation products generated in the receiver that fall into that narrow quiet spot. Adam measures the level in a 2.4kHz wide bandwidth in the bottom of the slot since this is a typical bandwidth for SSB and it fits neatly inside the 3kHz slot. The NPR is the ratio of the noise power inside the slot to the level of noise power in a channel the same bandwidth outside the slot. Since the SDR receiver has a spectrum display the result can be read straight off the screen. A 4MHz wide noise signal at just under clipping level is equivalent to more than 1200 SSB signals at S9 +30dB.

This is **the ultimate test of how well the SDR will perform in a busy band, like a contest weekend**. Imagine all of the international CW, SSB and digital mode contests being held on the same day! They fill up every bit of the band from 316kHz to 8.1MHz including all the bits that are not ham bands, but for some strange reason there is a gap exactly 3kHz wide where nobody is transmitting any signal at all, how much noise from intermodulation effects in the receiver will fall into that quiet spot where you want to work your most wanted DX ever? OK it can never get that bad in the real world, but it is a good way of simulating a worst case scenario. If the receiver does well in the NPR test a contest weekend should be a breeze. Of course splatter caused by over-modulated transceivers and poor amplifiers is a completely different problem. Considering that the 2 tone 3rd order IMD test is not a good basis for comparing SDR receivers against conventional receivers, the NPR test is a good replacement test. It effectively replaces the 2 tone test with a wideband test.

Adam measures NPR at four different frequencies, chosen because of the slots and noise band limits that are available on the NPR test set;

- A slot at 1940 kHz within a noise bandwidth from 60kHz to 2044kHz (approximately 160m)
- A slot at 3886 kHz within a noise bandwidth from 60kHz to 4100kHz (approximately 80m)
- A slot at 5340 kHz within a noise bandwidth from 60kHz to 5600kHz (approximately 60m)
- A slot at 7600 kHz within a noise bandwidth from 316kHz to 8160kHz (approximately 40m)

A NPR of better than 75dB is very good, better than 78dB is excellent.

Analog Devices issued a training note about NPR testing of DDC type SDR receivers (MT-005). It gives the theoretical maximum NPR performance for different analog to digital converters.

It shows that there is room for improvement in the real world and more importantly that using an 8bit ADC degrades the receivers IMD performance in addition to limiting its dynamic range (the ability to cope with large signals while not losing sensitivity to weak ones). The number of bits used by the ADC will affect the maximum 3rd order IMD dynamic range achievable as well.

Bits used by ADC	Max possible NPR (dB)
20	108.41
18	96.88
16	85.40
14	74.01
12	62.71
10	51.56
8	40.60

TRANSMITTER TESTS

There are tests to check that the transmitter puts out the correct power on all bands and modulates with no distortion even when running speech compression. Also things like the time it takes to go from receive to transmit which is important for CW and the shape of the CW waveform. ARRL tests the first few bits of a CW stream at 60wpm to check for truncation of the first dit. But I think that the key tests are the intermodulation and spectral purity tests. It is very comforting to know that your transmit signal is clean and not interfering with other band users. Nobody likes being pounced on by the infamous 'band police'.

Carrier and unwanted sideband suppression

When you transmit a single sideband signal you want all of the RF power to be in the wanted sideband. Any power in the unwanted sideband or on the carrier frequency is wasted energy and can cause interference to other band users.

Composite noise - why does it matter?

The source of transmitted composite noise in an SDR is the Digital to Analogue Converter and its clock rather like the purity of the local oscillator and its control mechanism in a normal transmitter. In a conventional rig the transmitter local oscillator is usually used for receive as well. The RMDR test measures the effect of receiver LO noise mixing with a strong signal near the wanted signal. In an SDR noise from the analog to digital converter (ADC) and its clock causes the same sort of distortion which can also be measured with the RMDR test.

TESTS THAT ARE NOT VERY RELEVANT TO SDR RECEIVERS

3rd order intercept (IP3) is another 2 tone test and is related to the IMD dynamic range test. Due to the AGC action of the receiver and its dynamic range, IP3 is always calculated rather than measured directly. Because the rate that the IMD products increase in relation to the rate of increase in the input level of the test signals is not a linear relationship the way it is in a conventional receiver, IP3 cannot be calculated for an SDR receiver.

In a conventional receiver with AGC turned off, 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. IP3 of +30dB or better is very good indeed, some receivers don't even manage to get above 0dB.

In a direct sampling SDR receiver the receiver audio is linear so a 3dB in input signal should give a 3dB increase in audio output, but the 3rd order IMD intermodulation does not get worse at 3 times the rate of the input signals. The two lines diverge and never cross, there is no 3rd order intercept point. Using dither (noise added to remove periodic errors in the ADC) further improves the SDR intermodulation performance, at the expense of a slight degradation of the noise floor.

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. BDR is not relevant to SDR receivers because large signals have no desensitising effect on weak adjacent signals. (The ADC does not block until clipping is reached then it crashes). The dynamic range is the difference between the clipping level and the noise floor, so SDRs always look like they have very good BDR.

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. In a conventional non SDR receiver 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. Again 2^{nd} order intercept is meaningless in an SDR but you can measure the effect of two interfering signals. A good SDR should have a 2^{nd} order dynamic range (DR2) of better than 80dB.

IF Rejection is a test to determine how an interfering signal at the receivers I.F. frequency can break through into the audio pass band. Direct sampling SDRs have no I.F. so the test cannot be performed. Most quadrature (QSD) SDRs are direct conversion to audio, so again there is no I.F. frequency to test.

Image rejection is a function of using mixers in the design. 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. Image signals are a problem in quadrature (QSD) SDRs and in fact all direct conversion receivers. In the QSD SDR the images are cancelled using the ‘I and Q’ audio streams (“the phasing method”). So in a QSD SDR you can measure the success of the image cancellation. The level of image signals is dependent on the relative level and phase of the ‘I and Q’ streams. Direct sampling SDRs do not have mixers so no images exist.

Much of the science and some of the paragraphs in this article were created by Adam Farson VA7OJ / AB4OJ, I thank him for his contribution to the article and for his excellent test reports on SDR and conventional transceivers. Reading his postings and reports and researching the article has really helped me to understand the way the tests are performed and their relevance to real world operating. I hope you found it entertaining and informative.

73 de Andrew ZL3DW