Band Pollution from Amateur Transmitters

by Leif Åsbrink, SM5BSZ

In 2005 I highlighted the fact that the dominant cause of inter-station interference between most modern transceivers is band pollution from the transmitters [1 or 2]. While receivers have generally improved over the years, transmitters in general have not, and even today we are still seeing examples of poor transmitter design. This article highlights one example: major noise sidebands in the transmitter part of a SDR (Software Defined Radio) transceiver that is specifically marketed for use as a transverter driver for VHF, UHF and microwaves.

Receiver performance is a major selling point in the highly competitive market of amateur radio transceivers. Modern receivers are designed to allow the reception of weak signals in an RF environment where strong signals are present at close frequency separation. Good modern receivers can handle interfering signals that are 100 dB stronger than the desired signal at a frequency separation of 20 kHz, and about 130 dB stronger at 100 kHz separation [3, 4]. But typical transmitters are less good, with much poorer suppression of spurious products. This gap between receiver performance and transmitter performance is what causes the problems for other band users.

The 2005 article identified widespread problems in transmitter design, above all the misuse of ALC that causes splatter on SSB and keying clicks on CW [1 or 2]. Splatter or key clicks from a strong station may prevent other stations from operating closer than 10 or 20 kHz, especially on the VHF, UHF and microwave bands where background noise levels can be much lower than on HF so the demands on dynamic range are much greater. Fortunately splatter and key clicks differ in character from the desired signal, being more intermittent and generally having a high peak to RMS power ratio, so a trained operator can copy desired signals through fairly high peak levels. This kind of interference can also to some extent be suppressed by a good AGC circuitry in the receiver. But such forms of band pollution should not be left to the receiving operators to resolve; both legally and ethically, poor-quality transmitted signals are completely the responsibility of the transmitter user.

It is usually not difficult to reduce splatter by disabling the ALC in the transmitter, and by driving the transmitter at levels such that the ALC does not function. That can be done by using a speech processor that gives a nearly constant RF level, in combination with an external DC voltage applied to the ALC input that reduces the transmitter gain to a level where the ALC does not vary at all. The loss in power from the exciter is very small, typically less than 3 dB, and a good external power amplifier can compensate for that without generating interference.

The problems identified in 2005 still remain, but this article now highlights a different source of band pollution from transmitters, namely sideband noise. Unlike the intermittent splatter and key clicks, sideband noise may be present whenever the transmitter is active (even with no modulation) and this continuous interference can create an even more difficult problem for other band users. **Table 1** shows performance data from Product Reviews in *QST* in the years 2008 to 2012, supplemented by receiver measurements from Sherwood Engineering [4].

The ARRL Laboratory measures reciprocal mixing on the receiver as well as the phase noise of a transmitted carrier. It is commonly assumed that these two quantities are closely related because the receiver and transmitter share the same Local Oscillator which is believed to be the major source of sideband noise; but that is not automatically true. Depending on how well the transmitter is designed, amplitude noise on the transmitted signals can also be important [5].

In Table 1, the **Rx@20kHz** and **Tx@20kHz** columns show the receiver reciprocal mixing performance and the transmitter phase noise at an offset of 20 kHz from the carrier frequency (dB below carrier level in ARRL's standard reference bandwidth of 500 Hz). As stated above, the **Rx** and **Tx** figures should ideally be very similar, but the **Diff** (= difference) column shows that often they are not. A negative figure indicates that the receiver dynamic range for reciprocal mixing is poorer than the sideband noise suppression of the transmitter; a positive **Diff** figure indicates that the transmitter is the better of the two.

The final column of Table 1 shows the main focus of this article: **Tx Wide** is the transmitter noise at wider frequency separations. Comparative performance tables are usually sorted in order of receiver performance [4] but Table 1 is sorted according to the suppression of wideband transmitter noise as shown in the **Tx Wide** column. The best transmitters come first, and the worst examples measured come last.

Model	**QST**	**Rx @20 kHz (-dBc)**	**Tx @20 kHz (-dBc)**	**Diff (dB)**	**Tx Wide (-dBc)**
K3	Jan 09	112 (104)	119	-7	128@100kHz, 120@360kHz
TS-599AT	Aug 11	115 (93)	108	7	112@100kHz
IC-7600	Nov 09	105 (100)	102	3	111@100kHz
IC-7700	Oct 08	109 (105)	108	1	110@100kHz
TS-590S	May 11	120 (104)	106	14	110@100kHz
KX3	Dec 12	120 (105)	97	23	107@100kHz
IC-9100	Apr 12	101	101	0	105@100kHz
FTdx5000	Dec 10	109 (104)	104	5	103@100kHz
FT-950	Mar 08	86 (105)	100	-14	102@100kHz
FTdx9000	Jul 10	114	101	13	100@100kHz
FT-450D	Nov 11	98	85	13	96@100kHz
IC-7200	Jun 09	103	95	8	94@100kHz
Flex-1500	Dec 11	107 (88)	101	6	81@300kHz
Flex-5000A	Jul 08	99 (96)	91	8	77@350kHz

Table 1: Published measurements of transmitter noise and receiver reciprocal mixing. Data are from ARRL Lab measurements [3] (with comparable receiver measurements from Sherwood Engineering where available [4]).

Table 1 shows that while some transmitters have a sideband noise level at 20 kHz that is compatible with their own good receiver performance, some examples have poor reciprocal mixing performance and the transmitter phase noise may be even worse [6]. The difference in the **Tx Wide** column, from the best to the worst, is more than 50 dB! Even more remarkable is that this enormous difference between best and worst passes without comment in the text of the ARRL reviews.

At 100 kHz frequency separation only one transmitter has noise performance that is compatible with good modern receivers. That is the K3 from Elecraft. Otherwise, Table 1 shows that many other amateur transmitters have poorer noise sideband performance than their receivers do. The reason as I see it is that the poorer transmitter performance does not get appropriate attention in the test reports.

Two transceivers stand out as particularly bad. Those are the Flex Radio SDR transmitters. They are different from all the others in that the noise sidebands have a maximum about 300 kHz from the carrier, and that noise is really strong – only about 80 dB below the carrier in 500 Hz bandwidth. Imagine you operate CW at the low end of 144 MHz and suddenly find your noise floor goes up by 10 dB. Tune around and you will find that the noise has a maximum around 144.050 MHz. What would you do? Just feel sorry? It is not easy to detect that the reason is that someone has switched on a Flex transmitter on 144.350 MHz because the noise does not carry that offending station’s modulation, and there is no particular noise near that station’s own frequency. To find out that the noise comes and goes with the Flex transmitter you would need two receivers or a wideband SDR. Yet there is no corresponding problem on the receive side in these transceivers, so the Flex owner has no idea about the interference he is causing.

These findings led me to borrow a Flex-1500 (a Flex-5000 was not available) and make a more detailed study of the problem of transmitter noise.

A study of the Flex-1500 transmitter

Studies of noise sidebands are usually difficult to make with standard spectrum analyzers which use YIG local oscillators at microwave frequencies to sweep a wide frequency range. Those YIG LOs have high levels of close-in sideband noise which will normally mask the sideband noise from an amateur transmitter – but that is not the case with Flex-1500, because the noise sidebands are so high. Figure 1 clearly shows the noise sidebands from the Flex-1500, as seen on a Tektronix 2753P when the Flex-1500 is transmitting 5W through a 20 dB attenuator into the analyzer input.

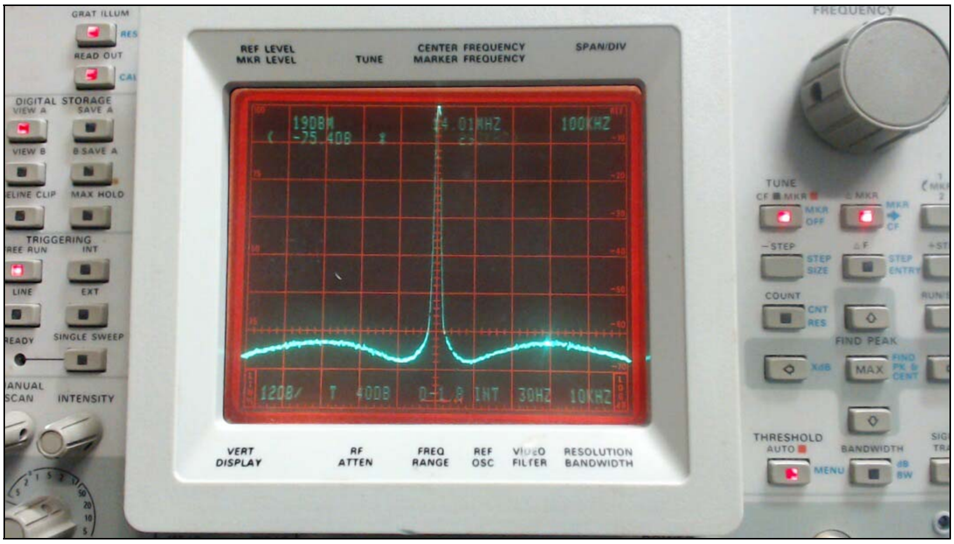

Figure 1: Clearly visible noise sidebands from a Flex-1500 at 5W output.

On-screen markers can just be seen on the peak of the carrier and on the maximum of the upper noise sideband. The measured maximum is -75.4 dBc at +293 kHz, and the lower noise sideband is a mirror image. Analog spectrum analyzers do not have true RMS detectors, which means that the reading on the 2753P is too good by 2.5 dB. The fact that the sideband noise from a carrier is so well visible on this old analog instrument is startling, so Figure 2 provides confirmation from another old analog spectrum analyzer, a HP 8591A. It shows very similar results to the 2753P, -73.8 dBc at +/-305 kHz. I do not know what detector is used in this instrument and whether some further correction should be applied; but the agreement with Figure 1 is clear so I made some further investigations using modern Software Defined Receivers. The 2753P bandwidth in Figure 1 is 10 kHz so the sideband noise level is -113.8 dBc/Hz according to this instrument.

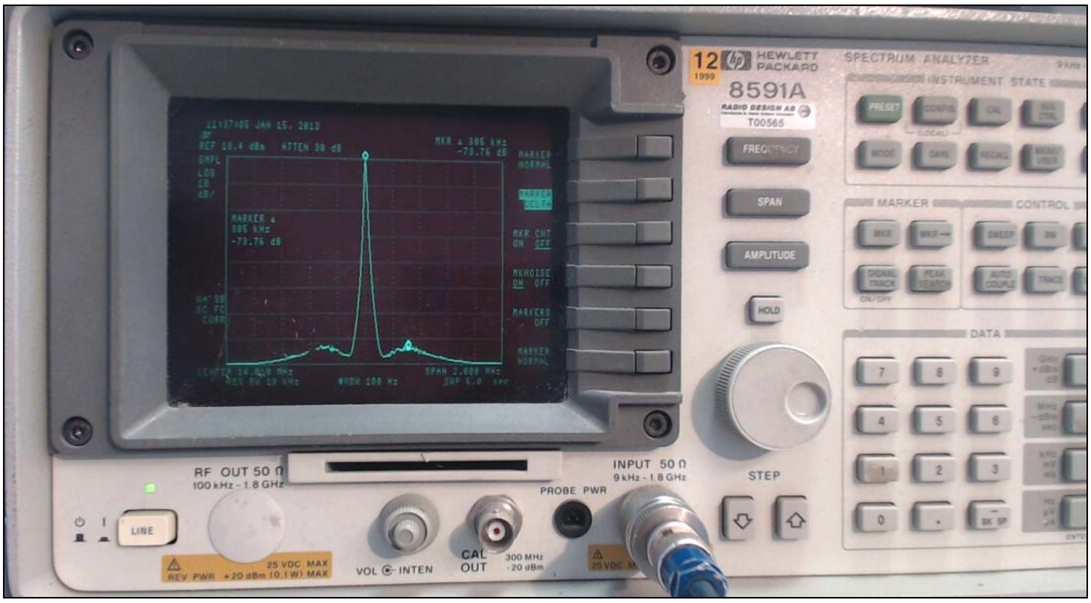

Figure 2: Flex-1500 transmitting a carrier at full power seen on a HP8951A.

Today it is easy to perform more accurate measurements of sideband noise levels with the growing number of high-quality direct sampling SDR receivers. Figures 3 to 5 show the spectrum of the Flex-1500 at full power, 37 dBm (=5W), 27 dBm and 17 dBm. The SDR is the ELAD FDM-S1 and Linrad is used for the display and evaluation. In these figures the signal was first placed within the rectangular 1 kHz wide filter and the S-meter graph calibration was adjusted for the S meter to read 0 dBm at full power. After allowing some time for the S-meter graph to draw a line, the peak of the noise sideband was selected and the noise levels can be read directly from the S-meter graph in dB below full power.

The results demonstrated in the below spectra can be normalized to 1 Hz bandwidth, and is -112 dBc/Hz for this particular example of a Flex-1500. Both the 2753P and ELAD/Linrad agree on that. An even worse result was reported in the *QST* product review, -108 dBc/Hz for the phase noise (or -105 dBc/Hz under the assumption that the AM noise is equally strong). This seems to indicate that the noise level can differ slightly between examples of the Flex-1500 units, but is probably in the region of -110 dBc/Hz.

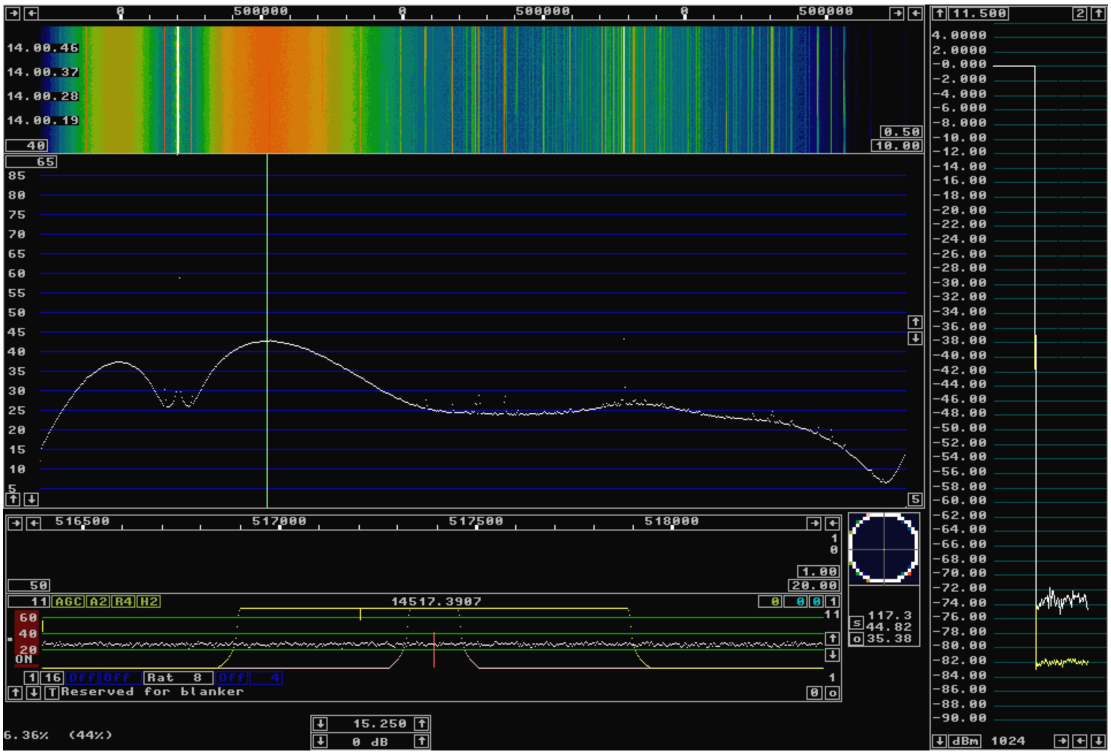

Figure 3: Flex-1500 transmitting a carrier at full power seen with an ELAD FDM-S1. The noise sideband is at -82 dBc in a bandwidth of 1 kHz.

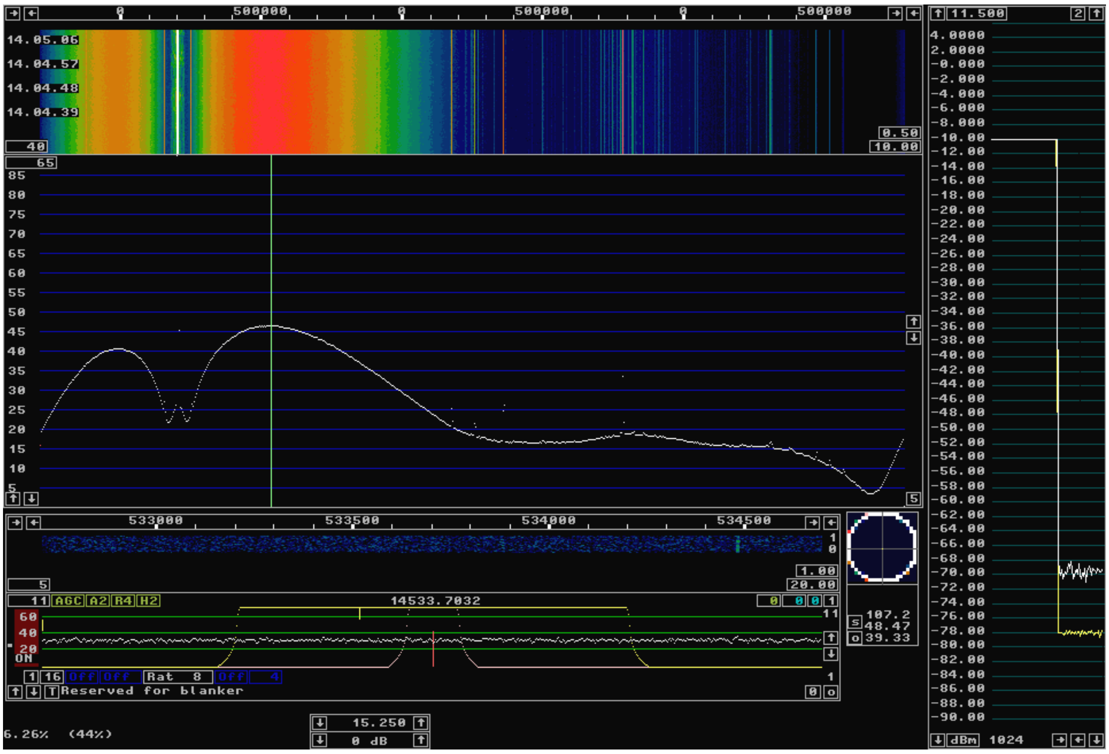

Figure 4: Flex-1500 transmitting a carrier at -10 dB reduced power seen with an ELAD FDM-S1. The noise sideband is at -68 dBc in a bandwidth of 1 kHz.

Figure 5 shows the noise sidebands when the carrier power of the Flex-1500 is reduced by software control to drive a transverter. When the power level is reduced by 20 dB (and assuming that the transverter does not add significant noise of its own) the noise received by another station at an offset of 300 kHz will be 58 dB below the carrier in a bandwidth of 1 kHz, or 54 dB below the carrier in a SSB bandwidth of 2.4 kHz. One S-point is defined as 6 dB, so a carrier that is 54 dB above the noise will be

S9. But this also means that whenever the carrier from the Flex-1500 is S9 or stronger, its noise sidebands will be increasing the noise floor of other unsuspecting stations who are operating 300 kHz away.

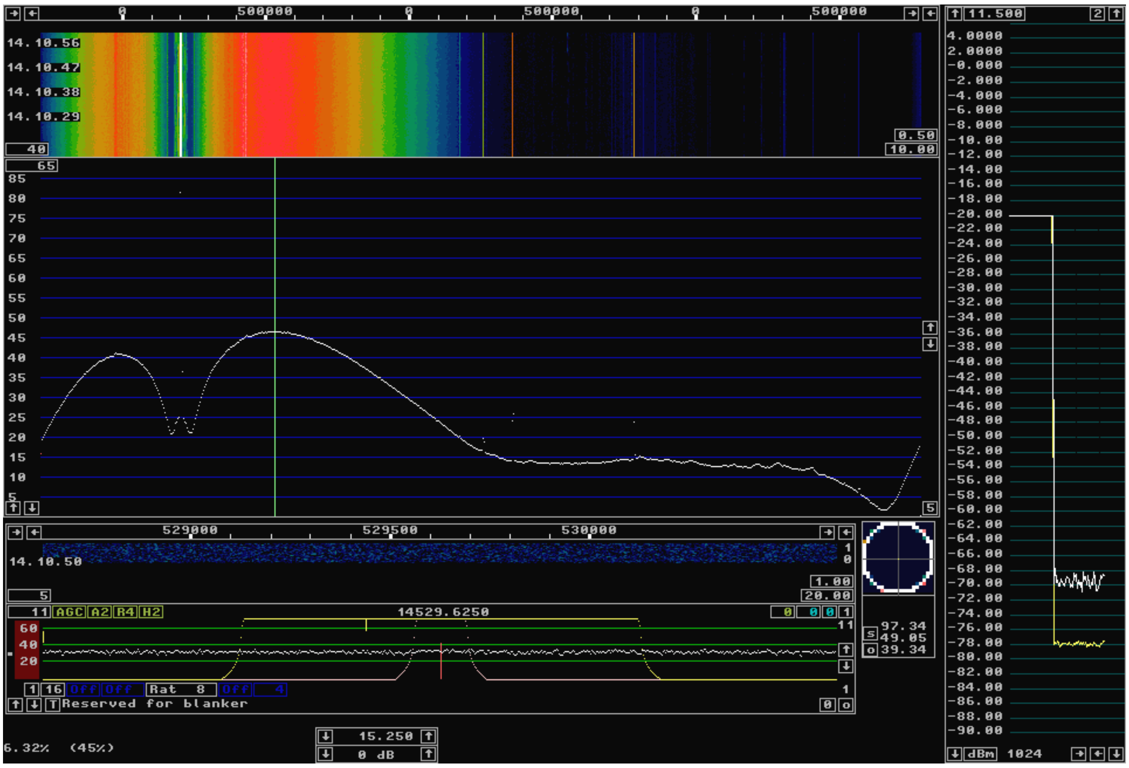

Figure 5: Flex-1500 transmitting a carrier at -20 dB reduced power seen with an ELAD FDM-S1. The noise sideband is at -58 dBc in a bandwidth of 1 kHz.

A significant improvement for other band users is possible if the low-level transverter drive is obtained by operating the Flex-1500 at full power, followed by an attenuator to reach the required power level. If a 20 dB attenuator is used, the carrier level would then need to be 24 dB above S9 before the 300 kHz noise sidebands would increase the noise floor of other stations by 3 dB. That would be helpful to other band users; but S9 + 24 dB is quite a normal signal level so even this improved method would not always be sufficient. The practical conclusion is this: to avoid the risk of raising the noise floor for other amateurs, the Flex-1500 transmitter should not be used in *any* circumstances where it could deliver very strong signals into someone else's receiver.

I find it highly inappropriate that the ARRL reviewer chose to characterize that level of performance like this: "Overall, the composite noise output as shown in Figure 3 is low" (*QST*, December 2011). In my opinion – and I am confident that many others will agree – those noise sidebands are unacceptably high because they will cause significant levels of interference to other band users who may not even suspect it. This applies above all when a Flex-1500 is used to drive a transverter for the VHF, UHF or microwave bands.

Details of the Flex-1500 transmitter

In the architecture of the Flex-1500, the transmitter uses a DDS to generate a LO signal close to the desired transmit frequency. Two audio signals are shifted by 90° with respect to each other and are mixed with this LO to generate a signal at the desired RF frequency. (There is also some LO leak through and a mirror image, but since the audio frequency is low those signals fall close to the main signal and do not normally present an interference problem to other band users.)

The observed noise sidebands are at a far higher level than would be expected from the DDS device used. Their origin has been traced to the device that supplies the modulating audio signals, a TLV320AIC33IRGZ audio codec from Texas Instruments. This device has 10 inputs and 7 outputs, and uses a delta-sigma DAC which generates the observed levels of high frequency noise. Figures 6 and 7 show the signal on one of the output pins on the codec while the unit is transmitting a carrier at full power with the pitch frequency set to 600 Hz. Similar signals are present on all the audio output pins.

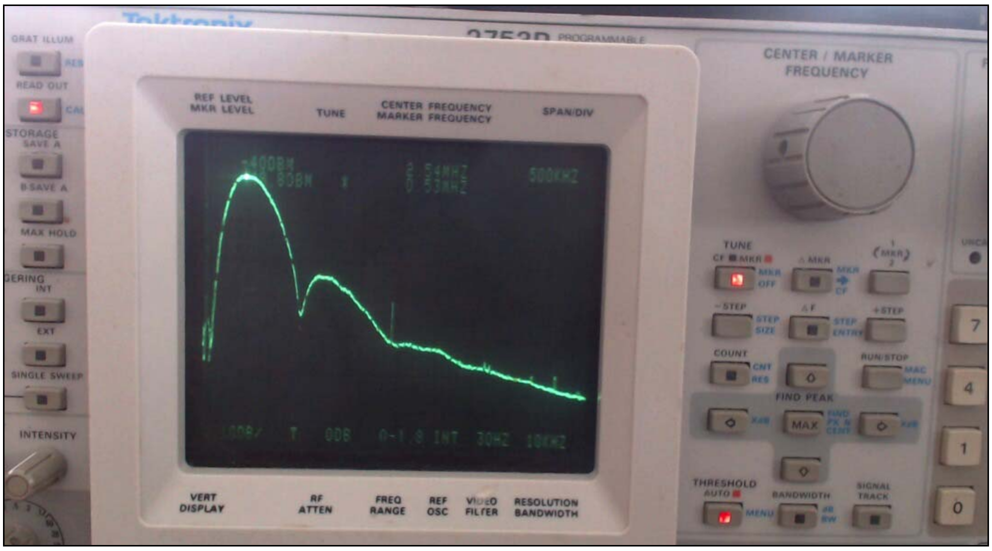

Figure 6: Spectrum of the signal on one of the audio output pins on the codec (all other output pins are similar).

Maximum noise in Figures 6 and 7 is at 530 kHz, directly at the output pins of the codec, but this spectrum is then modified by a 28 kHz low pass filter between the codec and the transmit mixer. The filter has two series connected RC links with two 12.7 Ω resistors and a 0.15 µF capacitor each. The attenuation might be 20 dB at 300 kHz (depending on source and load impedances) so the filter shifts the noise peak downward from 530 kHz to about 300 kHz, which is what was observed on the RF signals. Each DAC has a negative and a positive output and the filter only attenuates the differential voltage.

The attenuation needs to be made at least 20 dB larger than it is now, and filters to ground are probably needed in both lines for each DAC to deal with the common-mode issue. It would be possible to remove the existing low pass filter and replace it with a better designed filter on a small PC board. The cut-off could be lower than 28 kHz. The widest mode is NBFM which should be limited to 12 kHz so a bandwidth of 14 kHz should be appropriate on the Tx side.

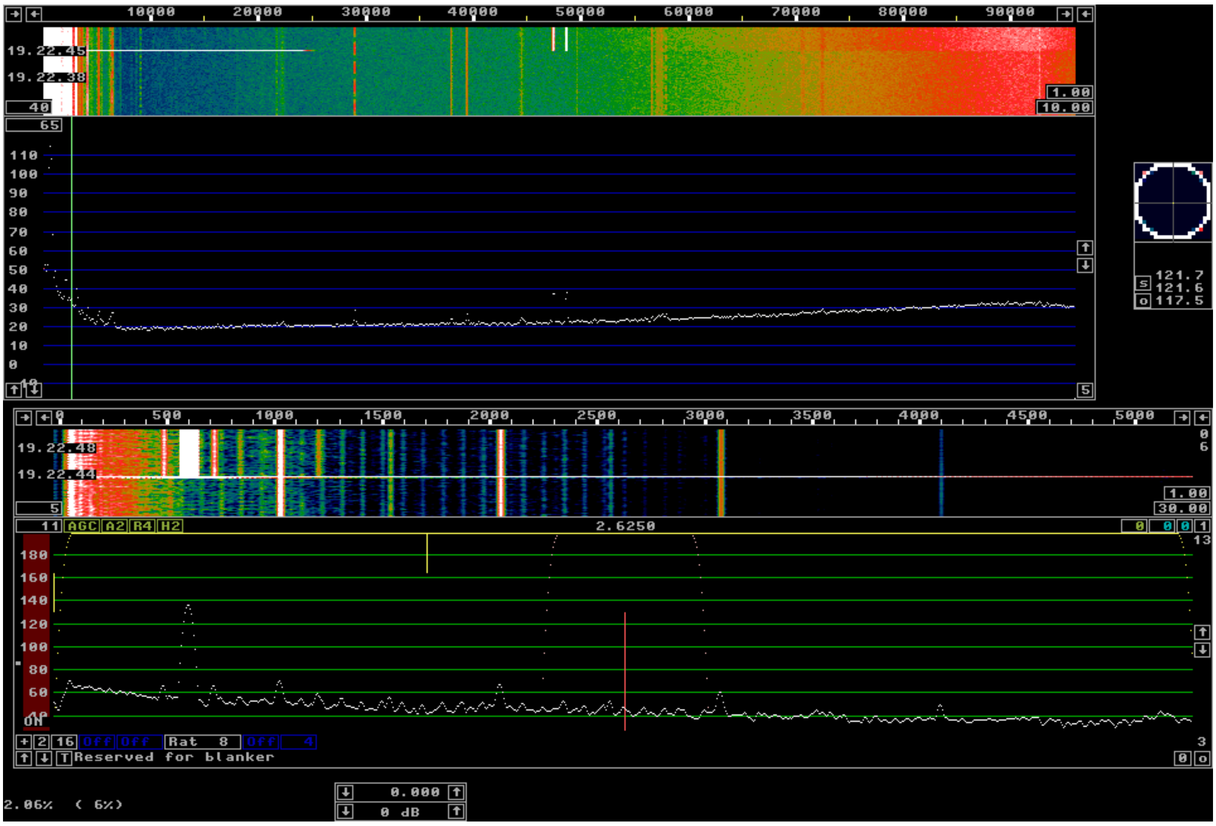

Figure 7: The same signal as in Figure 6, seen in Linrad with a soundcard sampling at 192 kHz. The upper part of the screen displays the full 96 kHz bandwidth while the lower part displays the range 0 to 5 kHz at a much higher resolution.

The signal on the output pins of the codec as seen on an oscilloscope is shown in Figures 8 and 9 where the drive levels are set to 0 and 100 respectively. One can see from these figures that the total noise power is very significant, only about 15 dB below the carrier power on the DAC output pins. The 2753P spectrum analyzer shows that the power in 10 MHz bandwidth is +17.6 dBm at drive level 100, while at drive level zero the power is -33 dBm (about 50% of which is carrier leak-through).

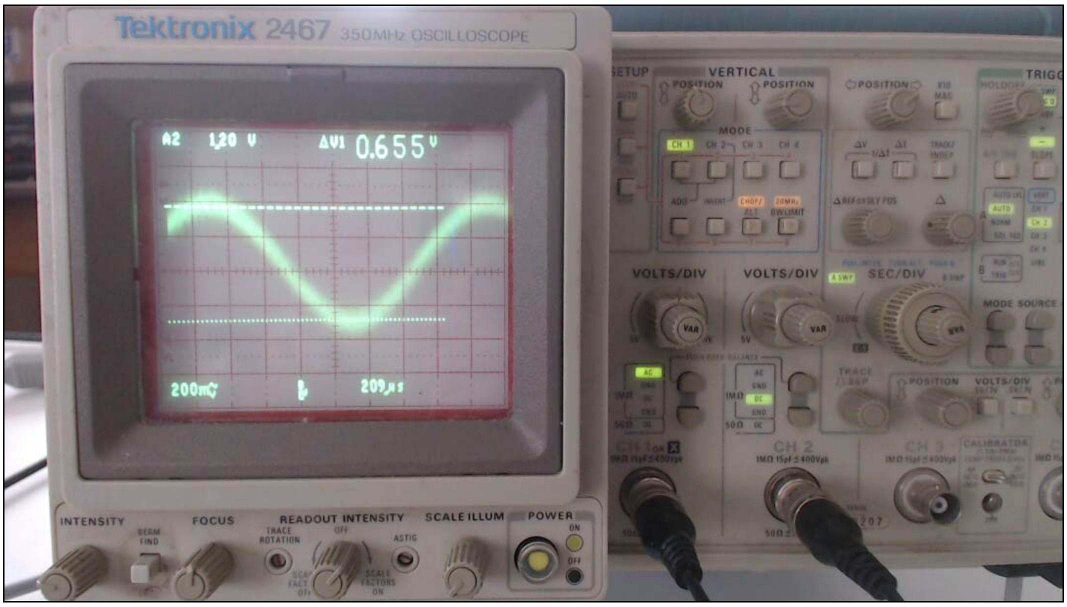

Figure 8: The signal on one of the audio output pins on the codec as seen with an oscilloscope. The total noise power is only about -15 dBc.

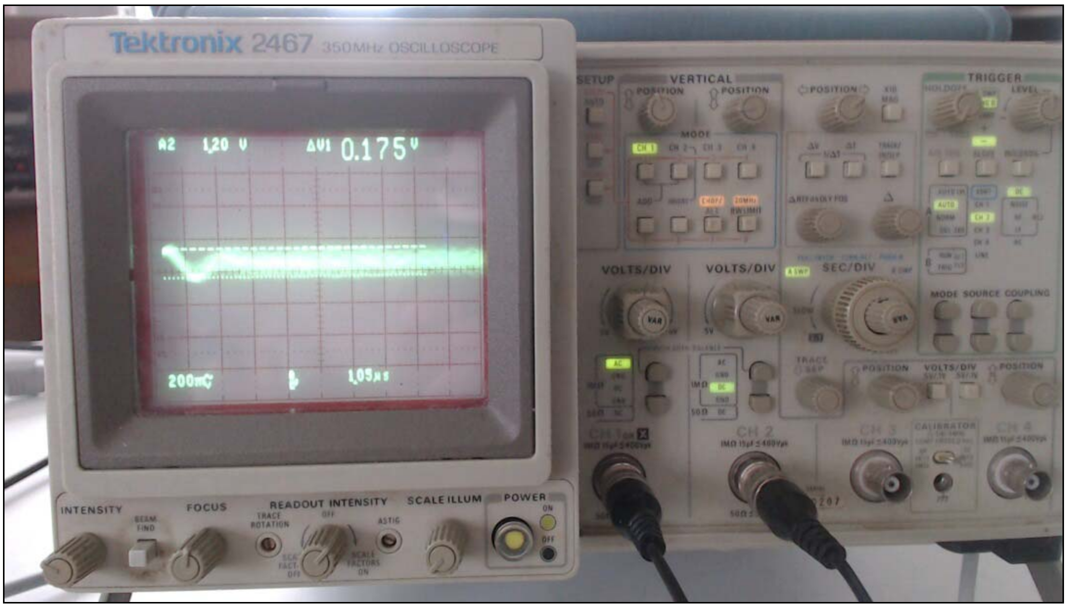

Figure 9: The signal on one of the audio output pins on the codec as seen with an oscilloscope. The drive level is set to 0. The noise voltage is in the order of 100 mV.

For the record, there is also a second pair of noise sidebands at 1.6 MHz above and below the carrier. At full power the 1.6 MHz noise sidebands are about 17 dB below the noise sidebands at 300 kHz (Figure 3) so they are about -99 dBc in 1 kHz bandwidth. However, these 1.6 MHz noise sidebands have a different cause: unlike the 300 kHz AM sidebands coming from the DAC, the 1.6 MHz sidebands follow the amplitude of the carrier, which demonstrates that they are coming from the LO. The LO chip used in the Flex-1500 is capable of much better performance than that, so this is probably a layout problem.

Conclusions

Modern transceivers have an absurd un-balance between receiver and transmitter performance. There are obvious problems with bad ALC design [1 or 2] but transmitter problems also occur for other reasons.

Of the transmitters that have been tested in *QST* in recent years, all but one suffer from excessive sideband noise when transmitting an unmodulated carrier, when compared against reciprocal mixing in their own receivers. This is the reason why inter-station interference today is almost always caused by problems in transmitters, as distinct from receiver overload.

The one transmitter that has been found to have satisfactory noise performance is the K3, which is fine up to a separation of about 250 kHz (although even the K3 suffers from a modest noise peak at about 360 kHz separation, and I am pretty sure that could be fixed easily if someone had paid attention to it in the design stage). But that is a minor detail, because at the same frequency separation the sideband noise from the Flex-1500 is 43 dB worse. Consider what 43 dB means: it is the difference between 50 mW and 1 kW! I think we should expect the test reports to tell us about difference of that magnitude between competing products, and to state clearly that such poor levels of sideband noise are incompatible with modern receiver performance. It should also have been clearly identified that these Flex transmitters are unsuitable for use with transverters for the VHF, UHF and microwave bands because of the higher demands on dynamic range on those bands.

Testing transmitter sideband noise has become very easy in recent years. The ELAD FDM-S1 was chosen for the tests in this article because it allows more bandwidth than any other SDR at my disposal; it is a budget SDR for less than US$ 600 and yet the dynamic range at 100 kHz is 108 dB (in a 500 Hz bandwidth) so it can see the offending sideband noise very well. More expensive direct sampling receivers are about 18 dB better. There are several models available to amateurs from different manufacturers.

I am sure that transceiver manufacturers can drastically improve their transmitters without increasing the production cost. The expensive parts for generating good LO signals are already fine, as we can see from the good performance on the receive side, so the only missing part is *attention* to the transmitter at the design stage. Somebody *must* have seen those noise sidebands at -75 dBc... but did nothing about it. If manufacturers could be convinced that better transmitters would help to gain market share, then I am sure they would invest in learning how to avoid these rather obvious design mistakes.

I also believe that product testing and reviews need a major change, because they are complicit in this problem. Comprehensive tables of measurement data are published, but the large majority of amateurs rely on the *text* of the review for guidance; and guidance about unacceptable transmitter performance is notably missing. However, product reviews are an area where ordinary radio amateurs can have an influence, because most of these reviews are carried out by National Societies (notably ARRL, RSGB and DARC) on behalf of their members. What is missing here is recognition that equipment reviews are not only for people who might buy the transceiver in question; a National Society has a responsibility to all of its members, including “the rest of us” who have to listen to those transmitters on the air.

With a good SDR (Perseus, QS1R, Excalibur, SDR-IP and others) it is very easy to measure the composite sideband noise that includes AM as well as phase noise. When thousands of amateurs already own such receivers, it is unacceptable that the test laboratories are not also using them to make those measurements. Perhaps if all of those SDR owners used them more, to check interference levels and to share their results and screen captures on the Internet, that too might help to bring more focus on the problem.

The only decent transmitter in Table 1 is the K3. The reason the other ones are so much poorer is that the test reports, by their silence, are effectively telling the manufacturers that “nobody cares”. I hope this will change.

References and notes

[1] Leif Asbrink, SM5BSZ - Real life dynamic range of Modern Amateur Transceivers, DUBUS 2/2005

[2] http://www.sm5bsz.com/dynrange/dubus205/dubus205.htm

[3] For ARRL members only: http://www.arrl.org/product-review

[4] http://www.sherweng.com/table.html

[5] The transmitter “composite noise” published by ARRL is actually the phase noise only. It is called “composite noise” because in the past the measurement was made with another method that included amplitude noise as well as phase noise. ARRL kept the original name to avoid confusion, assuming that amplitude noise is always negligible. However, this article clearly shows how that assumption can be false at large frequency offsets from the carrier. Sometimes it can be false at closer offsets as well – for

example, noise on the ALC feedback signal would create pure AM noise on the carrier.

[6] All of the measurements in Table 1 probably have quite large uncertainty bands, partly due to measurement errors but most often due to production spreads between different examples of the same model. This is why the Sherwood Engineering data [4] do not always agree with the ARRL data for the same transceivers, although there is no consistent pattern of differences.

Large positive values in the **Diff** column mean that the LO phase noise is not the dominant cause for the transmitter noise sidebands. In those cases, the noise is probably produced in amplifiers that work at too low signal levels or have too high a noise figure. This is white noise which is uncorrelated to the carrier. When detecting it as modulation one would find that the AM noise has the same level as the phase noise, so the true composite noise is 3 dB stronger than the value reported by the ARRL Lab which only includes phase noise.
