It's Time to Clean Up our Transmitters

Rob Sherwood, NC0B

Transceiver performance is of interest to most amateurs, but we tend to focus primarily on our receivers and largely ignore the performance of our transmitters — beyond measuring their output power, of course.

But there is more to consider than a transmitter's output power level. We must concern ourselves with the *cleanliness* of the output because it affects everyone else who shares the spectrum with us. "Dirty" output is a serious problem, and it is getting worse.

You would think that technological advancements would have resulted in progressively better transmit signals, but you'd be wrong. For more than 10 years, I've seen significant improvements in many aspects of receive performance, but at the same time, the quality of transmitted signals has, in many cases, *degraded.*

Three important factors can cause your transmitted signal to become unacceptably dirty: odd-order intermodulation (splatter), CW keying sidebands (key clicks), and broadband transmitted noise.

Broadband Transmitted Noise

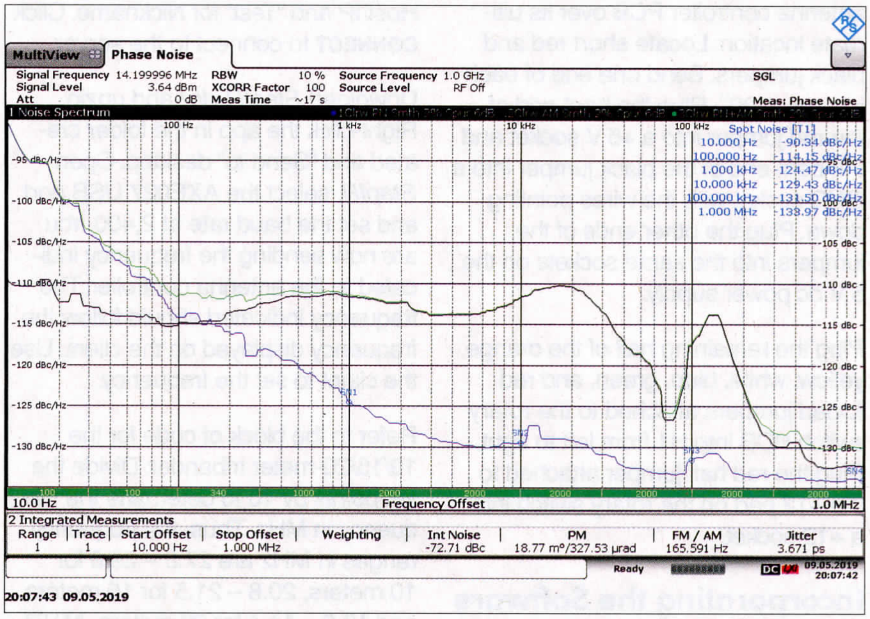
Broadband transmitted noise isn't often noticed until you have a situation where two stations are physically close. The problem tends to manifest on the higher HF bands as well as VHF. Transmitted noise from nearby hams on 17 through 6 meters is more likely to cause interference than on the 160- through 40-meter bands due to differences in band noise.

Broadband transmitted noise was not much of an issue in the days before synthesized radios, when ham equipment had a VFO or PTO and individual band crystals. When frequency synthesis appeared on the scene, *phase noise* reared its ugly head and was significant on both receive and transmit. Over the following decades, the phase noise problem slowly diminished.

Noise transmitted by other stations can seriously degrade your receive performance.

Noise in the receive or transmit chain is more complex than just phase noise, however. The other type of noise is *amplitude noise* (AM noise), which has received almost no discussion in transceiver evaluations. While Reciprocal Mixing Dynamic Range (RMDR) may be predominantly phase-noise related, transmit noise can be dominated by AM noise, which isn't measured at all with most phase-noise measuring test equipment.

When we are operating in a strong-signal environment, it doesn't matter whether noise is phase or AM; the *total noise* is most important. Total noise is defined as *composite noise*, which is what our radios hear on the air, and which may degrade reception. In *QST* Product Reviews,



Signal Frequency 14.199996 MHz
Signal Level 3.64 dBm
Att 0 dB
RBW 10 %
XCORR Factor 100
Meas Time ~17 s
Source Frequency 1.0 GHz
Source Level RF Off
SGL
Meas: Phase Noise

Spot Noise [T1]

10.000 Hz	-90.34 dBc/Hz
100.000 Hz	-114.15 dBc/Hz
1.000 kHz	-124.47 dBc/Hz
10.000 kHz	-129.43 dBc/Hz
100.000 kHz	-131.50 dBc/Hz
1.000 MHz	-133.97 dBc/Hz

2 Integrated Measurements

Range	Trace	Start Offset	Stop Offset	Weighting	Int Noise	PM	FM / AM	Jitter
1	1	10.000 Hz	1.000 MHz		-72.71 dBc	18.77 m°/327.53 µrad	165.591 Hz	3.671 ps

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Figure 1 — A demonstration of composite noise being dominated by AM noise, not phase noise. The blue line is phase noise, the black line is AM noise, and the green line is composite noise. At an offset of 20 kHz, the AM noise completely dominates over phase noise by 19 dB. At an offset between 100 Hz and 200 Hz, the AM noise and phase noise are equal, and as expected the composite noise is 3 dB higher than the individual values. At an offset of around 130 kHz, the composite noise is 17 dB stronger than the phase noise. [Conrad Farlow, PA5Y, photo]

the term "composite noise" has been used interchangeably with "phase noise," and often associated with the published graphical data.

Another aspect of transmitted broadband noise is whether the noise falls off with the offset from the transmit frequency. One Product Review in the April 2013 issue of *QST* demonstrates flat transmitted-noise spectra from 10 kHz to 1 MHz at a mediocre value of –120 dBc. If this transceiver was used at a multistation Field Day site, a CW station on the low end of the band and an SSB station on the high end of the same band would interfere with each other.

Measuring Composite Noise

With the impact of transmitted noise being as significant as receive RMDR, a transmitter needs to be properly tested for true composite noise. The test results in Figure 1 clearly demonstrate a case where composite noise is dominated by AM noise, not phase noise.

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In some *QST* Product Reviews, transmitted noise at 30 W output is sometimes included, as well as noise measurements at 100 W or maximum power output. When considering such measurements, keep in mind that many modern linear amplifiers only require 30 to 40 W of drive, particularly solid-state amplifiers. Unfortunately, transmitted noise is *worse* at reduced power than full output. There was a review in the June 2017 issue that cautioned against using a linear amplifier with that specific transceiver because the broadband noise was so bad.

The image in Figure 1 was produced with a Rohde & Schwarz FSWP analyzer, with the rig operated at 30 W output. The April 2016 *QST* review of the same transceiver used a Rohde & Schwarz analyzer that isn't capable of measuring AM noise or composite noise. In addition, the review only graphed phase noise at 100 W output, not at the more critical 30 W value.

While Rohde & Schwarz or Agilent/Keysight analyzers cost over $100,000, it is possible for interested amateurs to make transmit composite noise measurements for under $1,000 using a Perseus or similar high-performance, direct-sampling software-defined receiver.

Comparing results obtained with high-end test equipment to those obtained with an affordable receiver shows that amateurs can conduct composite noise measurements with an acceptable degree of accuracy. It has been demonstrated that by adding a +17 dBm Mini-Circuits mixer and a low-noise synthesizer (signal generator), the output of HF transceivers that cover 6 meters, and VHF and UHF transceivers, can be down-converted to the frequency range of the Perseus. A Perseus with factory-supplied software can only measure composite noise, not phase noise or AM noise alone, but composite noise is what matters to hams on the air, so it is still a useful exercise.

Key Clicks

The next transmitted noise source is the one we all know as *key clicks.* A key-down CW carrier has very little transmit bandwidth, but once we start sending information on CW, the bandwidth increases dramatically and can cause substantial interference. While there are multiple ways for a transceiver manufacturer to shape a keyed CW signal to prevent this, the user has little control over that parameter other than perhaps adjusting the rise time.

Most rigs today have a menu setting that adjusts CW rise time, but the selections are far too broad. This feature allows the operator to produce terrible key clicks if the rise time is set too fast. If we are trying to copy a weak CW signal, and a strong signal is present 1 kHz away, reception should not be overwhelmed by the transmitted key-click noise of the strong adjacent signal. Of course, when key clicks are in our passband, no amount of selectivity will eliminate the on-channel interference.

Figure 2 shows a spectrum analyzer screen capture of a modern transceiver that has a typical menu rise time

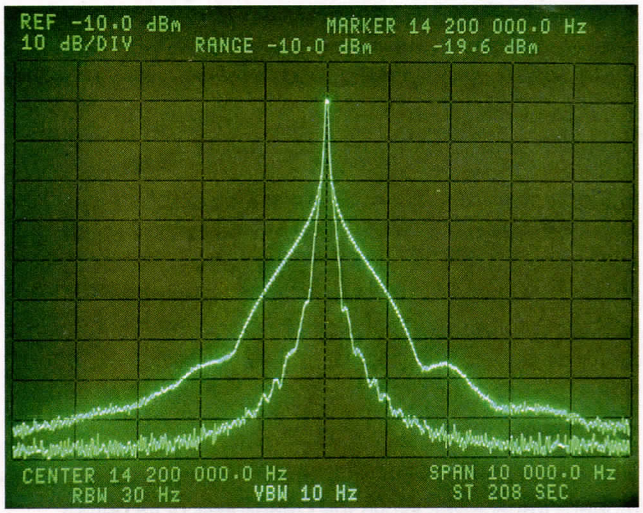

Figure 2 — A spectrum analyzer screen capture of a modern rig that has a typical menu rise time adjustment range from 6 to 1 millisecond.

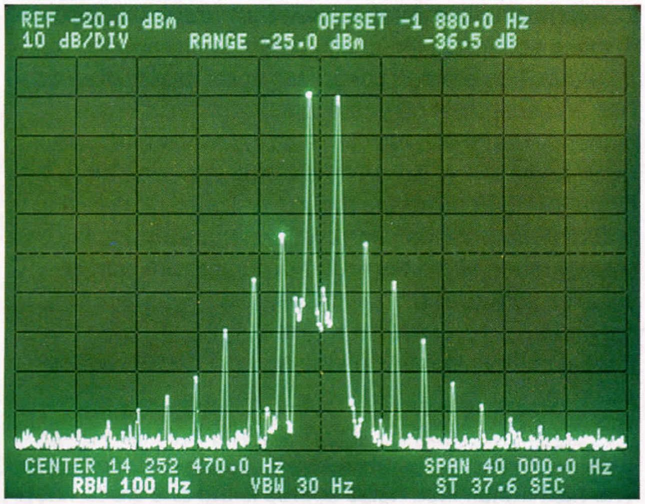

Figure 3 — A classic two-tone intermodulation test of the cleanest transmitter the author has ever owned — a Collins 32S-3.

adjustment range from 6 to 1 millisecond. The upper wide transmission was with a 1-millisecond rise time, while the lower narrow bandwidth was at 6 milliseconds.

At a 1 kHz offset from the two transmissions, the amplitude of the key clicks differs by 25 dB! As amateurs, we should strive to be "good neighbors" and not pollute our airwaves with extraneous key-click noise. The fact that manufacturers allow rise time selections of 1, 2, or 3 milliseconds seems inappropriate from my perspective.

Odd-Order Intermodulation

The final transmitted noise source is odd-order intermodulation (splatter). All transmitters have distortion products caused by non-linearity in their amplifier stages. These distortion products make an SSB signal wider than the nominal 2.1 to 3 kHz transmit bandwidth. How much wider depends on many factors, including poor choices on the part of the operator. Let's hope hams are not operating their speech processors at maximum, or driving their linear amplifiers with 100 W when they require only 50 W. But even when we attempt to operate properly, our transceivers still may be working against us.

In Figure 3 you'll see the results of a classic two-tone intermodulation test of the cleanest transmitter I have ever owned: a Collins 32S-3. The measured third-order product is down 36.5 dBc, or 42.5 dB reference PEP according to the way manufacturers and the ARRL Laboratory measure distortion today. The seventh order is down 60 dBc or 66 dB reference PEP. As you can see, this is an extraordinarily clean radio.

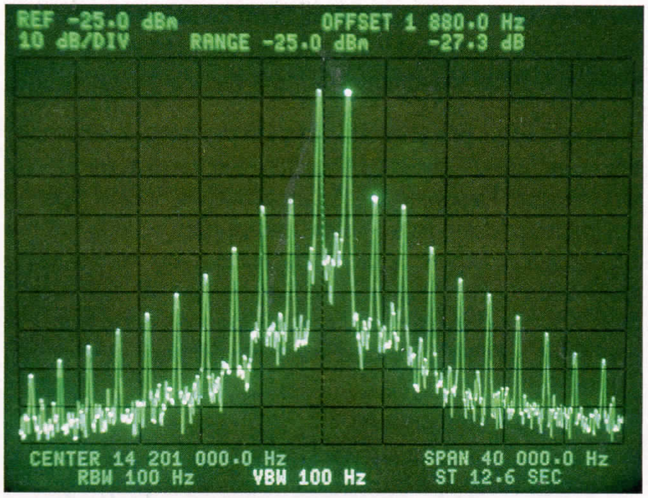

Figure 4 — The transmitted noise profile of a typical modern transceiver. Unfortunately, this was among the better radios; most are worse.

The next example in Figure 4 shows the output of a modern transceiver. While the cleanliness of its output pales in comparison to the Collins, it is at least better than some of its contemporaries. As you can see, instead of the third-order distortion being down 42 dB PEP, this transceiver is down only 33 dB PEP. Looking again at the seventh order, instead of being down 66 dB PEP, it is at 46 dB PEP, which translates to 20 dB more splatter on the band.

Beyond proper operation, we need to do more to reduce the splatter bandwidth of modern rigs. For the individual amateur, the answer is nothing. The solution rests with the manufacturers.

It is certain that transceiver design will never return to 6146A vacuum-tube final amplifiers with negative feedback that allowed the Collins 32S-3 to be so clean. But one step toward a cleaner future is to correctly measure and display this distortion in a way that everyone — including manufacturers — can immediately grasp.

Two-tone tests have been the gold standard for decades, but we don't transmit two tones when we are making a contact, and normal speech isn't easy to repeatedly reproduce and capture on a spectrum analyzer. What we

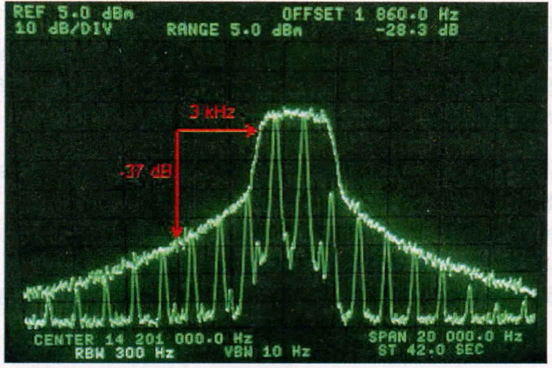

Figure 5 — An example comparing the distortion spectra of two-tones vs. white noise. As you can clearly observe, the odd-order distortion is the same.

can do, however, is feed band-limited white noise into the microphone jack. Figure 5 offers an example comparing the distortion spectra of two tones with the same spectra using white noise. As you can clearly observe, the odd-order distortion is the same.

When using noise as the input signal instead of simply two tones, a monotonic graph is produced. The white noise graph better demonstrates how wide the transmitted signal really is and how much interference it may cause to a station operating 3 kHz away. It clearly demonstrates the problem and provides a reference for those who design and evaluate the transceivers we purchase.

Toward Cleaner Transceivers

Reducing key clicks is straightforward, but manufacturers can better cleanse our transmitted signals of intermodulation distortion and broadband noise. Designing transceiver final amplifiers to operate in Class A is one solution, but it isn't feasible in many instances. A Class A amplifier can produce a very clean output, if the ALC doesn't ruin the signal, but it hasn't been a mainstream option for some time. Much more heat is produced in Class A, so cooling becomes an issue. There have been some reliability problems as well.

When it comes to cleanliness, however, the difference between Class A and typical Class AB or B operation is dramatic. I have seen one case in which splatter was down 60 dB at 6 kHz offset from the edge of a transmitted signal versus the same suppression at 1.5 kHz from the transmitting signal in a Class A transmission. I have also operated a Class A rig with no ALC and no speech processing driving a very clean linear amplifier that used a pair of 3CX800 tubes. During one conversation, a station broke in and said I had the cleanest signal he had ever seen on his spectrum scope. Hams who had the pleasure of talking to the late Pete Gaddie, W6XX, also know how clean — but powerful — his signal was.

Predistortion could also offer a solution. This is a way of dynamically correcting gain and phase distortions, or cancelling intermodulation products, before they are amplified. It is achieved by introducing "inverse distortion" (a kind of inverted feedback) at the input of the amplifier, cancelling any non-linearity the amplifier might have.

Promising as it may be, predistortion is used in only one amateur transceiver at the time of this writing, although other manufacturers have indicated that they are also investigating this approach. It is encouraging to see that many solid-state linear amplifiers that have come to market in the last few years have a sampler output that can connect to a transceiver to include the external amplifier in a predistortion correction loop.

ARRL published a compendium of distortion products of linear amplifiers in 1997, and every amp in the list had third-order distortion between 40 and 50 dB PEP. A 2019 review of a typical solid-state legal-limit linear amplifier reported third-order distortion only down by 30 dB, a 10 to 20 dB degradation compared to past performance. If all solid-state amps of today could include predistortion correction, a legal-limit SSB signal could be as clean as it was more than 20 years ago.

We Can Do Better

All amateurs could benefit if a typical SSB signal was only 5 kHz wide at –60 dB instead of 15 kHz wide. Transmitted intermodulation splatter is noise we don't need.

Today, the receive performance of top-of-the-line transceivers is outstanding. A close-in 2 kHz dynamic range over 95 dB is common, and some boast dynamic range figures of 110 dB. RMDR values of 105 to 125 dB are no longer unusual.

But this superb reception performance can be effectively crippled by a nearby signal that is dumping interference into the receiver's passband. This interference may be composite noise, key clicks, or odd-order intermodulation splatter. Regardless of the type, the receiver performance you hoped for and likely paid a substantial amount of money to enjoy is being shortchanged.

Transceiver receive performance today is excellent, so the next order of business should be to make a concerted effort to improve the transmit side of the equation. The Amateur Radio community deserves nothing less.

Rob Sherwood, NC0B, became a Novice in 1961 and soon upgraded to General. After graduating college in 1969 with a degree in physics, he moved to Denver to work as an engineer at KOA radio until 1987.

In 1976, he started measuring receiver performance on dozens of radios, because reviews in *QST* did not correlate with actual on-air observations at crunch time in CW contests. Receiver test data is now web based, with over 100 transceivers included at **www.nc0b.com/table.html**.

His most recent project has been making contacts on the new 630-meter band. He currently holds the world distance record on 475 kHz of over 8,000 miles between Colorado and Australia.

You can contact Rob at **nc0b@arrl.net**.

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