Rig TX and RX Performance and Field Day Inter-Station Interference

References on Field Day inter-station interference discuss issues with TX and RX key performance metrics for transceivers. These key metrics for rigs that are especially relevant for Field Day inter-station interference include: TX phase noise (or amplifier noise or just TX noise) and RX blocking. Other important metrics include: RMDR or Reciprocal Mixing Dynamic Range and 500 Hz RX noise floor and more.

The ARRL QST Magazine has published test results for the major commercially available rigs for many years. The test procedures can be found here: http://www.arrl.org/files/file/Technology/Procedure%20Manual%202011%20with%20page%20breaks.pdf. The test results for each rig can be found in QST Magazine articles, but many have been made available directly by the equipment manufacturers with permission from the ARRL. These results were used to compile the measurements listed in the table below for a number of Yaesu, Icom, Kenwood and Flex rigs as of April 2020. The top-line rigs are included to establish best in class performance, but also the most common and reasonably priced rigs are included.

rig / key metrics	noise at 100 KHz	noise at 20 KHz	blocking preamp Off/1/2	RMDR 20/5/2 KHz	500 Hz RX noise floor
Yaesu FT-950 (not in production)	(-) 127 dBc	(-) 126 dBc	128/127/127	86/69/57 dB	(-) 137 dBm
Yaesu FT-991A ($1070 on sale)	(-) 128 dBc	(-) 126 dBc	133/135/133	103/85/75 dB	(-) 143 dBm
Yaesu FTDX101D ($3250 on sale)	(-) 152 dBc	(-) 152 dBc	135/144/146	130/128/125 dB	(-) 138 dBm
Yaesu FTDX5000MP ($3710 on sale)	(-) 130 dBc	(-) 132 dBc	130/133/128	109/101/94 dB	(-) 142 dBm
Yaesu FTDX9000 (not in prod)		(-) 138 dBc	138/137		(-) 134 dBm
Kenwood TS-2000 (not in production)		(-) 131 dBc	126/121 dB		(-) 137 dBm
Kenwood TS-590SG ($1255 on sale)	(-) 139 dBc	(-) 133 dBc	139/134 dB	118/106/94 dB	(-) 139 dBm
Kenwood TS-990S ($6500 on sale)	(-) 140 dBc	(-) 136 dBc	138/143 dB	117/105/94 dB	(-) 137 dBm
ICOM 7300 ($900 on sale)	(-) 137 dBc	(-) 135 dBc	123/118/116	114/107/101 dB	(-) 143 dBm
ICOM-7610 ($2900 on sale)	(-) 146 dBc	(-) 141 dBc	120/117/113	127/116/113 dB	(-) 142 dBm
ICOM-7851 ($11,000)	(-) 146 dBc	(-) 145 dBc	131/144/142	125/119/114 dB	(-) 139 dBm
Flex 6300/6700	(-) 150 dBc	(-) 145 dBc	127/127	121/117/116	(-)136 dBm
Elecraft K3 (not in production)	(-) 156 dBc	(-) 145 dBc	139/134	114/106/96	(-) 137 dBm

** All measurements at 14 MHz

Several things stand out from the key performance metrics. Recent vintage Yaesu rigs have been weak on TX noise with the exception of the FTDX101D and MP which are very new. Recent vintage rigs with full-band or "true" SDR are more prone to RX blocking issues than rigs with traditional superhet architectures or hybrid SDR architecture, especially the ICOM 7300/7610, but the Flex series 6000 rigs do a fair to good job on blocking performance. For best in class RX blocking performance, rigs like the ICOM 7581, Yaesu FTDX101D and Kenwood TS-990S use a traditional superhet architecture with narrowband roofing filters in a 1st IF. These high-end rigs also include high performance narrowband preselectors at the front end (which may be optionally bypassed/enabled) similar to the preselectors on old tube rigs but with automatic tuning. The high-end ICOM and Kenwood rigs use a digital preselector while the Yaesu rigs with preselectors use an actual physically variable capacitor to avoid tuning discontinuities like an old tube rig, except with automated tuning via a step motor controlled by the rig's processors. Older rigs like the Kenwood TS-2000 do a fair job, especially for their vintage, but have limitations relative to high performance recent vintage rigs. The Elecraft K3 was introduced back in 2008 and provided excellent TX noise and RX performance which is still very good and near best in class even today. It was a high end rig in the $4000 price class, and has been used for a number of years by top Field Day clubs like W3AO. See these links:

http://k9yc.com/TXNoise.pdf

https://www.kkn.net/dayton2009/W3AO_2009.pdf

Recently (2019) Elecraft introduced the K4 which uses a direct sampling SDR RX, but a QST review is not yet released. So far, hybrid SDR RX architecture has provided the best RX performance, especially for blocking and it will be interesting to see the measured performance results for the K4.

Also recently (2020) Yaesu introduced the FTDX10 based on FTDX101D TX and RX technology in the $1700 price class. It does not have the preselector feature provided in the FTDX101D and only has a single RX, but the TX noise and the RX blocking, RMD and sensitivity should be very close. If the key TX and RX performance metrics match the FTDX101D, it will provide a low cost option for good performance for Field Day operation on the same band for CW, phone and digital operations.

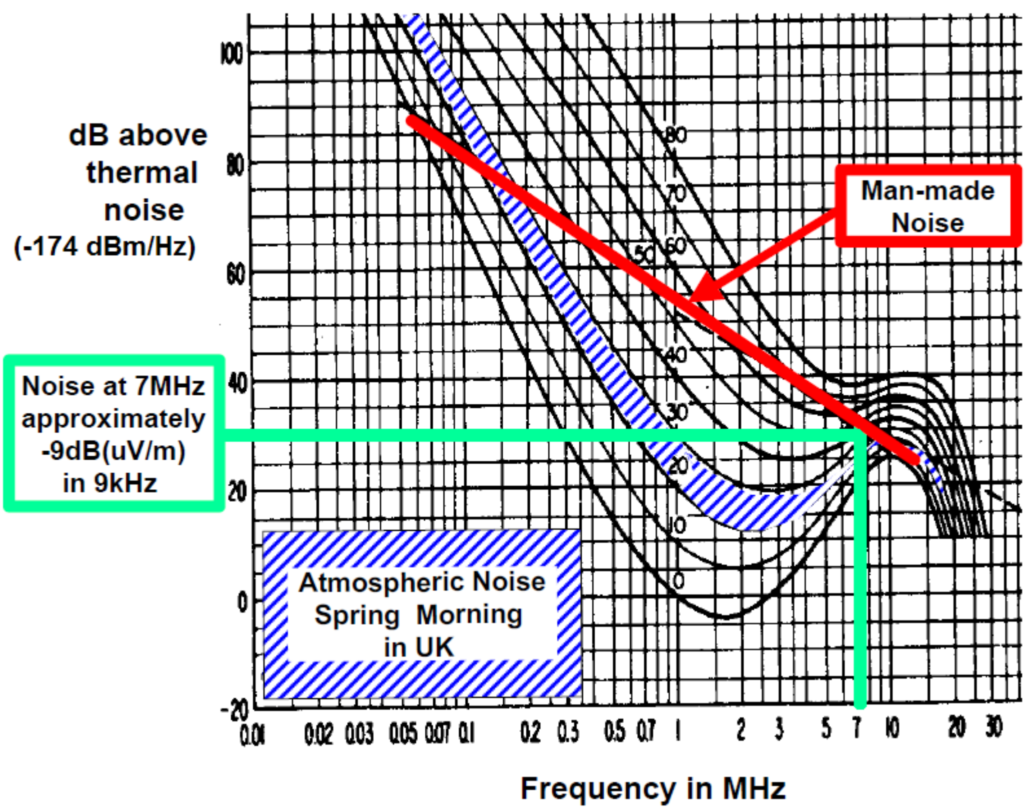
For the best performance for Field Day inter-station interference, the Yaesu FTDX101D and ICOM-7851 both provide outstanding TX noise and RX blocking performance. The Kenwood TS-990S is good also, but the TX noise is a bit inferior to the high-end Yaesu, Kenwood and Flex rigs. The Flex 6000 series rigs have very good TX noise performance, but the RX blocking performance is only fair/good. The Yaesu FTDX101D and ICOM-7851 rigs are both high-end rigs although the ICOM-7851 is in the $11,000 price class and the Yaesu FTDX101D is in the $4000 price class. But the Kenwood TS-590SG is a good option for a reasonable price in the $1500 range. The low-end Yaesu and ICOM rigs are generally great radios, but have weaker performance for TX purity and RX robustness. The weaknesses in TX and RX performance will usually not be an issue for ham radio operators, but for Field Day inter-station interference or multi-multi contest stations, the inter-station interference performance may be an issue, especially if simultaneous operation in the same band is planned in different modes with frequency separations only on the order of 20 KHz to several 100 KHz. The K3 still provides excellent performance and is a good option even today although it is no longer in production, and the lastest rigs such as the K4 and FTDX10 may be good options for new rigs.

As of 2020, the Kenwood TS-590SG provides good performance in its price class regarding inter-station interference, but better performance is possible, and the Yaesu FTDX10 now probably provides better

TX noise and RX blocking in that price class. The Flex 6000 series provides very good TX noise performance but its RX blocking performance is only good/fair. For top TX noise and RX blocking performance, the ICOM 7581 or Yaesu FTDX101D both show excellent TX noise and RX blocking performance.

Considering TX noise, a few examples would be enlightening. For the FT-950 with TX noise at -127 dBc with 100 KHz offset on 20 meters, the problem of inter-station interference may be significant. When transmitting CW at 100 watts of RF power or +50 dBm, and in an RX bandwidth of 500 Hz (+27 dB), then the transmitted power in a 500 Hz bandwidth offset by 100 KHz from the CW carrier is -50 dBm (+50 dBm carrier power -127 dBc + 27 dB for 500 Hz BW). Considering a noise floor in 500 Hz for a good receiver of -140 dBm (this corresponds to a noise figure of about 7 dB), then 90 dB of isolation is needed to bring the TX noise down to the level of the RX front end noise. However, data provided by the CCIR (see the figure below from Wikipedia) shows that atmospheric noise or the level of noise heard with a 0 dB gain antenna is typically 30 dB above the thermal noise floor, so an isolation of only about 67 dB is needed to bring the TX noise down to the level of the typical atmospheric noise.

For example, considering a Yaesu FTDX101D with TX noise at -152 dBc, 42 dB of antenna isolation would be needed to bring TX noise down to the level of the atmospheric noise on 20 meters. With only 42 dB of antenna isolation, RX front end blocking may be challenging since the RX front end would see +8 dBm inter-station interference signals given 100 watts of TX power or +50 dBm. Clearly the TX noise performance is a major benefit with the FTDX101D for inter-station interference and requirements on antenna isolation, but RX blocking and other possible issues must still be considered separately.

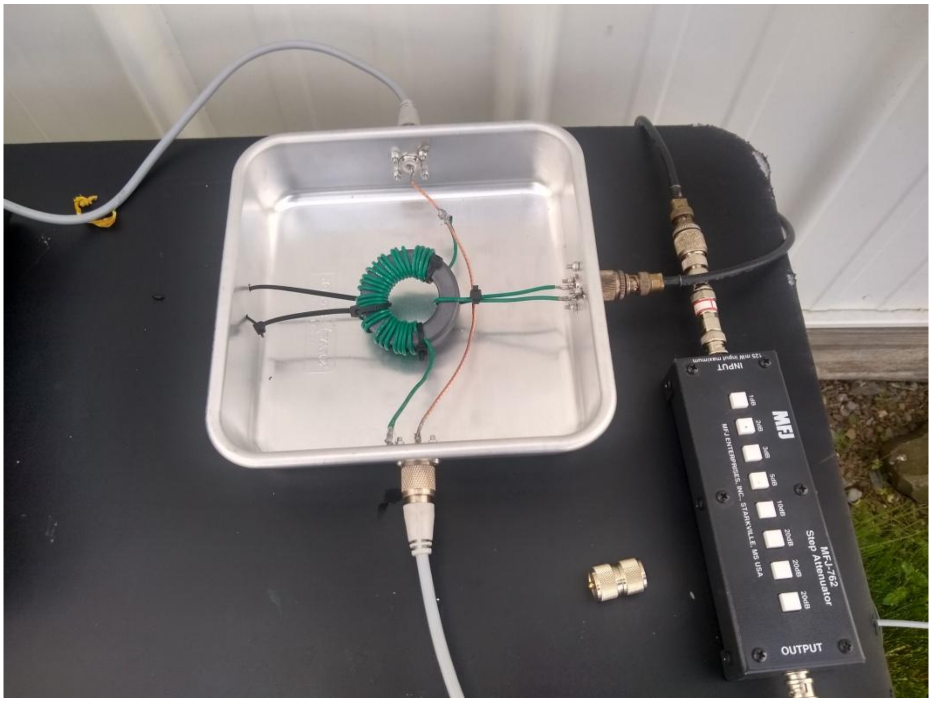


https://en.wikipedia.org/wiki/Atmospheric_noise

Antenna isolation testing with a Yaesu FT-991A and a Yaesu FTDX101D Transmitter

The ARRL lab test for TX phase noise requires an expensive dedicated setup. A high performance spectrum analyzer is not adequate. The problem is that the TX phase noise must be measured in the presence of the very strong TX signal and the required dynamic range exceeds that of even high quality spectrum analyzers. That noise test set uses custom very low noise variable crystal oscillators to mix the TX signal to baseband where the signal is then digitized and analyzed for several minutes to produce the results.

So, to test the TX noise performance of a Yaesu FT-991A (recent low end Yaesu) versus a Yaesu FTDX101D (recent high end Yaesu), a Yaesu FT-950 was used as a receiver on the 20 meters band while transmitting with the rigs under test. The transmitters need to operate at full 100 watts power to properly sample the noise output. In this test, the transmitters were set to 14.050 KHz at 100 watts and were keyed at about 20 WPM with a CW message keyer. The rig under test for TX noise was connected to a dummy load but with an RF transformer tap providing about -30 dB of coupling. The output of the -30 dB coupler was connected to a fixed 10 dB attenuator and then a step attenuator with 1 dB steps up to 80 dB. And the resulting signal was connected directly into the FT-950's antenna input to measure the noise versus frequency offset. The total attenuation was tested in the 50 to 70 dB range to model the expected range of antenna coupling for Field Day. The phase noise of the front end RX LO in the FT950 was a question for these tests, but it appears that it did not limit the results, but instead the noise results were limited by the TX performance of the FT991A and FTDX101D as desired.



This is a picture of the homebrew RF transformer providing a -30 dB coupling function. A 2.4 inch toroid is wrapped with about 30 turns on a primary, and a single turn on the secondary to the right side of the toroid. The single turn on the secondary drives the 50 ohm output to the following fixed 10 dB attenuator and then 80 dB maximum step attenuator at 50 ohms. The primary then appears to have an impedance of about 45,000 Ohms (although stray reactance and resistance probably limit this). The high power TX RF signal feeds directly through the box from the rig to a dummy load, but the signal is tapped in the box by the RF transformer primary referenced to ground. Since the RF transformer primary appears as about 45,000 Ohms and is placed in parallel to the high power 50 Ohms dummy load, it causes negligible loading of the high power TX at 100 watts. By coupling the RF signal at -30 dB, only 100 mW of RF power is fed to the attenuators to protect them from burning out since they may only handle about 1 watt maximum of power, and it also serves as a first stage in attenuating the strong TX signal before reaching the test receiver.

This is a picture of the TX setup for these tests. This was located about 50 feet from my radio shack to provide isolation for any stray RF coupling. Also, the TX was powered by a small generator to avoid any RF coupling over the power lines, and also a high performance RFI filtering TrippLite power strip was used to isolate the generator from the TX rig (to the left on the ground). So the only connection to the RX rig was the coax carrying the test signal. A dummy load is visible to the right on the ground. The rig is on the table along with a power supply and CW message keyer, and the -30 dB coupler is on the table to the right with the attenuators.

The FT950 RX rig was set with no antenna attenuation and with the preamp ON in SSB mode or 2800 Hz bandwidth and tuned over the 20 meter band from 14.1 to 14.35 MHz. The results were very consistent with the expected results based on the ARRL lab results and calculations. At 50 dB of coupling loss, the FT991A generated noise signals of about S6 in the FT950, and the FTDX101D generated noise signals of only about S1 to S2. Since an S unit is equal to 6 dB. This indicates that the FTDX101D is about 24 dB or more cleaner for TX noise than the FT991A (which is a very substantial difference). The ARRL measurements were -128 dBc noise for the FT991A and -152 dBc noise for the FTDX101D or 24 dB difference. At 70 dB of loss, the FT991A generated noise around S2 while the noise from the FTDX101D was imperceptible.

The TX CW hold time was set to keep the rigs continuously in TX mode while sending CW. With the FT991A, the noise was continuous in the victim RX and you could not hear the CW code. However, with the FTDX101D, the noise increased enough during CW dots and dashes to be able to discern the characters, but the noise with the FTDX101D was much lower both during spaces and during dots and dashes than for the FT991A.

The impact on the victim RX was also examined with only 20 KHZ spacing at 14.070 MHz RX. This is relevant for digital operations that may be very close to CW operations. The noise was a bit worse at 20 KHz spacing than for larger separations, and the CW characters were more obvious and audible for both the FT991A and the FTDX101D. But the noise was only moderately stronger than with 50 KHz and higher separations.

When a 3 element Yagi antenna is connected to the FT950, the background noise on 20 meters is S1 to S2. This means that with the FT991A, about 70 dB of antenna isolation is needed to lower the TX noise from the FT991A to a victim RX to about the atmospheric background noise level with 50 KHz or higher frequency separation on 20 meters. But for the FTDX101D, only about 45 to 50 dB of antenna isolation is needed to lower the TX noise to a victim RX to about the atmospheric background level with 50 KHz or higher frequency separation on 20 meters.

For example, with the FT991A, given TX at 100 watts or 50 dBm, then the TX noise at -128 dBc is -78 dBm per Hz. In a bandwidth of 2800 Hz, the noise power is about 35 dB higher or about -43 dBm at the TX output. With an antenna isolation of 50 dB, then the noise power at a victim RX is -93 dBm or just below S6. This is very close to what was measured in the FT991A test, and this comparison of calculated victim RX noise and measured RX noise gives confidence in the results.

Conclusion

The key TX and RX performance metrics play a significant role in inter-station interference issues for Field Day. The ARRL lab measurements on rig performance are very helpful when comparing available rigs. Of the current existing rigs, the Yaesu FTDX101D provides the cleanest available TX signal of any rig available assuming CW transmissions and for noise in the 20 KHz and higher frequency offsets. The ICOM 7581 and Flex 6000 are fairly close. The low cost Yaesu rigs have significantly poorer TX noise purity. The Kenwood TS-590SG does a fair/good job on TX signal purity and is good for its price class. The K3 still provides excellent performance and is a good option even today although it is no longer in production, and the lastest rigs such as the K4 and FTDX10 may be good options for new rigs.

The Kenwood rigs earn top honors for RX blocking performance, but the Kenwood RMDR performance is bested by the Yaesu FTDX101D, the ICOM and the Flex 6000 rigs. The low cost ICOM SDR rigs including the ICOM-7300 are a bit weak on blocking performance.

Overall, the Yaesu FTDX101D, the ICOM-7581 and Flex 6000 rigs provide excellent TX purity and RX dynamic range performance, and the Kenwood TS-590SG does well in its price class. The Yaesu FTDX101D (and possibly the FTDX10) has an edge on TX purity and RMDR and nearly best in class performance for all the key metrics compared in this paper.

TX purity and RX dynamic range metrics have significant differences between available rigs. These performance issues can contribute significantly to Field Day inter-station interference and should be carefully considered.