The DX Prowess of HF Receivers

Are you looking for a good receiver for DX hunting? Here are some distilled performance numbers that might point you in the right direction.

By Tadeusz Raczek, SP7HT

Comparing the performance of one receiver to another is quite a difficult task. Receiver-performance tests are described in detail in *The ARRL Handbook*, Chapter 26. Shortwave DX hunters and contest participants have requested that testing of receiver front ends be made at conditions representing real on-the-air situations. That is, we should test receivers when extremely weak DX signals from the other end of the world are present at the same time as several strong local signals that are close to that tiny DX signal. In contrast to standards set by Amateur Radio community, equipment manufacturers prefer that their products be evaluated at 50 kHz or even 100 kHz signal spacings, where much more optimistic results can be achieved. Table 1 illustrates IC-765 receiver front-end dynamic-range measurements performed by the ARRL laboratory at various signal spacings.

We can see a big difference between 5- and 50-kHz test results; that is, blocking dynamic range (BDR) and intermodulation-dynamic-range (IMD DR) measurements for widely spaced signals produce much better results than for 5-kHz spacing. That explains why manufacturers are opting for wide-spaced measurements.

Closely spaced tests can inform us much more realistically about a receiver's usefulness for DXing and contesting on our crowded HF Bands. The ARRL laboratory, G3SJX and W8JI have published measurement results for some HF receivers with closely spaced signals. The ARRL laboratory and G3SJX used 20 kHz for wide-spaced signals and 5 kHz for narrow-spaced signals. W8JI has used 10 kHz for wide-spaced signals and 2 kHz for narrow-spaced signals.

Skrytka Pocztowa 738
25-324 Kielce 25
POLAND
sp7ht@wp.pl

BDR and Two-Tone Third-Order Dynamic-Range Tests

BDR is the difference, in decibels, between the minimum discernable signal (MDS) and an off-channel signal that causes 1dB of gain compression in the receiver. Two-tone third-order dynamic range (IMD DR) is the difference between MDS and the levels of two interfering signals causing IMD products just equal to the MDS.

IMD DR depicts the strong-signal capabilities of a receiver; that is, how it behaves under real-world conditions, when strong signals are delivered from the antenna to the receiver input. Receiver IMD immunity is determined by the limits of its linear signal-handling capabilities. Those, in turn, are determined by the limiting effects of receiver active circuitry such as the preamplifier, mixer and first IF amplifier. Passive components may also exhibit such limiting effects. For instance, fast RF silicon diodes used for receiver input-filter selection and for receive-transmit switching or preamplifier/attenuator activation often cause additional IMD in some present-day HF transceiver models. Moreover, overload of varactor diodes in automatically tuned preselectors, as well as subminiature, inexpensive inductors and monolithic two-pole first-IF filters placed immediately after the first up-conversion mixer, can have a role in IMD generation and receiver performance degradation.

Table 2 demonstrates 20 and 5-kHz-spacing test results of BDR and IMD DR for some HF receivers tested in the ARRL laboratory. Two columns are added for convenience in analysis. In the fourth column, the decrease in BDR is calculated between the 20 and 5-kHz tests. In the sixth column, the decrease in IMD DR is calculated between 20 and 5-kHz tests. Italic numerals distinguish 5-kHz spacing test results.

Table 3 demonstrates 10 and 2-kHz-spacing test results of BDR and IMD DR for some HF transceivers tested by W8JI. Table 3 includes the same additional columns as in Table 2. In column four, the decrease in BDR is calculated between the 10 and 2-kHz tests. Consequently, in column 6, the decrease in IMD DR is calculated between 10 and 2-kHz tests. Italic numerals distinguish 2-kHz test results.

The 2 and 5-kHz closely spaced receiver tests represent real-world, on-the-air DX hunting (split operation), when many strong signals are very close to a very weak DX station signal barely copied in the noise. Less degradation of BDR and IMD DR values means better receiver performance for strong closely spaced signals. You can see that some receivers perform better and some are not as good as we want them to be.

Considering the decrease in BDR and the lowering of IMD DR between widely and closely spaced tests, I consider the best receivers for split-frequency operation with DX stations to be those of the following HF transceivers:

- Elecraft Model K2
- Ten-Tec Model Omni-VI+
- Heavily modified Drake R-4C

The three best results in Table 2 and one result in Table 3 are distinguished by boldface lettering.

K2 and OMNI-VI+: Design Concepts and Features

Elecraft and Ten-Tec manufacture the K2 and OMNI-VI+, respectively *[The Omni-VI+ has been discontinued as of 2001 in favor of a superior design–Ed]*. Drake discontinued the manufacture of the R-4C about 20 years ago.

Table 1—IC-765 Receiver Front-End Dynamic-Range Measurements

Signal Spacing (kHz)	***Blocking DR (dB)*** *IF Shift Off*	*IF Shift On*	***IMD DR (dB)*** *IF Shift Off*	*IF Shift On*
5	120	91	85	73
10	130.5	105	90	88
20	151.5	139.5	97	95
50	152	152	99	99

Table 2—20 and 5-kHz-Spacing BDR and IMD DR for some HF receivers tested by the ARRL

Manufacturer	*Model*	*BDR (dB)*	*BDR Decrease*	*IMD DR (dB)*	*IMD DR Decrease*
Elecraft	**K2**	**133** and ***126***	**only 7 dB**	**97** and ***88***	**only 9 dB**
ICOM	IC-706MkIIG	120nl and *86*	34 dB!	86 and *74*	12 dB
ICOM	IC-746	113 and *88*	25 dB!	92 and *78*	14 dB
ICOM	IC-756PRO	120 and *104*	16 dB	88 and ***80***	**only 8 dB**
ICOM	IC-775DSP	132 and *104*	28 dB!	103 and *77*	26 dB!
Kenwood	TS-570S(G)	119 and *87*	32 dB!	97nl and *72*	25 dB!
Kenwood	TS-570D	"	"	"	"
Kenwood	TS-2000	121nl and *99*	22 dB!	92 and *67*	25 dB!
Ten-Tec	**OMNI-VI**	128nl and ***119***	**only 9 dB**	100 and ***86***	14 dB
Ten-Tec	**OMNI-VI+**	"	"	"	"
Yaesu	FT-847	109nl and *82*	27 dB!	89 and *73*	16 dB
Yaesu	Mark-V FT-1000MP	126 and ***106***	20 dB!	98 and *78*	20 dB!

Table 3—10 and 2-kHz-Spacing BDR and IMD DR for some HF transceivers tested by W8JI

Manufacturer	*Model*	*BDR (dB)*	*BDR Decrease*	*IMD DR (dB)*	*IMD DR Decrease*
ICOM	IC-751A	98 and 83.5	14.5 dB	91 and 79	12 dB
Drake	R-4C (stock 1)*	109 and 57	52 dB!	82 and 48	34 dB!
Drake	R-4C (stock 2)†	116 and 80	36 dB!	86 and 68	18 dB
Drake	**R-4C (heavy mod)††**	**131 and 127**	**only 4 dB**	**119 and 118**	**only 1 dB**

*Stock 1 has MOSFET second mixer.
†Stock 2 has vacuum-tube second mixer.
††Heavy mod is rebuilt with solid-state doubly balanced high-level mixers and Sherwood 600-Hz roofing filter.

For CW-oriented DX hunters, the R-4C is not an impressive receiver when compared to recent models. But after radical modifications, an upgraded R-4C is a good receiver for weak DX signal CW reception on crowded amateur HF bands, thanks to the low phase noise of the R-4C PTO (permeability tuned oscillator). As shown in the ON4UN questionnaire results in the second edition of *The Antennas and Techniques for Low-Band DXing,* a significant number of responders have reported using the R-4C for DXing on 80 and 160 meters.

The K2 and OMNI-VI+ BDR for 5-kHz spacing between strong signals is (126 – 106) 20 dB and (119 – 106) 13 dB, respectively, greater than that for the third-ranked FT-1000MP Mark-V (106 dB). Accordingly, the two-tone third-order dynamic range (IMD DR) of the K2 and OMNI-VI+ for 5-kHz spacing from two strong signals is, respectively, (88 – 80) 8 dB and (86 – 80) 6 dB better than for the third-ranked IC-756PRO (80 dB). This advantage is especially useful for DX-oriented operators.

Such good receiver front-end parameters prove the design concepts implemented by Elecraft and Ten-Tec in the K2 and OMNI-VI+ models. Both makers have abandoned ideas commonly exploited during last 20 years by most other makers of HF transceivers and returned to proven designs used previously but with modern implementations.

The K2 and OMNI-VI+ use the following crucial design ideas in the receiver front end:

- HF ham-band coverage only, no general coverage capability
- Only single (K2) or double (OMNI-VI+) conversion is used instead of a chain of several mixers commonly used by other makers
- Both models have excluded the first up-conversion IF into the 50 to 90-MHz range with the associated wide bandwidth first-IF roofing filter (with its passband set wide enough for narrow FM transmission and adequate for noise-blanker operation)
- Both models use a relatively low first IF that allows installation of narrow SSB/CW crystal filters with good shape factors to greatly attenuate out-of-band IF signals just at the front of the IF amplifier
- The main IF selectivity of the crystal filters is very close to the receiver front end, which helps substantially to obtain high BDR and good IMD DR even for closely spaced strong signals
- Both models implement ham-band-only preselector filters that substantially suppress strong signals outside of the ham bands and prevent receiver front-end overload and IMD

In designing its K2, the main goal of Elecraft was to construct an HF transceiver devoted only to the ham bands, useful for DX hunting—mainly CW—with SSB as an option. As Table 2 indicates, this has been done successfully.

The K2 HF transceiver implements a single-conversion superhet receiver:

- A doubly balanced diode mixer offers excellent dynamic range. Narrow and ham-band-only double-tuned preselector filters are switched by relays, so the receiver front end offers much better IMD response than when diode switching is used
- A switchable HF preamplifier and switchable attenuator increase the range of receiver sensitivity adjustments, which allow the operator to adjust the receiver to particular propagation conditions and the receiving antenna actually in use
- AGC is derived from the IF signal. AGC offers fast attack time and smooth operation (without any popping effect on strong signals) for fast and slow settings. It is even possibile to switch the AGC off, which is sometimes the last chance to copy extremely weak DX surrounded by strong signals—experienced DXers know it.
- A sharp IF crystal filter is close to the mixer and because of the relatively low IF (4.915-MHz), the crystal filter greatly attenuates out-of-IF signals. That helps to prevent receiver overloading by strong signals from outside the IF-filter pass-band. The IF crystal filter offers an adjustable passband for CW from wide (2000 Hz) to narrow (200 Hz).
- A low-phase-noise PLL local oscillator

Implemented microprocessor control offers:

- Split operation with two VFOs
- Dual-range RIT and XIT
- Memory operation for mode (CW or SSB), dual VFO A/B split operation, receive IF crystal-filter passband selection, receive CW sideband selection (allows canceling of one-side interference from strong nearby station by switching to opposite received sideband—a rudimentary IF-shift function),
- Direct keypad entry of frequencies and memory channels
- Three tuning rates: 1, 10 and 100 kHz per main-knob revolution
- 10-Hz tuning resolution
- Adjustable receive CW offset with a tracking sidetone
- Auxiliary I/O RS-232 interface for computer logging and remote-control purposes

The K2 itself is devoted to CW QRP enthusiasts, but could be tailored for other preferences by adding following options:

- The SSB option offers an adjustable speech compressor and optimized seven-pole, 2.2-kHz-wide IF crystal filter,
- 100-W PA Module (offered since the Dayton 2002 convention)
- 160-meter band with second receive antenna
- An automatic antenna tuner
- A noise blanker
- An auxiliary I/O RS-232 interface
- An audio filter, eliminating residual noises outside the desired passband

The K2 is sold in kit form with assembly instructions that are well written. Anyone can complete the kit and buy what one really prefers. The K2 Product Review, written by Larry Wolfgang, WR1B, appears in *QST* (March 2000, pp 69-74). "Impressions of the Elecraft K2 Transceiver" by Rich Arland, K7SZ, appears in *QST* (April 2001, p 99).

In designing the OMNI VI+, Ten-Tec has also departed from the prevailing general-coverage receiver concept and returned to ideas used 20 years ago. Ten-Tec have abandoned:

- Wide semi-octave, noisy first local oscillators generated by synthesizers
- First-IF up-conversion into the 50 to 90-MHz region
- Wide first-IF roofing filters

The OMNI VI+ HF transceiver is designed for ham bands only, from 160 to 10 meters. There are only two mixers in receiver chain: first IF = 9 MHz, second IF = 6.3 MHz. All ham bands are covered in 12 segments of 500 kHz, each having 30-kHz margins at lower and upper band edges. This model is a successful comeback of already proven concepts but with an implementation using present-day components:

- The first local-oscillator signal is produced with band-dependent crystal oscillators mixed with a low-noise 4.97 to 5.53 MHz PLL. Therefore, all synthesis noise problems causing reciprocal mixing have been avoided.
- The first IF is low enough to implement a narrow IF crystal filter with a good shape factor (having a passband adequate for SSB and CW) offering great attenuation of out-of-passband signals

The first IF is at 9 MHz and can be fitted with the following passband IF crystal filters:

- SSB: 1.8 kHz or 2.4 kHz

- CW: 250 Hz or 500 Hz
- A special 500-Hz, 6-pole IF crystal filter centered for digital modes

The second IF at 6.3 MHz can be equipped with the following bandpass crystal filters:

- SSB: 1.8 kHz
- CW: 250 Hz or 500 Hz

Such a mixing concept allows installation of narrow crystal filters in both IF chains right at the beginning of first and second-IF receiver amplifiers. Therefore the receiver main selectivity filters are close to the mixers, where they should be according to DXers—and where they are not in most ham radio HF transceivers made in the last 20 years.

Depending on chosen crystal-filter combinations, the following good shape factors should be achieved:

- 1.3 for 2.4-kHz first and second-IF crystal filters for SSB reception
- 1.4 for 1.8-Hz first and second-IF crystal filters for SSB reception
- 2.6 for 500-Hz first and second-IF crystal filters for CW reception
- 2.9 for 250-Hz first and second-IF crystal filters for CW reception

Other combinations of first and second IF crystal filters are possible. All installed IF crystal filters can be selected independently of the mode. Superior receiver selectivity significantly decreases interference even from very close signals.

DSP noise reduction (5 to 15 dB), DSP auto-notch elimination of interfering carriers and DSP low-pass (five choices) help to customize receiver selectivity in addition to the selectivity already offered by IF crystal filters.

Influence of Phase Noise

The main limiting factor of modern receiver performance is local-oscillator phase noise. Phase noise contributes to poor receiver BDR in the form of desensitization by nearby strong signals resulting from reciprocal mixing.

In the OMNI VI+, phase noise is –122 dBc for 1-kHz spacing, –123 dBc for 10-kHz spacing and –138 dBc for 20-kHz spacing. In the K2, phase noise is –120 dBc for 4-kHz spacing and –126 dBc for 10-kHz spacing.

Therefore, both OMNI VI+ and K2 have superb ham-band performance with an extremely high close-in dynamic selectivity. That enables reception of very weak signals from DX stations when strong signals are only a few kilohertz away. Several on-the-air A/B reception comparisons (using the same switchable receive antenna) of HF transceivers made by other makers against OMNI VI+ and K2 have been made recently. Generally, these comparisons favored the OMNI VI+ and K2, especially in the case of CW reception on 160-meter band.

Fig 1 explains the superior performance of the OMNI VI+ and K2. The figure demonstrates a typical situation where a barely heard DX station—only a few decibels above the receiver noise floor (dotted line)—is operating SSB on 14.195 MHz. That DX station is operating split and listening upward a few kilohertz. A pile-up of strong stations is calling where he is listening. For simplicity, only four signals are shown on the graph. Also for illustration, let us say that a QSO is in progress just 3 kHz higher on the neighboring frequency of 14.198 MHz.

The ability to copy such a weak DX station in presence of many nearby strong signals will depend on several receiver qualities: selectivity, BDR, IMD DR and the amount of phase noise on the LO signal.

We can presume that almost any modern HF receiver has enough sensitivity and selectivity to copy the weak DX station with no other signals present. Nevertheless, for real, on-the-air situations when plenty of strong signals are present near DX-station frequencies, some receivers will do better than the others. That will depend on how great is their BDR, how great is their IMD DR and how much phase noise accompanies the LO for any particular HF transceiver.

If the receiver has only average BDR, even a single adjacent signal —for instance, on 14.198 MHz, if it is strong enough—will desensitize that receiver and the weak DX station will not be heard in the presence of strong interference.

When many strong stations are calling, spread out 3-20 kHz up from weak DX signal, the IMD DR plays a big role in performance of the receiver. We can find in pile-up situations that many combinations of $2F_1 - F_2$ and $2F_2 - F_1$ are present. Those will produce intermodulation products on the weak DX station's frequency and these IMD products will interfere with or distort the weak DX signal. They can even completely bury the DX signal in noise and hiss. As the tables show, some receivers are more and some are less prone to IMD.

Most present-day HF transceivers implement synthesizers to produce LO signals for mixing. Analyzing BDR and IMD DR results, you can judge for yourself which makers do better and which ones are not as good—look for noise-limited remarks in test results. Some synthesizer designs produce more phase noise than one can obtain using methods implemented by Elecraft in the K2 and by Ten-Tec in the OMNI VI+ models. Therefore, K2 and OMNI VI+ models are better predisposed to deal with pile-ups on crowded ham bands.

The dotted line on Fig 1 indicates the receiver noise floor. The noise-floor levels of the OMNI VI+ and K2 do not change in the presence of strong nearby signals, because the OMNI VI+ and K2 have much less phase noise than most HF receivers using frequency synthesis. The dot-dash line illustrates the general situation for synthesized LOs. The presence of many strong signals near a weak DX-station frequency leads to the appearance of reciprocal mixing signals on the DX frequency that will

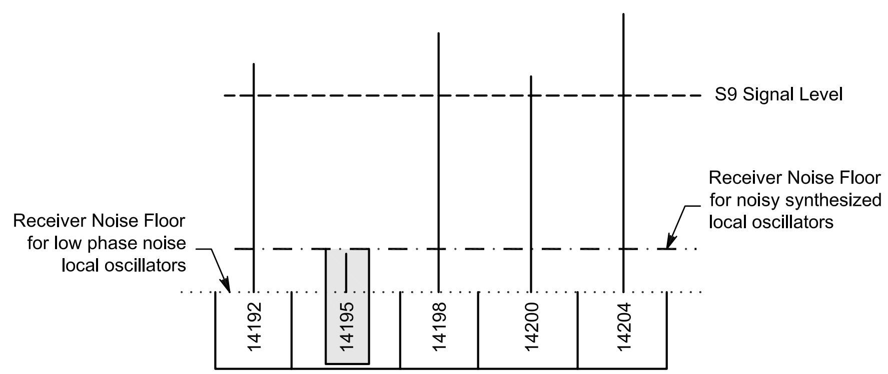

Fig 1—A representation of a typical DX pileup situation in the frequency domain. Vertical lines represent the strengths of incoming signals. There is a weak DX station (shaded) at 14.195 MHz. The dotted line is the receiver noise floor for low-phase-noise receivers. It does not change in the presence of nearby strong signals and allows the tiny DX station (shaded) to be heard. The dot-dash line indicates the noise floor for a noisy synthesized local oscillator, which has increased in the presence of nearby strong signals. The increased noise floor hides the DX station at 14.195 MHz. The dashed line is the S9 signal level.

interfere with that signal. When LO phase noise and calling stations' signals are high enough, then reciprocal-mixing products can bury a DX station signal completely in noise. That case is illustrated by the shaded bar around 14.195 MHz.

Summary

The K2 by Elecraft and the OMNI VI+ by Ten-Tec are relatively new. American makers have manufactured both. As far as I know (as of October 2001), there is no response to the call for superior dynamic range from other makers of HF transceivers yet. DX hunters can optimistically expect that good times have come at last for them and other makers will offer their new models designed appropriately for DX hunting and contesting. Nevertheless, this is still a market economy and the next steps of other makers will depend on how much popularity and admiration the K2 and OMNI VI+ achieve among the DX community.

I've analyzed equipment-review articles published in *QST* and some articles devoted to receiver front ends published in *QEX* for some time now. At the same time, I was gathering components to build my own homemade dream receiver to perform better in extreme DX-hunting situations than equipment offered commercially on the market—European QRM on low HF bands is much, much stronger than in other parts of the world. I've planned to begin construction upon retirement. Recently, I've noticed that there are models on the market performing almost as well as I need. Additionally, Elecraft offers the K2 as a kit. Its many options can be purchased and tailored according preferences, without the unnecessary bells and whistles found in general coverage multipurpose machines.

According to W8JI, there is also a challenge for ambitious constructors to upgrade old R-4Cs having the narrow 600-Hz Sherwood roofing crystal filter in the first IF. You can replace the poor second mixer with a high-level-input doubly balanced low-noise mixer and add more gain after the narrow IF filters following the second mixer (using a solid-state IF amplifier instead of a tube version). An R-4C upgraded that way, with gain properly distributed in the receive chain, could offer better performance for extreme DX situations than most modern HF transceivers.

Perhaps I am an old-fashioned man. But my motto is: If equipment is designed properly to achieve best performance in some specific and narrow area—in this case solely for reception of weak CW and SSB DX signals only on crowded HF hambands—you can expect better performance from it than from general-coverage multiband machines.

Therefore, if an HF transceiver is used mainly for CW and SSB DXing only inside the ham bands, a general-coverage receiver with its associated up-conversion and its first-IF wide roofing filter is not the best way to reach the main goal. Adversely to the concept used in general-coverage receivers, the main bandwidth selection should take place at a point as close to the front end as possible. That will enable us to achieve the greatest immunity against strong adjacent signals.

Unfortunately, that crucial demand is not acted upon in most of HF transceivers offered in the ham-radio market at the present time. Being myself a devoted DX hunter, I recognize the concepts implemented by Elecraft in the K2 and Ten-Tec in the OMNI VI+ as a step in the right direction. To meet demands of DX hunters, first of all, we need very good receiver performance and immunity to strong adjacent signals. In my opinion Elecraft in the K2 and Ten-Tec in the OMNI VI+ have properly designed receiver front ends for DX-oriented hams. This article was written late in the autumn of 2001. Since then, Ten-Tec has announced their ORION Model new HF Transceiver. I believe this is a big step in the right direction.

References

I've drawn material from many sources to produce this article. These include:

Many Product Review articles in *QST*. My articles published in SP HF Magazines

J. Devoldere, ON4UN, *Low Band DXing,* second edition (Newington, Connecticut: ARRL). The third edition is available from ARRL as Order No. 7040, ISBN: 0-87259-704-0; $28.

Web sites: W8JI's (**www.w8ji.com**, receiver measurements as of 8 Aug 2001) and several others: **sherweng.com/table. html**; **drakelist@baltimoremd.com**; **www.tentec.com**; **www.elecraft.com**; Elecraft mailing list **Elecraft@mailman. qth.net** (throughout the summer and autumn of 2001).

SP7HT has been involved in DX hunting for last 45 years. During the first 25 years of his activities all of his HF equipment was homemade (including SSB crystal-filter production). Until recent years, a homemade rig has been the only way to be on the air from this part of the world. The last 20 years he has used several ICOM and Kenwood HF transceivers, but he's had no experience with other makers.

Tadeus was the very first DXer from Poland to reach the DXCC Honor Roll (1981) and DXCC Honor Roll #1 (1986). For last 28 years his occupation has been associated with microwave satellite telecommunication. Actually he is a specialist at the Polish Telecom Satellite Services Center "TP SAT" in Psary, Poland. He will retire in January 2003.