Explaining ARRL Technical Reviews of Radios

*a brief tutorial on radio testing*

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Why test a radio?

- To facilitate comparison of different radio architectures
  - in advance of a selection/purchase decision.
- A modern radio is a highly complex piece of equipment
  - We need to examine all aspects before making a purchase.
- To help identify “best match” to buyer’s needs
  - based on comparison of key parameters.
- To help determine usability for intended purpose
  - e.g. mobile operation: size, weight, power consumption.
- To derive performance benchmarks
  - These give a sense of how well the radio will perform on the bands.
- Caution is needed in interpreting test data
  - Avoid fixating on any one parameter at the expense of others!
The “car analogy”

- This car does 0 – 100 km/h in 3.9 sec.”
  - “Great, but I only need to drive the kids to school and go shopping.”
- The car in question is optimized for acceleration -
  - but it burns 20 l / 100 km with fuel at $1.40 / l.
- Do I need this in my life?
  - No! I need the best balance of decent performance, road-holding, interior space, economy and safety for my intended application.
- The analogy also applies to transceivers:
  - “This radio has a 200W TX and 110 dB IMD3 dynamic range at 2 kHz!”
  - “Neat, but it costs $6K. Now all I need is a 100W radio to drive my amplifier for casual SSB rag-chewing on 75m. I can buy one for $2K.”
- A balanced test report facilitates choice of a radio which best suits one’s needs.
ARRL Lab Test Reports

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The ARRL Lab tests radio equipment according to standardized test procedures, using calibrated professional test equipment.

♦ This ensures accuracy and repeatability. It also facilitates comparison of several radios of differing makes and/or models.

♦ The scope of a test suite for an all-mode HF or HF/VHF/UHF radio is greater than that for a VHF/UHF FM radio.

In a typical ARRL Product Review of an HF transceiver, which is the subject of this presentation, we see two groups of test parameters:

♦ Receiver test results
♦ Transmitter test results

We will list these tests, briefly explaining the purpose of each test.

Finally, we will discuss the impact of each parameter on the operating experience.
Receiver Tests

Sensitivity group:

• Minimum Discernible Signal (MDS)
  ▸ Input power in dBm to raise noise floor by 3 dB.

• AM Sensitivity
  ▸ µV input for 10 dB (S+N)/N (signal + noise to noise).

• FM Sensitivity
  ▸ µV input for 12 dB SINAD: signal/(noise + distortion).

• Noise Figure
  ▸ A measure of the receiver’s noise floor.

• Spectrum Scope Sensitivity
  ▸ Input power in dBm for minimum visible vertical spike.
Receiver Tests
(continued)

Dynamic performance group:

- Blocking gain compression
  - Input power in dBm for 1 dB reduction in audio output.
- 2-signal, 3rd-order IMD dynamic range
  - Relative 2-tone input level for IM3 products at specified level.
  - Tested in CW and FM modes (FM at 20 kHz spacing only).
- 2-signal, 2nd-order IMD dynamic range
  - Relative 2-tone input level for IM2 products at specified level.
- Reciprocal mixing dynamic range
  - Relative level of undesired signal offset $n$ kHz from RX passband to raise noise floor by 3 dB.
- Spurious, image and 1st-IF rejection
  - Relative level of test signals at these frequencies to raise noise floor by 3 dB.
Receiver Tests
(continued)

• Miscellaneous group:
  • IF selectivity
    ▶ -6/-60 dB bandwidth of IF filters in various modes.
  • DSP noise reduction (NR)
    ▶ (S+N)/N increase in dB at maximum NR setting.
  • Notch filter depth
    ▶ Relative 2-tone input level for IM3 products at specified level.
  • Squelch threshold
    ▶ Input power level for squelch to open (SSB, AM, FM).
  • S-meter accuracy
    ▶ Input power level for S9 reading with preamps off/on.
  • Receiver audio output
    ▶ Audio power output at speaker jack (typ. 2W @ 10% THD).
Transmitter Tests

- RF power output
  - Measured in all supported modes at nominal supply voltage.

- Spurious signal and harmonic suppression
  - dB below nominal output; tested in all covered ranges (HF, 6m etc.).

- Carrier and undesired-sideband suppression
  - dB below nominal output; measured in SSB mode.

- SSB 2-tone intermodulation
  - dB below nominal 2-tone PEP output, in all covered ranges.

- Transmitted composite noise
  - Measured at 100 Hz – 1 MHz offset, in all covered ranges.

- CW keying characteristics
  - Keyer speed range; keying sidebands and envelope.

- Receive/transmit turn-around time
  - in msec. Tested in CW, SSB and FM modes.
“How do these test results affect me, the radio buyer?”

- Impact of each test parameter on the operating experience:
- Receiver: how I hear distant stations
  - Sensitivity (MDS, AM/FM sensitivity): “If I can’t hear them, I can’t work them.” This is almost never an issue in modern HF receivers.
  - The noise floor of even an average modern receiver is at least 10 dB below ambient band noise for f < 15 MHz.
  - There is a trade-off between sensitivity and linearity.
  - Strong undesired signals will generate IMD in a preamp; usable sensitivity can be worse than with preamp off!
  - Modern radios have a switchable RF amplifier (preamp). Some have two preamps, optimized for f < 20 MHz and f > 20 MHz respectively. On 7 MHz and below, band noise is high, so preamps should be off.
  - Typical MDS figures (500 Hz CW): -126 to -134 dBm (preamp off), -140 to -143 dBm (preamp on).
  - Bottom line: “Don’t shop based on sensitivity alone.”
On 2m and higher bands, antenna noise ≤ internal noise of receiver. Noise figure (NF) is specified at VHF and above.

Noise figure is a measure of the degradation due to the receiver’s internal noise. Unlike MDS or sensitivity stated in µV, NF is bandwidth-independent.

Typical NF values: HF 10 – 15 dB, 2m 5 dB, 70cm 4 dB. For weak-signal ops, an antenna-mounted preamp can reduce NF to <1 dB.

Spectrum-scope sensitivity: Input power in dBm for minimum visible vertical spike. Typically -125 dBm (preamp on). This allows the operator to see the “weak ones” on the scope screen.
Dynamic performance tests:
Blocking, IMD3 dynamic range, IP3

- These parameters all affect our ability to hear a weak signal when a strong unwanted signal is nearby.
- Blocking gain compression: A strong signal 5 kHz from a weak SSB signal or 2 kHz from a weak CW signal will desense the receiver, pushing the weak signal below the noise floor.
  - At 2 kHz spacing: Acceptable: 110 – 120 dB. Excellent: 130 – 140 dB.
- IMD3 dynamic range: Two closely-spaced strong signals will generate IMD3 products in the receiver passband, masking a weak signal. A highly linear receiver front end yields less IMD3.
  - At 2 kHz spacing: Acceptable: 80 dB. Good: 90 dB. Excellent: 110 dB.
  - FM, 20 kHz spacing: Acceptable: > 60 dB. Good: > 70 dB. Excellent: > 75 dB.
- 3rd-order intercept (IP3) is a theoretical number derived from IMD3 dynamic range. At 2 kHz spacing, preamp off:
  - Acceptable: +5 to +8 dBm. Good: +10 to +15 dBm. Excellent: +30 dBm.
  - See charts, Slide 13-14.
Dynamic performance tests:
IMD2 dynamic range, IP2, reciprocal mixing noise

- IMD2 dynamic range: Two signals on non-amateur bands can mix to “drop” an IMD2 product onto a weak signal in a ham band.
  - Example: 6 and 8 MHz, product on 14 MHz.
  - Of particular relevance in ITU Region 1 (many HF broadcasters).
- 2nd-order intercept (IP2) is a theoretical number derived from IMD2 dynamic range. IP2 is stated in ARRL test reports.
  - Acceptable: +65 to +70 dBm. Good: +80 dBm. Excellent: +96 dBm.
  - A preselector (internal or external) or an ATU in-line on receive will greatly improve IP2.
- Reciprocal mixing noise: Excessive local-oscillator phase noise will mix with strong unwanted signals to yield noise at IF, masking a weak signal.
  - Modern transceivers with Direct Digital Synthesis have much lower reciprocal mixing noise. Direct-sampling SDR has virtually eliminated this problem.
  - At 2 kHz spacing: Acceptable: 78 to 80 dB. Excellent: > 90 dB. Superb: > 100 dB.
  - See chart, Slide 15.
Impact of IMD on a weak signal

IMD products are:
- $2f_1 - f_2$
- $2f_2 - f_1$

Example:
$f_1 = 14050$ kHz
$f_2 = 14052$ kHz
IMD products:
14048, 14054 kHz

Upper IMD product masks weak signal at 14054 kHz

Weak signal
If the base and 3\textsuperscript{rd}-order response lines are extended as shown, they intersect at the 3\textsuperscript{rd}-order intercept point (IP3). The slope of the 3\textsuperscript{rd}-order line is 3X that of the base response line.

IP3 is a theoretical value, and cannot be directly measured. It is calculated from IMD3 dynamic range. IP3 is a useful predictor of strong-signal performance.

Acceptable: +5 to +8 dBm. Good: +10 to +15 dBm. Excellent: +30 dBm.
Impact of reciprocal mixing noise on a weak signal

Reciprocal mixing noise can degrade and even completely mask a weak desired signal.
Impact of spurious and poor image/IF rejection

  - “Birdies” are caused by mixes of internally-generated signals, and appear as tones. A strong “spur” can mask a genuine signal.
  - Careful IMD studies during design phase will minimize these problems.
  - Tone level at MDS is maximum acceptable, but a few “birdies” outside ham bands can be tolerated in an amateur transceiver.

- Spurious, image and IF rejection:
  - Spurious responses are due to improper mixes of RF signal with stray internal signals “throwing” products into the IF.
  - Image example: 14.1 MHz signal, 5.1 MHz LO: (14.1 – 5.1) = 9 MHz IF.
  - Image response is opposite sideband at (9 – 5.1) = 3.9 MHz.
  - IF breakthrough is due to poor mixer balance or layout.
  - Images or IF leak will cause false signals to appear in the IF.
  - Up-conversion (1st IF > top of tuning range) largely eliminates these issues.
Miscellaneous RX tests as they affect operating convenience

IF selectivity: ARRL specifies this as “Equivalent Rectangular Bandwidth” (rectangular passband of equal area to filter tested).

- Acceptable: CW 500 Hz, SSB 2.5 kHz, AM 6 & 9 kHz, FM 15 kHz.

DSP noise reduction efficacy:

- 7 to 10 dB maximum reduction is typical.

Notch filter depth:

- Analogue: typically 40 – 50 dB. DSP: 70 dB or greater.
- DSP Auto Notch: typically > 60 dB tone suppression.

Receiver audio output at speaker jack:

- Acceptable: 2 – 5W at 10% THD.
Transmitter: how distant stations hear me

RF power output:
- Measured in all supported modes at nominal supply voltage.
- Measured with power attenuator and RF power meter.
- SSB PEP output measured with oscilloscope calibrated against power meter.
- Acceptable range: 100 – 110% of rated power output.

Spurious signal and harmonic suppression:
- Measured on spectrum analyzer at various spot frequencies, at rated CW output.
- Note that at 1 kW, -43 dBC = 50 mW – can still cause QRM. A resonant antenna will provide further harmonic suppression. See plot (Slide 19).

Carrier and opposite-sideband suppression:
- Measured on spectrum analyzer at rated PEP output.
- Inadequate carrier or unwanted-sideband suppression can potentially cause severe co-channel or adjacent-channel interference.
- Generally better in DSP radios than in purely analogue designs.
Typical spurious/harmonics test run (IC-7410)
Typical carrier/opposite sideband suppression test (IC-7410)

IC-7410 #02001066. Opposite-sideband/carrier suppression at 100W, 18/07/2011.

<table>
<thead>
<tr>
<th>ATTEN</th>
<th>10dB</th>
<th>MRK</th>
<th>-10.50dBm</th>
</tr>
</thead>
<tbody>
<tr>
<td>RL</td>
<td>-10.0dBm</td>
<td>10dB</td>
<td>14.100992MHz</td>
</tr>
</tbody>
</table>

- **carrier**
- **opp. sideband region**
Transmitter:
how clean is my signal?

SSB 2-tone intermodulation (IMD):
- Measured at rated PEP output, with 2-tone generator & spectrum analyzer.
- 3\textsuperscript{rd}, 5\textsuperscript{th}, 7\textsuperscript{th}, 9\textsuperscript{th}-order IMD products recorded. See plot (Slide 22).
- Transmitted IMD can cause severe adjacent-channel interference.
- ITU-R guideline: -31 dB ref. 2-tone PEP (not binding on Amateur Radio Service).

Transmitted composite noise:
- Measured at rated CW output, with phase-noise test system.
- Swept test, 100 Hz – 1 MHz offset.
- Composite noise consists mainly of local-oscillator phase noise with a thermal-noise component. Modern DDS much quieter than earlier PLL designs.
- Excessive transmitted noise degrades weak-signal performance of nearby receivers (e.g. Field Day).
- Acceptable: -100 dBc/Hz at 100 Hz offset, -120 dBc/Hz at 10 kHz, < -130 dBc/Hz at 1 MHz. See plot (Slide 23).
Typical transmitted intermodulation plot (IC-7410)

-34 dBc
Typical transmitted composite noise plot (IC-7410)
Transmitter: how clean is my CW keying?

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- Keyer speed range:
  - No industry standard. 6 – 48 wpm range is typical.

- Keying sidebands:
  - Measured with spectrum analyzer at various CW rise-time settings.
  - Excessively short rise-time can generate broad sidebands, causing key-clicks.
  - Rise-time user-selectable on modern DSP transceivers. (See chart, Slide 25).

- Keying envelope:
  - Measured with oscilloscope and external keyer at ≈ 60 wpm.
  - Usually tested in full break-in mode. (See chart, Slide 26).
  - Excessively “square” envelope may indicate severe key-clicks.

- Receive/transmit turn-around time:
  - Excessively long transition time can compromise QSK, as receiver will not recover between code elements.
  - Acceptable range: 20 – 30 msec.
Typical plot of CW keying sidebands (IC-7410)

- 100W, 14 MHz
- Speed: 60 wpm
- Rise-time: 4 ms

Frequency in kHz

Response, dB
Typical plot of CW keying envelope (IC-7410)

100W, 14 MHz
Speed: 60 wpm
Rise-time: 4 ms

Time (s)
Thanks for watching!

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- Link for further study: