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Explaining ARRL Technical Reviews of Radios

a brief tutorial on radio testing

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Why test a radio?

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- 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”

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- “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

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- **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)

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- **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)

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- **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

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- 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?"

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- **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."**

Receiver noise figure, spectrum scope sensitivity

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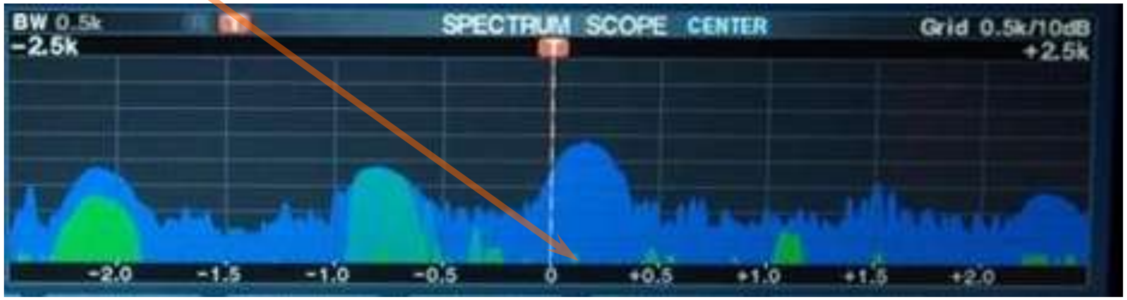
- On 2m and higher bands, antenna noise ≤ internal noise of receiver. Noise figure (NF) is specified at VHF and above.
- Noise figure is a measure of the degradation due to the receiver's internal noise. Unlike MDS or sensitivity stated in µV, NF is bandwidth-independent.
- Typical NF values: HF 10 – 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

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- 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

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- **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

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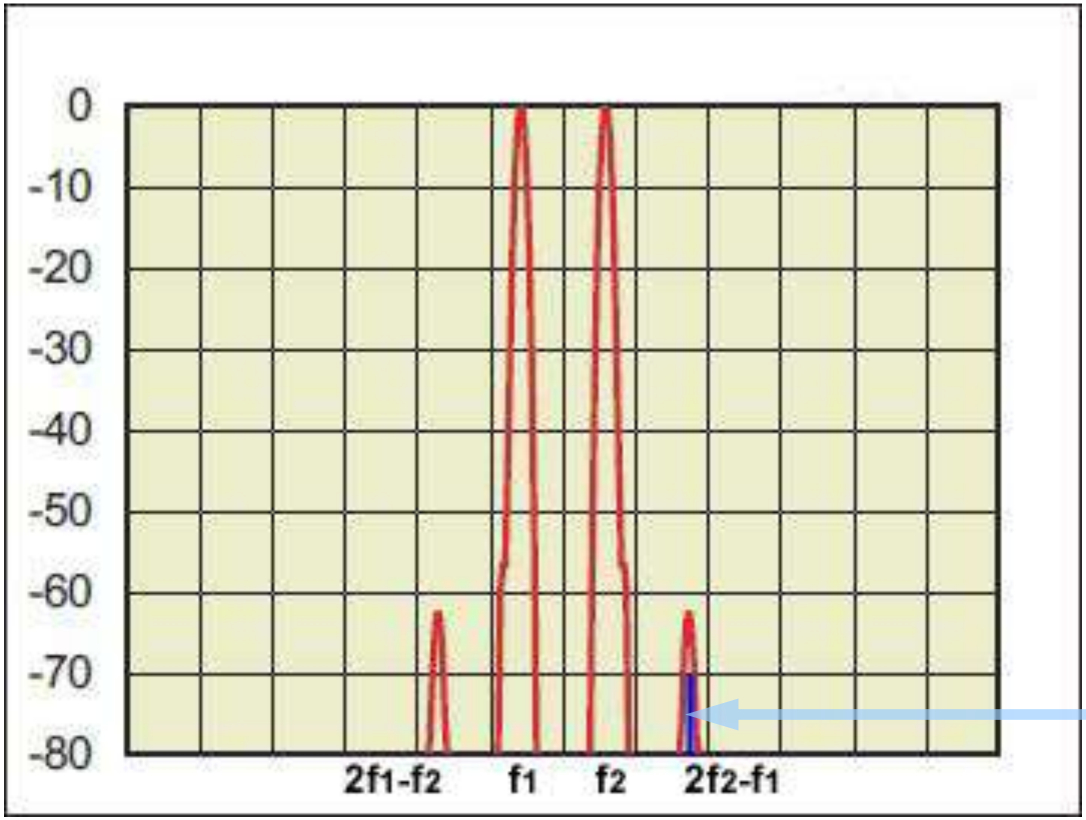
IMD products are:
- $2f_1 – f_2$
- $2f_2 – f_1$

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

3^{rd}-order intercept point:
simplified diagram

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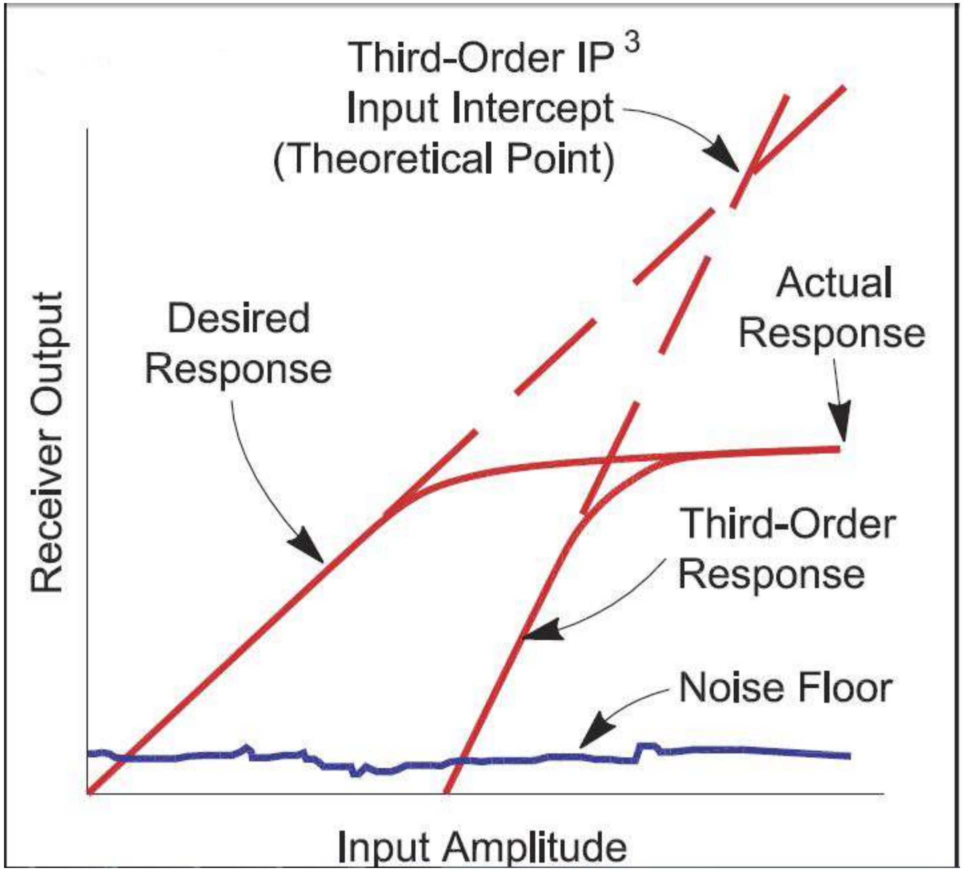
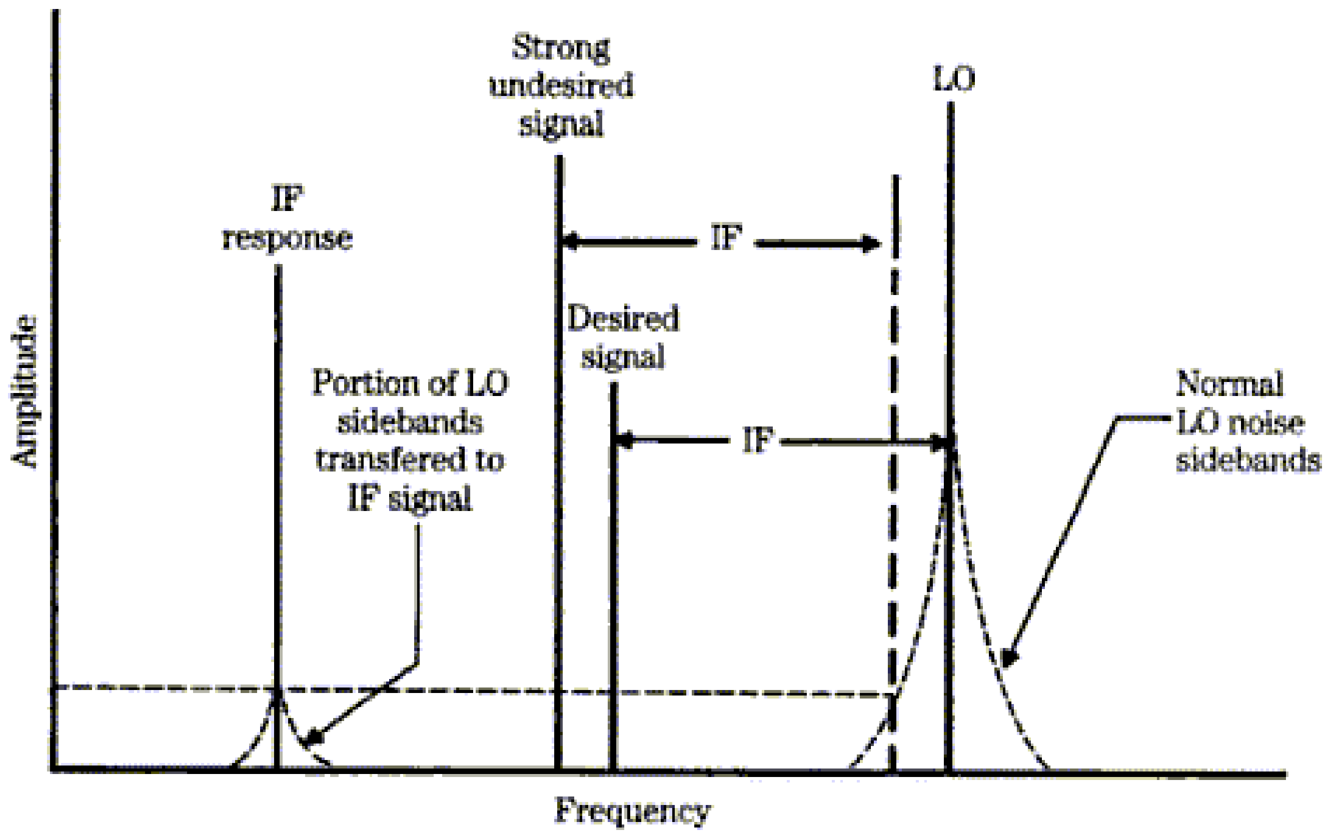
If the base and 3^{rd}-order response lines are extended as shown, they intersect at the 3^{rd}-order intercept point (IP3) The slope of the 3^{rd}-order line is 3X that of the base response line.

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

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- **2 types of RX spurious: spurious signals ("birdies", "spurs") and spurious responses ("ghosts").**
  - **"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.**
  - **Rejection: Acceptable: > 70 dB. Good: 80 – 90 dB. Excellent: > 90 dB.**

Miscellaneous RX tests
as they affect operating convenience

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- 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

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- **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.
  - FCC 97.307(d): -43 dBc min. Acceptable: -50 dBc. Very good: -70 dBc.
  - 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.
  - Acceptable: < -55 dBc. Very good: -80 dBc. See plot (Slide 20).
  - Generally better in DSP radios than in purely analogue designs.

Typical spurious/harmonics test run (IC-7410)

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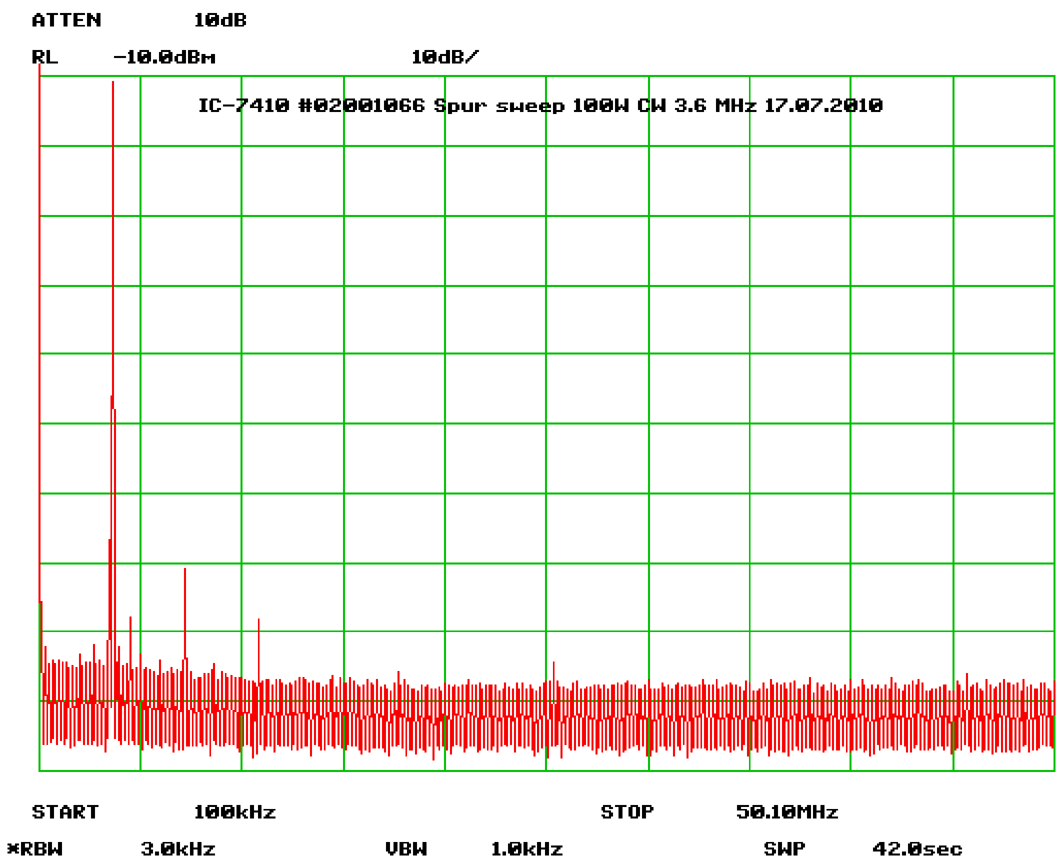
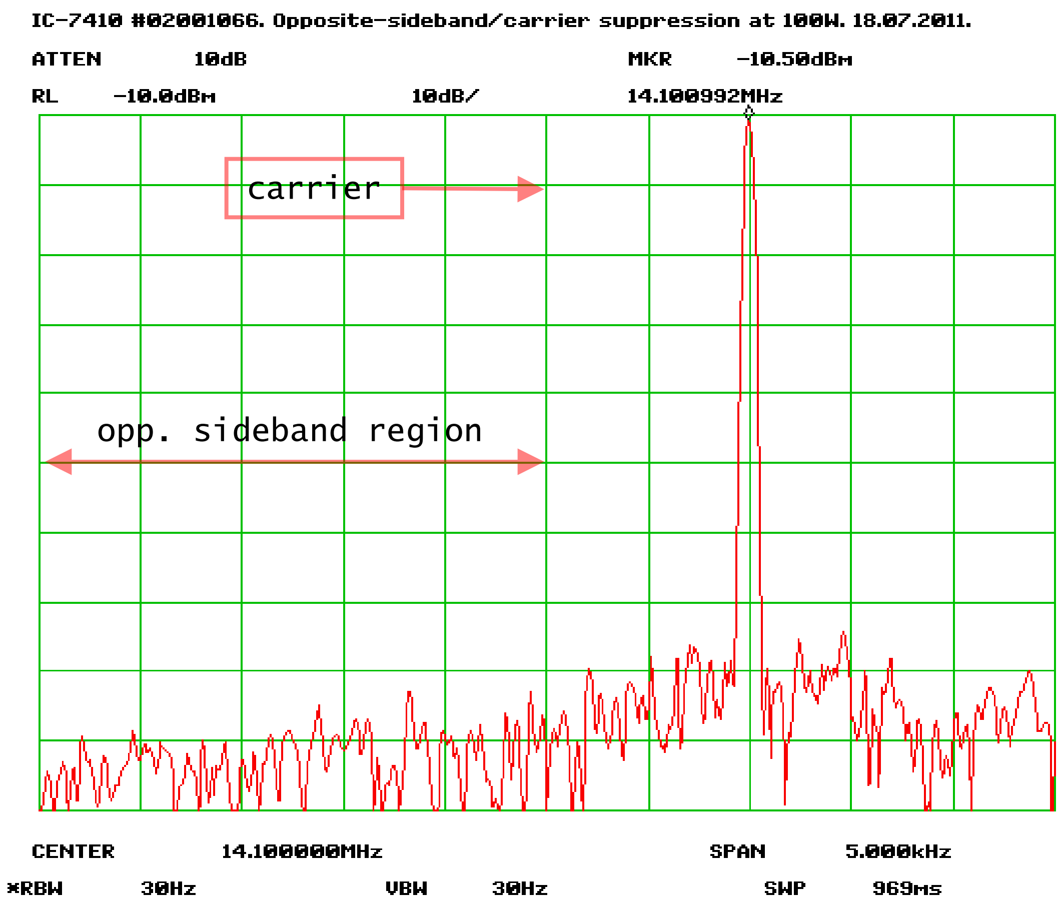


Typical carrier/opposite sideband suppression test (IC-7410)



Transmitter:
how clean is my signal?

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- **SSB 2-tone intermodulation (IMD):**
  - Measured at rated PEP output, with 2-tone generator & spectrum analyzer.
  - 3^{rd}, 5^{th}, 7^{th}, 9^{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).
  - Acceptable: -30 dB. Good: -35 dB. Excellent: < -40 dB. (Worst case.)
- **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)

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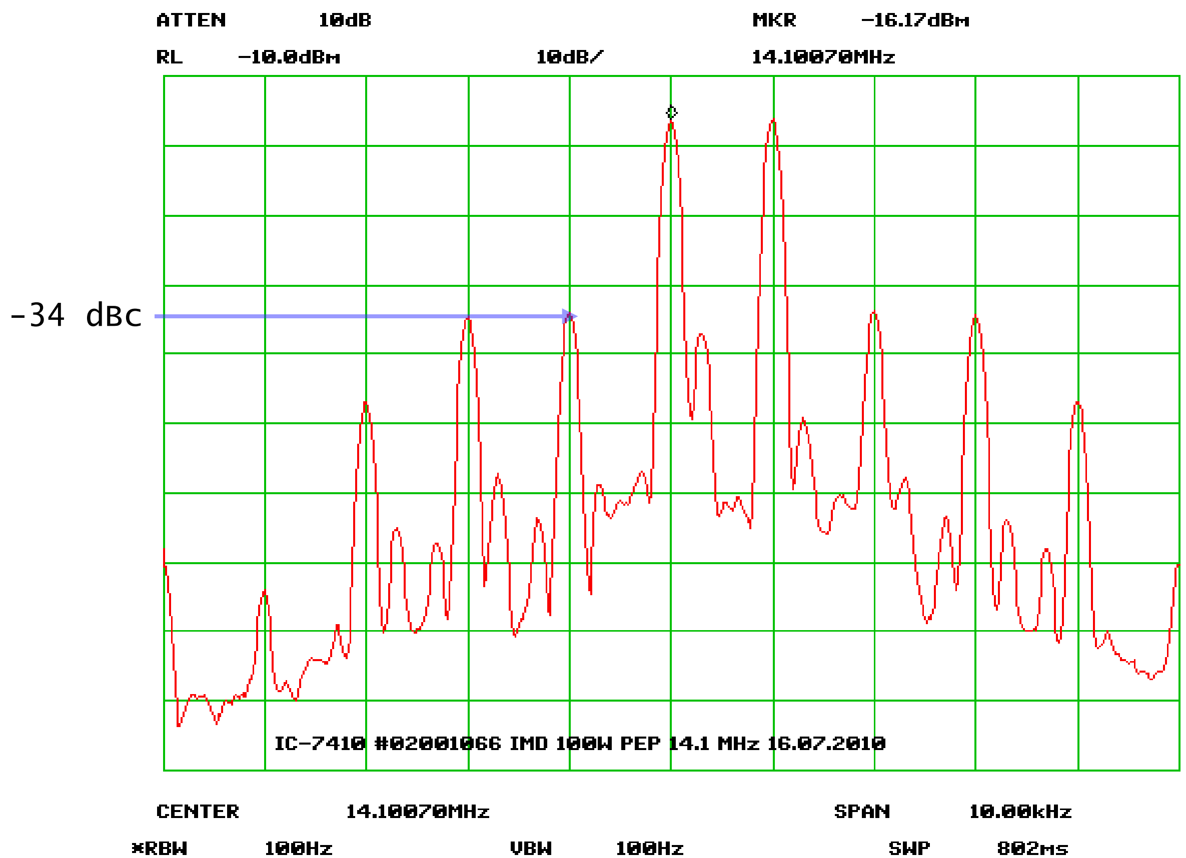
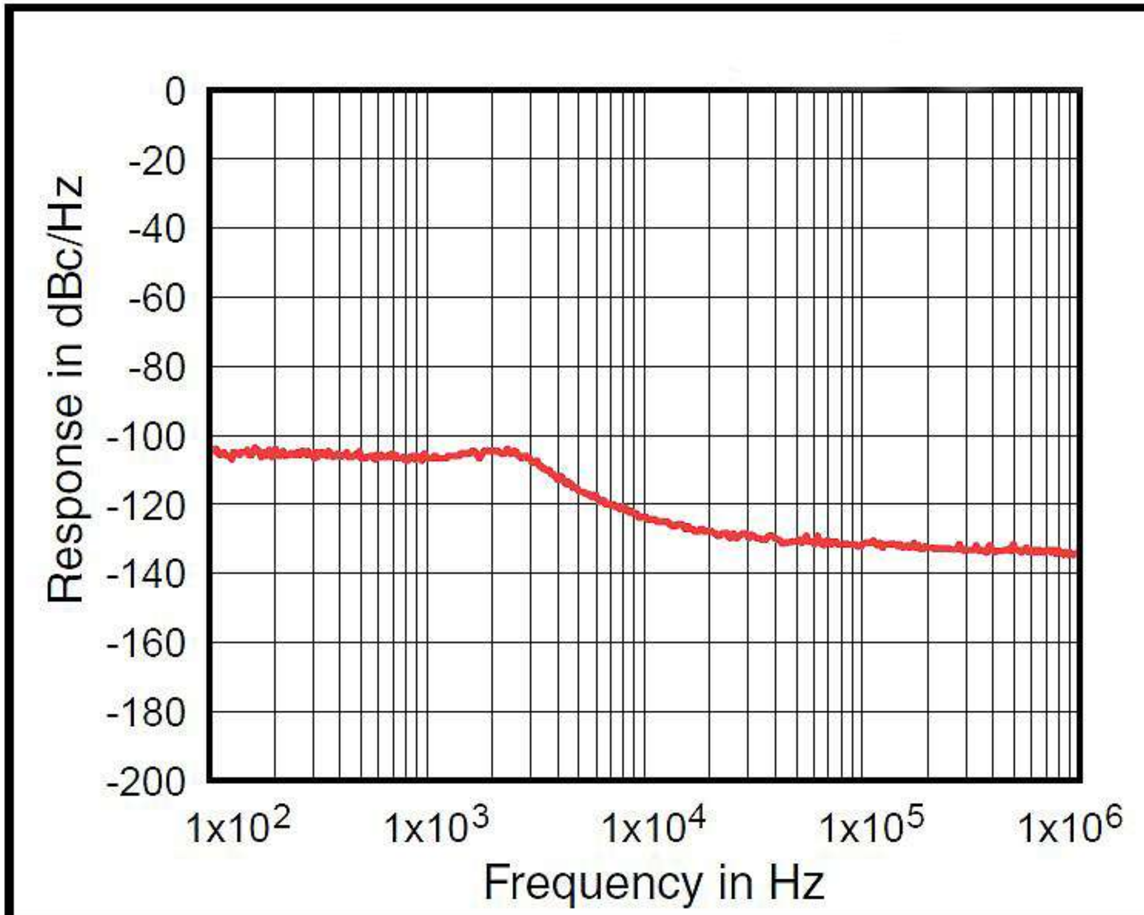


Typical transmitted composite noise plot (IC-7410)



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)

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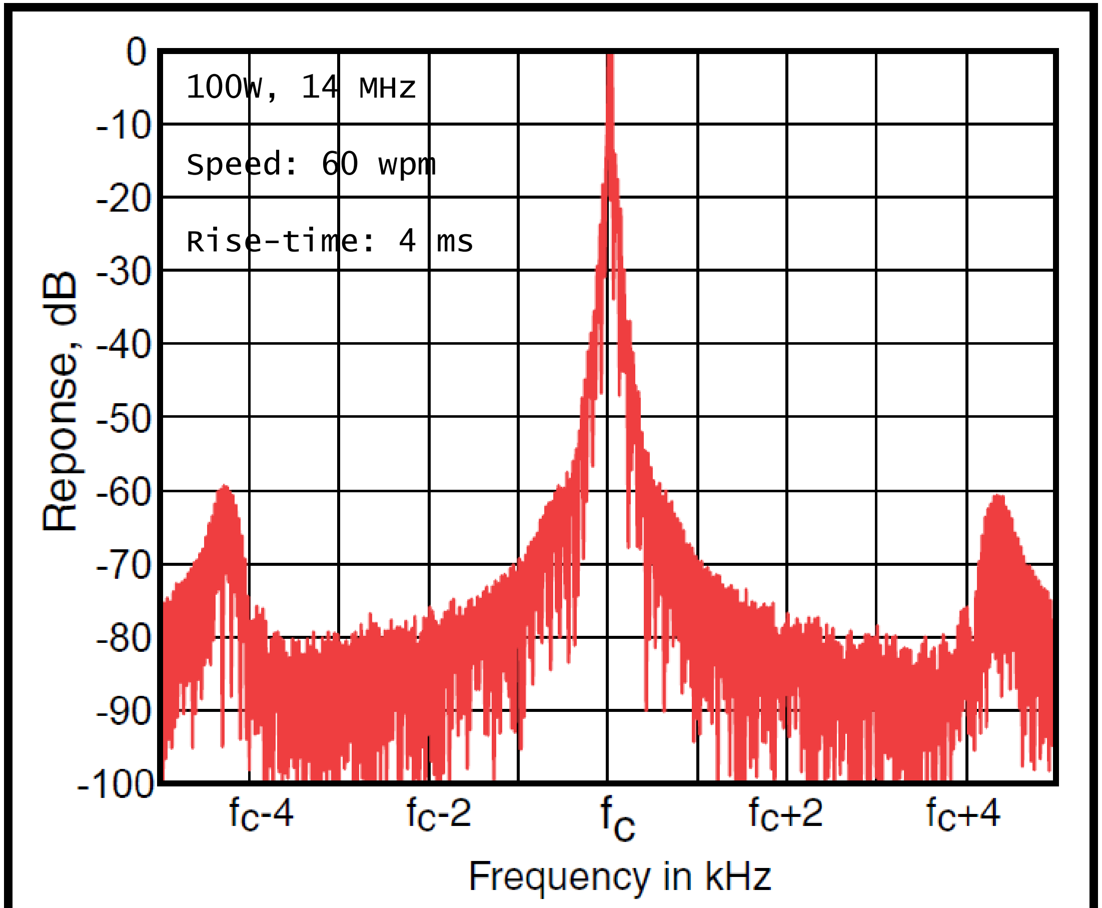

Typical plot of CW keying envelope (IC-7410)

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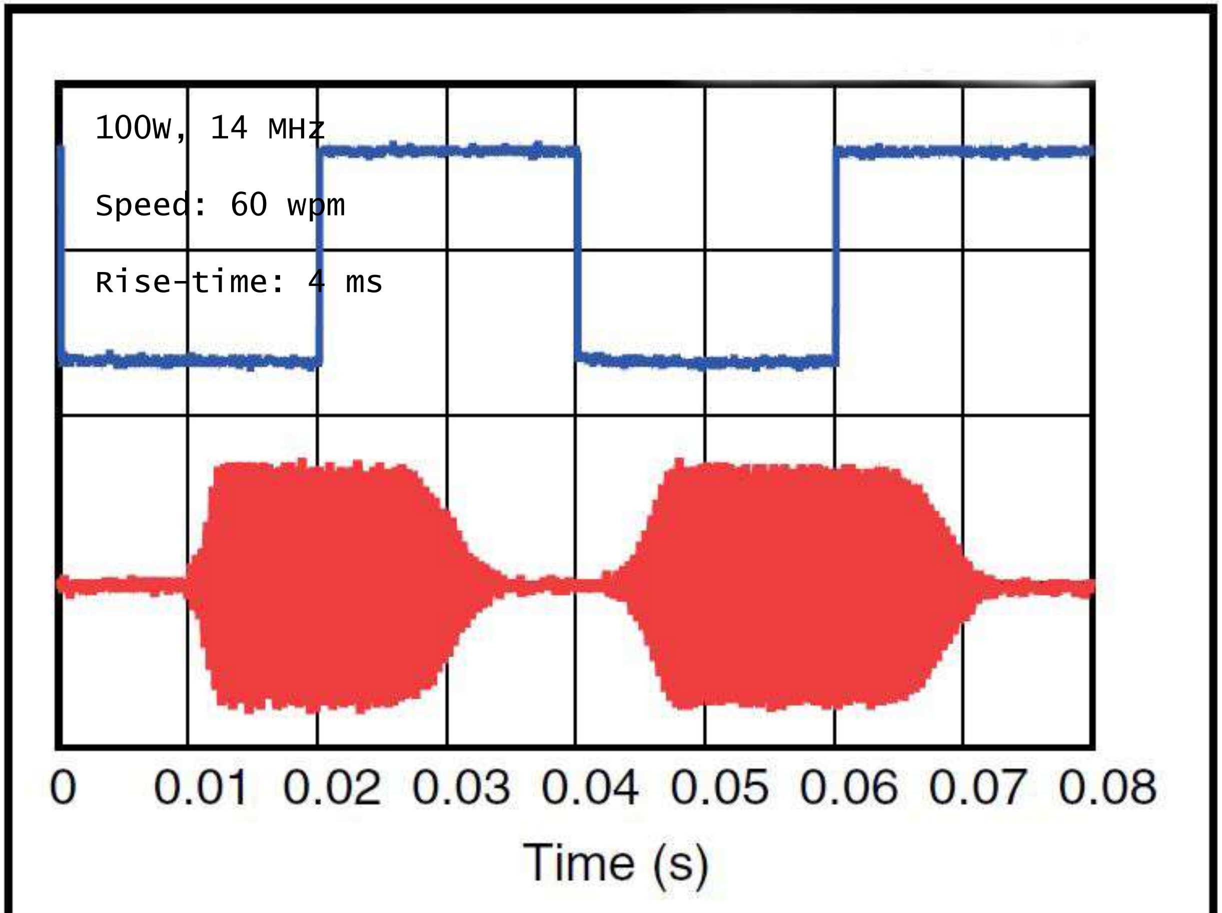

Thanks for watching!

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- **Link for further study:**
  - **ARRL Test Procedures Manual, 2010 Edition**