Receiver Performance Transmitted BW Contest Fatigue

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Limitations to a better contest score may not always be obvious.

- **What is important in a contest environment?**
- Good Dynamic Range to hear weak signals in the presence of near-by strong signals.
- Be a good neighbor: i.e. Have a clean signal.
- Subtle factors affect receiver performance, but are never tested or even discussed by ARRL.
- You need a better receiver for CW than for SSB.
- **New technology is not automatically better.**
- Minimize fatigue factors to maximize you score.

What Parameter is Most Important for a CW Contester?

- Close-in Dynamic Range (DR3)
- (We have to know the noise floor to calculate Dynamic Range)

What is Noise Floor?

Sensitivity is a familiar number, normally applies to SSB.

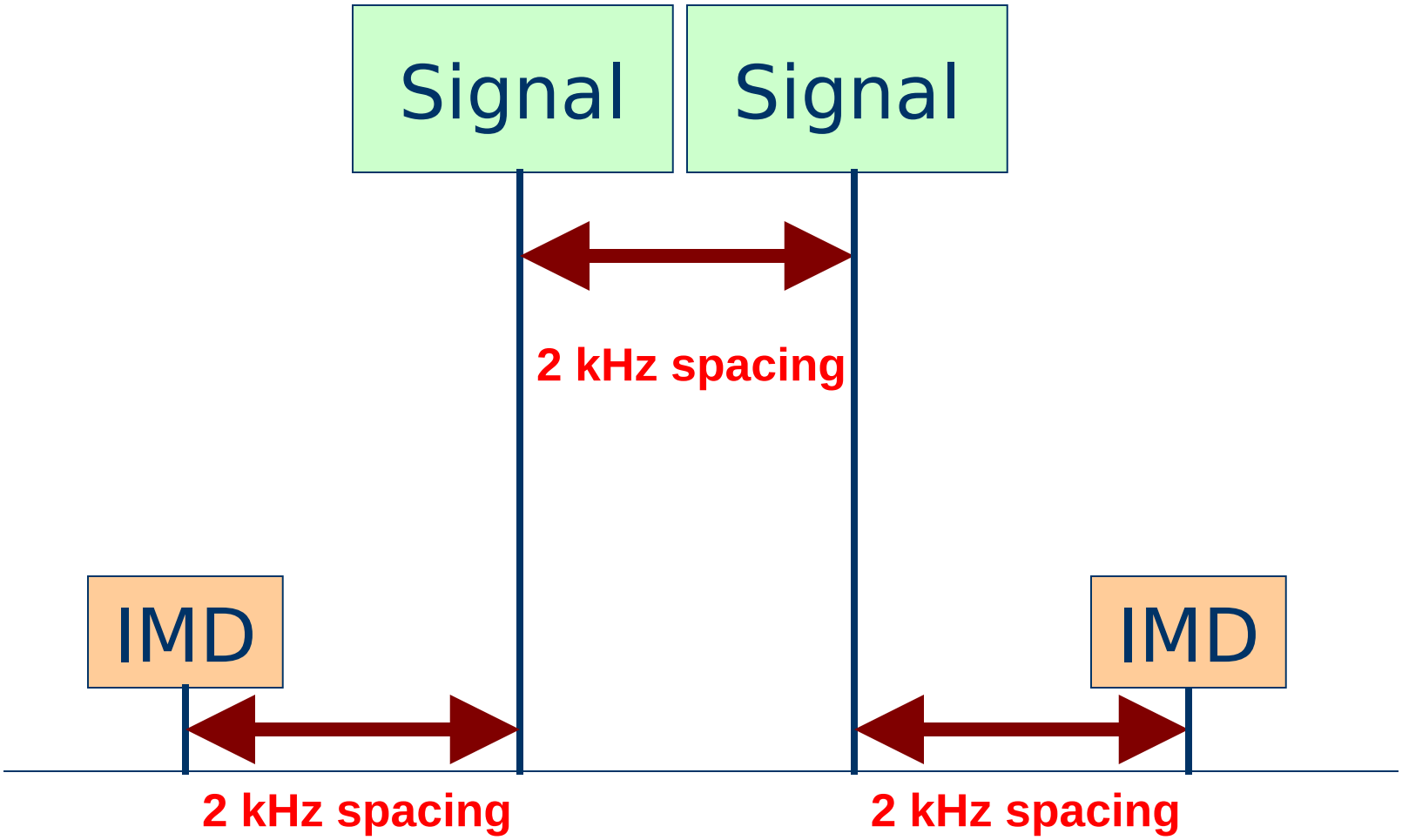
Sensitivity = 10 dB Signal + Noise / Noise (10 dB S+N/N)

Noise Floor = 3 dB Signal + Noise / Noise (3 dB S+N/N)

Noise floor can be measured at any filter bandwidth, CW or SSB, for example, and is bandwidth dependent.

League normally only publishes noise floor for a CW bandwidth, typically 500 Hz CW filter.

Third Order IMD



What is Dynamic Range?

The range in dB of very strong signals to very weak signals that the receiver can handle At The Same Time

What is Close-in Dynamic Range vs

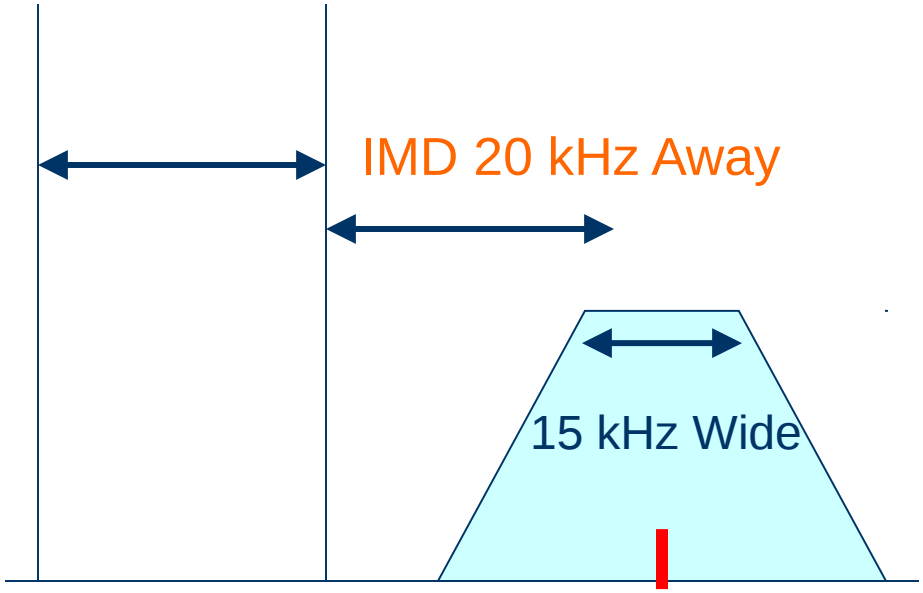
Wide-Spaced Dynamic Range?

Why is Close-in Dynamic so important for CW ops?

Why is it less important for SSB operators?

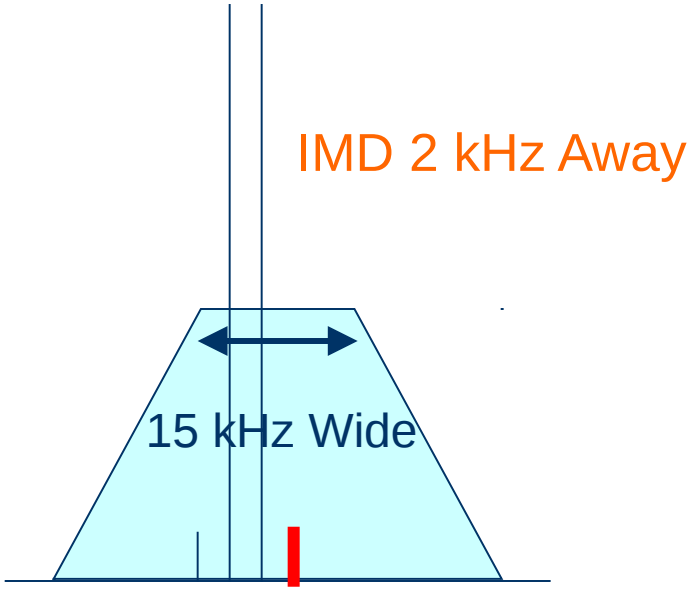
Wide & Close Dynamic Range

20 kHz Spacing



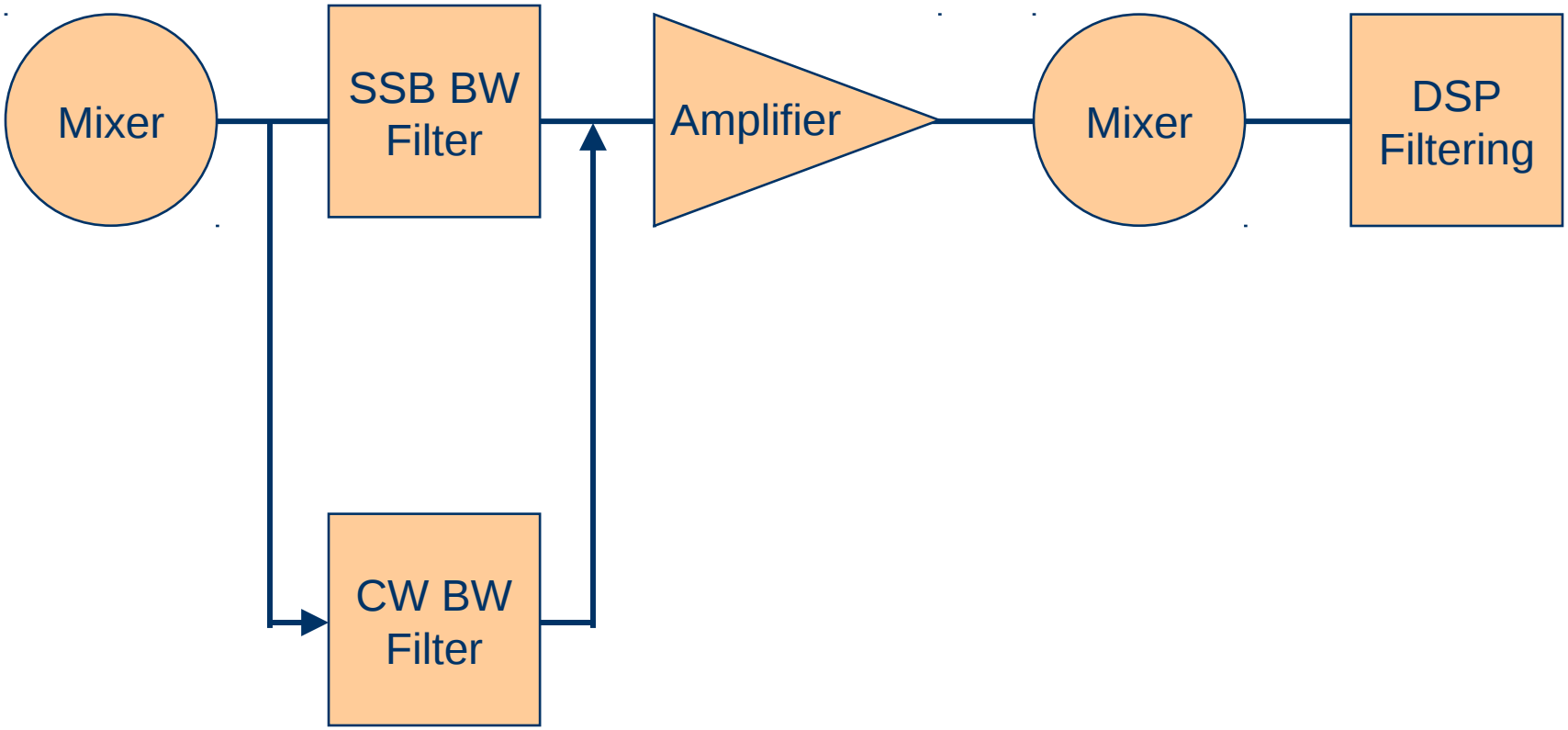
First IF Filter at 70.455 MHz

2 kHz Spacing



First IF Filter at 70.455 MHz

Highest performance with a bandwidth appropriate filter right up front after the first mixer, such as Orion & K3.



This keeps the undesired strong signals from progressing down stream to the next stages.

When are 2 Out of Pass Band Signals a Problem?

- If you know the close-in dynamic range of a radio, at what signal level will IMD start to be a problem?
- S Meter standard is S9 = 50 μV, which is –73 dBm
- Assume a typical radio:
  - 500 Hz CW filter
  - Noise Floor of -128 dBm
  - Preamp OFF

Dynamic Range	Signal Level Causing IMD = Noise Floor	
55 dB	S9	FT-757 (56 dB)
60 dB	S9 + 5 dB	FT-2000 (61 dB)
65 dB	S9 + 10 dB	IC-7000 (63 dB)
70 dB **Typical Up-conversion**	S9 + 15 dB	1000 MP / Mk V Field (68 / 69 dB)
75 dB	S9 + 20 dB	756 Pro II / III (75 dB)
80 dB	S9 + 25 dB	Omni-VII / IC-7800 (80 dB)
85 dB	S9 + 30 dB	R9500 (85 dB)
90 dB	S9 + 35 dB	Flex 3000 (90 dB)
95 dB	S9 + 40 dB	Orion II & Flex 5000A (95 / 96 dB)
100 dB	S9 + 45 dB	K3 (95 to 101 dB, roofing filter)

List of 70* dB Dynamic Range Radios

- * Radios listed between 72 dB and 68 dB, descending order
- Collins 75S-3C
- IC-756 Pro
- Drake R8
- IC R9000
- IC-761
- TS-830S
- TS-870S
- FT-1000 Mk V Field
- TS-430S
- FT-1000 MP
- CX-11A
- TS-180S
- TR-4C
- IC-735

The DR3 “window” is not fixed

The dynamic range of a radio is the same with an attenuator ON or OFF.

If on a noisy band, attenuate the noise and all signals to make better use of the dynamic range, and reduce the chance of overload.

If band noise goes from S6 to S2 by turning on the attenuator, you have lost nothing, yet your radio is being stressed much less.

A Comment on IP3 (3rd Order Intercept)

I don't publish IP3. It is a theoretical number.

It has more meaning for a block amplifier or mixer.

Almost meaningless if the AGC of a receiver is involved

October 2007 QST Product Review FT-2000D

DR3	Spacing	Level	IP3
98 dB	20 kHz	Noise Floor	+25 dBm
69 dB	2 kHz	Noise Floor	-19 dBm
29 dB	2 kHz	0 dBm = S9+73 dB	+15 dBm

Attenuators, Preamps & IP3

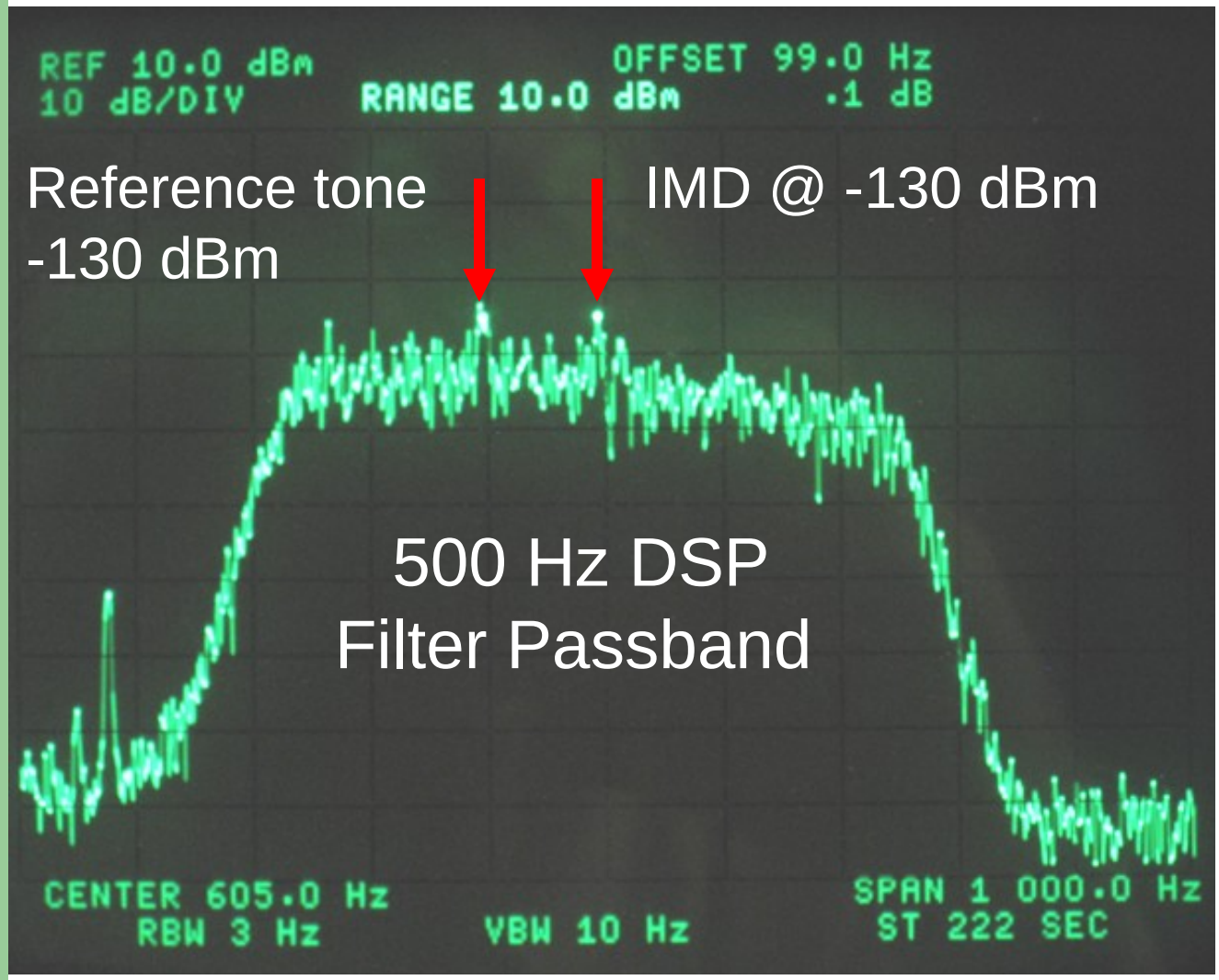
Dynamic range is constant if you enable an attenuator and nearly constant with a preamp enabled. IP3 varies all over the map. Data from March QST 2008 FT-950

Gain	Dynamic Range	IP3 dBm	
Pre 2	95	+4	(published)
Pre 1	95	+13	(published)
No Preamp	94	+22	(published)
Att 6 dB	94	+28	(calculated)
Att 12 dB	94	+34	(calculated)
Att 18 dB	94	+40	(calculated)

Bogus ARRL Dynamic Range Numbers

- Many modern transceivers are phase noise limited, particularly close-in at 2 kHz. The League wanted be able to measure the IMD buried in the phase noise, and came up with a new method a few years ago using a spectrum analyzer with a 3-Hz filter.

IC-7600 with 3-Hz Spectrum Analyzer



Phase noise limited dynamic range is 78 dB at 2 kHz.

Measured with a 3-Hz filter on the analyzer, the dynamic range is 87 dB at 2 kHz!

What the New ARRL DR3 Method Means

- Old method, IMD or noise increased 3 dB.
- This was DR3, either IMD or noise limited.
- With the new method, noise increased 10 dB, and by ear you hear nothing but noise.
- Unless you work a contest using a 3-Hz CW filter, the League dynamic range measurement is meaningless.
- IC-7600, as an example, the new method increases the DR3 from 78 dB to 87 dB!

IC-7800 ARRL Old vs. New Method

- 4/18/2006 IC-7800 test data, old method
- 2 kHz, Phase Noise Limited @ 80 dB
- 1 kHz, Phase Noise Limited @ 67 dB

- 2/6/2007 IC-7800 test data, new method
- 2 kHz, dynamic range = 86 dB
- No measurement at 1 kHz.

- Number inflation to keep the advertisers happy? You decide?

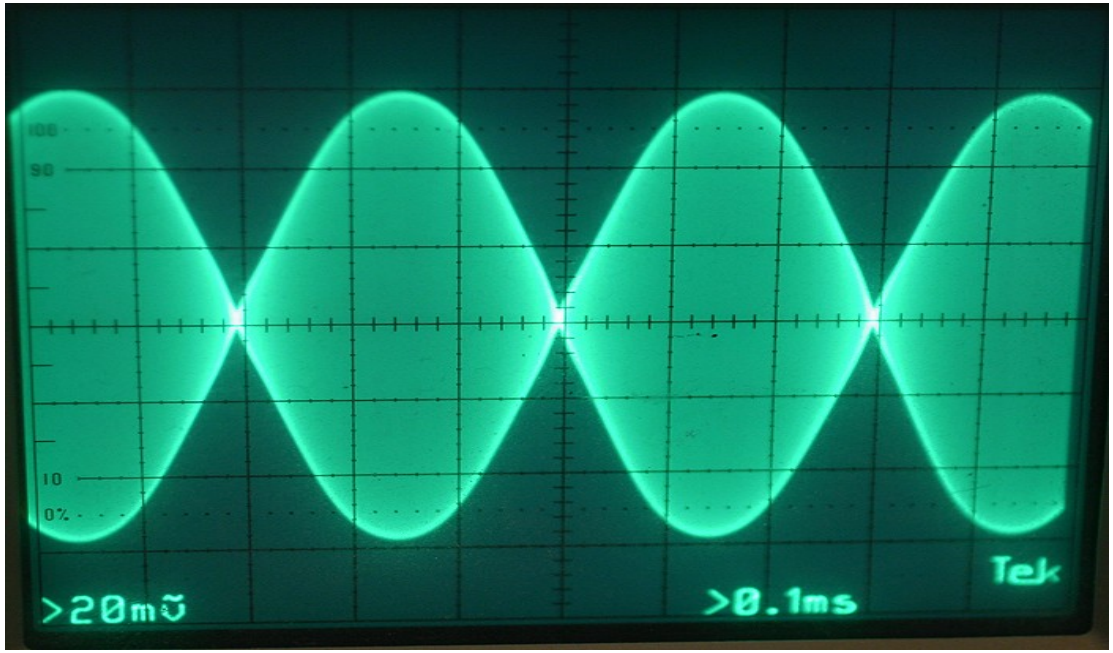
Flex 3000 Old Method vs. 3 Hz Filter

- Flex 3000 with Old Method: DR3 = 90 and is completely phase noise limited.
- Flex 3000 with 3 Hz Spectrum Analyzer method measures a dynamic range between 95 and 99 dB, depending on the spacing.
- The Orion II and the K3 perform better, but now you cannot tell that by the numbers.

Lets now move from CW to SSB

Why are the dynamic range requirements less stringent on SSB than on CW?

Let’s look at 2-Tone IMD Tests.

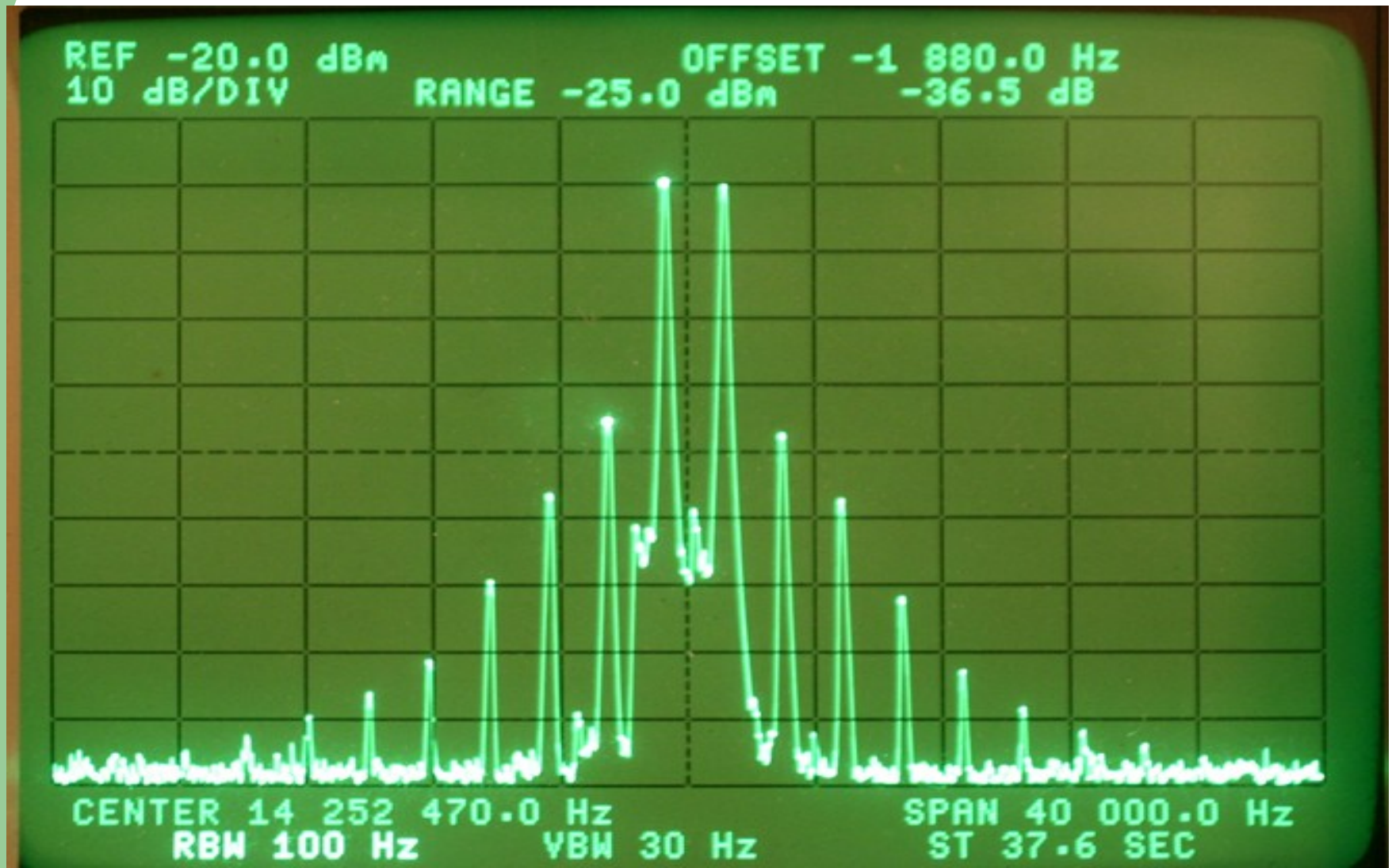


Normal time domain scope picture.

My cleanest transmitter

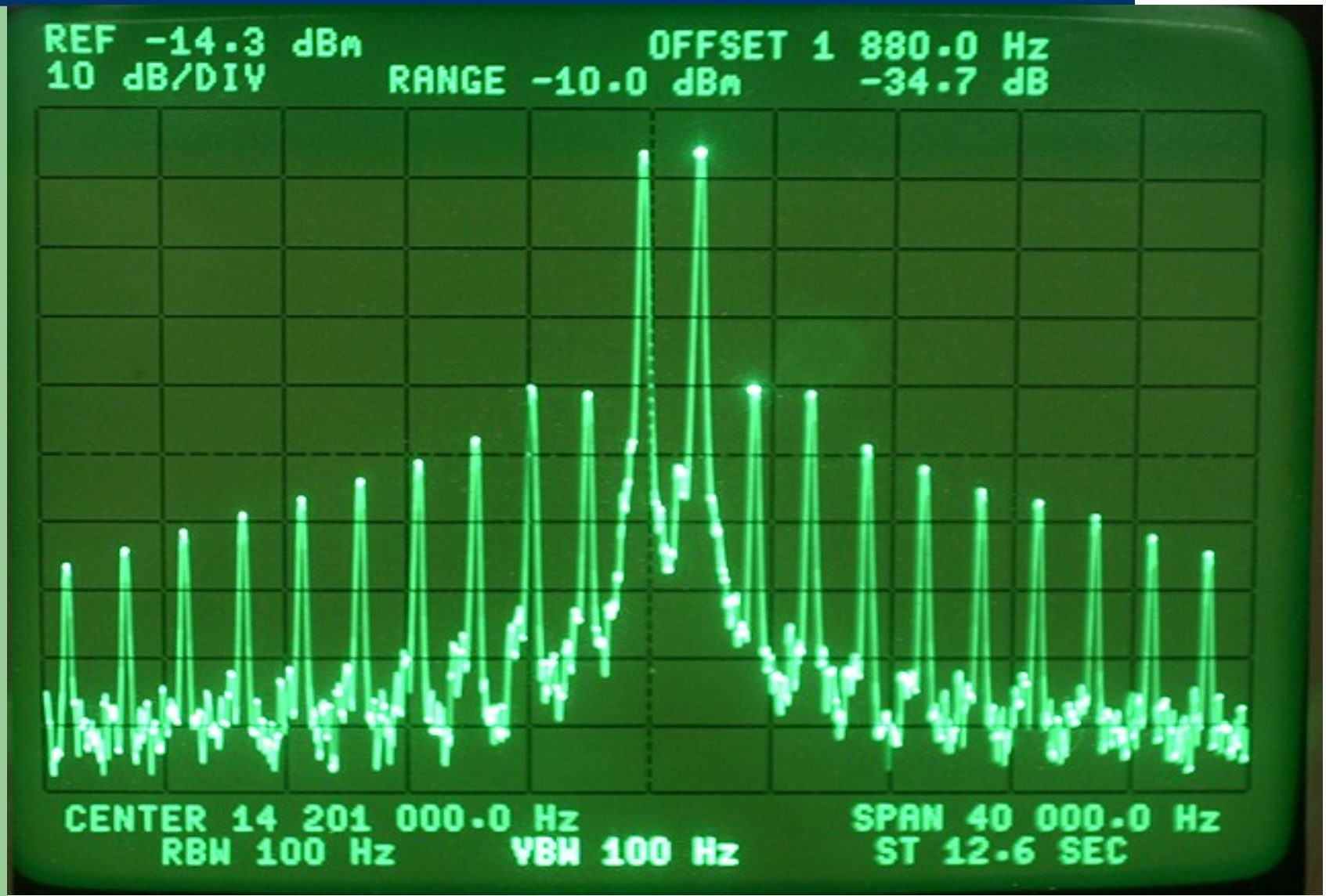
-36 dB 3rd Order, -60 dB 7th Order

Collins 32S-3 on 20 meters @ 100 W



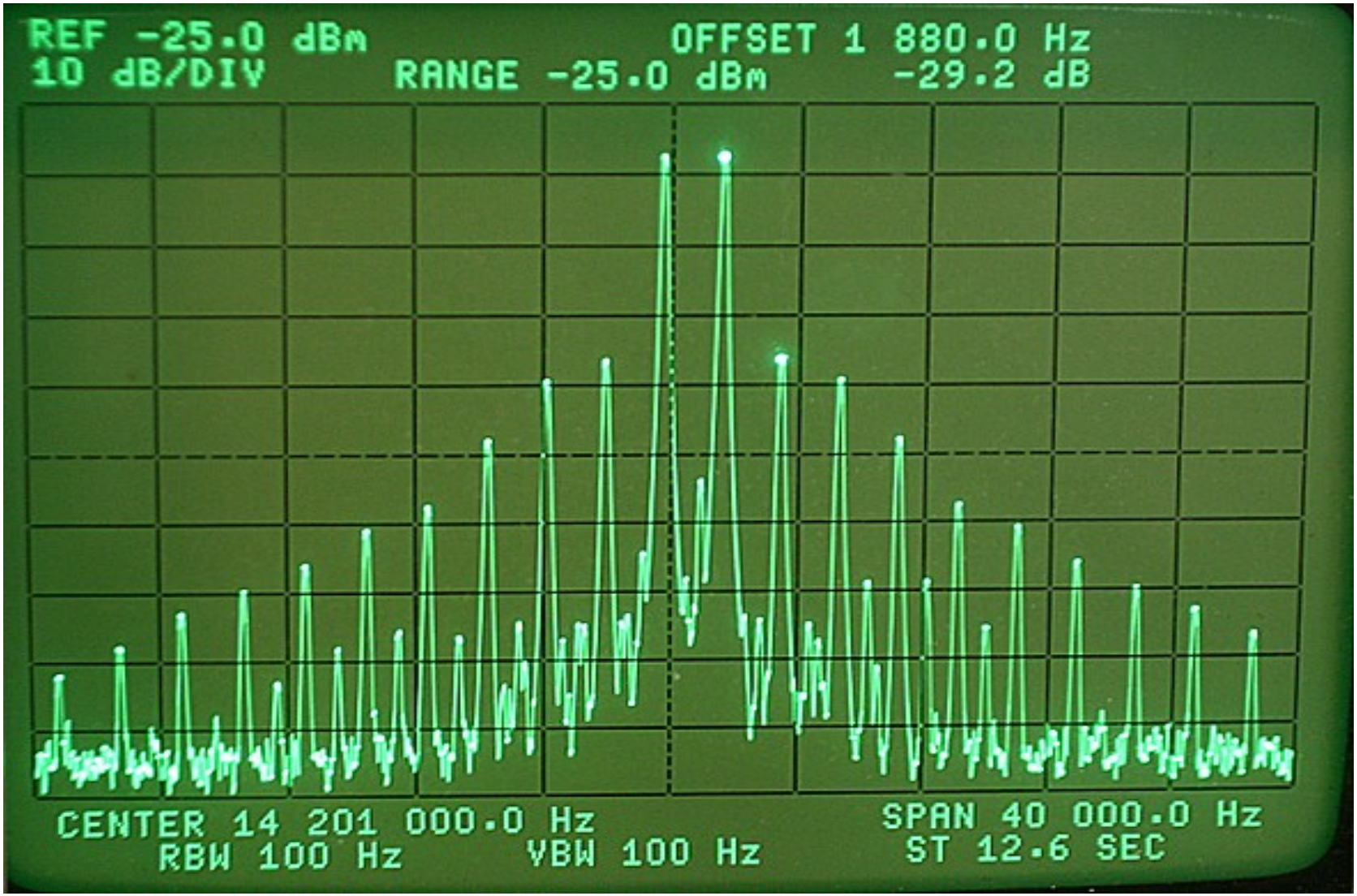
-34 dB 3rd order, -43 dB 7th order

Icom 781 on 20 meters @ 150 Watts



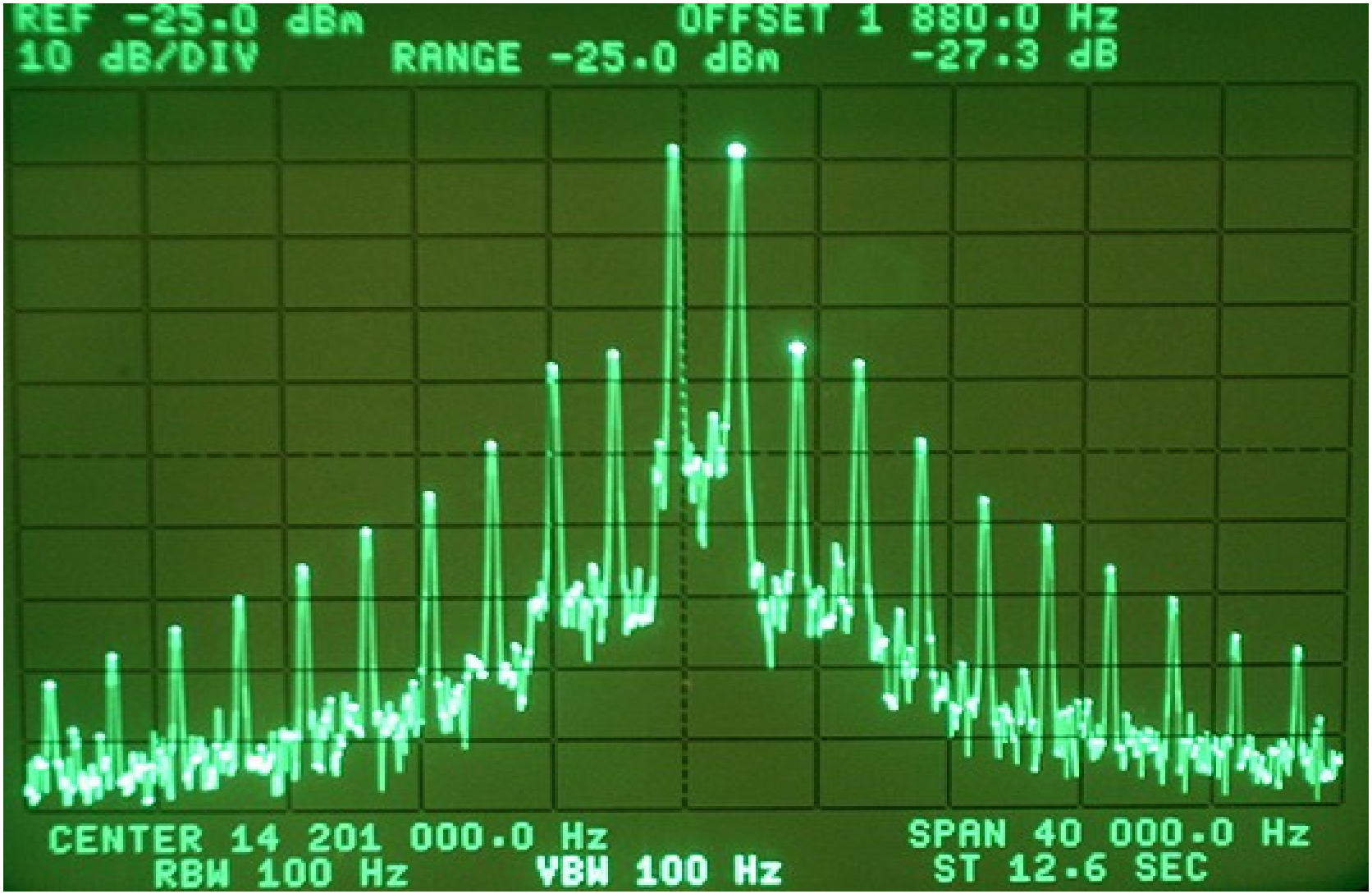
-29 dB 3rd order, -41 dB 7th order

Flex 5000A on 20 meters @ 70 Watts



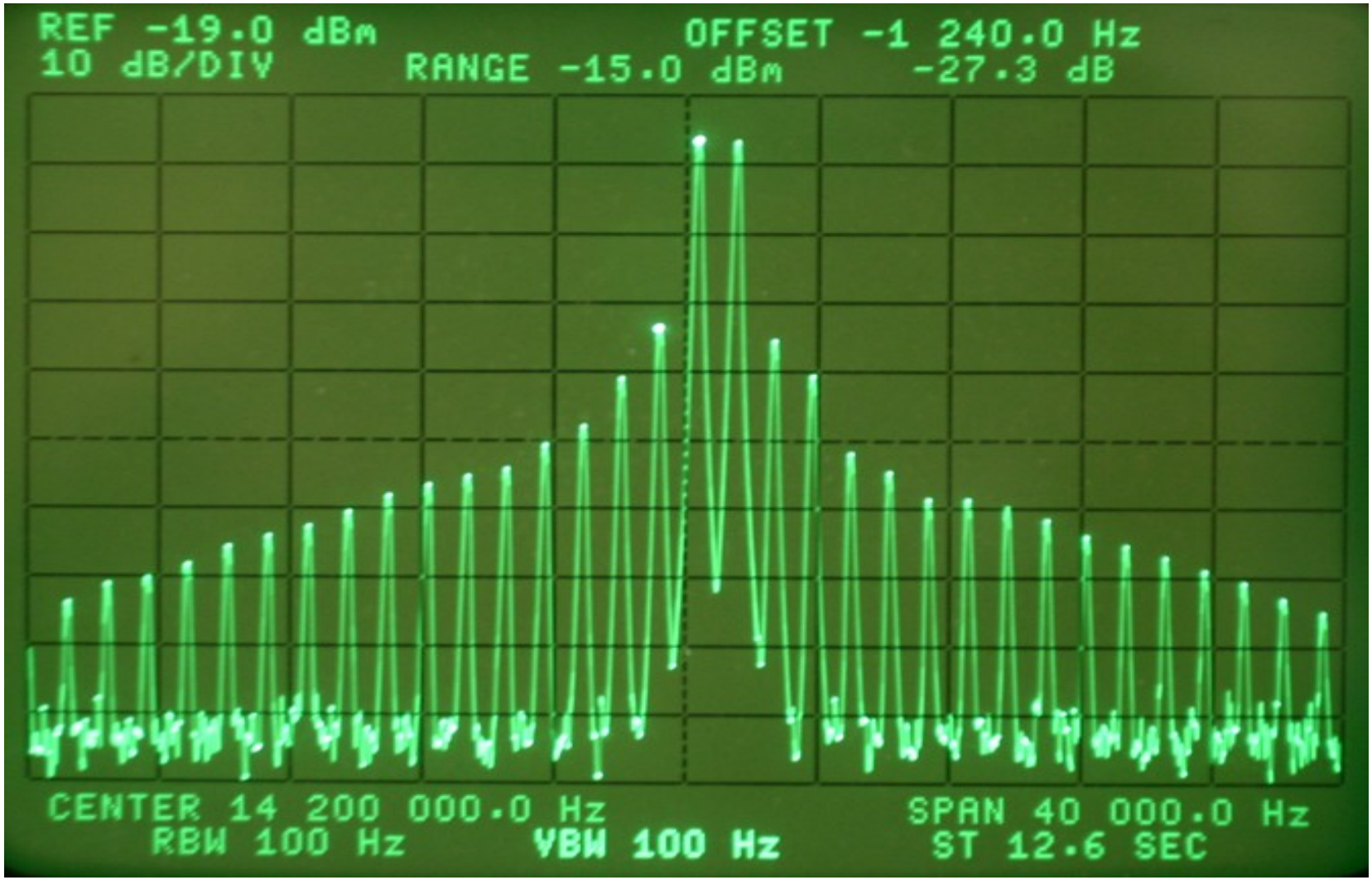
-27 dB 3rd order, 40 dB 7th order

Icom 756 Pro III on 20 meters @ 70 W



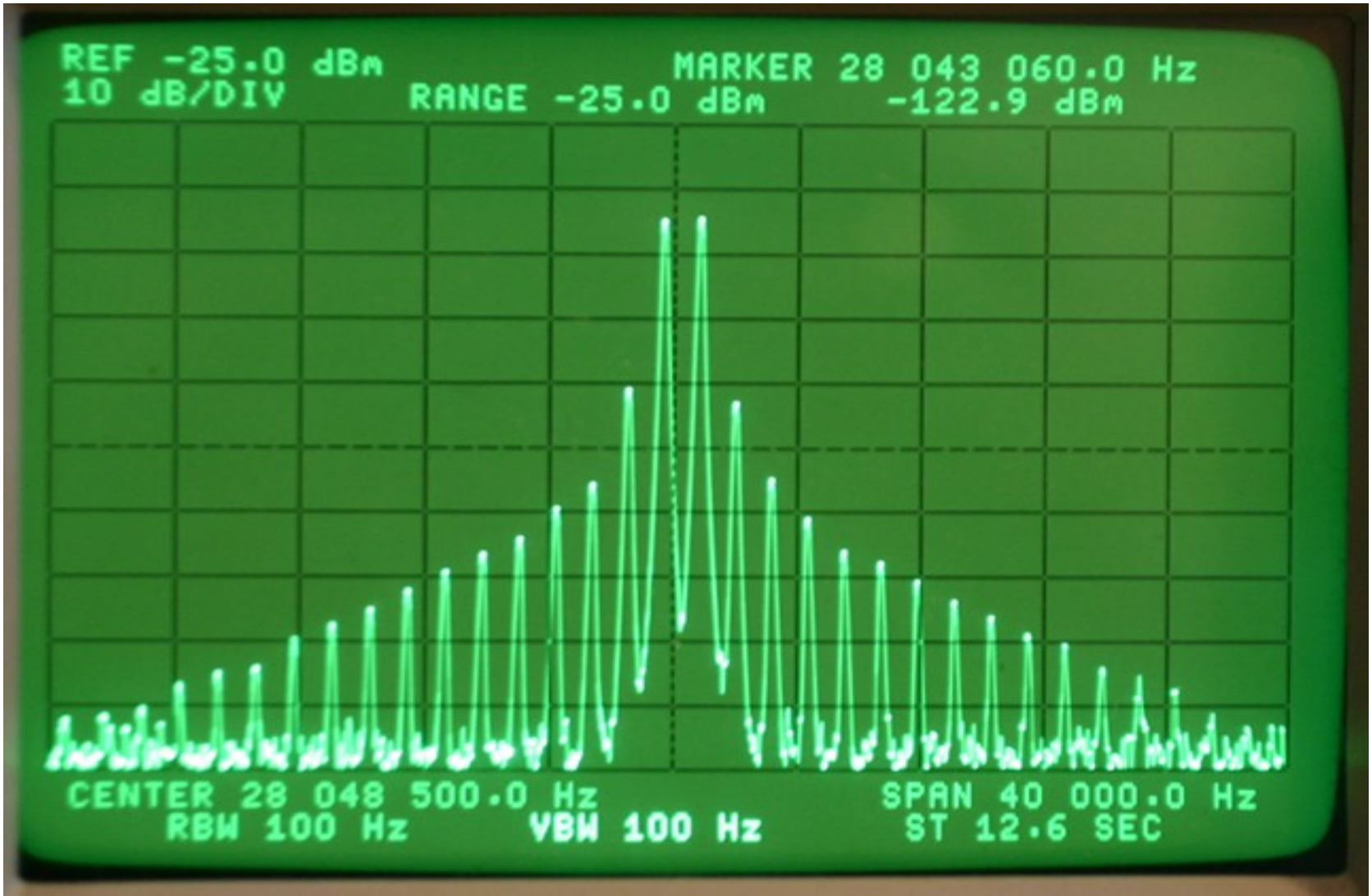
-27 dB 3rd order, -42 dB 7th order

K3 Transceiver on 20 meters @ 100 W



-27 dB 3rd order, 46 dB 7th order

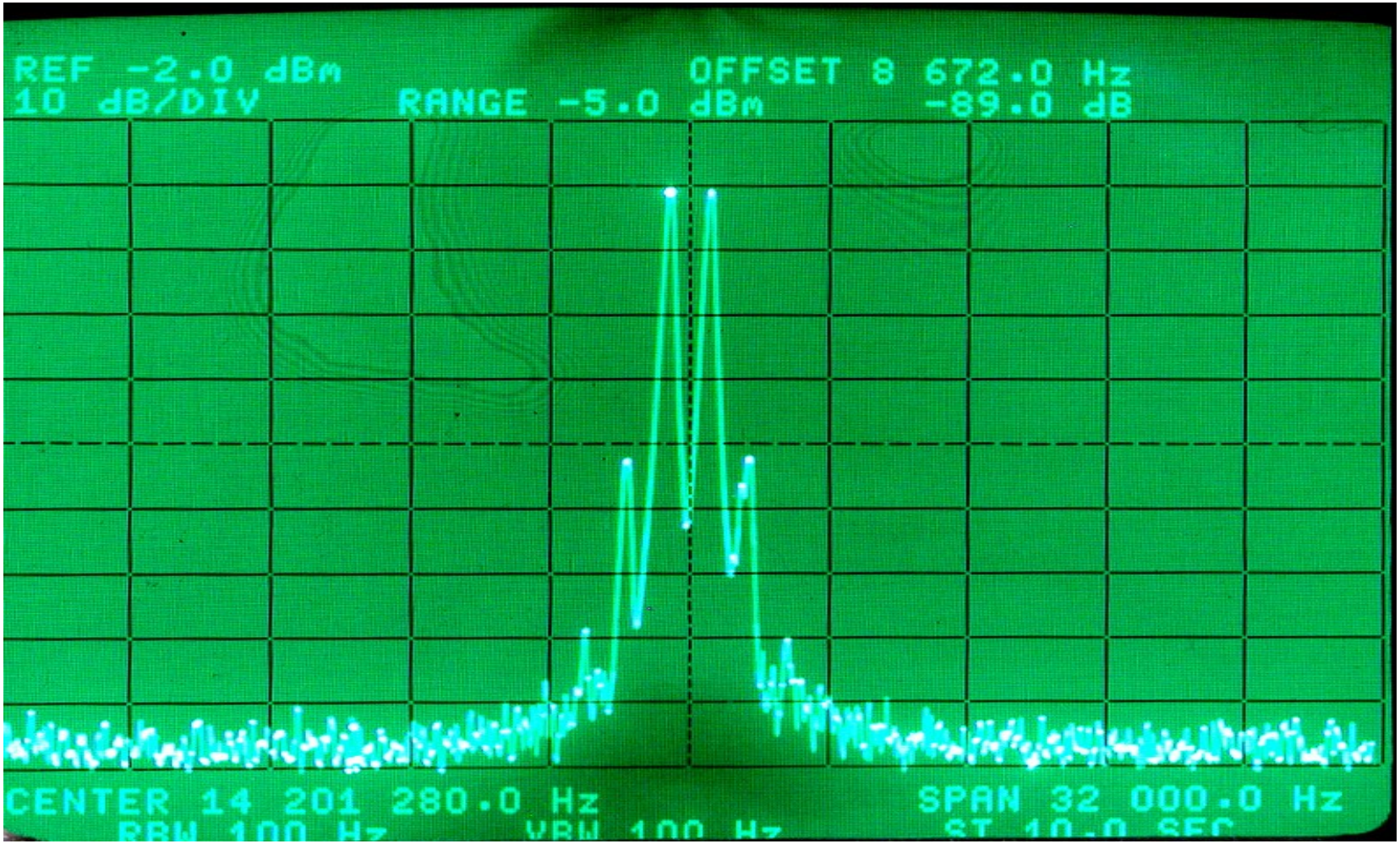
K3 Transceiver on 20 meters @ 50 W



-42 dB 3rd Order, -70 dB 5th Order

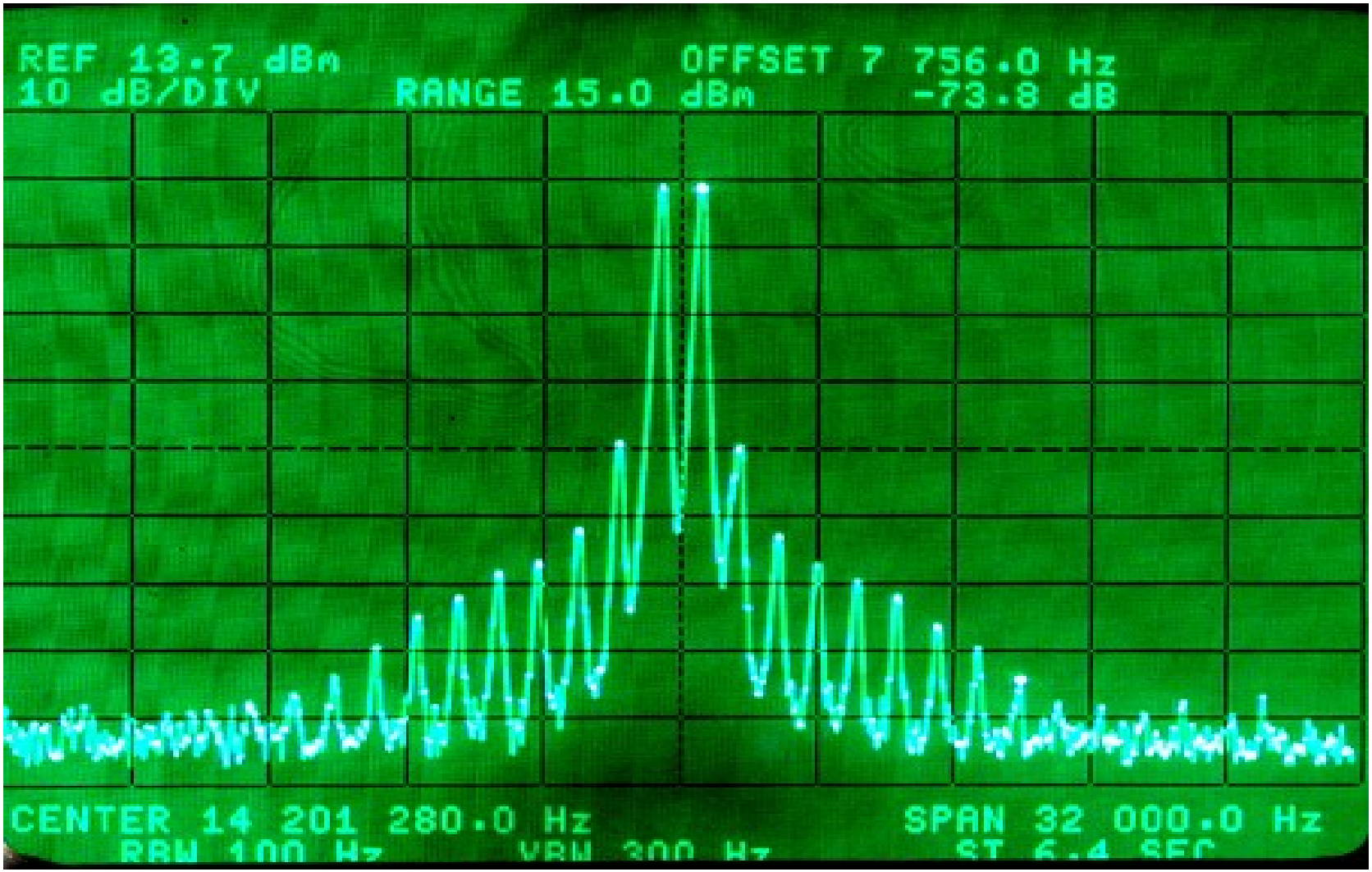
Yaesu FT-1000 Mk V, 20 M, Class A @ 75 W

Provided by Pete, W6XX



-40 dB 3rd Order, -52 dB 5th Order

Mk V Class A + 8877, 20 meters @ 1.5 kW



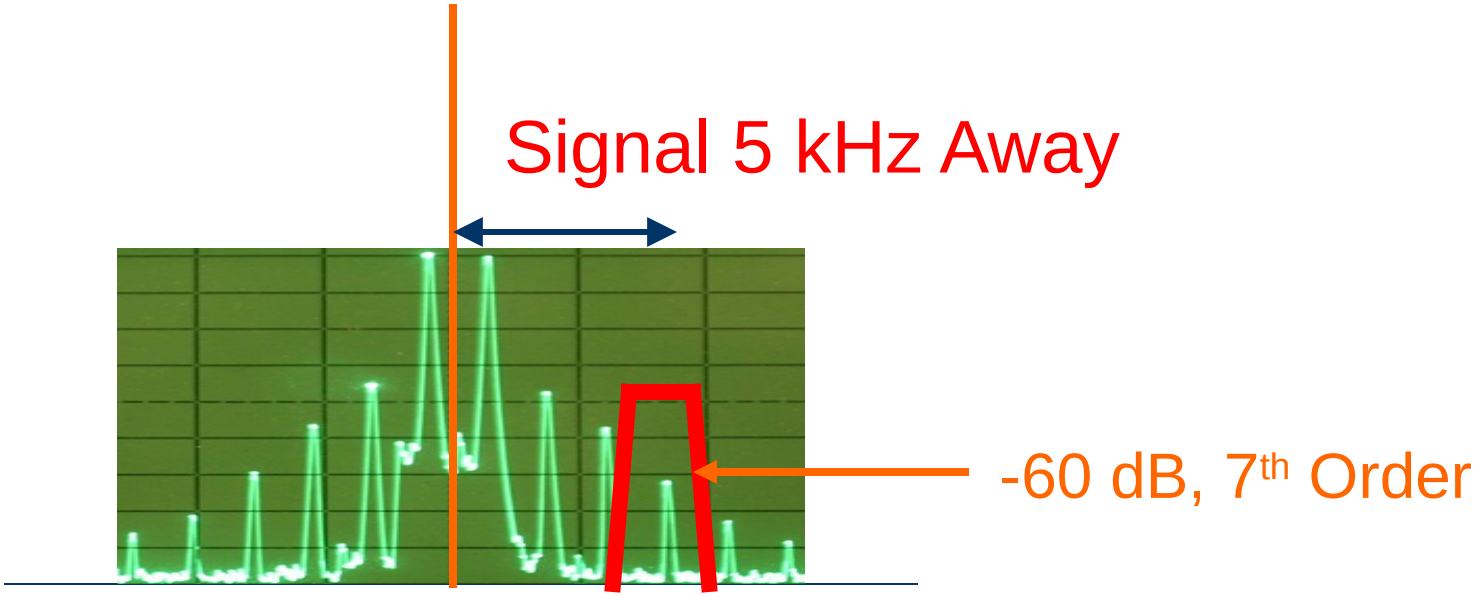
Note: Must add 6 dB to spectrum analyzer IMD measurements to compare to League & OEMs.

Compare the Old vs. New

Order IMD	Collins 32S-3	Yaesu FT-450 QST	Difference in dB
3rd	-42 dB	-30 dB	12 dB
5th	-53 dB	-37 dB	16 dB
7th	-66 dB	-42 dB	24 dB
9th	-77 dB	-48 dB	29 dB

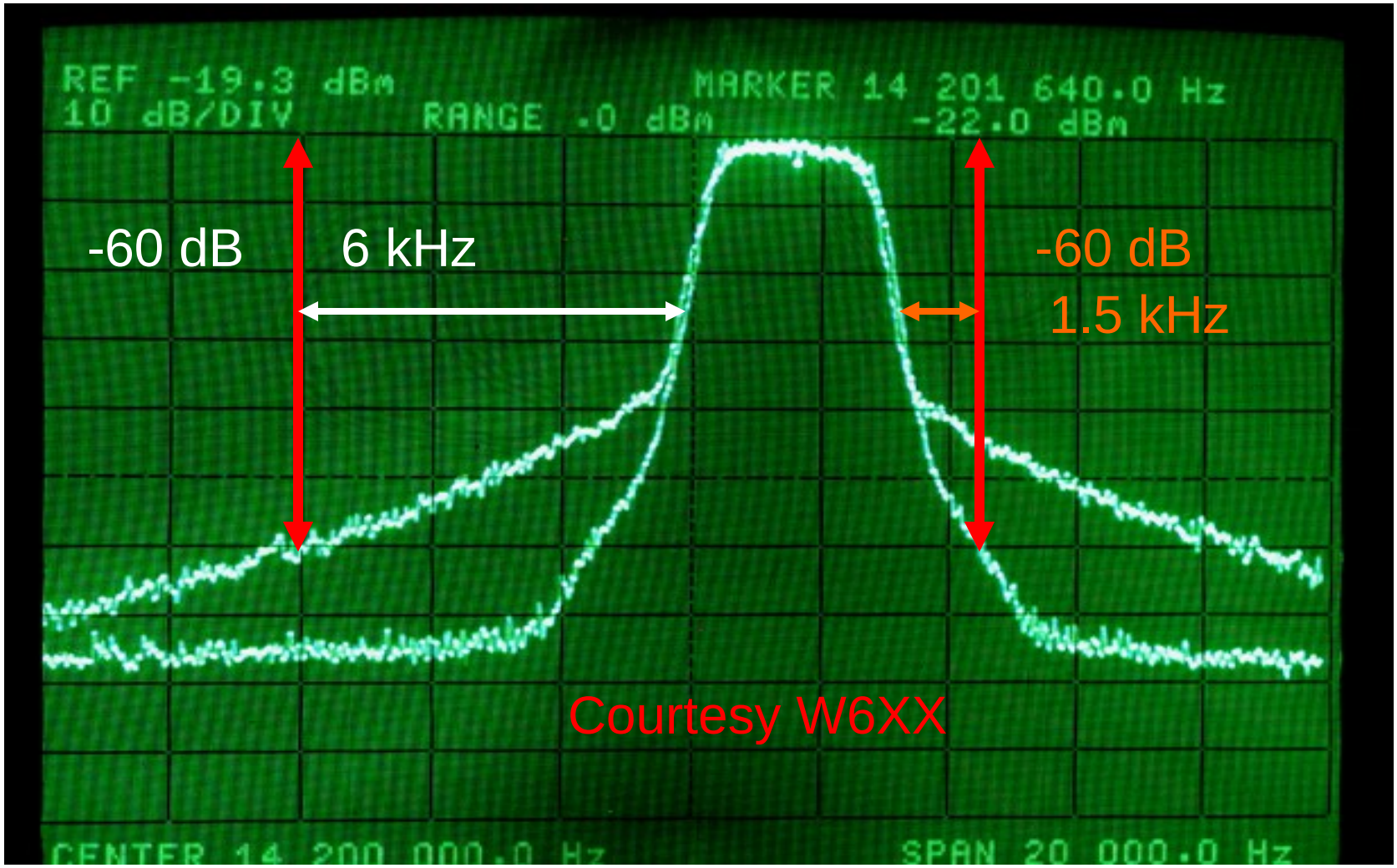
Close-in Signal and Splatter

Typical radio = 70 dB, Typical spatter = 60 dB down



IF Filter vs. Adjacent Signal and IMD Splatter

White Noise Mk V Class A vs. K3 Class B @ 75 Watts



Back to CW signals

We have seen how width of an SSB signal & its IMD products affects how close you can operate to another station.

How does CW compare?

How close can we work to a strong adjacent CW signal?

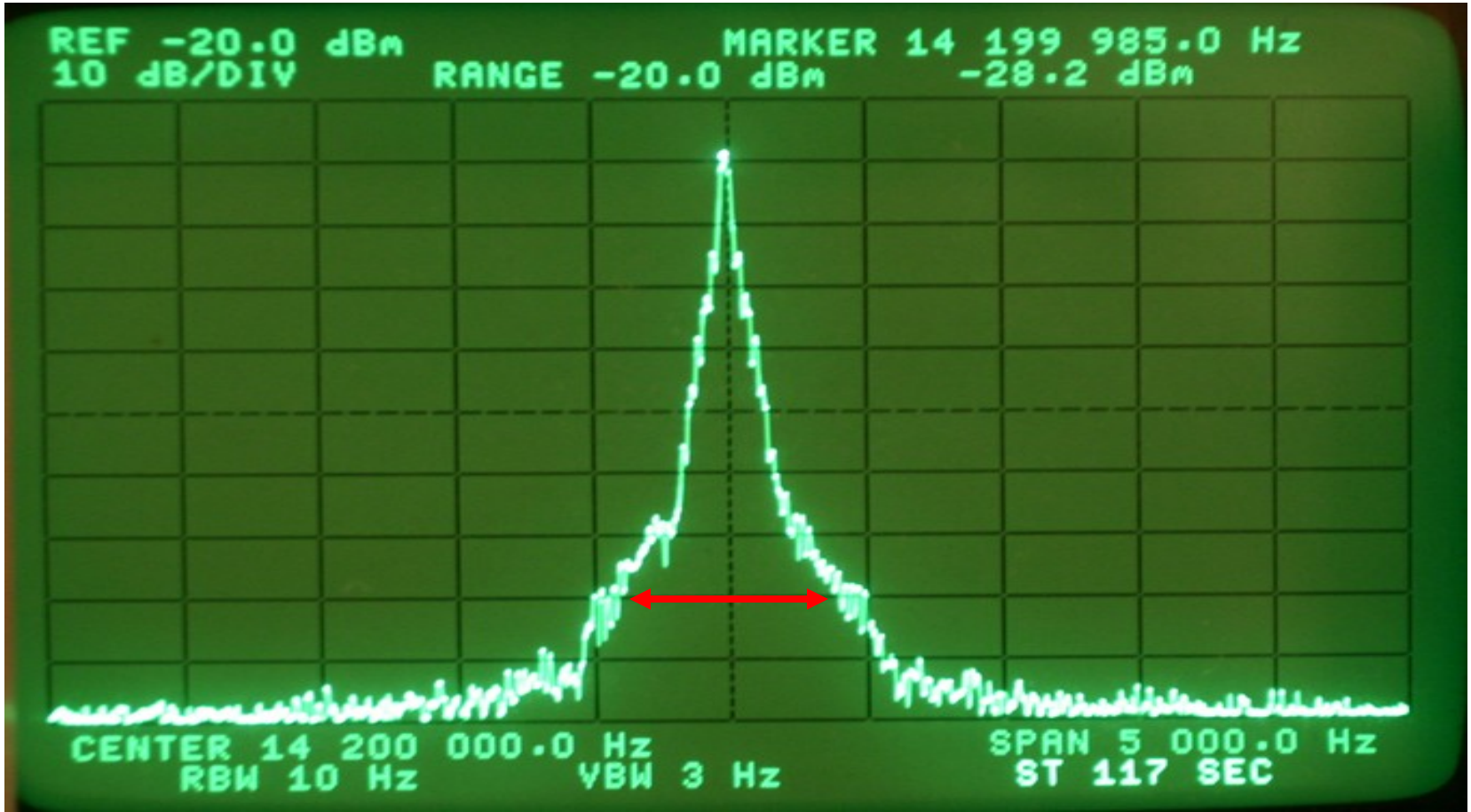
What is the Bandwidth of CW Signal?

On channel signal = S9 + 40 dB (-33 dBm)
Receiver = K3, 400 Hz 8-pole roofing + 400 Hz DSP Filter
Transmitter = Omni-VII with adjustable rise time
Undesired signal 700 Hz away, continuous “dits” at 30 wpm

Rise time of Omni-VII	Strength of CW sidebands		
Signal	S9 + 40	-33 dBm	Ref
3 msec	S7	-83 dBm	-50 dB
4 msec	S6	-88 dBm	
5 msec	S6	-88 dBm	
6 msec	S5	-93 dBm	22 dB !
7 msec	S4	-99 dBm	
8 msec	S4	-99 dBm	
9 msec	S4	-99 dBm	
10 msec	S3	-105 dBm	-72 dB

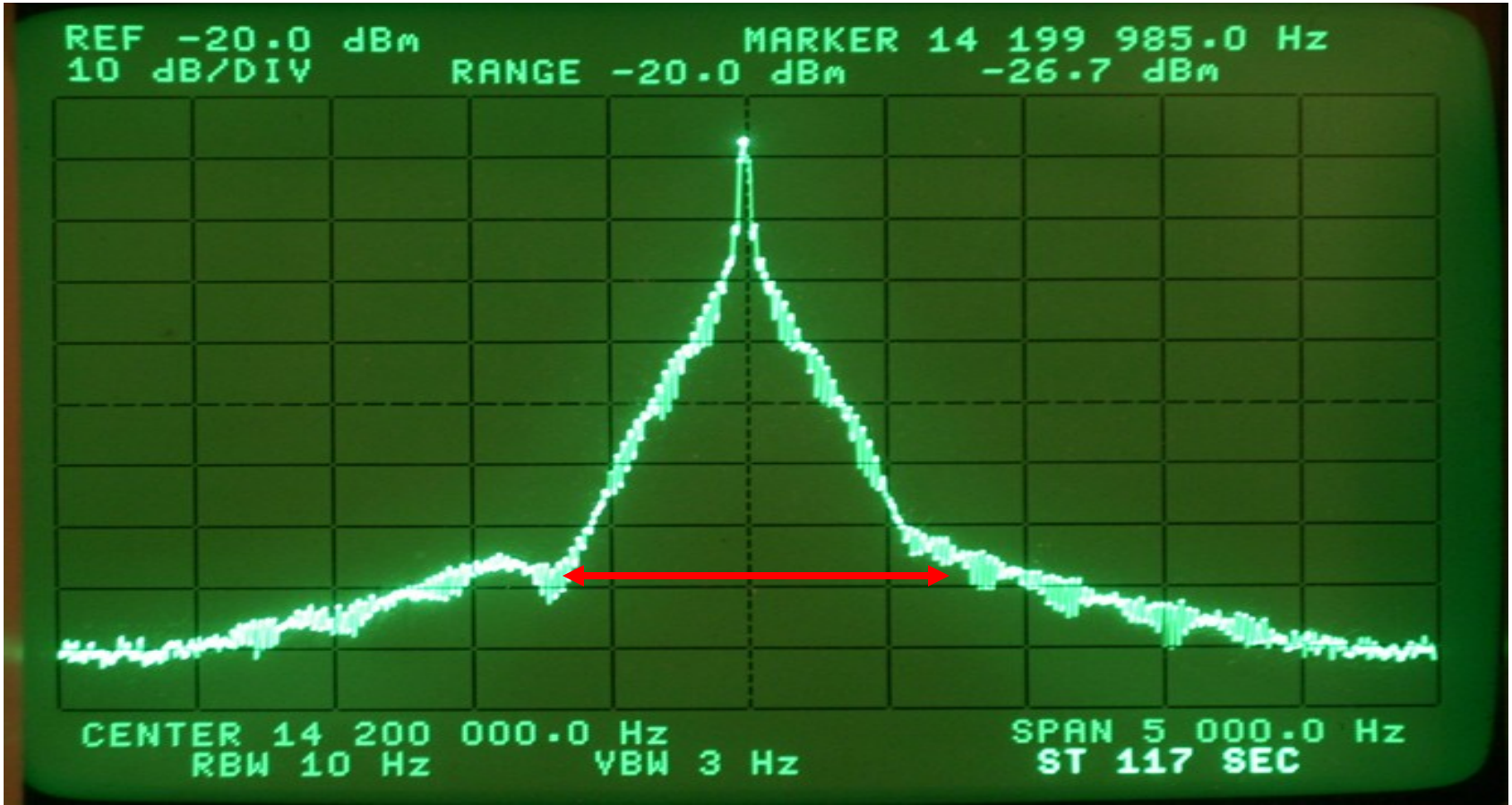
Spectrum of CW Signal on HP 3585A Analyzer

Rise Time 10 msec, “dits” at 30 WPM,
Bandwidth -70 dB = +/- 450 Hz = 900 Hz



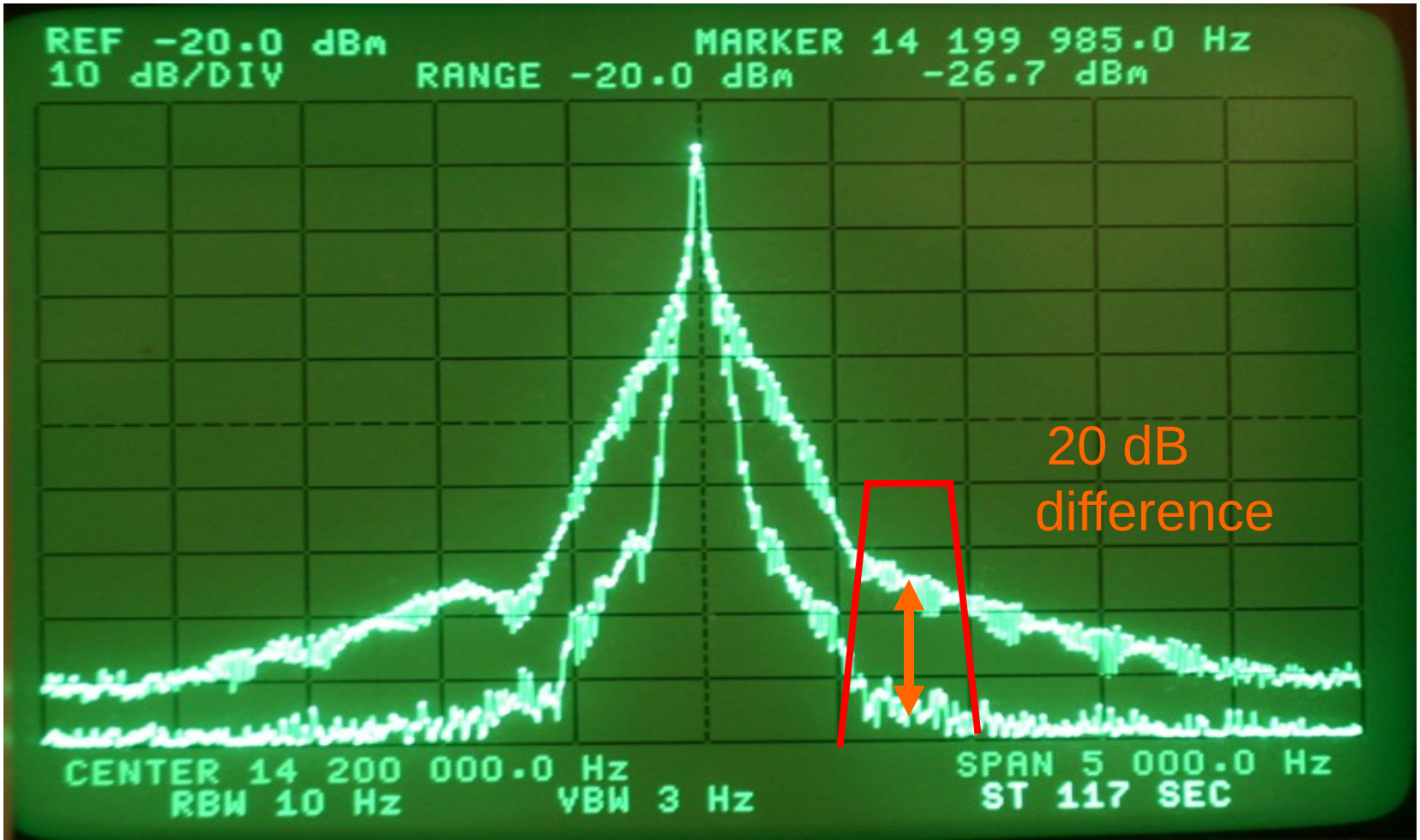
Spectrum of CW Signal on HP 3585A Analyzer

Rise Time 3 msec, “dits” at 30 WPM,
Bandwidth -70 dB = +/- 750 Hz = 1500 Hz

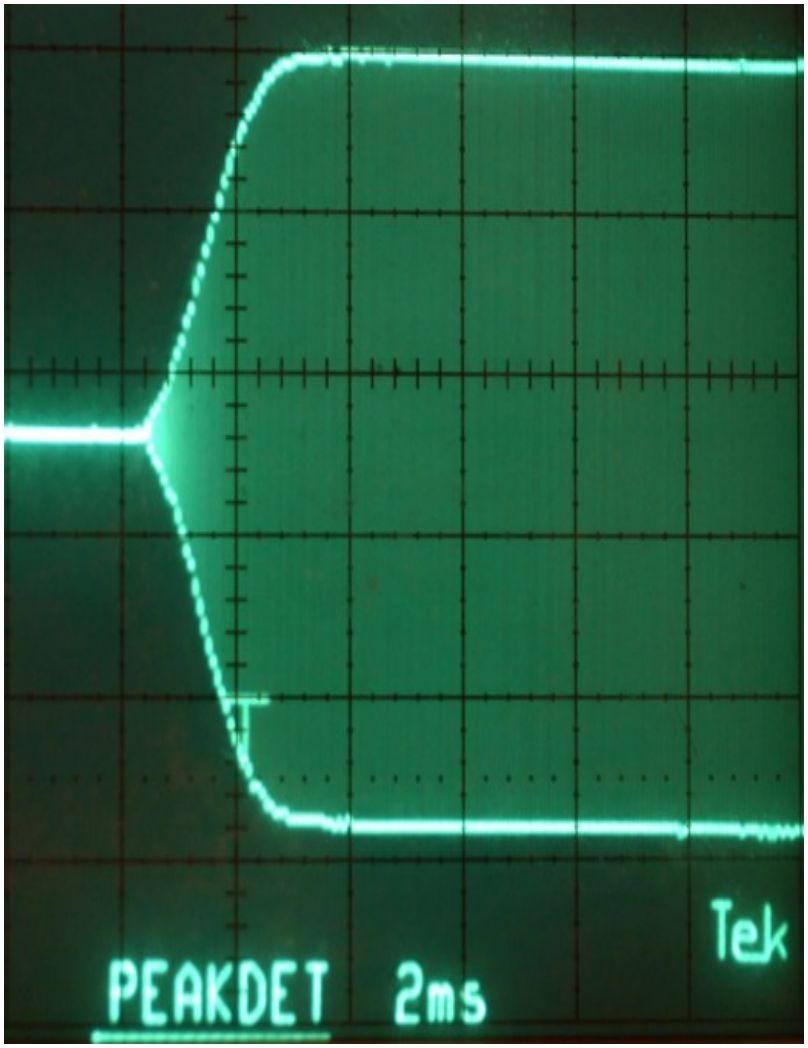


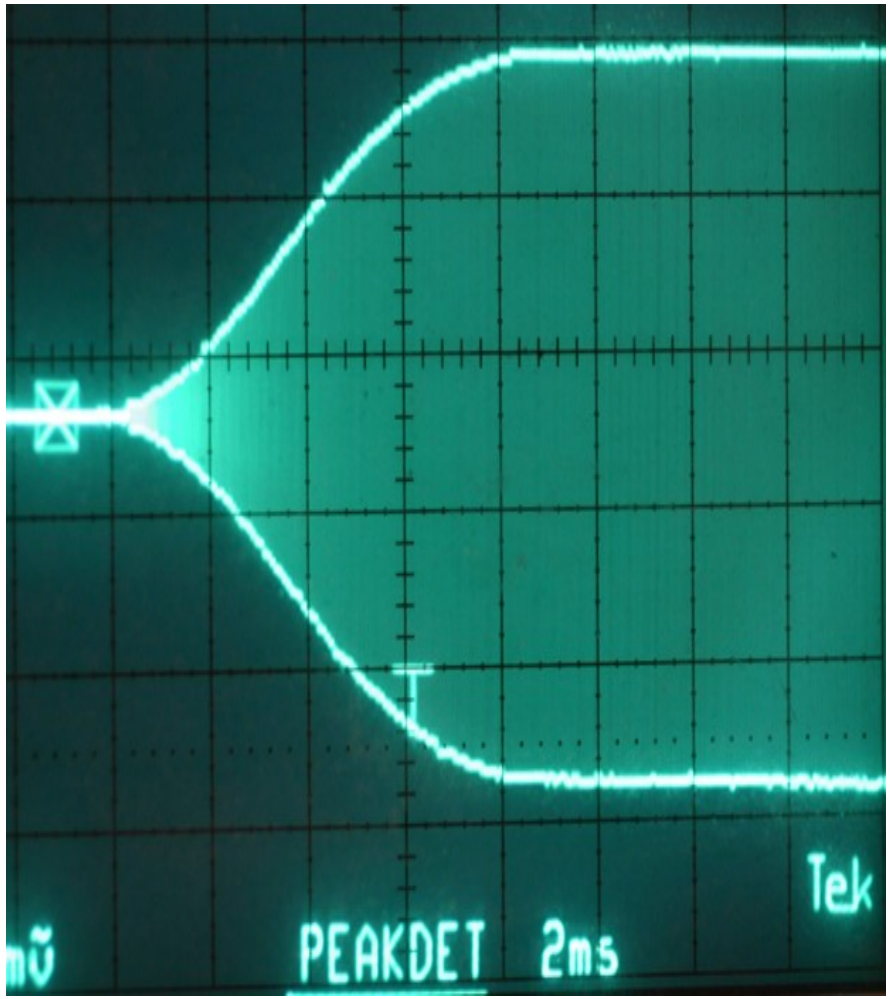
Spectrum of CW Signal on HP 3585A Analyzer

Comparison of 3 msec vs 10 msec rise time



Leading edge of “dit” 3 & 10 msec





Just the Facts

On SSB you want DR3 = 70 dB, or more.

On CW you want DR3 = 80 dB, or more.

This is most economically accomplished with low IF (5 to 9 MHz) selectable crystal roofing filters.

It is much more difficult to deliver 80 dB or higher DR3 with the more common Up-Conversion design.

Transmitted bandwidth of the interfering signal is often the limit, not the receiver, particularly on SSB.

What dynamic range is possible and needed for CW?

80 dB or better @ 2 kHz.

1976 Sherwood / Drake R-4C: 84 dB

2001 Ten-Tec Omni-VI+: 80 dB

2003 Icom IC-7800: 80 dB

2003 Ten-Tec Orion I: 93 dB

2005 Ten-Tec Orion II: 95 dB

2007 Flex 5000A: 96 dB

2007 Ten-Tec Omni-VII: 80 dB

2008 Perseus (receiver): 99 dB

2008 Elecraft K3: 95 to101 dB (roofing filter dependent)

Other radios for comparison, 2 kHz dynamic range data

Elecraft K2:	**80 dB**
Collins R-390A:	**79 dB**
Kenwood TS-850S:	**77 dB**
Icom Pro II / Pro III	**75 dB**
Collins 75S-3B/C:	**72 dB**
Kenwood TS-870S:	**69 dB**
Yaesu FT-2000:	**63 dB**
Icom IC-7000:	**63 dB**
Yaesu FT-One:	**63 dB**
Yaesu FT-101E:	**59 dB**
Drake R-4C Stock:	**58 dB**
Yaesu FT-757:	**56 dB**
Yaesu VR-5000:	**49 dB**

Contest Fatigue & Audio Quality - The Forgotten Spec

I find many radios tiring in a long contest.

The audio is harsh on SSB and CW.

All meet OEM Specs.

OEM spec = 2 watts @ 10% distortion = clipping

What makes audio harsh and fatiguing?

High Odd-Order Harmonics and / or IM Distortion

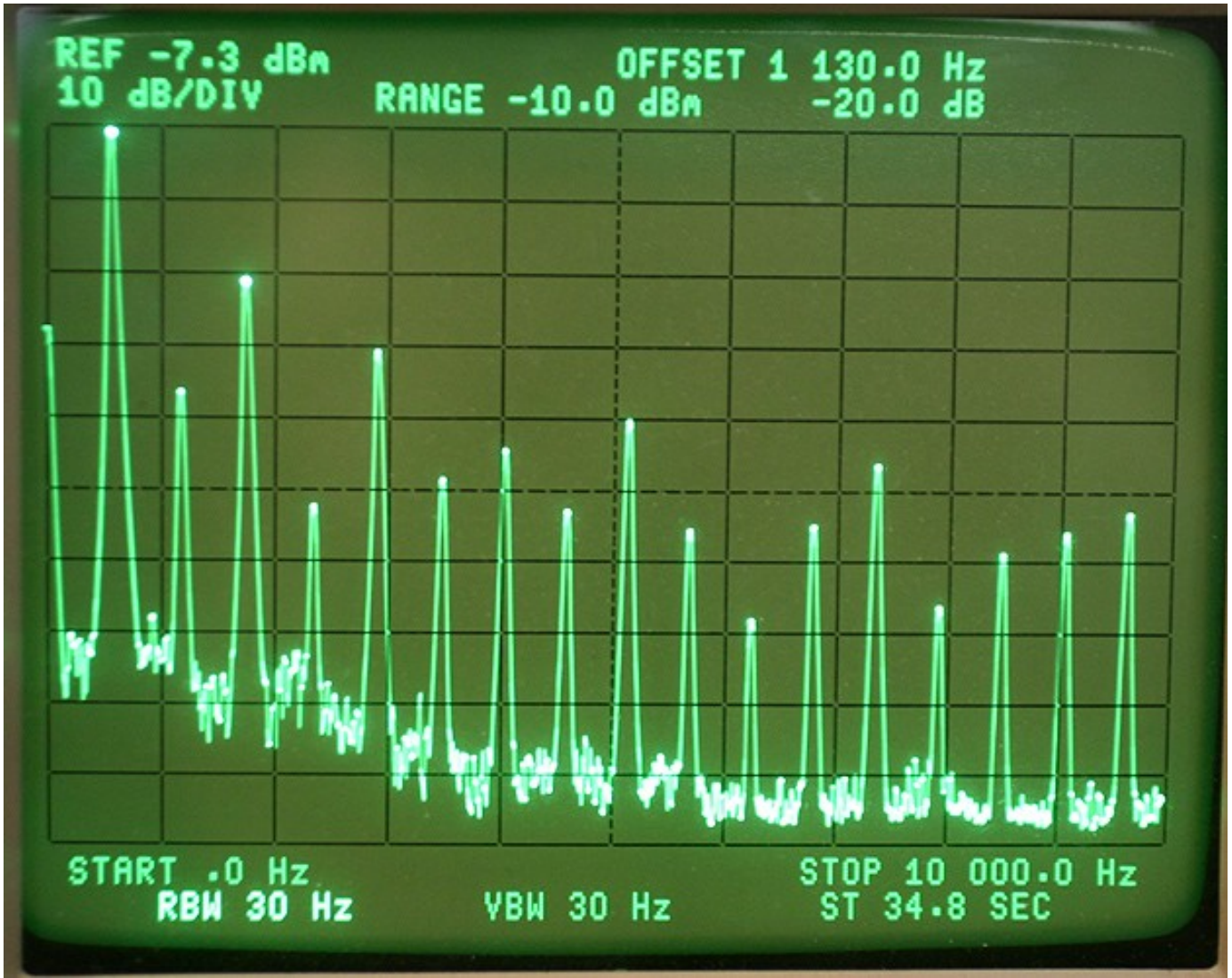
Any radio will meet a 10% spec

Thus the spec is meaningless.

The Amazing Ear / Brain “Detector”

- We can easily detect distortion 60 dB down.
- 10% distortion is only 20 dB down !
- 1% distortion is 40 dB down.
- Why in the world does anyone use a 10% spec?
- It may take guidance to learn to interpret what you are hearing, and why a radio is causing fatigue.

10% Distortion on Spectrum Analyzer



Pro III driven into clipping to meet the 2 W. into 8 ohm spec.

Contest Fatigue & New Technologies

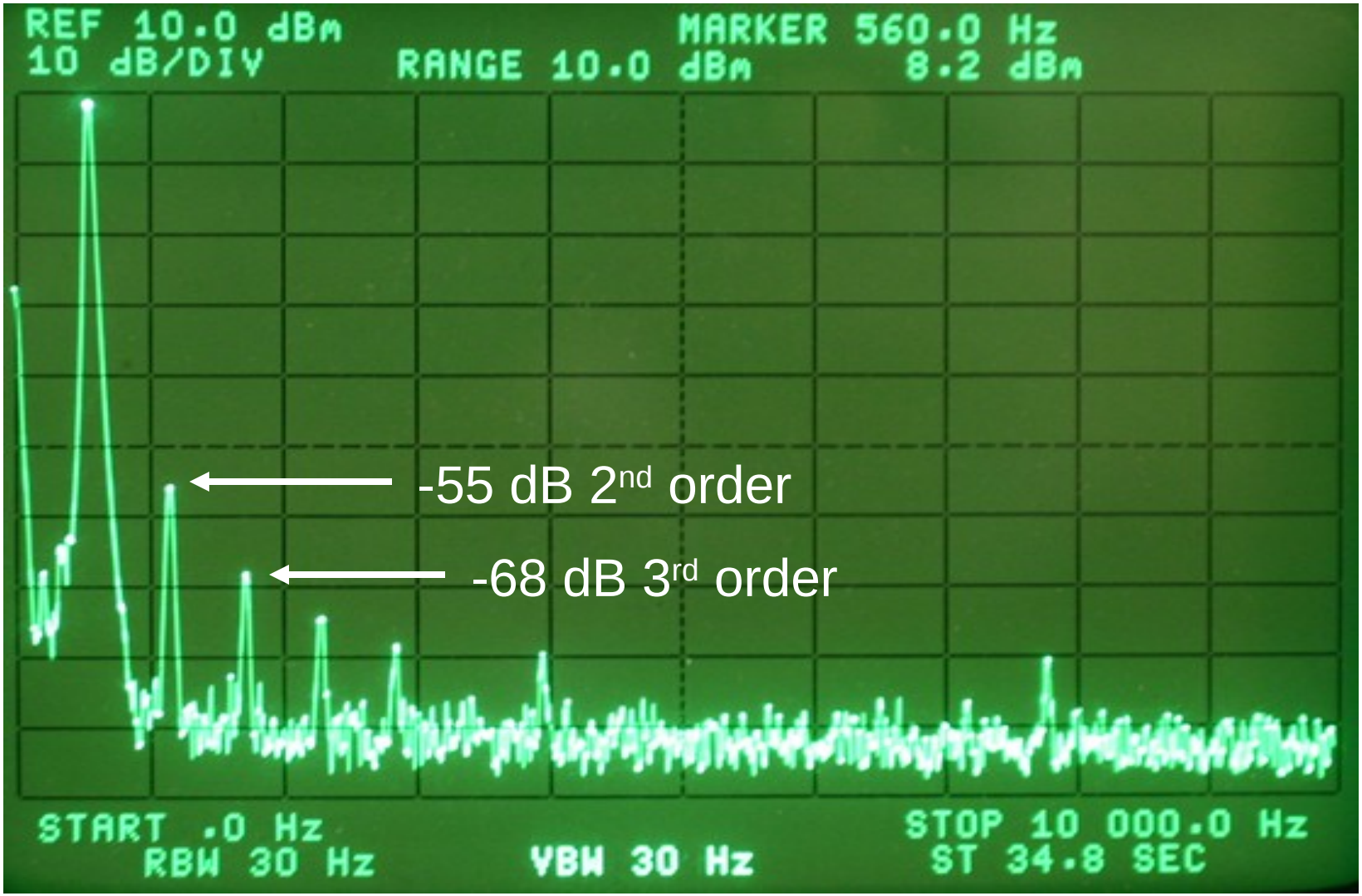
Laboratory tests are important, but radios also need to be evaluated in a contest environment.

I use two operating positions to compare a “reference radio” to a “test” or “evaluation” radio, going back and forth between station A and B during a contest.

Interesting problems have come to light in on-air A / B comparisons.

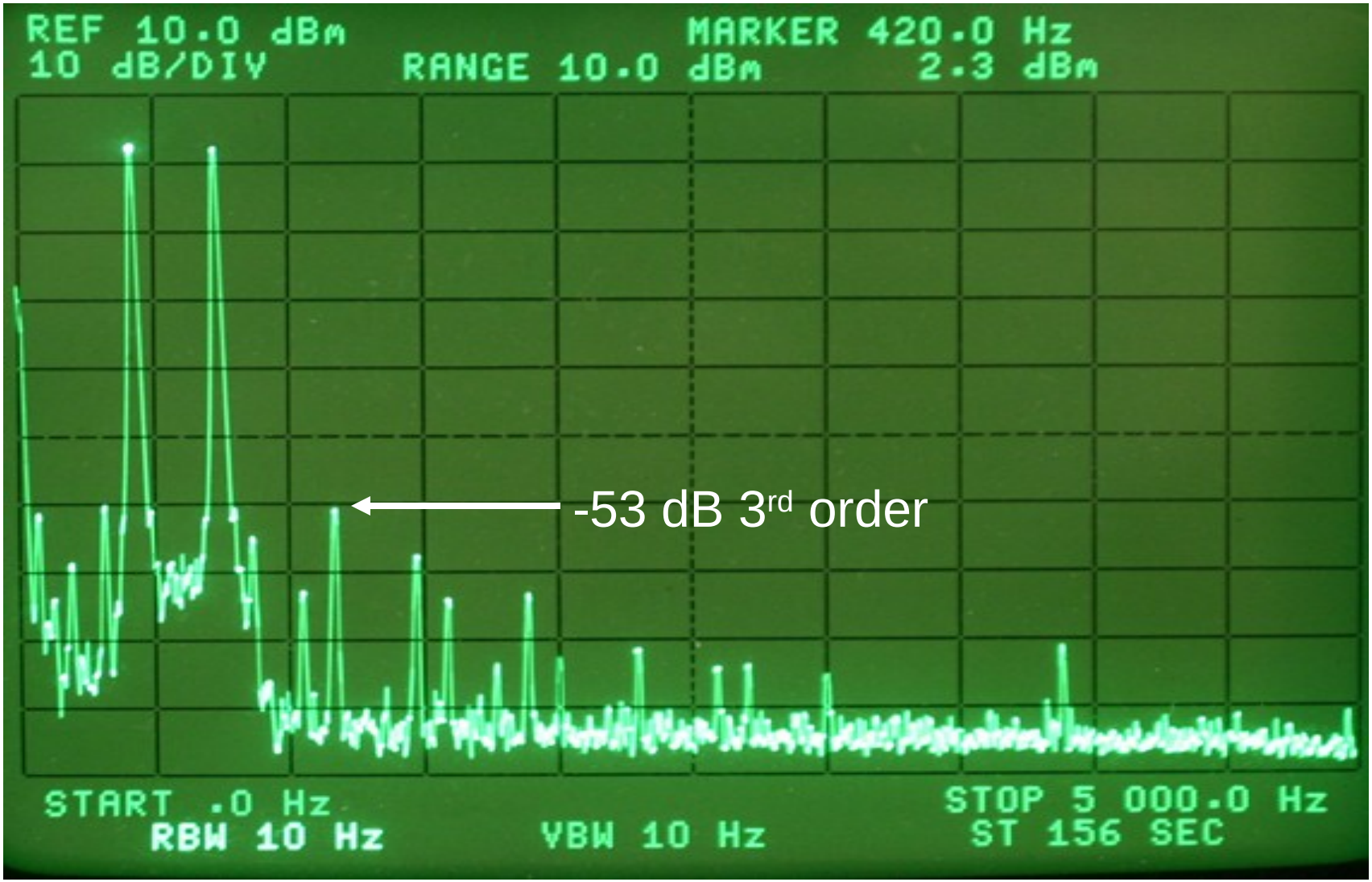
Distortion < 0.3 % & sounds fine

Harmonic Distortion – Good Receiver



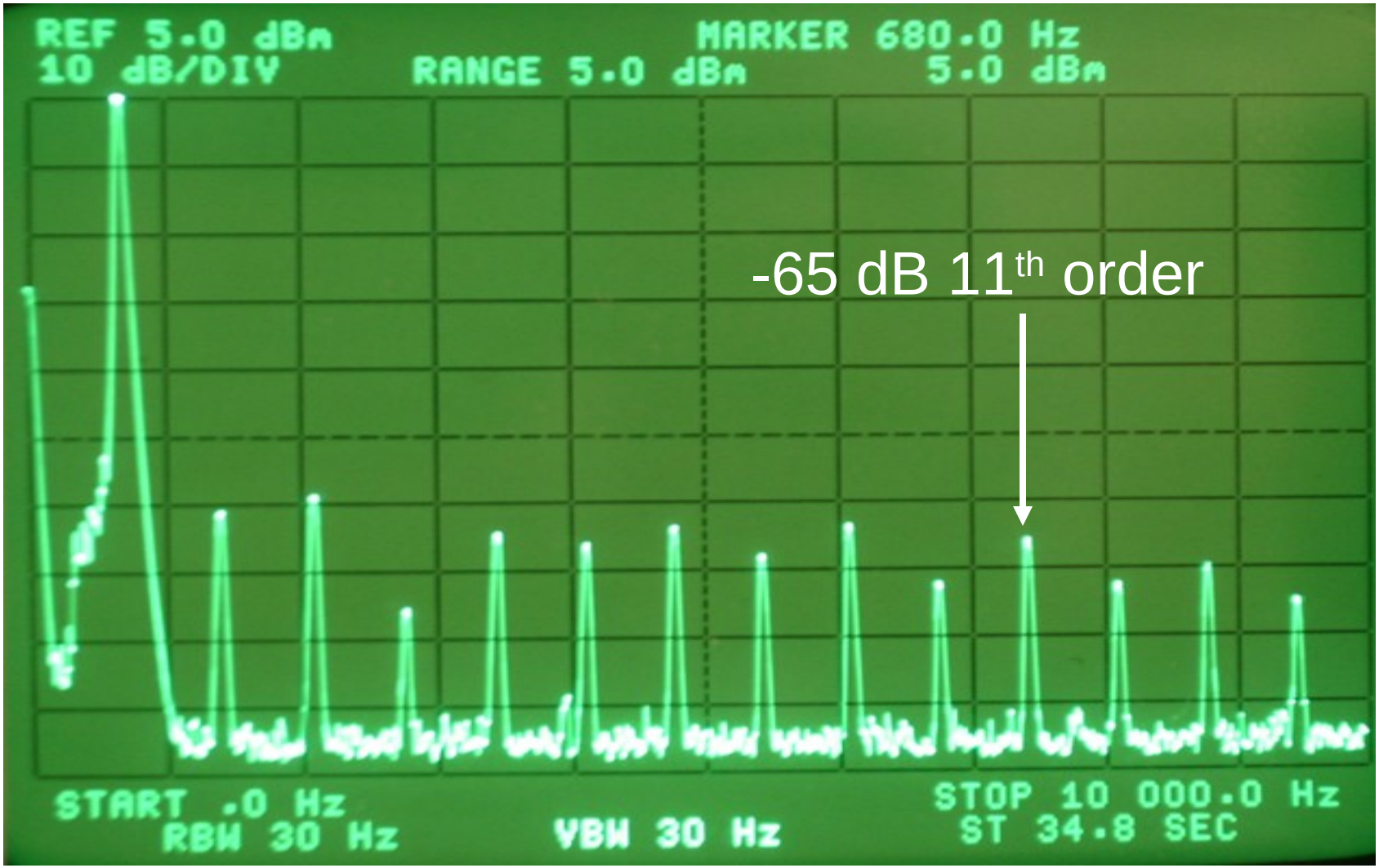
Distortion = 0.3 % & sounds fine

IM distortion - Good Receiver



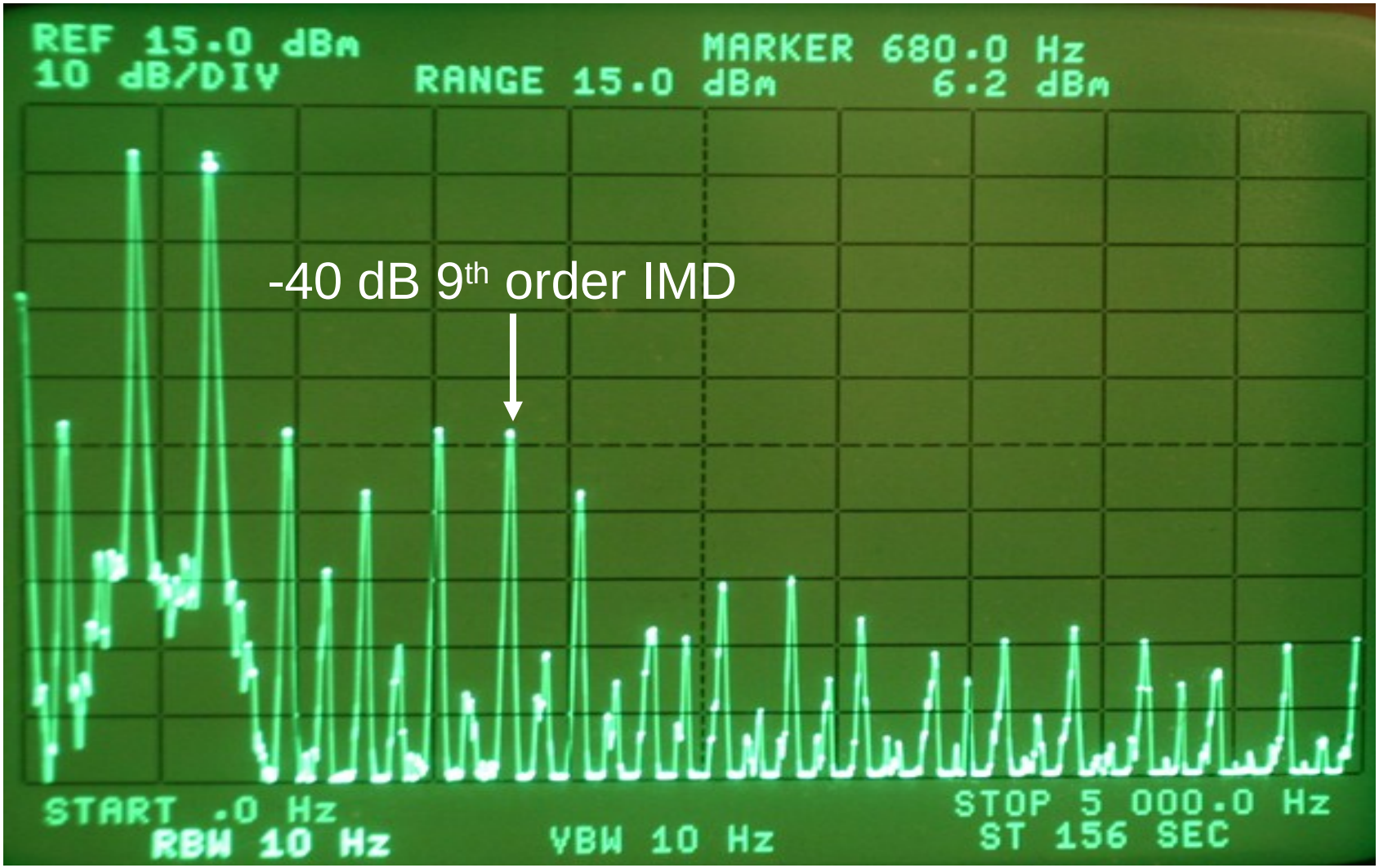
Distortion = 0.2 % but sounds bad

K3 Audio Spectrum of 700 Hz beat note

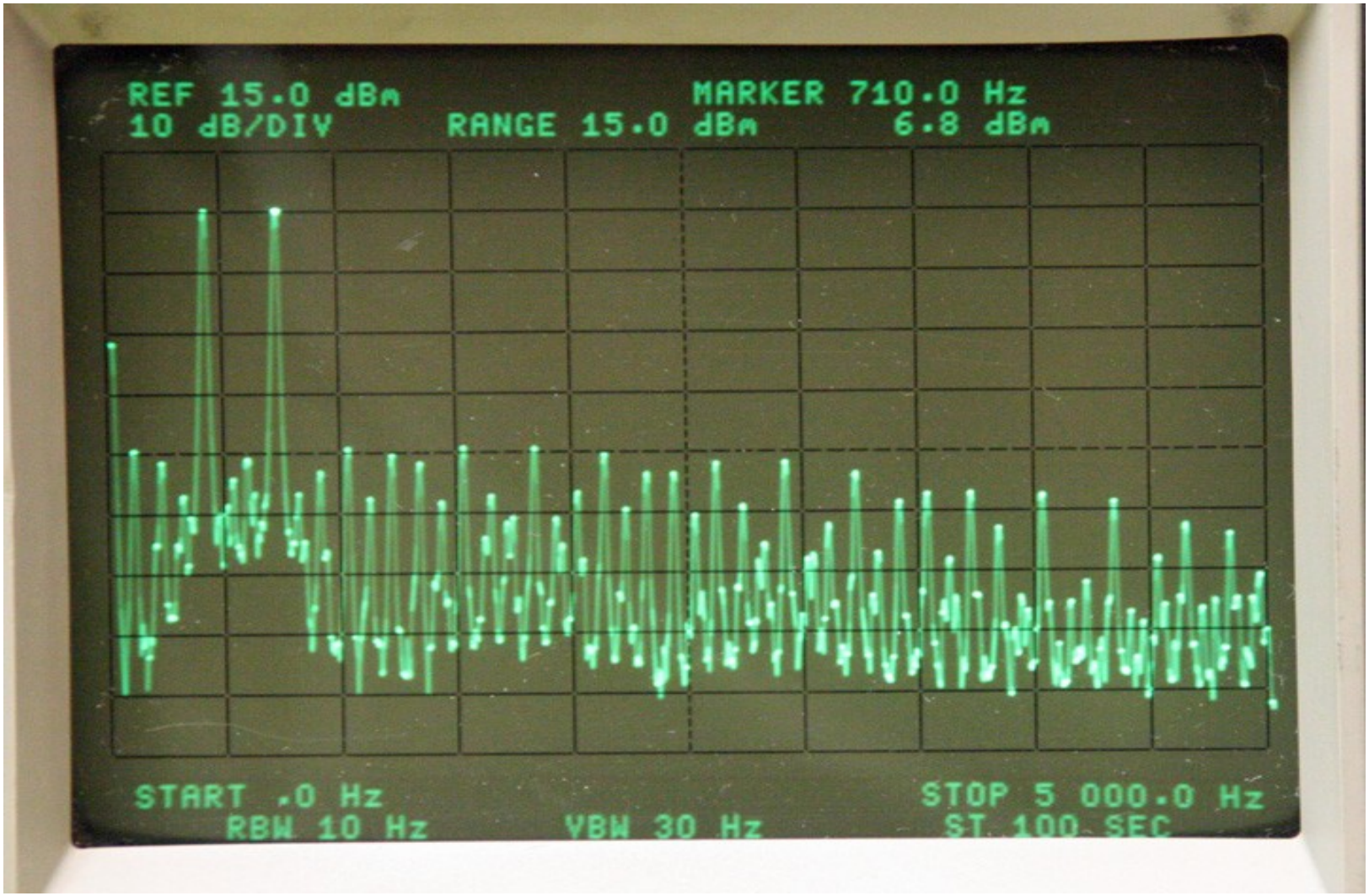


2% distortion but sounds tiring !

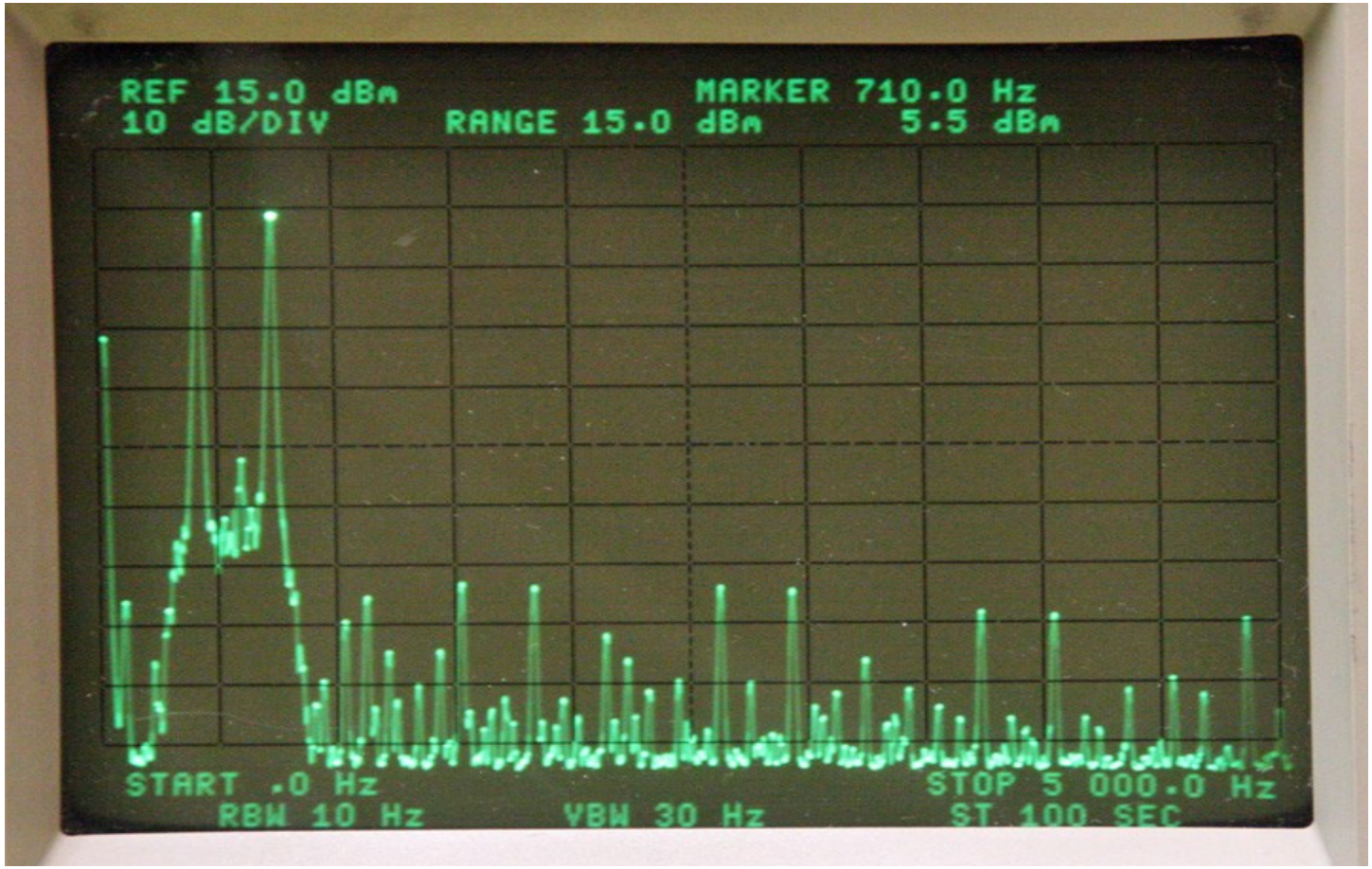
Way too much IM Distortion in K3 Audio



Screen shot from Elecraft Lab

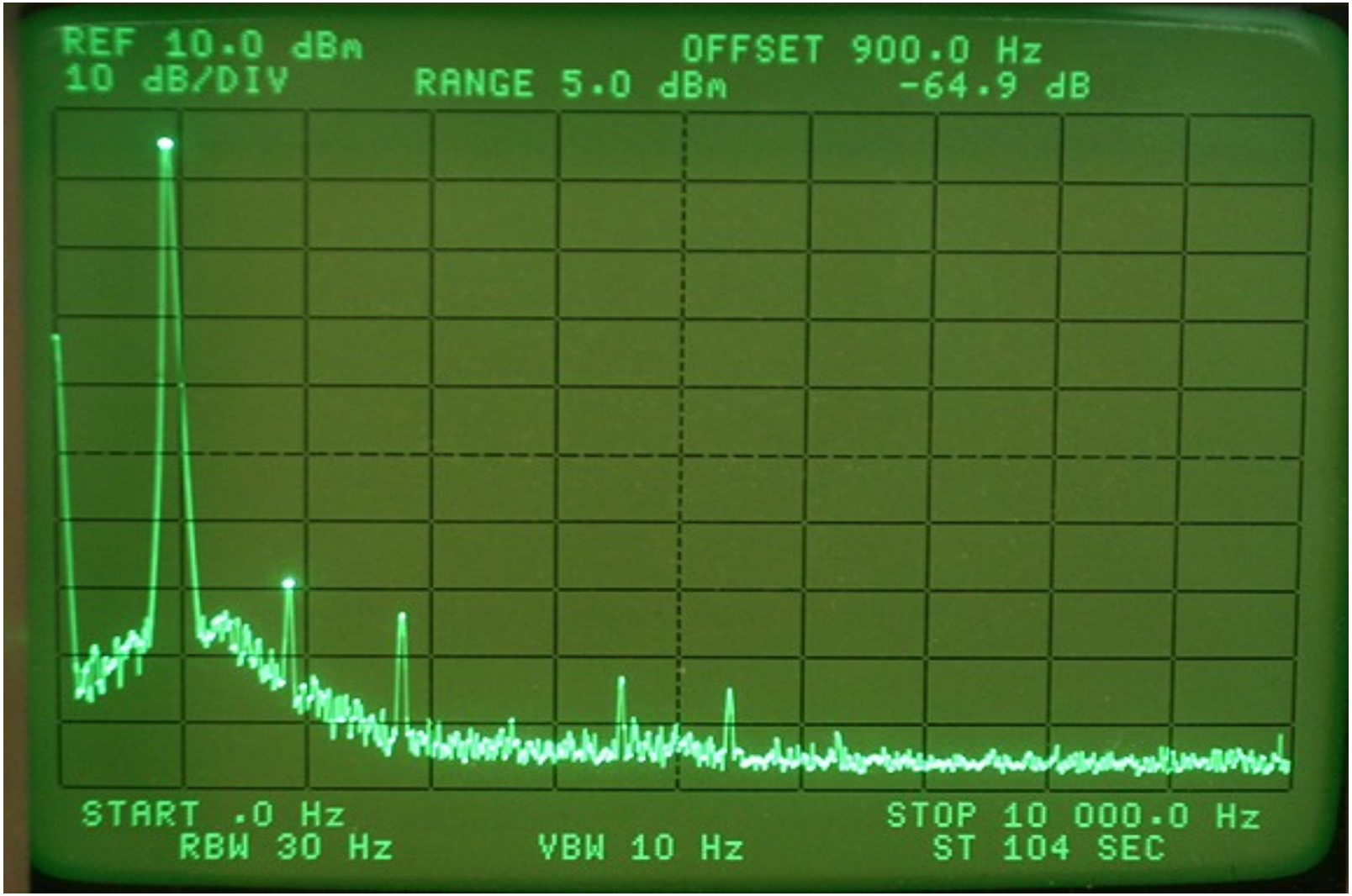


K3 After New Choke Installed



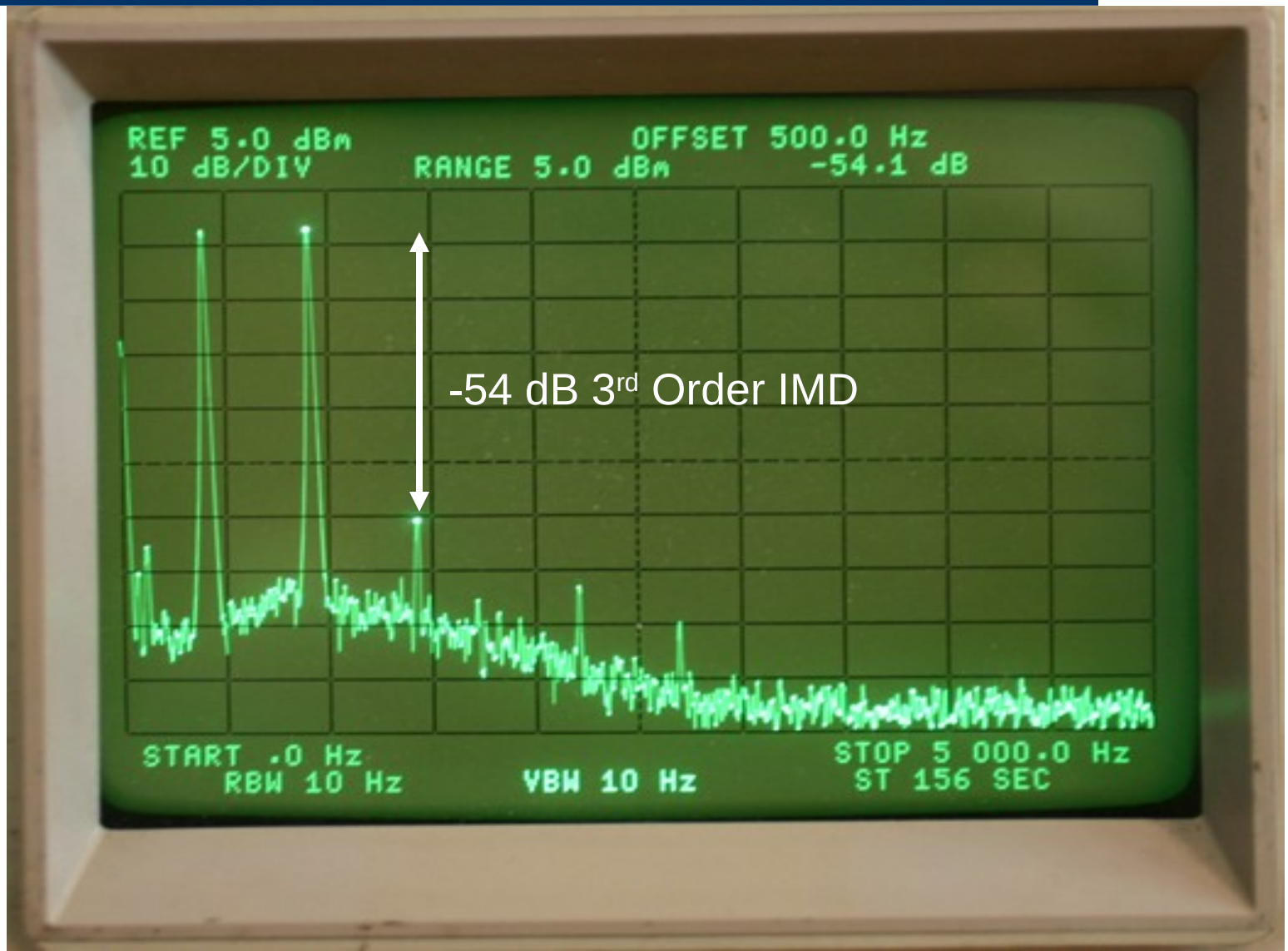
0.1 % distortion

Icom 756 Pro III Harmonic Distortion

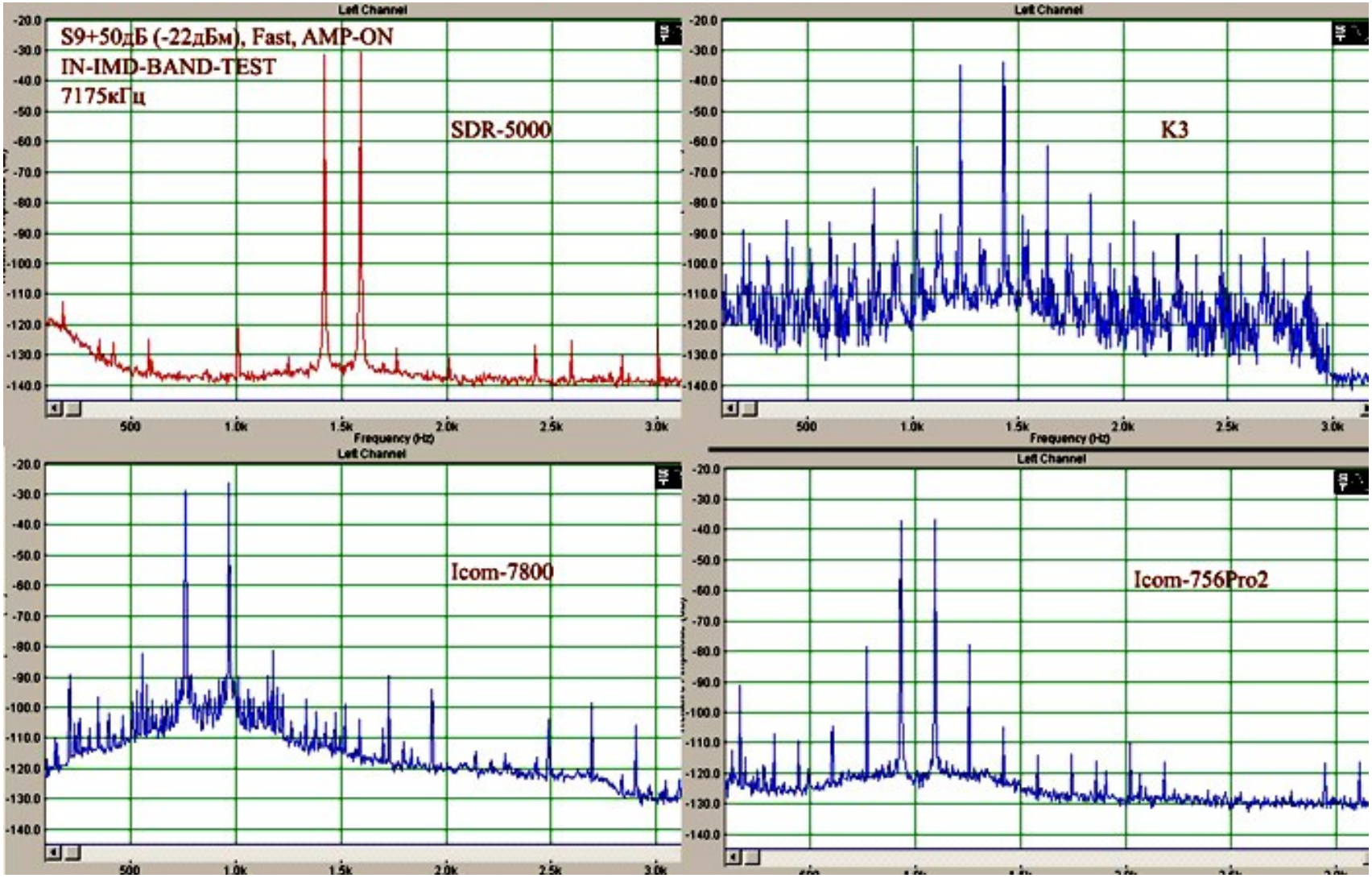


< 0.3 % distortion

Icom 756 Pro III in-band IMD Distortion



Data from UR5LAM on 4 Transceivers



How to Prove what you can Hear?

- Some problems are “dynamic”, and not easy to measure with a steady-state signal generator or two.
- One solution: A Fast Fourier Transform or “FFT” spectrum analyzer for near real time analysis.

HP 3561A FFT Analyzer

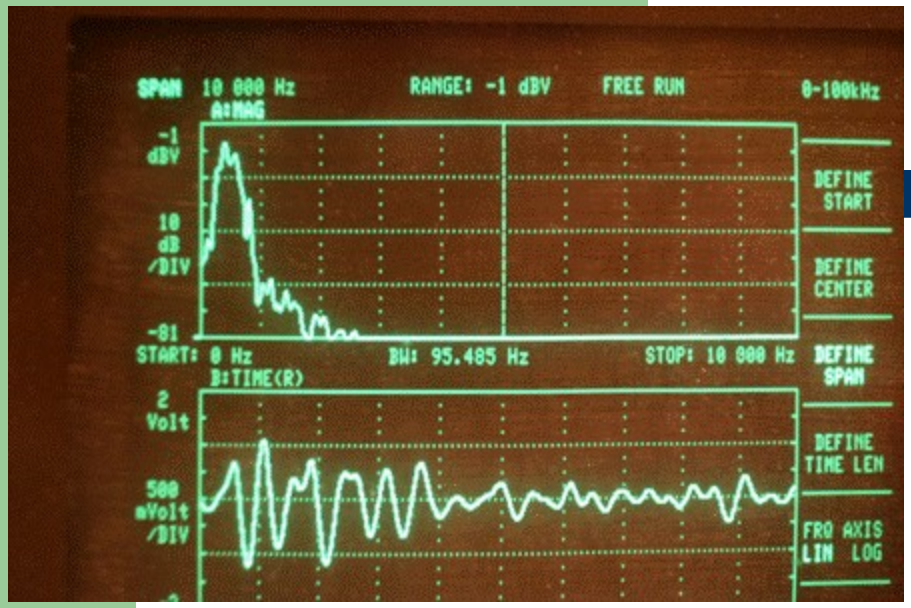
QRN Sneaks Through

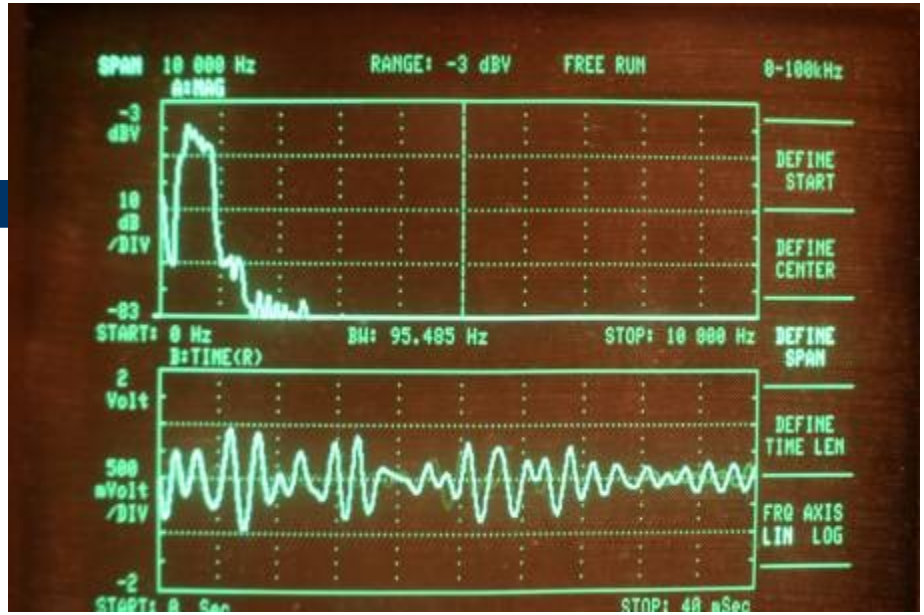
- At least three modern DSP transceivers do not cope well with QRN (static) crashes.
- FT-2000 / 2000D & IC-7000
- If you do any low-band contesting, you know how fatiguing QRN can be.
- I was hearing QRN crashes 15X the bandwidth of the CW filter in my headphones.

R-4C

QRN

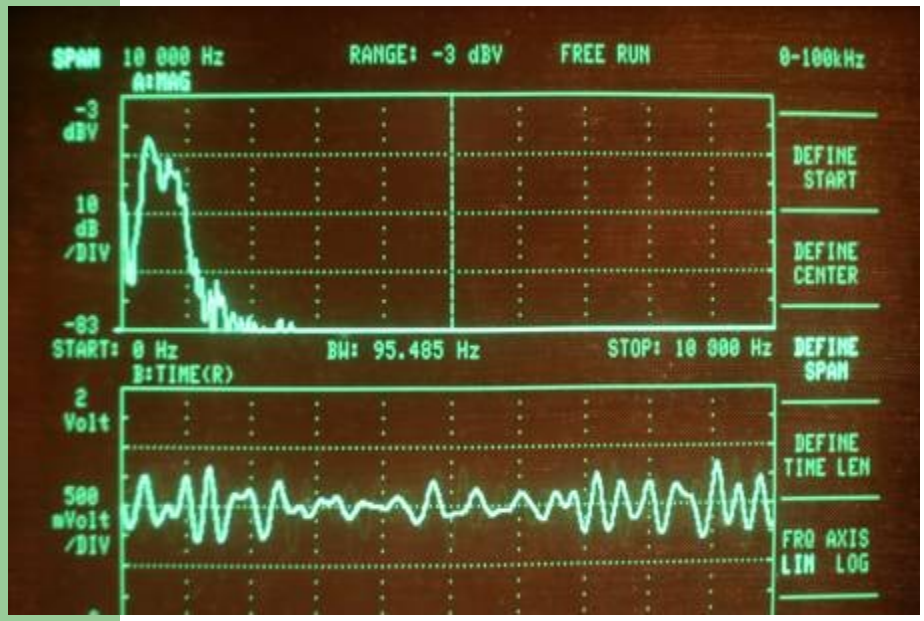
781

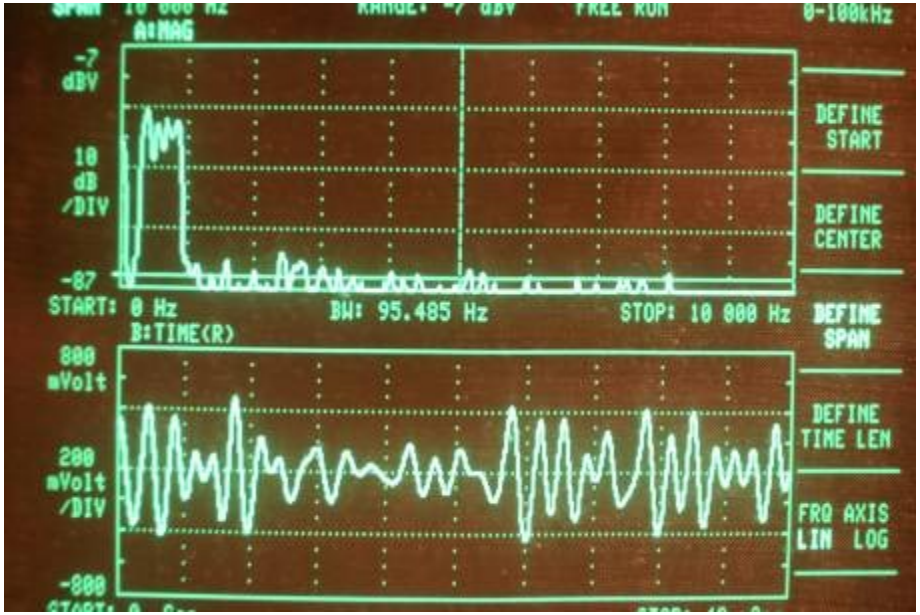




706

7000

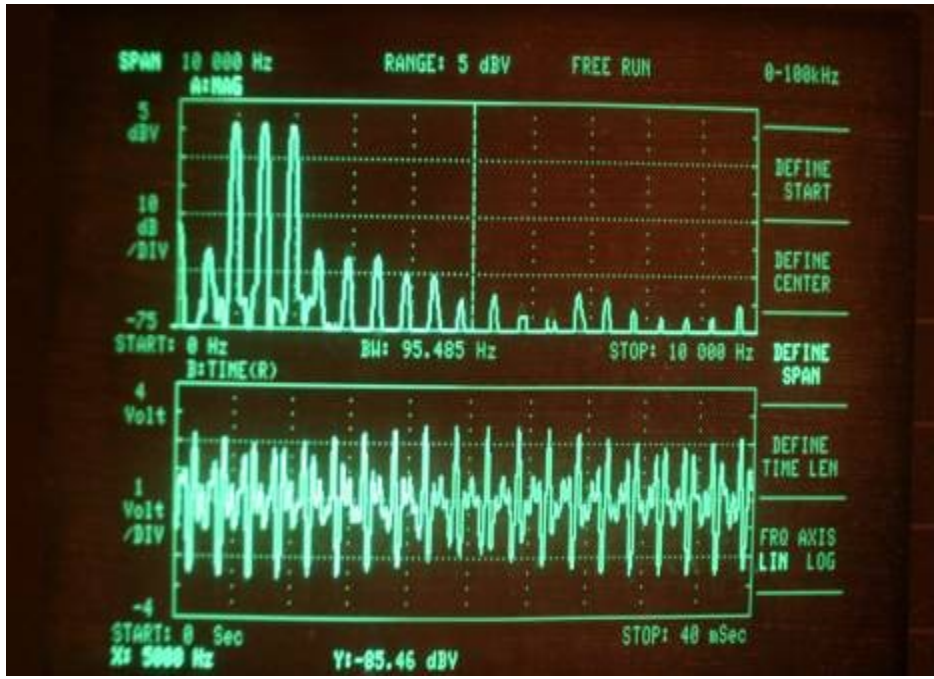




How to Approximate QRN in the Lab?

- Used multiple tones to approximate broadband QRN static crash.
- QRN = hundreds of tones.

781 3 Tones **7000**



QRN is like 100s of tones at once. Look at out-of-passband products with just three tones!

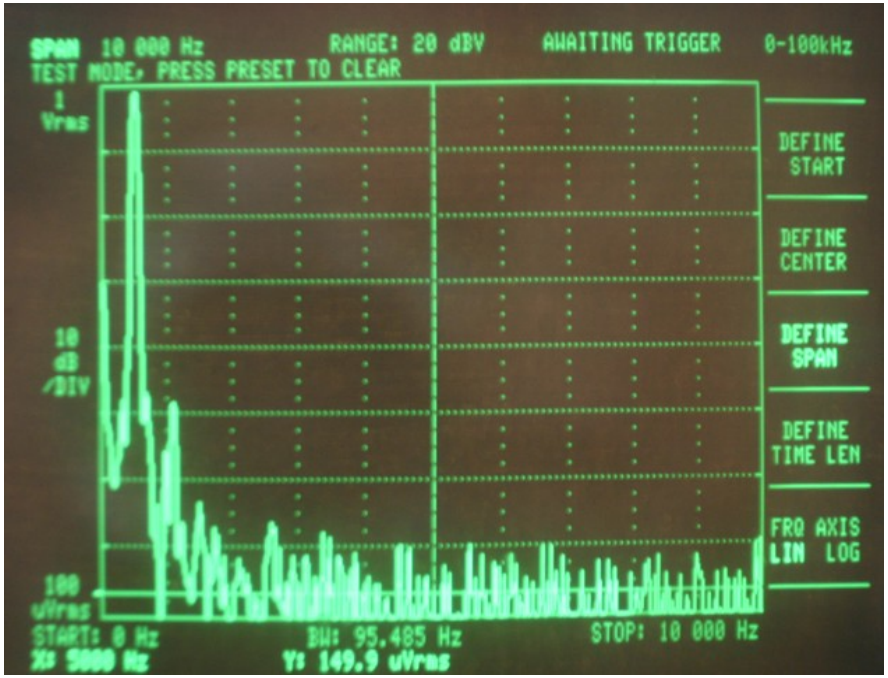
The QRN crashes way outside the filter passband appear to be intermodulation distortion, rather than leakage around the filter.

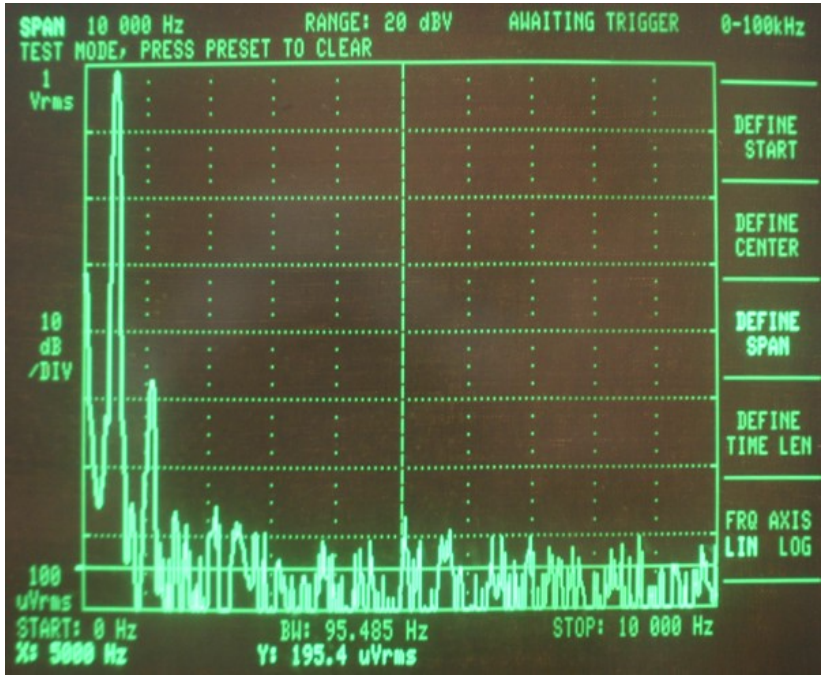
Another Dynamic Fatigue Problem

- In January 2009 CQ 160 meter CW contest, I went back and forth between a 20 years old analog IC-781 and a 1 year old IC-756 Pro III DSP radio.

- I could not listen to the Pro III for more than an hour at a time before my ears were complaining due to CW AGC attack distortion.

FFT of the IC-781



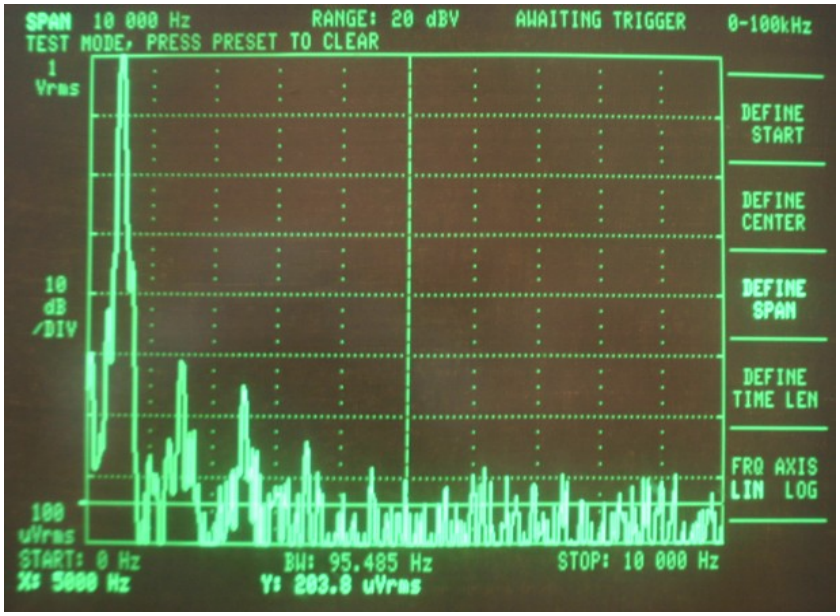


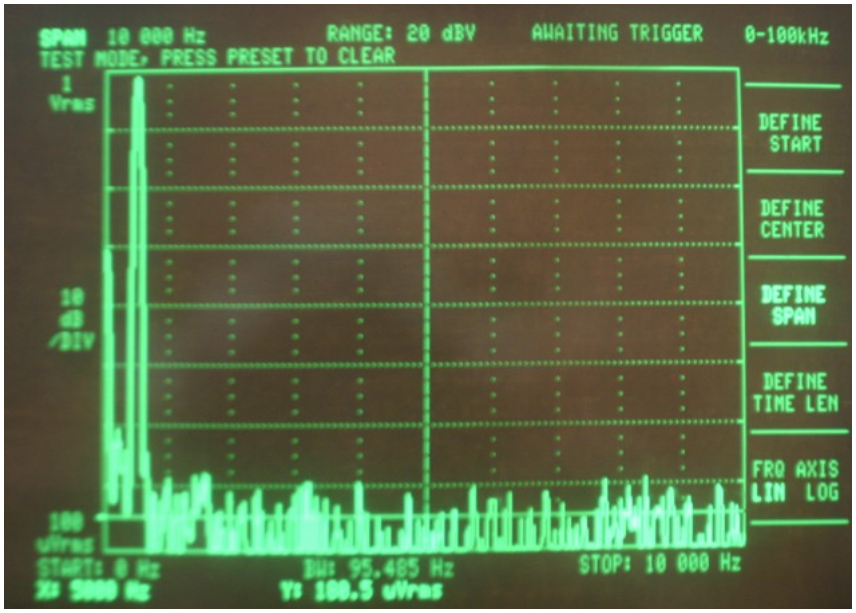
A single 500 Hz “dit”
Second harmonic only

Steady tone
Second harmonic only

The two are virtually identical.

FFT of IC-756 Pro III





A single 500 Hz “dit” with 3rd, 5th, 7th & 9th harmonics to 4.5 kHz.

Steady tone
Very clean

AGC Impulse Noise Anomaly

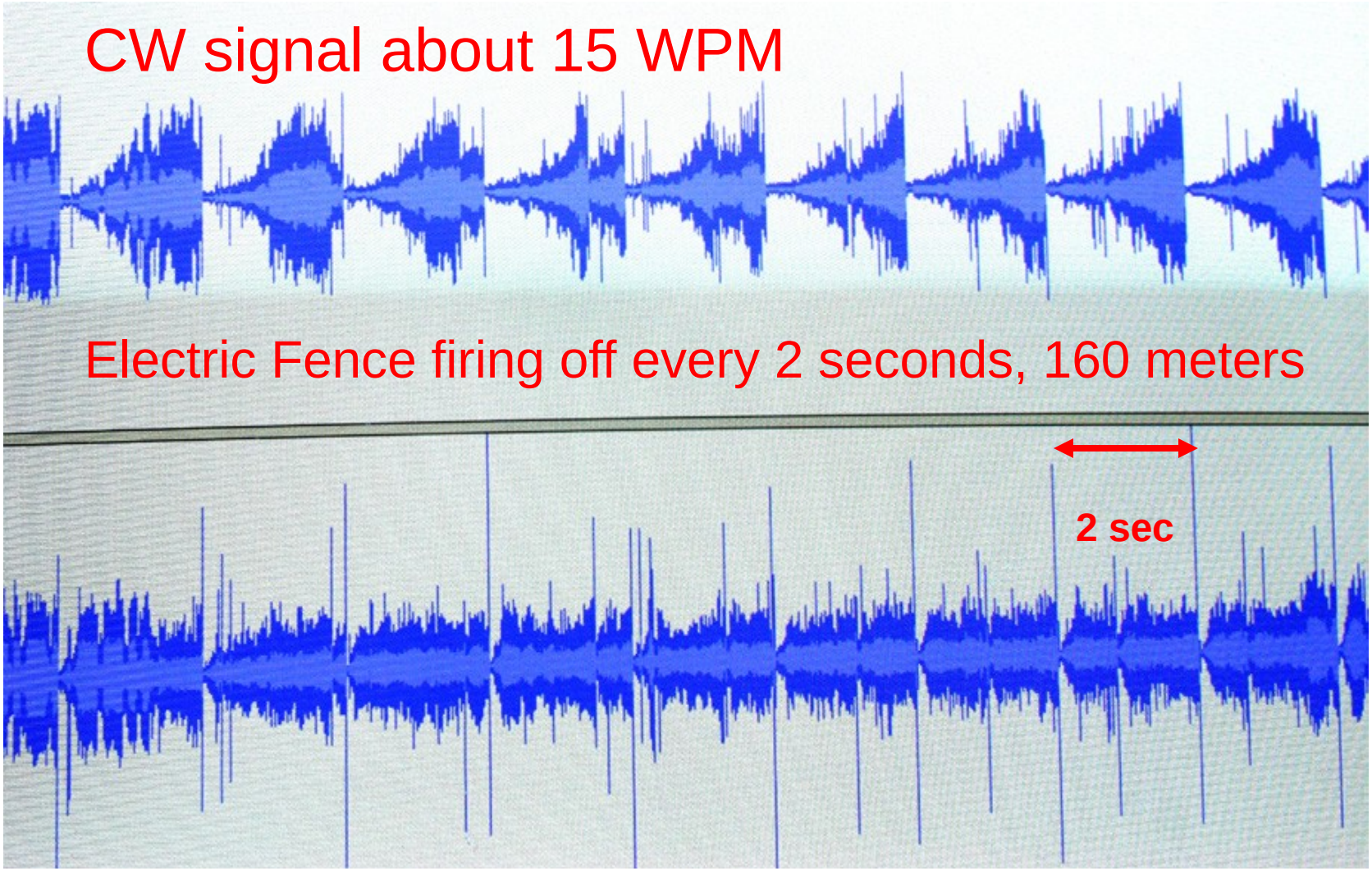
Most new radios since 2003 exaggerate impulse noise.

The exceptions: Elecraft K3, Flex 5000 & Perseus

Programmed DSP to ignore a tick, click or pop.

Elecraft calls it the Sherwood Test.

Omni-7 on Top - Pro III on Bottom



Listen to 30 second audio clip

- Audio Icom 756 Pro III
- 160 meters, 4 PM, Dec 13, 2008
- Electric fence & CW signals
- KV4FZ calling DX station
- Note volume level relatively constant

Audio clip with DSP AGC problem

- Audio Ten-Tec Omni-VII
- 160 meters, 4 PM, Dec 13, 2008
- Electric Fence & CW signals
- Exact same signals as with Pro III
- Note AGC being hammered by impulses
- Other rigs with the same AGC problem:
- IC-7800, IC-7700, IC-7000
- FTdx-9000, FT-2000, FT-2000D
- Orion I & II

The Challenge = Get OEMs to Listen

In a 24 hour or 48 hour contest, you need every edge.

High Dynamic Range Receiver

Good Speech Processor on SSB

Good Antennas.

But Your Brain Can Get “Fried” due to operator fatigue.

Audio problems / artifacts are a factor in that fatigue.

10% distortion specs are ridiculous.

Dynamic distortion is not even evaluated.

Conclusions

- Contesters – DXers – Pileup operators need a good receiver for SSB and an even better receiver for CW.
- Designing good DSP is very difficult.
- Subtle issues are being complete overlooked.
- Feedback to OEMs is critical if products are going to improve.

Sherwood Engineering

http://www.sherwood-engineering.com

http://www.NC0B.com