Transceiver Performance and how do we measure it?

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NCØB

What's important when it comes to choosing a radio?

Why Did I Start Testing Radios ?

- Purchased a new Drake R-4C in the 1970s.
- Used it during the ARRL 160m CW contest
- **Radio performed miserably, yet Specs Were Good**
- 1970s: **QST** and ***ham radio magazine*** introduced new terminology: Noise Floor & Dynamic Range.
- R-4C tested well for Dynamic Range, but flunked CW contest 101.
- The ARRL dynamic range test did not approximate a real-world environment, especially in a CW contest.

- Dynamic Range - measures the ability to hear weak signals in the present of near-by strong signals.
- A 20 kHz Dynamic Range measurement in a multi-conversion radio only tests the radio's front end.
- If the first IF was 6 - 20 kHz wide, be it at 5 MHz, 9 MHz or 45 - 70 MHz, the radio could overload in a CW pile up.
- 20 kHz dynamic range test showed **no** hint of the problem
- ***Solution***: Place test signals close together so they pass through **1st IF Filter → the Next Amplifier → Mixer**
- Close-in dynamic range numbers are almost **ALWAYS** worse than the wide-spaced numbers, for a radio with a single wide roofing filter. (Hilberling the exception)

What 2 Numbers are Most Important for a CW Contester or DX Pile-up?

- Close-in Dynamic Range (DR3)
- Noise floor

(Noise floor need to calculate DR3)

What is Noise Floor?

Sensitivity is a familiar number, normally applies to SSB.

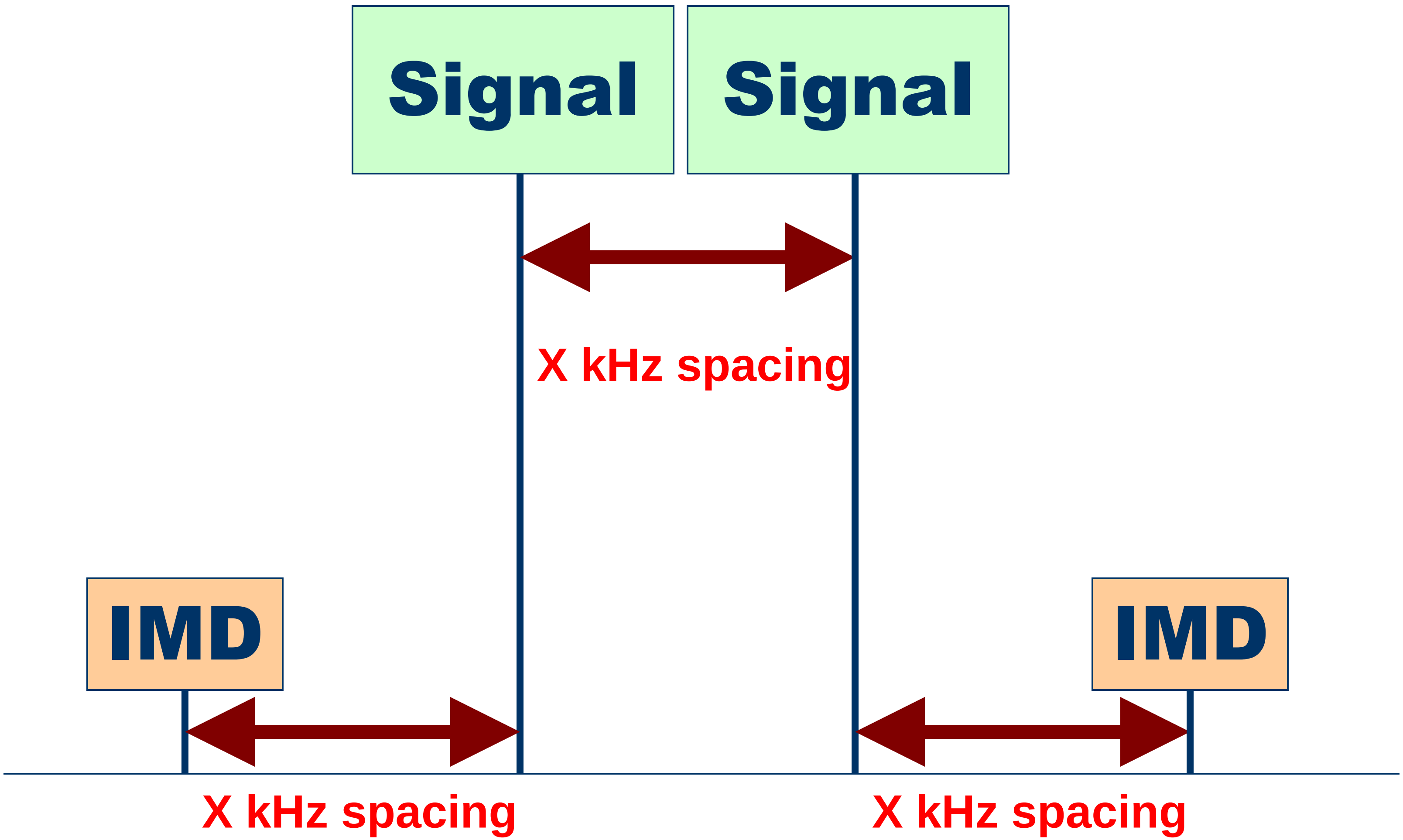
Sensitivity = 10 dB Signal + Noise / Noise (10 dB S+N/N)

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

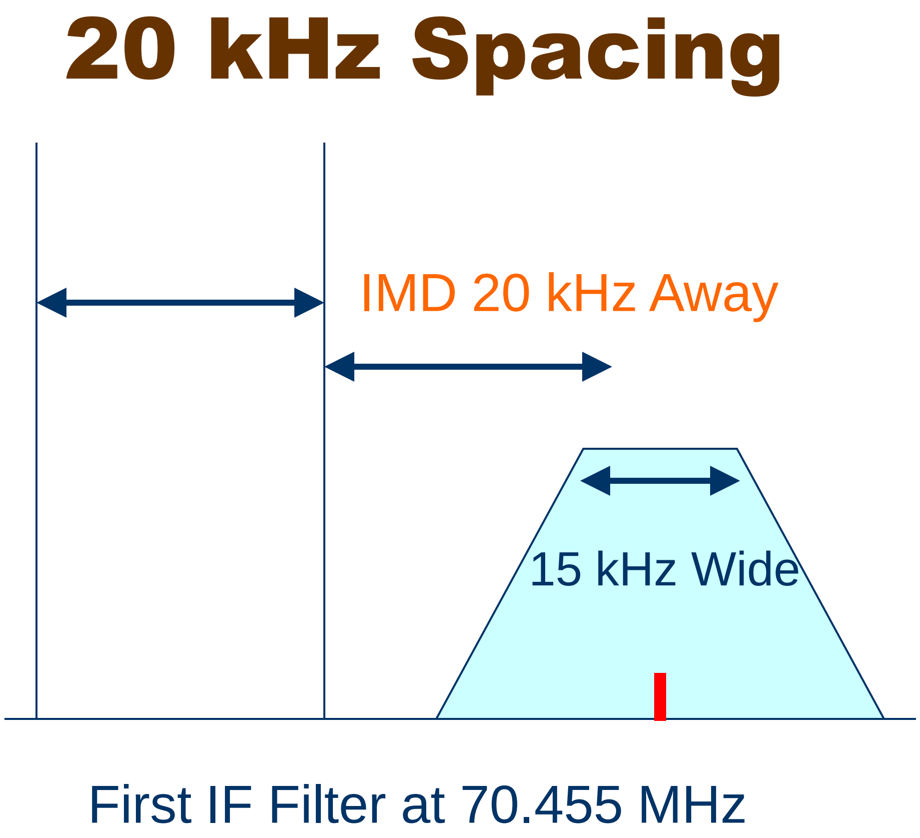
What is Close-in Dynamic Range vs

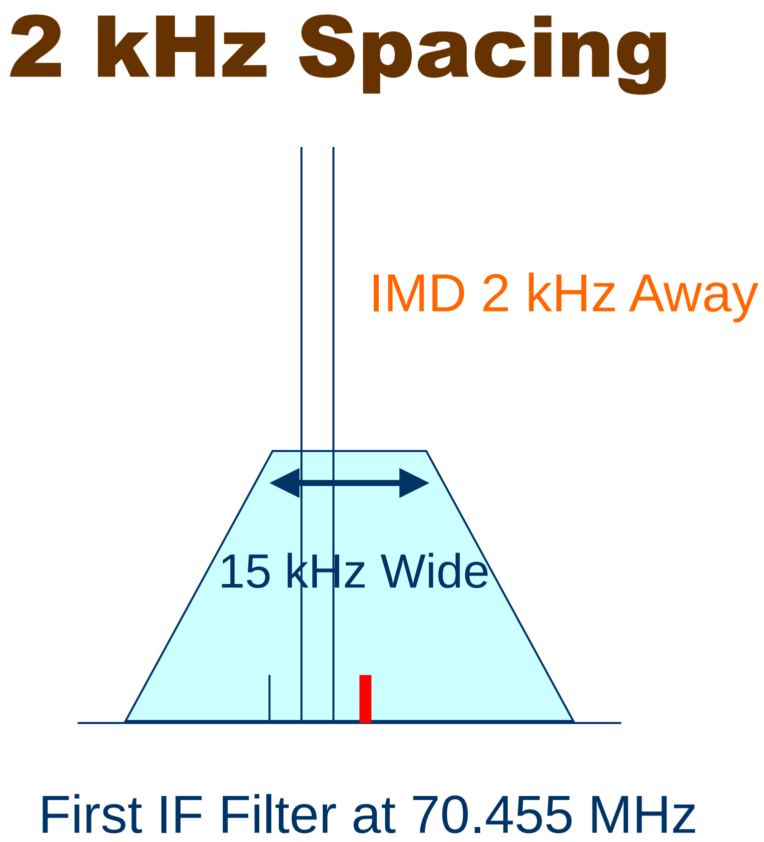
Wide-Spaced Dynamic Range?

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

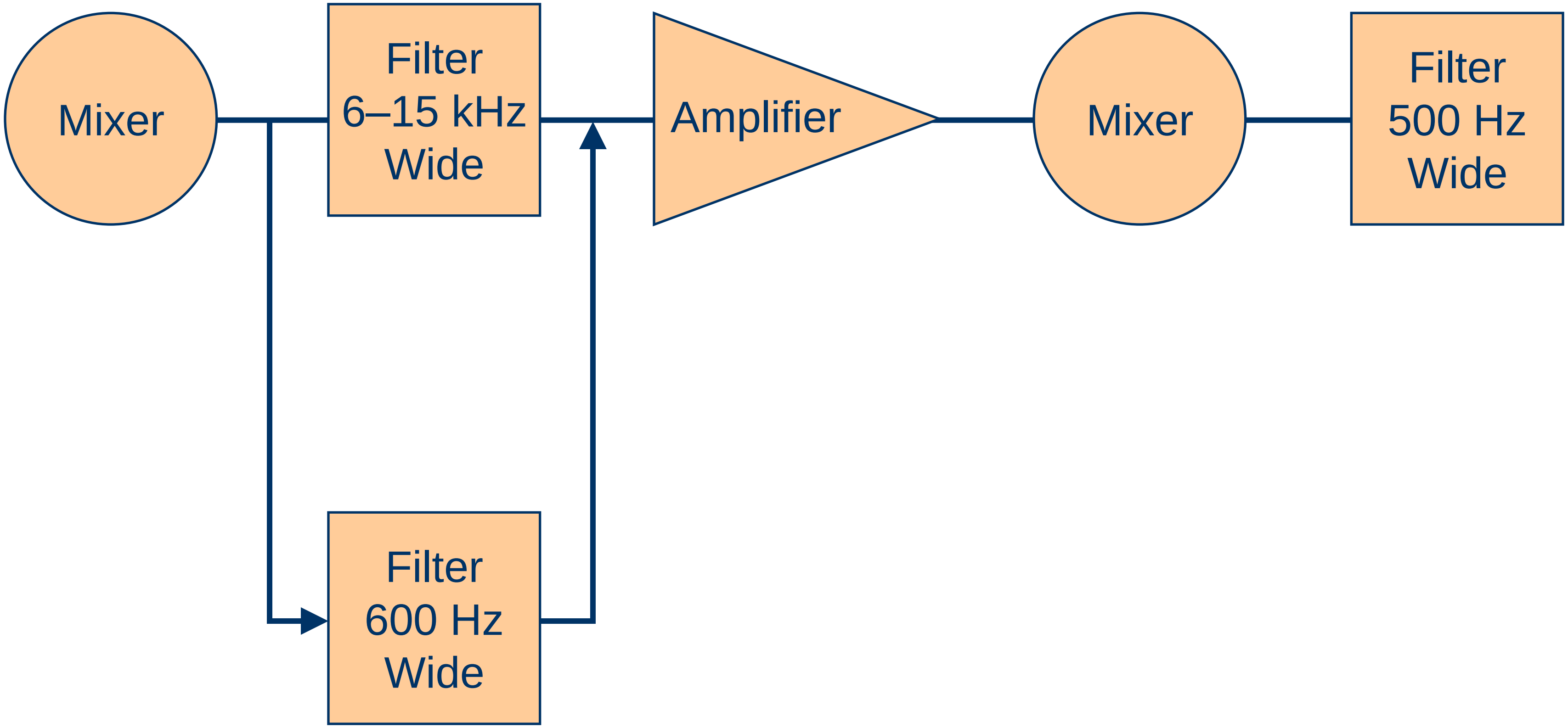
Why is it less important for SSB operators?

Wide & Close Dynamic Range





What if we could switch in a narrow Roofing Filter only slightly wider than the final selectivity?



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

What are roofing filter limits?

Fractional bandwidth of the filter is a big issue.

It is easy to make a 500-Hz filter at 9 MHz, but not at 70 MHz

Passive IMD in the roofing filter itself is often the limit for radios with a true dynamic range (DR3) of 90 dB or greater.

I have observed passive IMD in Ten-Tec, Kenwood and Elecraft roofing filters.

With the K3, for example, you can spend up to $700 for roofing filters for the main receiver, and an additional $700 for the sub receiver !

What is required in the Lab?

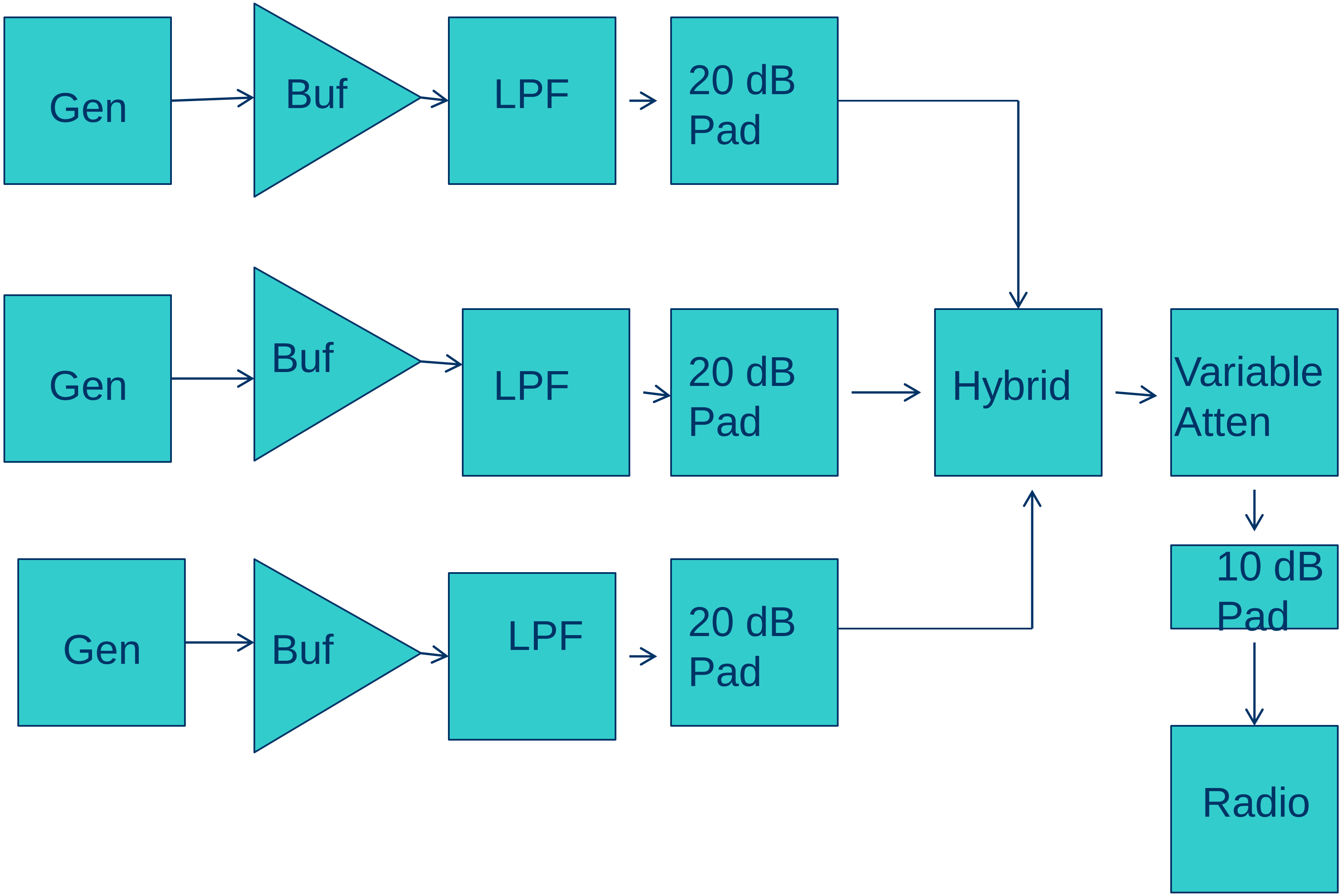
- In the "old days" I used an HP 606A and an HP 608C, a hybrid combiner and a set of HP step attenuators.
- Generators were not "Leveled".
- The two generators didn't interfere with each other causing 3rd order IMD in the setup.
- Generator leakage and thus noise floor measurement were likely a source of error.
- As radios got better, the laboratory equipment also had to improve.

Progression of Sig Gens over time

- 606A & 608C, low noise, no leveling problem but leakage issues at sub-microvolt levels.
- 8640Bs, low phase noise, leveling problem but lower leakage for noise floor test.
- 8662As, lower close-in phase noise, leveling issue and excellent low leakage.
- 8642As, even lower phase noise, leveling issue, and excellent low leakage.

Leveled generators cause problems !

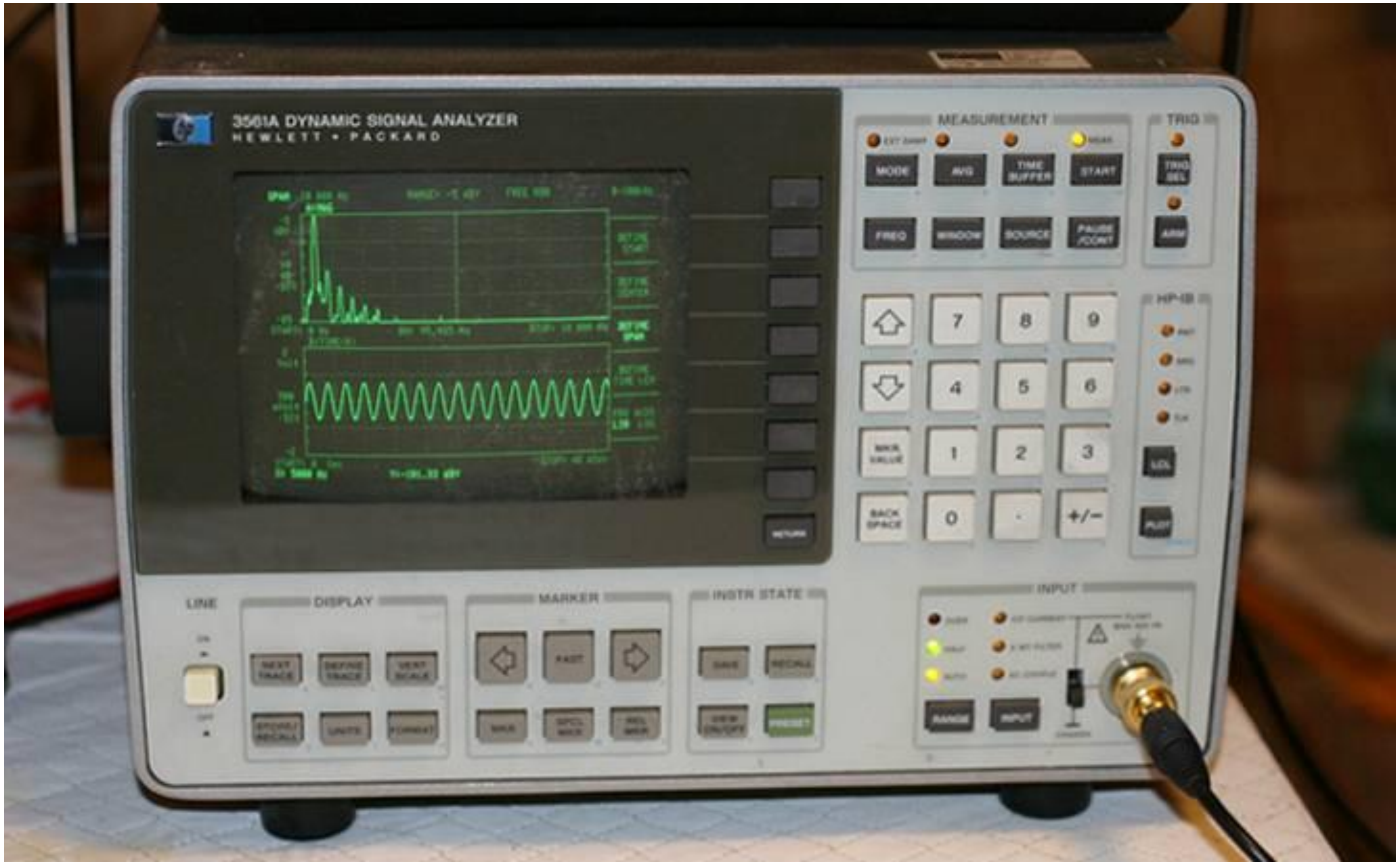
The lab setup requires high isolation



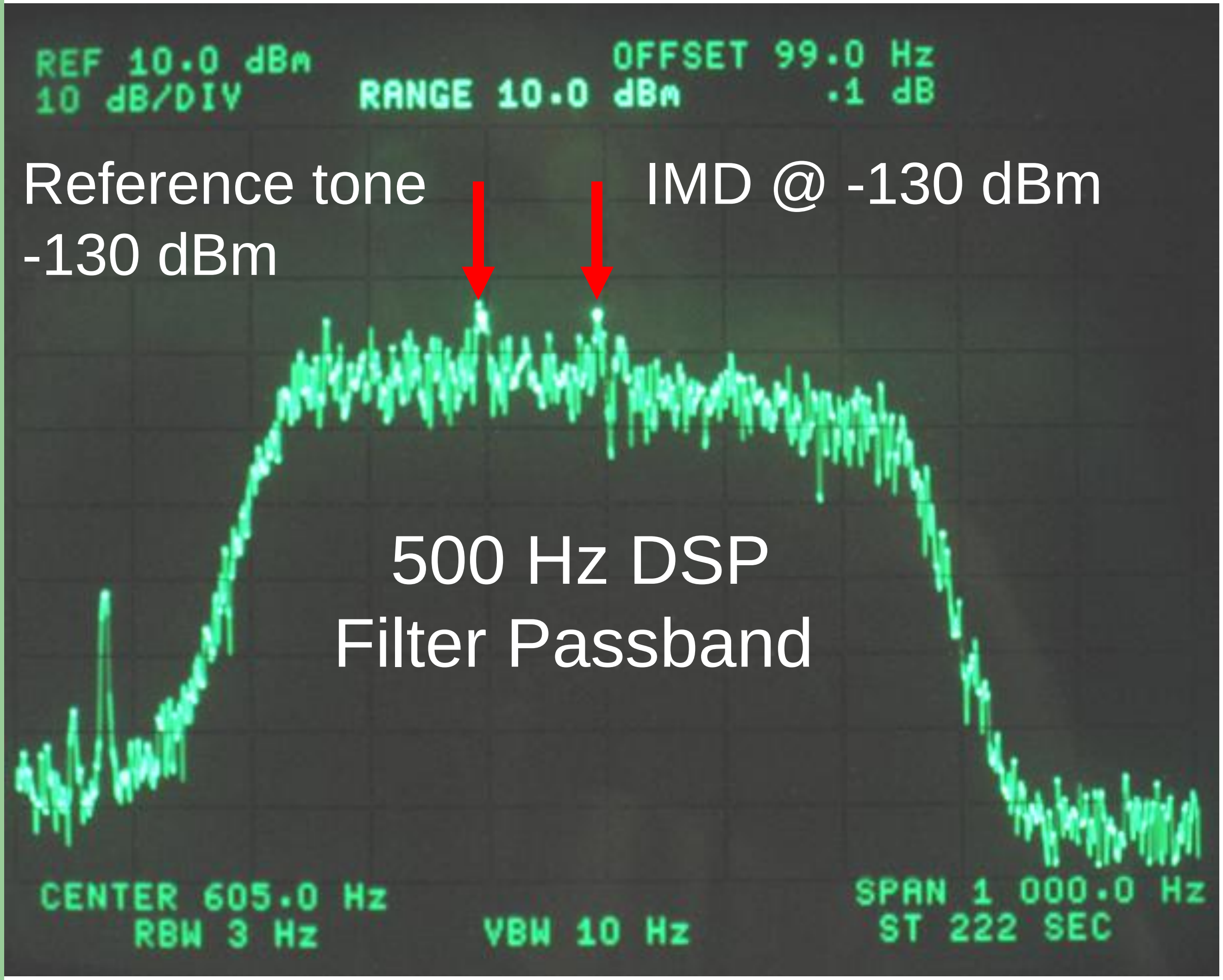
ARRL Dynamic Range Numbers

- Many modern transceivers are phase noise limited, particularly close-in at 2 kHz. The League wanted to be able subtract out the phase noise when measuring IMD, and came up with a new method in 2007 using a spectrum analyzer with a 3-Hz filter using an audio spectrum analyzer.
- Later used a 1-Hz or narrower filter with an FFT analyzer make measurements quicker.

HP 3561A FFT Analyzer



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!

ARRL 2007 – 2011 DR3 Method

- 2006 and earlier, IMD or noise increased 3 dB. This was published as the dynamic range, either IMD or noise limited.
- With the 2007 - 2011 method, phase noise buried the IMD product.
- 3-Hz filter used for the third-order dynamic range measurement, and the published values were greater than in 2006 and before.
- Non synthesized rigs (S-Line / C-Line) would not have any reciprocal-mixing issues.

IC-7410 Dynamic Range Data

Example

Spacing	Value
100 kHz	107 dB some noise
20 kHz	102 dB noise limited
5 kHz	90 dB noise limited
2 kHz	78 dB noise limited
2 kHz ARRL*	89 dB noise ignored

- * (Using spectrum analyzer and narrow BW)

The ARRL / Sherwood Compromise

- In September 2011 the League agreed to add emphasis to their reciprocal-mixing data. The first Product review with the testing change was April 2012.
- The League's reciprocal-mixing (RMDR) values should equal their pre-2007 noise-limited data, and my published noise-limited or IMD limited data.
- IC-7410 RMDR limited dynamic range = 78 dB
- Sherwood noise-limited DR3 = 78 dB
- The IC-9100 review uses the new reporting, and has a nice sidebar on page 55 explaining the changes.

Phase Noise Revisited in IC-9100 review

- The League’s third-order dynamic range is measured in such a way to eliminate phase noise from the equation. Their new 2-kHz reciprocal-mixing dynamic range can be equated to 2006 and older “phase noise limited” dynamic range data.
- Icom IC-9100 data, April QST 2012
- 2-kHz 3rd order DR3 = 87 dB (with 1-Hz filter)
- 2-kHz reciprocal mixing dynamic range 77 dB

You choose which data to consider

Now both RMDR and 1-Hz Data is Presented

- Currently ARRL blocking and DR3 use a 1-Hz filter to remove phase noise.
- For most radios RMDR is the limit.
- If DR3 is 100 dB, but RMDR is 80 dB the smaller value is the performance limit.

- The 1-Hz data is useful to the design engineer.
- RMDR data is more useful to the ham operator.

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	TS-590S (88 dB)
90 dB	S9 + 35 dB	Eagle & Flex 3K (90 dB)
95 dB	S9 + 40 dB	Orion II & K3 (95 dB)
100 dB	S9 + 45 dB	FTdx-5000, Flex 6700

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 often constant even with 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)

Comments on Blocking & Phase Noise

Blocking is the onset of gain compression.

This can be an issue with another ham within “line-of-site”.

It is an issue on Field Day and multi-multi contest stations.

Low phase noise is desirable, but a very good low phase-noise receiver has to contend with transmitted phase noise.

Dealing with transmitted phase noise is like dealing with transmitted IMD products and splatter.

We cannot do much about it.

Blocking & 1 Hz FFT measurements

The ARRL measures blocking since 2007 in a 1 Hz bandwidth.

With most radios, if we measure blocking in a 500-Hz bandwidth, the signal at the speaker goes UP, not DOWN !

In other words, the phase noise (reciprocal mixing) dominates over gain compression.

Just like DR3 numbers being higher with a 1-Hz measurement, the blocking numbers are exaggerated when measured at audio with an FFT spectrum analyzer.

The bottom line: Understand what the numbers really mean.

Lets now move from CW to SSB

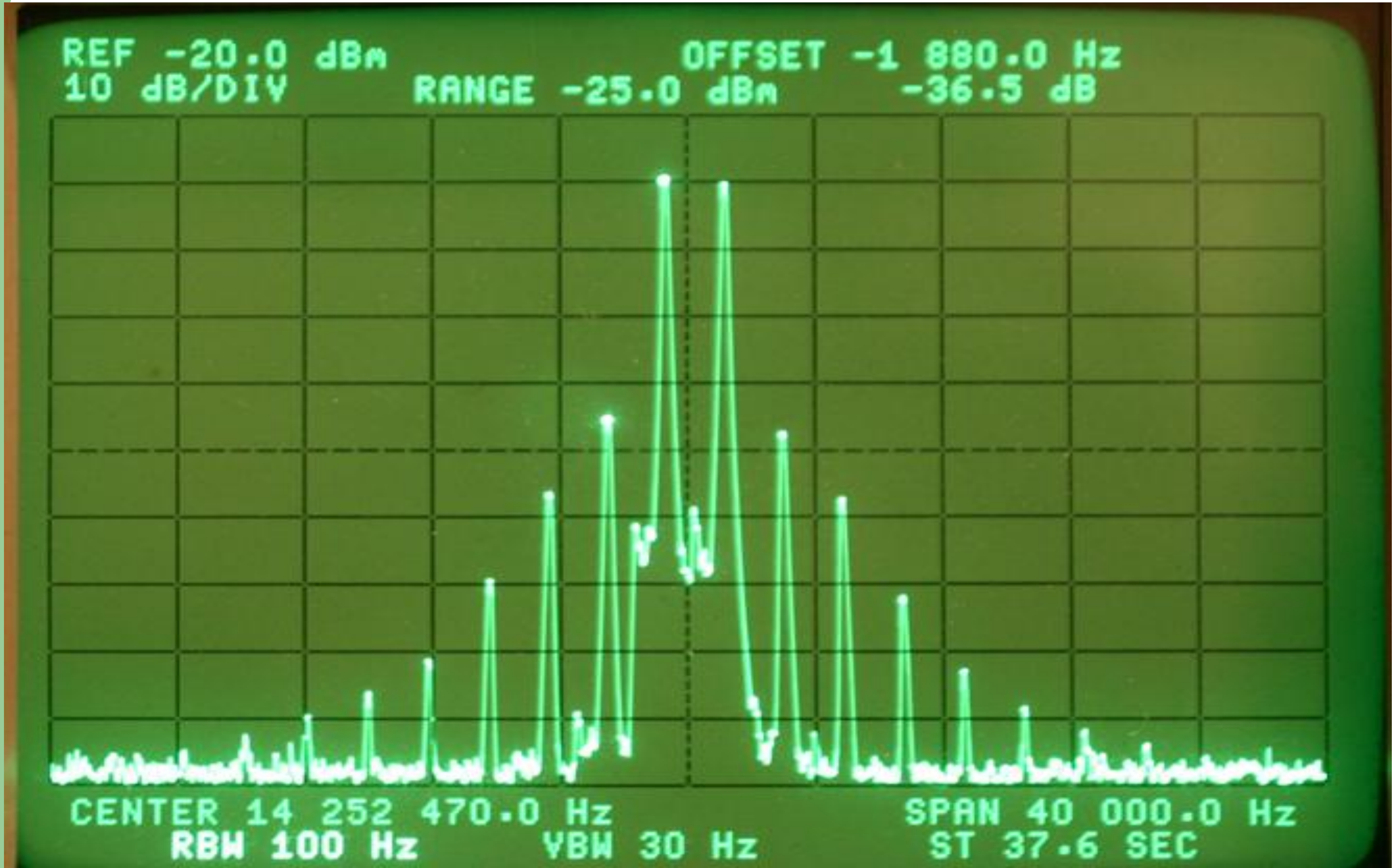
Why are the dynamic range requirements less stringent on SSB than on CW?

On CW the limitation on working weak signals very close to a strong signal is often the keying sidebands of the QRM, once the dynamic range is good enough. (Discussed later)

On SSB the limitation is often the distortion products from an adjacent station a few kHz up or down the band.

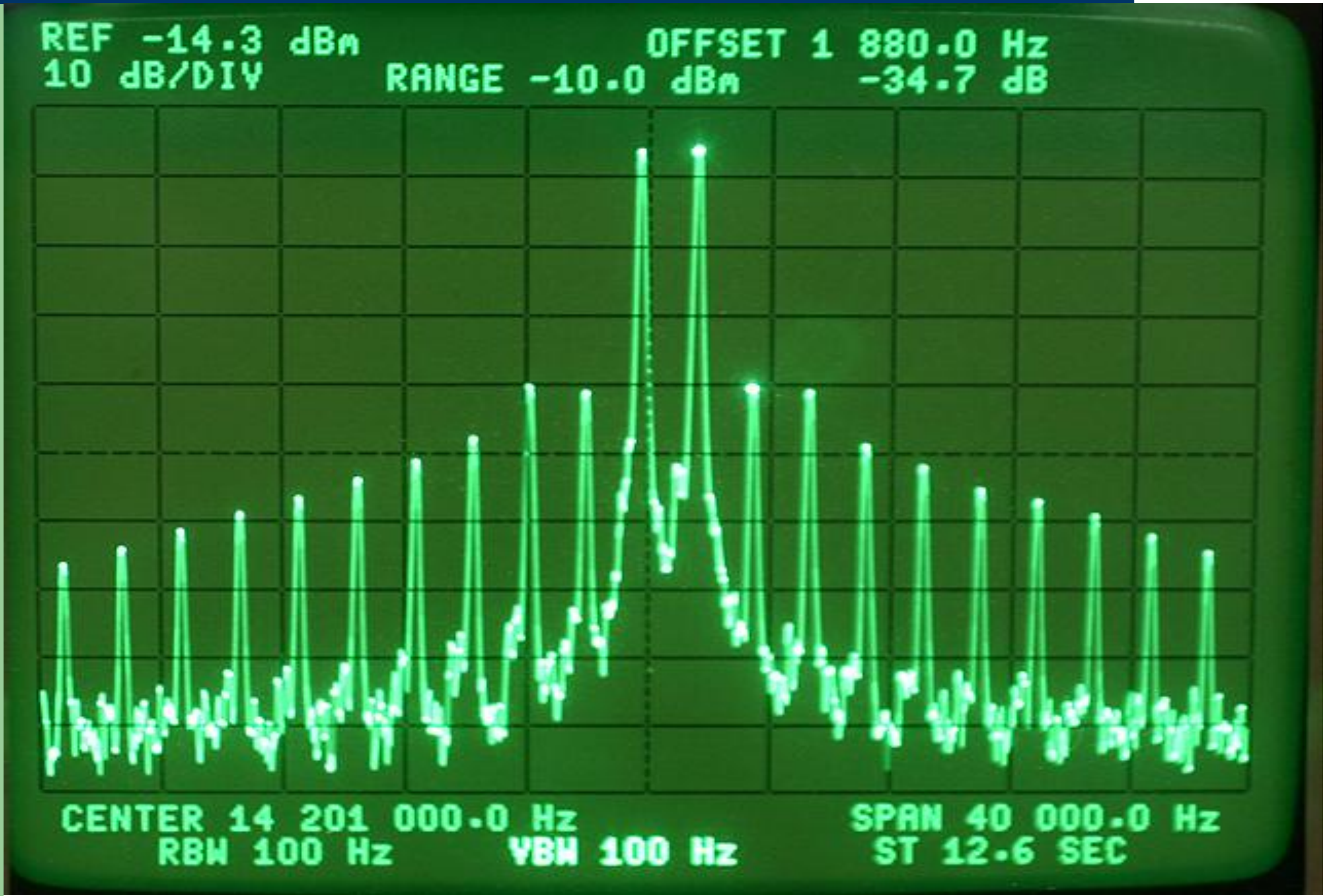
Third order down -36 dB

Transmitted IMD Collins 32S-3



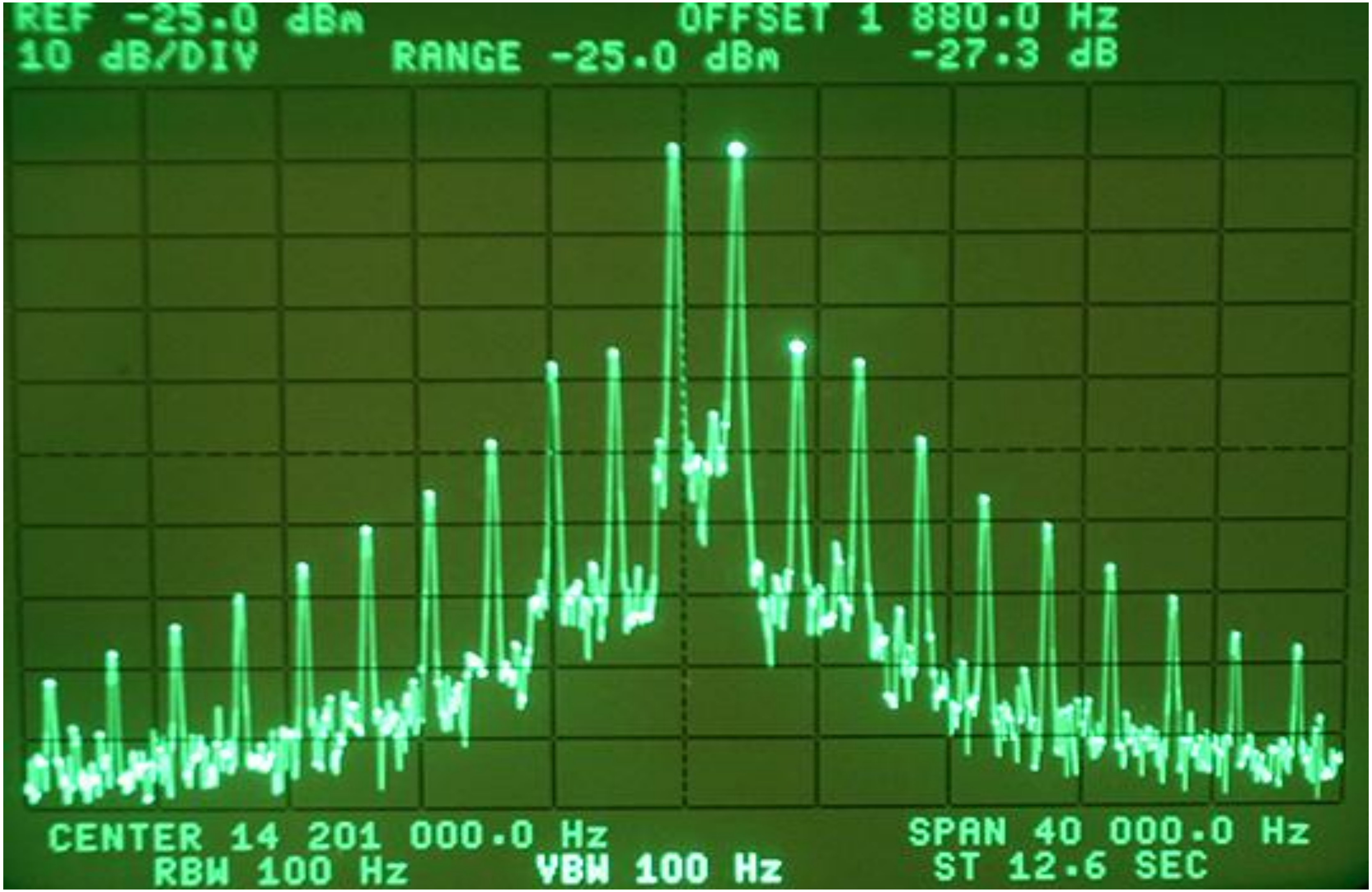
-34 dB 3rd order, -43 dB 7th order

Icom 781 on 20 meters @ 150 Watts



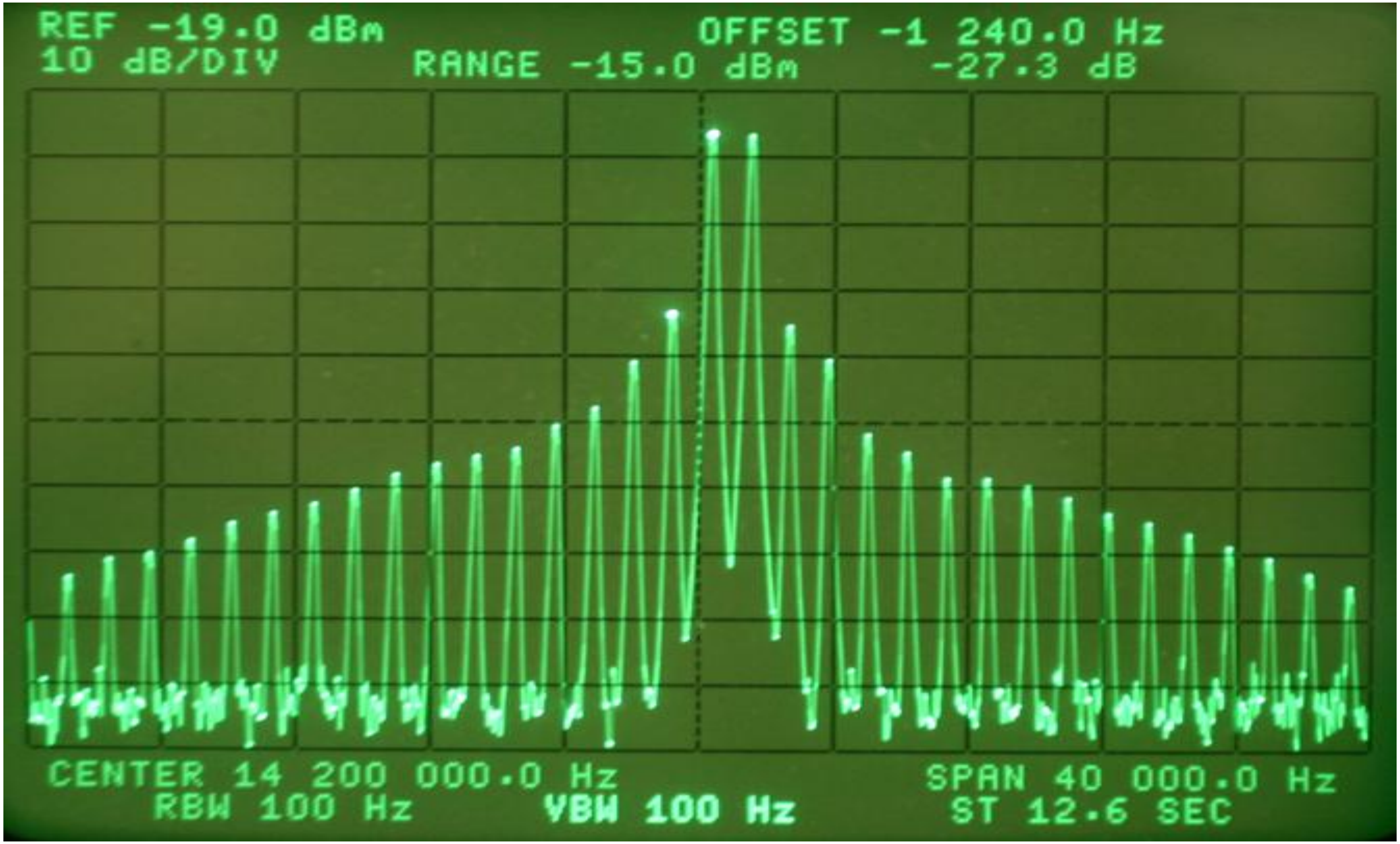
-27 dB 3rd order, 40 dB 7th order

Icom 756 Pro III on 20 meters @ 70 W



Third order IMD down only -27 dB

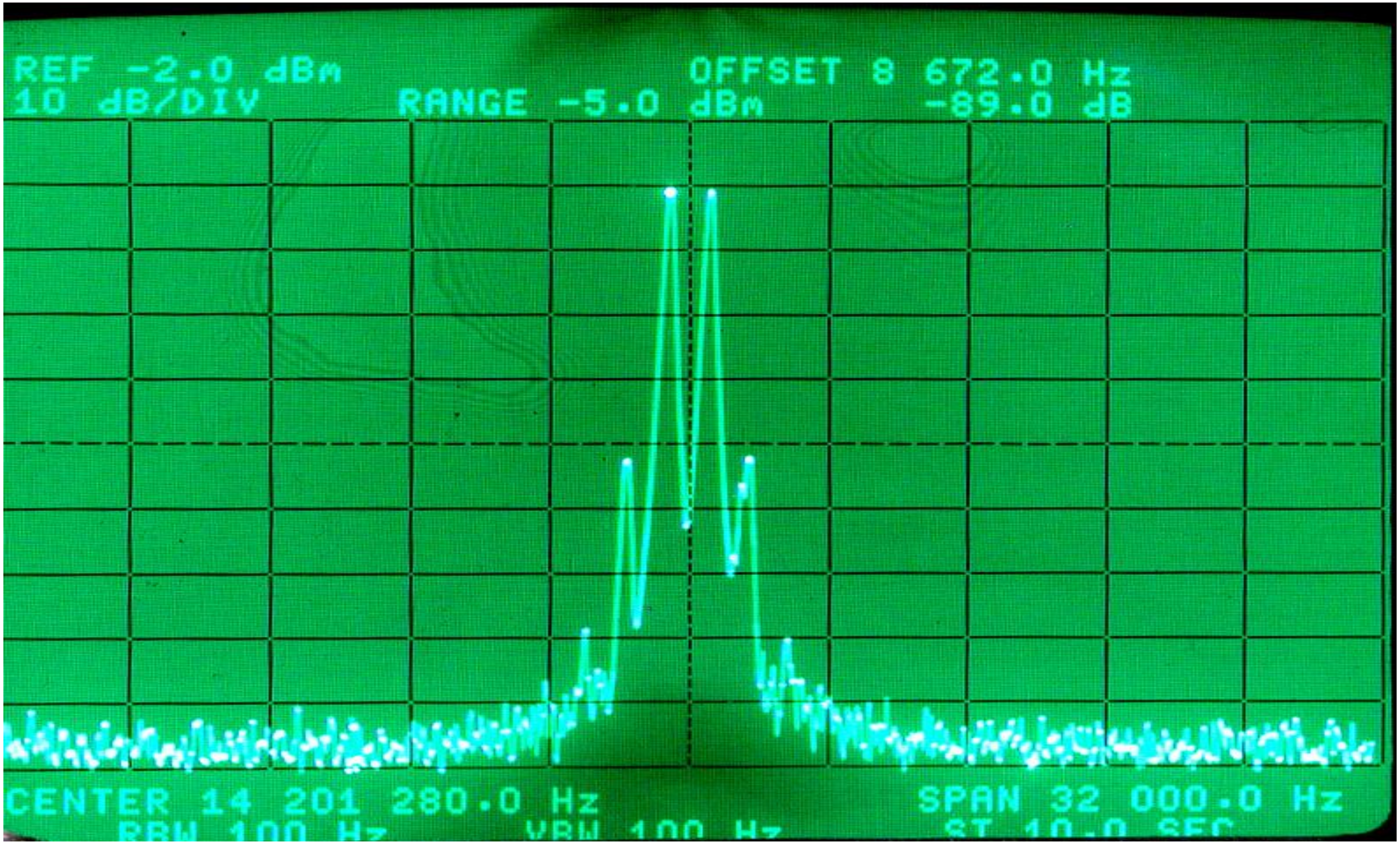
Elecraft K3 on 20 meters



3rd order dowm -42 dB, 5th -70 dB

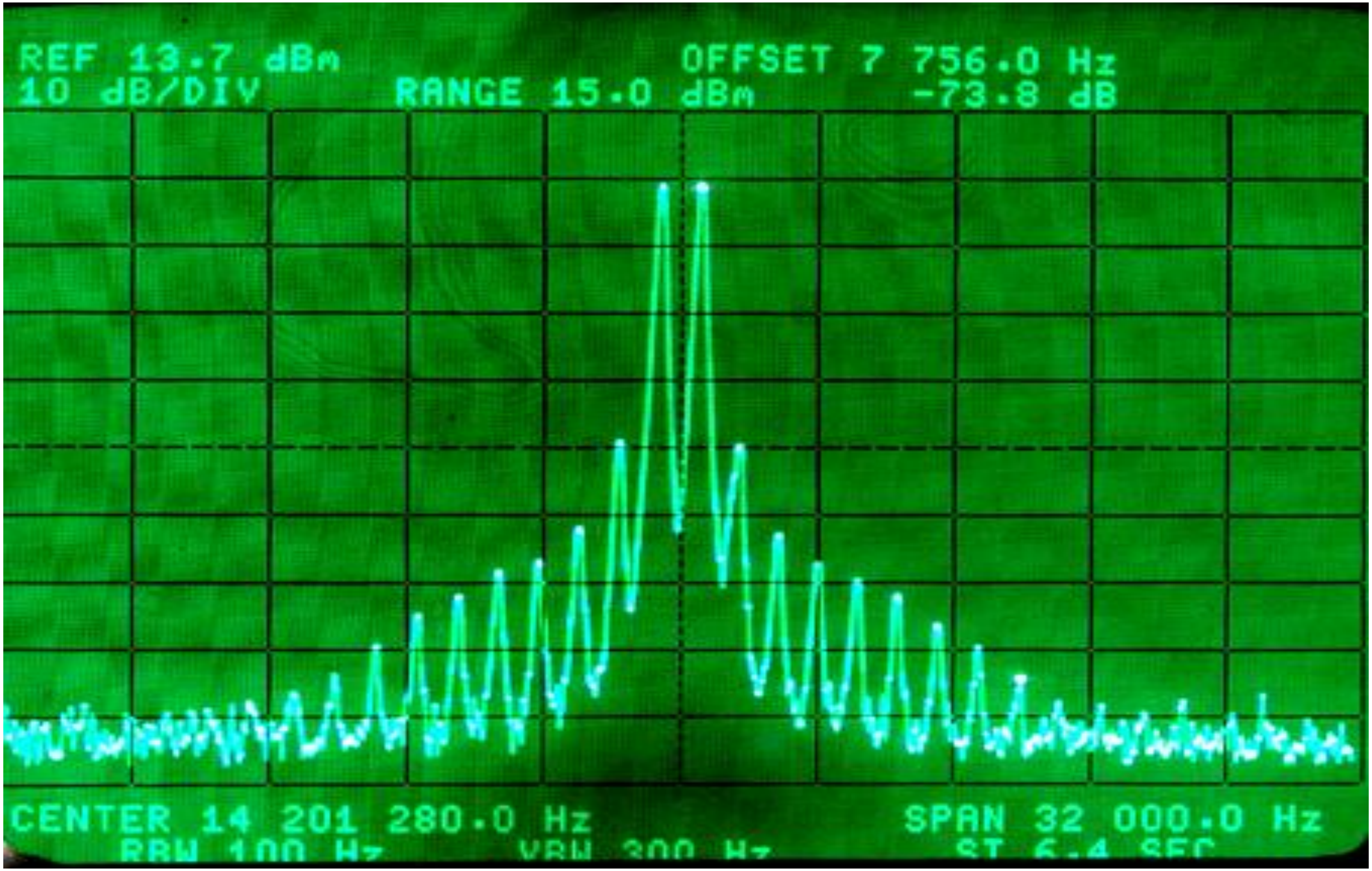
Yaesu FT-1000 Mk V in Class A

Provided by Pete, W6XX



3rd order only 2 dB worse @ -40 dB

Mk V Class A + 8877 Linear Amplifier

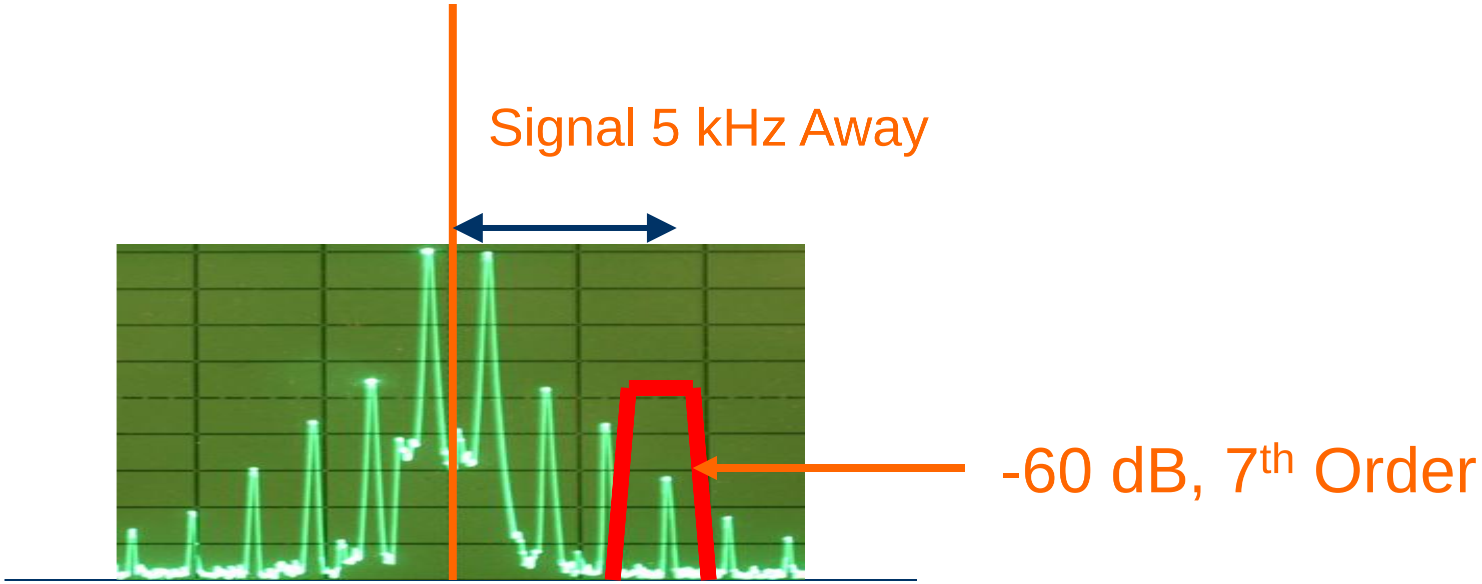


Have to add 6 dB to compare to PEP method

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 (Note)
9th	-77 dB	-48 dB	29 dB

Close-in Signal and Splatter



IF Filter vs. Adjacent Signal and IMD Splatter

Steady-State vs. Dynamic Splatter

Some transceivers, in addition to normal IMD products, produce additional ALC-Induced splatter. On CW the ALC can cause leading-edge key clicks.

ALCs could be driven hard in a 32S-3 or a T-4XC, for example, and not add to splatter.

Some modern rigs splatter more if the ALC is more than “tickled”, or induce clicks on CW.

The League has chosen not to address this problem in its equipment reviews. SM5BSZ & I tried to no avail.

How Many Roofing Filters are Needed?

- It depends on your mode of operation.
- For SSB, a single 15 kHz roofing filter is adequate, such as in the Icom 756 Pro II / Pro III with a close-in dynamic range of 75 dB.
- Other radios with similar performance: Drake R7 and TR7, IC-781, Collins 75S-3B/C, TS-930, FT-1000x, T-T Omni-V or VI.
- Would a 2.7 kHz roofing filter be better?
- Yes, K3, Orion, Omni-VII
- On CW, a single wide roofing filter is not optimum.
- CW signals do not have IMD products. Strong adjacent signals do not have as much energy in the CW passband of your filter.
- A CW Signal Does have a Bandwidth. It is NOT zero bandwidth

Roofing Filter BW on SSB

Do you need more than one SSB BW Filter?

Best if Roofing & DSP bandwidths are equal.

More selectivity up front is always desirable.

Better shape factor than depending of last IF only.

Omni-VII the 455 kHz filters really help total selectivity.

Orion & K3 both offer a 1.8 kHz roofing filter.

Reduces load on DSP !

Just not as dramatic improvement as on CW.

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?

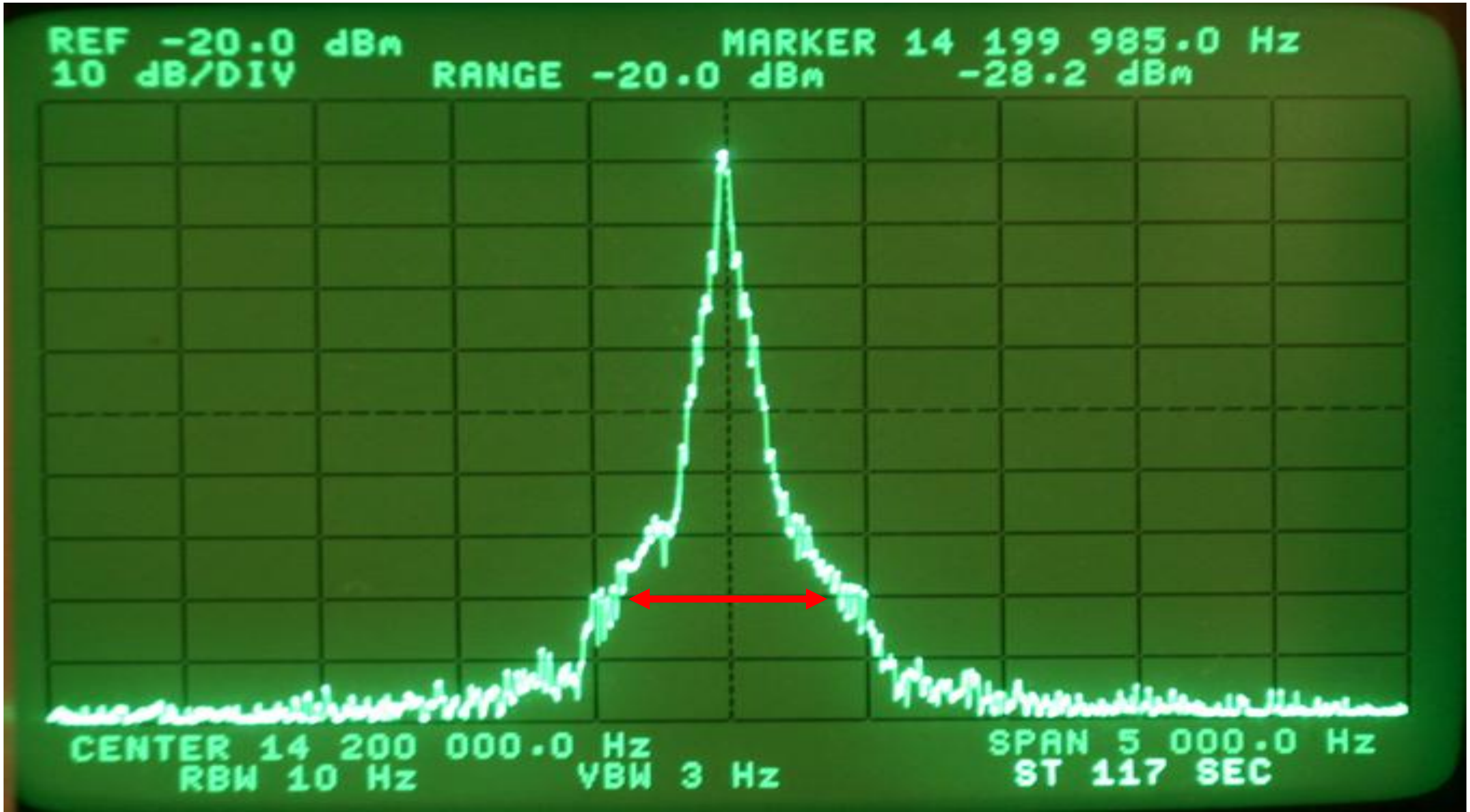
What is the Bandwidth of CW Signal?

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

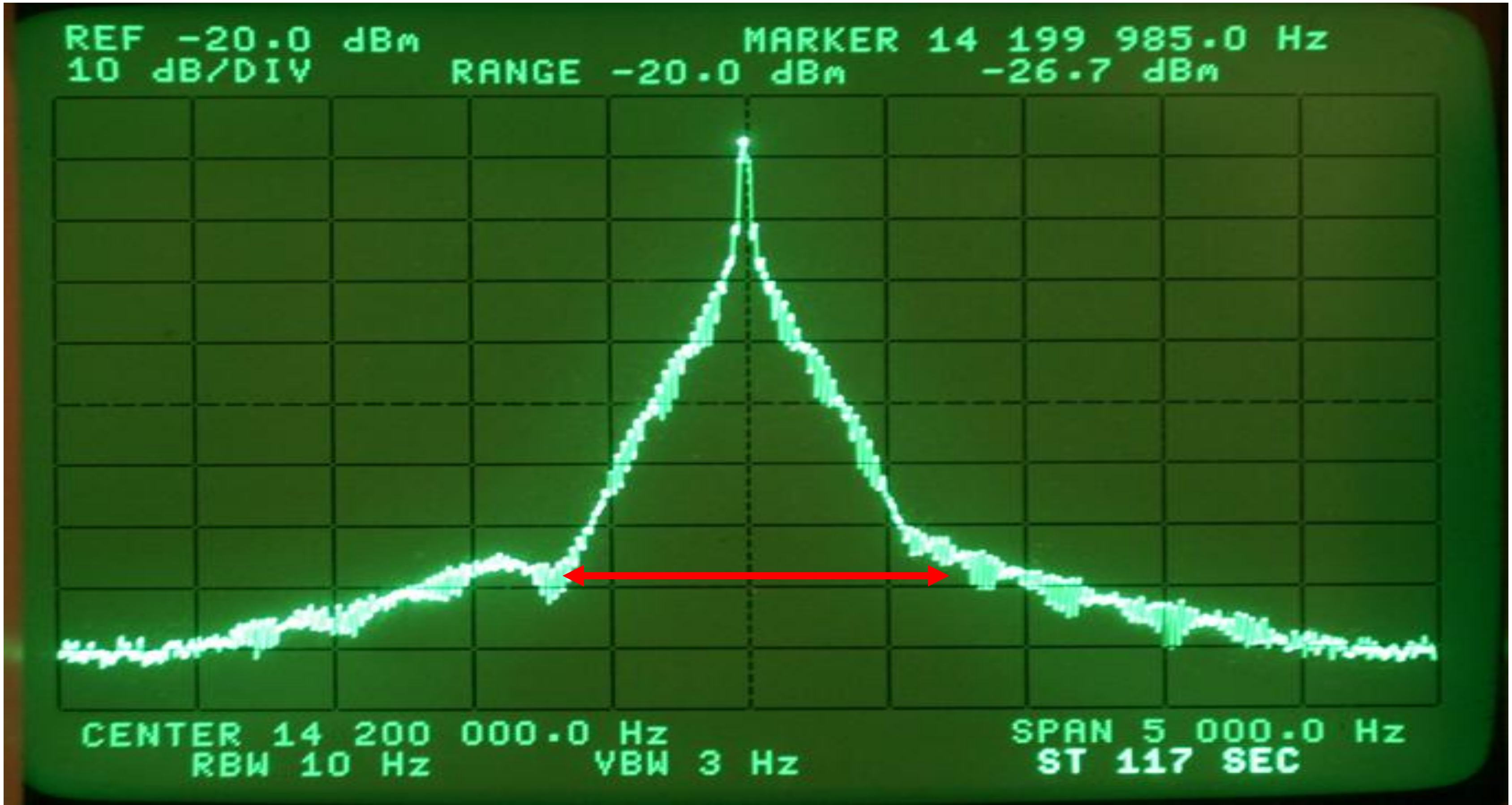
Spectrum of CW Signal on HP 3585A Analyzer

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



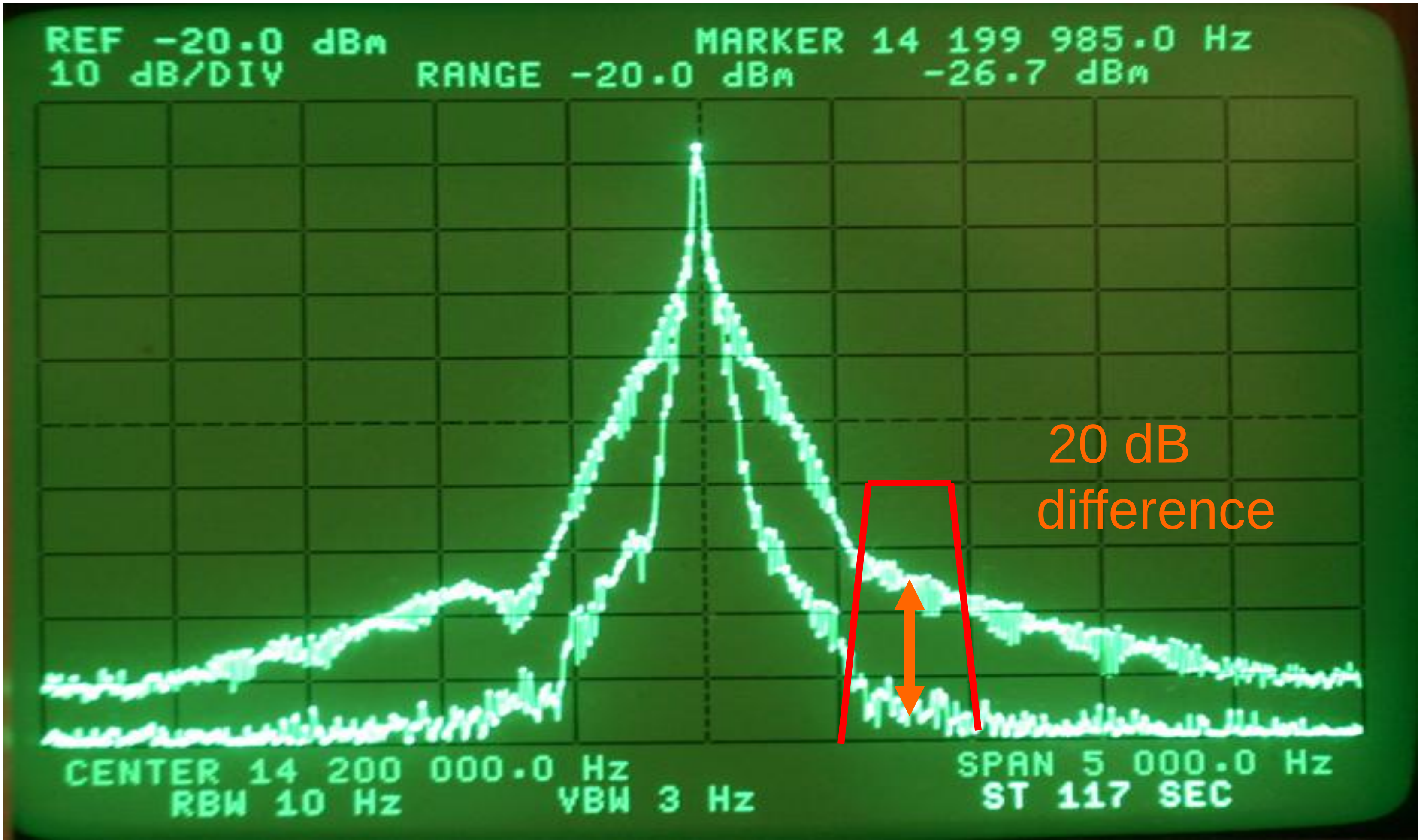
Spectrum of CW Signal on HP 3585A Analyzer

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

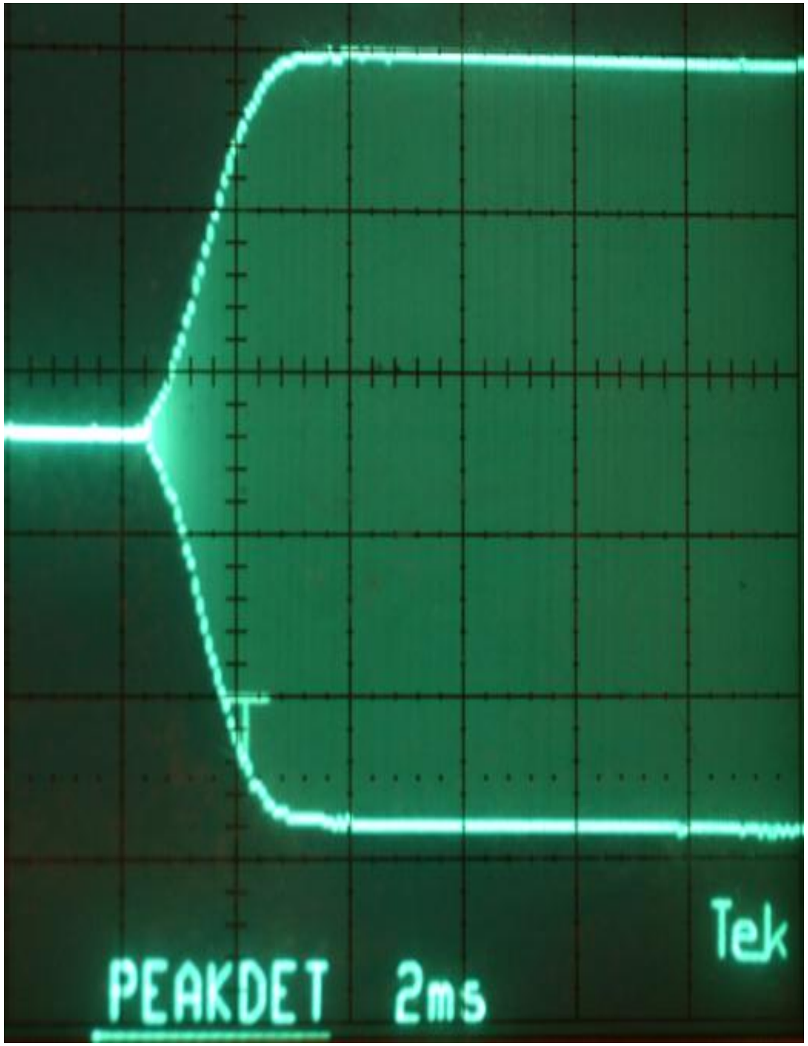


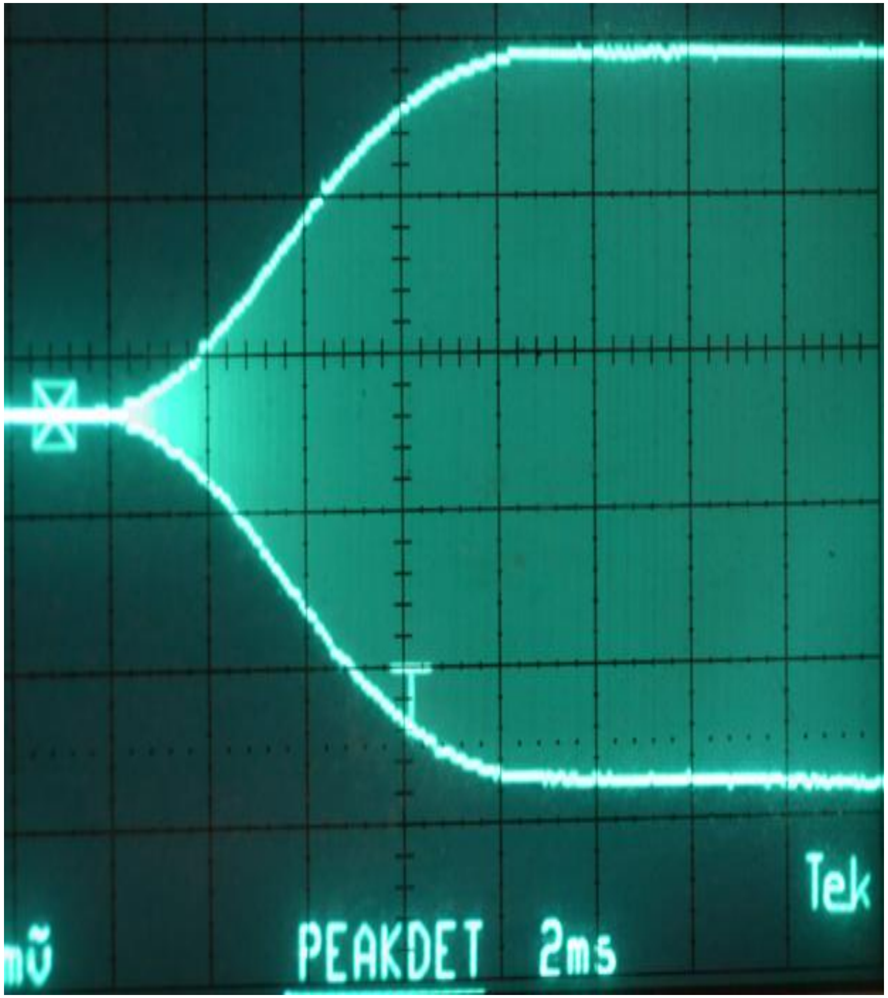
Spectrum of CW Signal on HP 3585A Analyzer

Comparison of 3 msec vs 10 msec rise time



Leading edge of “dit” 3 & 10 msec





How Many Poles Are Needed for a narrow CW roofing filter?

Orion II 600 Hz 4-pole filter is - 30 dB @ +/-700 Hz
Orion II 600 Hz 4-pole filter is – 50 dB @ +/-1200 Hz
A signal 2-kHz away is in the stop band of any filter.
Typical CW signal is +/- 700 Hz wide at –70 dB

The Orion II uses 4-pole roofing filters.
Sherwood has used a 6-pole filter for 32 years.
Elecraft uses both 5 and 8-pole filters.

I see no significant advantage of one choice over another.

Just the facts

From a Dynamic Range standpoint, reducing a strong adjacent signal 30 dB with a roofing filter is adequate.

All the roofing filters from Elecraft, Kenwood, Ten-Tec or Yaesu do the job. More poles have more insertion loss and cost more. Its a trade-off.

Compared to a 15 kHz roofing filter, a 500 Hz CW roofing filters will pass about 3% of those signals on to the later stages of the radio.

You likely cannot work a weak signal 500 Hz from an S9 +40 dB CW signal with any radio with the best roofing filter due to the transmitted bandwidth (keying sidebands) of the interfering signal.

Conclusions

- Contesters – DXers – Pileup operators need a good receiver for SSB and an even better receiver for CW.
- The Sherwood 600-Hz CW roofing filter fixed the R-4C in 1976.
- Ten-Tec Orion put that concept in a commercial design in 2003.
- Elecraft K3 offered multiple roofing filters in 2008.
- Now Kenwood & Yaesu have followed suit.

- 25 years of up conversion radios have generally offered a 20 kHz dynamic range in the 90s but a 2 kHz close-in dynamic range in the 70s. Typical degradation of dynamic range within the up conversion filter bandwidth is 25 dB.

- Some brands offer a 3-kHz roofing filter in up-conversion radios, though filter is often wider than spec.

- IC-7800 3-kHz filter is 5+ kHz wide, 6-kHz is 11+ kHz

- FT-2000 3-kHz filter is 7 kHz wide, and with my sample, it had 9 dB worse IMD than its 6 kHz filter.

How Narrow Can a VHF Filter Be?

It is not possible to offer CW bandwidth Roofing Filters at VHF frequencies.

It all comes down to fractional bandwidth.

A 500-Hz filter at 5 MHz is like a 1-kHz filter at 10 MHz, or a 2 kHz filter at 20 MHz or a 4 kHz filter at 40 MHz & an 8 kHz filter at 80 MHz.

FTdx-9000 IF = 40 MHz, 3-kHz reasonable.

FT-2000 IF = 70 MHz, “3 kHz” = 7 kHz wide

The Orion II and the K3 roofing filters are in the 8 to 9 MHz range, similar to the R-4C at 5 MHz. Narrow filters are no problem here.

Flex Radio and Apache ANAN

Flex and Apache have are now using a direct sampling architecture.

There are no mixers or roofing filters.

The number crunching can be done in the computer (Apache) or in an FPGA in the radio (Flex).

While the hardware costs money, the real cost of development is in the software.

I have used both the Flex 6700 and ANAN-200D in recent CW contests.

Both perform very well, with limitations in respect to logging.

We can discuss this later if there is interest.

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

2008 Elecraft K3: 95 dB

2010 to date: Yaesu, Hilberling, Flex: 100 dB

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

Two transceivers made me tired in a long contest.

The audio was harsh on SSB and CW. Met OEM Spec

OEM spec = 2.5 watts @ 10% distortion = clipping

What makes audio harsh and fatiguing?

High Odd-Order Harmonics and / or IM Distortion

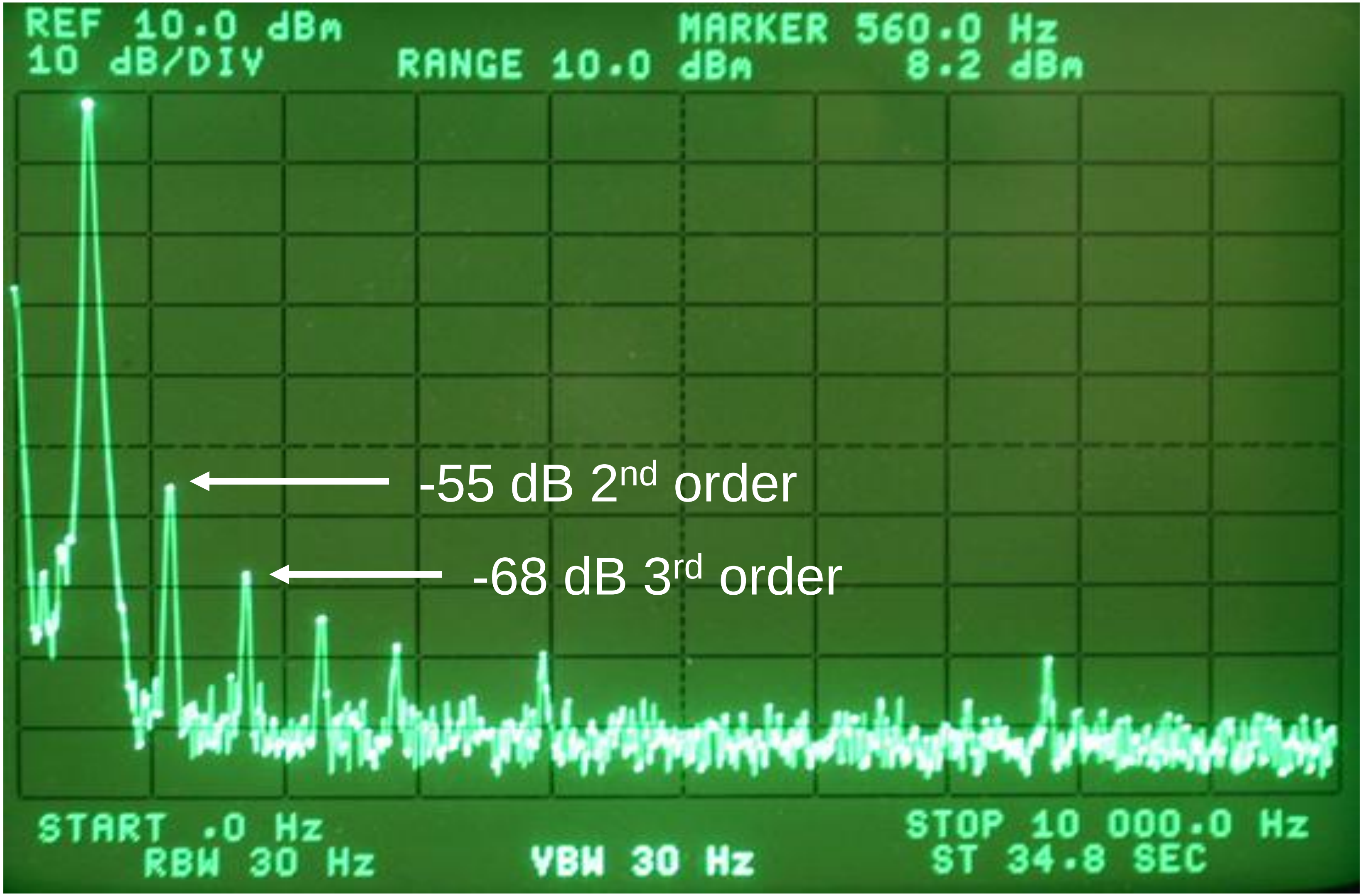
The ear / brain is very sensitive to these products.

Any product detector & audio amp will meet 10% spec

Thus the spec is meaningless.

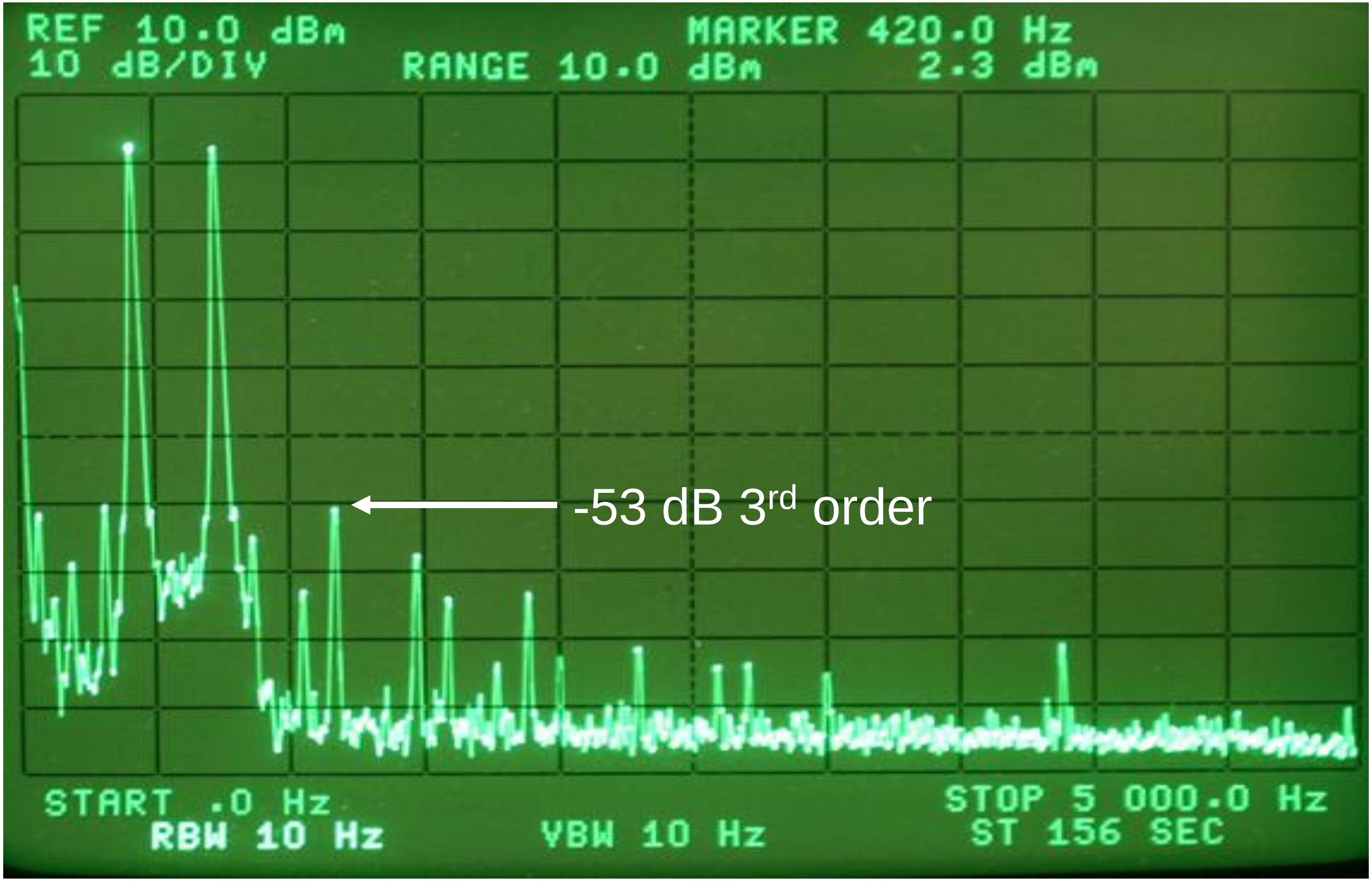
Distortion < 0.3 % & sounds fine

Harmonic Distortion of a Good Amp



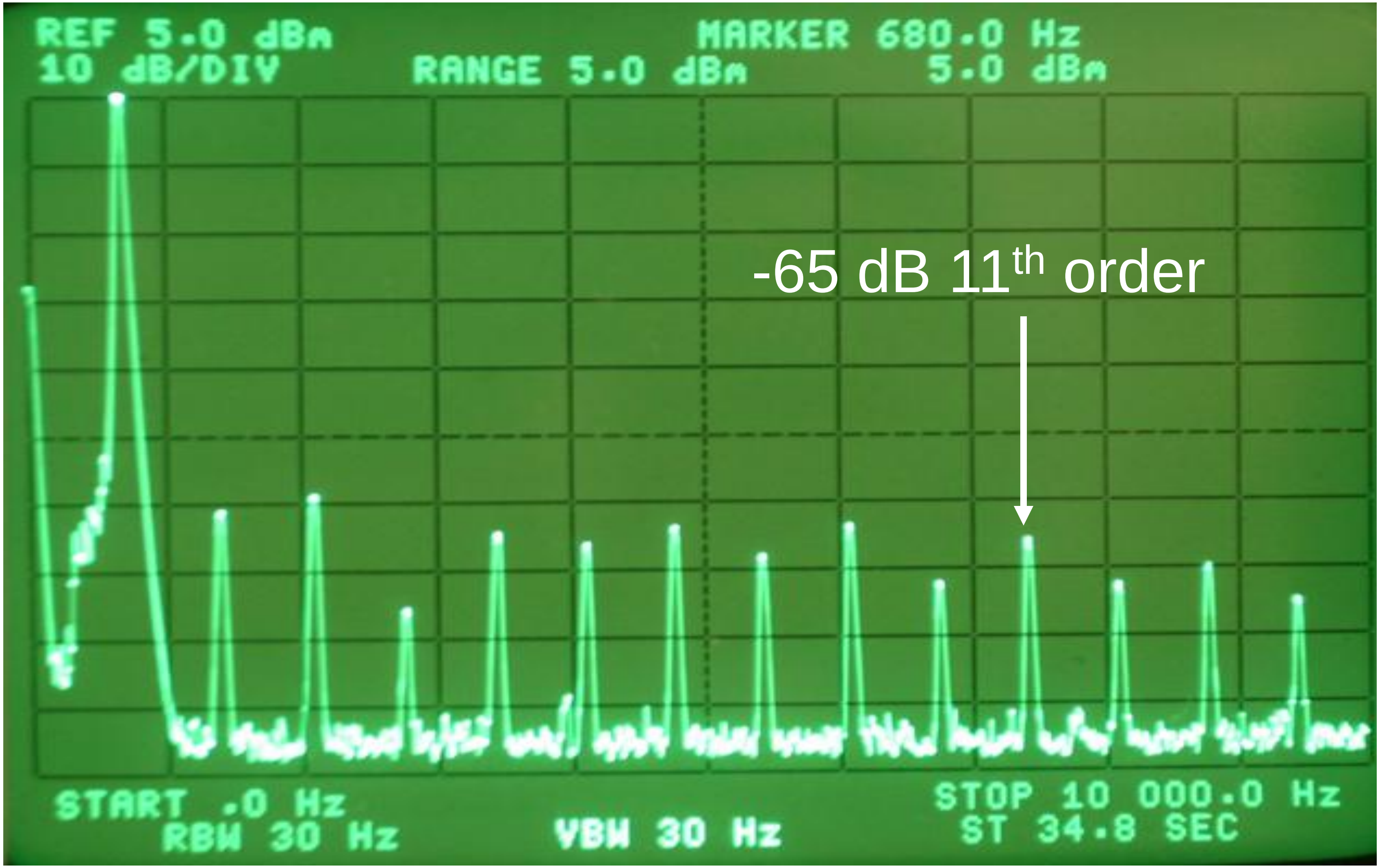
Distortion = 0.3 % & sounds fine

IM distortion of Good Amp



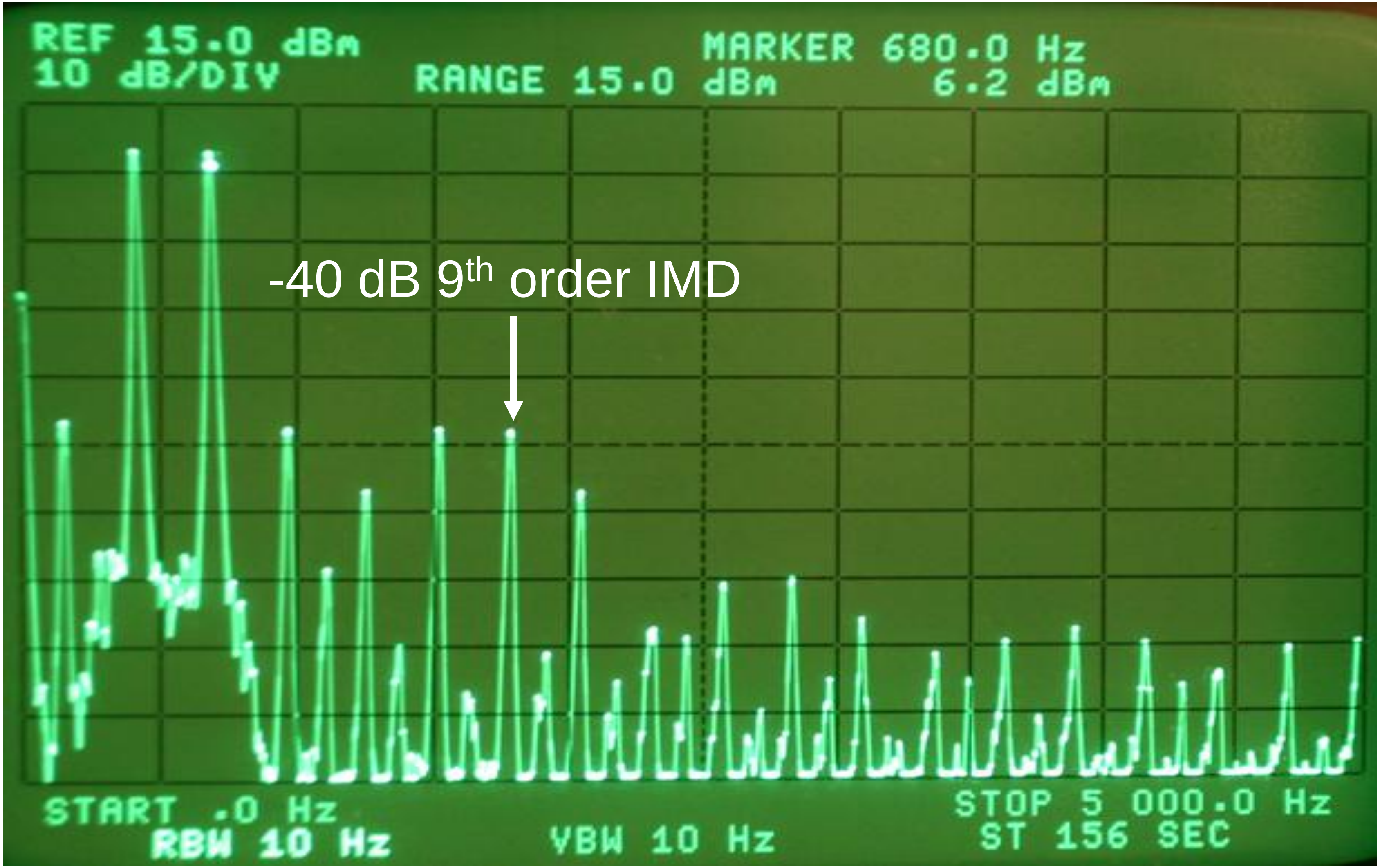
Distortion < 0.3 % but sounds bad

Not So Good Amp & Odd Order > Even



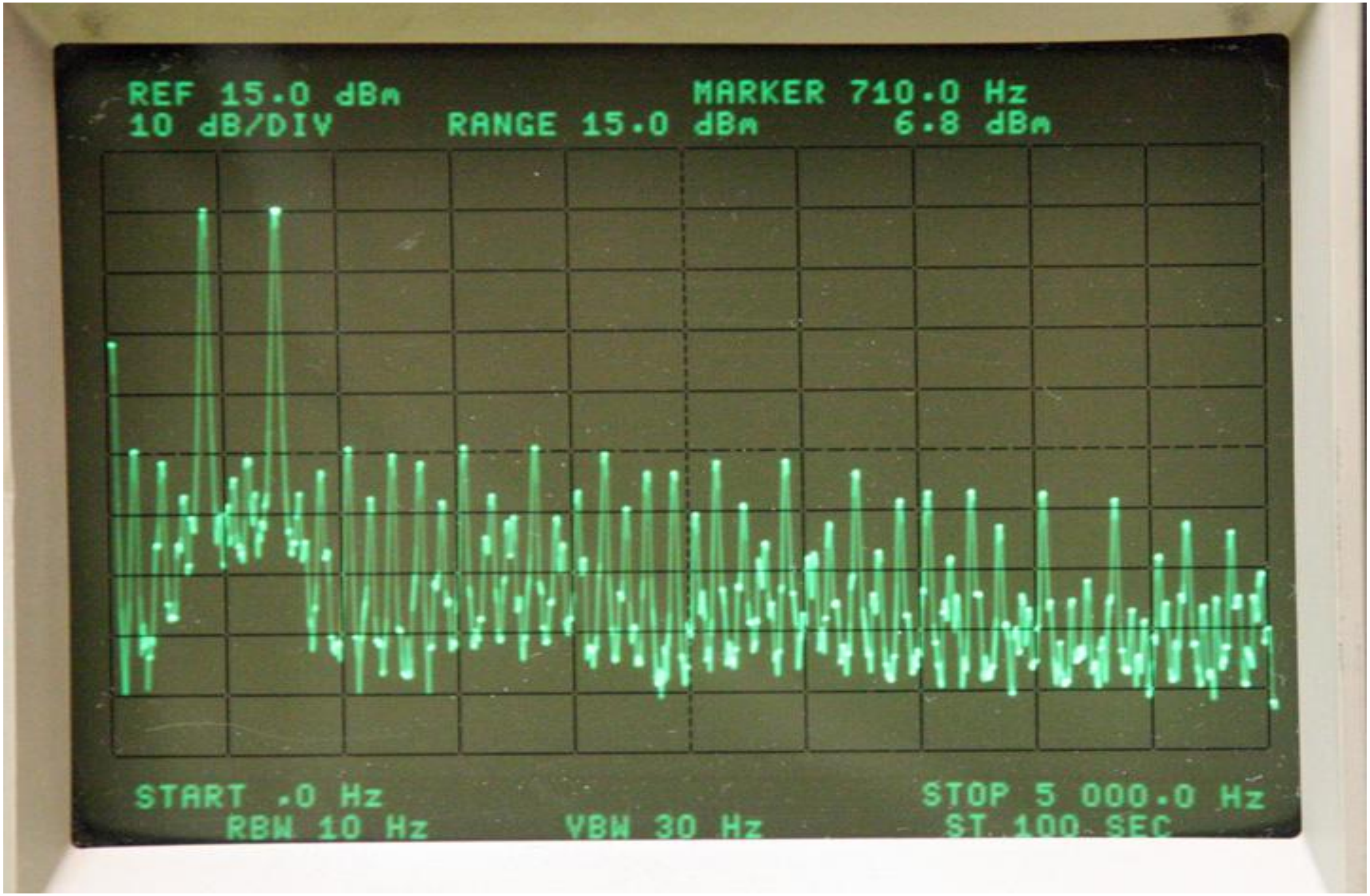
3% distortion but sounds terrible !

Way too much IM Distortion



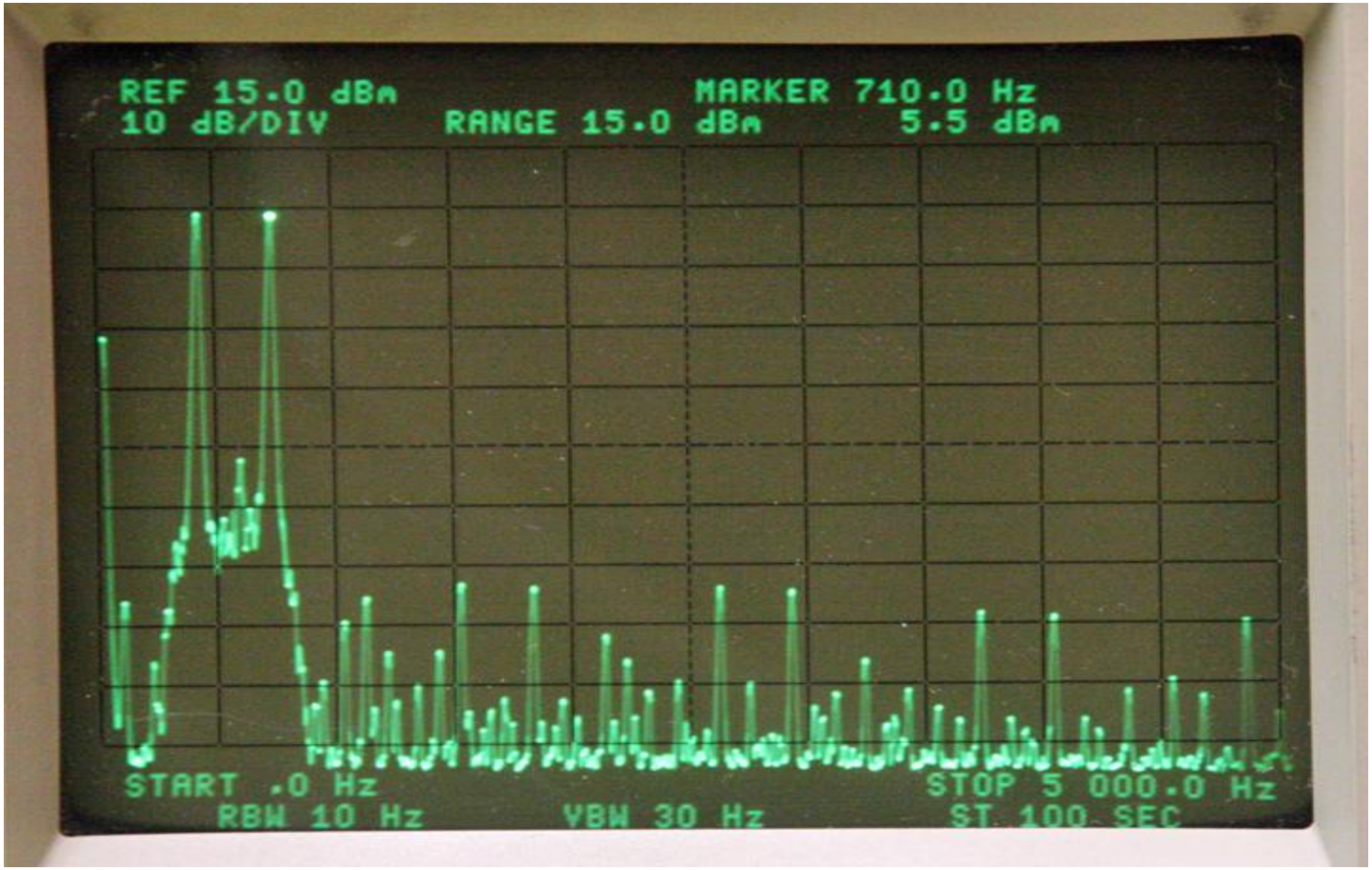
Factory Confirms K3 Audio Problem

Screen shot from Elecraft Lab Fall 2008



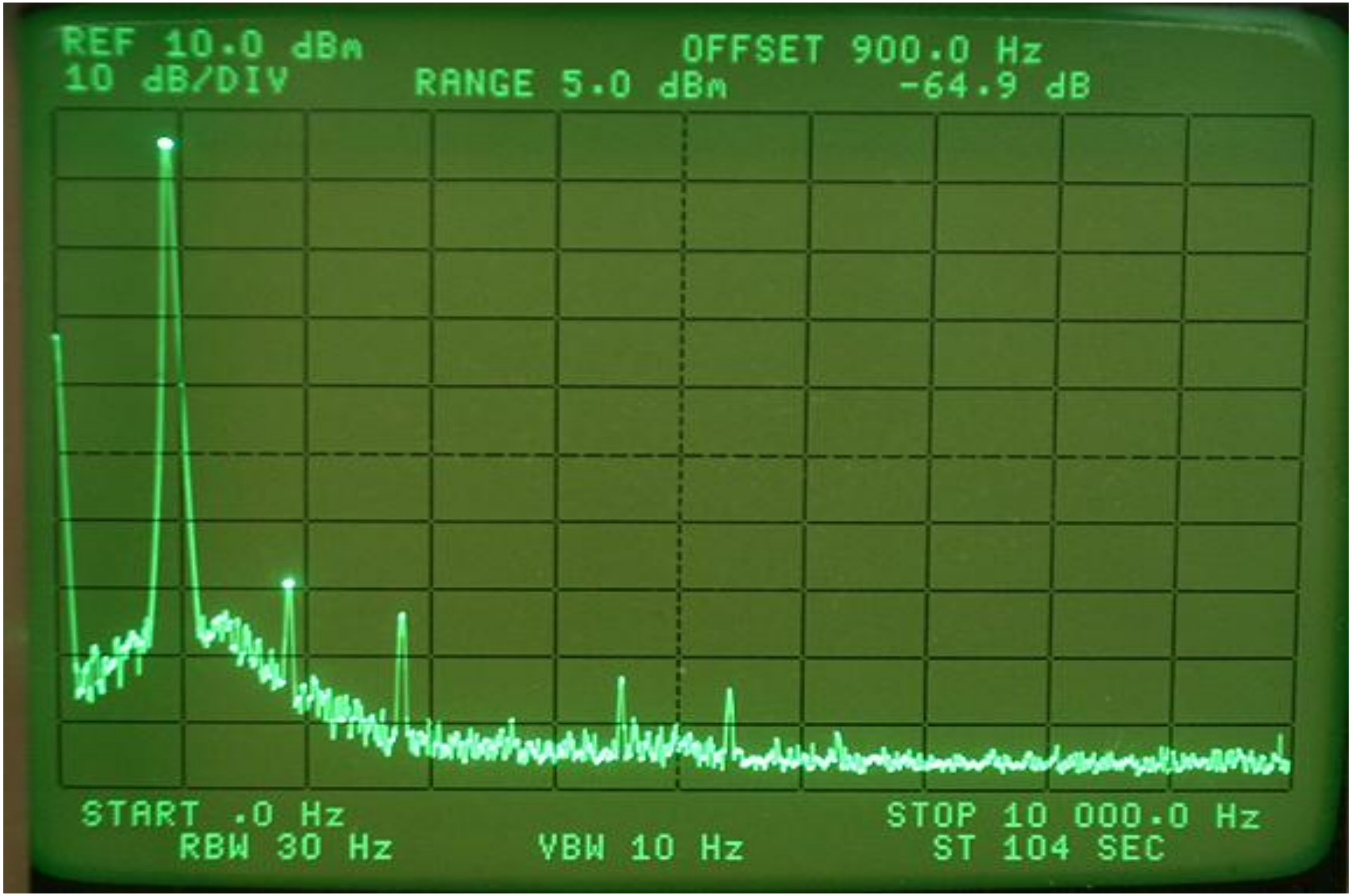
Factory Addresses K3 Audio Problem

K3 After New Choke Installed



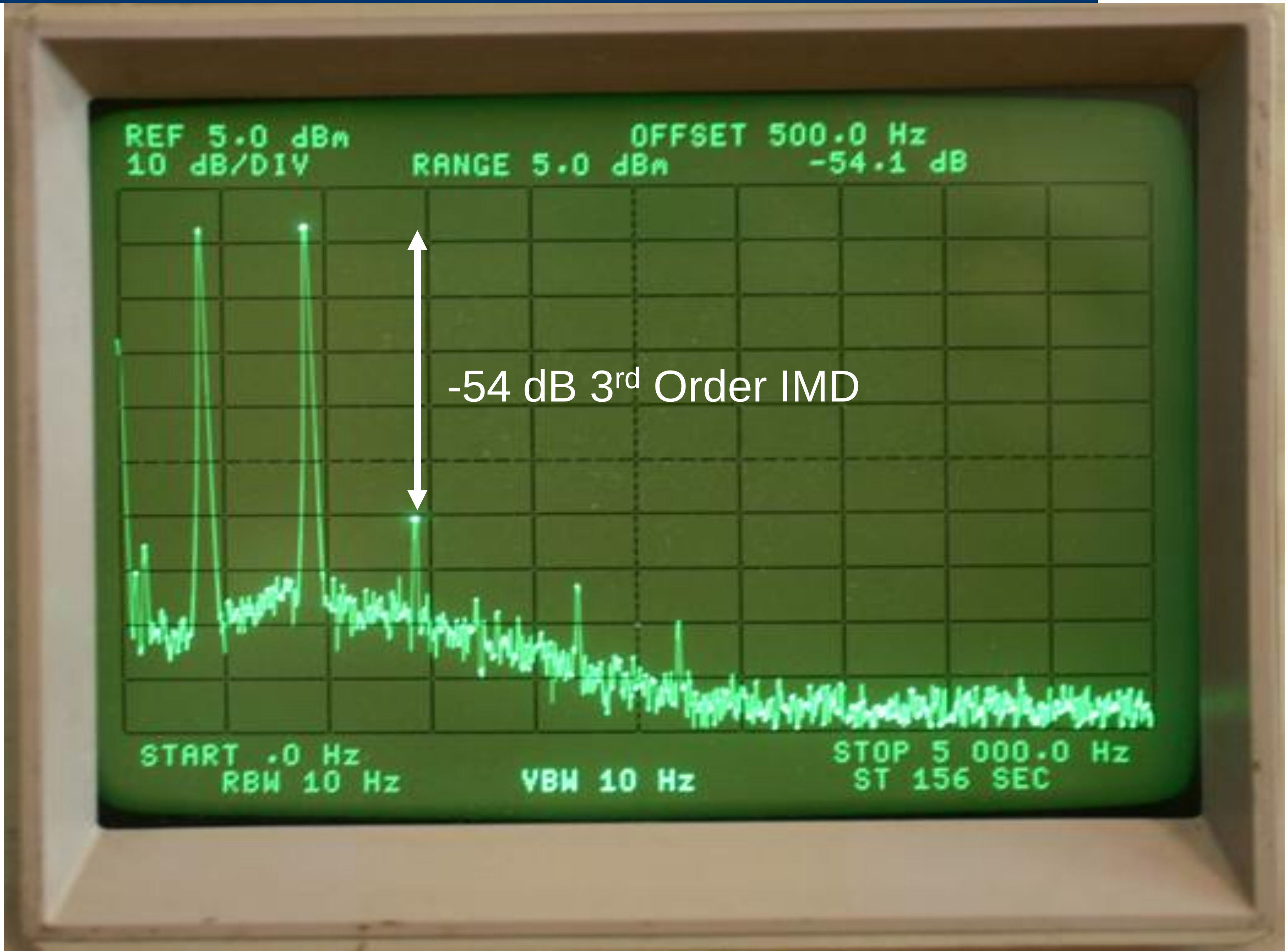
0.1 % distortion

Icom 756 Pro III Harmonic Distortion



< 0.3 % distortion

Icom 756 Pro III in-band IMD Distortion



Considerations in Choosing a Transceiver

High close-in dynamic range (copy S1 in crowded band)

Low noise floor (copy very weak signals)

Low phase noise (low noise on the Local Oscillator)

Low in-band spurious on both receive and transmit

Low IMD on SSB transmit, and low key clicks on CW transmit

Effective SSB speech processor (more talk power)

Good receive and transmit audio quality (intelligibility)

Smooth AGC for low fatigue (noise doesn’t fill in spaces)

AGC that doesn’t exaggerate impulse noise (hangs up AGC)

Good ergonomics of controls and menus (easy adjustments)

Good display that also shows important settings

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

Big Tower and Good Antennas, etc.

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

Bad audio can be a factor in that fatigue.

Sherwood Engineering

http://www.sherwood-engineering.com

http://www.NC0B.com