

Choosing a Transceiver Far From Simple

Rob Sherwood
NCØB

The “Numbers Game” is no longer a level playing field.

- **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.
- **You need a better receiver for CW than for SSB.**
- Do differences of a few dB matter? No !
- If performance numbers are similar, what should you look at next?

Test Data – The Wheat and the Chaff

- It is difficult to approximate a contest or DX pile-up with two signal generators in the lab.
- Beyond dynamic range, what is important?
- What new tests might be useful?

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.

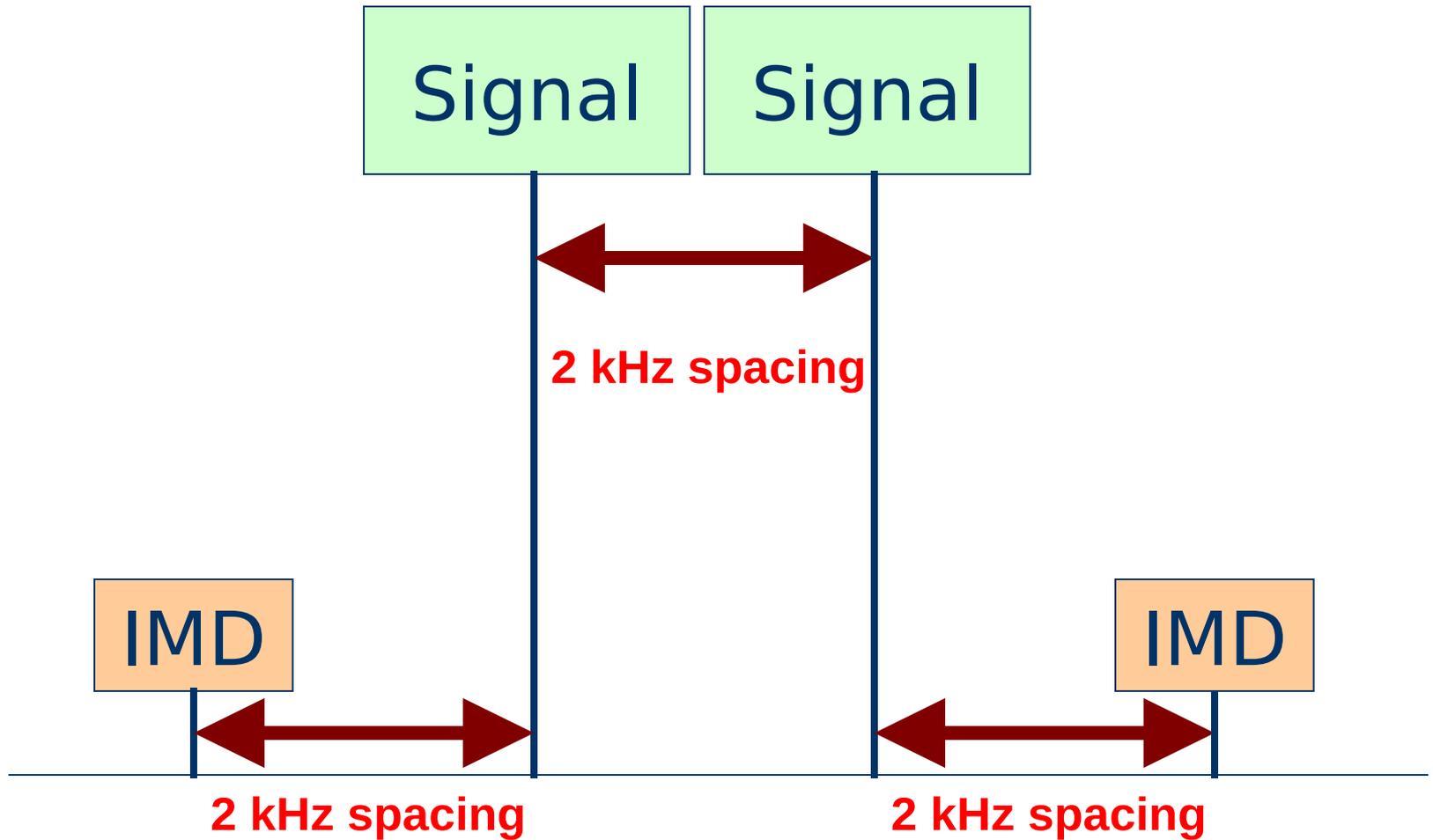
Noise Floor – Rarely an Issue on HF

- On 20 meters and below, atmospheric, galactic and man-made noise predominates.
- On 15 meters, in a quiet rural location, the receiver is rarely the limit. Example:
- NC0B, 5 element yagi at 70 feet, 270 feet of 7/8th inch hardline, antenna pointed in the quietest direction (30 degrees) at 4 PM on 2/28/2010.
- No preamp, connect antenna noise gain + 3.5 dB
- 10 dB preamp, connect antenna noise gain 8.5 dB
- Receiver sensitivity, no preamp = 0.5 uV
- Receiver sensitivity, with preamp = 0.2 uV

LJ-155CA yagi in the previous example



Third Order IMD to measure DR3



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

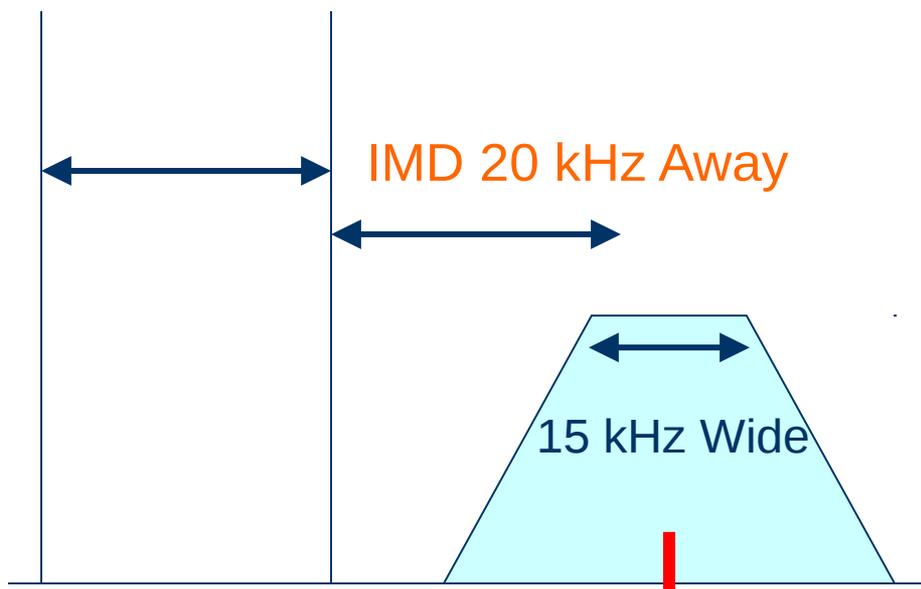
Wide-Spaced Dynamic Range?

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

Why is it less important for SSB operators?

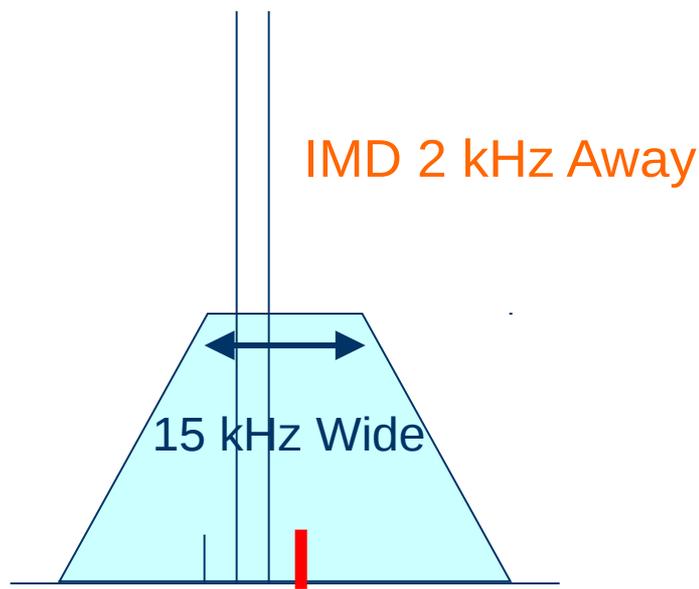
Wide & Close Dynamic Range

20 kHz Spacing



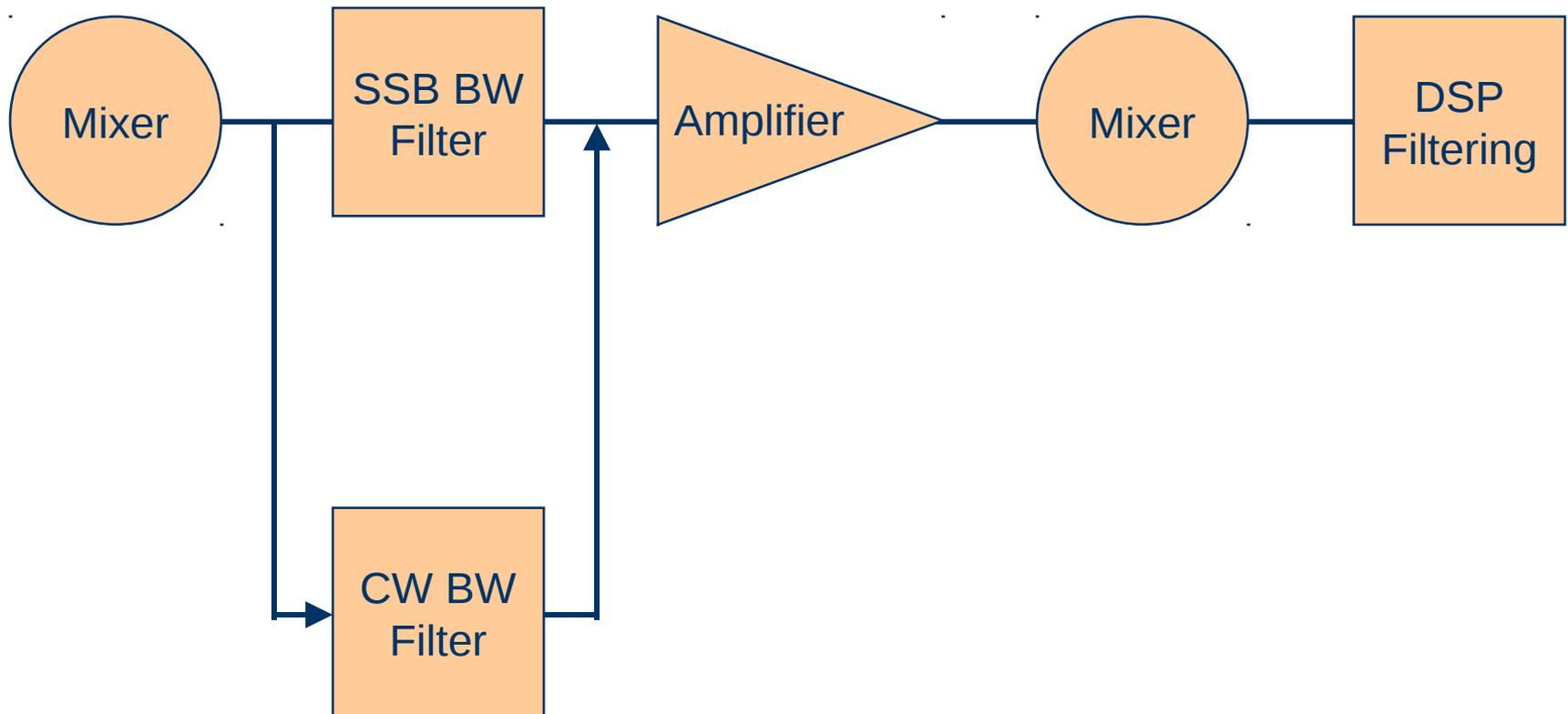
First IF Filter at 70.455 MHz

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.

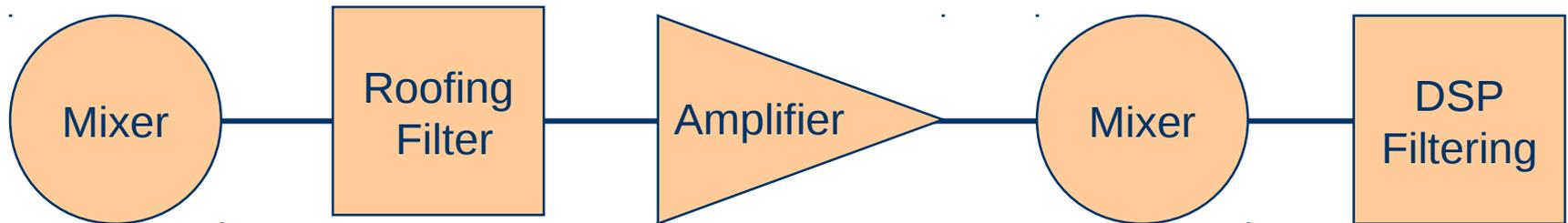


This keeps the undesired strong signals from progressing down stream to the next stages.

Transceiver conversion designs over time

- 1960 – 1980 First IF 5 to 9 MHz first IFs
- 1976 Sherwood modified R-4C with 600 Hz roofing filter
- 1978 – 2009 single wide VHF 15 kHz roofing filter Drake TR-7, IC-765, FT-1000 MP, IC-756 Pro III, etc.
- 2003 Orion I changed back to 9 MHz First IF 2.4 kHz to 250 Hz
- 2004 IC-7800 VHF roofing 20 & 11 kHz wide First IF
- 2005 FTdx9000 40 MHz roofing 15, 6 & 3 kHz wide First IF
- 2006 IC-7800 Mk II VHF roofing 20, 11 & 5 kHz wide First IF
- 2007 Elecraft K3 8 MHz 2.8 kHz to 200 Hz First IF
- 2009 IC-7600 VHF roofing 20, 11 & 7 kHz wide First IF
- 2010 FT-5000 back again to 9 MHz First IF 15 kHz to 300 Hz

For CW ops, Narrow First IF Filter = Better



On CW, the wider the roofing filter, the worse the problem. The more signals inside the roofing filter, the more the DSP filtering is stressed. Example: The IC-7600 has a roofing filter that is about 1/3rd the width of the Pro III, and a stronger front end.

Adding the Inrad 5 kHz roofing filter to the Pro III helps, but it is a complicated installation. (QST, April 2010)

Observations by K3CT @ KP2M CQ WW CW

- TS-850 with dual 500 Hz filters, CW turned to “mush”
- 1000MP was terrible
- Pro III needed 6 to 12 dB attenuation due to IMD
- Inrad roofing filter helped a lot on Pro III
- IC-7600 did well with no attenuation
- Filter BW less than 450 Hz unusable with 7600
- Generally used 500 Hz & listened slightly off freq
- Note: John and K3TEJ had 13,000 Qs during their 6 days on the air at KP2M.

Comparisons NC0B CQ 160 CW 2010

- Test rig this year Orion II. Reference IC-781
- Better QSK Orion. No overload problems.
- Problem w/ T-T = Sound of the band noise.
- AGC threshold carefully adjusted to optimum.
- Band noise much louder, ringy and annoying.
- Possibly the DSP filter is slope detecting the band noise, adding to what is really there.
- How in the world do we test that parameter?

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 $S9 = 50 \mu V$, 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)

The DR3 “window” is not fixed

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

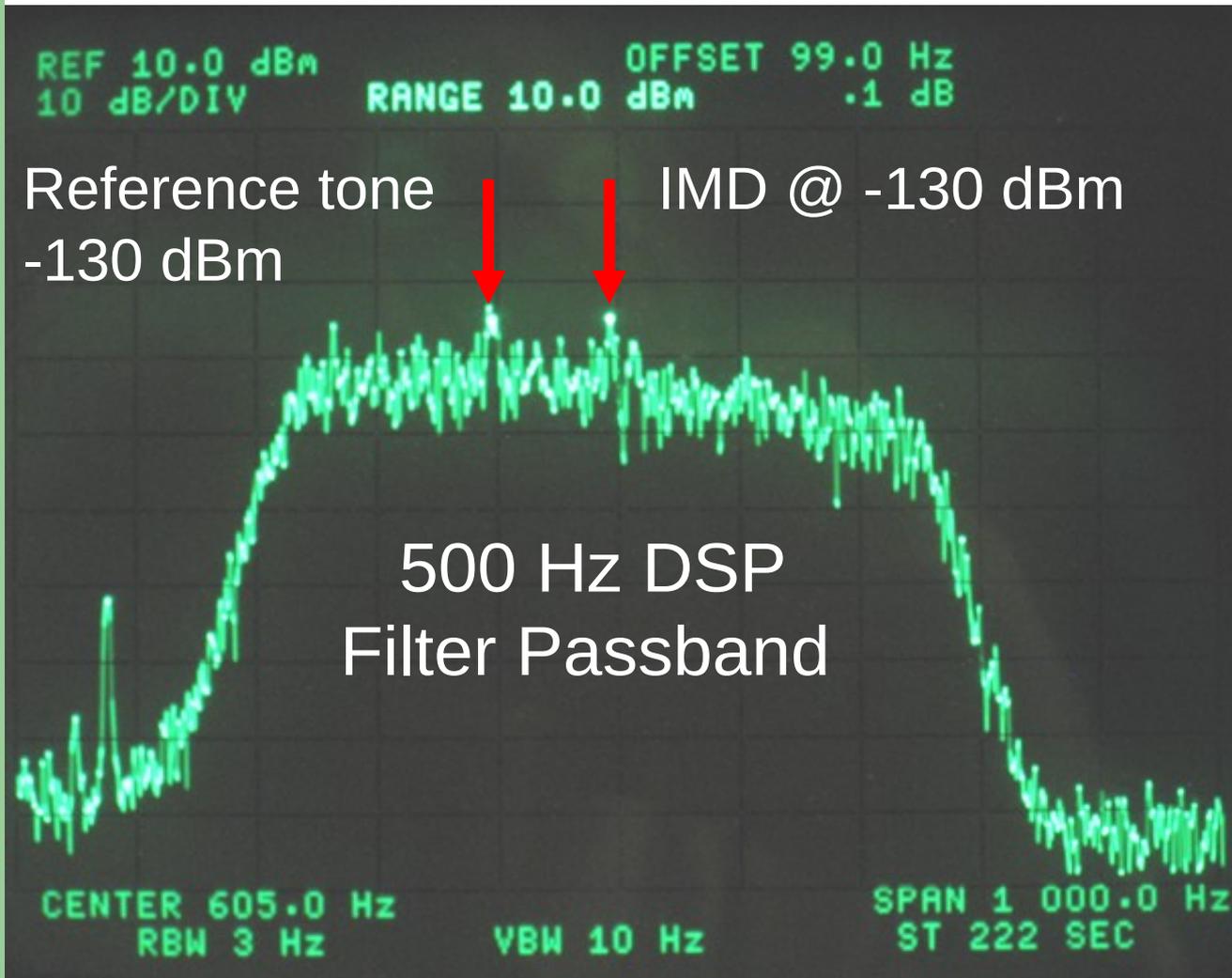
If on a noisy band, attenuate the noise and all signals to make better use of the dynamic range, and reduce the chance of overload.

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.

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.
- IMD tone at noise floor = 
- This was DR3, either IMD or noise limited.
- With the new method, noise increased 10 dB, and by ear you hear **nothing but noise**.
- How is this the same? 
- Unless you work a contest using a 3-Hz CW filter, the new League dynamic range measurements are meaningless.

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.

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 QST numbers.**

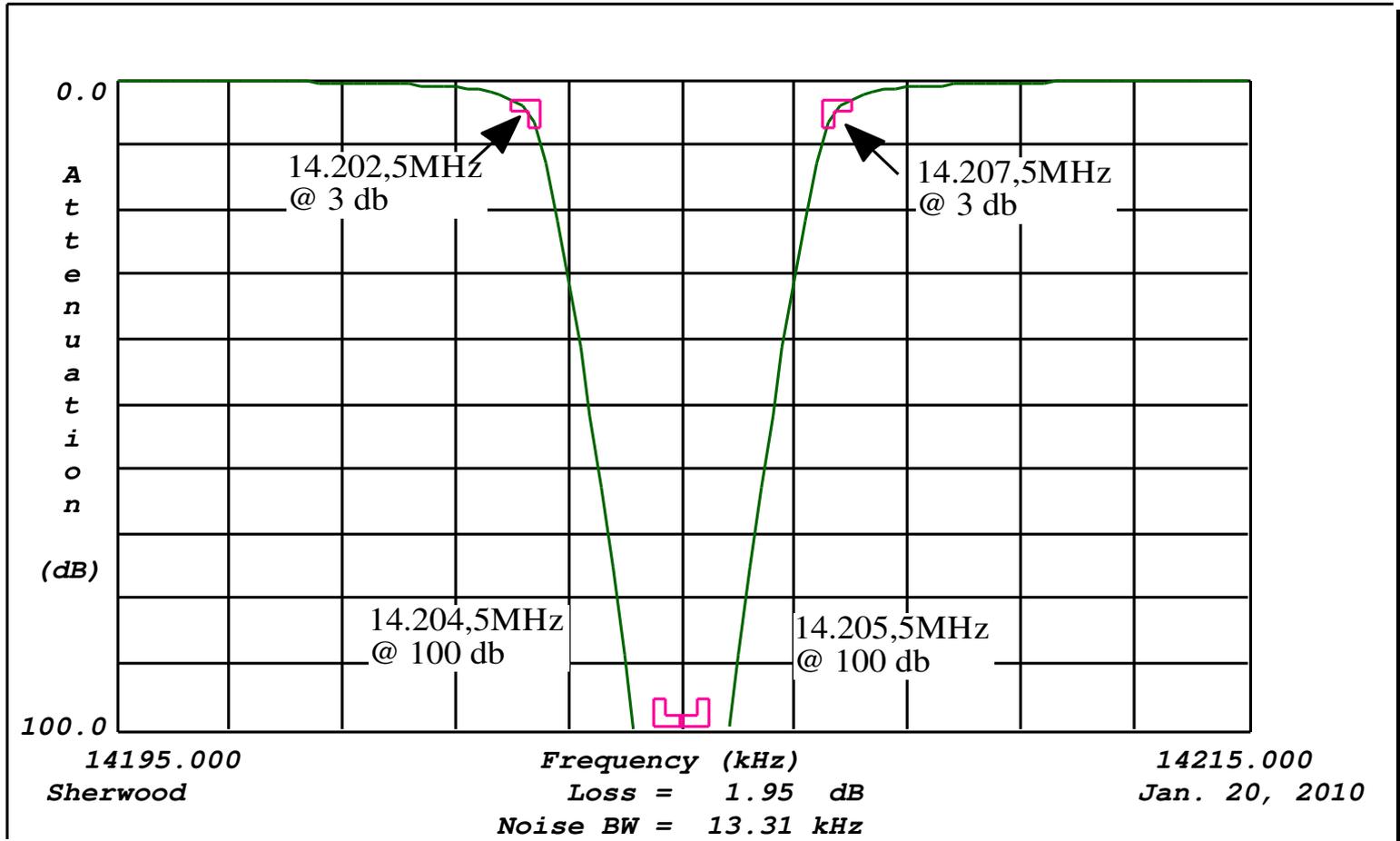
Lab numbers should have real meaning

- Lab measurements should correlate to on-air performance. For 25 years wide-spaced 20-kHz dynamic range (DR3) numbers did not properly evaluate CW contest performance.
- For about 5 years ARRL 2-kHz DR3 numbers were valid, but from 2007 to present they again are not indicative of CW pile-up performance, **if the radio is phase noise limited.**

Is there a better way to test a receiver?

- Two-tone dynamic range testing has been our standard for almost 40 years, but what could be better?
- Would 10 tones be better? Maybe, but who has 10 signal generators?
- Would broad-band noise approximate a CW contest or pile-up?
- **Noise Power Ratio (NPR)**
 - Fill the 20 meter band with noise, but put a 1-kHz notch in the middle of the band.
 - Tune the radio to the notch and see how much noise is present.

Custom filter to test the concept



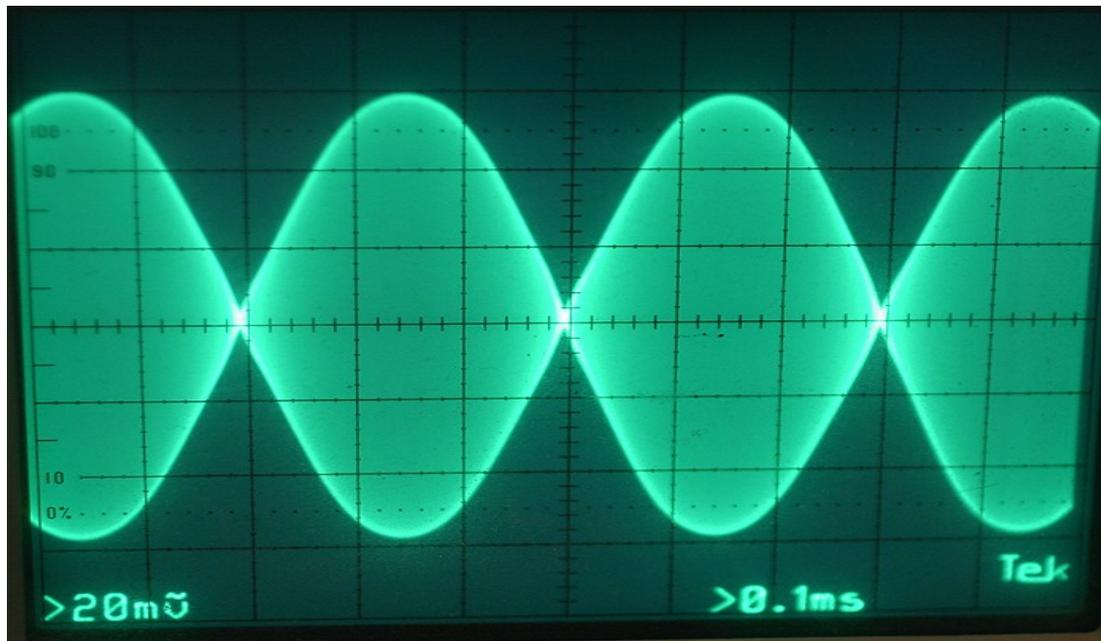
NPR test method is not a new concept

- The concept of Noise Power Ratio (NPR) has been around since the early 1950's. It is still used today in analog Frequency Division Multiplexing (FDM) telephone systems and cell phone site evaluation.
- The individual channel can then be measured for its NPR using a narrow-band notch (band stop) filter and a specially tuned receiver which measures the noise power inside the 4-kHz notch. NPR is simply a measure of the “quietness” of the unused channel in this multi-channel system.

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.

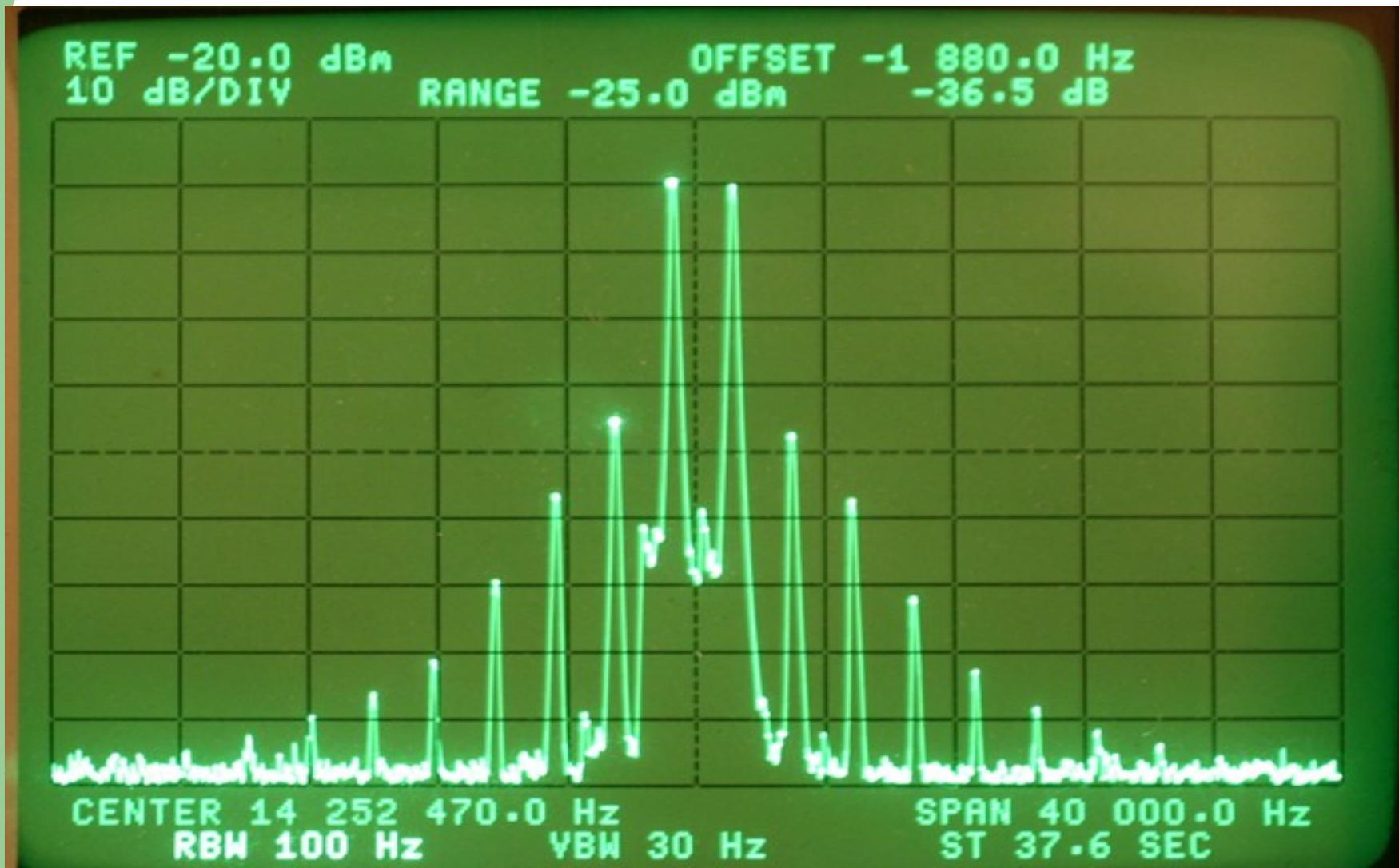


Normal time domain scope picture.

My cleanest transmitter

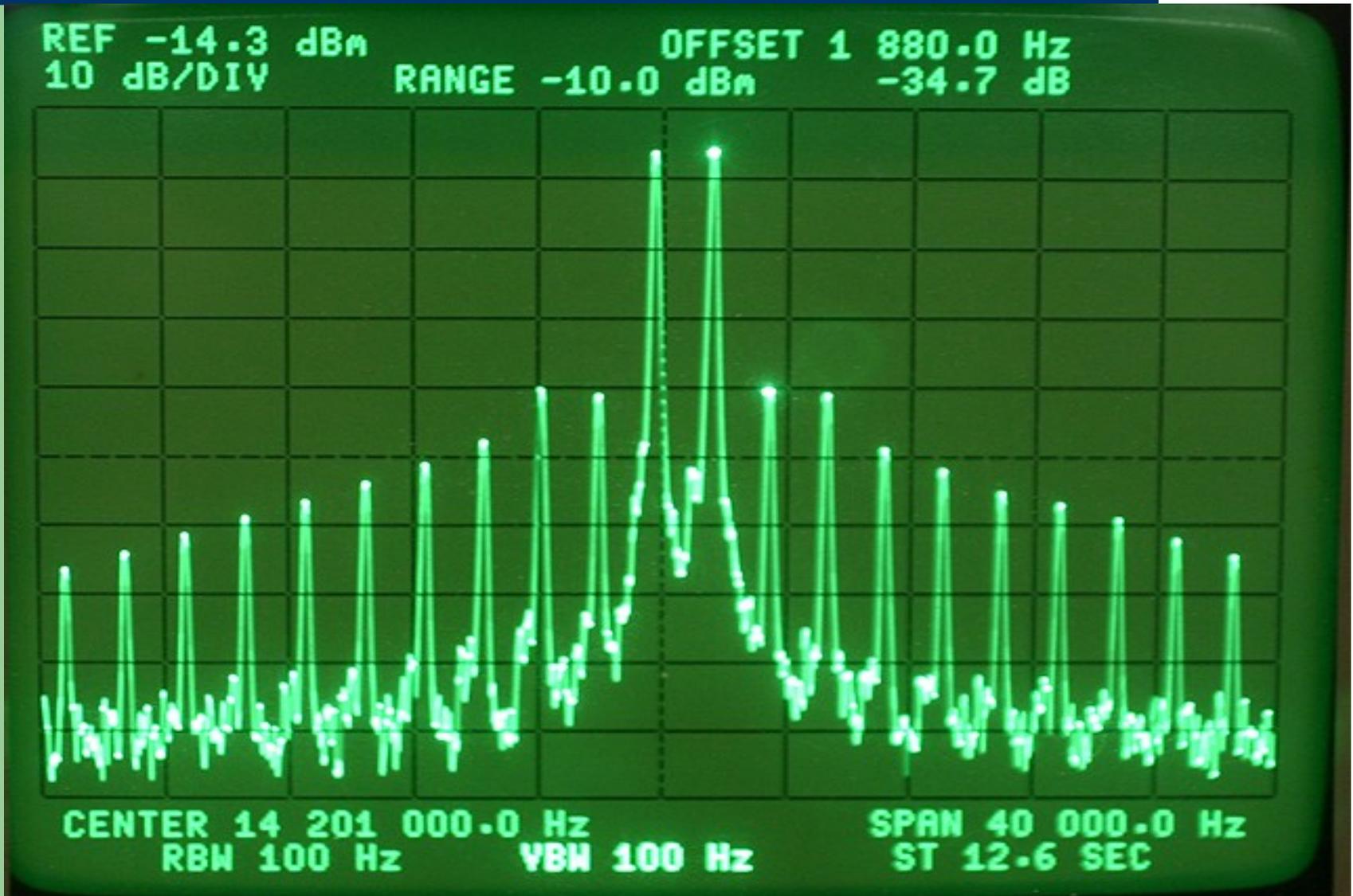
-36 dB 3rd Order, -60 dB 7th Order

Collins 32S-3 on 20 meters @ 100 W



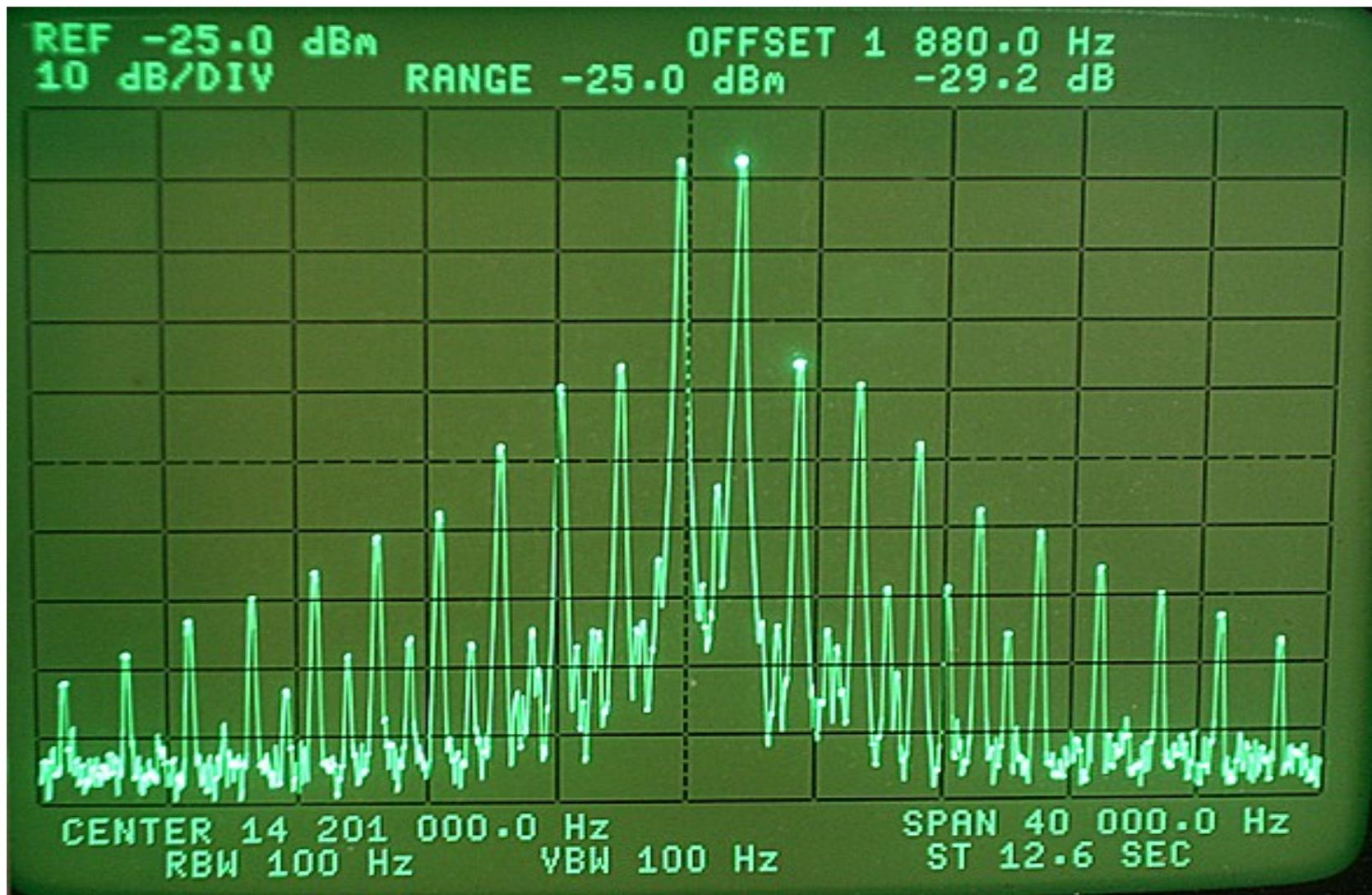
-34 dB 3rd order, -43 dB 7th order

Icom 781 on 20 meters @ 150 Watts



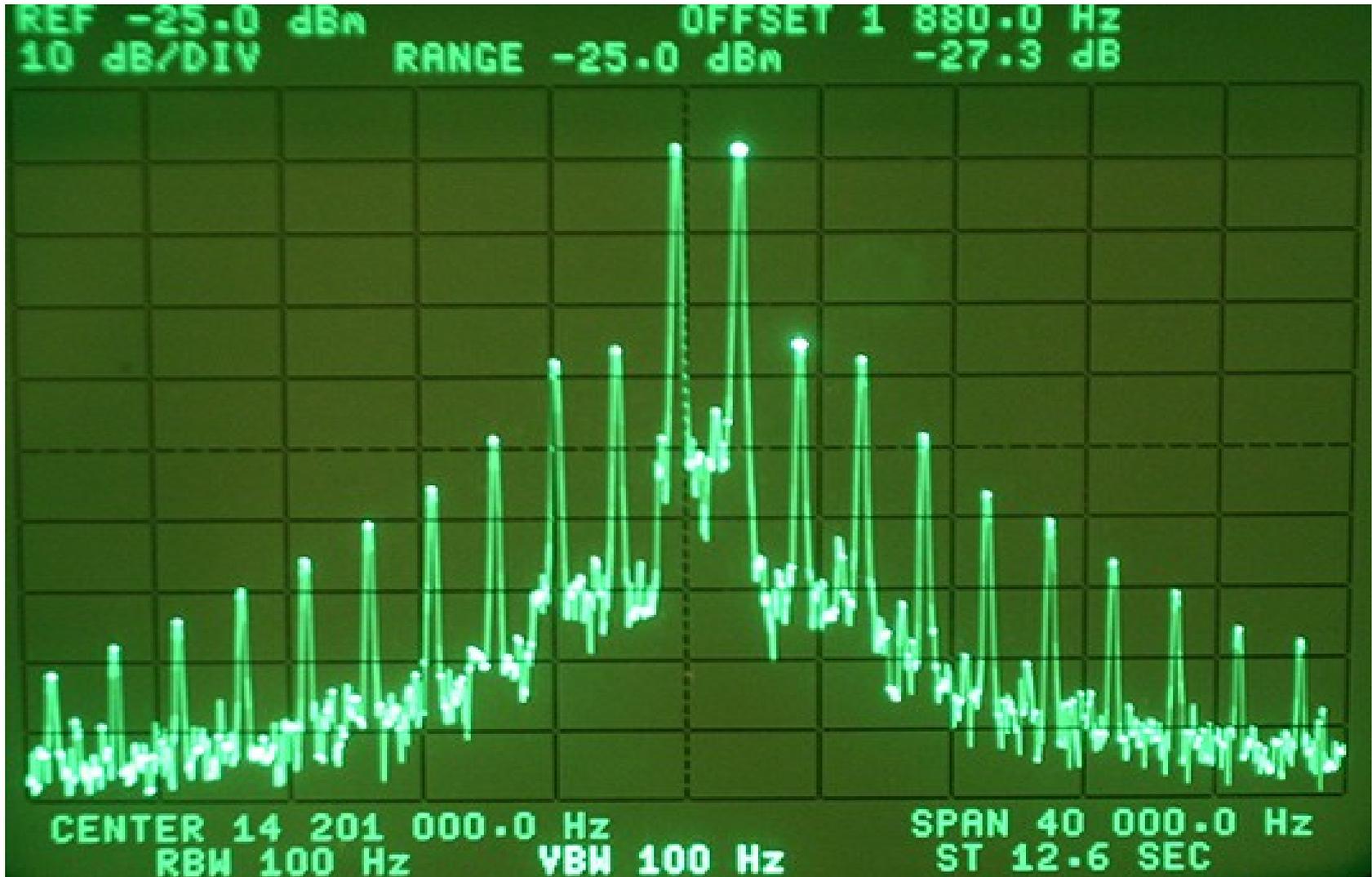
-29 dB 3rd order, -41 dB 7th order

Flex 5000A on 20 meters @ 70 Watts



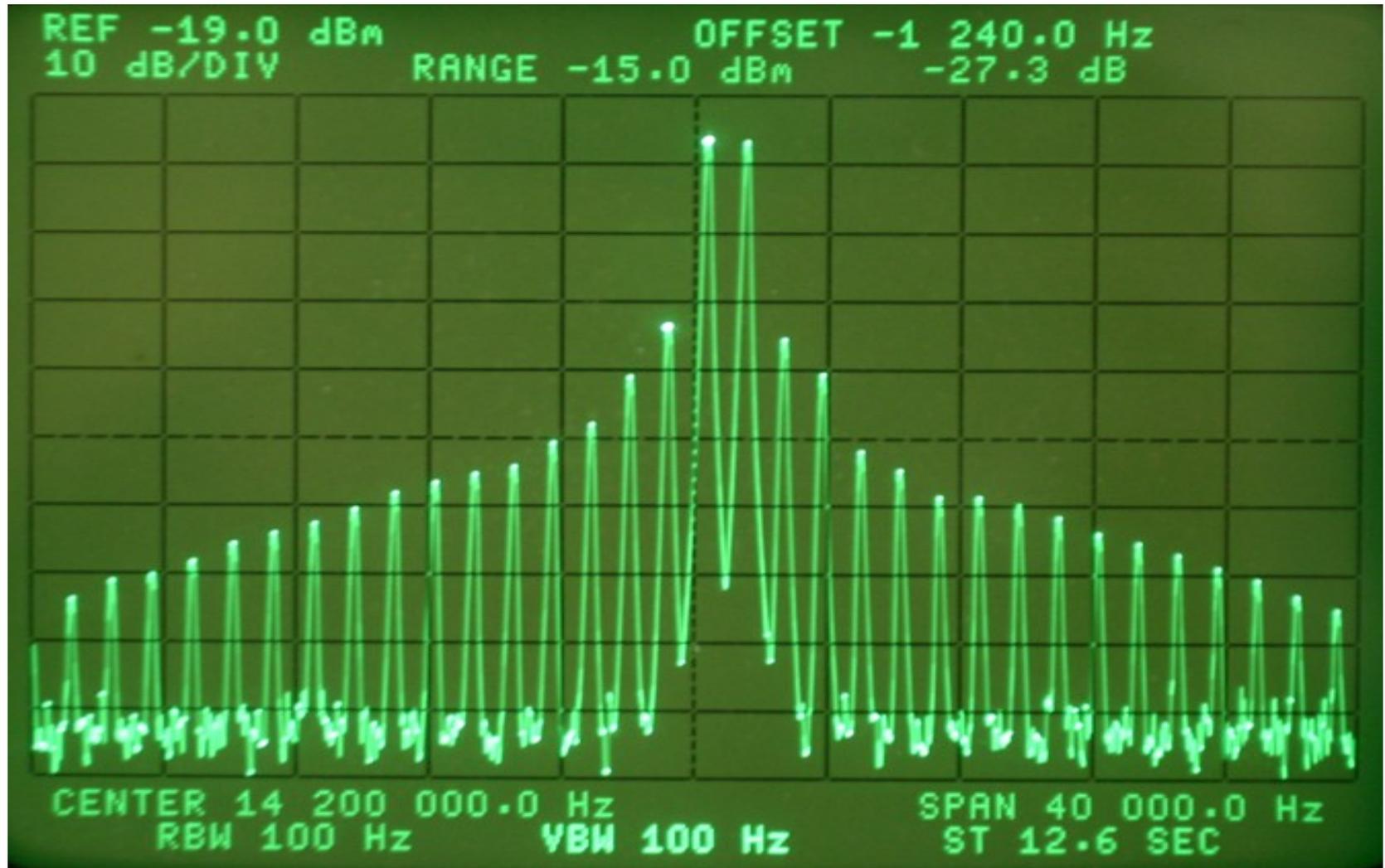
-27 dB 3rd order, 40 dB 7th order

Icom 756 Pro III on 20 meters @ 70 W



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

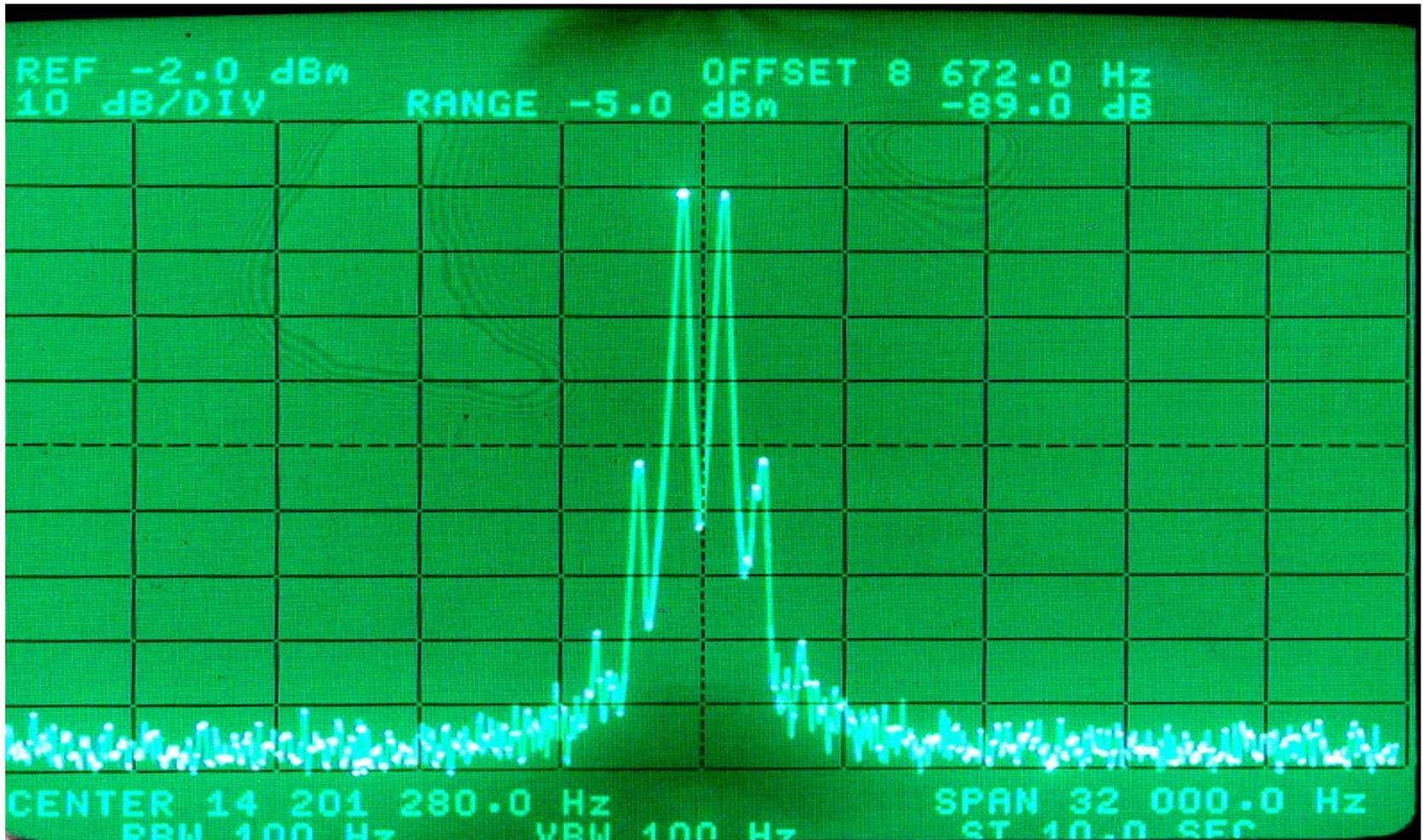
K3 Transceiver on 20 meters @ 100 W



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

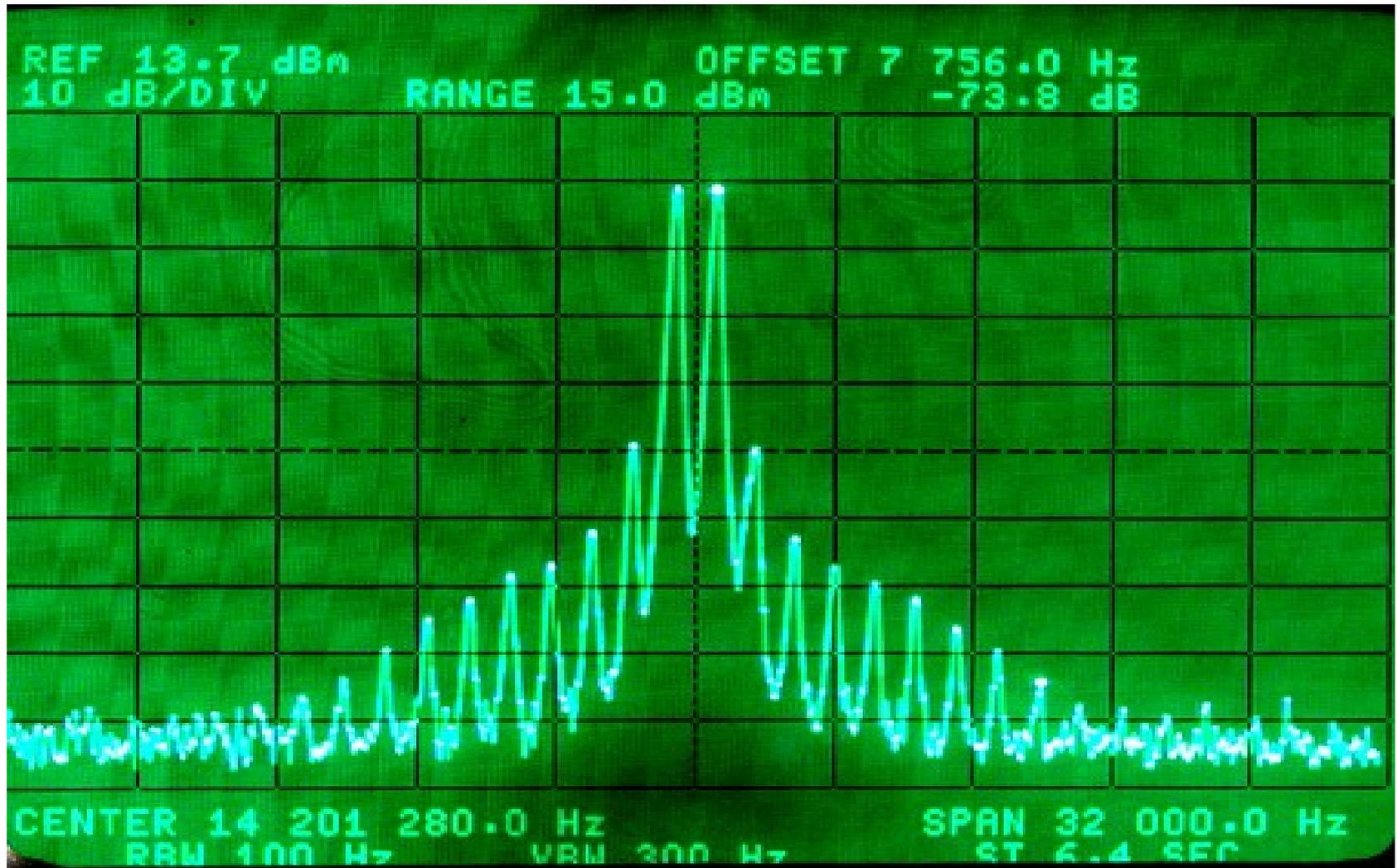
Yaesu FT-1000 Mk V, 20 M, Class A @ 75 W

Provided by Pete, W6XX



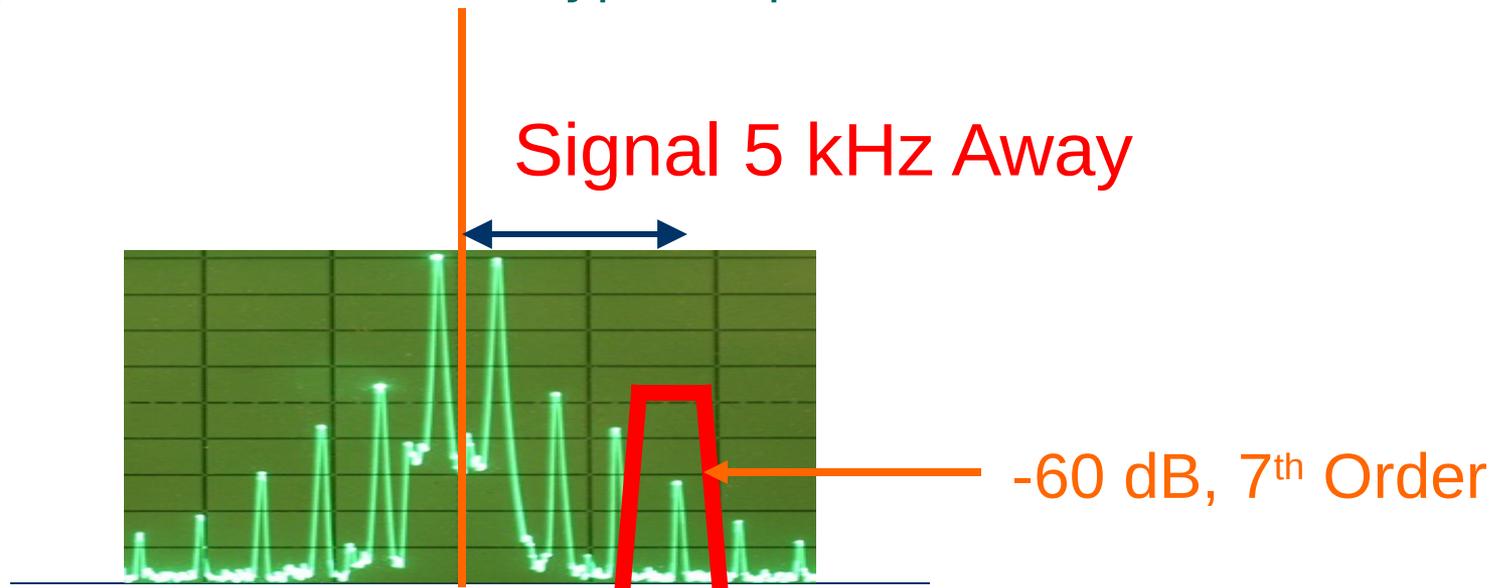
-40 dB 3rd Order, -52 dB 5th Order

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



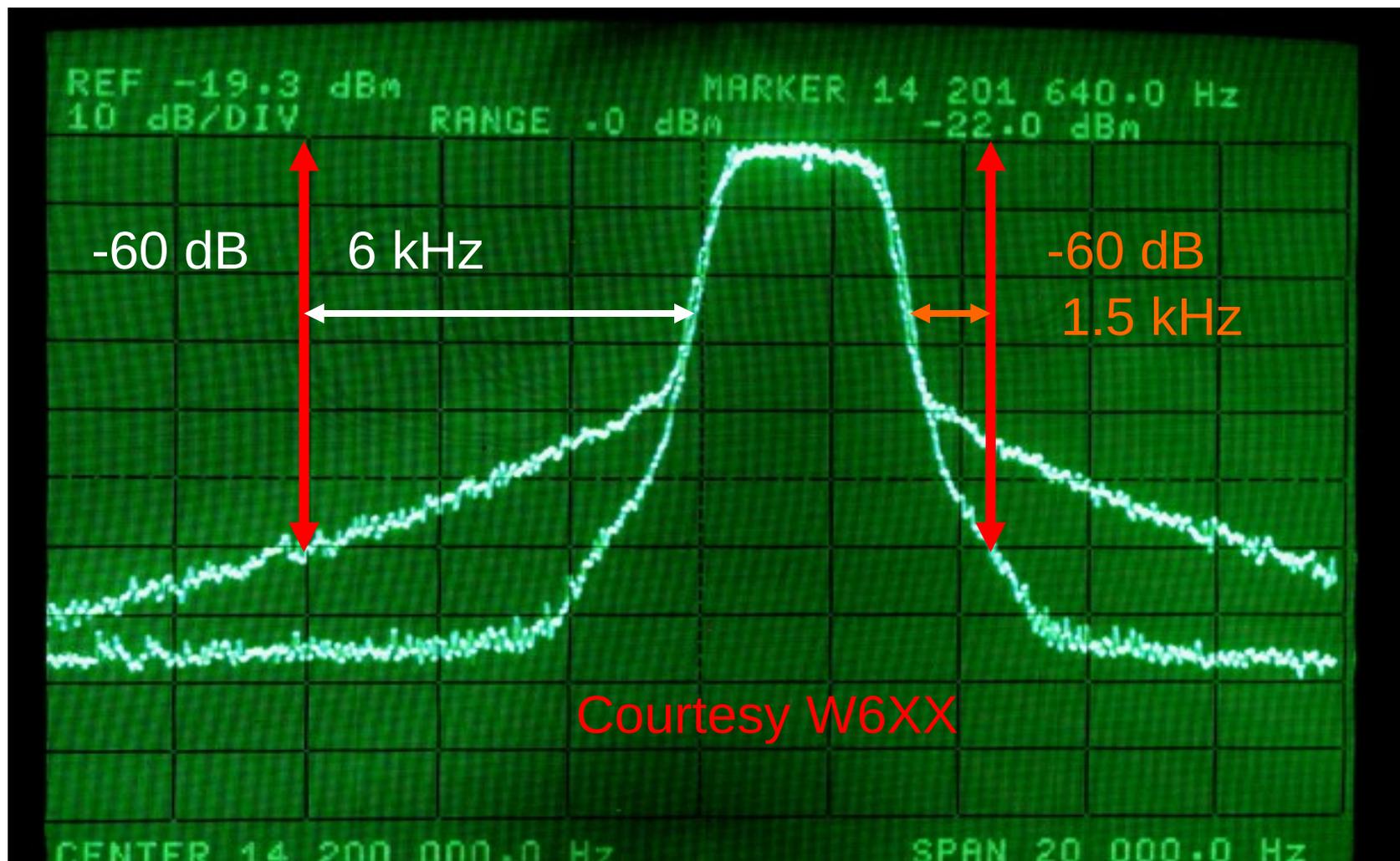
Close-in Signal and Splatter

Typical radio = 70 dB, Typical splatter = 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	Signal	Strength of CW sidebands	
	Signal	S9 + 40	-33 dBm
3 msec		S7	-83 dBm
4 msec		S6	-88 dBm
5 msec		S6	-88 dBm
6 msec		S5	-93 dBm
7 msec		S4	-99 dBm
8 msec		S4	-99 dBm
9 msec		S4	-99 dBm
10 msec		S3	-105 dBm

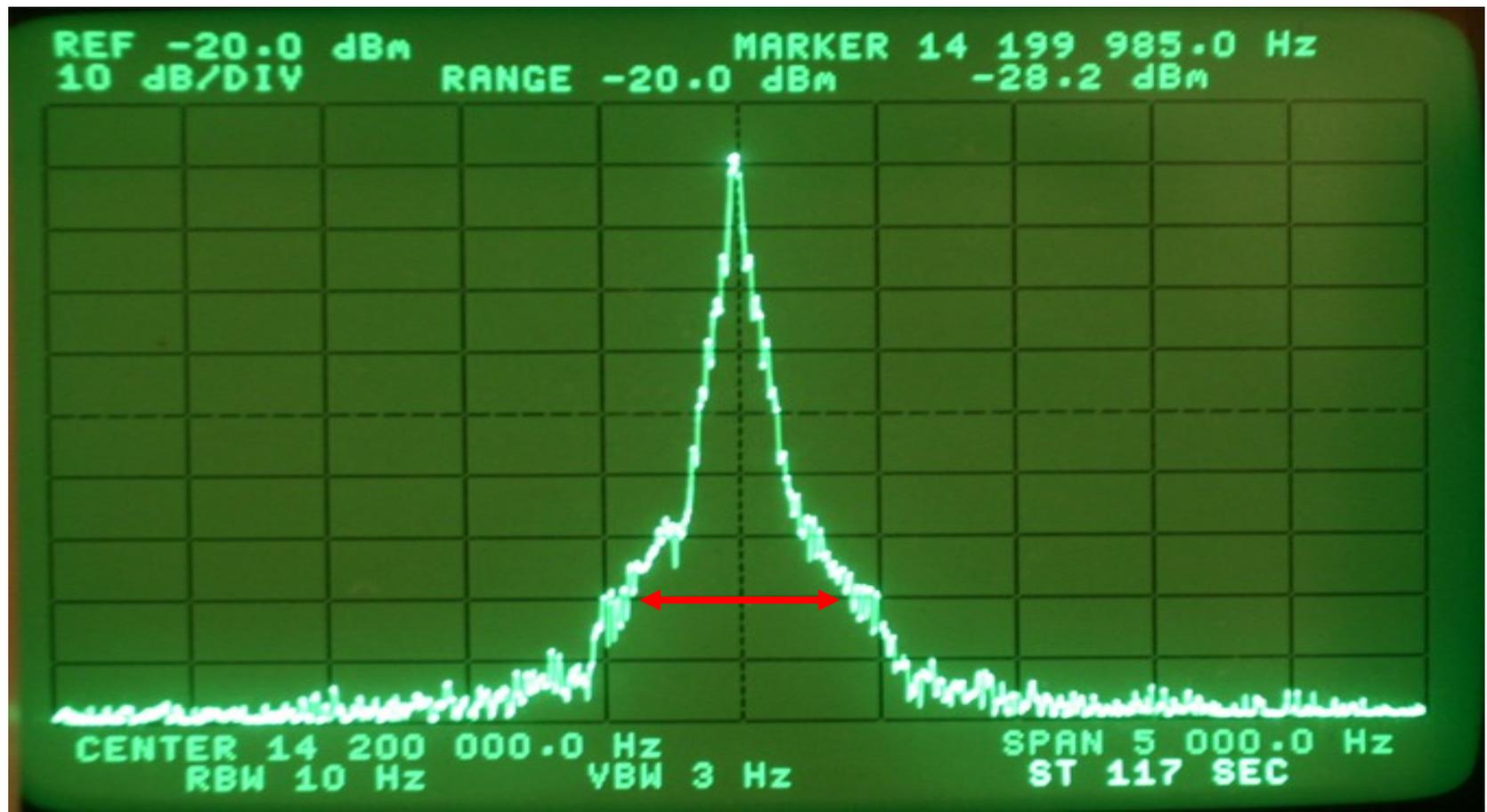
Ref -50 dB

22 dB !

-72 dB

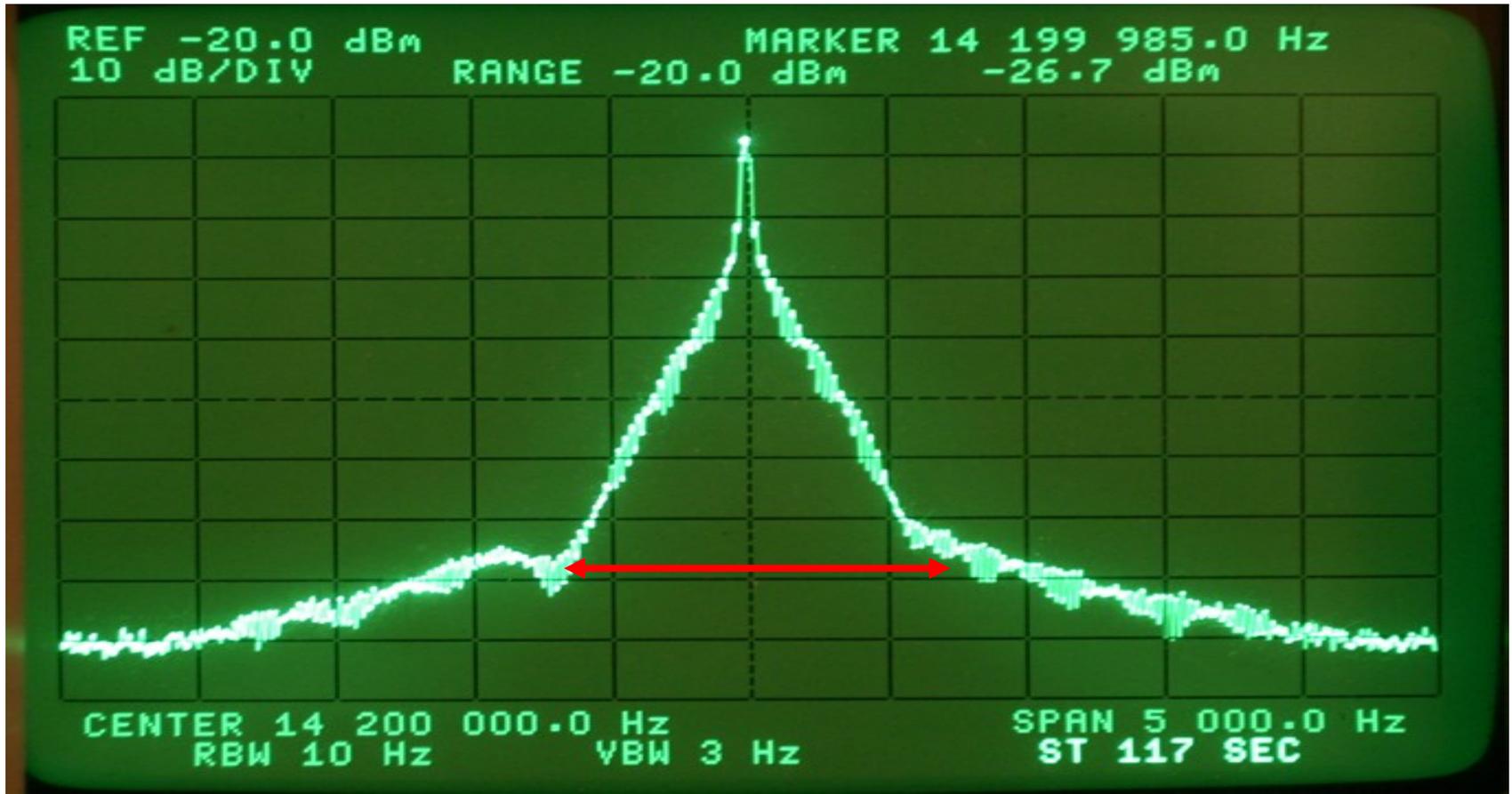
Spectrum of CW Signal on HP 3585A Analyzer

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



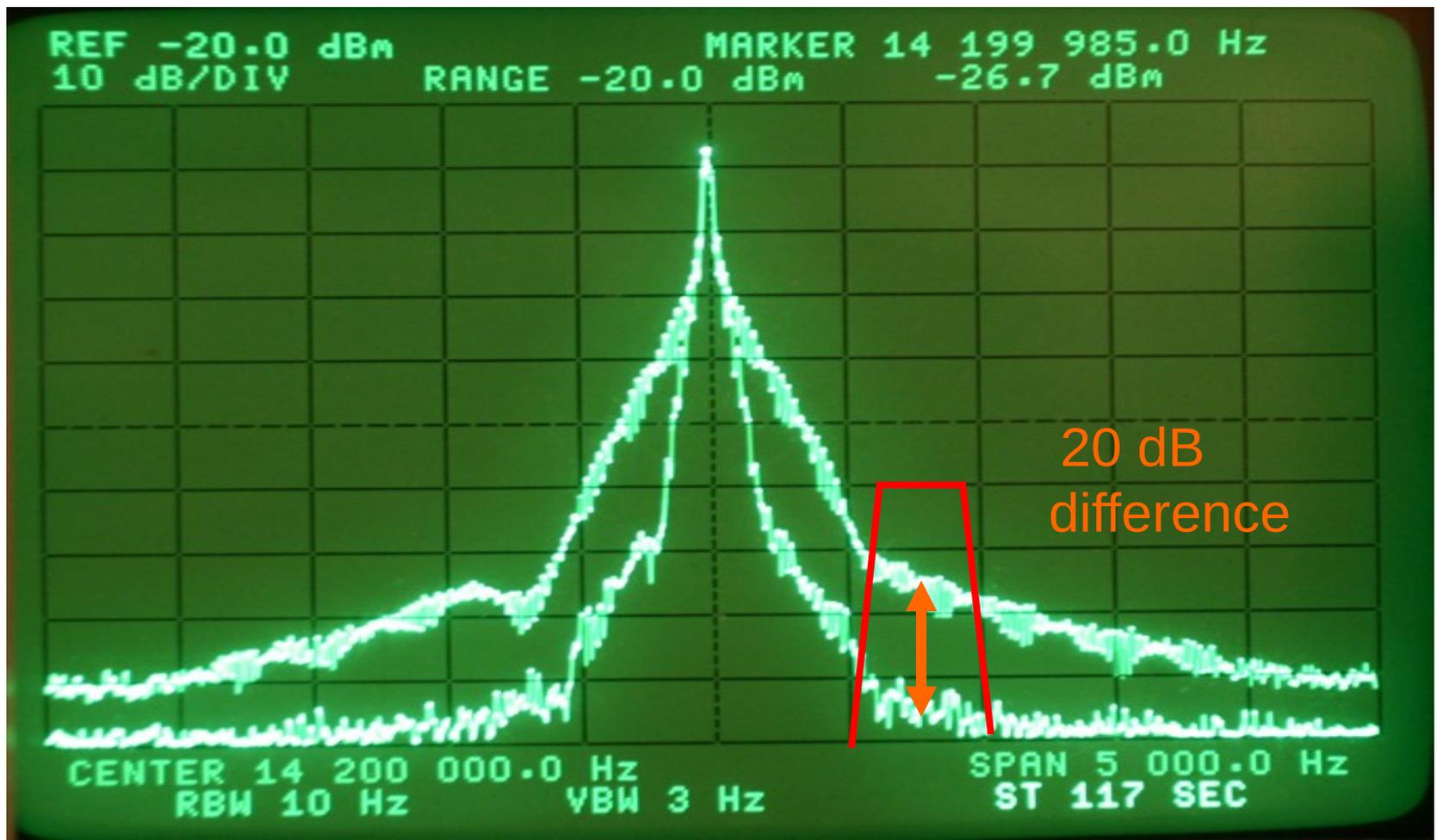
Spectrum of CW Signal on HP 3585A Analyzer

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

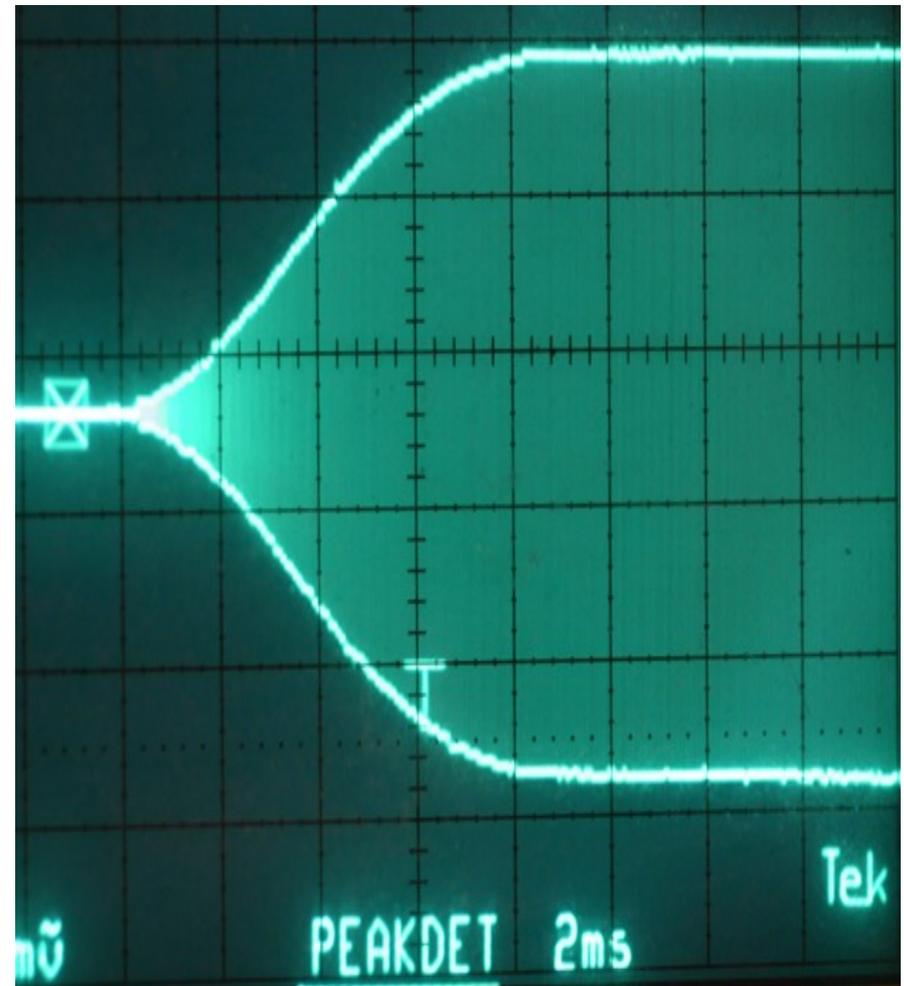
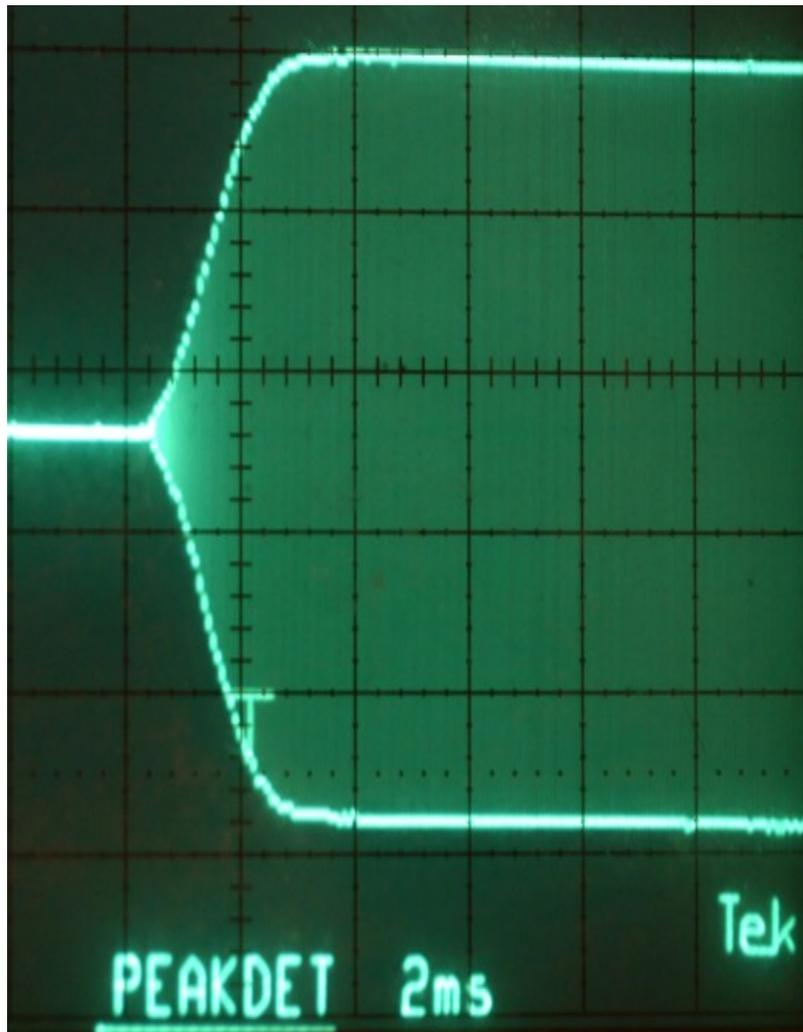


Spectrum of CW Signal on HP 3585A Analyzer

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 to 101 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	This is shockingly bad
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	Worst radio I have ever tested !

What are the worst contest environments?

- Multi-multi stations, including Multi-two
- Hams within a few miles of each other
- Field Day !

What kills you with multiple transmitters?

Phase Noise and Blocking.

Larry W0QE and Ken N0QO from the Boulder Amateur Radio Club ran tests on four transceivers to see if there was much difference in how they interfered with each other.

With multiple transmitters on the same band, the problem comes down to isolation between the transmitter and another receiver.

This can be a “run” station and a “mult” station in a multi-multi contest.

On Field Day you likely have a CW and Phone station on the same band, particularly 40 and 20 meters.

How much Isolation do you need?

Transmitted phase noise is a big problem even with 100 kHz spacing on the same band. (20 meter data)

Rig Isolation need for minimal degradation

Elecraft K3 54 dB isolation was needed

Orion II 69 dB isolation was needed

Flex 5000 74 dB isolation was needed

Flex 3000 74 dB isolation was needed

20 dB is a lot of difference just due to differences in rig design. In the case of the Flex, the flat phase noise characteristic makes the problem much worse.

Phase noise again !

- This brings us back again to the problem that the League is now measuring dynamic range in such a way to eliminate phase noise from the equation. Phase noise (reciprocal mixing in a QST review) gets but a single line of data.
- An Elecraft K3 at 99 dB is not the same as a Flex 3000 at 99 dB, yet you would never know that from a QST review.

Now another problem !

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

CW signal about 15 WPM



Electric Fence firing off every 2 seconds, 160 meters



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-7600, IC-7000
- FTdx-9000, FT-2000, FT-2000D
- Orion I & II

Cannot measure everything in the lab

- KL7QOW listening to NC0B, 75 meter SSB
3/14/2010 - 6:15 PM Alaska daylight time
- Band noise about S4 to S5
- R-4C K3 IC-765 IC-761 FT-1000MP
- Q3 Q3 Q0 Q0 Q0
- Not a classic sensitivity issue
- Recovered audio is the difference
- Don't know how to measure this in the lab

What was heard before and after?

- 15 minutes earlier there was no copy on any receiver.
- 15 minutes later there was good copy on all receivers.
- Yet during that critical period, when signals were just coming out of the noise and were Q3 copy on the R-4C and the K3, the other radios had zero copy !

Question: How good is good enough?

High Dynamic Range Receiver (DR3).

Minimum 70 dB for SSB & 80 dB for CW

If the “real” DR3 > 90 dB, your receiver is fine.

Differences of a few dB are NOT significant.

Sensitivity 15 meters and below, preamp ON: 0.2 μ V

Noise floor 15 meters and below, preamp ON: -135 dBm

AGC issues with impulse noise needs attention.

Phase noise is very important in a multi-transmitter setup.

Receiver testing needs to approximate the real world.



<http://www.sherwood-engineering.com>

<http://www.NC0B.com>