Exotic Antenna Pattern Measurements

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Overview

- NEC-Based Antenna Modeling is an indispensable part of antenna design.
- But… I've never made a single contact on a model!
- No lack of confidence in NEC, but rather a lack of confidence in my ability to model (antenna and environment), and then implement the model.
- Trust but verify (the more I can measure, the better I sleep).

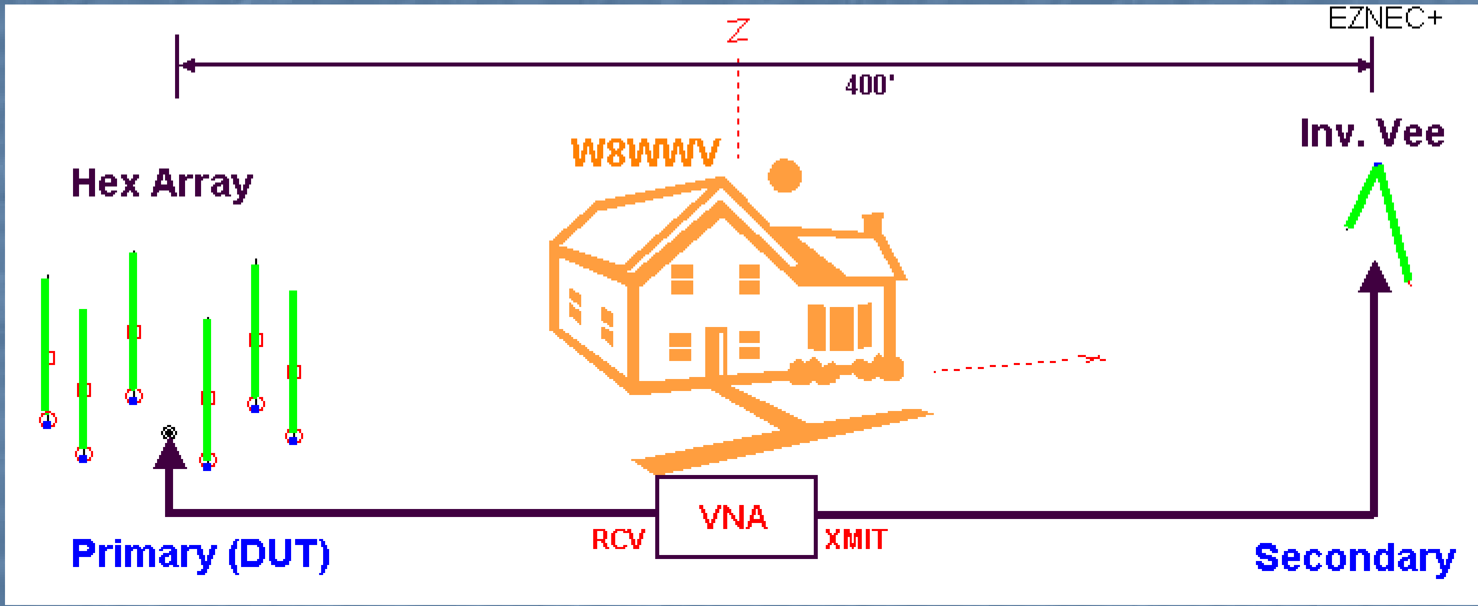
Two Years Ago on this very Spot…

- At the Antenna Forum in 2008 I presented some work on measuring complex antenna currents on phased arrays using a VNA, a little custom hardware, and some custom software.
- Measured currents were inserted back into models to create gain and pattern predictions, across the whole band, not just 1 frequency.
- I wanted to *cross check* my results, especially when they seemed *a little strange*.

Two Years Ago…

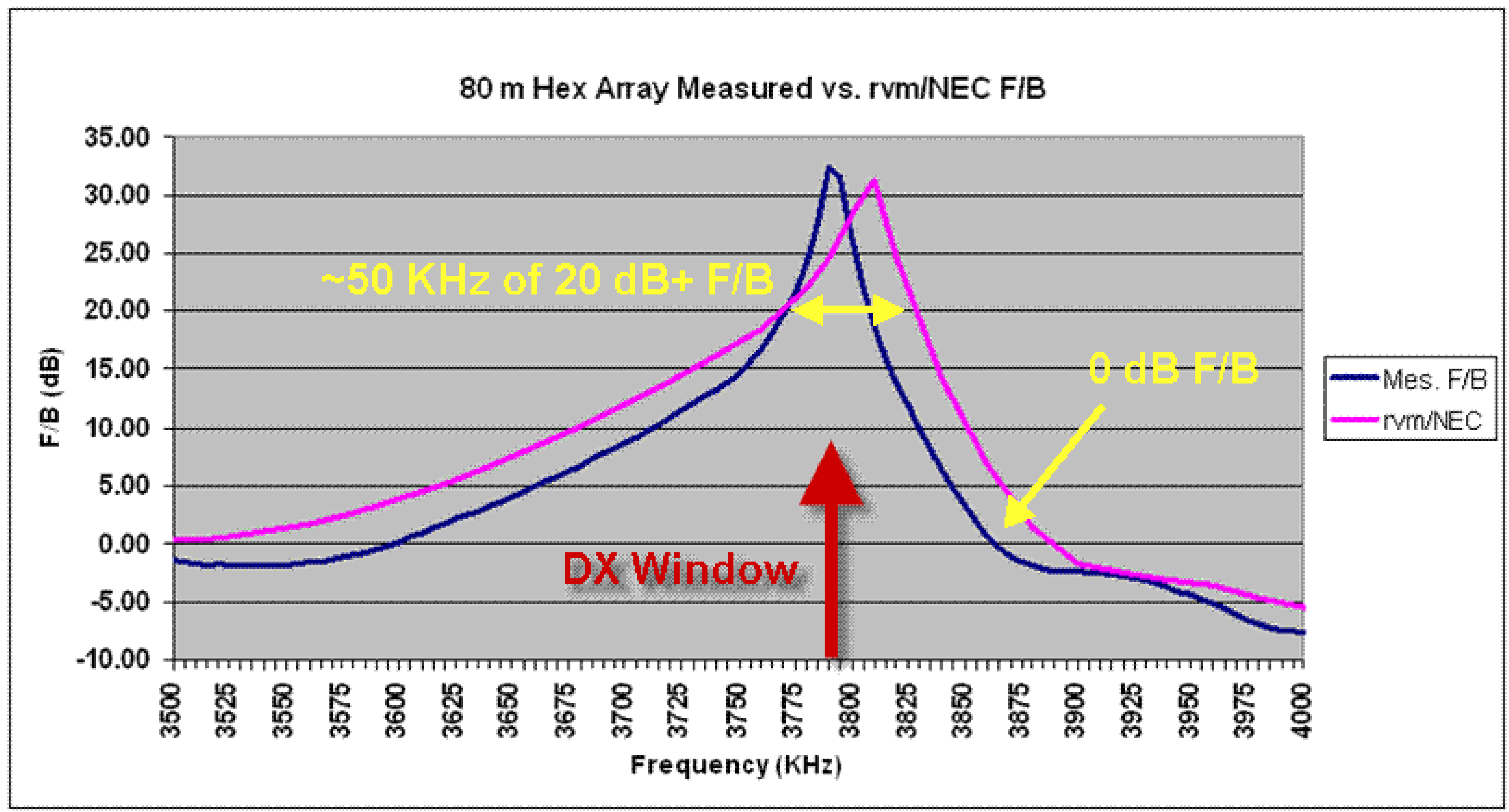
- Consider my 6-element 80 meter phased vertical array, targeted for the SSB DX window.
- Due to the use of trapped elements (for 2 band operation) and compromise spacing (40’), I always expected a small performance bandwidth on 80 m.
- Initially, I was happy to hit my target currents at the single design frequency, but that’s one frequency.
- Because I had an 80 m Inverted Vee several hundred feet away, located on a major axis, I realized that I could measure the F/B ratio using both antennas and two VNA transmission measurement sweeps.

Two Years Ago (2)...



- Sweep the transmission response in one direction, then the other, transfer to an Excel spreadsheet, subtract back from front to produce the F/B ratio, graph the result.

Two Years Ago (3)…



- Similar results using two different approaches – cross checking.

Two Years Ago (4)

- Measurement of the F/B ratio using my home *antenna test range* was fast and easy, but it was a lucky accident to have a second antenna close to the desired alignment, and preexisting transmission lines coming to a central point.
- I wanted to generalize the measurement approach, and use it in other situations. This presentation describes what happened next…

Let's Get Through the *Theory…*

- What are the factors controlling the signal level between the transmitter and receiver?
  - Transmit Power Level
  - Cable Losses
  - DUT Antenna Response (AUT)
  - Path/Propagation Characteristics
  - Secondary Antenna Response
  - Receiver Settings (attenuator/preamp/detector calibration)
- All we care about, and what we want to isolate, is the AUT response.
- We can do that by *trapping* the desired AUT characteristic between two measurements that are then subtracted.
- So long as *everything* **but** the AUT response is held constant, the AUT characteristic is all that remains.

Theory (2)

Measurement A — Measurement B

$$F/B = (AUT_{Dir1} + S) - (AUT_{Dir2} + S)$$

$$F/B = AUT_{Dir1} - AUT_{Dir2}$$

- It is obviously essential that all conditions (S) other than the AUT response be held constant across measurements.
- If not, their difference will show up in the final result.
- This is not a true F/B measurement, since it's comparing one directions front to another's back (unless we rotate).
- We are making signal strength transmission measurements, and ignoring the phase response.

What Can We Measure?

- Most anything that can be captured as a pair of subtracted measurements.
- F/B Ratio: Perhaps the most obvious.
- Gain: By comparing against a reference, such as the gain of a single element in the array.
- Side to Side Ratio: Helps detect pattern distortion/symmetry.

Antenna Test Range

- We are talking about creating a traditional Antenna Test Range environment around our backyard antennas.
- Much has been written on this topic, many good references.
- The #1 requirement is to be able to test in the *far field,* beyond the Fraunhofer distance ($d = 2D^2/\lambda$). Other rules of thumb suggest 3 to 10 λ separation (minimum).
- For the HF bands, the distance between the AUT (Antenna Under Test) and the secondary antenna needs to be several hundred to several thousand feet.
- This means that we need to be able to operate and synchronize a transmitter and receiver connected to the two antennas within a few miles of each other.

Antenna Test Range (2)

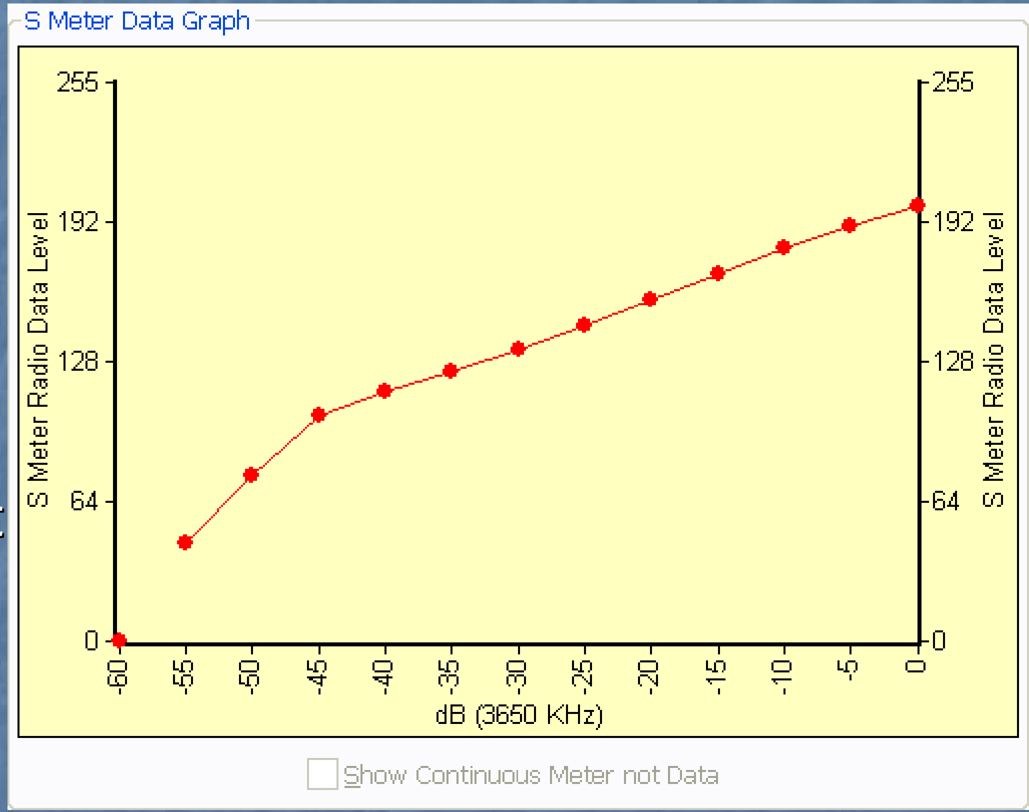
- Given the distance, we aren't going to be able to run cables between the antennas, so we will need two separate synchronized and calibrated stations.
- Each station consists of a radio, control computer and antenna.
- Two relatively close stations, or one fixed and one mobile station.
- How do we synchronize the stations?
- Being a computer geek, a wireless Internet scheme was considered, but in the end, a simple *trigger and sweep* scheme has worked well.

The Software

- A single program (Soil) is used on both sides (transmit and receive) of the measurement.
- The program controls a radio transceiver.
- Needed capabilities are minimal – CW transmit, change frequency, read S Meter.
- Currently works with ICOM radios, but is built upon an extensible *device driver* model.
- Based upon S Meter calibration across a 60 dB range. Given the typical distances and signal levels, 0 dB is mapped close to +40 to +50 over S9 on the S Meter.

S Meter Calibration

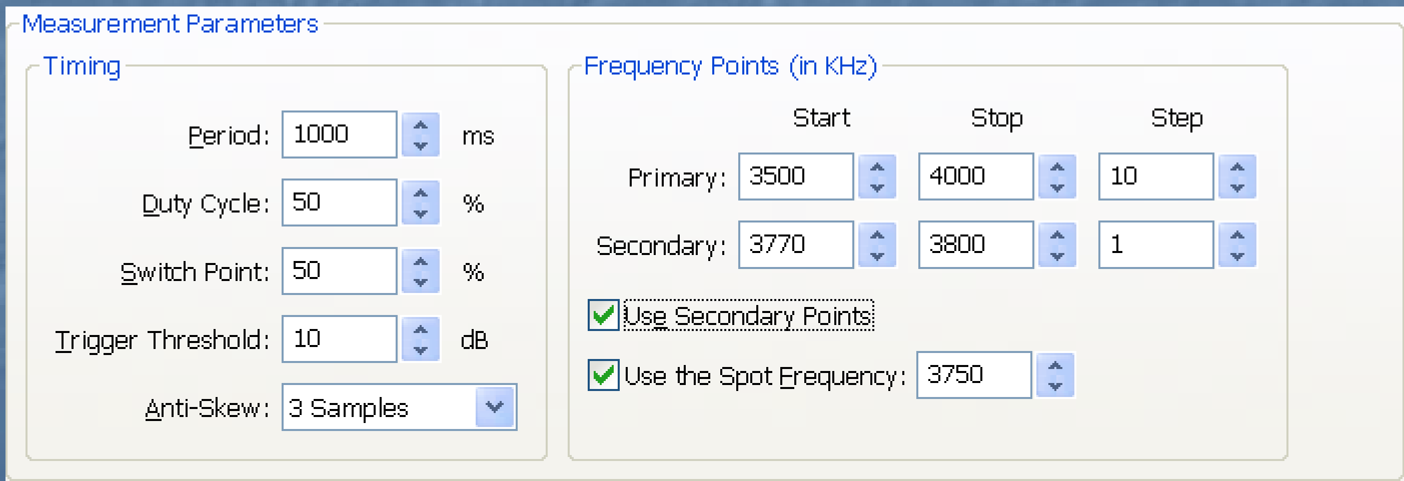
- S Meters are usually poorly calibrated on the meter, but if you can read the meter over the computer interface, you can create your own calibration curve.
- Creating a 60 dB range with 1 dB accuracy is not difficult.
- Use an RF Generator and calibrated step attenuator for setup.



My IC-706MKIIG Calibration Curve

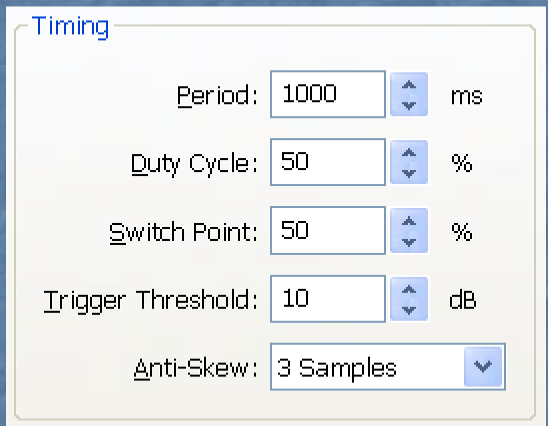
Sweep Description

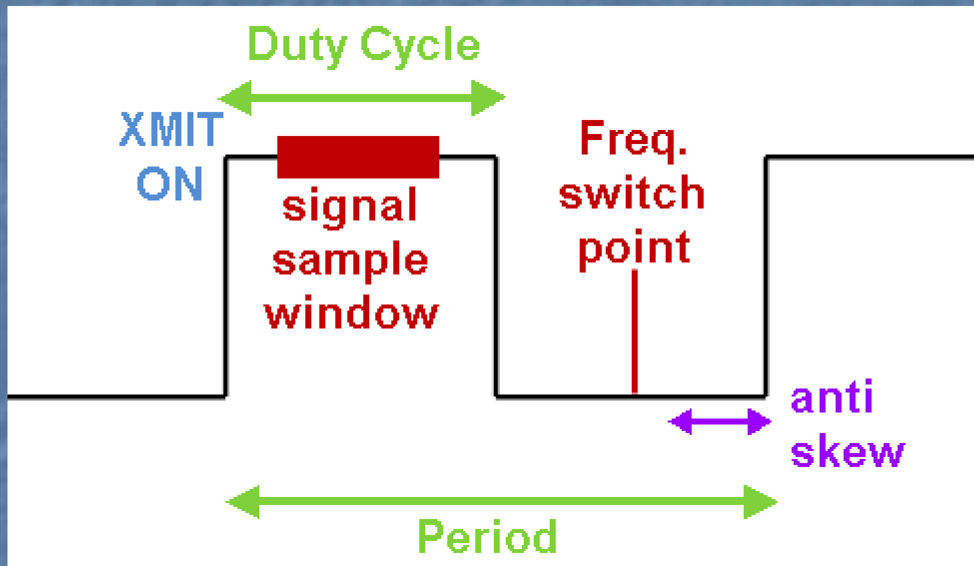
- Each radio must follow the same frequency list.
- The list specification has 3 parts.
  - Spot Frequency (optional) (for setting signal levels).
  - Primary Start/Stop/Step.
  - Secondary Start/Stop/Step (optional) (region of higher detail).



Timing and Control

- Each station sits idle until the sweep is started on the transmitter computer by the operator.
- The receiver computer constantly reads the S Meter and detects the first signal that exceeds the signal threshold. That starts the receiver cycle.

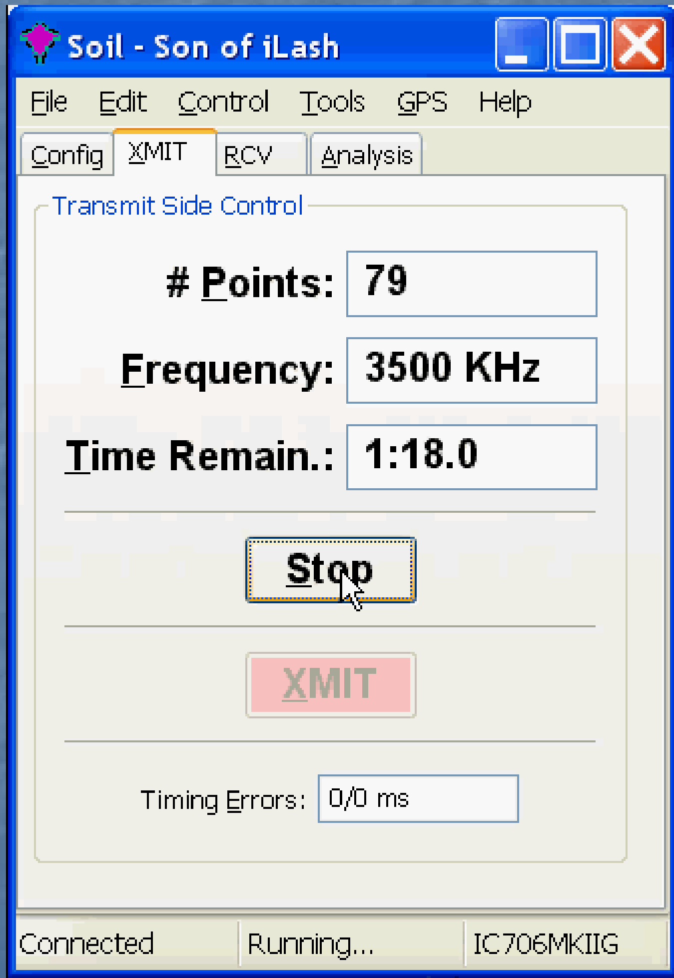




With 1 sec. Period and 40 CPS, ~8 samples are averaged to make one reading. A whole band can be swept in around a minute (60 points).

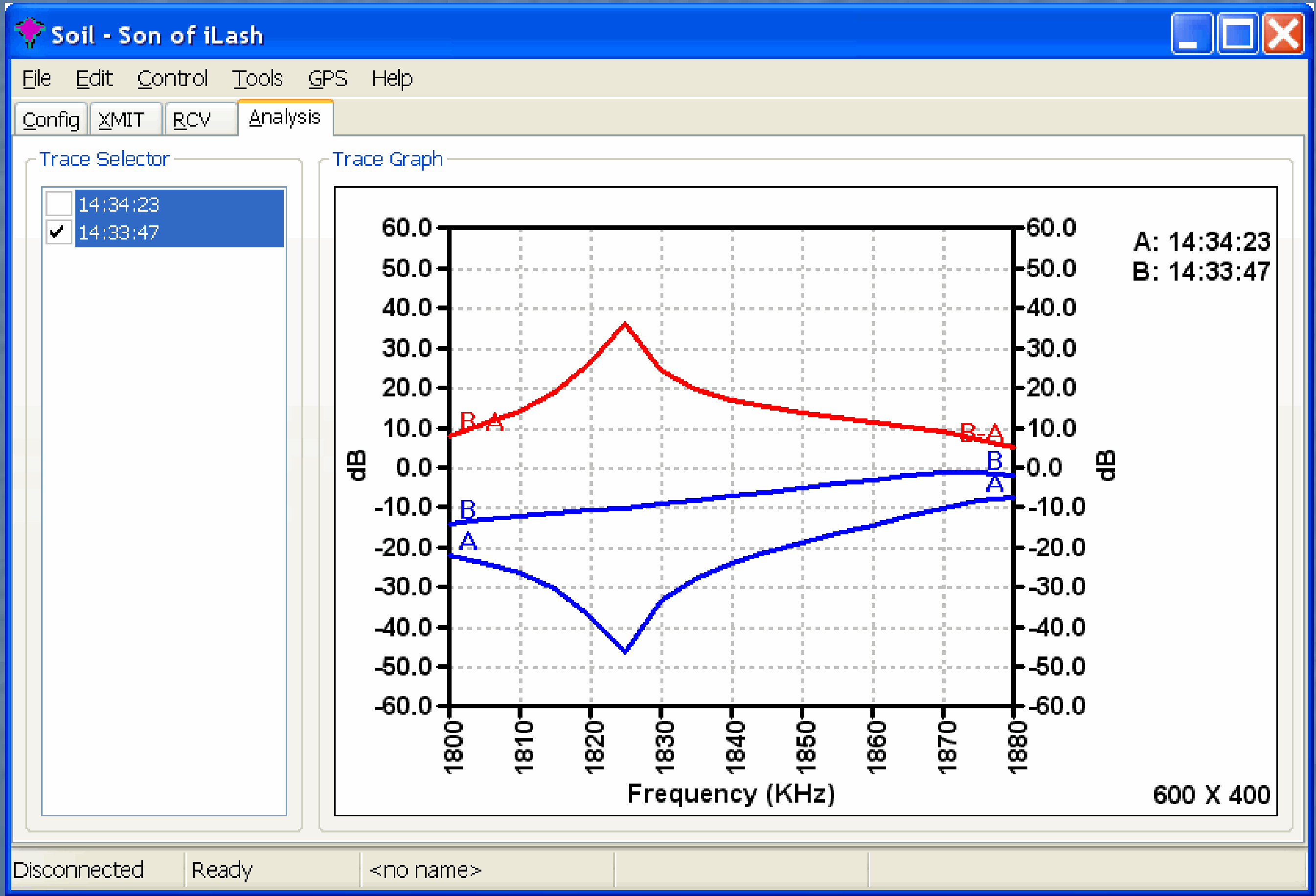
Transmitter Perspective

- The **XMIT** button turns on the transmitter for setting signal levels.
- **Start** begins the sweep.
- Timing errors show deviations from the high resolution CPU counter, which is very accurate in the short term.



Receiver Perspective

Analysis Perspective

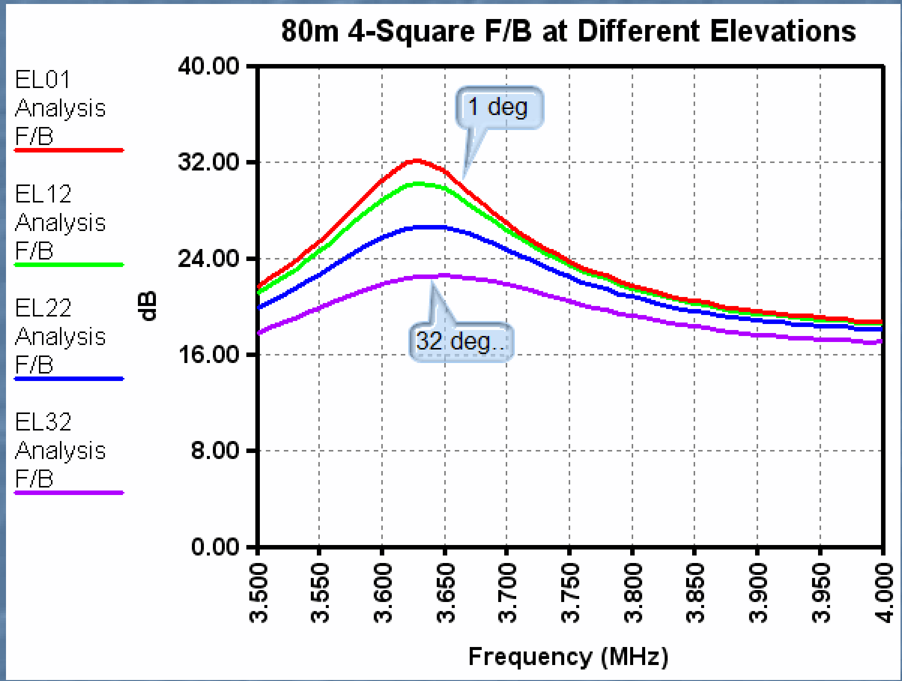


Pitfalls and Potential Problems

- Many. For example, probably not appropriate for NVIS.
- QSB/QRN/QRM. Best done on a dead band with no QSB.
- Groundwave rather than Skywave signals. Ground clutter. Better to be located higher than the AUT rather than lower.
- Develop Expectations from Models (understand Groundwave/low angle behavior).
- Signal Overflow/Underflow.
- Antenna Alignment Errors.

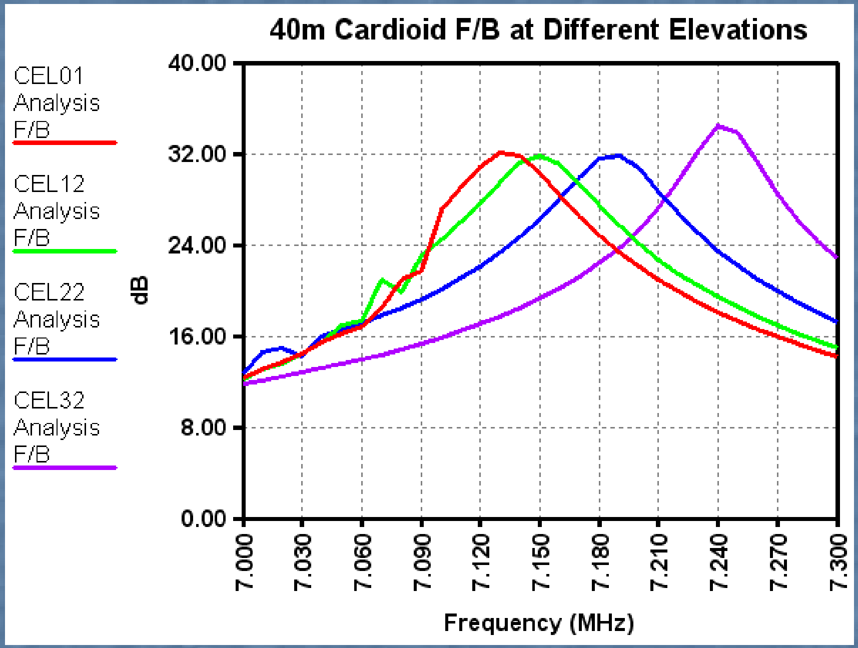
Groundwave Characteristics

- The antenna behavior may *shift* at groundwave elevations. Modeling can help reveal what to expect.
- Consider how the F/B might change as a function of take-off angle.
- Lower angle, higher F/B in this example.



Groundwave Characteristics (2)

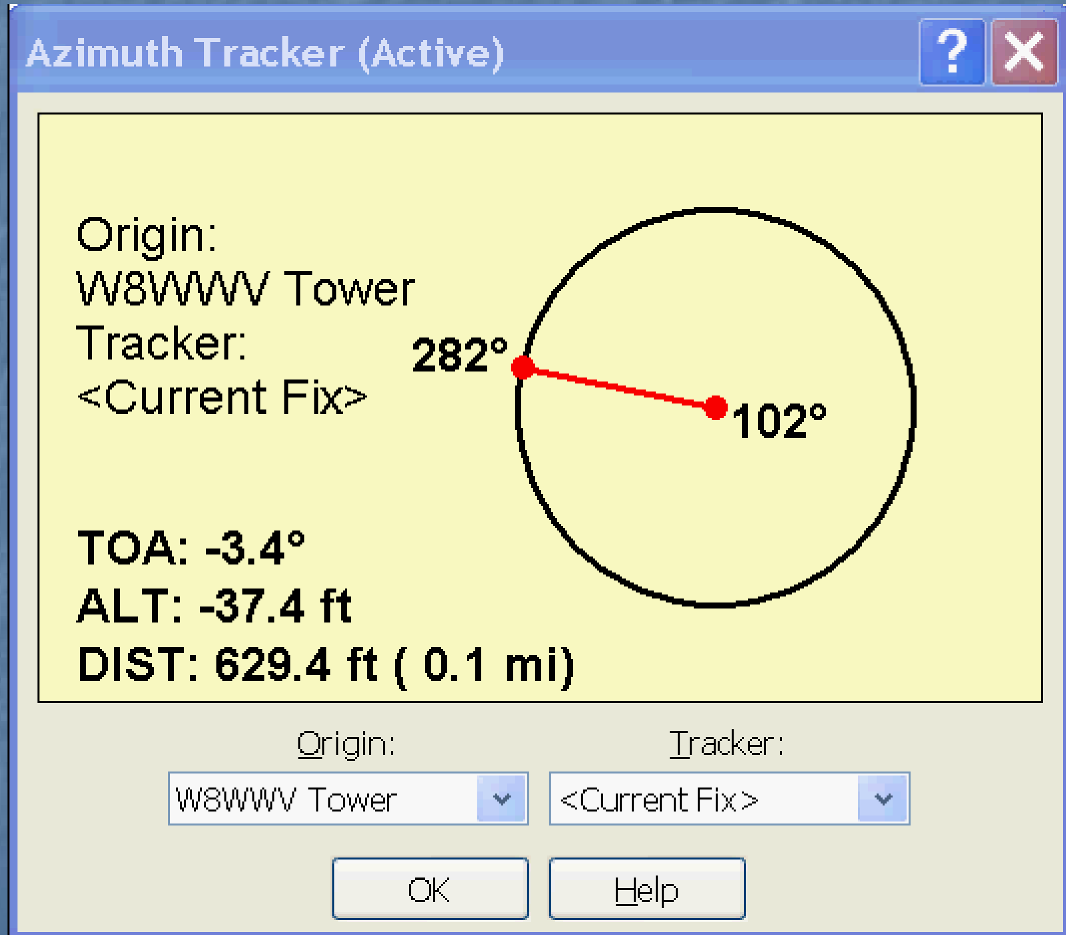
- The frequency of the F/B peak may even shift as function of take-off angle.
- This is a 40m 2-EL array with a cardioid pattern. As the take-off angle drops the F/B peak freq. drops too.



Antenna Alignment

- Use a decent Compass (<= 1° accuracy) and GPS.

I learned my array was off by 6°.
Be sure to factor in declination.



Minimal Mobile Requirements

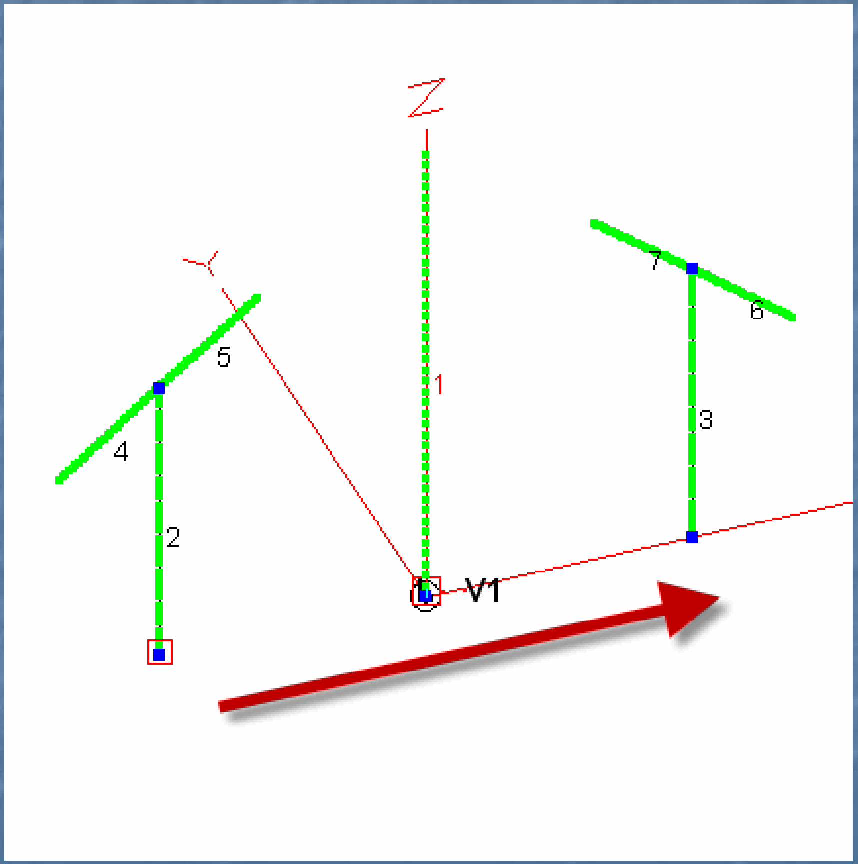
It's a joke.

Apologies to the owner..

Radio/Computer Mobile Test Stack

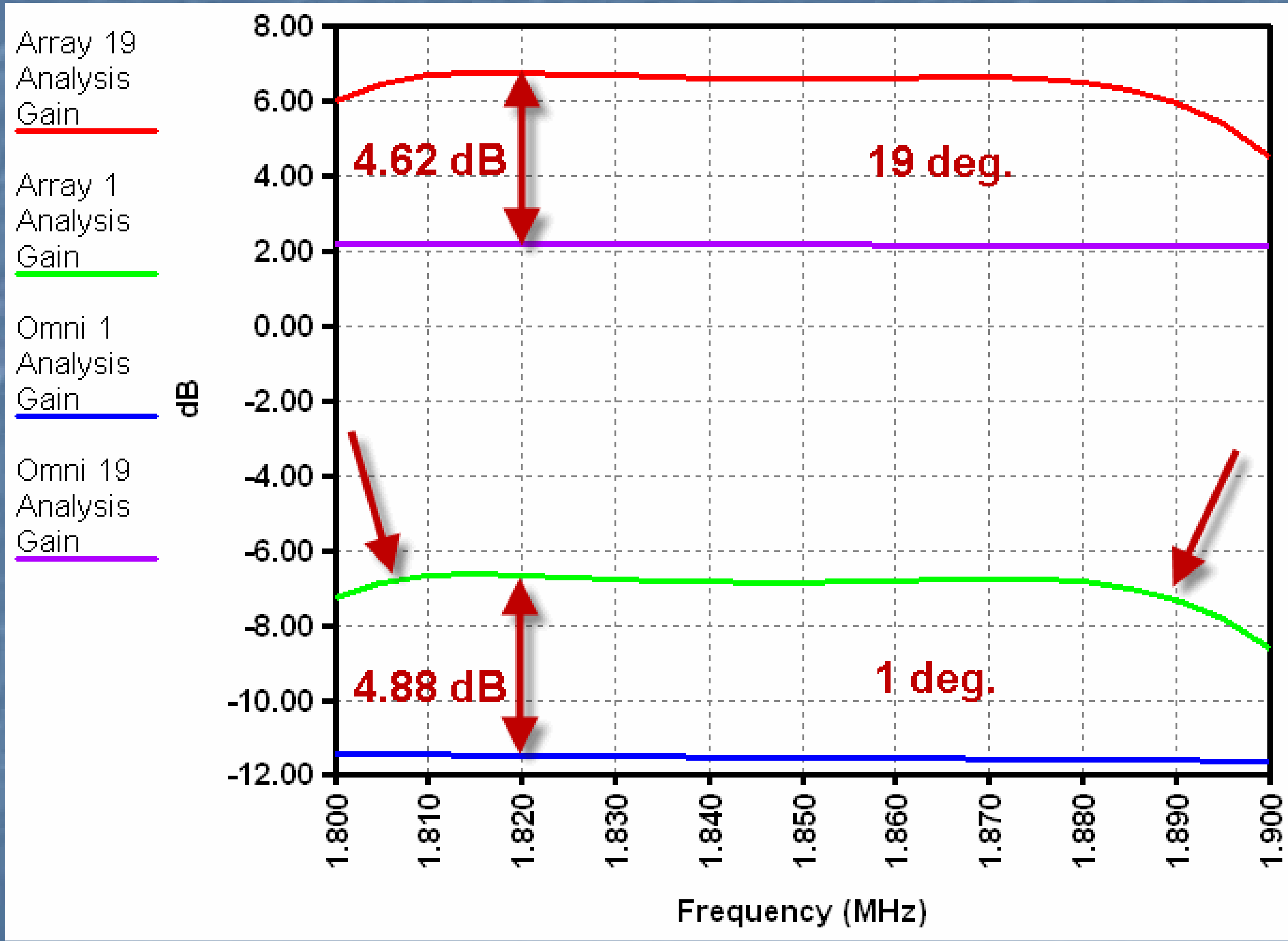
Results: 160 m K3LR Array

- Described in 4th edition of ON4UN's LowBand DXing.
- Driven ¼ λ center element surrounded by 4 parasitic T elements, tuned as either open, director, or reflector.
- 3-El end-fire array in 4 directions, plus omni mode.



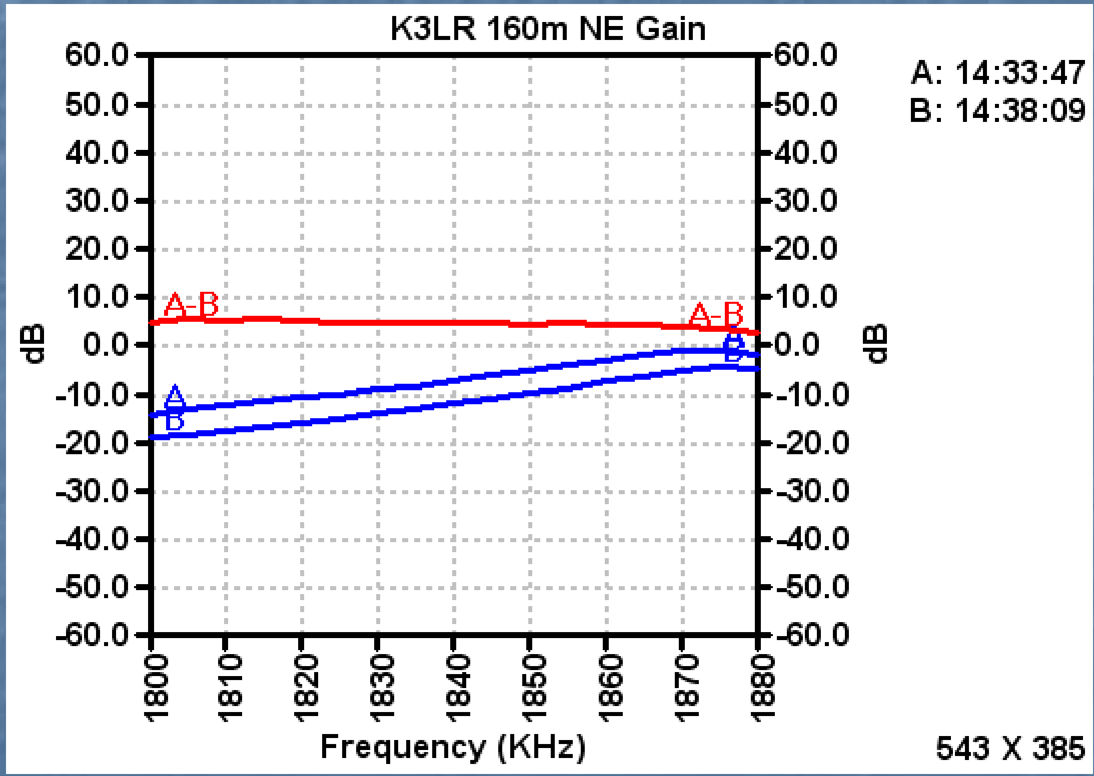
160 m K3LR Array: Gain from NEC

- NEC Model Results at 19° and 1° take-off angles
- ~5 dB gain over omni, roll off on ends.



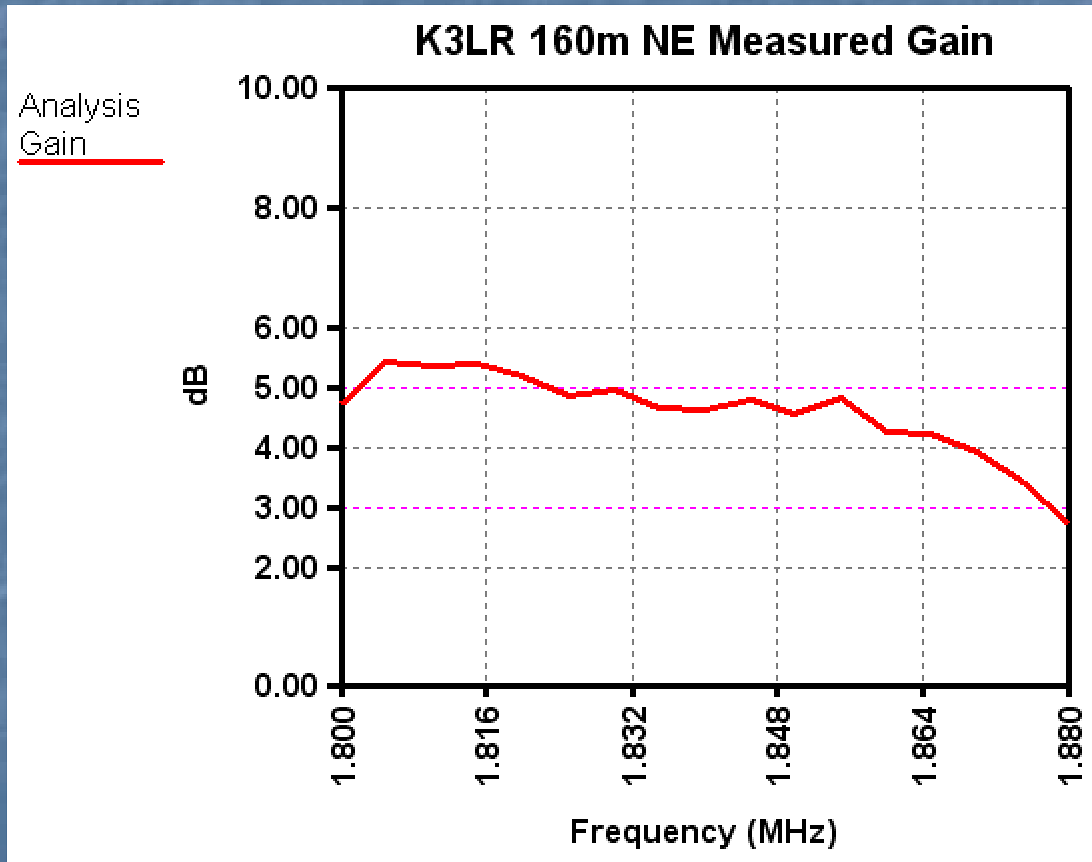
160 m K3LR Array: Gain from Measurement

- Measured array and omni, with secondary antenna response and comparison.



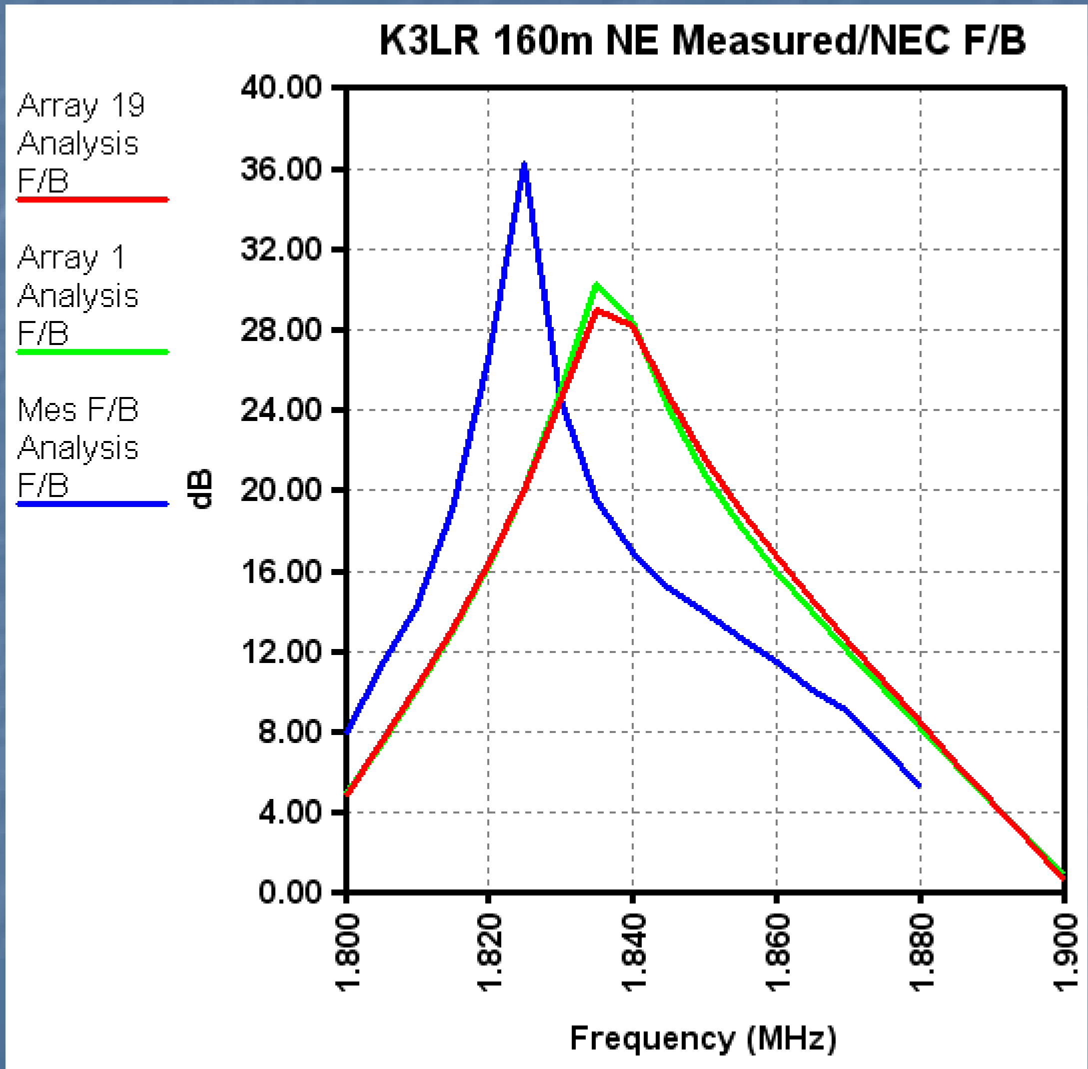
160 m K3LR Array: Gain from Measurement (2)

- Closer look at the measured array gain over the omni gain.



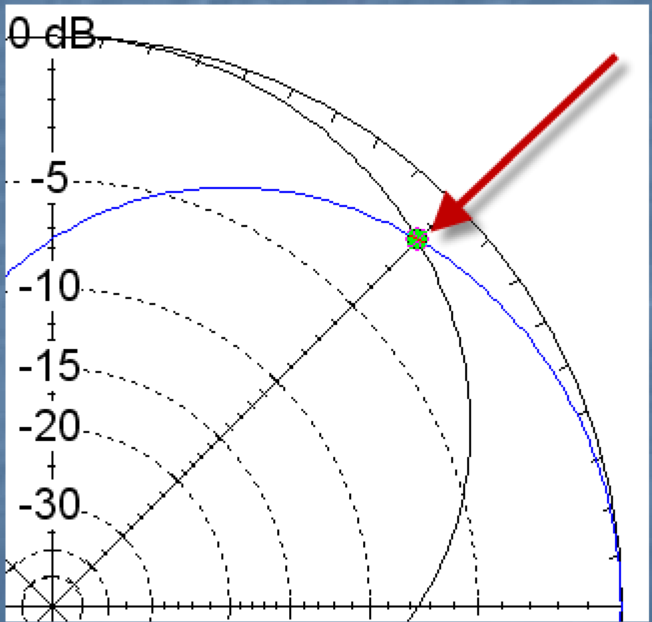
160 m K3LR Array: F/B

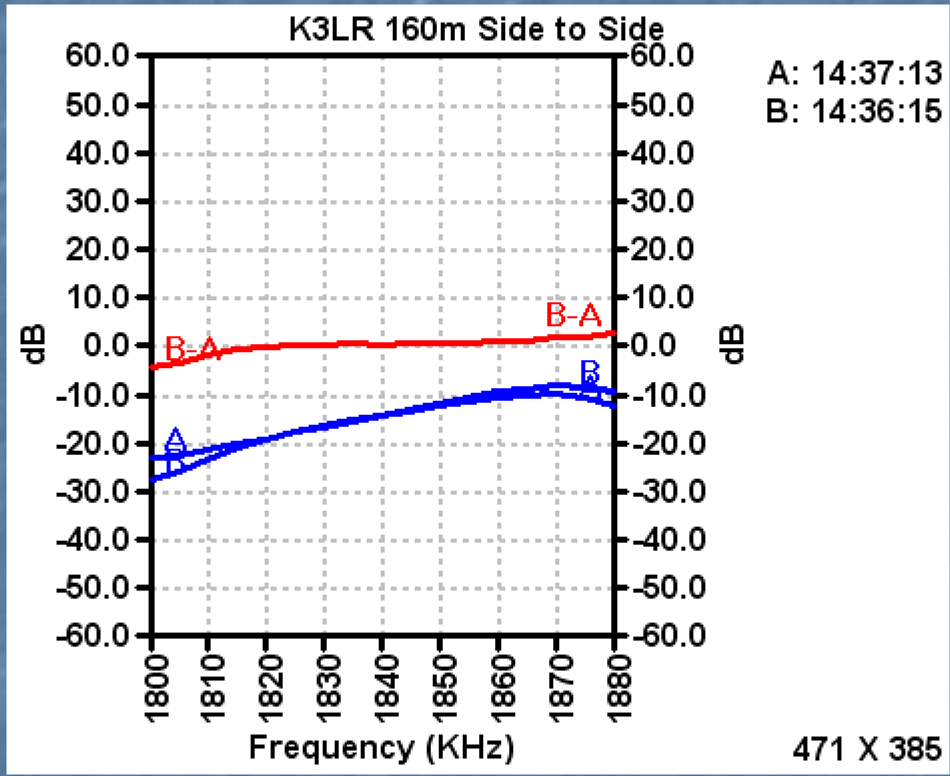
- 1 and 19° F/B are virtually identical.
- Not really pure F/B.
- LBDXView – ON4UN 5th edition.



160 m K3LR Array: Side to Side

- Useful to check for pattern distortion. Sensitive to azimuth alignment.



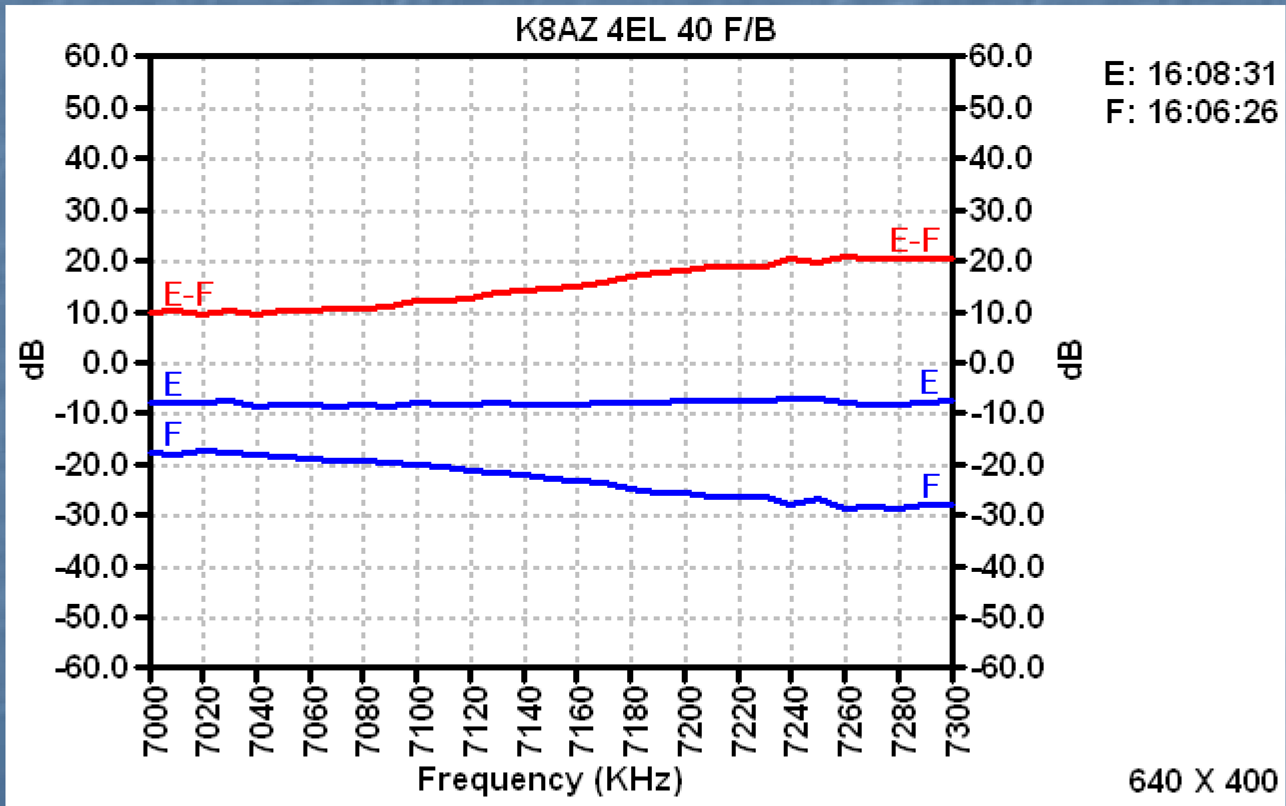


K8AZ 40 m Yagi's

- 3 different 40 meter Yagi's
  - 4L @ 130'
  - 2L @ 70'
  - 2L @ 65' (fixed 140)
- I used my 20 meter Yagi (@ 60') as a secondary antenna.

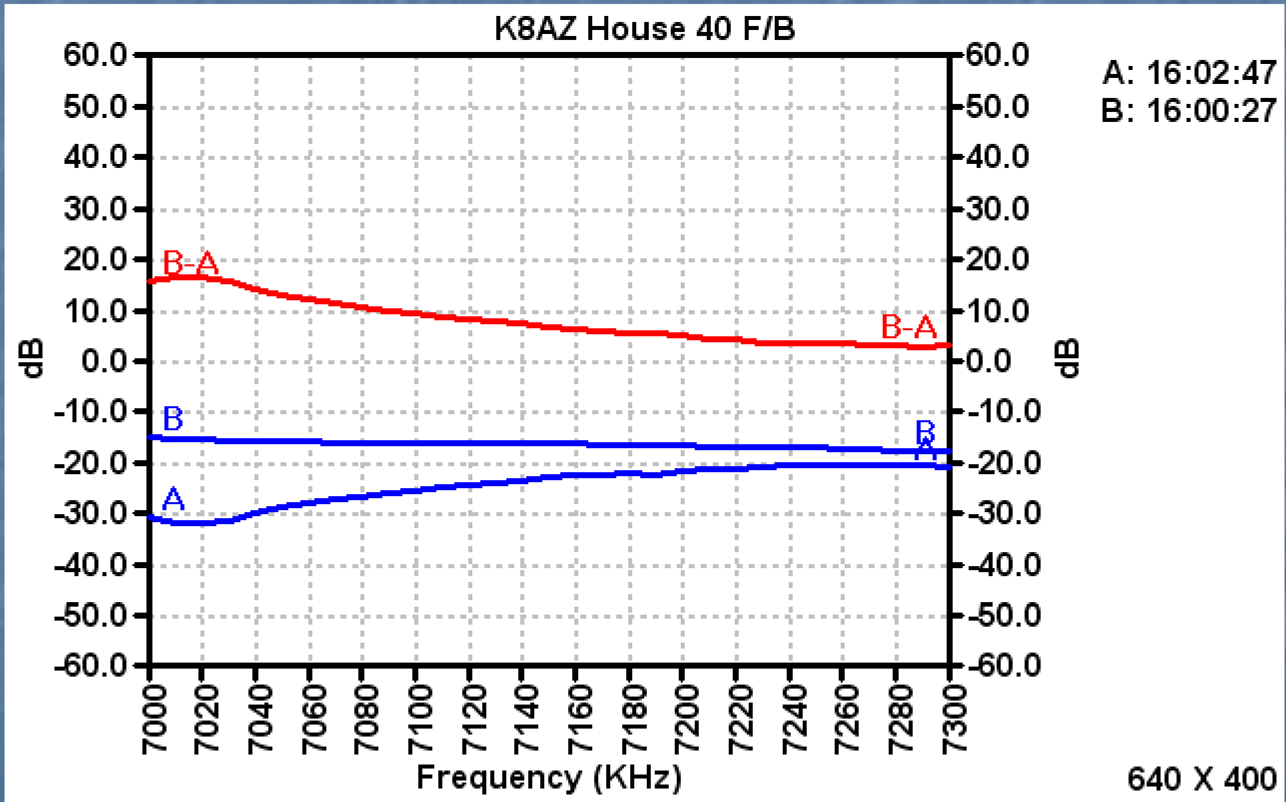
K8AZ 40 m Yagi's (2)

- 4L F/B Measurement:



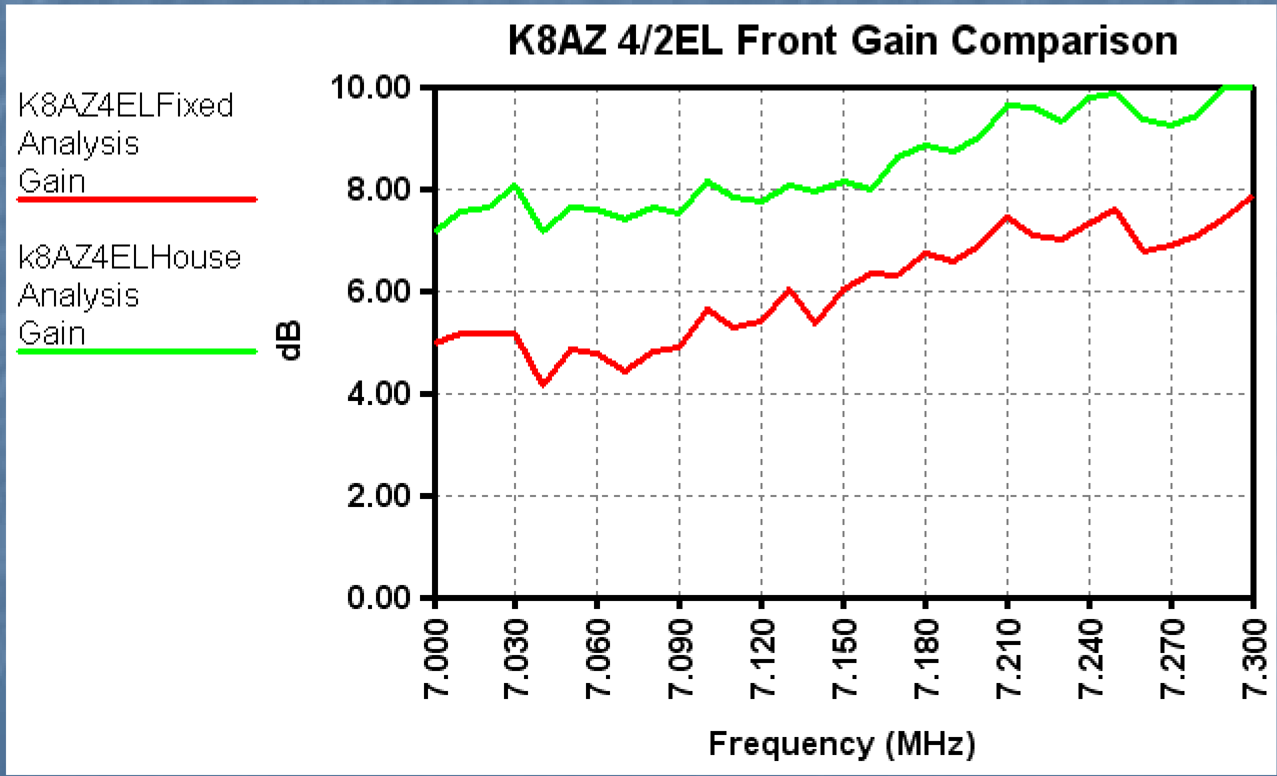
K8AZ 40 m Yagi's (3)

- 2L "House" F/B Measurement:



K8AZ 40 m Yagi's (4)

- 4L Versus 2L Gain Comparison:



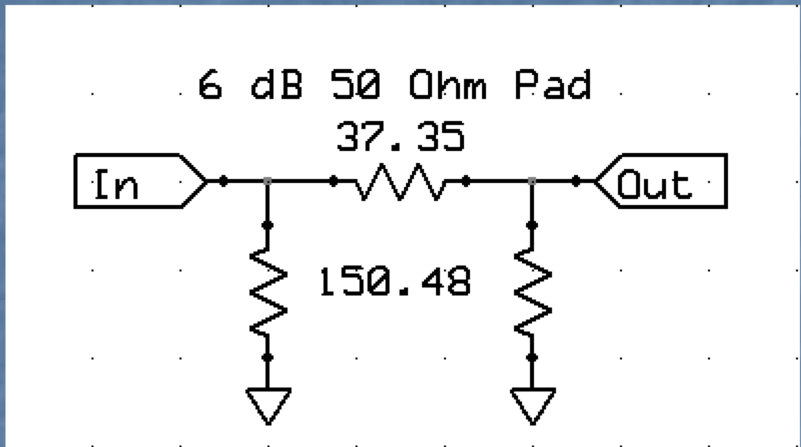
Power Attenuator Pads

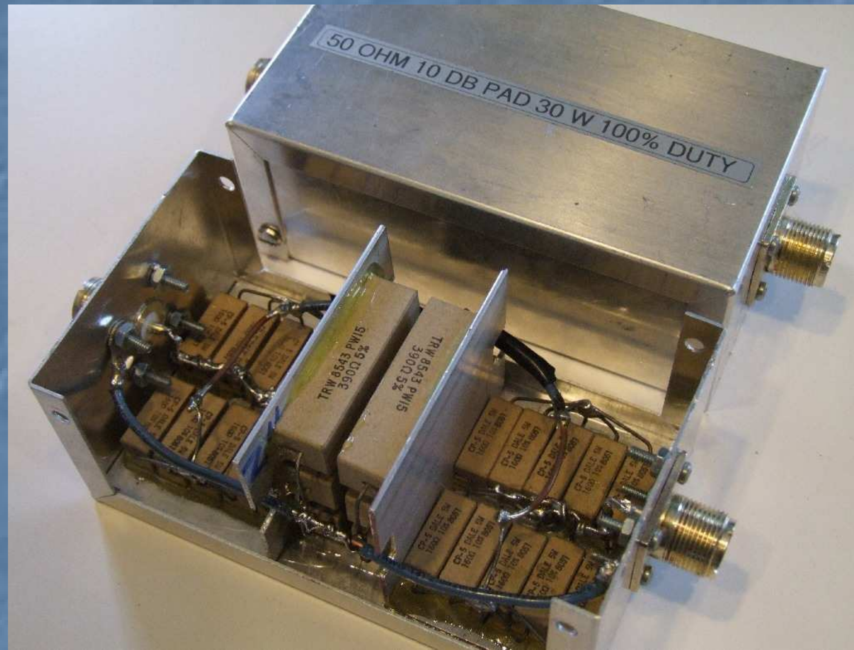
- Spill power for Receive or Transmit to help set signal levels.
- Protect Transmitter from large SWR swings on small antennas (such as mobile).
- Values such as 3, 6, and 10 dB are usually useful.

Power Attenuator Pads (2)

- Formulas and Calculators all over the place (books & Internet).
- PI and TEE designs – select based upon hunting results for non-inductive power resistors.
- Good brush up on Ohm’s Law and resistor networks.

Power Attenuator Pads (3)

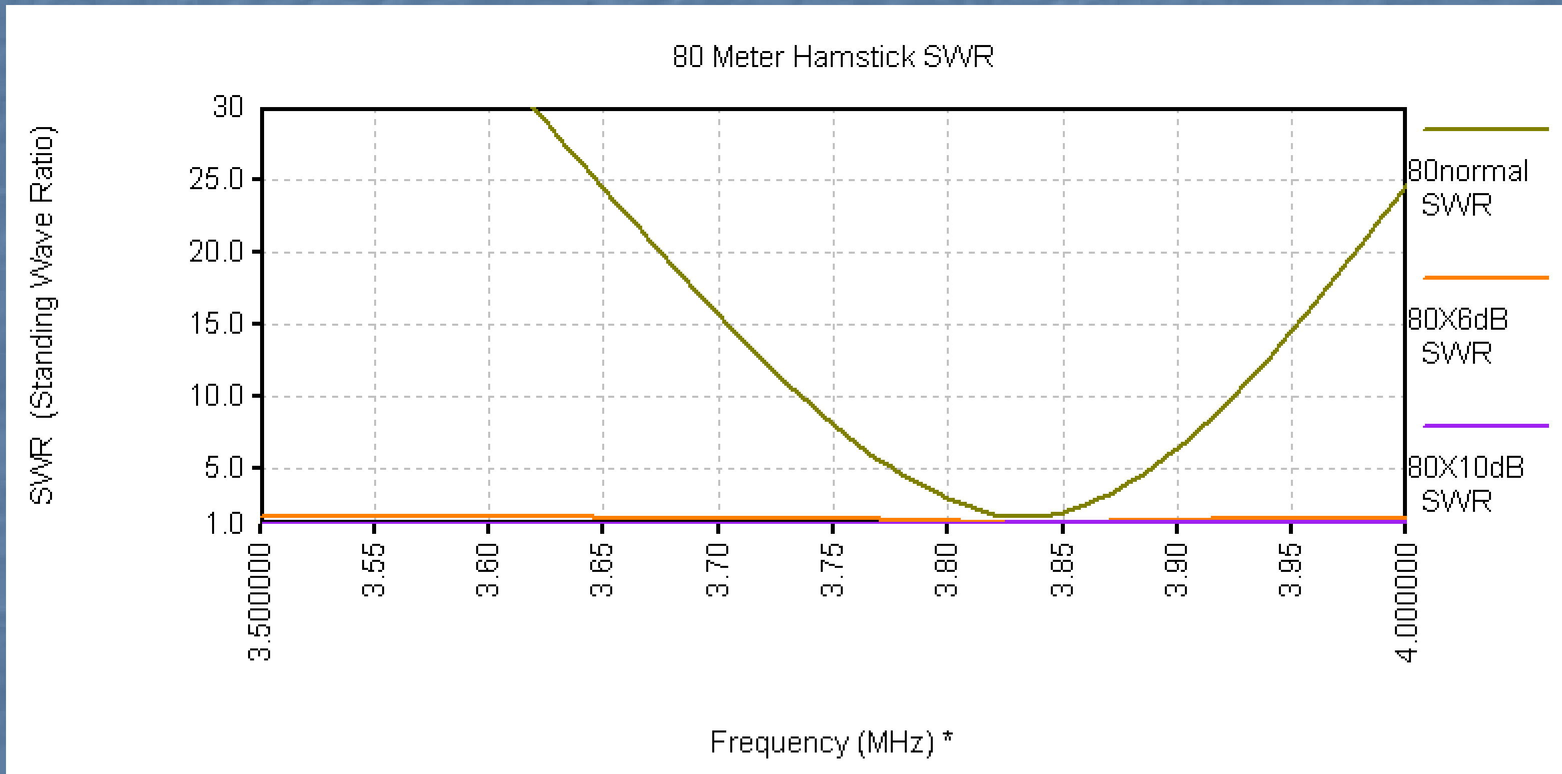




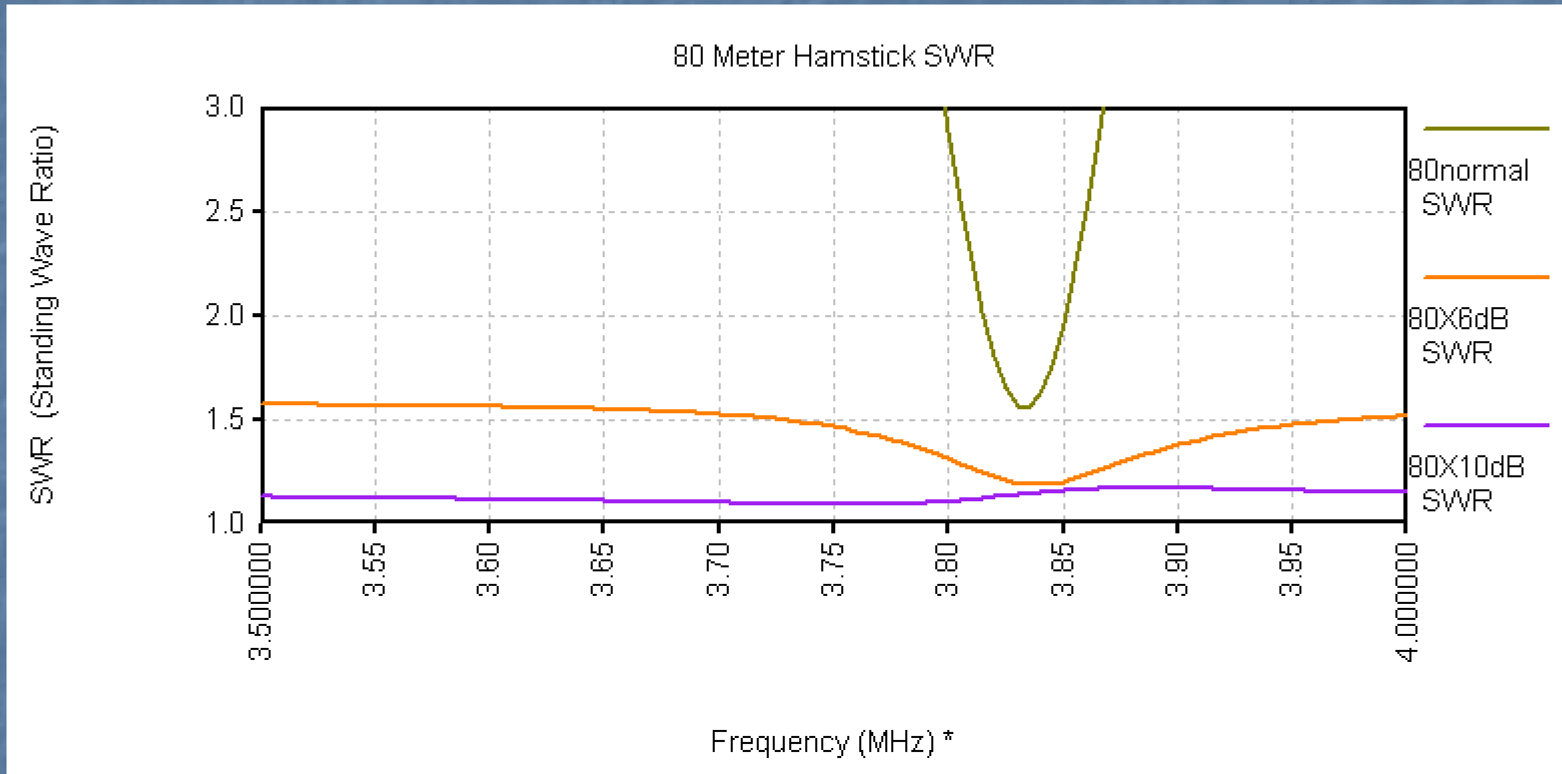
- Use Open and Short on output to quickly characterize SWR limiting.
- More attenuation = more limiting = more dissipation.

w/Open: Z = 83.5, SWR = 1.67
w/Short: Z = 29.8, SWR = 1.67
(6 dB pad)

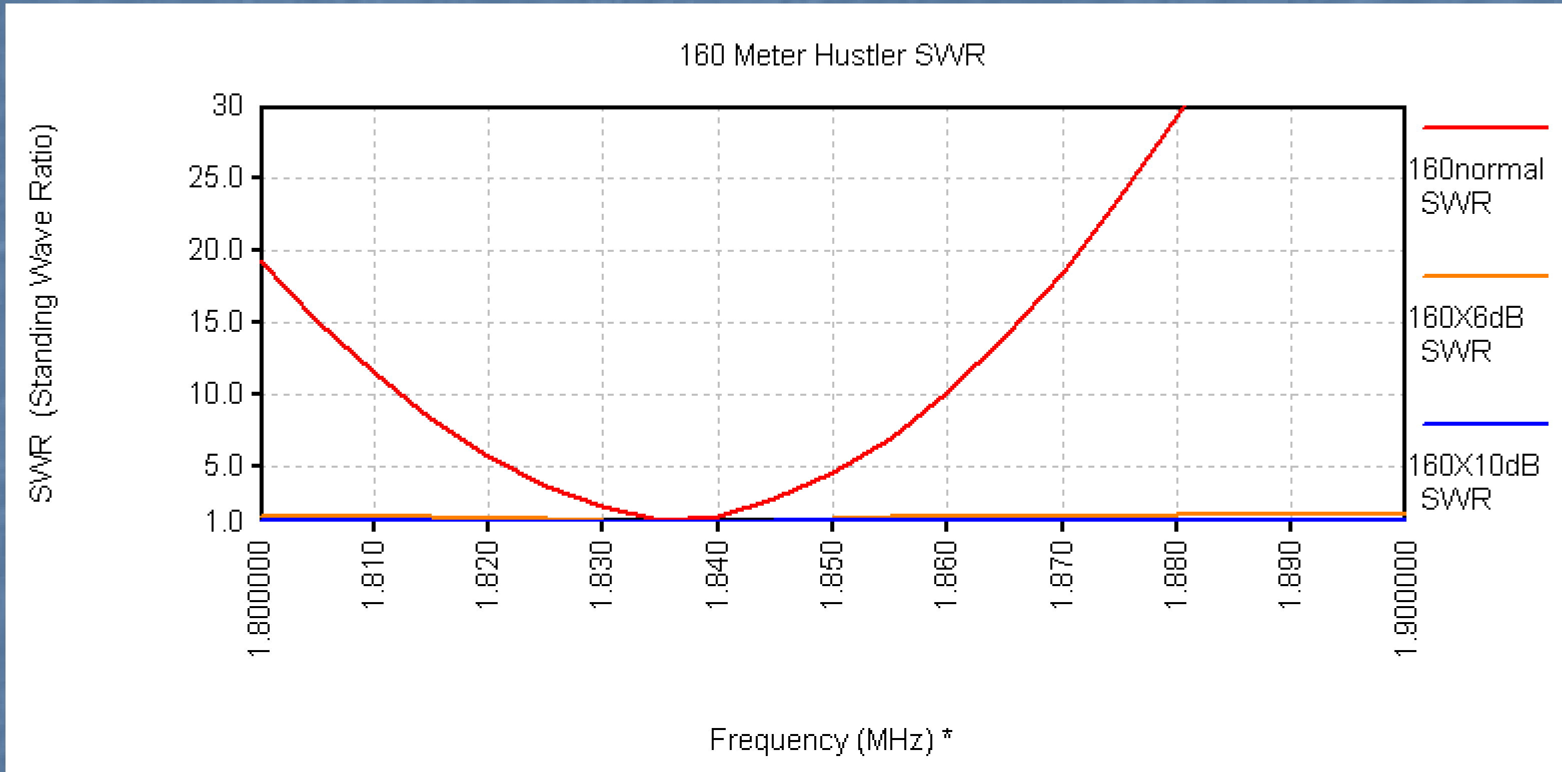
Power Attenuator Pads (80m)



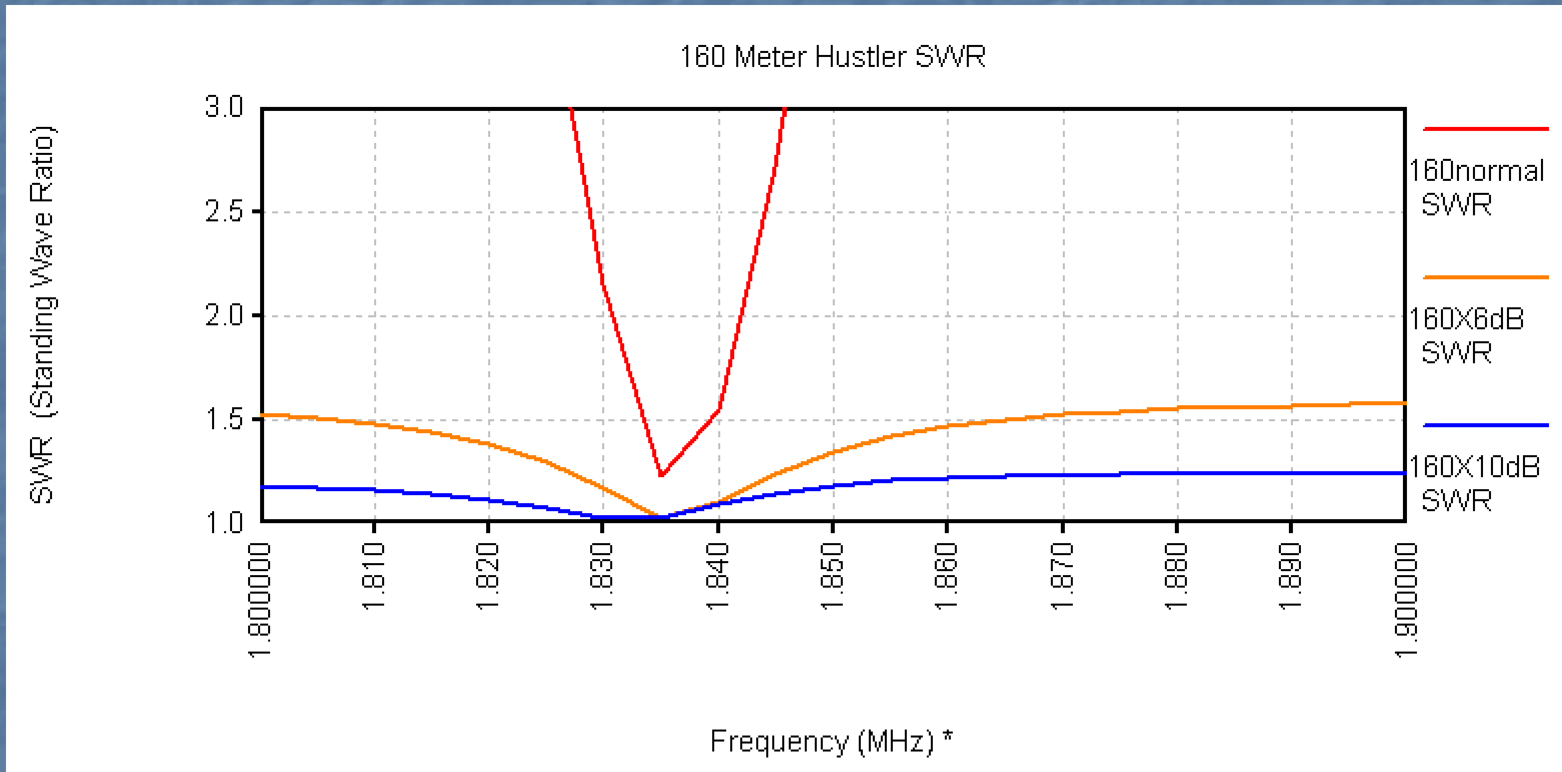
Power Attenuator Pads (80m)



Power Attenuator Pads (160m)



Power Attenuator Pads (160m)



Conclusion

- Another tool for the kit. Never enough checking and cross checking.
- Takes some time to set up, but once you are measuring, large amounts of data are quickly collected.
- Don’t kill yourself (especially when mobile).
- Don’t cause QRM, dead bands are good for stable measurements and reducing QRM.
- Please contact me if you are interested in the software.
- Thanks to K3LR and K8AZ for their help and time.