An overview of radio site measurements

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RadioSiteTest.com

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Background (CV)

- 40 year of RF Test and Measurement Applications engineering
  - Anritsu S412E LMR Master
  - Anritsu Spectrum and Network Analyzers
  - HP Spectrum and Network Analyzers
  - Tektronix Spectrum Analyzers, Oscilloscopes

- Certifications
  - FAA sUAS Pilot License, October 2016
  - Drone Cell Tower Inspection Training, December 2016
  - Certified Climber /Rescuer, January 2017
  - Anritsu PIM Master Certification 2015
  - Network Associates Sniffer Certified Professional 2000

Presentations and Papers

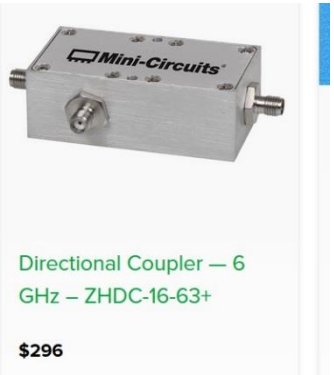
- Presentations:
  - Using Drones for Site Surveys, IWCE, March 2017
  - Testing Indoor Coverage, IWCE, March 2017
  - Measurement and Optimization of Talk-in Coverage for VHF and UHF TDMA Radio Systems, IWCE, March 2017
  - In-Building Distributed Antenna Systems (DAS) Planning for Public Safety, IWCE March 2016
  - Public Safety Distributed Antenna System (DAS) Measurements, Web seminar August 2015
  - Receiver Blocking Measurements, APCO WRC May 2015
  - Optimizing Simulcast Systems, IWCE March 2015
  - Using SINAD Coverage Mapping to Locate Receiver Blocking, APCO WRC 2015
  - Using a VNA to Tune N-Way Combiners, IWCE March 2014
  - P25 Receiver Testing, IWCE 2013
  - Fundamentals of Interference Analysis IWCE 2011
  - Session Chairman for Wireless Data Technical Session at the Wireless Design Trade Show from 1992 to 1999
- Application Notes / White Papers:
  - Solving mm-Wave Test Challenges, Microwave Journal March 2017
  - In-Building Propagation Measurements for 5G Communications August 2016
  - In-Building Mapping March 2016
  - Accuracy of DTF Measurements of New Spools of Transmission Line, December 2015
  - Measuring Antenna Pattern with the Anritsu S412E, November 2015
  - High Q Notch Filter Measurements; August 2015
  - Measuring Delay Through a Repeater or DAS, August 2015
  - Receiver Testing January, 2012
  - Mapping BER of P25 Radio Systems, May, 2015
  - Indoor Mapping, August 2010

Agenda

- Network Analyzers
  - Cable and antenna testing
  - Filter tuning
  - Distance to fault
- Spectrum Analyzers
  - Emission mask testing
  - Interference
    - Passive Intermodulation
    - Broadcast to LTE
- Using a drone with camera and spectrum analyzer to characterize tower sites

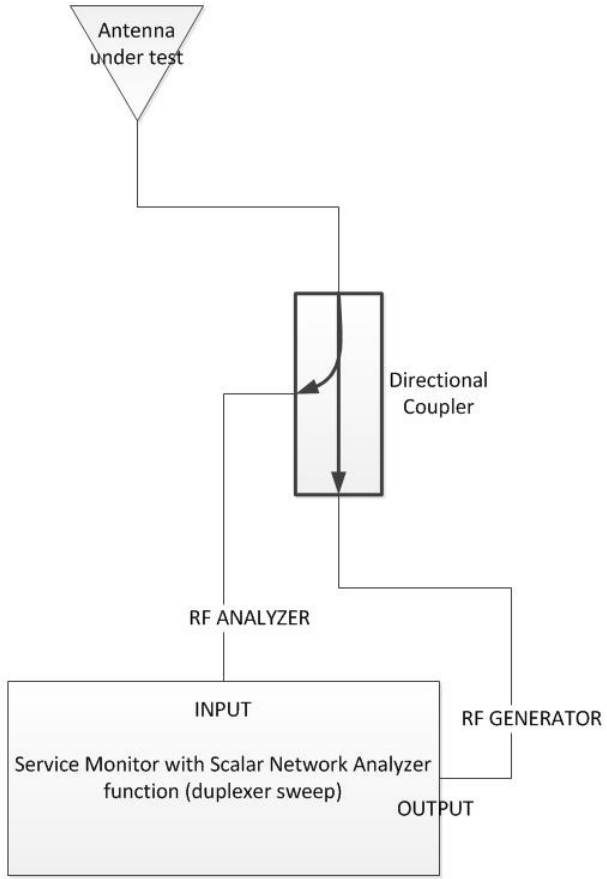
Antenna Test

- Spectrum analyzer with TG
- Service Monitor
  - IFR, Motorola
- Calibration is Short



FEATURES:

- Coverage: 5 Mhz to 3000 MHz
- Five Watt Power Rating
- Covers all Cell and PCS bands
- Directivity >40 dB
- RF reflected port
- Internal 50 ohm Reference
- Rugged case and connectors
- Great for Antenna Work



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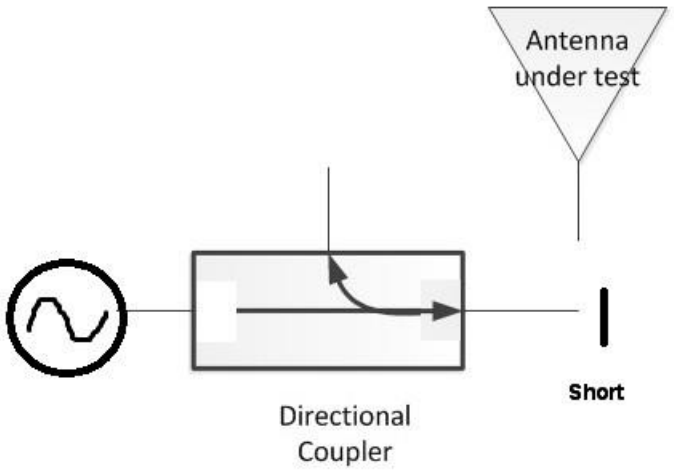
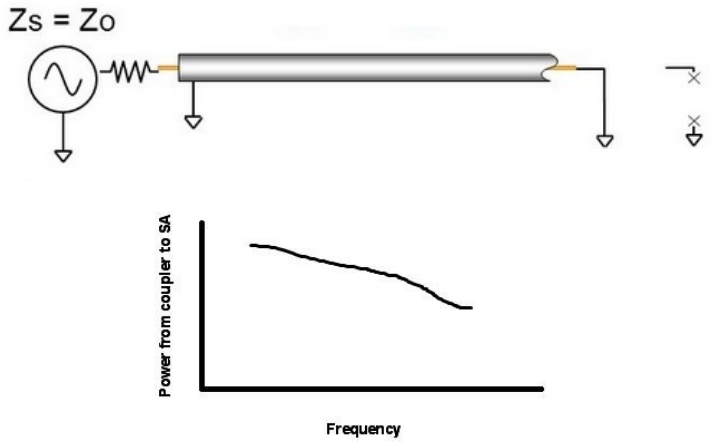
Cable Test Basics

- Perfect situation
  - Source 50 ohms, cable 50 ohms, antenna 50 ohms, Perfect bridge or coupler
  - Calibrate > Reference Line

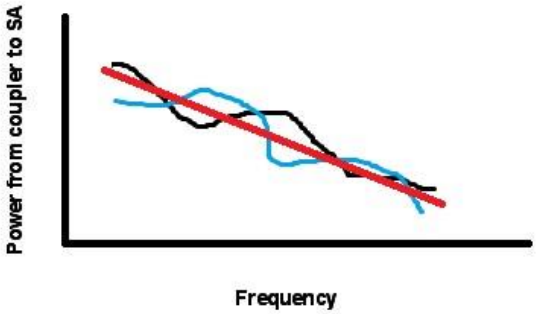


Cable and Antenna Calibration

- Short calibration sets reference line 100 % reflection



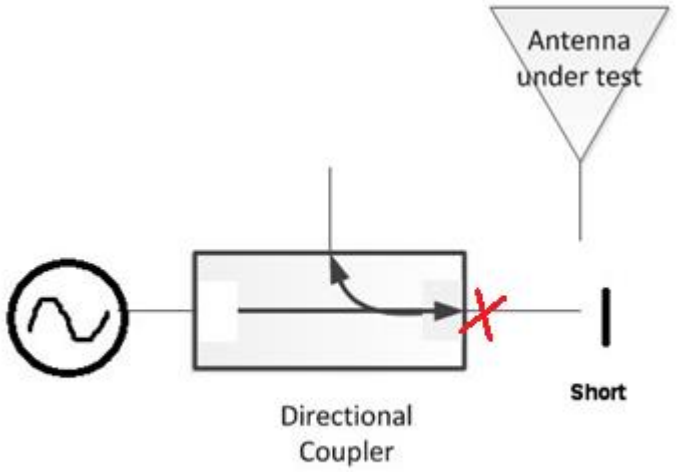
Why use a Short and an Open?



- Average between open and short removes ripple due to mismatch between the DUT and the signal generator
- Open- Short calibration removes frequency response of bridge, test port cable, adapters, etc

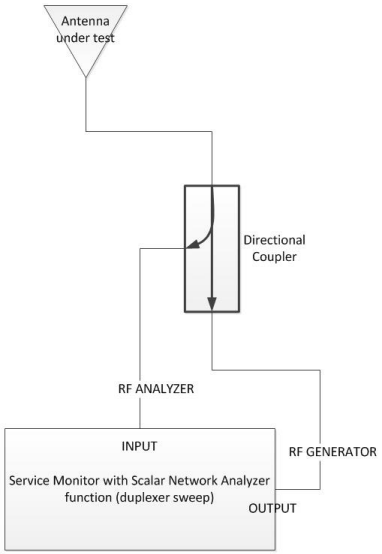
Termination Calibration

- Couplers and bridges are not perfect
- A termination calibration removes error from a bridge or coupler



RF Immunity

- Testing an antenna where other transmitters are on



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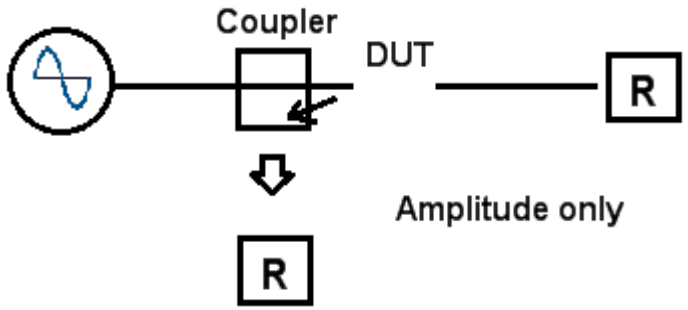
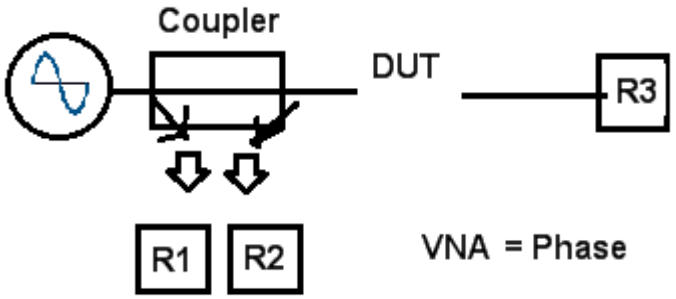
Vector Network analyzer

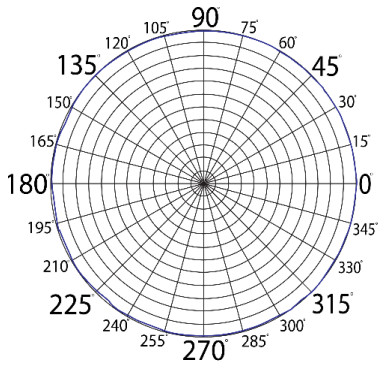
- A VNA has a separate reference receiver and coupler to measure phase (and improve accuracy)

SA with Track Gen.



VNA with Reference Receiver (R1)





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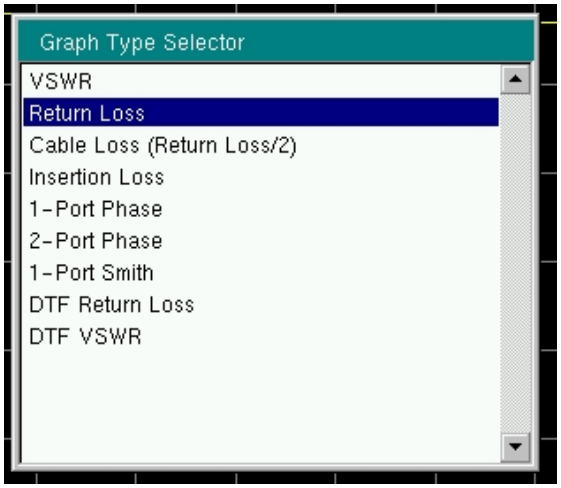
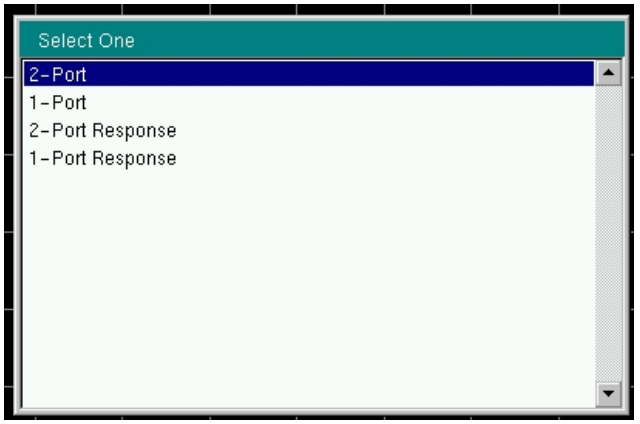
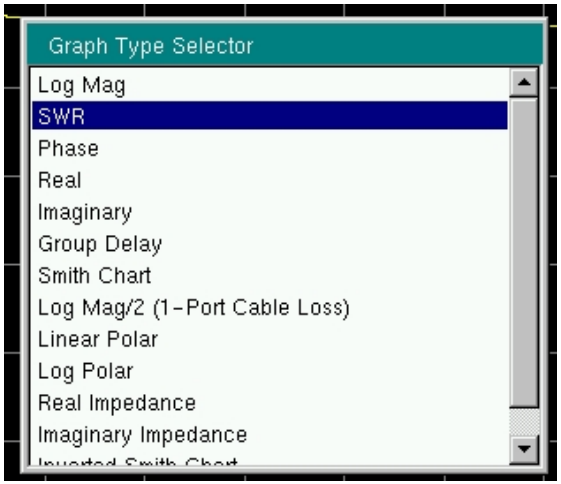
S412E Field Mode vs. VNA Mode "Terminology"

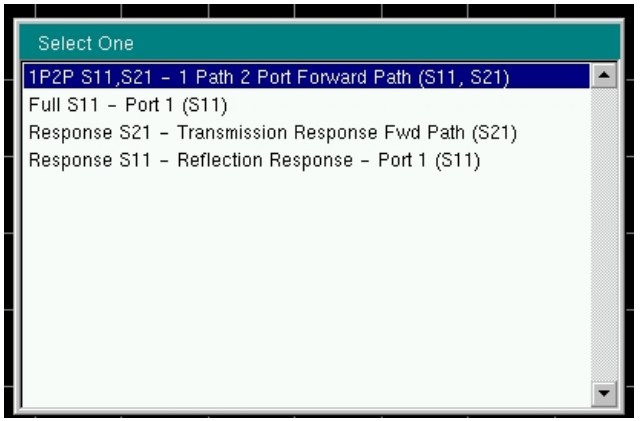
- Field Mode
  - VSWR
  - Return loss (dB)
  - Insertion loss (dB)





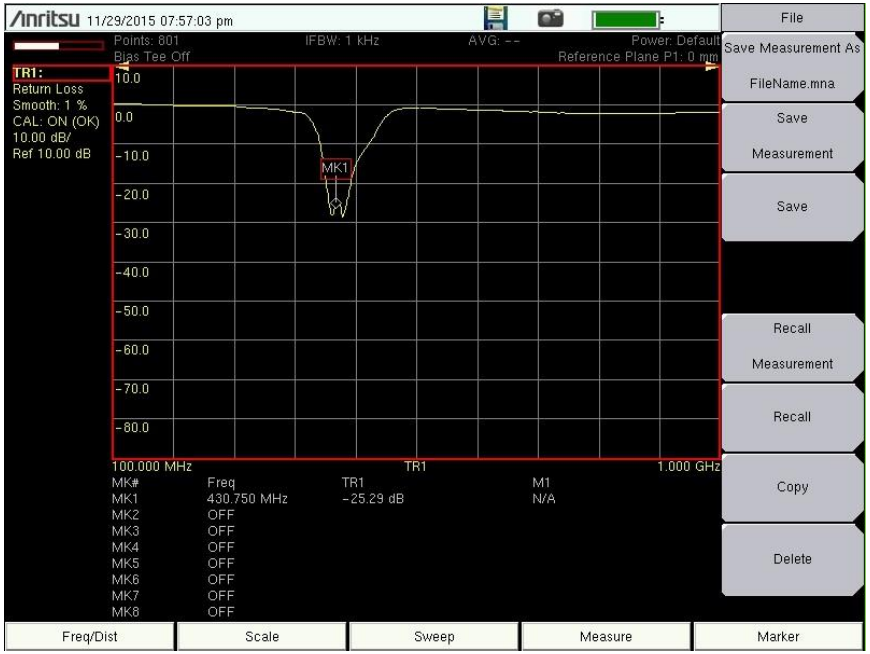
- VNA Mode
  - S11 Log Mag
  - S21 Log Mag





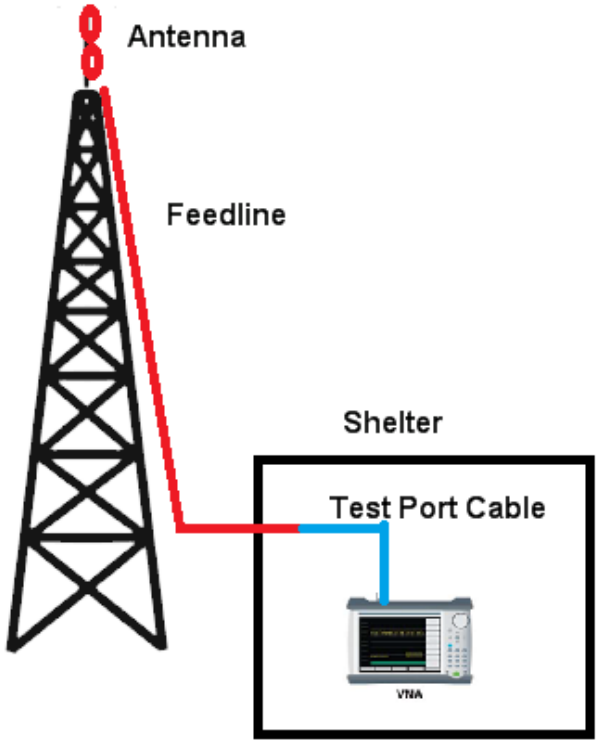
Testing an Antenna (Match RL or SWR)

- Away from metal (unless final mount on tower)
- Return Loss vs. Frequency (0.1 to 1 GHz)
- 0 dB RL = full reflection
- 20 dB RL = 99/100 watts radiated.



Testing an Antenna and Feed line

- 600 ft. LDF-2 Feed line and Yagi Antenna
  - Immunity to other RF



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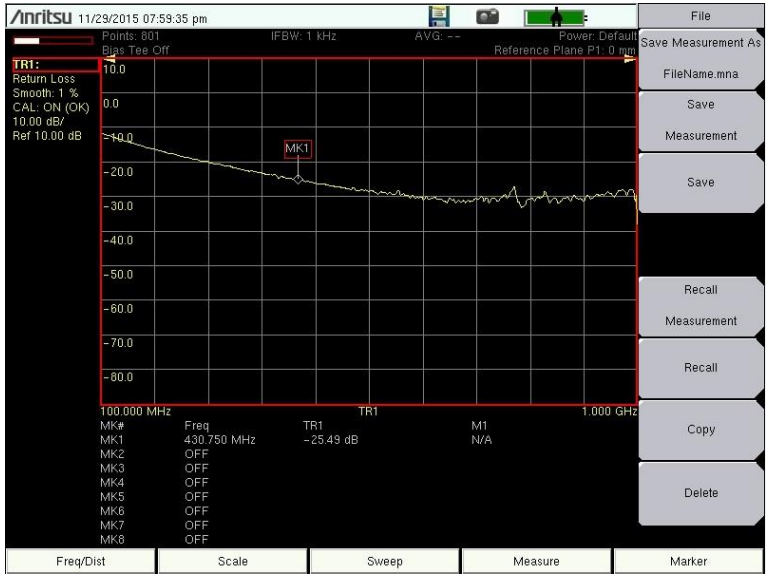
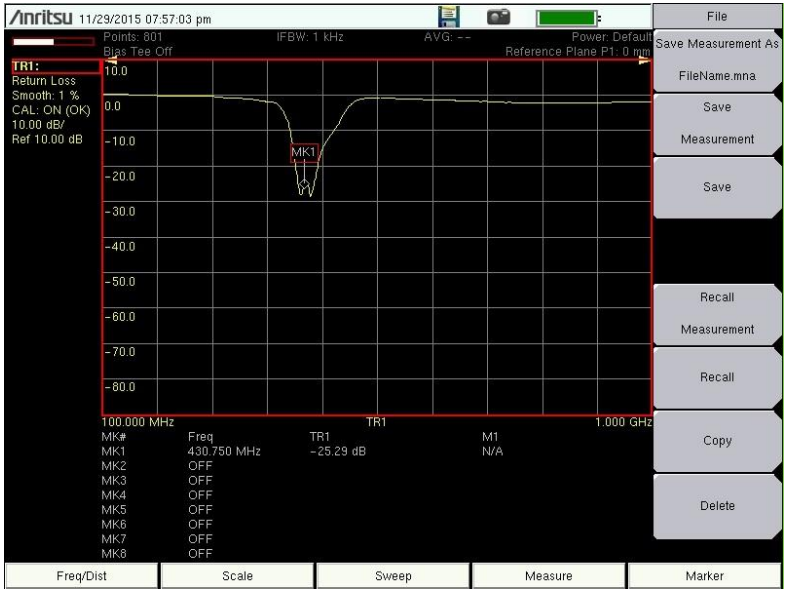
Feed line Loss = RL/2



- 600 ft. LDF -2



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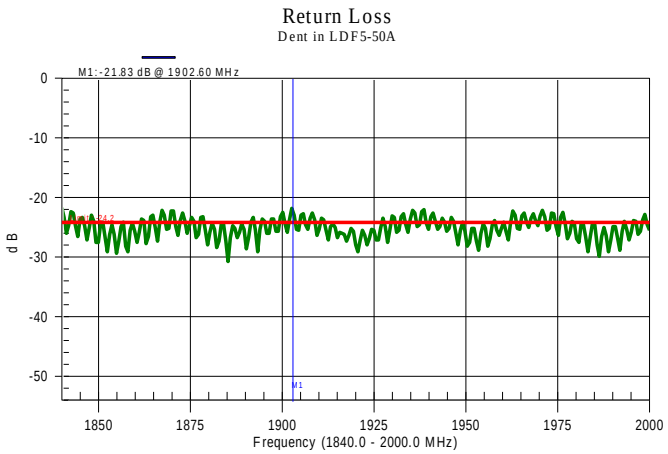
Return Loss vs. Distance to Fault

Return Loss/SWR

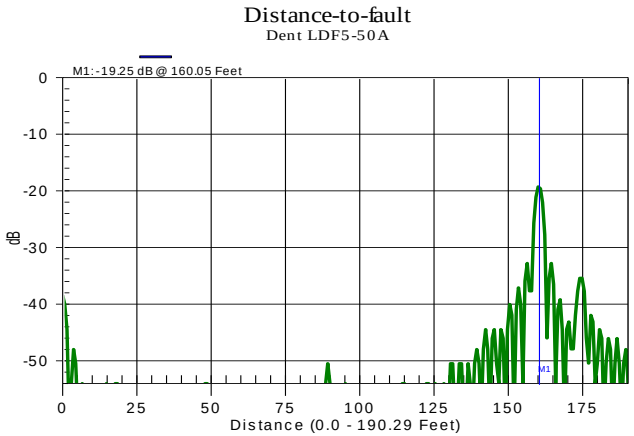
Distance to Fault



Resolution: 259
Date: 04/14/2003
Model: S331C

CAL:ON(COAX)
Time: 09:23:15
Serial #: 00201068

CW: OFF



Resolution: 259
Date: 04/14/2003
Model: S331C

CAL:ON(COAX)
Time: 09:23:41
Serial #: 00201068

CW: OFF
Ins.Loss:0.018dB/ft
Prop.Vel:0.890

Telewave
ANT450D3-3T

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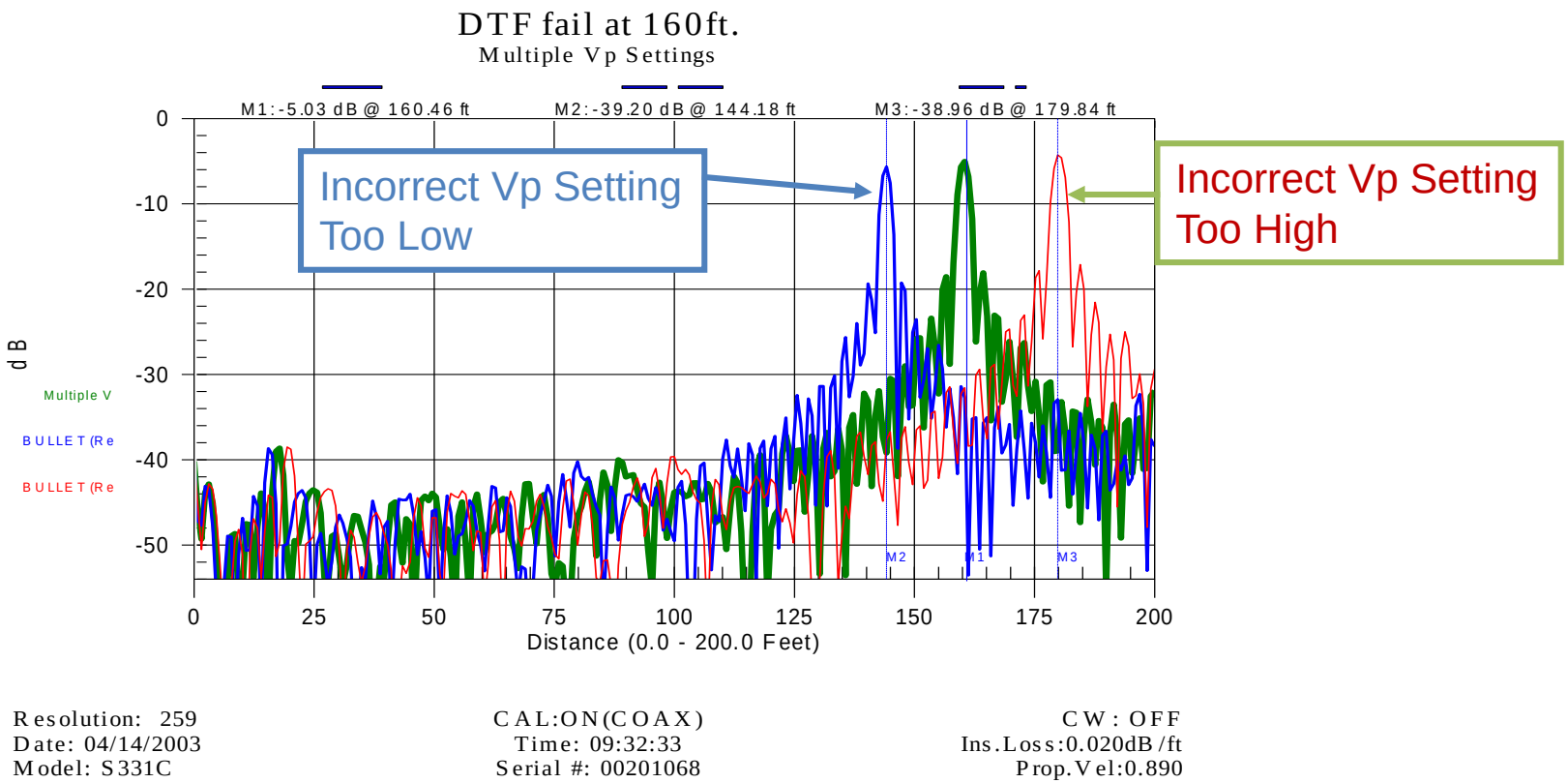
Distance to Fault

Distance to Fault Accuracy

- *Distance – Vp (Propagation Velocity) Setting*



An incorrect Vp setting causes incorrect distance reading

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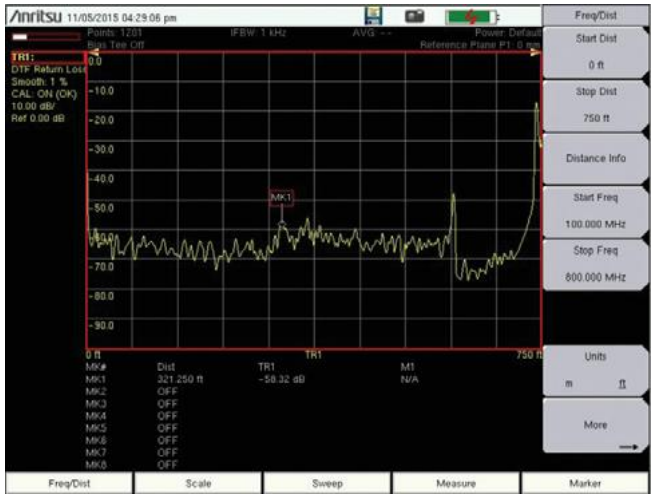
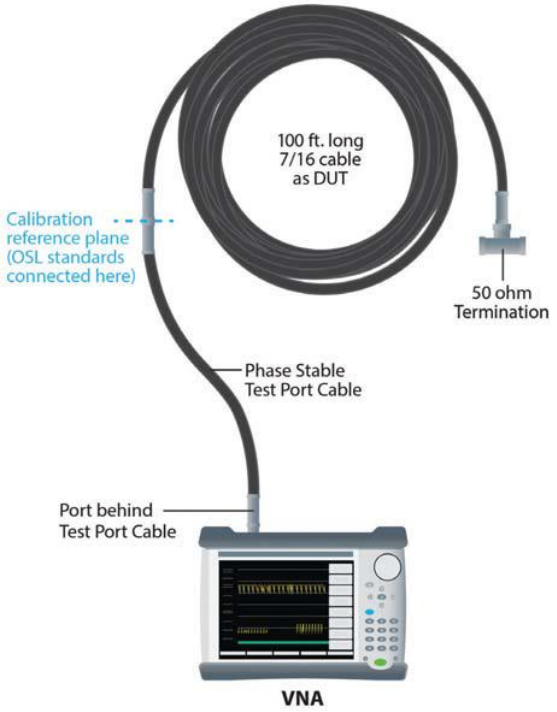
Testing New Spools of Feedline at Tower Sites

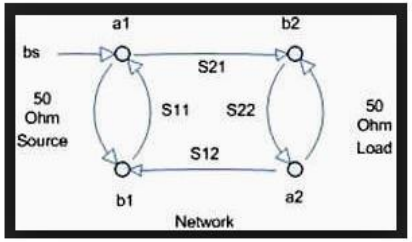
- 50 Ohms +- 1 Ohm = 40 dB Return Loss
- With care, DTF measurements can support 40 dB RL within +- 1 dB
  - Locate damage from shipping / installation



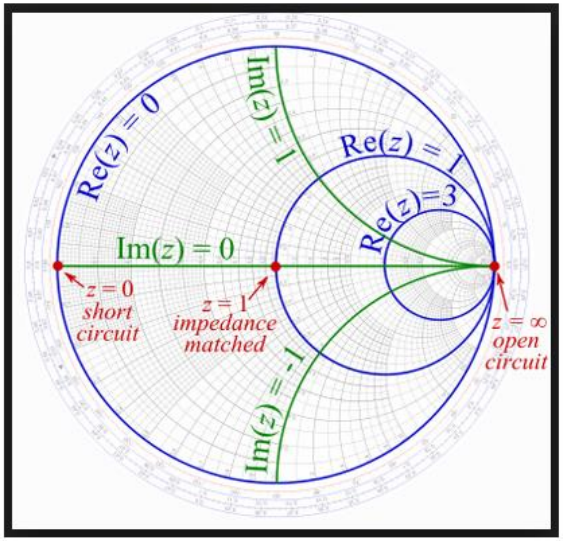


Smith Chart and "S-Parameters"

- 4 Receivers (full 2 Port VNA)
  - a1, a2 forward
  - b1, b2 reverse (reflected)



- S412E has one path 2 port VNA
  - 3 Receivers
  - No reference receiver on port 2 (b2)



- Smith chart
  - Complex impedance
    - R+jX
    - Mag angle (deg)
- Easy to cut ¼ or ½ wavelength cables

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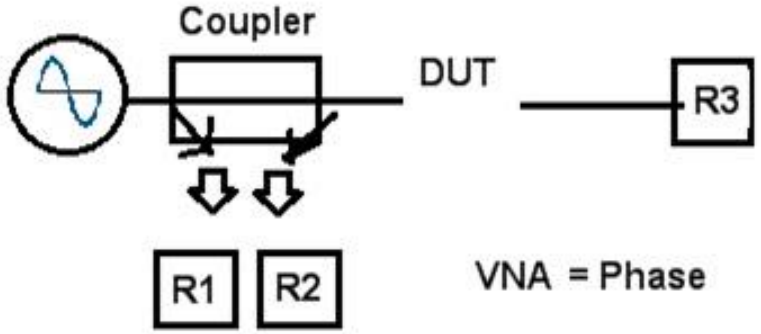
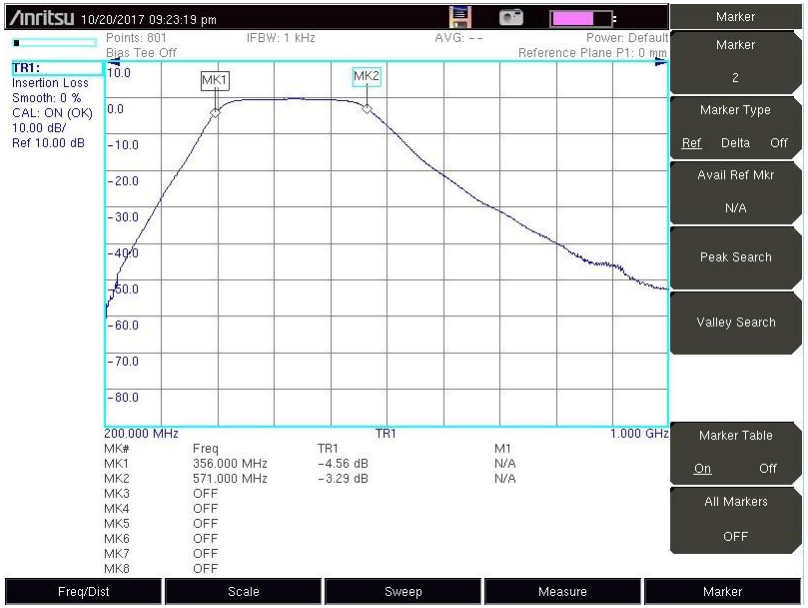
2 – Port VNA Measurements (cable loss / filter tuning)

- Source flatness (and match) corrected



2 – Port VNA Measurements (cable loss / filter tuning)



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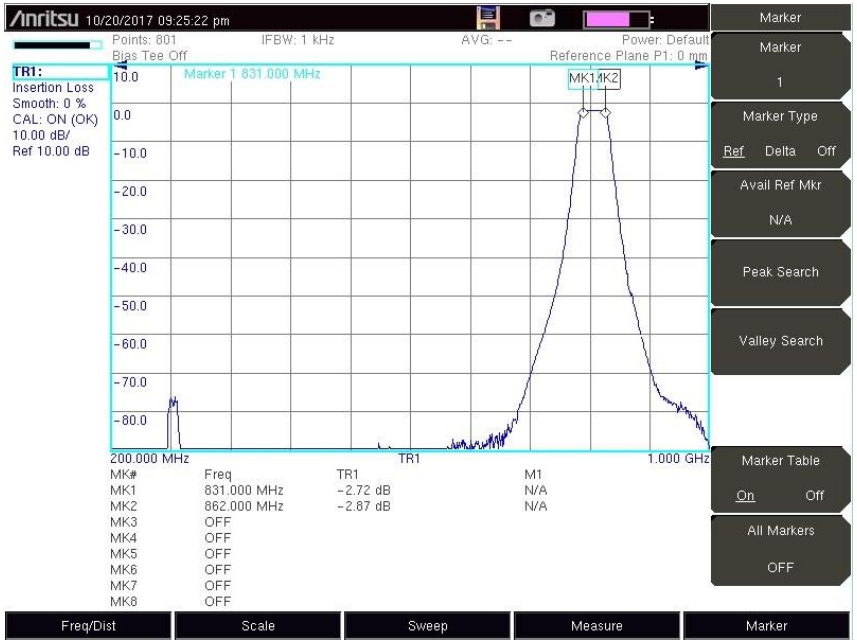
2 – Port VNA Measurements (cable loss / filter tuning)



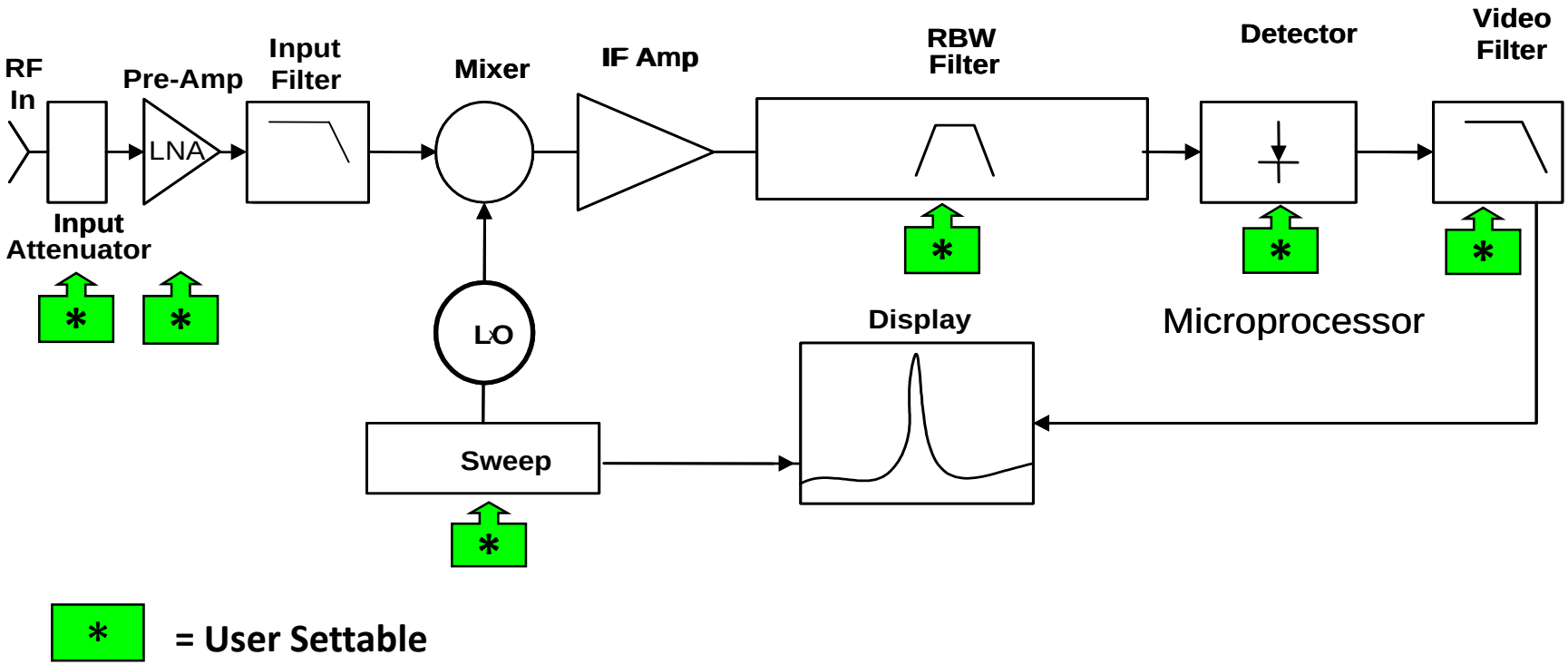
Spectrum Analyzer

What we are going to cover:

- **Basic Operation**
- **SuperHeterodyne Principle**
- **Some characteristics of a Spectrum Analyzer**
  - **Frequency Range**
  - **Frequency Resolution**
  - **Sensitivity and Noise Figure**
  - **Signal Display Range**
  - **Dynamic Range**
  - **Resolution Bandwidth (RBW)**
  - **Video Bandwidth (VBW)**

Superheterodyne Principle

Simplified Block Diagram:

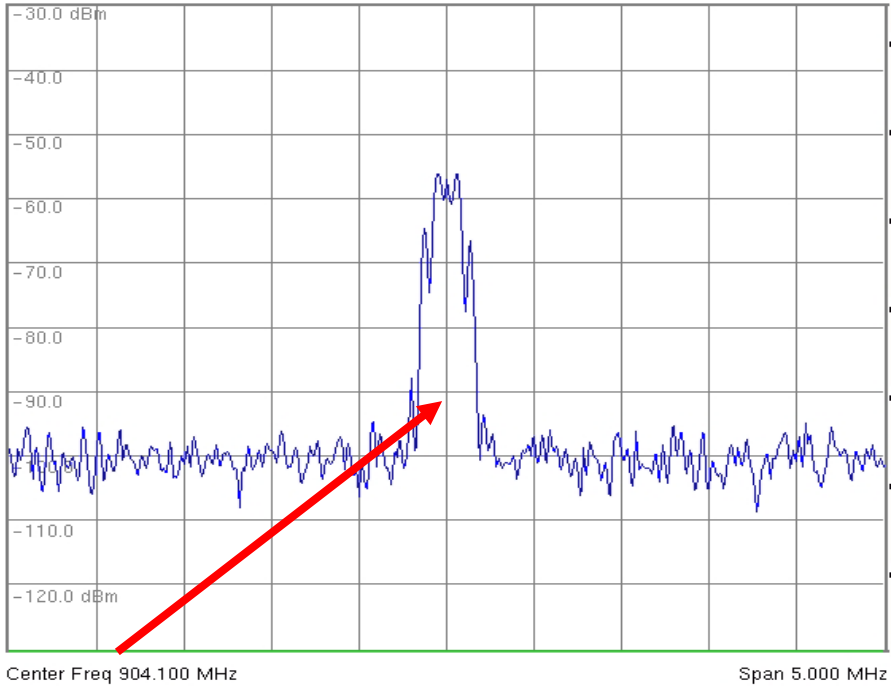


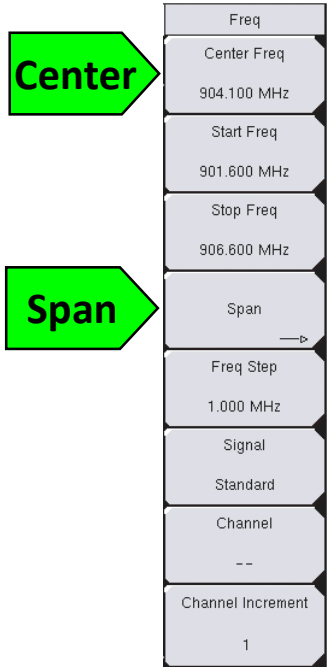
Spectrum Analyzer Fundamentals

Spectrum Analyzer Settings:

- Frequency Range may be set two ways

Set
Center & Span





Set Center Frequency

Center and Span are typically used when examining a certain signal

Set the Span wide enough to see the signal

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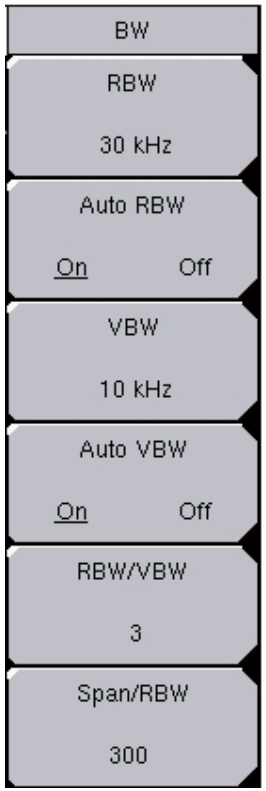
Spectrum Analysis Function
Bandwidth

Bandwidth Menu

- Allows RBW and VBW to be set manually
- Defines the formula to be used when set automatically

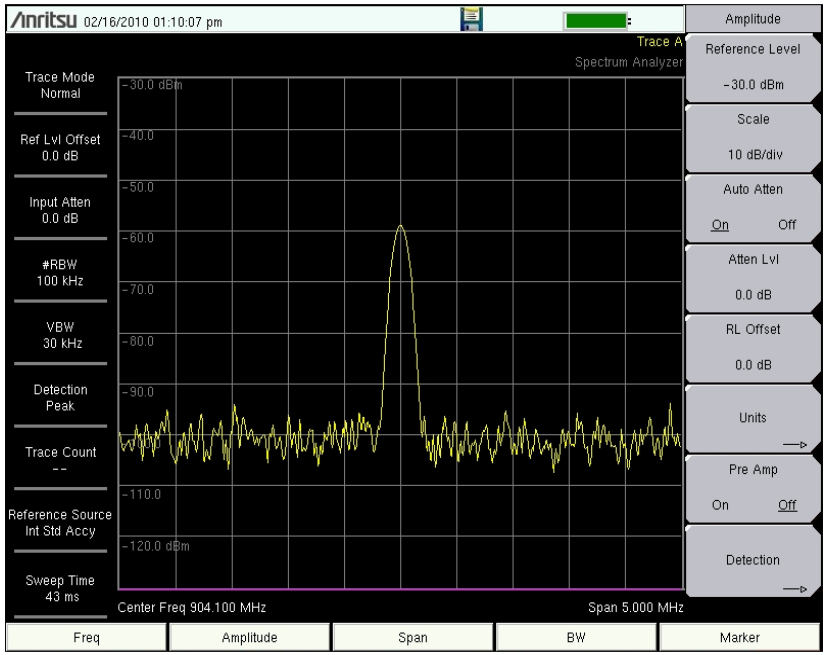


Bandwidth Menu

- **RBW** manually sets the bandwidth of the IF filter
- **Auto RBW** sets RBW according to the formula below when **On**
- **VBW** manually sets the bandwidth of the Video Filter
- **Auto RBW** sets VBW according to the formula below when **On**
- **RBW/VBW** is the formula for the setting of VBW (it follows RBW)
- **Span/RBW** is the formula for Auto RBW when Auto RBW is on

Spectrum Analyzer
Amplitude

- **Selecting Amplitude Range**
  - **Reference Level**
    - **Minimum -130 dBm**
    - **Maximum +30.0 dBm**
  - **Scale**
    - **Minimum 1 dB/Div**
    - **Maximum 15 dB/Div**
  - **Attenuation/Preamp**
    - **Auto**
    - **Manual**
    - **Preamp On/Off**



Amplitude Key

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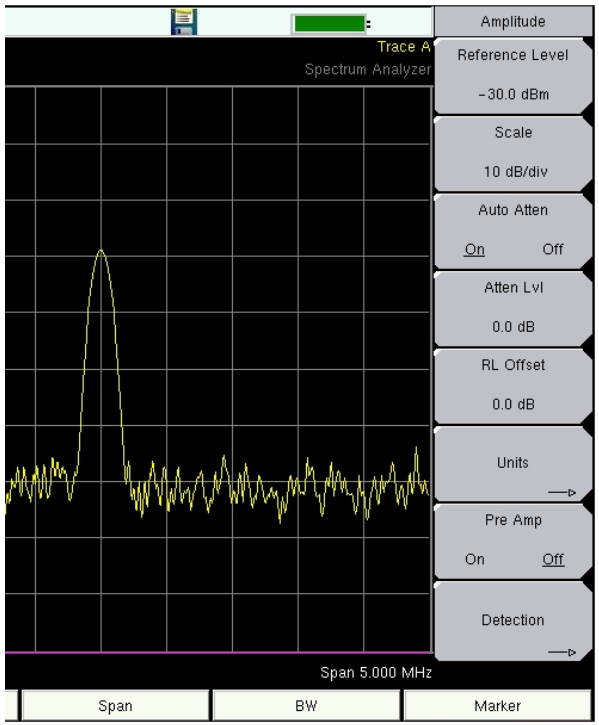
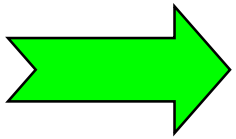
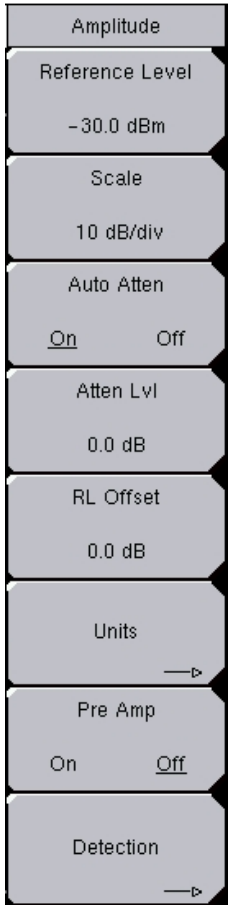
Spectrum Analyzer

Amplitude







Amplitude Menu

- **Reference Level** is the setting of the top line of the display
- **Scale** changes the units per division of amplitude
- **Auto Atten** changes attenuation as Reference Level changes
- **Atten Lvl** is the setting of the input attenuator (0 to 65 dB)
- **RL Offset** compensates for external attenuators
- **Units** changes from dBm to dBV to Watts to Volts
- **Pre-Amp On** improves noise level and sensitivity
- **Detection** sets type of detector

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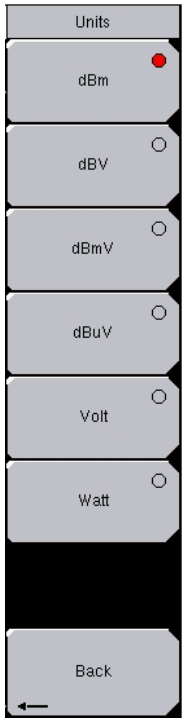
Spectrum Analyzer
Amplitude

- **Amplitude Units**
  - **Log**
    - **dBm**
    - **dBv**
    - **dBmv**
    - **dBuv**
  - **Linear**
    - **Volts**
    - **Watts**



Note:

- Scale (dB per division) only functions in log units

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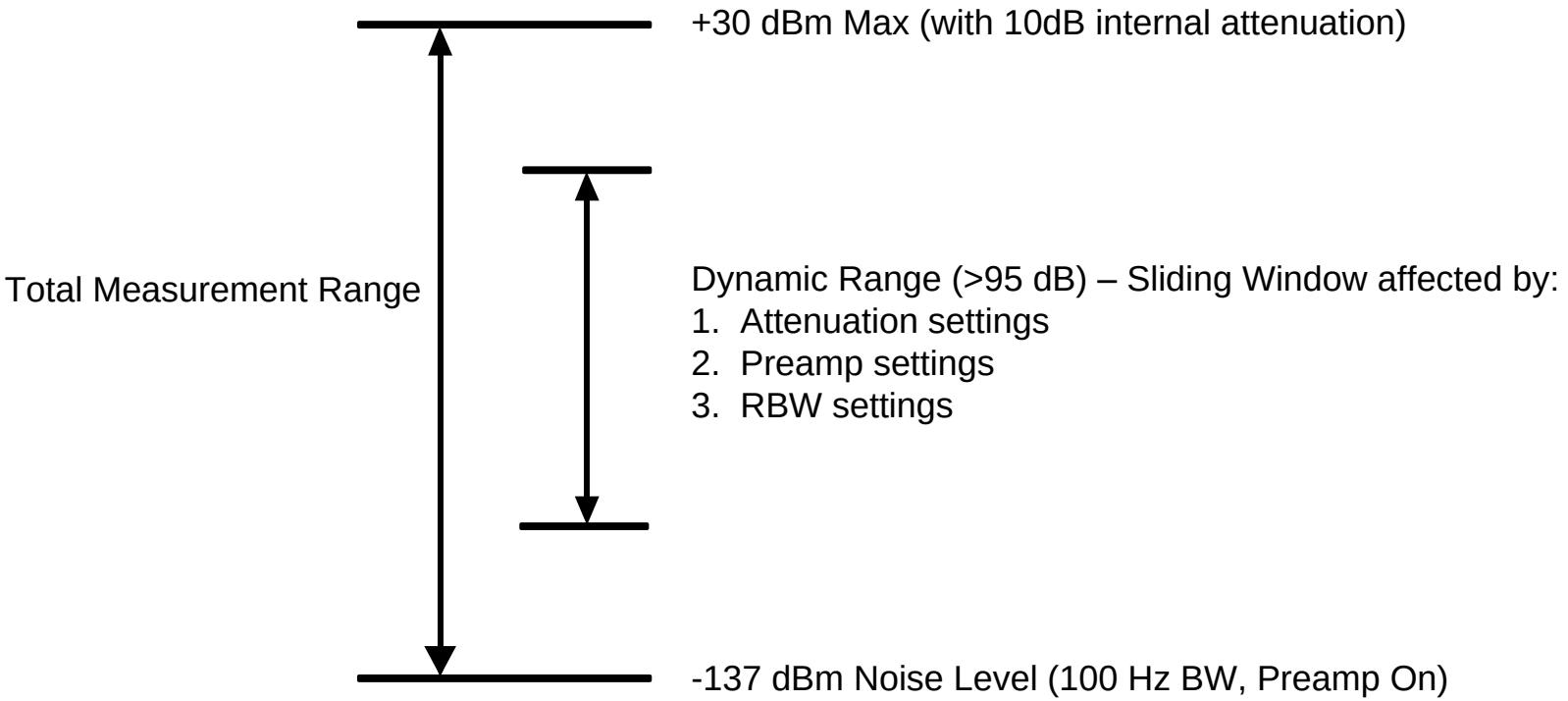
Spectrum Analysis

Display Range

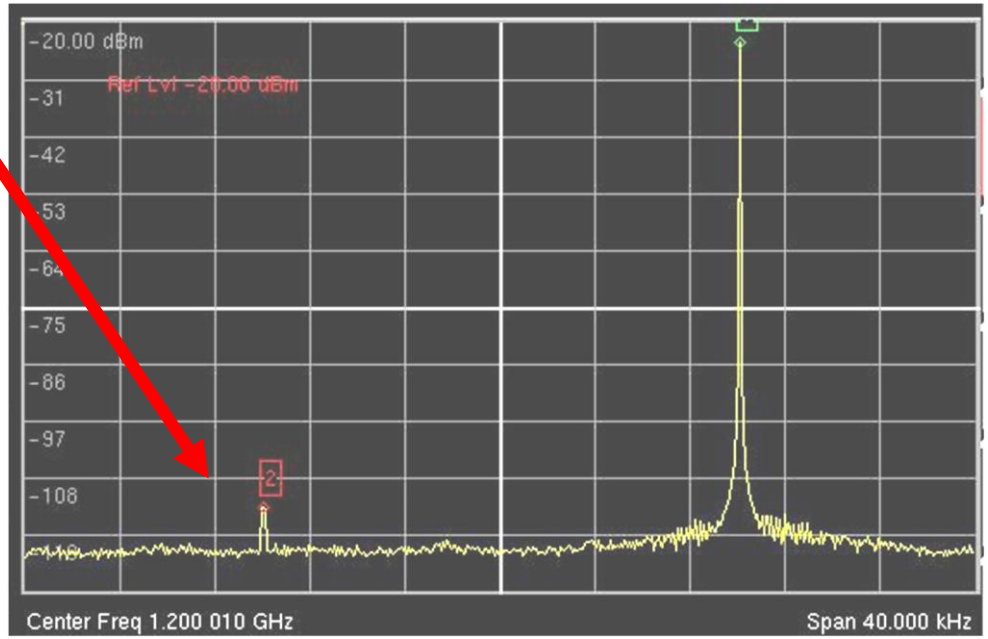
Typical Signal Display Range



Spectrum Analysis

Spurious

Is this a real signal
or is it a spurious caused by
mixer overload?



Spurious Test:

- Note the level of the suspected spurious signal
- Increase Spectrum Analyzer Input Attenuation by 5 dB
- Check the level of the suspected spurious signal again
- It should change 5 dB. If it changes 15 dB or more, it's a spurious signal

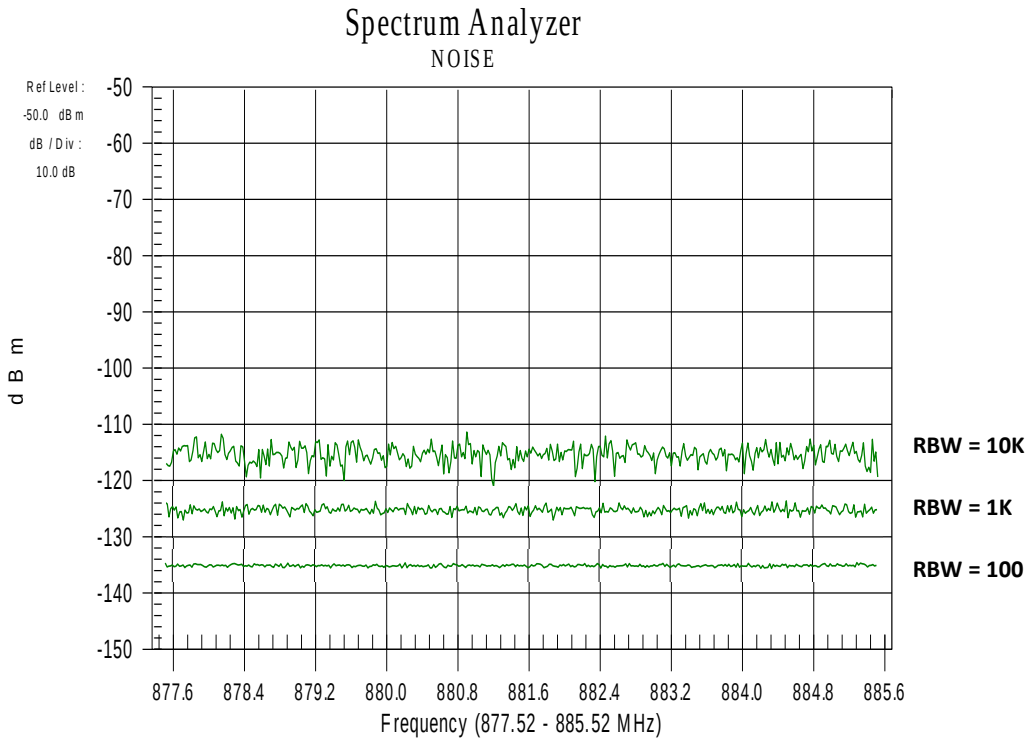
Spectrum Analyzer Characteristics

- Wide frequency range.
- Amplitude and frequency calibration via internal calibration source and error correction routines.
- Flat frequency response where amplitude is independent of frequency.
- Good frequency stability using synthesized local oscillators and reference source.
- Low internal distortion.
- Good frequency resolution.
- High amplitude sensitivity.
- Linear and logarithmic display modes for amplitude (voltage and dB scaling).
- Absolute and relative measurement capabilities.

Spectrum Analyzer
Basic Theory of Operation

Sensitivity and Noise Figure

Effects of RBW on Noise Floor



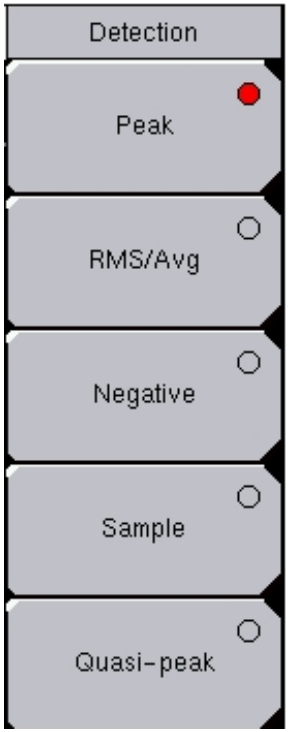
Maximizing Sensitivity:

- A signal must be stronger than noise to be measurable
- Noise decreases as RBW becomes narrower
- Noise decreases as instrument noise figure improves
- To maximize sensitivity, turn on the pre-amplifier, turn off all attenuation and reduce RBW setting as much as feasible

Spectrum Analyzer
Amplitude

Amplitude Detection

- The Spectrum Analyzer takes several amplitude measurements per display pixel
- The Detection menu selects the method to display the measurement

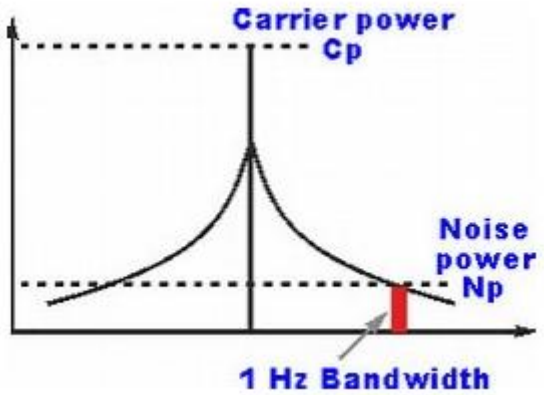


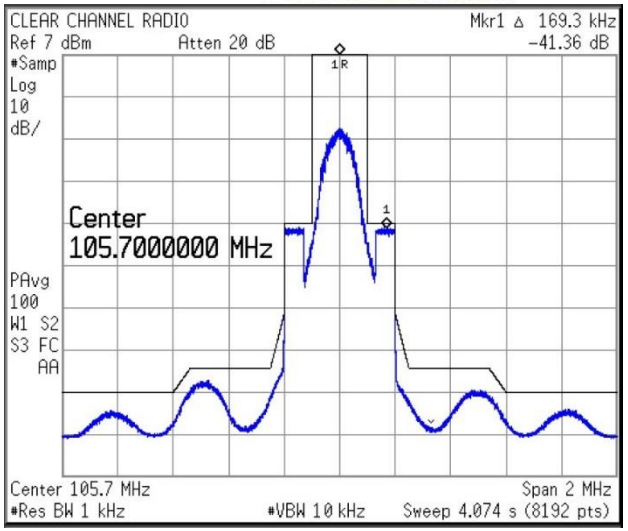
Detection Menu

- **Peak** displays the strongest of all the measurements (Default)
- **RMS** displays a root-mean-square calculation of all the measurements
- **Negative** displays the weakest of all the measurements
- **Sample** displays the middle measurement, whatever it is
- **Quasi-peak** measures the amplitude as specified by CISPR

Phase Noise

- Need low Phase Noise analyzer to make broadcast emission mask measurements
- -110 dBc/Hz @ 1 kHz offset at 1 GHz





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Spectrum Analyzer

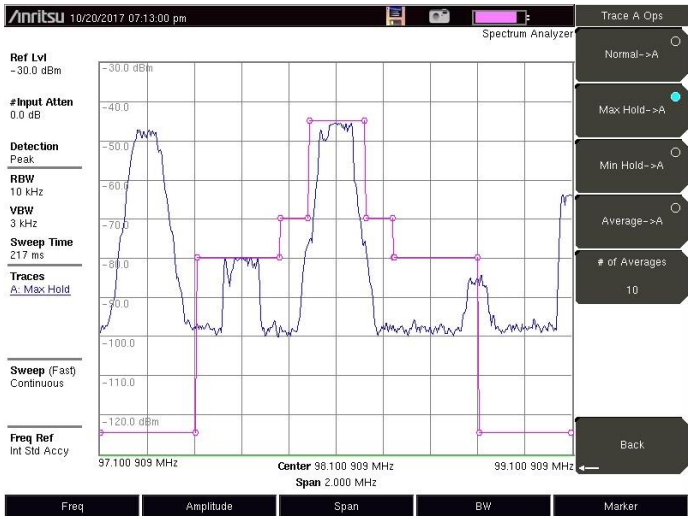
Field Measurements:

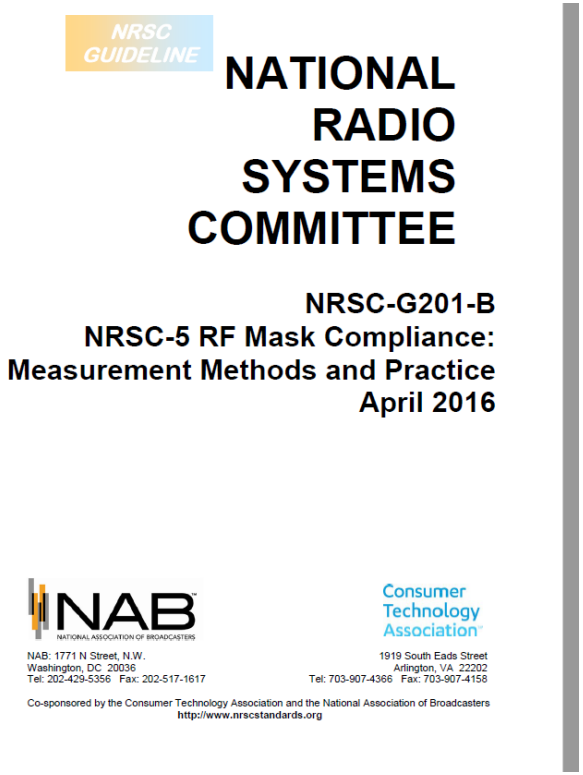
- Spectrum analyzers default to power into 50 ohm input.
- Field Strength
  - Antenna and analyzer combined
  - Need “Antenna Factor”
  - The magnitude of an electric, magnetic, or electromagnetic field at a given location
  - The strength is measured in Amplitude Units/”length” which is in meters
  - The field strength can be measured in dBm/m^2, dBV/m, dBmV/m or dBµV/m
  - A linear unit such as mV/m or nW/m^2 can also be used

Spectrum Analyzer

- **Steps to set up a Field Strength Measurement**
  - Connect an antenna to the RF in port
  - Press **Menu,** then **Spectrum Analyzer** (if not already set)
  - Press **Freq** then enter frequency and span
  - Press **Shift, Measure (**4**)**, then **Field Strength** Soft Key
  - Press **Antenna** and select a standard or custom Antenna
  - Press **On** soft key to begin the measurement
  - Press **Amplitude,** then **Units** and select the measurement units
  - Press **Back** and change the **Reference Level**, as needed
  - Press **Shift, Measure** (4), **Field Strength,** then **Off** soft key to stop the measurement

Emission Mask Measurements





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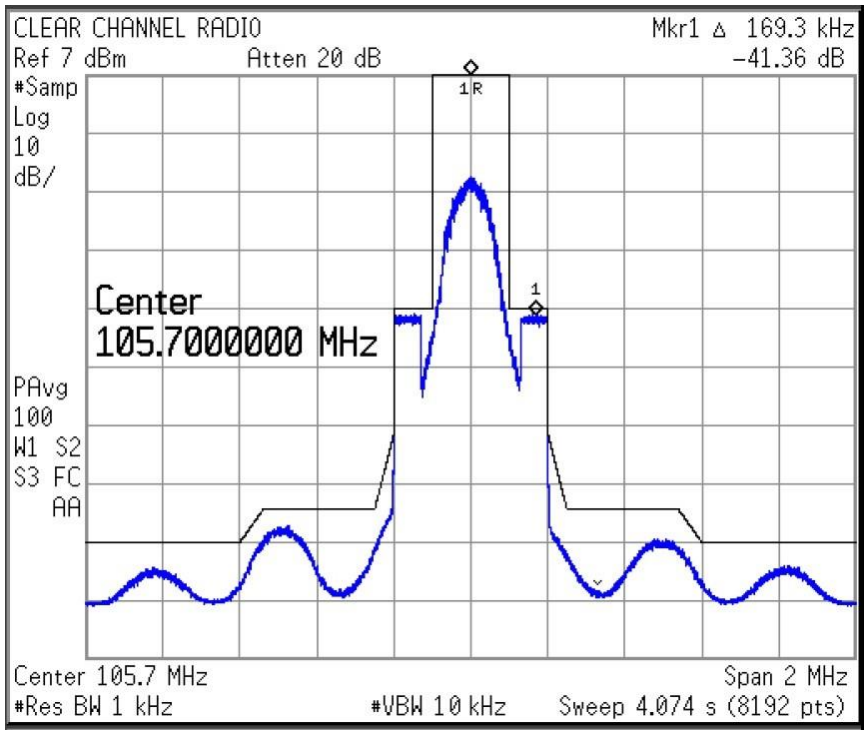
Emission Masks

- Consequently, over-the-air measurements are not recommended for assessing hybrid IBOC FM signals for RF mask compliance.
- Establish the “analog reference level”
- Resolution Bandwidth 1.0 kHz Video Bandwidth to 10 kHz or higher. Then restart the averaging to clear the memory of old display data. After 100 sweeps,



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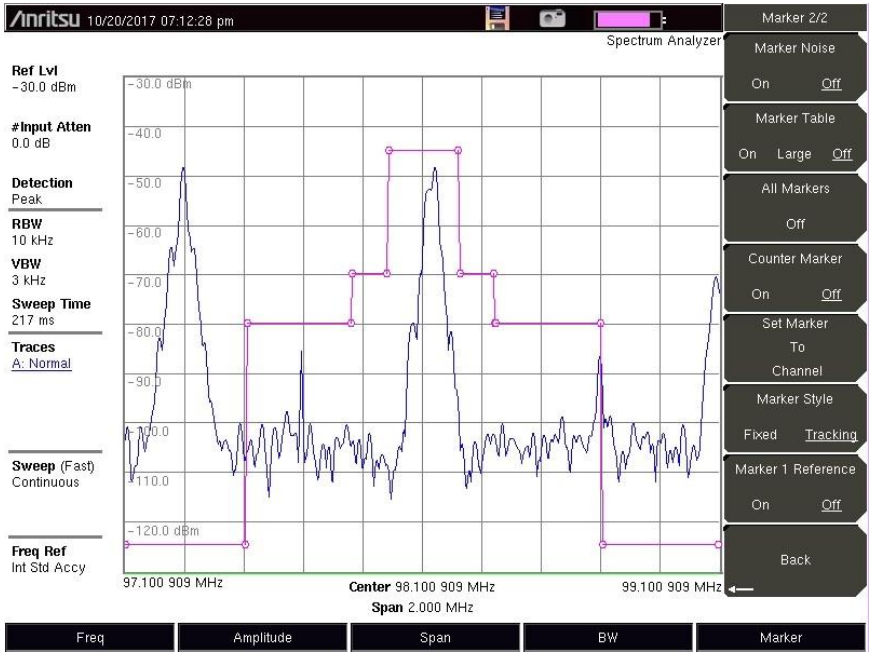
Anritsu Broadcast Emission Masks

- Free
- Easy to build/ adjust



- AM_ANALOG_21B11
- AM_ANALOG_MASK_1-KW_21B(1)11
- AM_ANALOG_MASK_158_WATTS11
- AM_iBiquity_IBOC_MASK(1)11
- AM_NRSC_73.44_5KW11
- DTV_MASK_21B11
- FM_ANALOG_MASK_21B11
- AM_ANALOG_21B
- AM_ANALOG_MASK_1-KW
- AM_ANALOG_MASK_1-KW_21B(1)
- AM_ANALOG_MASK_158_WATTS
- AM_iBiquity_IBOC_MASK
- AM_NRSC_73.44_5KW
- DTV_MASK_21B
- FM_ANALOG_21B(1)
- FM_ANALOG_21B(2)
- FM_ANALOG_MASK_21B
- FM_ANALOG_MASK1

RadioSiteTest

Interference Measurements,

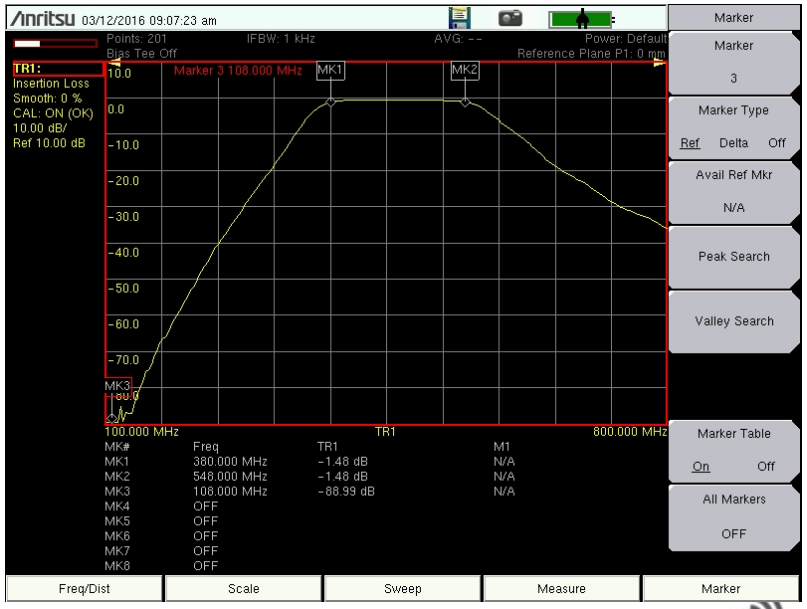
- Setting up the Spectrum Analyzer
  - CW interference
    - Reducing RBW improves viewing
  - Noise interference
    - Noise floor setting critical
    - Antenna gain critical

Interference Measurements,

- Setting up the Spectrum Analyzer
  - Noise floor vs RBW
  - Noise Floor vs attenuation
  - Verify noise floor, remove antenna
  - 551 horizontal points vs. RBW / SPAN

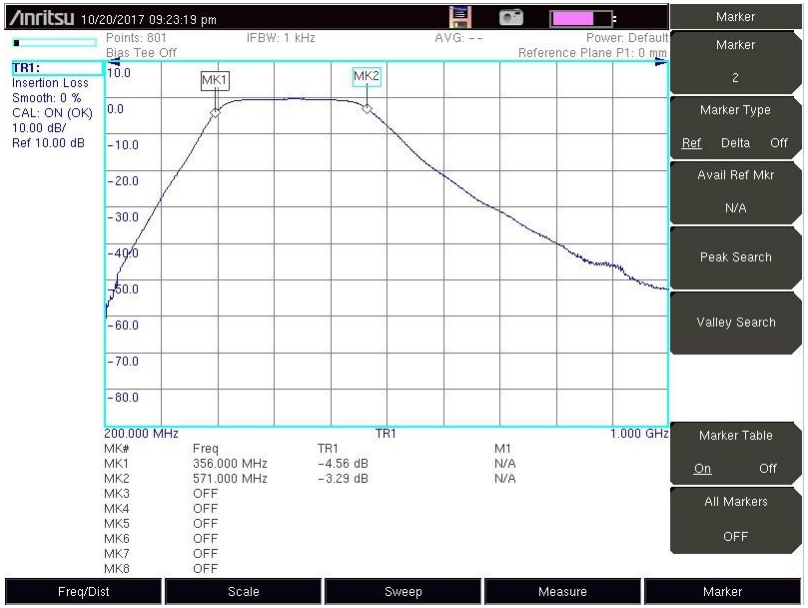
Interference Measurements

- Typically Interference is < -90 dBm
  - Front end Overload
  - Must Filter off Broadcast



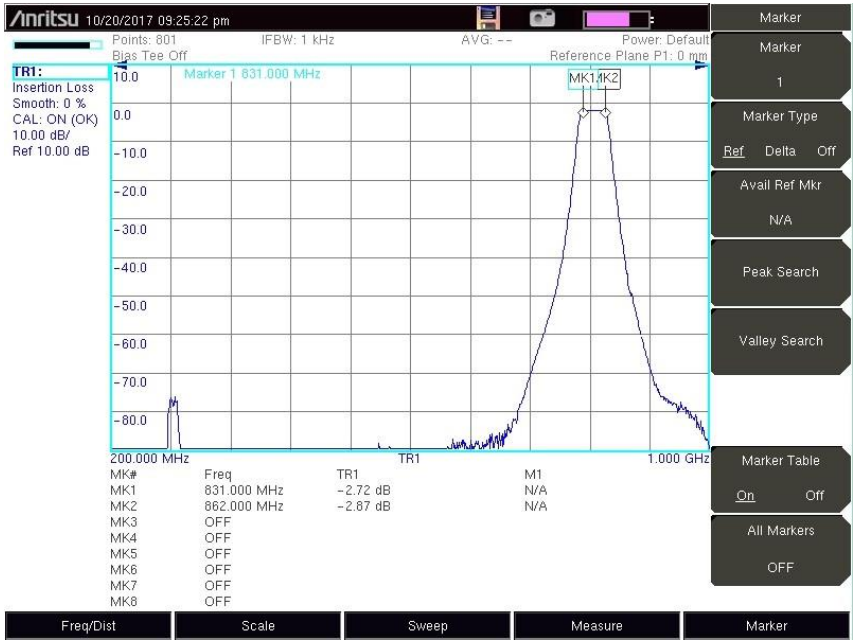
RadioSiteTest

Filters for finding sensitive interference with broadcast signals on test antenna



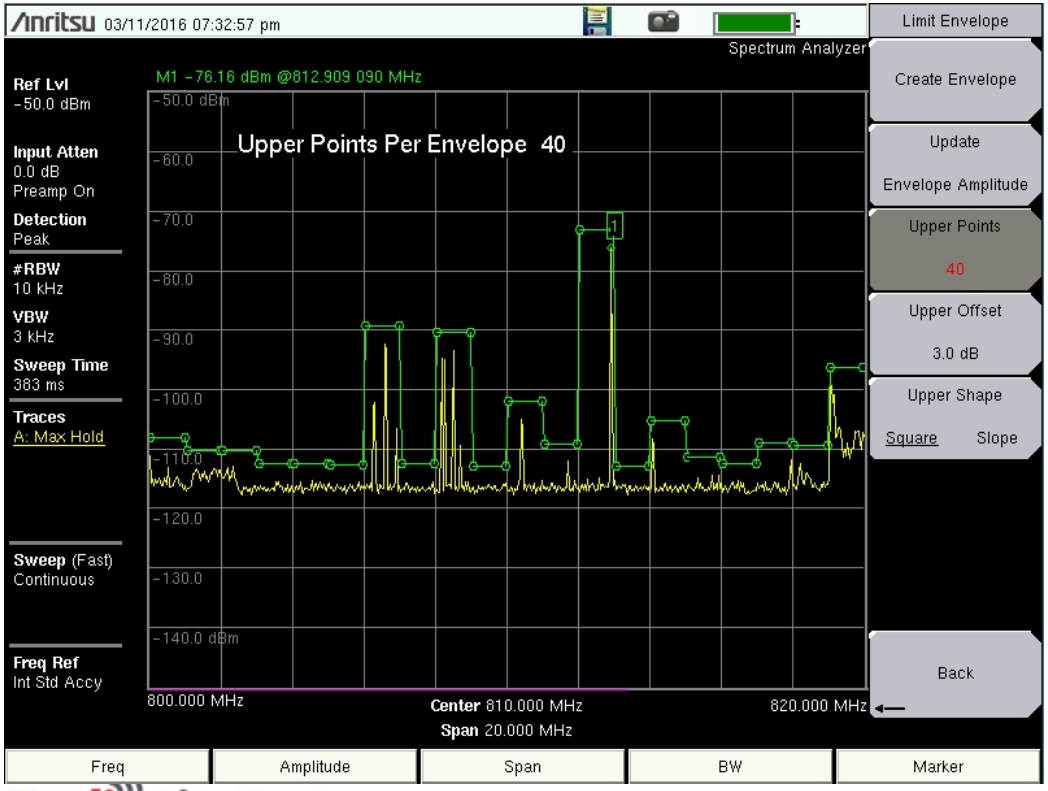
RadioSiteTest

Filters for finding sensitive interference with broadcast signals on test antenna



Interference Measurements, Spectrum Analyzer Mode

- Max-Hold Good Signals
- Envelope Limit Line



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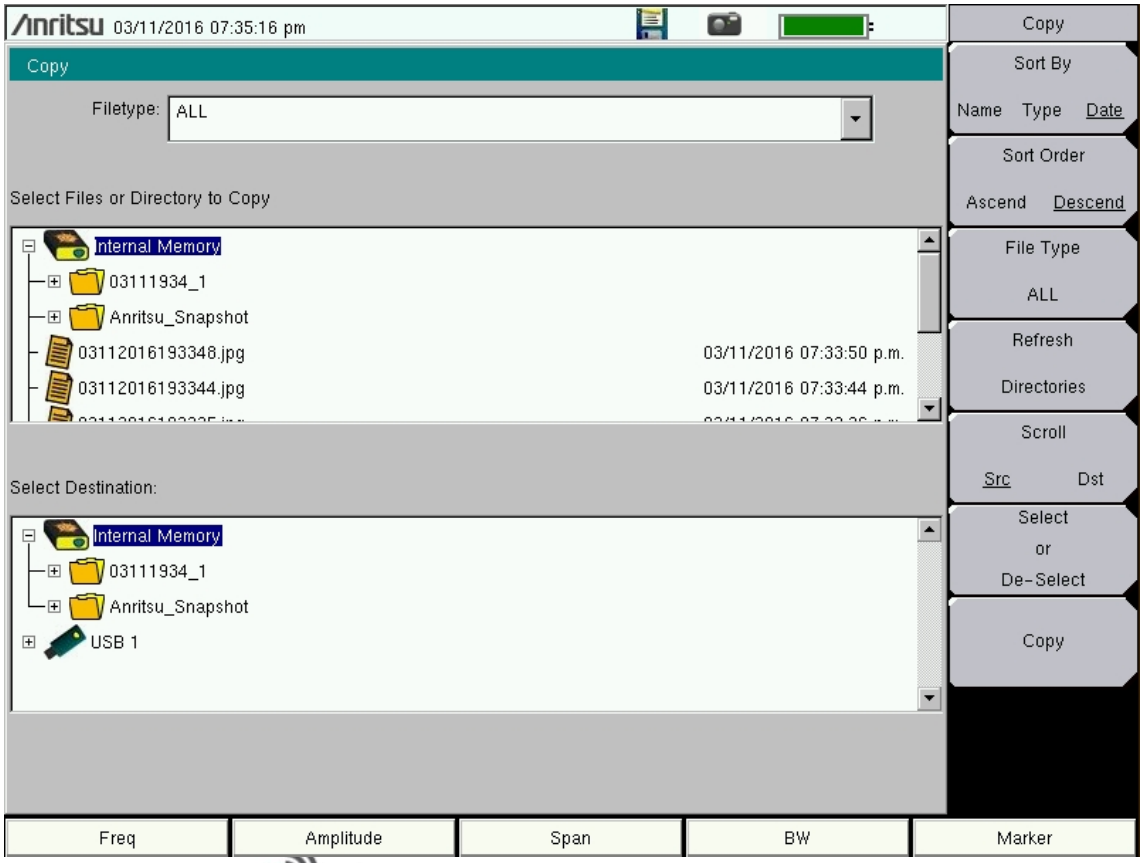
Interference Measurements, Spectrum Analyzer Mode

- Folder of Captured Spectrums



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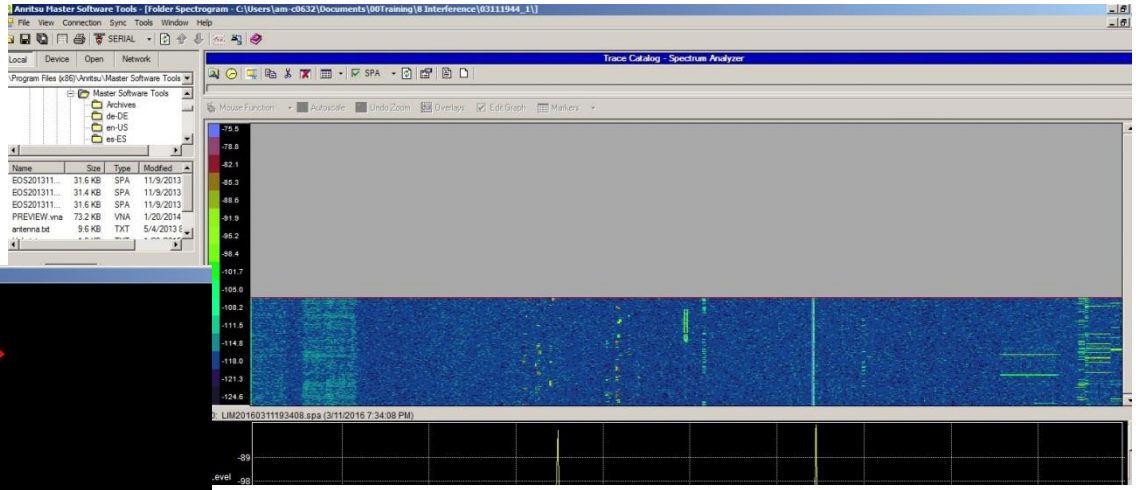
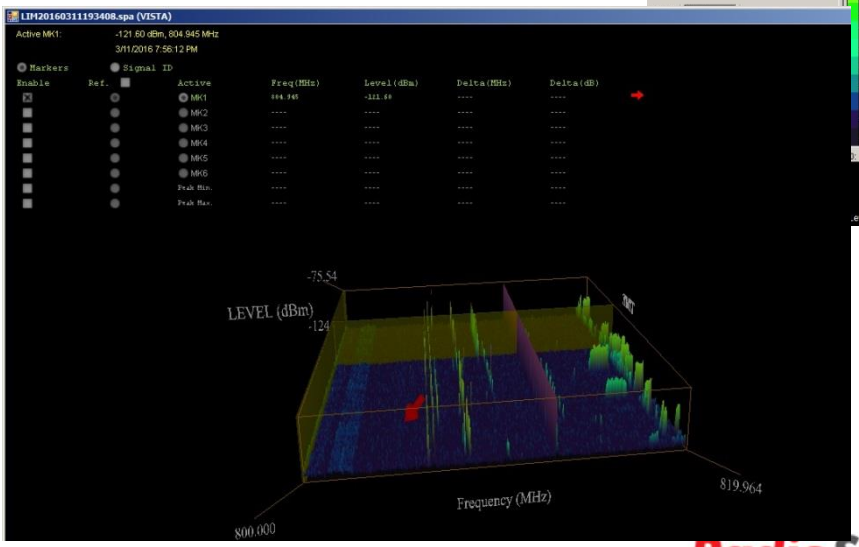
Interference Measurements, Spectrum Analyzer Mode

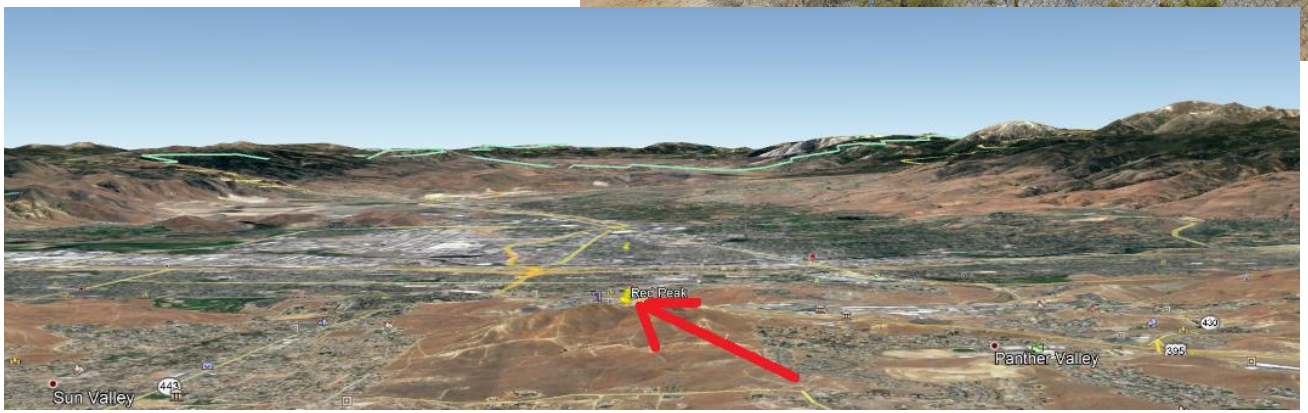
- Spectrogram from “Exceed Limit
- 3D View
- AVI Video
- Marker Readout





Intermodulation Interference

- "Good Sites"
  - Overlooking city
  - Easy to get to
  - Fences



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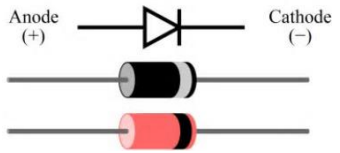
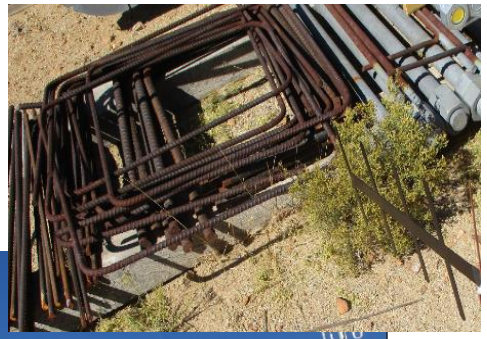
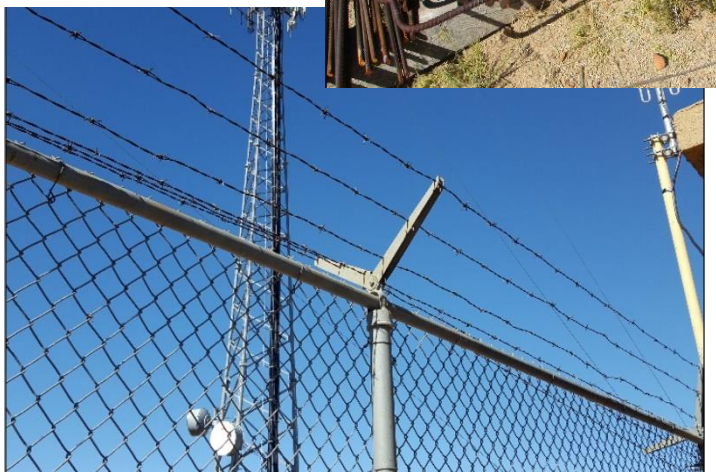
Environmental “Diodes”

- 3rd order
  - 2f2-f1, 2f1 –f2
- 5TH order
  - 3f2-2f1, 3f1-2f2
- Harmonics
  - 88.9 x 8 = 711.2 MHz







http://www.commscope.com/calculators/qimdcalculator.aspx

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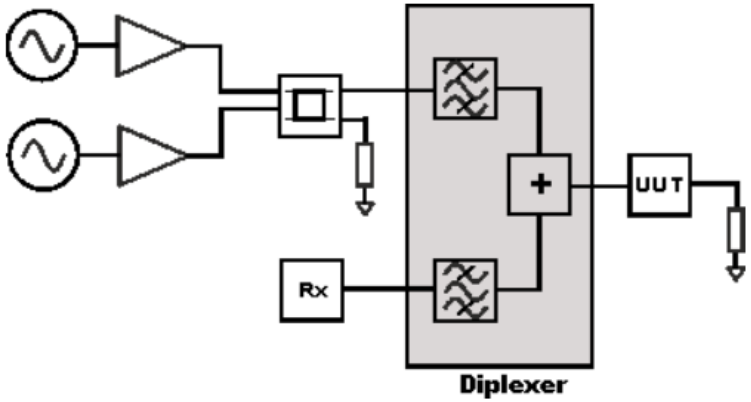
Intermodulation Interference

- PIM Tester
- IP3 -150 dBc
  - Antennas
  - Cables
  - Connectors
- Environmental PIM



Basic block diagram of a PIM tester

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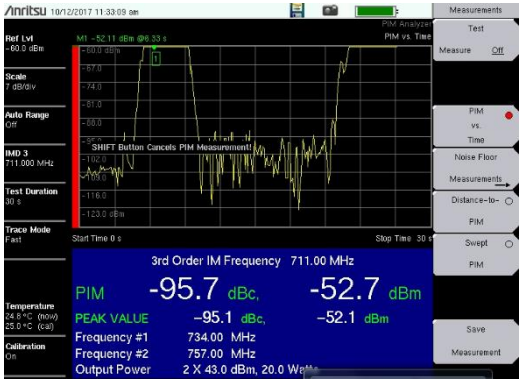
Environmental PIM

- PIM Tester
  - Pulses 5%
  - LTE downlink
- UHF Antenna 3 ft from Barbed wire fence



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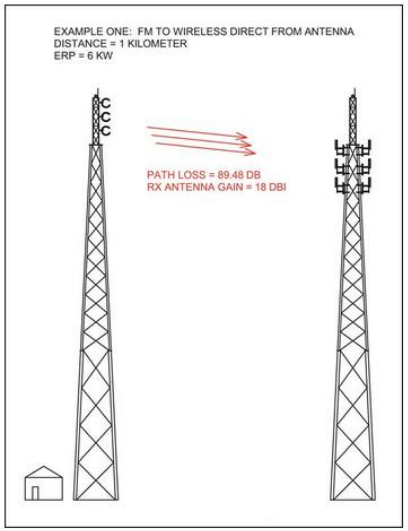
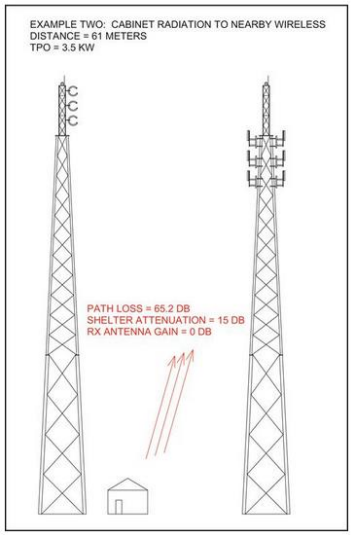
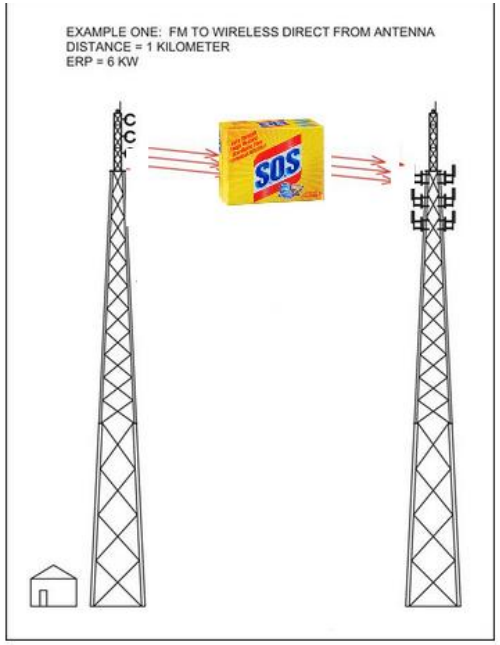
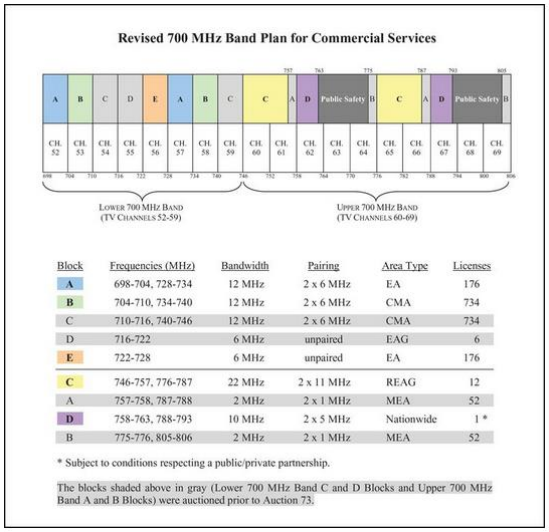
FM Broadcast to LTE

- Harmonics
  - 88.9 x 8 = 711.2 MHz









Block	Frequencies (MHz)	Bandwidth	Pairing	Area Type	Licenses
A	698-704, 728-734	12 MHz	2 x 6 MHz	EA	176
B	704-710, 734-740	12 MHz	2 x 6 MHz	CMA	734
C	710-716, 740-746	12 MHz	2 x 6 MHz	CMA	734
D	716-722	6 MHz	unpaired	EAG	6
E	722-728	6 MHz	unpaired	EA	176
C	746-757, 776-787	22 MHz	2 x 11 MHz	REAG	12
A	757-758, 787-788	2 MHz	2 x 1 MHz	MEA	52
D	758-763, 788-793	10 MHz	2 x 5 MHz	Nationwide	1 *
B	775-776, 805-806	2 MHz	2 x 1 MHz	MEA	52

* Subject to conditions respecting a public/private partnership.

The blocks shaded above in gray (Lower 700 MHz Band C and D Blocks and Upper 700 MHz Band A and B Blocks) were auctioned prior to Auction 73.

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Drone Measurements

- Detailed visual Inspections

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Drone Measurements

- Detailed visual Inspections

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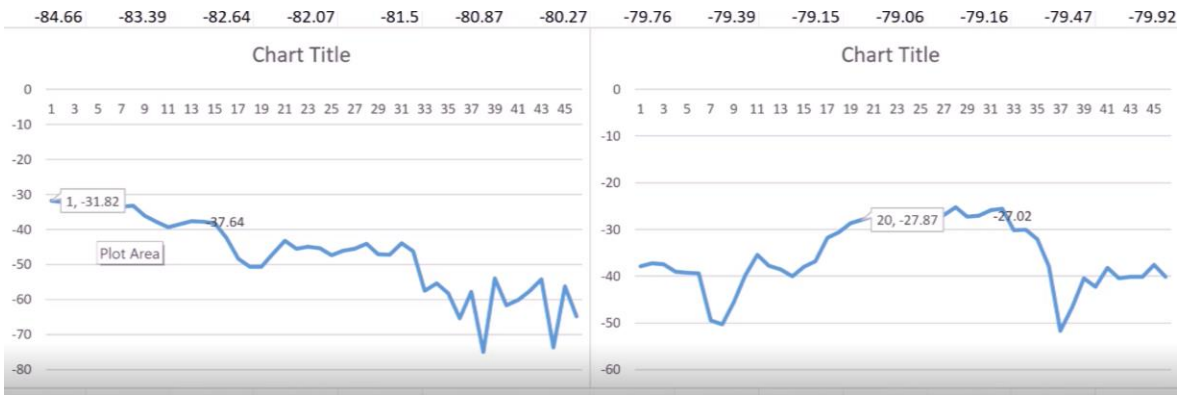
Drone Measurements

- Antenna Downtilt



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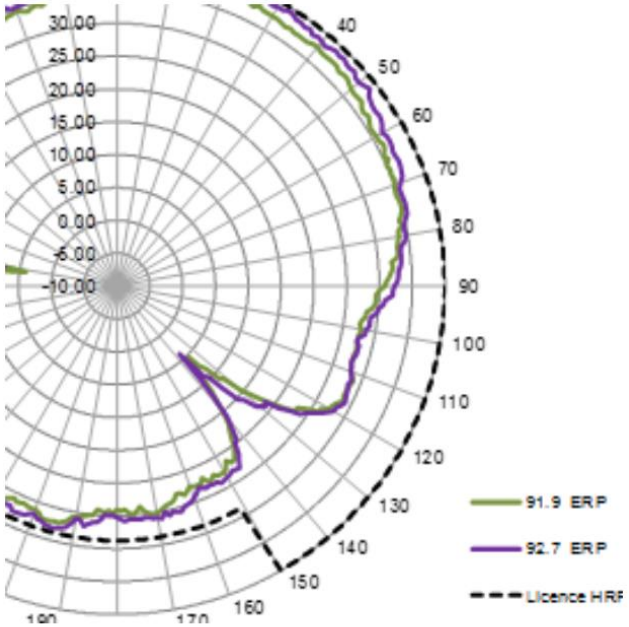
Drone Measurements

- Broadcast Antenna Pattern
  - Sixarms.com



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Summary

- Very fast review of many topics
  - Network Analysis
    - Cable and antenna
  - Spectrum analysis
    - Interference
    - PIM
  - Drone measurements

- Welcome to call me with questions (and site work)
  - Cell (408) 592-3759

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