Introduction to VNAs & the NanoVNA

Alan Wolke – W2AEW

ARRL NNJ Technical Coordinator

http://www.youtube.com/w2aew

Agenda

- WHY do we want to talk about this?
  - *Ridiculously inexpensive ($50-$60) NanoVNA makes VNAs accessible to hobbyists*
- First – what is a Vector Network Analyzer
- Second – what is a VNA good for
- Then – a look at the NanoVNA

What is a VNA?

- **VNA** = Vector Network Analyzer…
  - *An instrument that measures the magnitude and phase of the reflection and transmission properties of the ports of a device vs. frequency.*
- ***WTH?***
- Let's break it down…

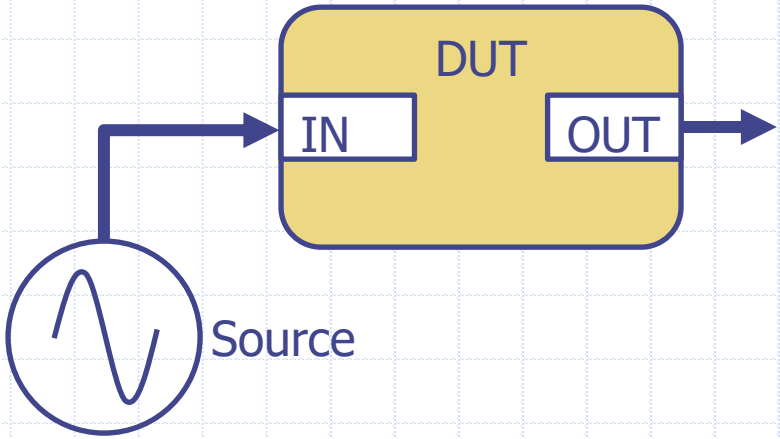
VNA is…

- Instrument that is used to characterize RF devices
- Used to be only used by RF engineers due to cost
- Professional units cost thousands or more!

- *Lots of acronyms and terminology…*

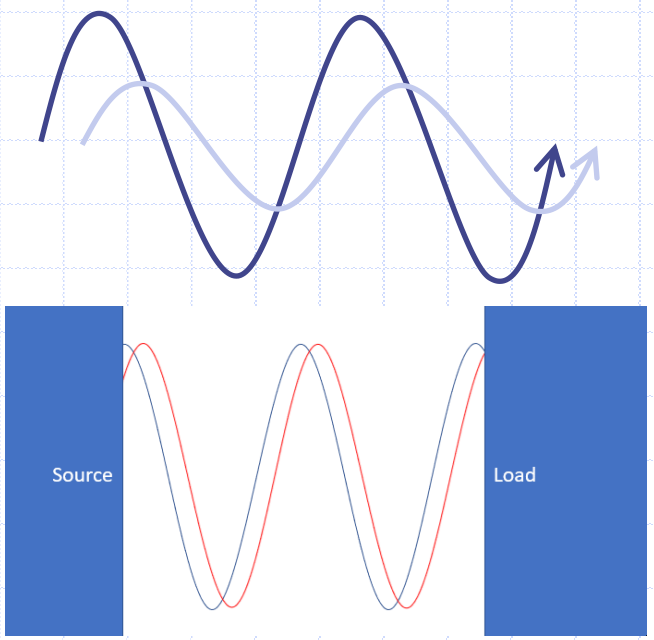
The DUT

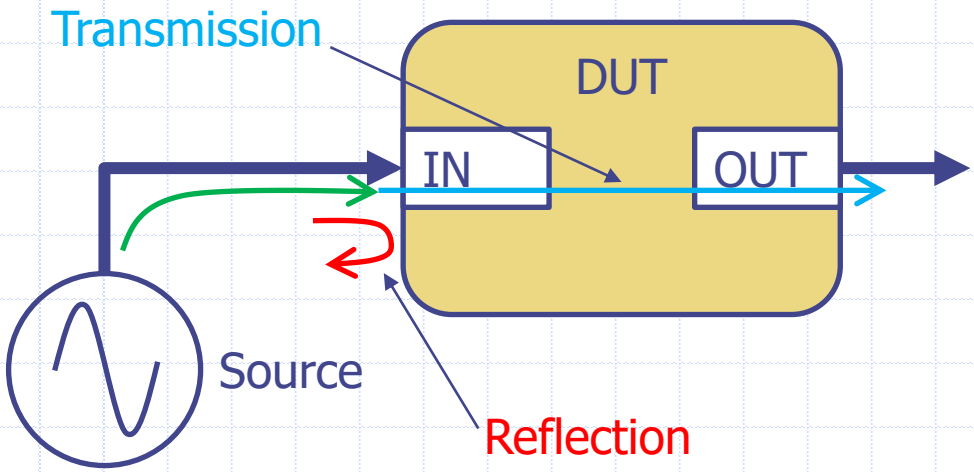
- **DUT** = Device Under Test
  - Affects signal going thru it
  - Input impedance affects the applied signal
- **Max Power Transfer**
  - $R_L = R_S$
  - In more general sense:
    - $R_S + jX_S = R_L - jX_L$ (complex conjugate)
- Important to measure complex Z to design matching networks



Signals as Waves

- In RF, we think of signals as waves – with magnitude & phase



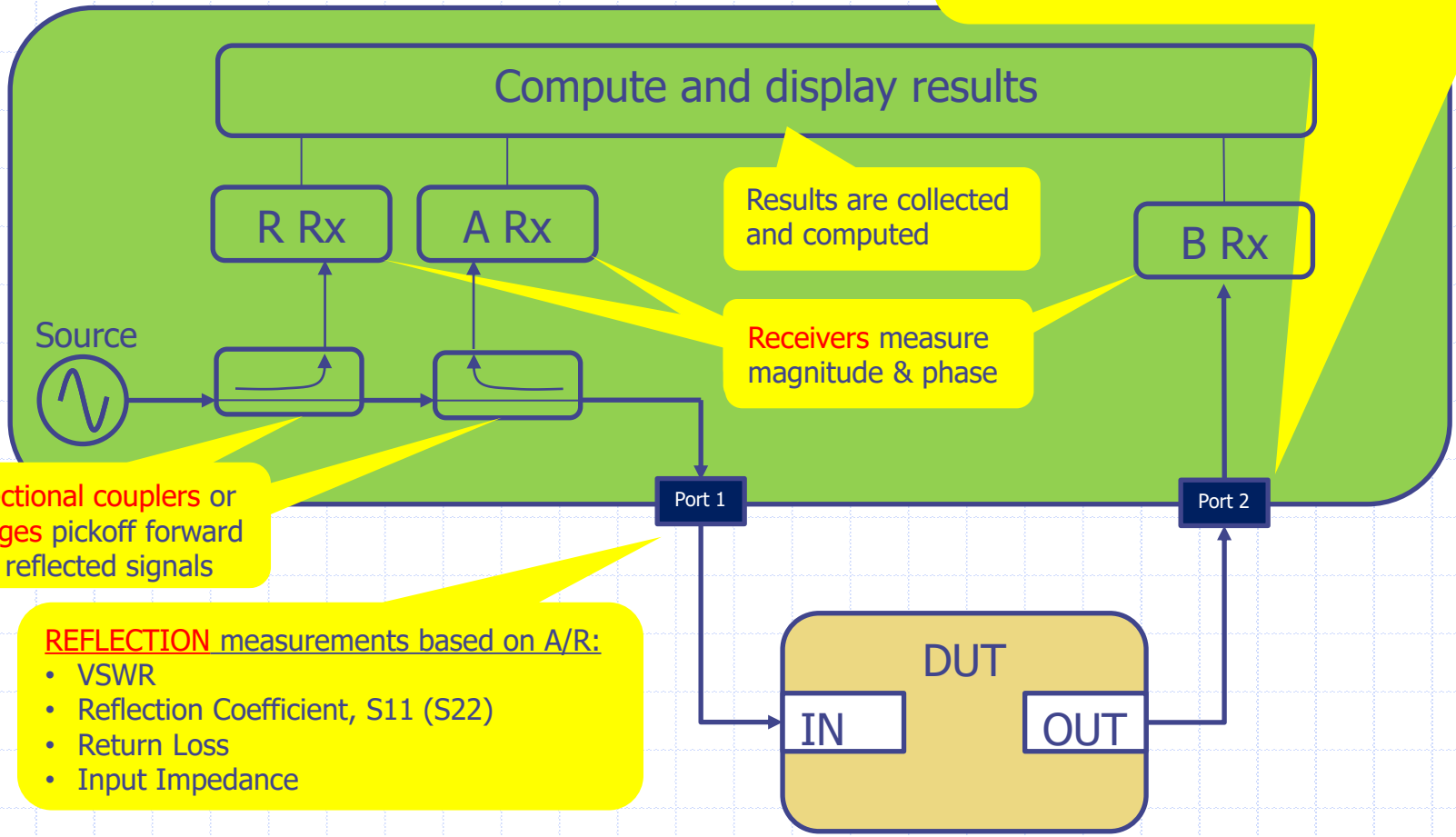


DUT reflection and transmission alter the magnitude & phase of the source signal

Basic VNA

Most "pro" VNAs have couplers/source on both ports

TRANSMISSION measurements based on B/R:
- Gain/Loss
- S21 (S12)
- Transmission Coefficient
- Insertion Phase / Group Delay



REFLECTION measurements based on A/R:
- VSWR
- Reflection Coefficient, S11 (S22)
- Return Loss
- Input Impedance

What is a VNA good for?

Single Port

- **Reflection**
  - SWR of Antenna
  - Complex Impedance
  - Components (R,L,C)
  - Feedline Length
  - Distance to fault

Two Port

- **Transmission**
  - Filter shape/loss
  - Loss in feedline
  - Delay in DUT
  - Amplifier gain & frequency response

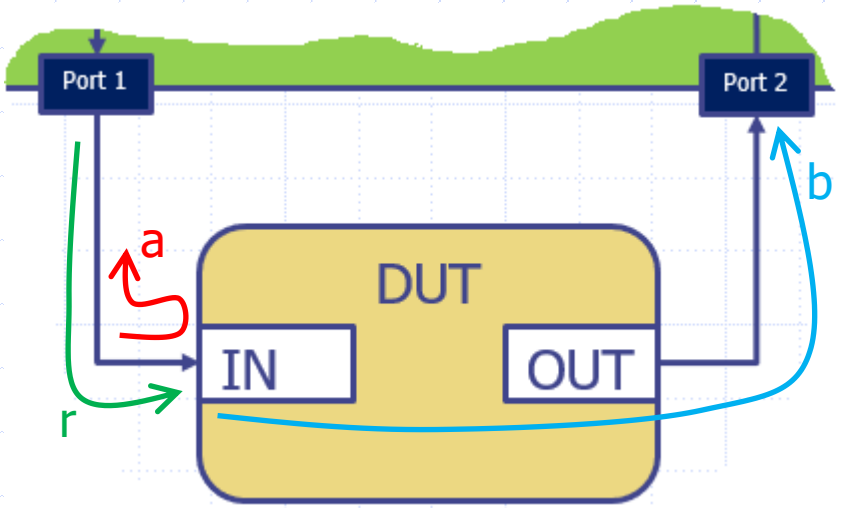
Measure antennas, duplexers, diplexers, filters, inductors, capacitors, amplifiers, splitters, baluns, chokes, phasing networks, attenuators, etc.

What are S-Parameters?

- "Scattering" parameters
- Simply ratio of a measured response to stimulus

Sxy

Response at port x resulting from stimulus applied to port y



Reflection at a DUT port → **S11**: a/r

Response thru a DUT → **S21**: b/r

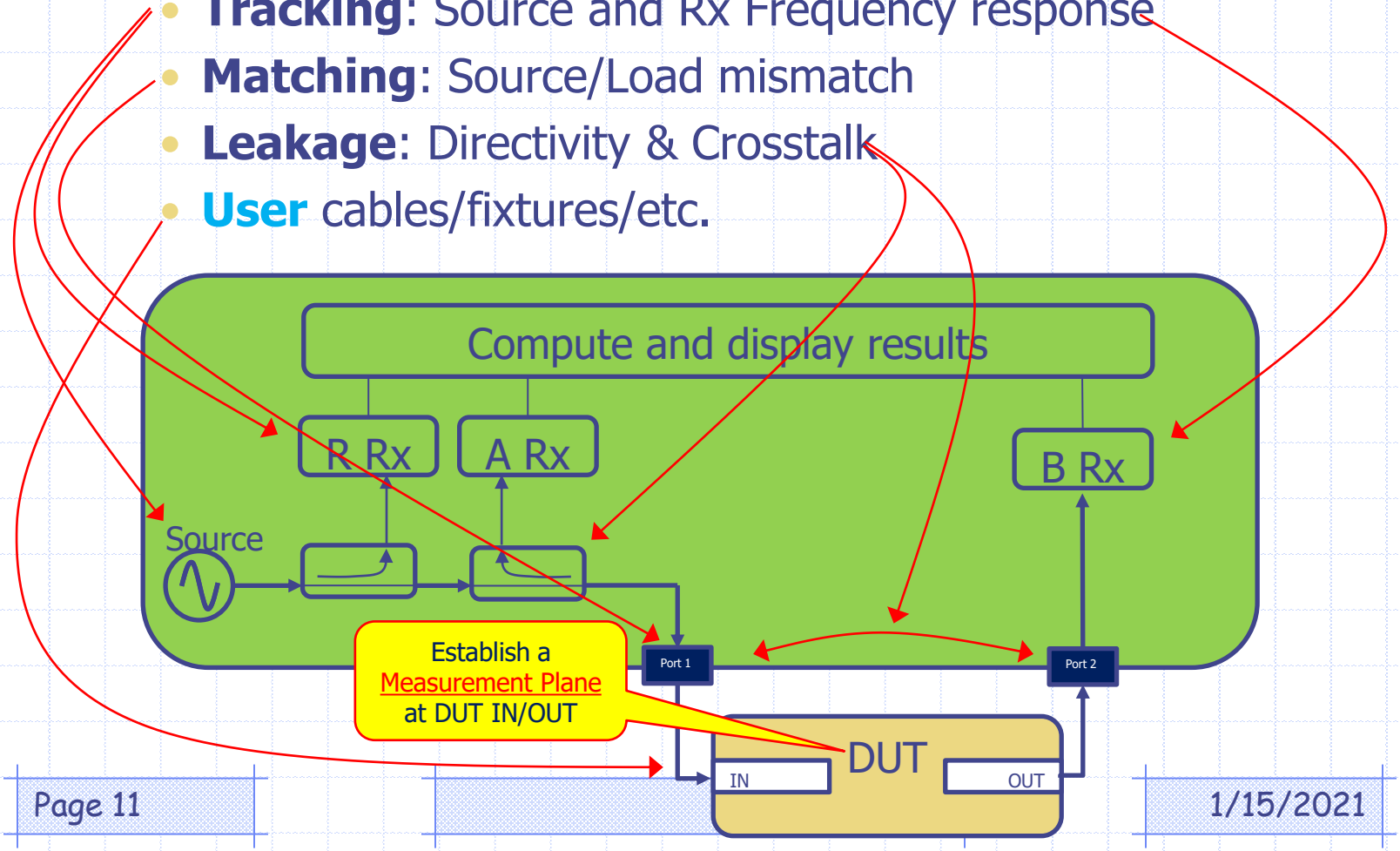
(r=the applied signal reference)

VNA User Calibration

- Why we need a User Calibration:
  - Large dynamic range
  - Phase measurement
  - Measurement plane
  - "Factory Cal" can't account for these things
- Whenever there's a configuration change
  - New cables, adapters or fixtures
  - New frequency range

VNA User Calibration

- Corrects for **Systematic** error sources:
  - **Tracking**: Source and Rx Frequency response
  - **Matching**: Source/Load mismatch
  - **Leakage**: Directivity & Crosstalk
  - **User** cables/fixtures/etc.

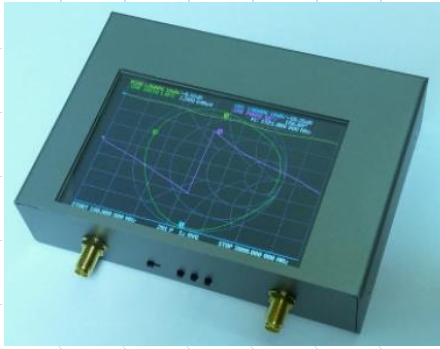


Common VNA Display formats

- **Most measurements made vs. Frequency**
  - Reflection Coefficient or S11 --- LOG-Magnitude
  - VSWR --- linear ratio x.x : 1
  - Complex Impedance --- Smith Chart
  - Transmission Coefficient or S21 --- LOG-Magnitude
  - Delay, Insertion Phase, Group Delay --- linear
- The TRANSFORM measurements are vs Time
  - Often helpful to use "Linear" to get sharper peak

The NanoVNA

- Several developers & variants:
  - Original (H) w 2.8” display
  - -H4 with 4” display
  - -F also with 4” display
  - “V2” SAA-2 – to 3/4GHz



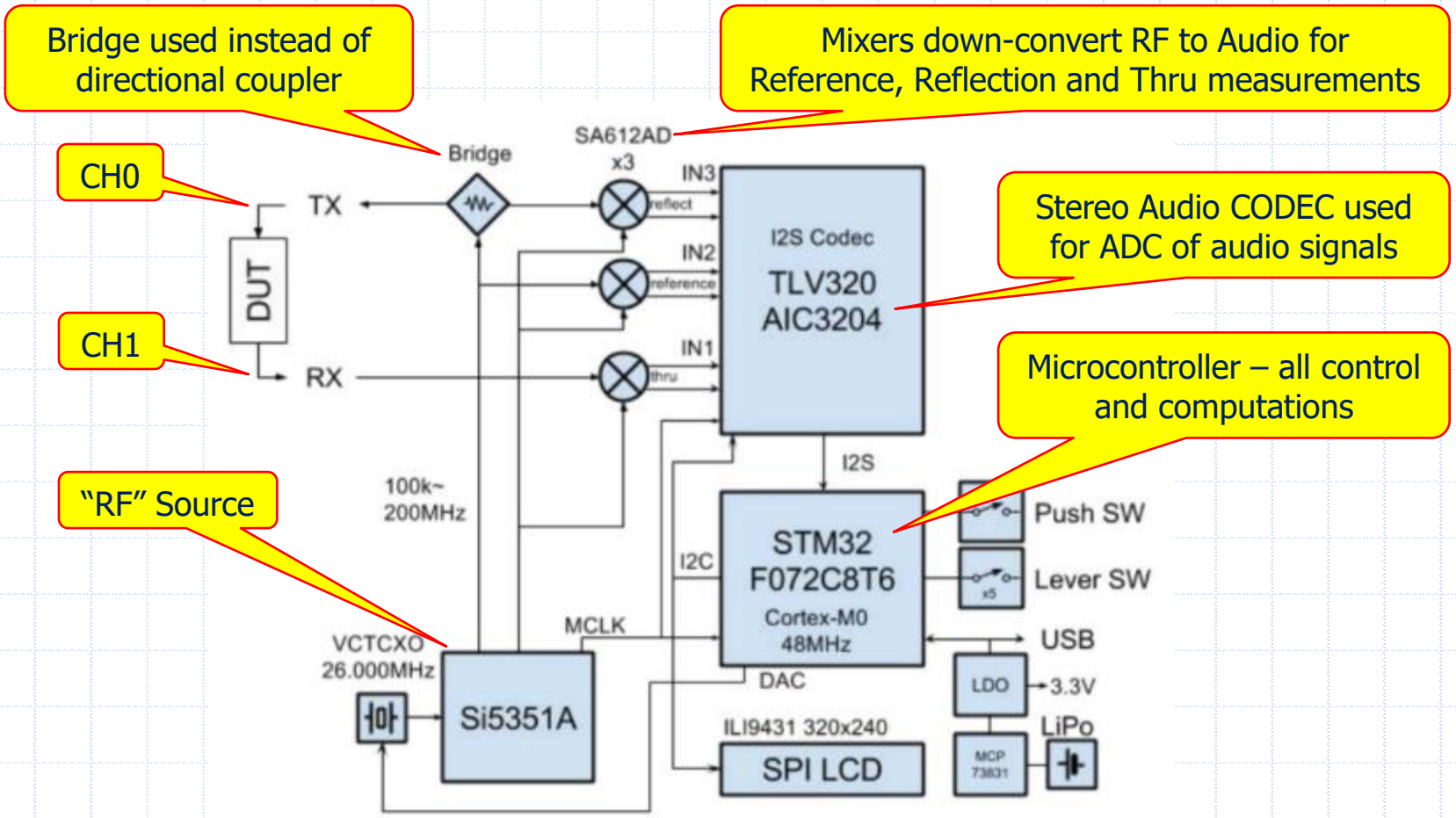
- As of Winter-2020/2021:
  - I like the H4 (stable, good support, easy to get, $60)
  - SAA-2 (NanoVNA-V2) better performance than H4. Initially 2.8” display, but now available with 4” display and N-connectors – SAA-2N
  - SAA-2 guys developing improved units – NanoVNA-V2 plus 4, etc.

NanoVNA – more details

- All are 2-Port, 1-Path
- H4 goes to 1.5GHz
- Standalone operation
- PC application available (NanoVNA Saver and others)
- https://nanovna.com/
  - https://groups.io/g/nanovna-users
- There are separate groups for SAA-2, V2 plus 4, etc.:
  - https://nanorfe.com/nanovna-v2.html

- About NanoVNA
- Start using NanoVNA
- How to read NanoVNA screen
- Calibration NanoVNA
- Start measurement
- Upgrade NanoVNA use DFU
- NanoVNA-Web-Client / WebApp
- NanoVNASaver
- NanoVNA Menu Structure Map
- Wiki & User group

NanoVNA – Under the hood (H, H4)



NanoVNA – user interface

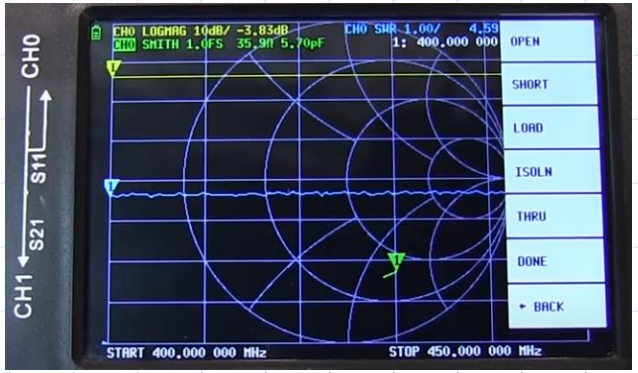
- "Jog-wheel"
  - Up/Down/Push
- Touch screen
  - Tap/Slide
- Fairly simple menus
- Setup/Cal "save" slots
- USB charging and PC interface

HOME MENU

DISPLAY	Traces, channels, format, scale, etc
MARKER	Add, function, search, etc.
STIMULUS	Start, Stop, Center, Span, etc.
CAL	Calibration process
RECALL	
CONFIG	

NanoVNA Calibration

- Only 101* points per sweep
- Wide range calibration will have coarse spacing
  - Spacing = SPAN/101*
- Most "interpolate" between points, but…
- ALWAYS a good idea to calibrate over your range

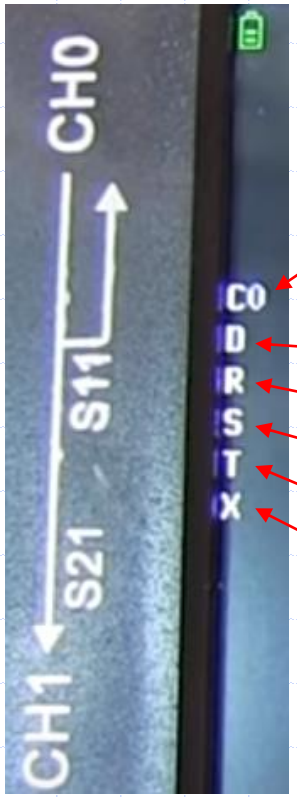


Note:
Firmware from other developers, like DiSlord, have increased this to 201 or even 401 points!

- And V2 Plus4 has 201 pts

NanoVNA Calibration cont…

- Display indications



Required for all measurements

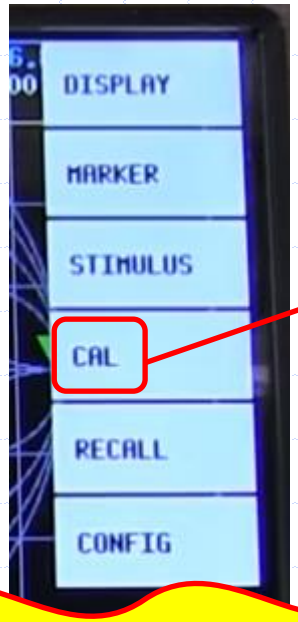
C: Calibrated for current frequency range
c: Calibration loaded but doesn't match frequency range
0,1,2,3,4,*: Calibration values storage location (*=none)

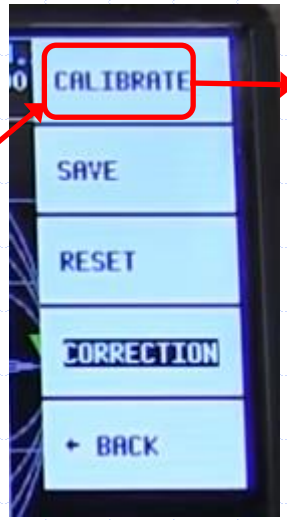
D: Directivity error correction applied (CH0)
R: Reflection Tracking error correction applied (CH0)
S: Source Match error correction applied (CH0)

T: Transmission Tracking error corr. applied (CH1)
X: Crosstalk error correction applied (CH1)

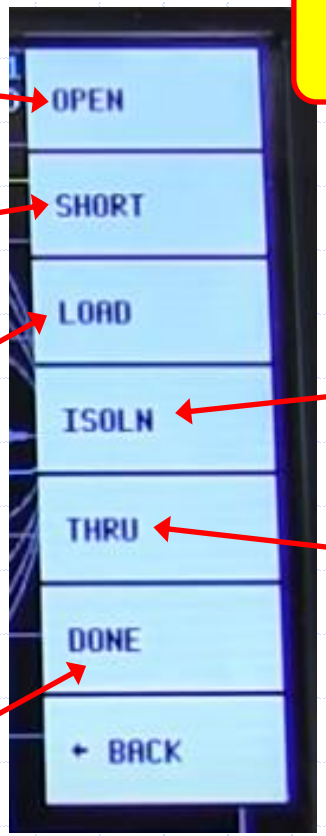
Required for transmission measurements

NanoVNA Calibration Process





Attach to **CH0**



Required for ALL measurements

Only required for S21 (CH1) measurements

CH1

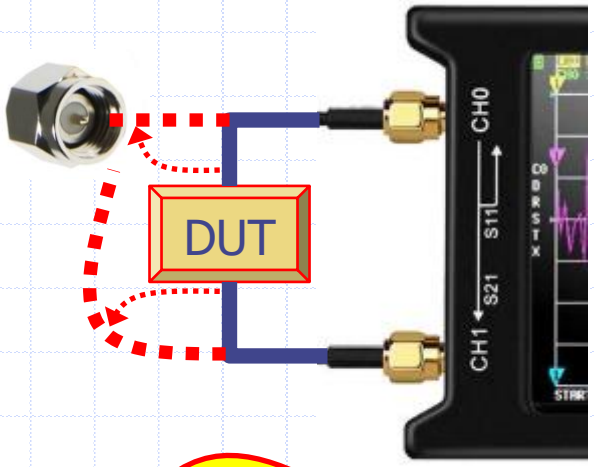
Coax CH0 to CH1

Connect all of the CAL-standards where DUT will connect

Hit **DONE** and then save to desired slot (0, 1, 2, 3, 4)
Slot 0 recalled on powerup

Calibration Plane and Port Extension

- When possible – connect CAL-standards same as the DUT
- This "removes" the phase of the connections to the DUT ports
- When you must use an adapter, coax, fixture, PCB trace to attach DUT – use **Port Extension** to move the Measurement Plane
- *Only important when you must have accurate Phase measurement*



- NanoVNA calls this **ELECTRICAL DELAY**
- Adjust using short/open at **DUT** location until phase rotation is removed on the Smith Chart

NanoVNA Channels & Traces

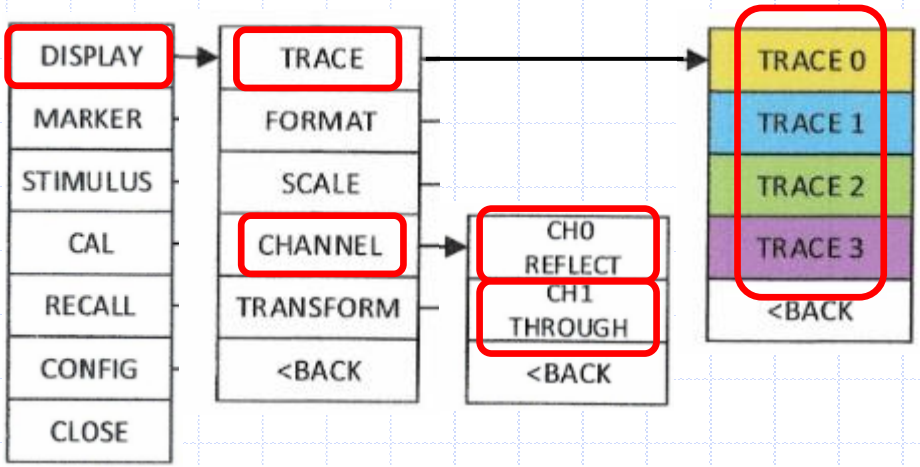
Channels

- **CH0**: Reflection (Port1)
  - S11: reflection coefficient
  - VSWR
  - Input Impedance
  - Distance to fault (transform)
- **CH1**: Transmission (Port2)
  - S21: loss/gain
  - Group Delay

Traces

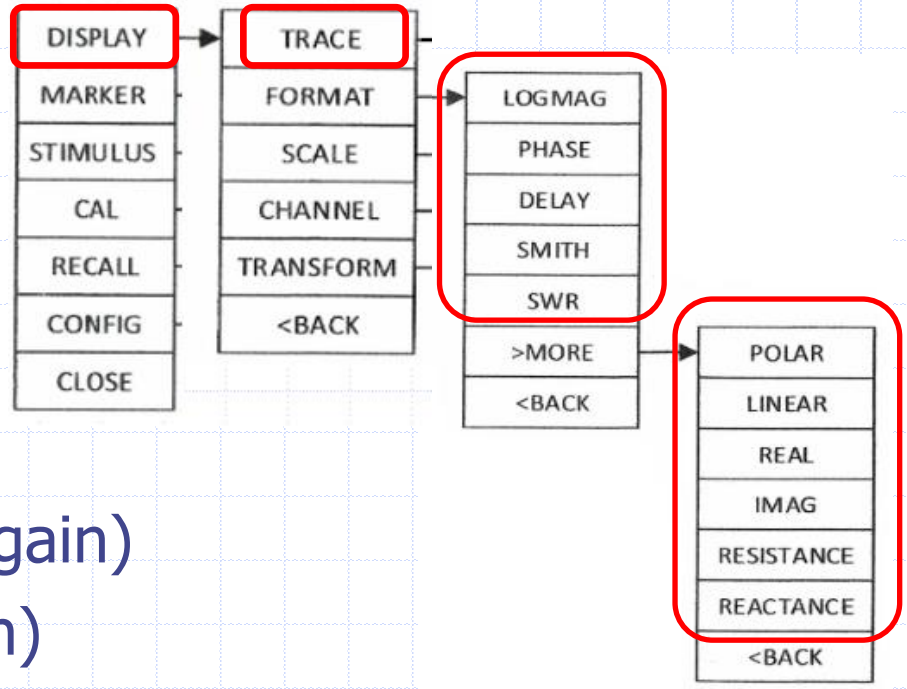
- Four traces
  - Can be assigned to any CH
  - Each can be on/off

When a trace is selected, it appears as INVERSE text on the display



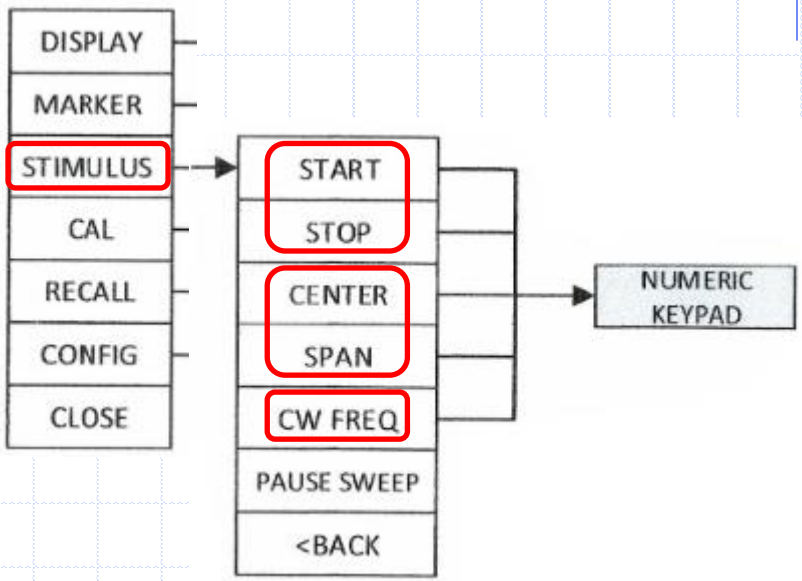
Common Trace Formats

- **CH0**: Reflection
  - LOGMAG: S11
  - Smith: complex Z
  - SWR
- **CH1**: Transmission
  - LOGMAG: S21 (loss/gain)
  - Phase: S21 (insertion)
  - Delay (group delay)
- More…



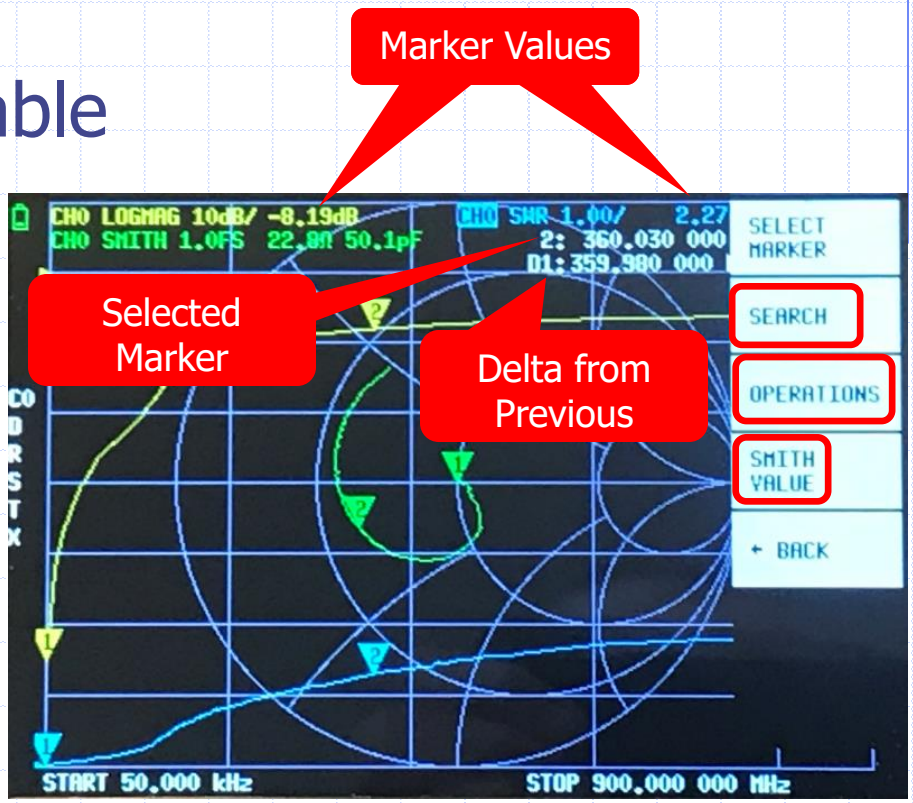
Setting the Source (Stimulus)

- Pick which is easier
  - Start & Stop
  - Center & Span
- CW for single frequency analysis



Markers

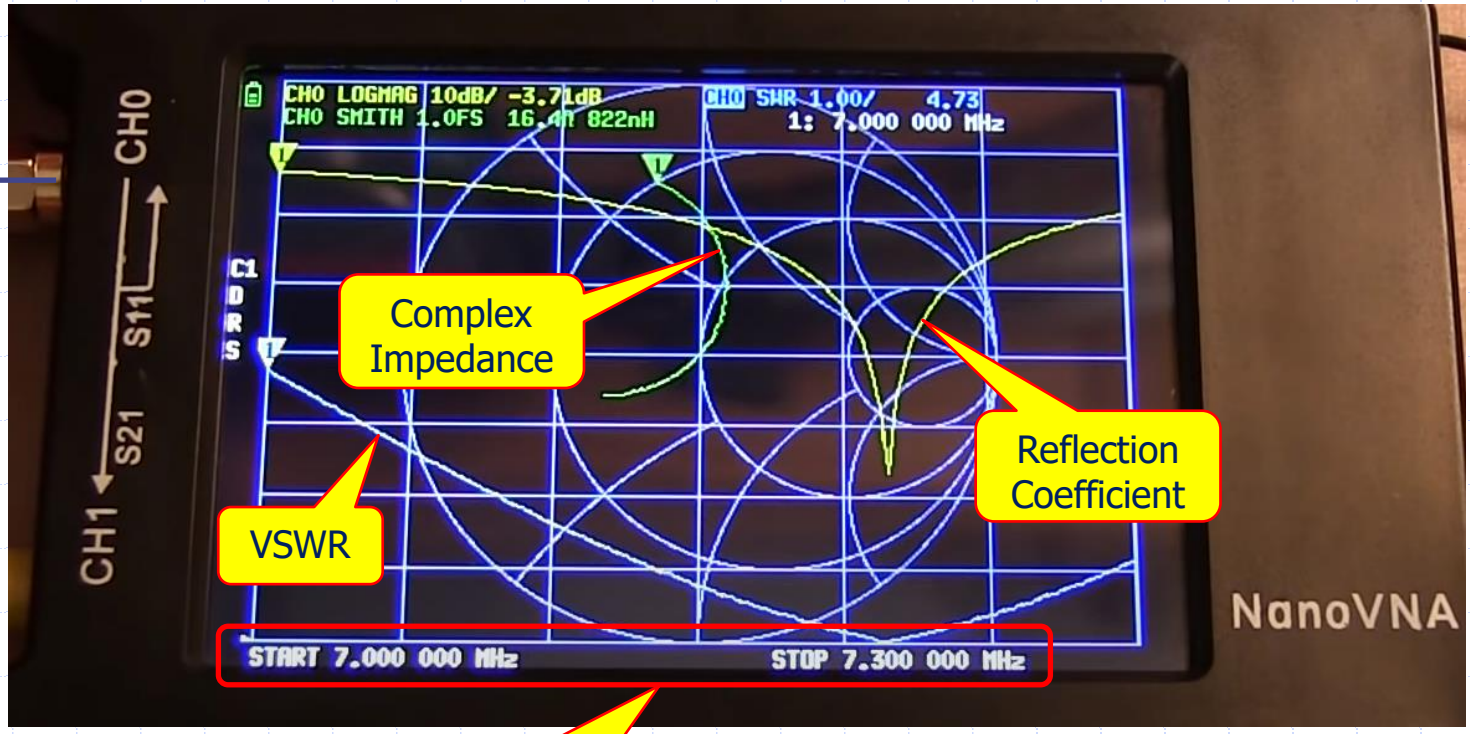
- Up to 4 Markers available
  - Jog wheel or drag
  - Delta from last two
- All track each other
- **Search** Features
  - Min/Max/Left/Right
- **Operations**
  - Marker to…
    - Start/stop/center/span
- Set **Smith** Chart units



Basic NanoVNA Setup Process

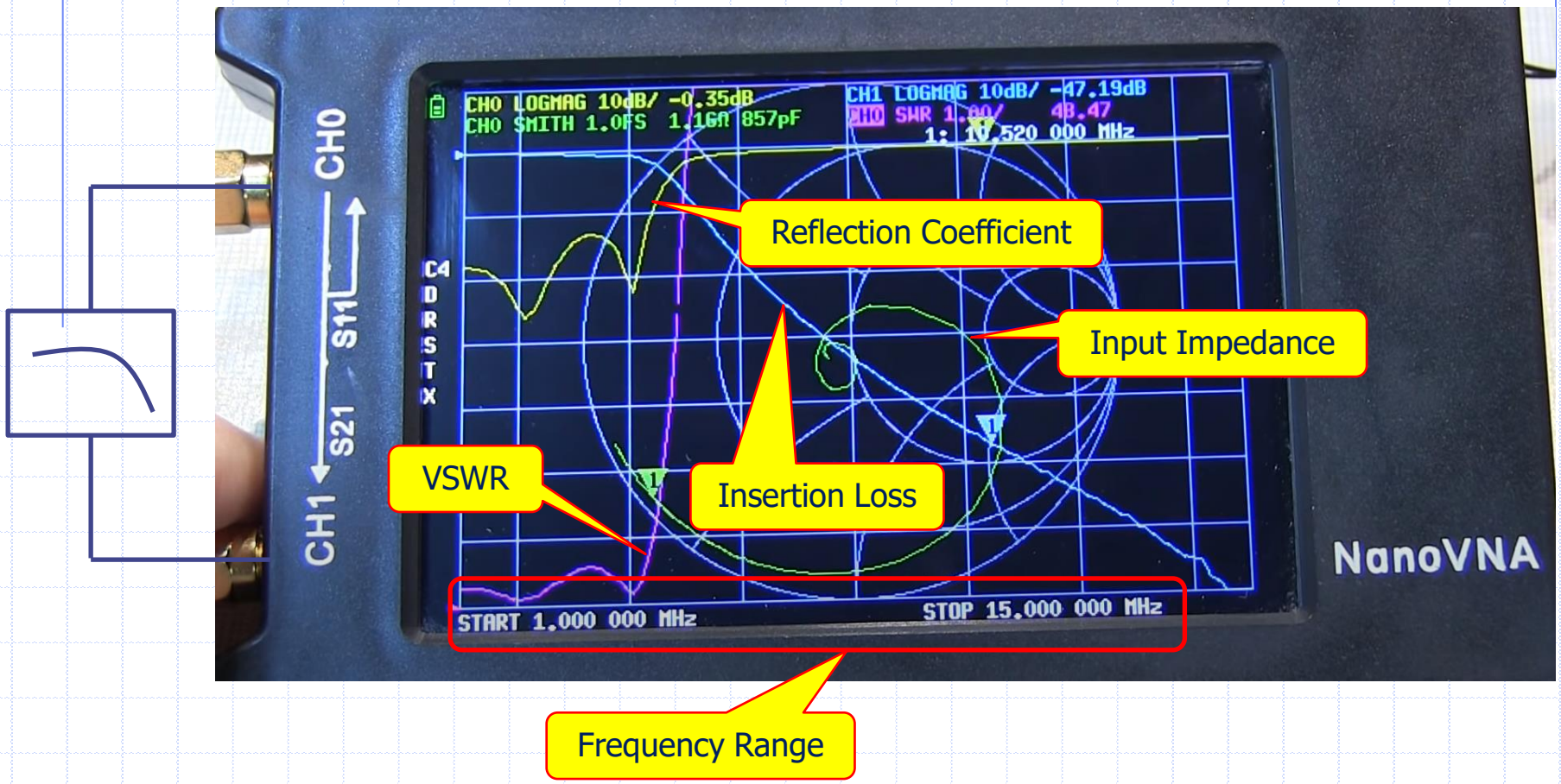
1. Configure TRACES, CHANNELS and FORMATS
2. Setup STIMULUS
3. CALIBRATE & Save
4. Connect DUT & test
5. Use MARKERS, etc.
6. Adjust traces & formats as needed

Example: Measure Antenna

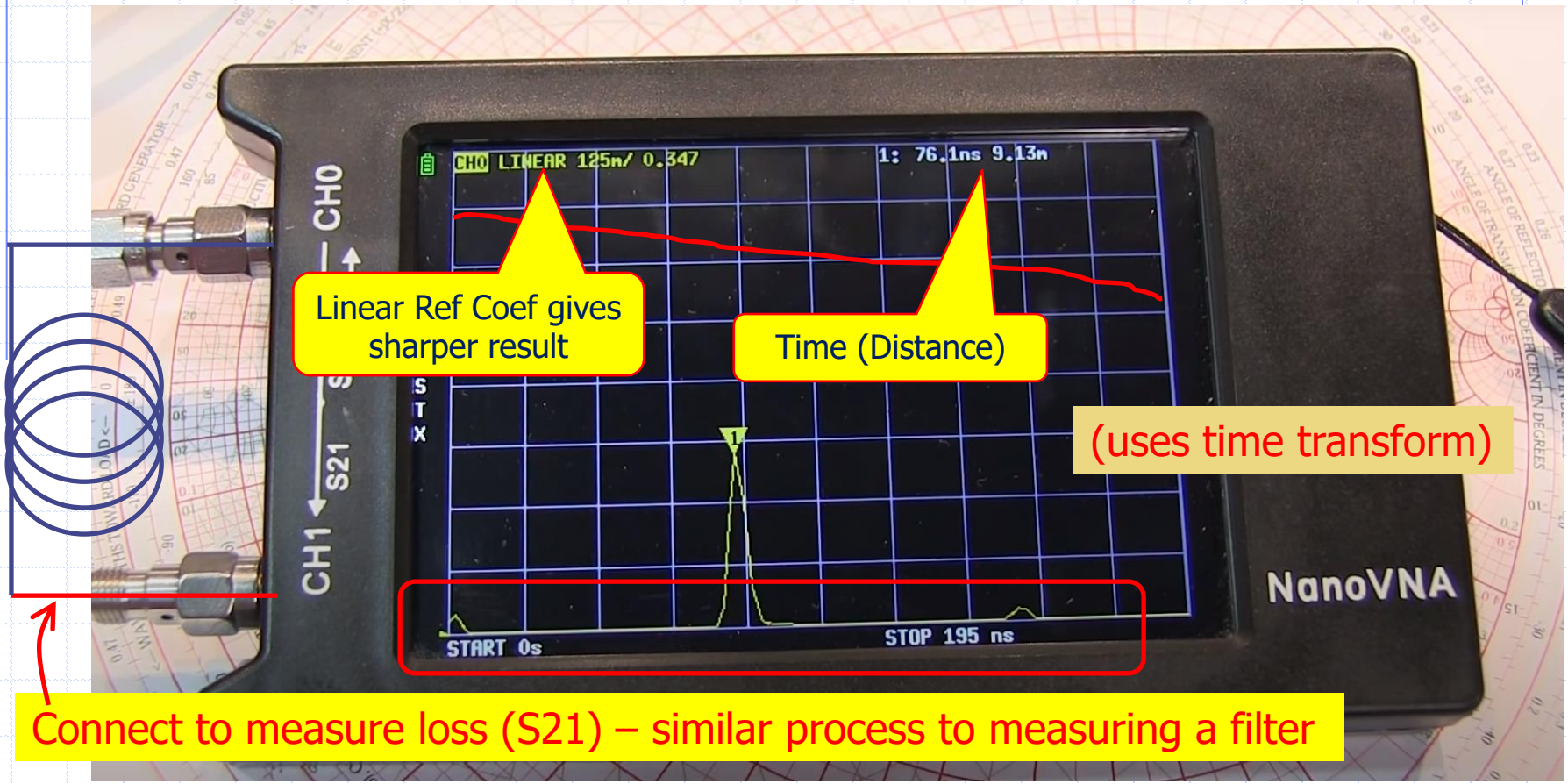


Frequency Range

Example: Measure Filter



Example: Measure Coax Length



The good, the bad & the UGLY

LIMITATIONS & DOWN-SIDES

- Only 101 trace points
  - External s/w helps this one
- Output is a square-wave - ~600mVpp
  - 300-900MHz uses 3rd harmonic
  - 900-1500MHz uses 5th harmonic
  - Broadband device problems?
- Output power is NOT adjustable
  - 50kHz to 300MHz: ~ +2dBm to 0dBm
  - 300MHz to 900MHz: ~ -8dBm to -12dBm
  - 900MHz to 1500MHz: ~ -17dBm to -24dBm
- Receive (CH1) reference level not adjustable
- Limited Dynamic Range
- RBW (Resolution BW) is not adjustable
- More….?

H4

H4

…as does later 3rd party firmware, NanoVNA V2 plus 4 has 201 pts

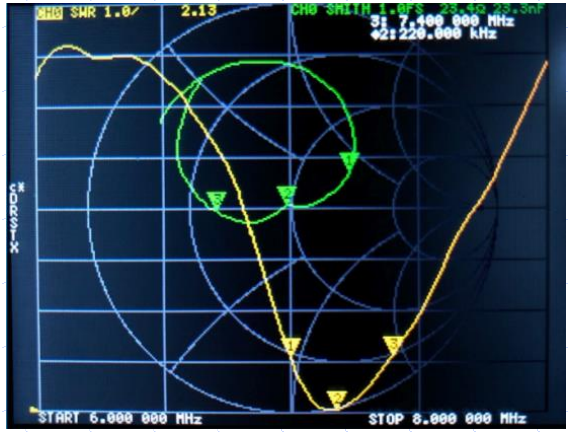
- Correct for DUT?
- No Gain Compression Meas, etc.

3rd party firmware address this

Same output for 200MHz, 600MHz & 1GHz

Summary

- NanoVNA – the RF tool/toy of the year
- Amazing capability of ~$60
- LOTS of videos, etc.
- Active user groups
- Good US source: www.randl.com



Thank you! Questions?

Shameless Plug: http://www.youtube.com/w2aew

More than 300 videos
Over 140,000 Subscribers
Over 17 Million views