Care and Feeding of your nano VNA

Practical use of VNAs

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RSGB 2023 Convention

Introduction

- VNA nano variants and ‘competition’
- Calibration - what is it and why so important
  - No maths
- Measurements
  - Just the basics and some examples
- Tips – better understanding and results
- Software

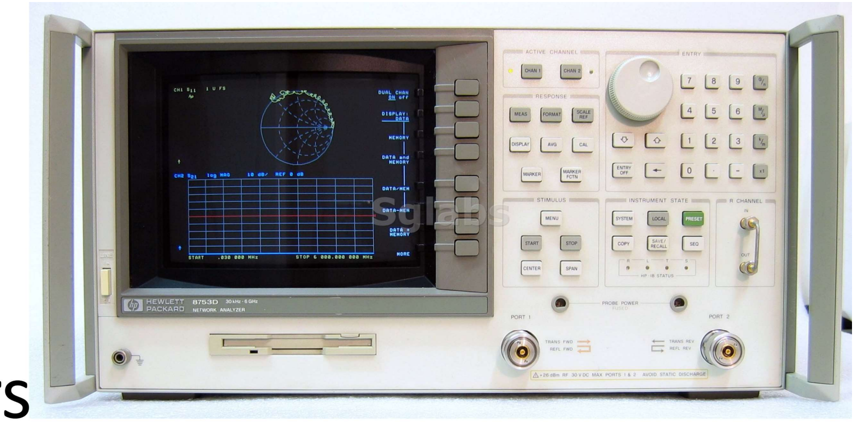
nVNA – are Everywhere

- Beware, there are many clones
  - Just search in ‘shopping’ for nano VNA
  - Various names
  - Different screen sizes, accessories
  - Claimed frequency ranges
- I have no idea which are good
- The official site is good [1]
  - And you support the actual developers
  - Batteries not included- for Nano VNA Plus 4 [2]

nVNA vs Other Brands

- Professional VNAs are generally more accurate
  - Better stability and repeatability
  - Also higher freq. options
- But much more expensive
  - Examples – just 2 of many others
  - HP (Agilent, Keysight)
  - Copper Mountain
- Nano VNA is from 10 to 100 times lower cost

HP8753
~£35,000

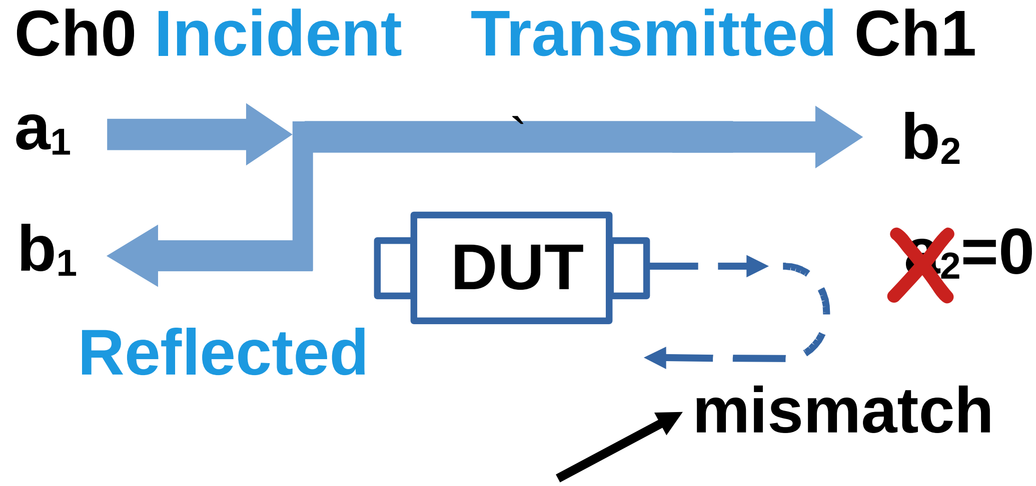


Copper Mountain
M50451300
~£8,000

VNA – Vector Network Analyser

- Measures both magnitude <u>and</u> phase
  - Your SWR meter just measures magnitude
- Measures impedances at RF frequencies
  - Your LCR meter only measures at ~100kHz
- Measures over a range of frequencies
  - e.g. shows antenna BW, filter response etc
- Measures over a wide dynamic range
  - Easily measures a filter stop band (>60dB)

VNA Measurements



- S Parameters
  - Reflection coefficient
    - Ch0 is S11

$$S_{11} = \frac{Reflected}{Incident}$$

  - Transmission coefficient
    - Ch1 is S21

$$S_{21} = \frac{Transmitted}{Incident}$$

  - For a low loss device under test (DUT) - like a filter
    - Reflections from ch1 port flow back through it and contribute to b1 as an error - ‘Ch1 mismatch’

a_2 = 0 <u>from</u> ch1
but there is a reflection
from any Ch1 mismatch

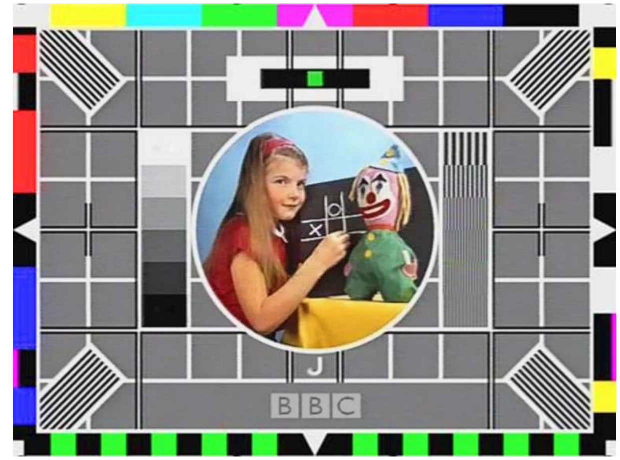
Calibration

- Calibration is needed to achieve good results
  - Most devices come with a ‘cal’ kit
    - Open, short, load and through cable
  - Calibrate every time you change frequencies
- Easy to do - just follow one of many good guides [3]
  - Also only accurate at the physical plane measured
- BUT
  - It is important to verify the cal – periodically
    - Particularly as early nVNAs are subject to drift

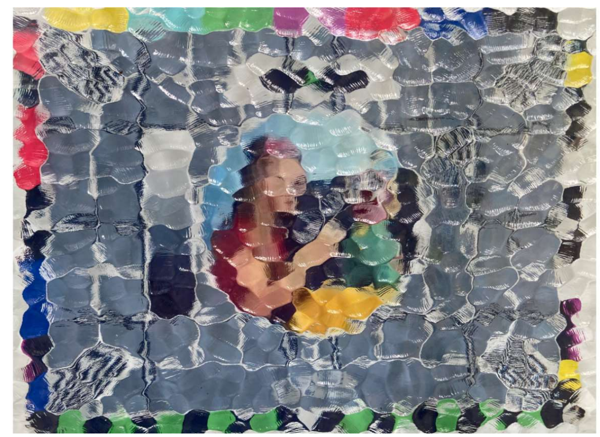
How Calibration Works

- A visual analogy – no maths
  - Not mathematically rigorous
    - But hopefully understandable
- The measurements are via couplers, detectors etc
  - Like seeing through flawed glass
  - These all introduce systematic errors
  - If the device under test is a picture
  - The measurement is blurred by the glass

Device Under Test

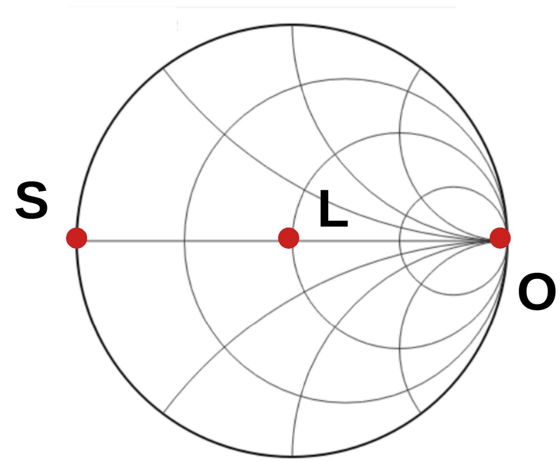


Measurement



How Cal Works - Reflection

- To account for the blur
  - Measure some known images
- Calculate the effect of the blur
  - So that it can be subtracted



The Calibration Correction

- The calibration is a set of numbers:
  - Magnitudes and phases representing the blur
  - One set for every frequency point measured
    - The blur also has a frequency response
- BUT more importantly, there is physical length involved
  - So every frequency has a different phase shift
  - Greater shifts for longer lengths and higher frequencies
- Imagine the blur distortion is also rotating as the frequency steps
  - Repeatability requires freq. accuracy between cal and test

Calibration - Effects of Phase

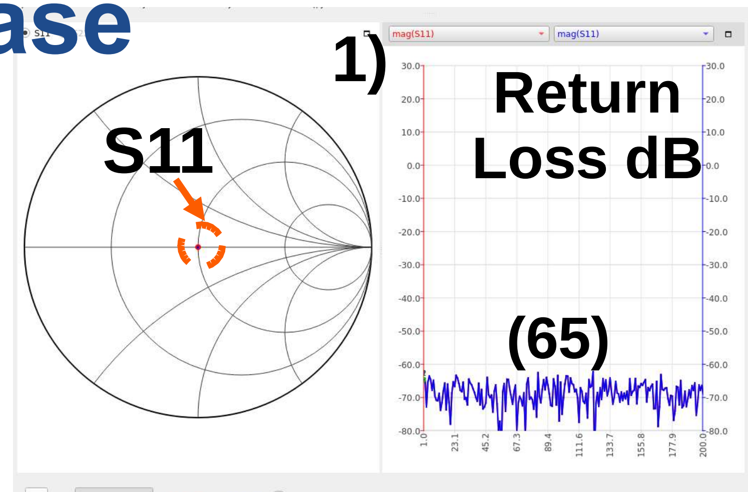
1) After cal, remeasure the load

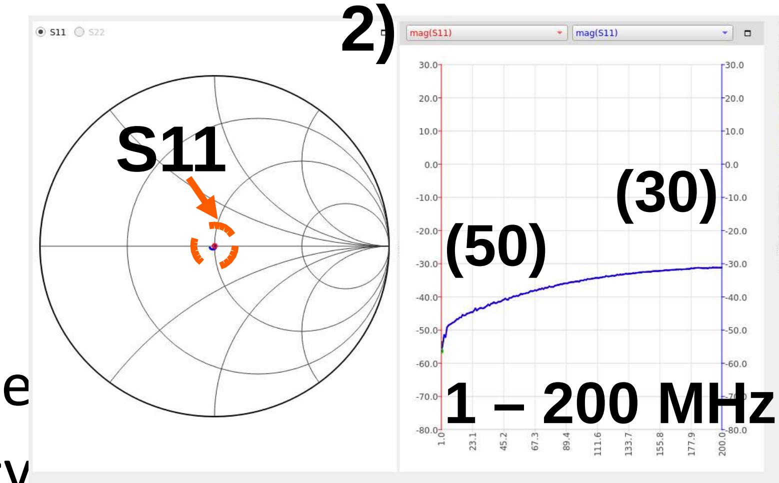
- Looks great - S11 = 50Ω RL > 65 dB

  NOT real, just noise, essentially (x – x) = 0

2) Measure the load at end of cal cable

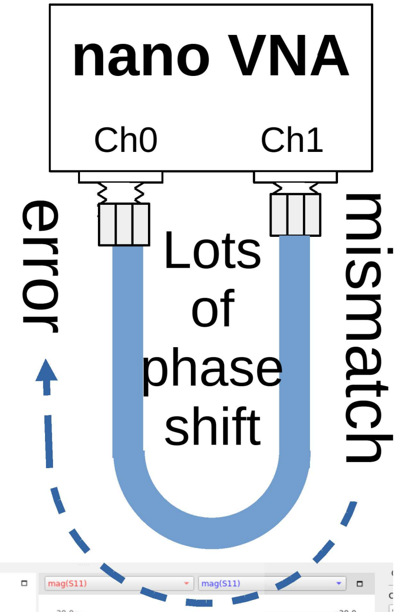
- S11 phase rotated, no visible change
- RL lower, going from 50 dB to 30 dB
  - Observing the cable phase shift
    - Same load as 1) - so same magnitude
    - But the phase is different - changes the
      - Phase error increases with frequency

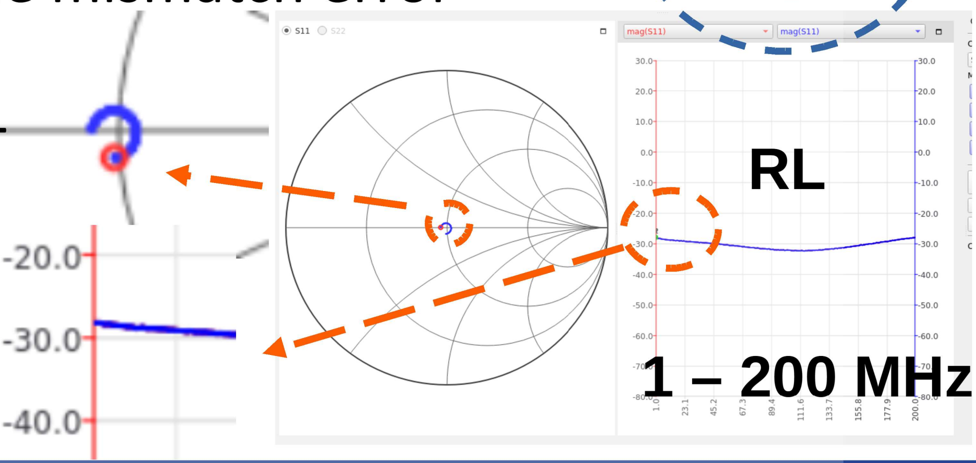




How Cal Works - Transmission

- Transmission goes through DUT and on to Ch1 port
  - Like shining light through the blurred glass
- – Calibration measures the Ch1 port as a load
  - Then subtracts those values - BUT
- S11 cal cannot take into account the mismatch error
  - Error from ‘light’ reflecting back from Ch1 through the DUT
- – You can see this by looking at S11 after calibration





Calibration Verification

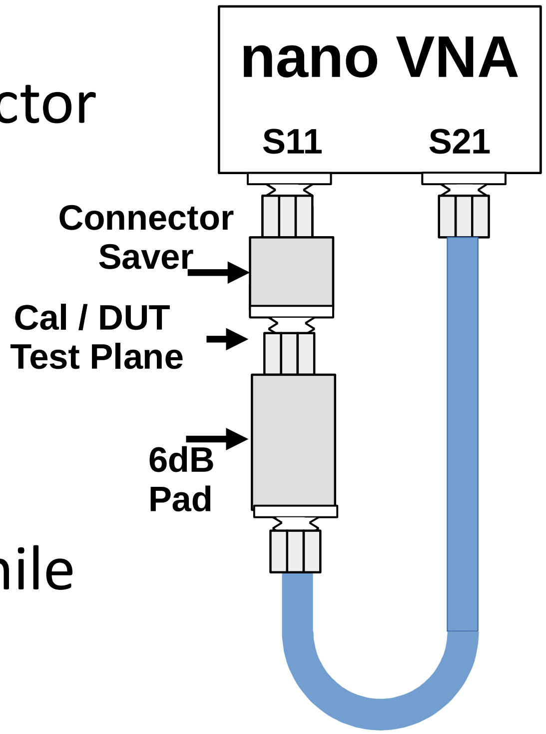
- Good practice to check the calibration
  - Initially in case of some error, but also periodically
    - Early version nVNAs are prone to drift
- Do <u>not</u> re-measure one of the standards
  - That just confirms the maths - need a different device
- Measure some other device - good candidates
    - A known attenuator (pad)
    - Cal Load on the end of the cable

Additions to Your Purchase

- nVNA usually includes an SMA cable
  - Some even have two
- Also SMA cal standards
  - Open, short and fixed load
- Useful additions – not expensive
  - An SMA male to female (connector saver)
    - You only need one - beware of ‘reverse SMA’
  - A 6 dB SMA attenuator (aka pad)

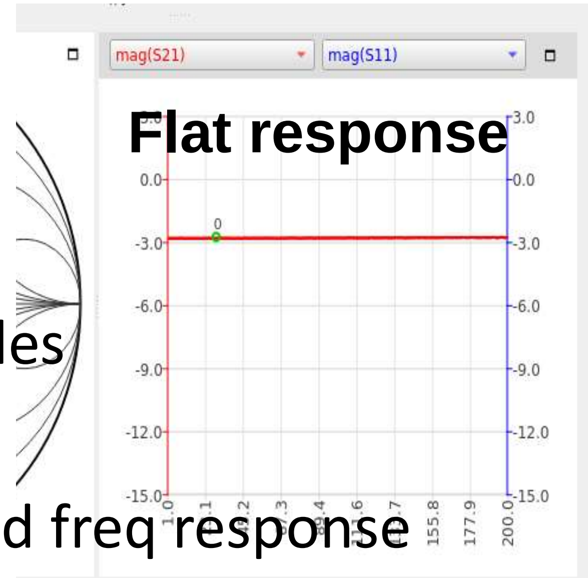
Tips for a Good Cal

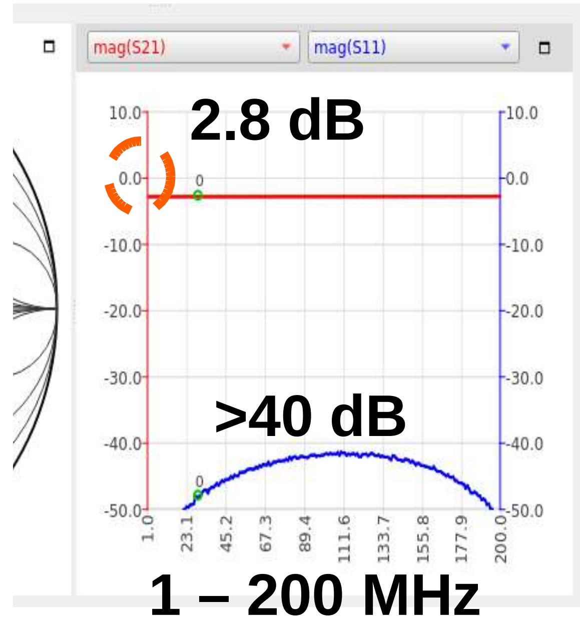
- Calibrate S11 close to the Ch0 connector
  - Add a connector saver to protect the nVNA connector
    - Adds length but not much and worthwhile
- Calibrate S21 via a 6 dB pad
  - At the DUT end of the cable
  - Provides 12 dB return loss at the DUT output
    - It costs 6 dB in dynamic range but again worthwhile
- Validate the calibration
  - Measure the short via the 6 dB pad
    - Repeating periodically to observe any drift



Calibration Verification

- Calibrate with connector saver and 6 dB pad
  - Measure a 3 dB pad – showing S11 an S21
    - Flat freq response, expected loss ~ 3 dB and good S11 >40 dB
- Watch out for:
  - Changes in the 2.8 value
    - Magnitude error/drift
  - Loops in S11 or S21 ripples
    - Resonances
  - Deviations from expected freq response
    Phase drift/errors



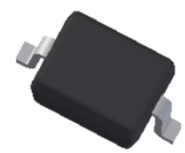


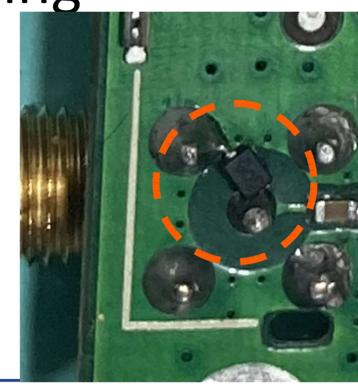
Transient Protection

- It is possible to damage the S11 port with DC
  - I know through first hand experience
- There is a DC blocking capacitor on the port
  - So a steady DC voltage is not a problem
  - But a short enough transient will get through the capacitor
- Solution - a bidirectional transient suppression device
  - Fits nicely between SMA inner and ground
    - Inside the box, access under the screening can
- Advice only - not a fool proof guarantee

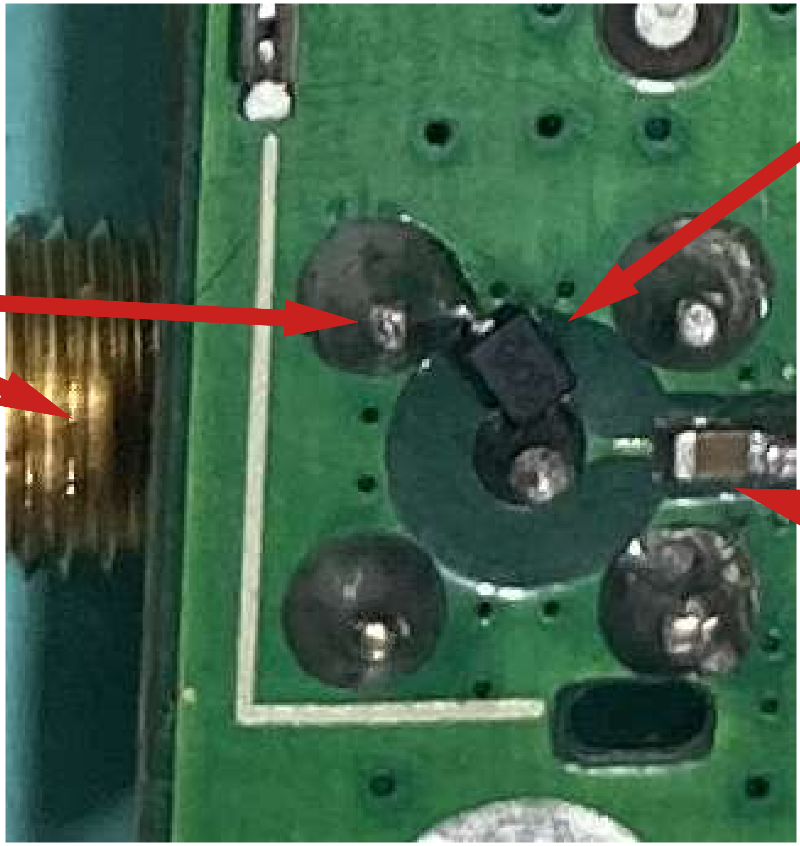
Transient Protection Recommendation

- The key parameters are:
  - low capacitance (<1pF) – look for very low power devices
  - low trigger voltage (<5V) – working voltage ~1.5V lower
- One recommendation [4] ESD101B102ELE6327XTMA1
  - But challenging to fit – very small package (0.3 x 0.6 mm)
  - Solder pads on the bottom – inaccessible for hand soldering
- Alternative DBLC03CI-7 (1.3 x 1.7 mm) [5]
  - Big enough to fit between existing PCB pads
  - Typical values 0.7 pF, 4-7 V trigger and 0.7nS turn on





Ch0
SMA



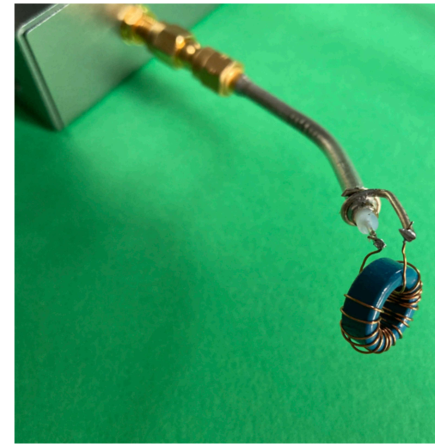
Suppression
Diode

DC
Blocking
Cap

Basic Measurements - Reflection

- Antenna – simple and effective
  - Can work in the field
  - Connect directly to the coax feed point
- Inductors and Capacitors – solve mystery device values
  - Measures at RF frequencies and shows self resonance
  - Great for hand wound RF inductors
    - Weed out useless LF ferrites
  - For SMD capacitors where there are no markings
- Locate feed lines faults

Basic Measurements - Reflection



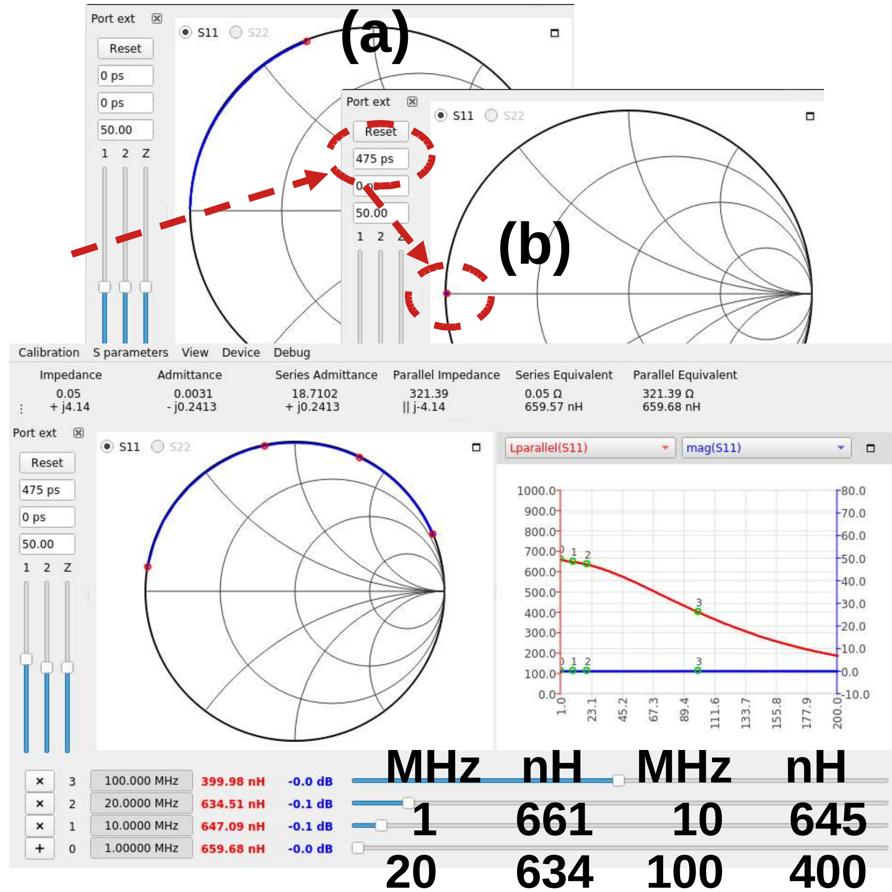
- Mystery LC values - you don’t need a fancy test jig
  - A short piece of semi-rigid coax
    - Extend the cal reference using a temporary short
    - Solder device to the ends and measure
  - Measure the unloaded Q of devices [6]
- Feed line Faults – e.g. a broken connector connection
    - With a load and/or short on one end
    - Can usually tell which end is faulty
- Feed line velocity factor
  - Terminate in a short, compare electrical to physical length

Basic Measurements - Reflection

- Measuring a hand wound inductor
- 1 – 200 MHz sweep

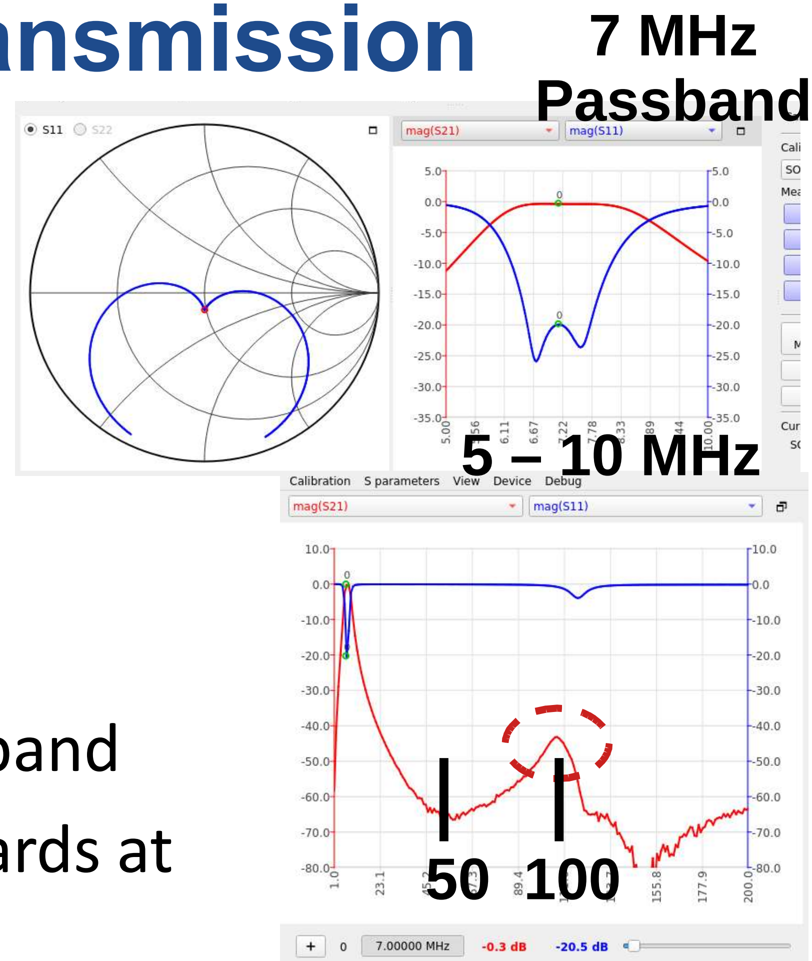
  (a) Temp s/c – the arc

  (b) ref extension (475 pS) – a dot
- Connect the inductor
  - Display L_Parallel(S11)
  - Markers show inductance vs Freq
  - Gradual reduction in inductance
  - Self resonance at ~ 200 MHz



Basic Measurements - Transmission

- Filters – can measure S11 and S21
  - Beware of the ‘Ch1 mismatch’ error
    - Particularly for low loss passband and high freq. filters
      - Calibrate with a 6 dB pad
- As well as the passband
  - Remember to measure a wide stop band
  - The stop band invariably turns upwards at some point



1 – 200 MHz

Basic Measurements - Transmission

- Amplifiers
  - Usually uni-directional, so less problem with 'Ch1 mismatch'
  - But have gain, so the output can saturate the S21 detector
    - Adding a pad at the output can help
- Mixers – are very tricky and not recommended
  - More expensive VNAs often have this as an added feature
  - Problems: – LO leakage, the opposite sideband and more
- You can measure back to back baluns for home brew mixers

Software

- nVNA is a self contained instrument
  - All measurements and results can be made ‘in the field’
    - Perfect for antennas for example
- But the screen is small – newer versions are better
    - Software can greatly enhance usability ‘in the shack’
    - Improves both the display and adds capabilities
- There are various options – much is personal choice
  - Nano VNA QT [7] - cross platform – I run this on a Raspberry Pi
  - Nano VNA Saver – cross platform
  - Nano VNA Sharp – windows only

Nano VNA QT

- A single executable for Windows, OSX and Linux
  - Simple and uncluttered display
  - Easy to install

1) Smith Chart - S11

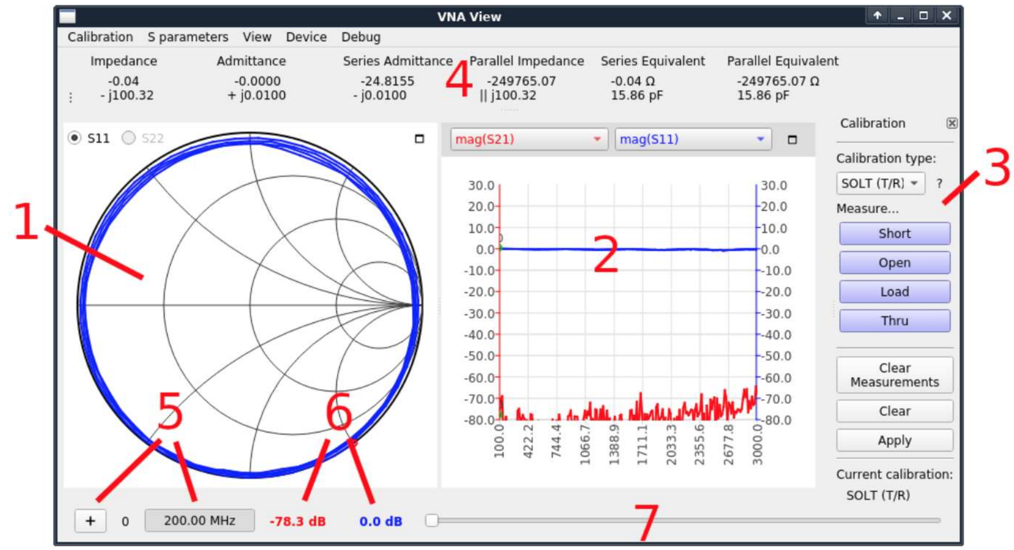
2) Line graph – various options

3) Calibration – display

4) Impedance/Admittance – S11

5) Marker control and 6) values

7) Marker slider



Software - Extra Capabilities

- Uses computer display
  - Capture screen plots, see different measurements
    - e.g. plots of capacitance/inductance with freq
  - Ease of use e.g. slider controls
- Data capture – export csv, s1p or S2p files
  - csv files for more general use, e.g. spreadsheets
  - s?p is a ‘Touchstone’ file format
    - Can be imported into simulation software, e.g QUCS

Summary

- Nano VNA is remarkable device
  - Exceptional price/performance value
- Calibration is essential to get meaningful measurement
  - I hope I have shed some '*light*' and helped understanding
    - Errors in phase are just as important as magnitude
- Basic measurement examples for reflection and transmission
  - Much more than a VSWR meter or simple LCR meter
- Software like Nano VNA QT can enhance what you can do

Find out more… *Thank You for your Attention*

[1] Official web site https://nanorfe.com/

[2] A battery option https://tinyurl.com/nVNA-battery

[3] From W2AEW https://tinyurl.com/vna-calibration

[4] User group discussion https://tinyurl.com/ch0-protection

[5] Transient suppressor https://tinyurl.com/DBLC03CI

[6] Using your VNA to demystify RF filters, Rad Comm April 2022

[7] https://tinyurl.com/nanoVNA-QT - the manual

[8] http://tinyurl.com/nVNA-Pads - 6dB pads

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