Quantifying and Verifying trace stability of vector network analyzers at frequencies below 1GHz

Hamdi Mani, Chris Groppi, Judd Bowman

***Abstract*—we describe measurements done to check the low frequency stability of network analyzers from different vendors. The data on this report shows that the Agilent PNA N5230A and the PNA-X N5242A magnitude and phase measurements are more stable at frequencies below 100MHz than the R&S ZVA24. The stability of the PNA VNA is needed for low frequency measurements including- but not limited to- video amplifiers, low loss transmission lines, low frequency dipole antennas, measurement of VHF components…**

***Index Terms*—Vector Network Analyzers, test equipment precision, noise in instruments, VHF band.**

I. Introduction

There is a need for characterizing radio telescope components below 1GHz in experimental cosmology such as the experiments to detect the epoch of re-ionization. These experiments are trying to measure the faint power spectrum of the highly red shifted 21cm hydrogen line. The spectral line frequency is red shifted (z>6) from the microwave L Band region of around 1420 MHz to the 75-200MHz frequency range [1]. Measuring components in this frequency range requires precise and accurate test equipment .The requirement for precision is not hard to satisfy since there are well established calibration techniques and NIST traceable calibration standards. The accuracy requirement deals with repeatability of the measurement over some period of time or what is referred to as trace noise. It defines the maximum resolution of the measurement. The latter requirement is investigated in this report.

The trace noise of both magnitude and phase of the reflection coefficient are studied since the impedance is a complex quantity and the uncertainties of the magnitude and phase contribute to the uncertainty of the impedance.

Hamdi Mani is a physics student at Arizona state university and works at the Terahertz instrumentation (http://thz.asu.edu/cgroppi/)and low frequency Cosmology Labs. He can be reached at: hamdi.mani@asu.edu

Chris Groppi is an assistant professor at ASU and is the Terahertz astronomy group leader.(cgroppi@asu.edu)

Judd Bowman is an assistant professor at ASU and is the group leader for the Low Freq radio astronomy and Cosmology group (Judd.Bowman@asu.edu)

II. Measurement Procedure

To quantify the stability of the trace of a vector network analyzer at low frequencies, we need to measure the statistical dispersion over time of few sample readings. Few quantities can describe this dispersion:

- Standard deviation
- Interquartile range
- Range
- Mean difference
- Median absolute deviation
- Average absolute deviation
- Distance standard deviation
- Coefficient of variation
- Quartile coefficient of dispersion

The author choose standard deviation as the statistical parameter. But other parameters might be used.

Physical scientists and especially electrical engineers use the term "Root Mean Square" (RMS) as a synonym for standard deviation. The 2 quantities are actually different. The standard deviation is the root mean square of the deviation of the individual samples from the mean .The RMS of samples is equal to the standard deviation only if the mean of the samples (i.e. the expected value) is equal to 0.

The definition of the standard deviation for N samples: x_i whose arithmetic mean $\bar{x}$ is defined by :

$$\sigma=\sqrt{\frac{\sum_1^N (x_i-\bar{x})^2}{(N-1)}}$$

A large standard deviation from the mean is an indication of higher trace noise; a lower standard deviation indicates more stable trace.

The network analyzers settings are:

- Freq: 10MHz-1GHz

- Number of Points: 991(1MHz Step)
- Test port power: 0dBm
- IF Bandwidth: 500Hz (reduce IF Bandwidth at low frequency option was enabled)

A 1-port SOLT Calibration was performed on all analyzers, the cal kit used is the HP 85052B 3.5mm manual kit (broadband load used).

The PNA N5230A [2] was calibrated at the end of test cables after a long warm up time (more than 12 hours).The PNA-XN5242A was calibrated at the test port after 10 minutes warm up time. The ZVA24 [3] was calibrated at the test port with no cables after 10 minutes warm up time. The 2 network analyzers were terminated by good 50 ohm load, the averaging was turned off and 10 traces were saved within 5 minutes. The data was saved as a touchstone s1p file and analyzed and plotted in Microsoft Excel and in AWR Microwave Office.

Data was also collected with the averaging set to 10 and then to 100.

It is important to mention that measuring 50ohm load (instead of a short, open or any other termination value) is most demanding since the reflected power is very small and thus is a tough test of the dynamic range and stability of the instruments.

III. TRACE NOISE ON THE MAGNITUDE DATA

The 10 s11[dB] measurements taken with the Agilent PNA-L N5230A are shown on Fig1a.The 10 measurements taken with the R&S ZVA24 are plotted with the same scale and shown on Fig1b.The measurements by the PNA-X N5242A are shown on Fig1.c

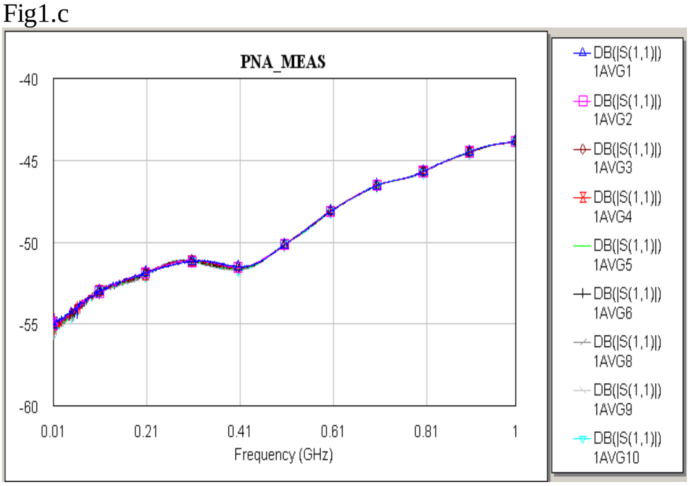


Fig1a. 10 traces measured by the Agilent PNA

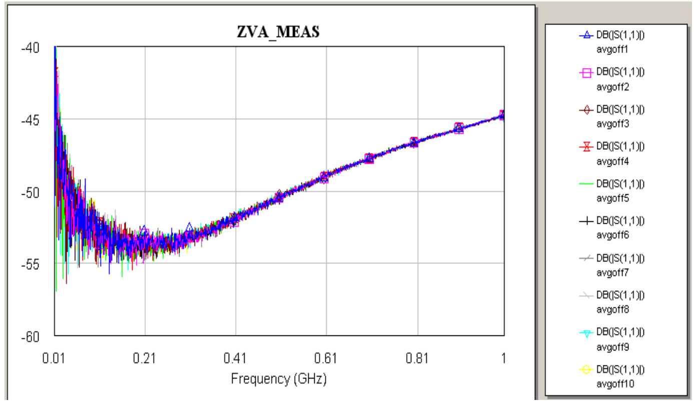
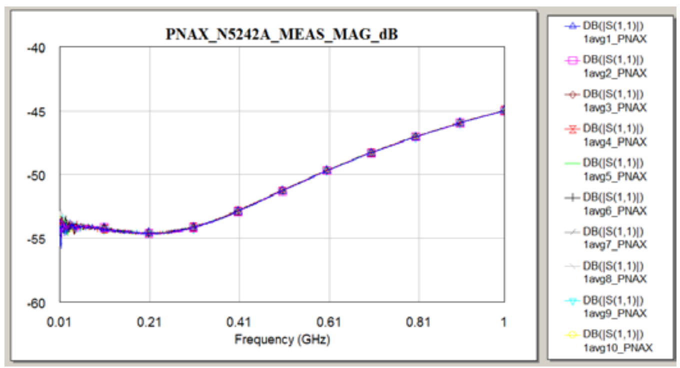


Fig1b. 10 traces measured by the R&S ZVA24.



The 3 plots 1.a, 1.b and 1.c show differences both in absolute measurement and on trace noise especially below 200MHz.

The standard deviation is computed at all frequency points and plotted on Fig2a and Fig2.b for the PNA and ZVA VNAs respectively. Fig3a and Fig3b are the same plots than 2a and 2b just zoomed on the frequency range of interest.

The standard deviation at 10MHz is very high for both instruments; this is due to coupler roll off at 10MHz.

At 100MHz, the 10 measurements taken with the PNA N5230A are about 0.1dB from the mean while the 10 measurements taken with the ZVA24 are within 0.9dB.

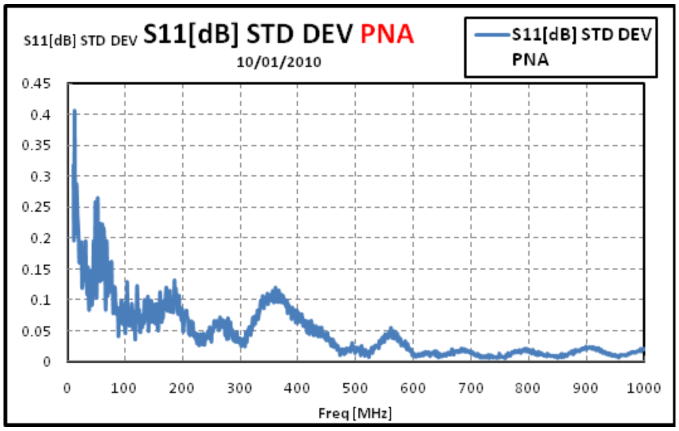


Fig2a. Standard deviation in [dB] of the 10 samples reflection coefficient (S11) measured by the PNA N5230A VNA and plotted on the 10MHz-1GHz range.

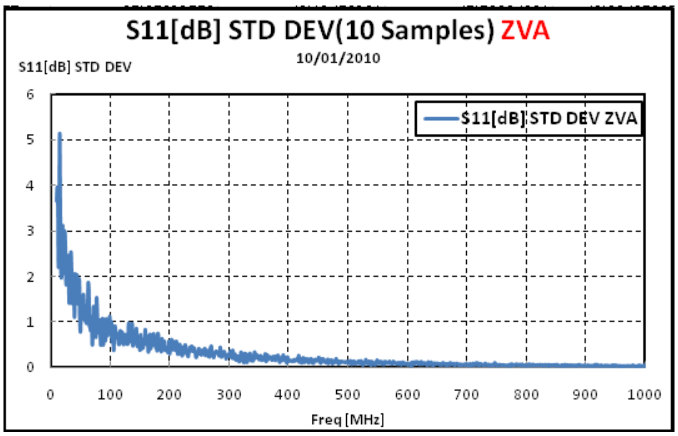


Fig2b. Standard deviation in [dB] of the 10 samples reflection coefficient (S11) measured by the ZVA24 VNA and plotted on the 10MHz-1GHz range.

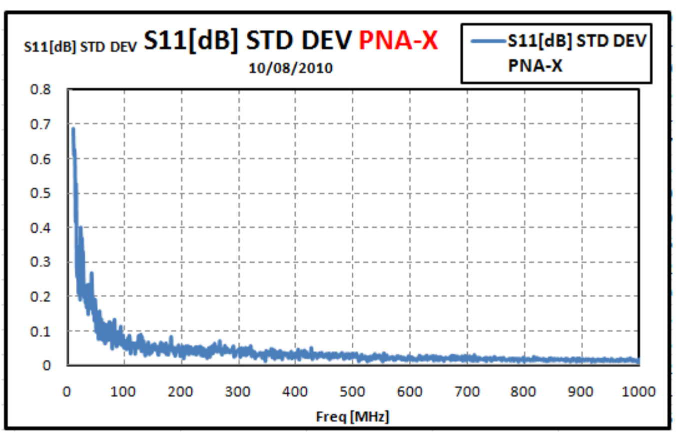


Fig2c. Standard deviation in [dB] of the 10 samples reflection coefficient (S11) measured by the PNAX N5242A VNA and plotted on the 10MHz-1GHz range

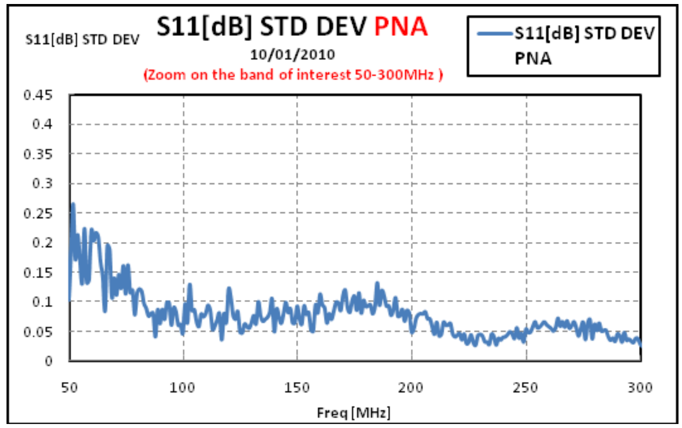


Fig3a. Standard deviation in [dB] of the 10 samples reflection coefficient (S11) measured by the PNA N5230A VNA and plotted on the 50MHz-300MHz range.

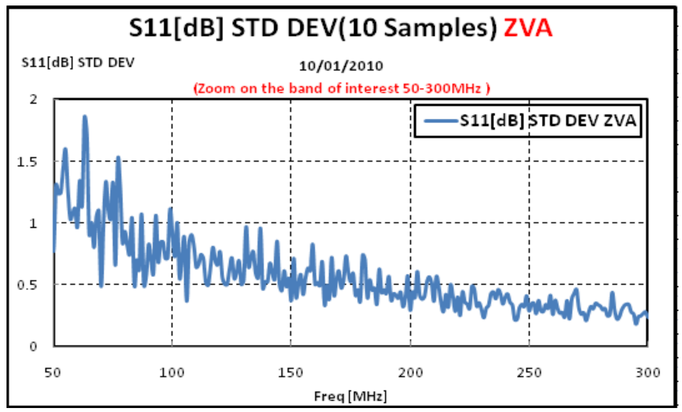


Fig3b. Standard deviation in [dB] of the 10 samples reflection coefficient (S11) measured by the ZVA24 VNA and plotted on the 50MHz-300MHz range.

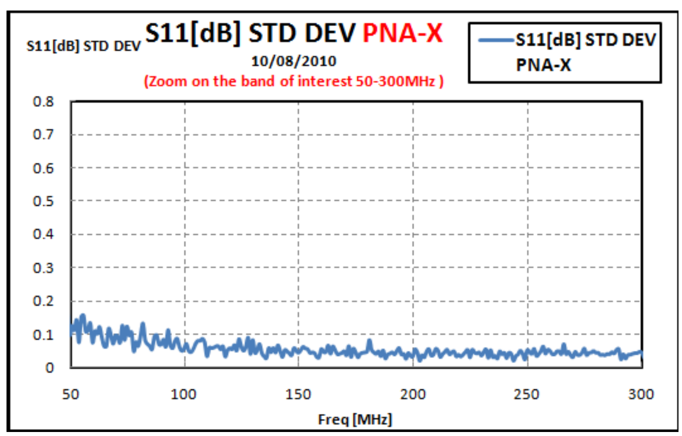


Fig3c. Standard deviation in [dB] of the 10 samples reflection coefficient (S11) measured by the PNAX N5242A VNA and plotted on the 50MHz-300MHz range.

The reflection coefficient value is converted from dB to linear and the standard deviation is plotted in Fig4a and Fig4b.

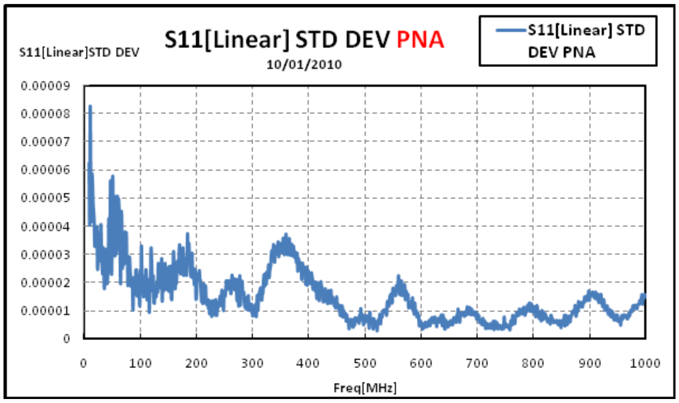


Fig4a. Standard deviation in [linear] of the 10 samples reflection coefficient (S11) measured by the PNA N5230A VNA and plotted on the 10MHz-1GHz range.

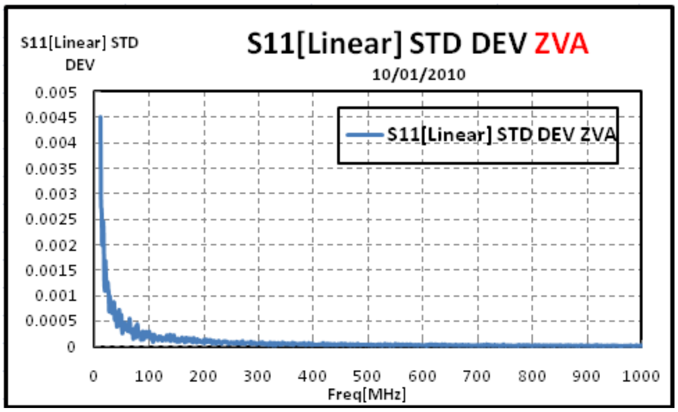


Fig4b. Standard deviation in [linear] of the 10 samples reflection coefficient (S11) measured by the ZVA24 VNA and plotted on the 10MHz-1GHz range.

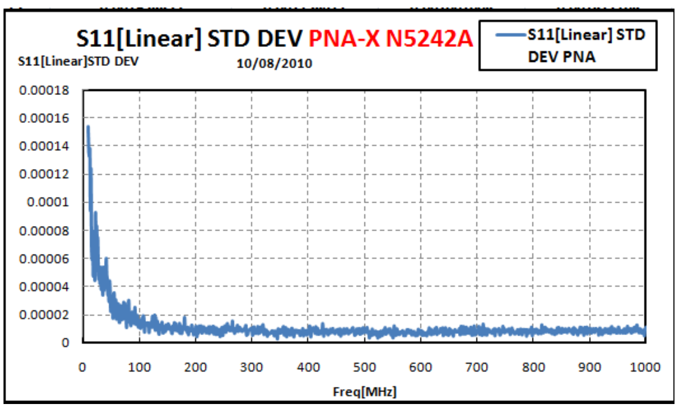


Fig4b. Standard deviation in [linear] of the 10 samples reflection coefficient (S11) measured by the PNA-X N5242A VNA and plotted on the 10MHz-1GHz range.

The standard deviation in linear s11 is plotted on the 50MHz-300MHz (Fig5a and Fig5b)

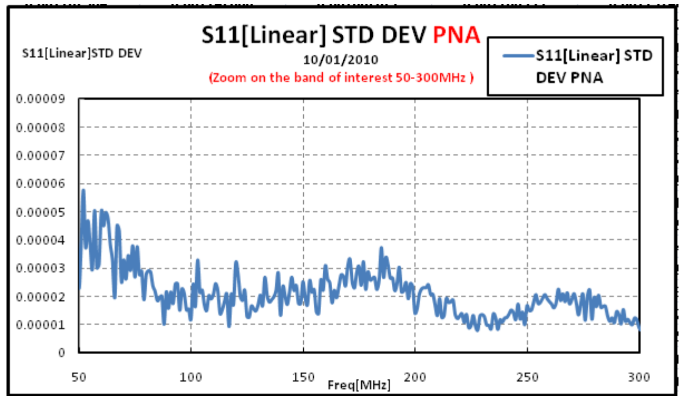


Fig5a. Standard deviation in [linear] of the 10 samples reflection coefficient (S11) measured by the PNA N5230A VNA and plotted on the 50MHz-300MHz range.

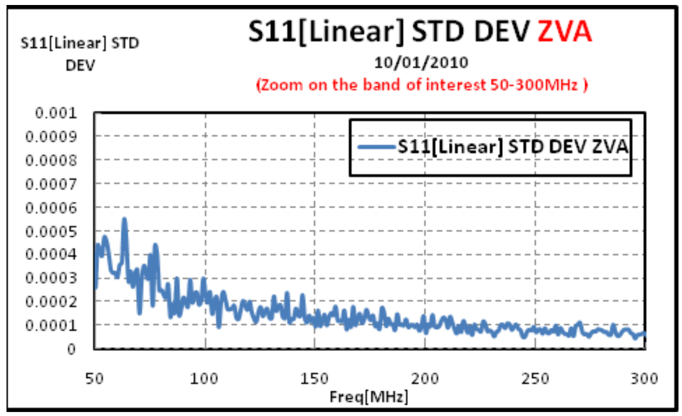


Fig5b. Standard deviation in [linear] of the 10 samples reflection coefficient (S11) measured by the ZVA24 VNA and plotted on the 50MHz-300MHz range.

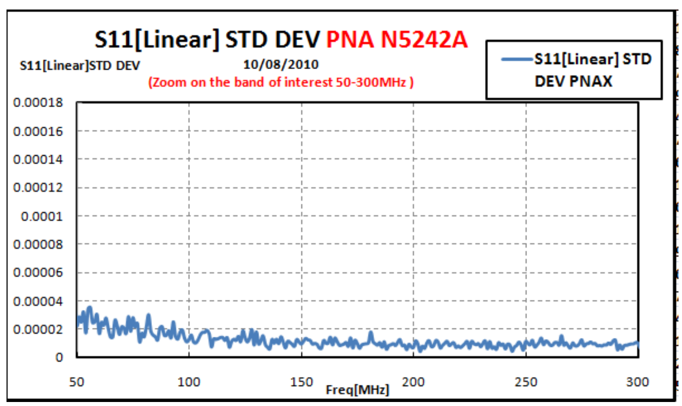


Fig5c. Standard deviation in [linear] of the 10 samples reflection coefficient (S11) measured by the PNA-X N5242A VNA and plotted on the 50MHz-300MHz range.

The standard deviation is then plotted in % Reflection. The reflection coefficient S11 varies from 0% (total absorption for an ideal matched load) and 100% for a total reflection (perfect open or short).Fig6a and Fig6b are plots in the 10MHz-1GHz range and Fig7a and Fig7B are zoomed plots in the 50MHz-300MHz band.

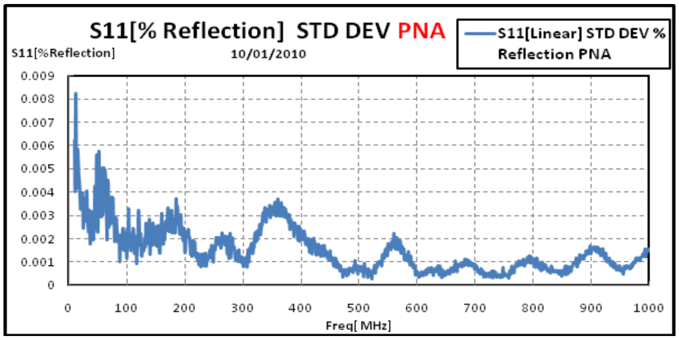


Fig5a. Standard deviation in [% reflection] of the 10 samples reflection coefficient (S11) measured by the PNA N5230A VNA and plotted on the 10MHz-1GHz range.

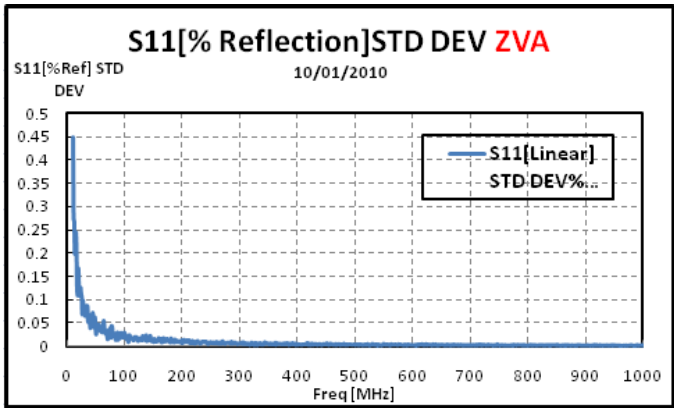


Fig5b. Standard deviation in [% reflection] of the 10 samples reflection coefficient (S11) measured by the ZVA24 VNA and plotted on the 10MHz-1GHz range.

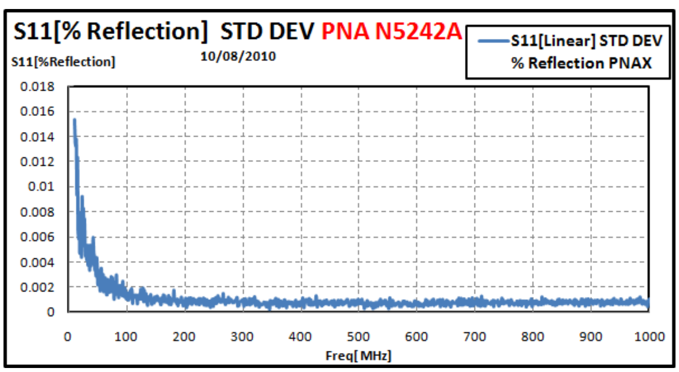


Fig5c. Standard deviation in [% reflection] of the 10 samples reflection coefficient (S11) measured by the PNAx N5242A VNA and plotted on the 10MHz-1GHz range.

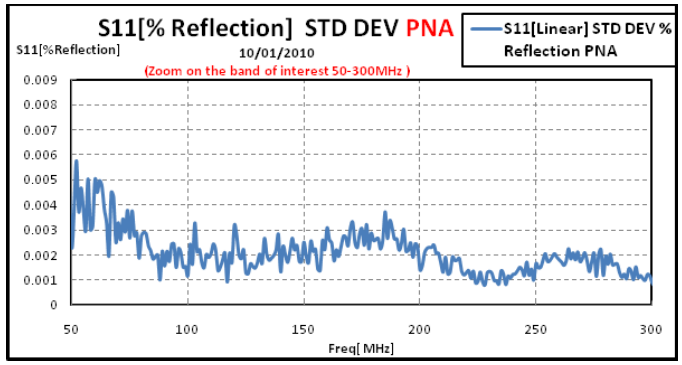


Fig6a. Standard deviation in [% reflection] of the 10 samples reflection coefficient (S11) measured by the PNA N5230A VNA and plotted on the 50MHz-300MHz range.

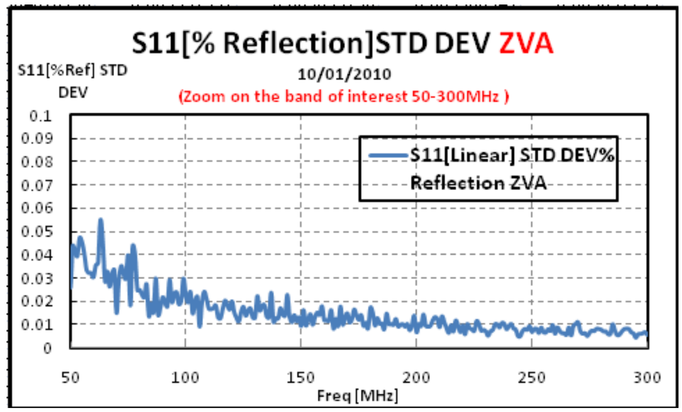


Fig6b. Standard deviation in [% reflection] of the 10 samples reflection coefficient (S11) measured by the ZVA24 VNA and plotted on the 50MHz-300MHz range.

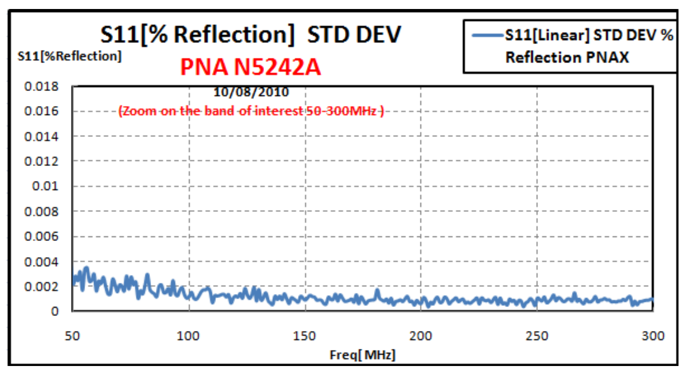


Fig6c. Standard deviation in [% reflection] of the 10 samples reflection coefficient (S11) measured by the PNAX N5242A VNA and plotted on the 50MHz-300MHz range.

The standard deviation of S11 in [dB], [Linear] and [% Reflection] are plotted on the same graphs for both instruments for comparison: Fig7a, Fig7b and Fig7c.

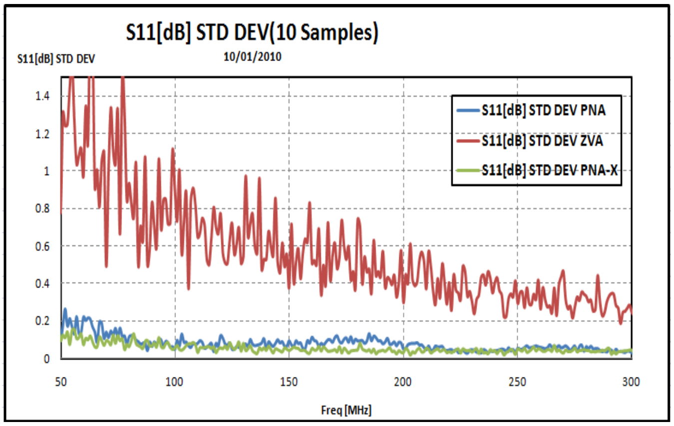


Fig7a. Standard deviation in [dB] of the 10 samples reflection coefficient (S11) measured by the PNA N5230A,PNAX N5242A and ZVA VNAs and the plotted on the 50MHz-300MHz range.

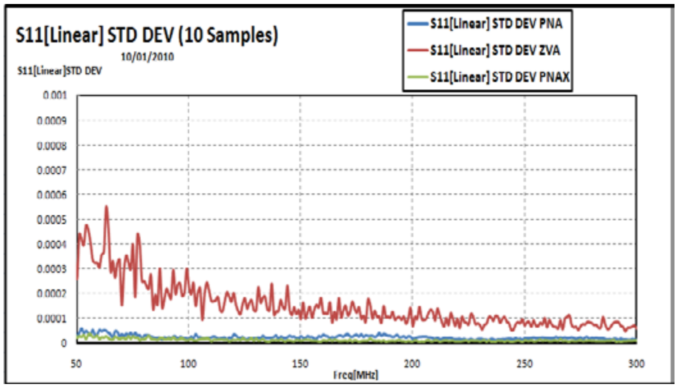


Fig7b. Standard deviation in [Linear] of the 10 samples reflection coefficient (S11) measured by the PNA N5230A ,the PNAX N5242A and ZVA VNAs and the plotted on the 50MHz-300MHz range.

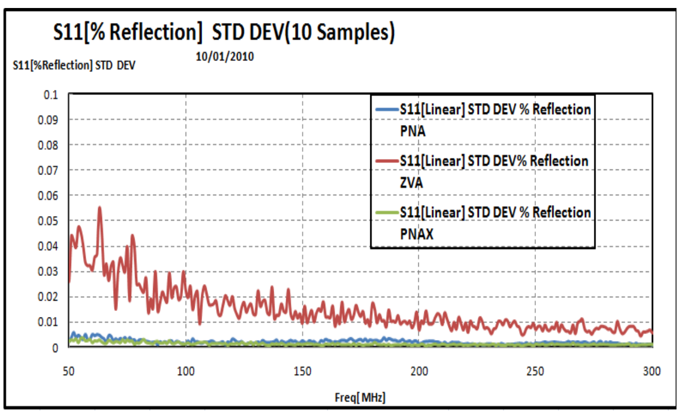


Fig7c. Standard deviation in [% Reflection] of the 10 samples reflection coefficient (S11) measured by the PNA N5230A and ZVA VNAs and the plotted on the 50MHz-300MHz range.

It is interesting to note that since the trace noise is a random phenomenon, the standard deviation of the ZVA is higher and varies more in frequency as is shown on Fig7d.

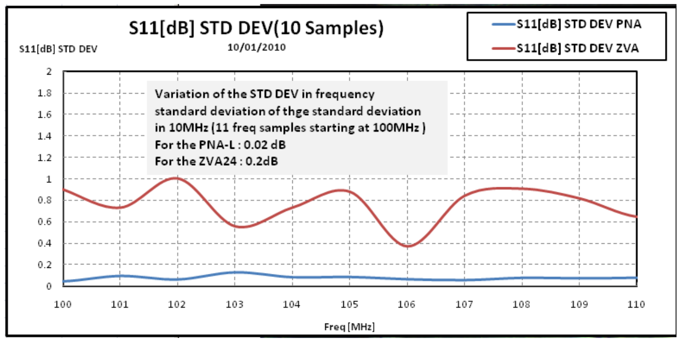


Fig7d. This plot shows how the standard deviation varies in a 10MHz bandwidth starting at 100MHz for both instruments.

Data was also taken with the averaging was turned on.
Data was taken after averaging 10 measurements for the first measurement (Fig8a and Fig8b) and 100measurements (Fig9a and Fig9c).

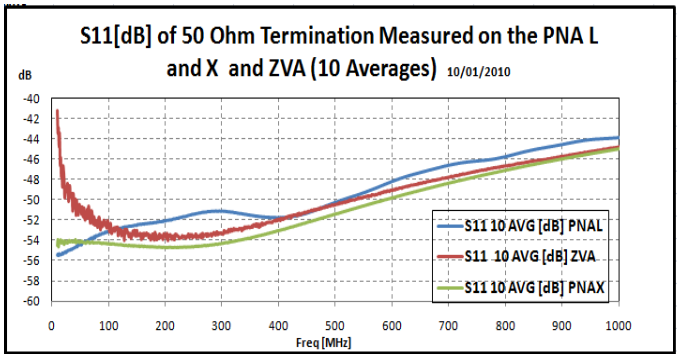


Fig8a. 10 averaged S11 [dB] measurements recorded on the ZVA24 and PNA N5230A and N5242A from 10MHz to 1GHz.

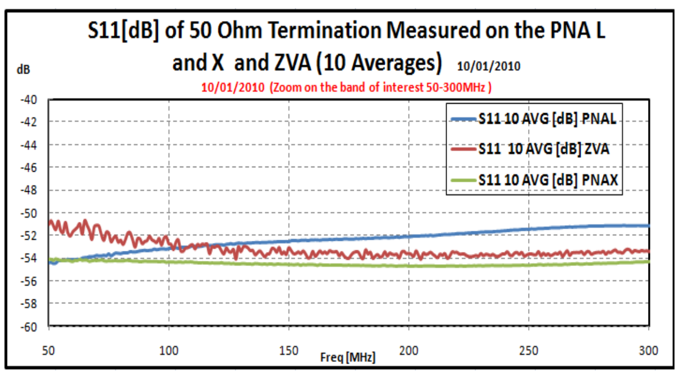


Fig8b. 10 averaged S11 [dB] measurements recorded on the ZVA24 and PNA L and X from 50MHz to 300MHz.

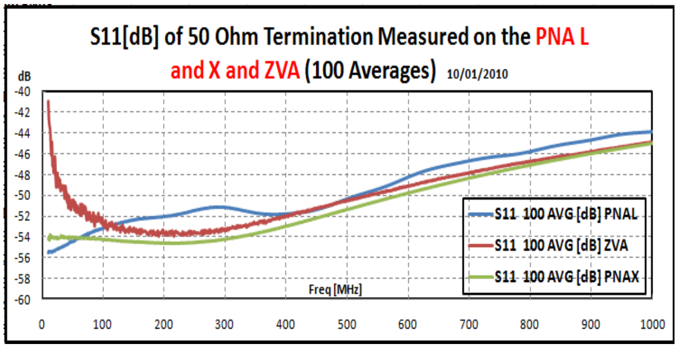


Fig9a. 100 averaged S11 [dB] measurements recorded on the ZVA24 and PNA L and X from 10MHz to 1GHz.

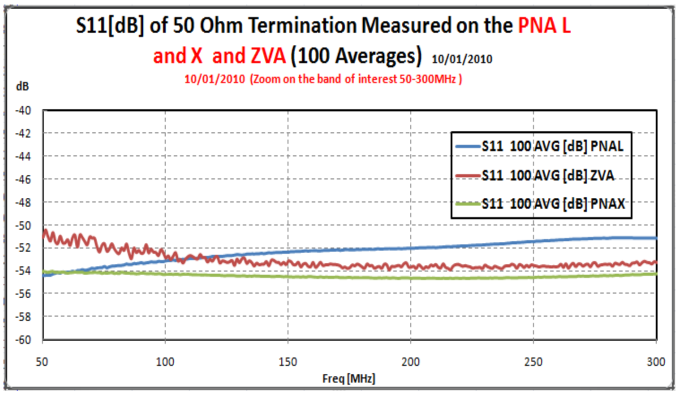


Fig9b. 100 averaged S11 [dB] measurements recorded on the ZVA24 and PNA L and X from 50MHz to 300Hz.

IV. TRACE NOISE ON THE PHASE DATA

The 10 measurements of the Phase of the reflection coefficient of the 50 ohm load with No averaging is plotted in Fig10a and Fig10b for the PNA N5230A and ZVA VNAs respectively.

The standard deviation of both measurements is shown on Fig11a and Fig11b.

The standard deviation of the phase for both instruments is shown on Fig12.
We can see that the noise of the phase measurements is higher for the ZVA24 VNA and also varies a quicker in frequency. This latter is shown on Fig12 by the width of the trace of the standard deviation curve.

The averaging was turned on and phase data was taken with 10 and 100 averaging factors.
The data for the 10 and 100 averaging is shown on Fig13a and Fig13b.

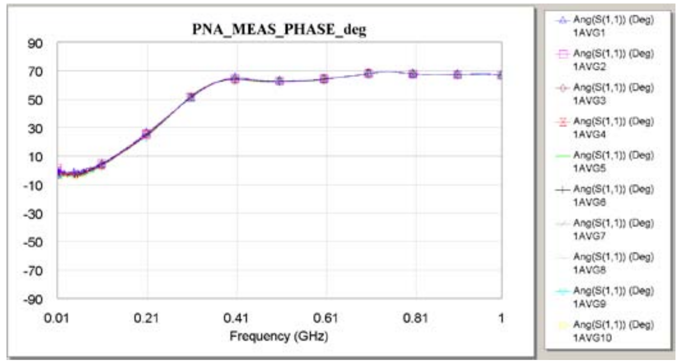


Fig10a. The 10 measurements of the phase of S11 taken with the PNA N5230A with no averaging

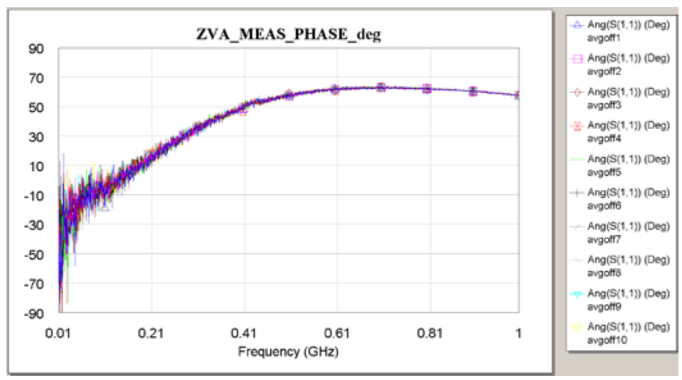


Fig10b. The 10 measurements of the phase of S11 taken with the ZVA24 with no averaging

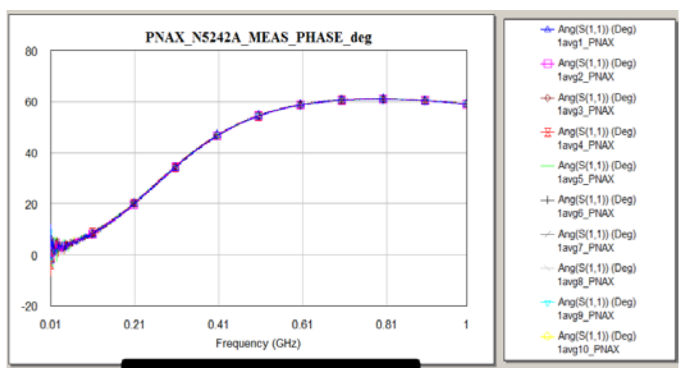


Fig10c. The 10 measurements of the phase of S11 taken with the PNAX N5242A with no averaging

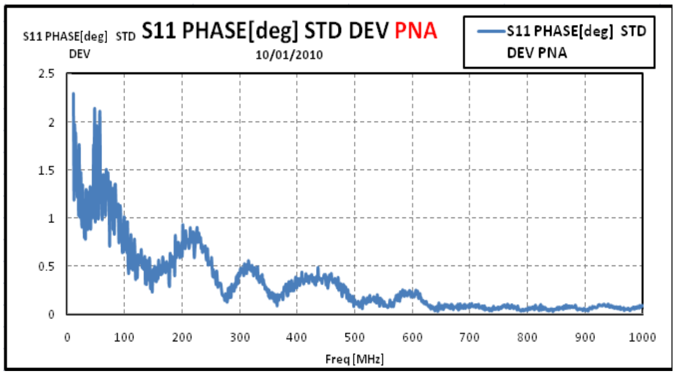


Fig11a. Standard deviation from the mean for the 10 measurements of the phase of S11 taken with the PNA N5230A with no averaging

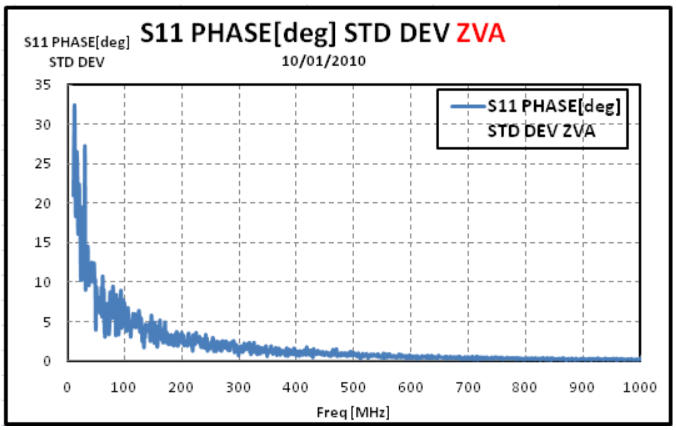


Fig11b. Standard deviation from the mean for the 10 measurements of the phase of S11 taken with the ZVA24 with no averaging

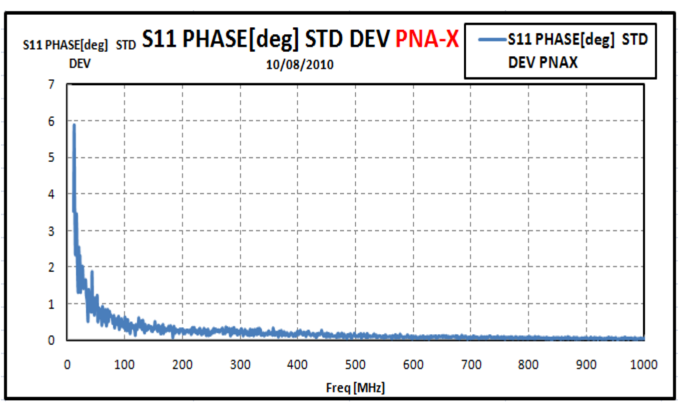


Fig11c. Standard deviation from the mean for the 10 measurements of the phase of S11 taken with the PNAX N5242A with no averaging

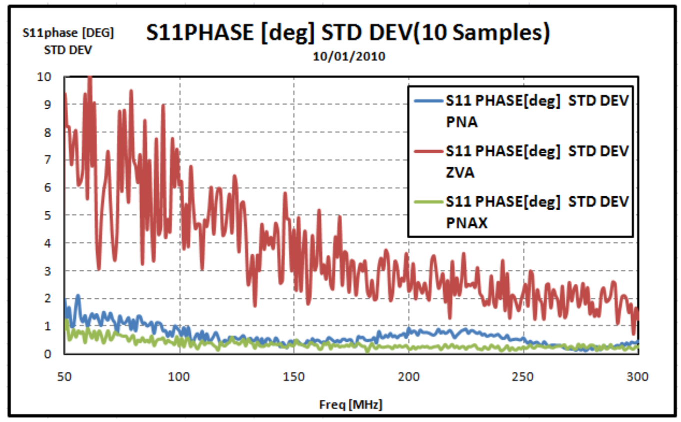


Fig12a. Standard deviation from the mean for the 10 measurements of the phase of S11 taken with all instruments and plotted on 50MHz-300MHz band with no averaging.

On Fig12b.the standard deviation is plotted on a 10MHz band starting from 100MHz.As for the magnitude data, it shows variation of the standard deviation on a narrow bandwidth

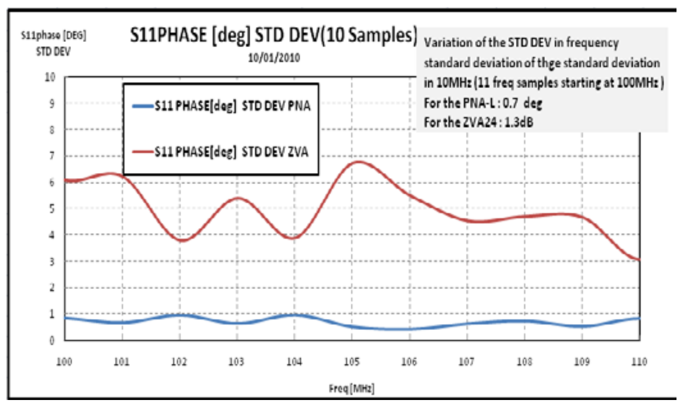


Fig12b. This plot shows how the standard deviation varies in a 10MHz bandwidth starting at 100MHz for both instruments.

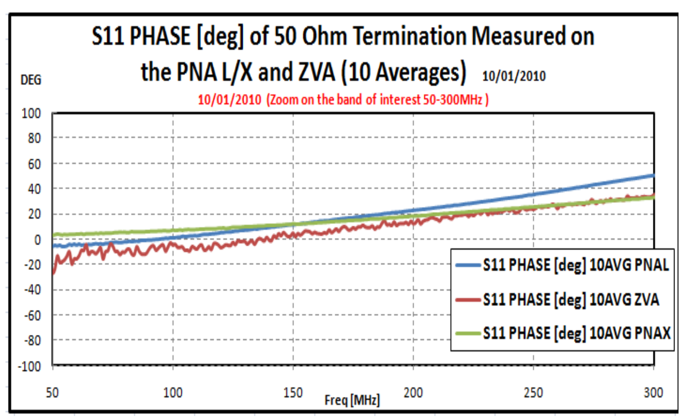


Fig13a. 10 averaged S11 PHASE [deg] measurements recorded with the ZVA24 and PNA N5230A from 50MHz to 300MHz.

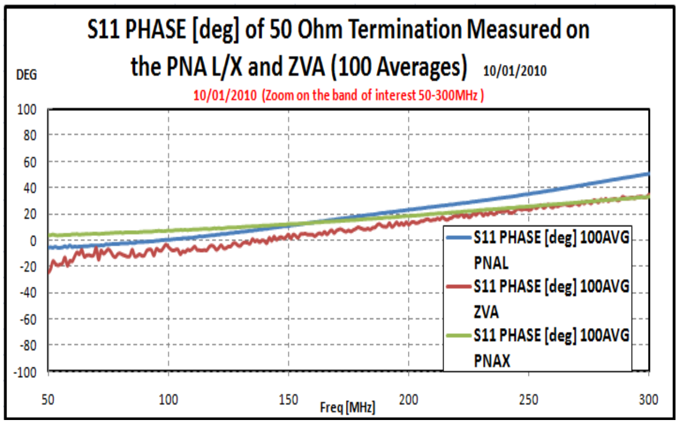


Fig13b. 100 averaged S11 PHASE [deg] measurements recorded with the ZVA24 and PNA N5230A from 50MHz to 300MHz.

V. SUMMARY OF MAIN RESULT

VNA	S11[dB] STD DEV @100MHz	S11 Phase[deg] STD DEV @100MHz
Agilent PNA-L N5230A	0.05	2.1
R&S ZVA24	0.9	6.1
Agilent PNA-X N5242A	0.05	0.3

VI. DISCUSSION

As mentioned earlier, using a matched load to check the stability of the vector network analyzer is an extreme case. In practical measurements, it is rare to encounter components or systems that have better than 25dB return loss or a reflection coefficient of 0.06 (6% reflection).
The trace noise is due to random errors and can e reduce by:

- Increasing the averaging
- Reducing the IF bandwidth: this reduces the noise floor of the VNA's receivers and improves the signal to noise ratio.
- Increasing the test port power: this improves the signal to noise ratio at the input of the VNA receivers.

VII. CONCLUSION

It seems that, although the PNA VNA showed better trace stability, both instruments are stable enough for the needed measurements.

APPENDIX

ACKNOWLEDGMENT

We like to thank the R&S application engineers and the agilent application engineers as well for giving us the opportunity to try their instruments.

REFERENCES

[1] http://www.astro.caltech.edu/~jdbowman/
[2] http://www.home.agilent.com/agilent/techSupport.jspx?pid=343726&pageMode=MN&cc=US&lc=eng
[3] http://www2.rohde-schwarz.com/en/products/test_and_measurement/network_analysis/ZVA24_%284-Port%29.html
[4]