Comparing a NanoVNA with a LabVNA Part 2: Three NanoVNAs, Two H4 NanoVNAs, and One HP 8505A VNA

N.I. Yannopoulou, P.E. Zimourtopoulos

Antennas Research Group, Austria - www.op4.eu

Abstract

The "Handheld Vector Network Analyzer" H4 NanoVNA, has a top working frequency of 1500 MHz - well above the 900 MHz of NanoVNA. This fact motivated us to carry out a comparison not only between these two ToyVNA models, but also a comparison with our LabVNA. This paper presents our comparison results regarding six different VNAs, three NanoVNAs, two H4 NanoVNAs, and one HP 8505A VNA, using the measurements of the DUT Device Under Test we use as "standard 50-Ohm box DUT" we mentioned in Part 1. Interestingly enough, these comparisons reveal various jump-discontinuities in the frequency response of all five NanoVNAs, which were unnoticed until now, because NanoVNA measurements limited to 900 MHz. In order to somehow remedy this unpleasant situation, we suggest the use of our simple solution that we already successfully applied.

Keywords

Microwave measurements, network analyzer, differential error region, differential error interval, calibration, NanoVNA

Introduction

The very encouraging results we got from comparing the measurements of the same DUT with both our LabVNA and our NanoVNA, the 50-Ohm box, in the frequency range 0.05 - 900 MHz, led us to decide to acquire the new NanoVNA H4 model, and attempt the same measurements with it in order to extend the measurements to frequencies up to 1500 MHz. Thus, a new comparison will cover the whole frequency range of our LabVNA up to 1300 MHz.

In our previous work we tried to gain confidence in the device results by establishing that the S-parameter model for one-port measurements is the well-known model, the same used in measurements with a LabVNA. Here we will try to gain confidence in the operation of the device itself by presenting results from two different H4 NanoVNAs as well as comparative results from three different NanoVNAs of the first model up to 900 MHz. A problem that came out with the H4 model concerns the transition from one frequency band of operation to the other, a fact that did not receive much attention in the first NanoVNA model due to its small to negligible effect on the final results.

In an attempt to highlight this issue, we will present a more detailed presentation of the initial measurements of the calibration loads for the two different models. We will propose an a posteriori way to deal with this rather annoying but clearly technical problem.

It is worth noting that the new, advanced model was accompanied by many additional useful functions as well as a fairly detailed description of how it works [1], [2], so there is no need to repeat what is already publicly available. For the measurement process, we applied the same technique for collecting and saving the initial data on our computer as described in detail in [3]. We will limit ourselves to report the small differences in the order of manipulations on the screen of the H4 NanoVNA only for the procedure we used and detailed presented in [3].

Finally, the intermediate quantities, D, M, R are presented in comparison for all used NanoVNAs while the promised attempt to give a graphical hint for the analogy between the two technological totally different instruments, LabVNA and NanoVNA is left for the forthcoming future.

Significant differences of H4 NanoVNA model

As mentioned above, of the many interesting changes and additions of functions of the H4 NanoVNA model, such as the ability to save to or load from an SD Card, to choose a connection method e.g. USB, a series of different settings via the CONFIG option of the MENU, etc., we will limit ourselves to listing only the differences that are directly related to the measurement procedure we adopted in [3]. Thus:

1. The first significant change concerns the number of possible measurement points in sweep mode: from the fixed number of 101, the option of selecting 51, 101, 201, 301 and 401 points is now available.

2. RECALL has been separated from SAVE:

MENU → RECALL

where it is possible to have six different calibration sets and to load calibration from a SD CARD

[LOAD FROM SD CARD].

You can only do SAVE through the option:

MENU → CALIBRATE → SAVE

3. To apply or not the calibration:

MENU → CALIBRATE → APPLY

where APPLY has a check box and the corresponding symbol Cx appears on the left of the screen in white colored letters depending on the location where the calibration was saved or it does not appear and the letters turn red. It is still a toggle key but now with the check box it is clear what values you get on screen or with the [data] command through PuTTy.

4. PAUSE SWEEP is now done directly from the initial MENU with a check box too:

MENU → PAUSE SWEEP

Finally, the virtual COM port in device manager of windows is explicitly referenced as "NanoVNA-H4", as it is shown in Fig. 2. Fig. 1 shows Putty's console window after [info] command.

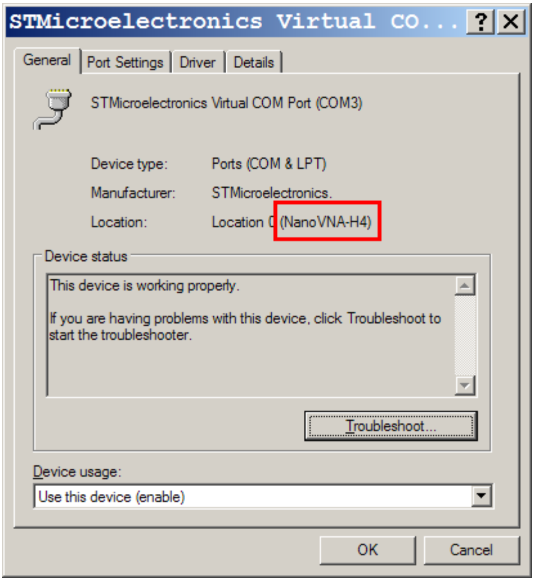

Fig. 1: COM Port for NanoVNA in Device Manager of Windows

Fig. 2: PuTTy's console window - [info] command

NanoVNA measurements

The procedure used for all the presented below measurements either with the initial model or with H4 model of NanoVNA was the same as described in detail in our previous work [3].

a. Three initial models

The first encouraging results with NanoVNA [3] led us to repeat the test procedure for two more instruments of the same model. The DUT was the same 50-Ohm Box and the same Type-N male SLO standards with the same SMA-male to Type-N-female adapter were used for calibration, keeping the same reference plane. The frequency range was 0.05 to 900 MHz.

Fig. 3 shows the reflection coefficient in the complex plane as S_{11} and Fig. 4 the impedance Z in real R and imaginary X part for the three (3) NanoVNAs. The symbols #1, #2, #3 and an "1-1" correspondence with the colors Red, Green, Blue were used to describe the results for each NanoVNA. The comparison of reflection coefficient results between the three different NanoVNAs and our LabVNA together with the stripe of our LabVNA Differential Error Regions, DERs, and some selected DERs, is given in Fig. 5 in the complex plane. In Fig. 6 the corresponding results for the impedance with the LabVNA rectangular Differential Error Intervals, DEIs, for R and X are shown.

Apparently there is a very good agreement both between the tested three different NanoVNAs and with our LabVNA.

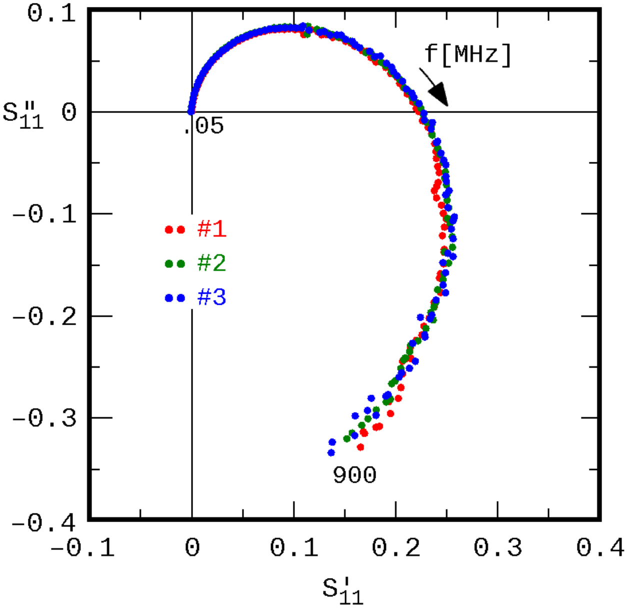

Fig. 3: S_{11} - Three NanoVNAs

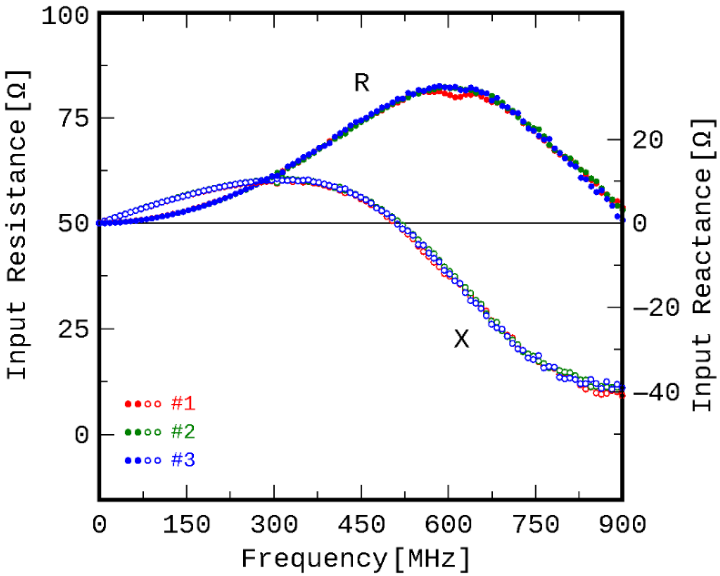

Fig. 4: Impedance - Three NanoVNAs

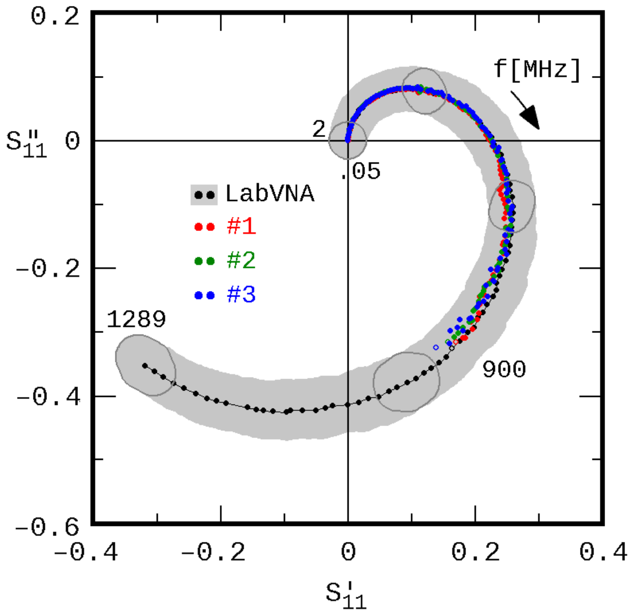

Fig. 5: S_{11} - Three NanoVNAs with LabVNA

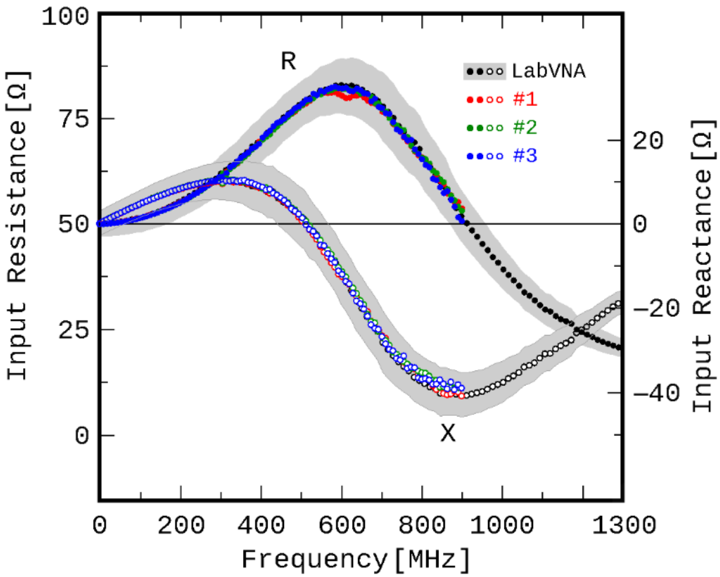

Fig. 6: Impedance with rectangular DEIs - Three NanoVNAs

However, a closer view in the region of frequencies where a transition is taken place due to the harmonics used in order to achieve frequencies up to 900 MHz, that is nearby 300 MHz, revealed a small discontinuity - "jump", which was not noticed in our previous work since its effect to the final results of reflection coefficient and impedance was insignificant. It is only after the use of the new H4 model that we realized the its existence.

Short circuit s and open circuit o are the standard loads that show this jump most strongly in their measurement. Fig. 7 shows the magnitude of the measured s and o. The closed points represent the s values while the open points the o values. The color correspondence is as mentioned above for the three NanoVNAs. The gray vertical line delimits the region where the jump occurs.

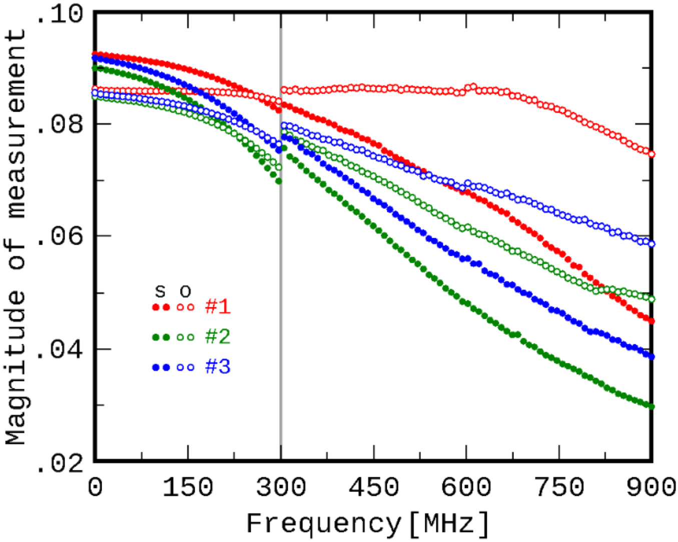

Fig. 7: Magnitude of s, o measurements - Three NanoVNAs

b. Two H4 models

The first tests with the H4-model was done for the frequency range 2 - 1302 MHz with 101 sweep points, that is, with a step of 13 MHz, in order to take measurements at the same frequencies with our LabVNA. Following exactly the same procedure for the two (2) available instruments as described above, Fig. 8 shows

S_{11} in the complex plane, and Fig. 9 the impedance Z as R, X parts. The symbols #4 and #5 together with dark red and dark blue color respectively were used for these H4 NanoVNA. Fig. 10 contains the compared results between the three NanoVNAs, the two H4 NanoVNAs and our LabVNA and Fig. 11 the corresponding comparison for the impedance as R and X where the shown DERs and DEIs belongs to our LabVNA error estimations.

A good agreement both between the tested two different NanoVNAs and with our LabVNA still exists for frequencies up to 900 MHz and even up to 1300 MHz the agreement can be considered acceptable. However, for the higher range there is a difference both between the two NanoVNAs and with our LabVNA, that worth a further attention. Now a jump near 900 MHz is immediately apparent, that is, about the frequency where a second change in the used harmonic takes place, and the small jump around 300 MHz has no effect on the results again. Fig. 12 shows the magnitude of the measured s and o. The two gray vertical lines delimit the regions where the two jumps occur.

It is worth noting that the consequence of these jumps, especially the second one at ~900 MHz, is that the curve for S_{11} and thus for R, X too, shifts upwards, i.e. takes higher values and is driven outside the DEIs and DERs, as shown in Fig. 10 and 11. The question is: what can be done in this case?

c. H4 frequency jumps

We followed a series of tests starting from the simplest and fastest and ending with the most complex and time consuming:

1. We used the smoothing filter [4] option which is one of the additional features of H4 model:

MENU → DISPLAY → DATA SMOOTH → SMOOTH Arith avg

or by clicking on it

→ SMOOTH Geom avg

and then one of the option buttons ×1, ×2, ×4, ×5, ×6 is selected.

We successively applied all available filters to the reflection coefficient after calibration. Of the 5 filters with arithmetic average, the one that seems to best approximate the LabVNA curves is ×5, while of the 5 available filters with geometric average, the closest is ×2.

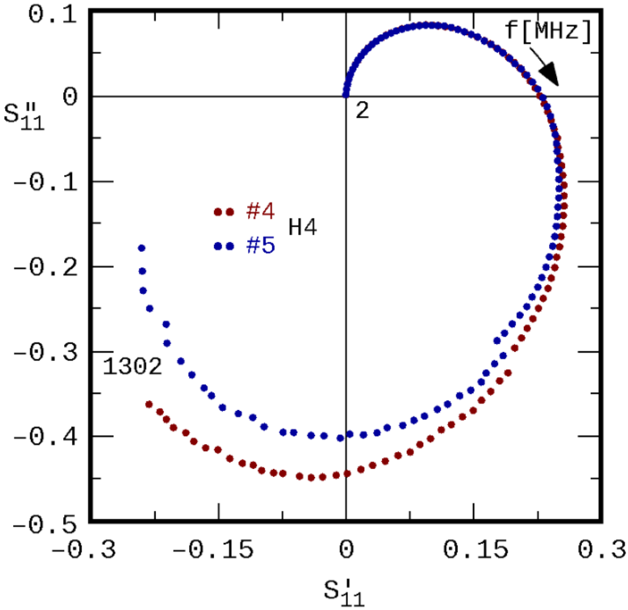

Fig. 8: S_{11} - Two H4 NanoVNAs

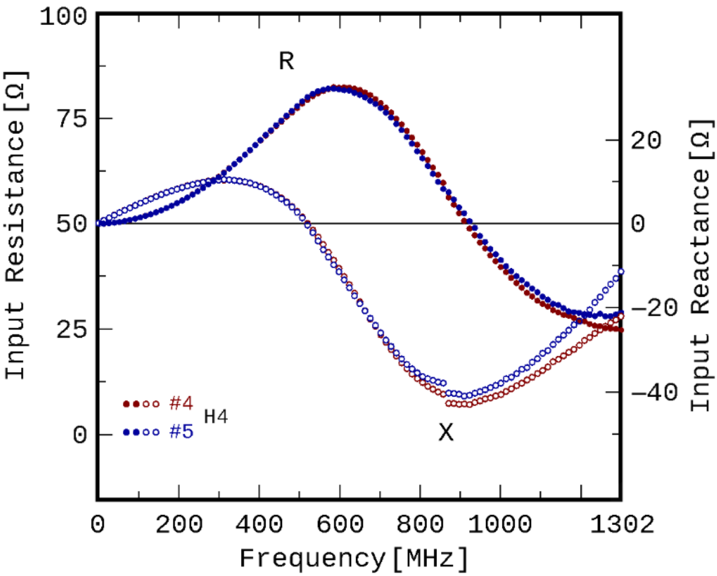

Fig. 9: Impedance - Two H4 NanoVNAs

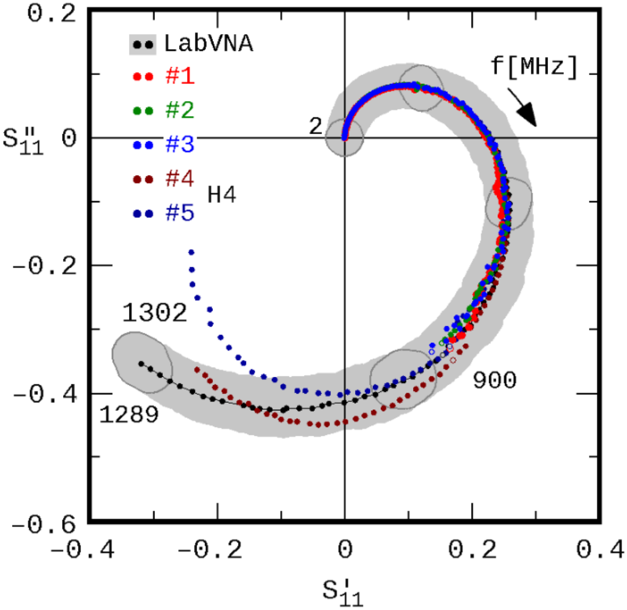

Fig. 10: S_{11} - comparison between six VNAs

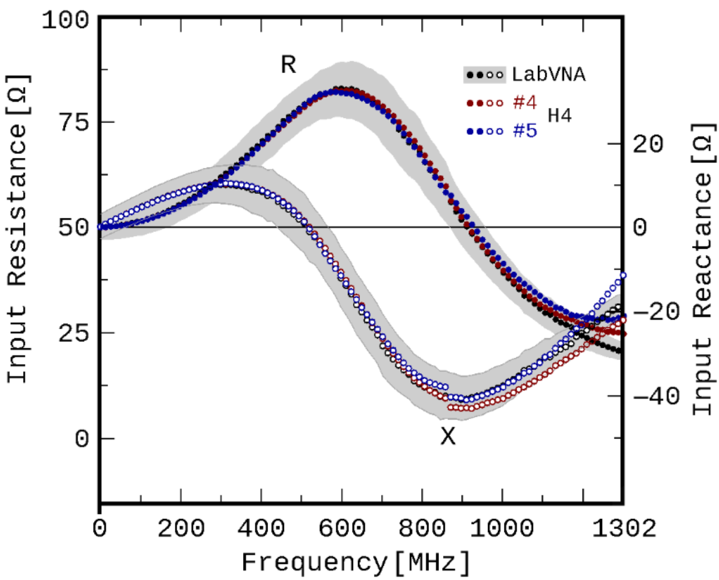

Fig. 11: Impedance with rectangular DEIs – Two H4 NanoVNAs

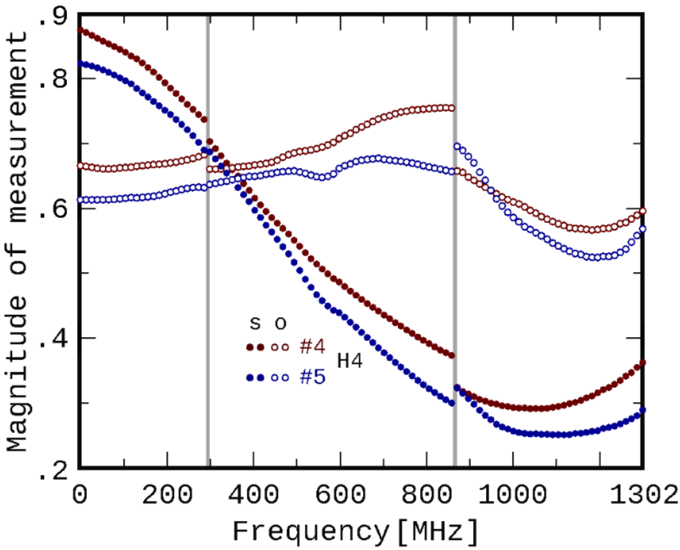

Fig. 12: Magnitude of s, o measurements – Two H4 NanoVNAs

Fig. 13 shows the results for both filters along with the reflection coefficient from H4 and LabVNA while in Fig. 14 four frames of Fig. 13 are given, focusing on the two frequency ranges where the jump occurs. In (a) and (b) the results for A×5 and G×2 are given separately in the second frequency region around 900 MHz respectively, while in (c) are shown together. The LabVNA S_{11} is shown in black, the corresponding H4 in dark blue, the A×5 result in red and the G×2 in blue. In (d) the result of both filters are shown for the region around 300 MHz. In this region we do not observe any disturbance in the initial results and the filters do not have any effect.

These filters were used here abusively and for the sake of completeness. It cannot be a general solution since it is not possible to know in advance the behavior of an unknown load. In this specific case it was possible to decide A×5 or G×2 may have a positive effect.

2. We repeated the measurements for #5 at 401 points in 2 - 1302 MHz range. The result was the same with greater detail as shown in Fig. 15 for R, X and in Fig. 16 for the s, o measurements. The jump interval was reduced considerably as we will see in Tab. 1 below.

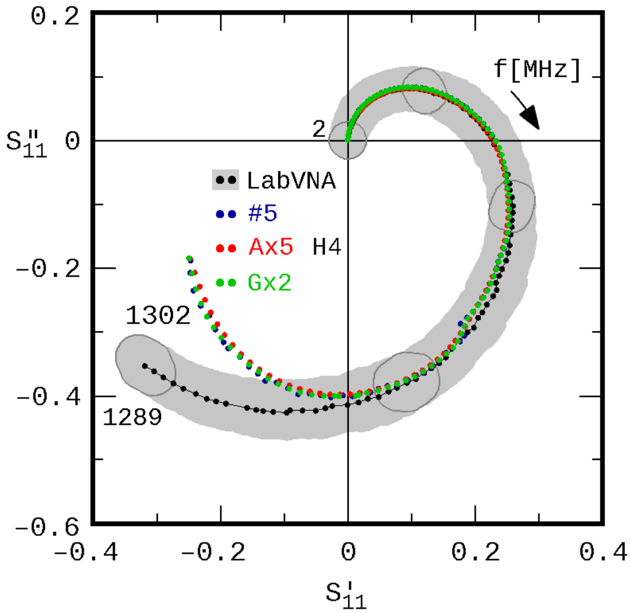

Fig. 13: S_{11} with A×5, G×2 filters for #5 H4 NanoVNA

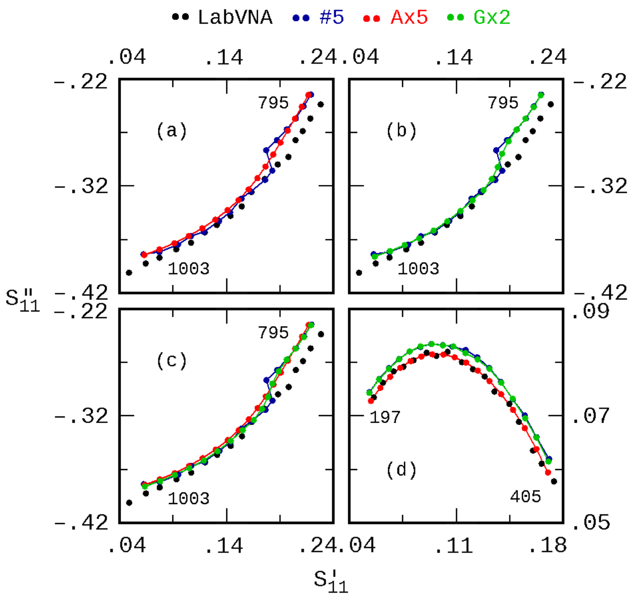

Fig. 14: Frames of A×5, G×2 filters for #5 H4 NanoVNA

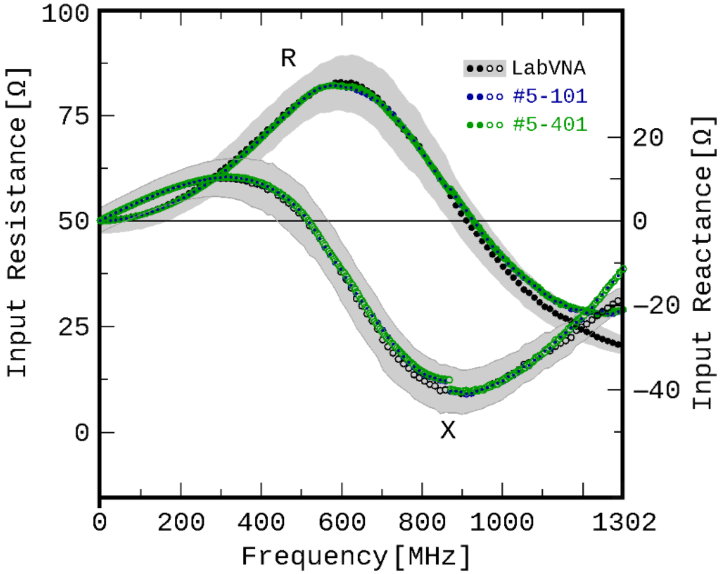

Fig. 15: Impedance of #5 H4 NanoVNA

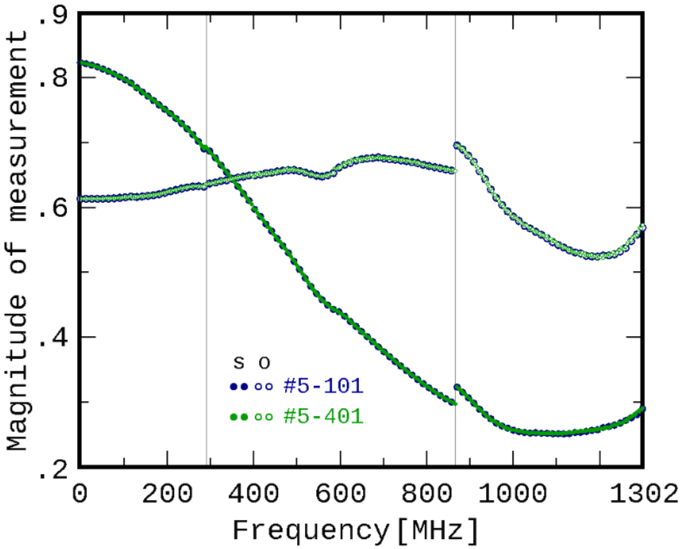

Fig. 16: Magnitude of s, o measurements #5 H4 NanoVNA

3. Since all the previous measurements were taken with IF BW = 1000Hz we changed it to the lowest possible value, 30 Hz, in order to achieve the largest time margin for the measurements. The same results for #4 in 2 - 1302 MHz at 101 points were obtained as shown in Fig. 17 for R, X.

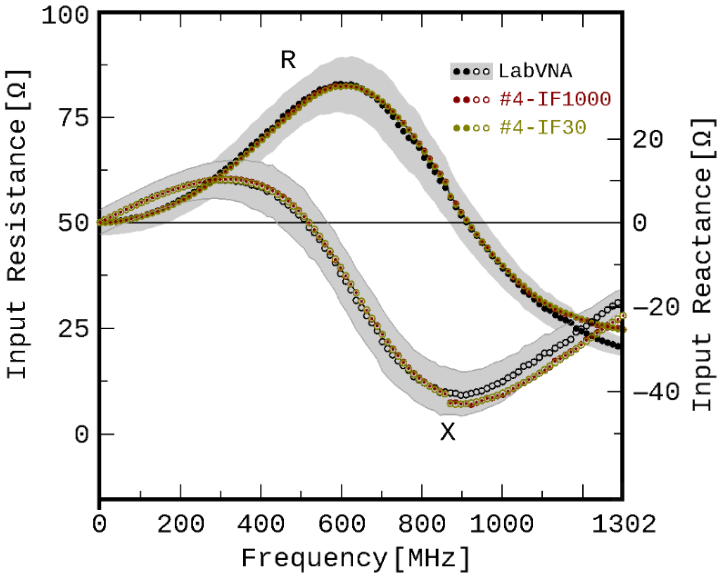

Fig. 17: Impedance of #4 H4 NanoVNA with IF-BW = 30Hz

4. We measured both #4, #5 over the entire available frequency range 0.05 - 1500 MHz with 401 sweep points and IF BW = 30 Hz. Fig. 18 gives S_{11} where the dashed gray line indicate the jump, Fig. 19 shows R, X and Fig. 20 the s, o measurements. The jumps are 3 three with the third to appear towards the end of the band around 1450 MHz (Tab. 1).

5. We measured #4 again with 101 points in the three ranges: 288 - 301, 860 - 873 and 1445 - 1455 MHz where a jump occurs. Thus we managed to get closer to the jump point, as shown in Tab. 1. Then we simply shifted the parts of the curves by the constant vector of the difference between the jump points on either side and the result is shown in Fig. 21 in 3D for S_{11} and in Fig. 22 for R, X and this is what may be expected from a LabVNA above 1300 MHz, which we do not have at the moment.

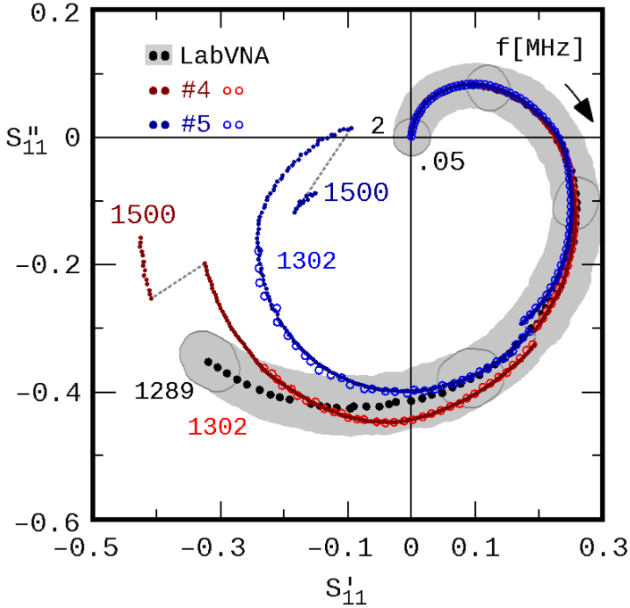

Fig. 18: S_{11} for #4, #5 H4 in full band

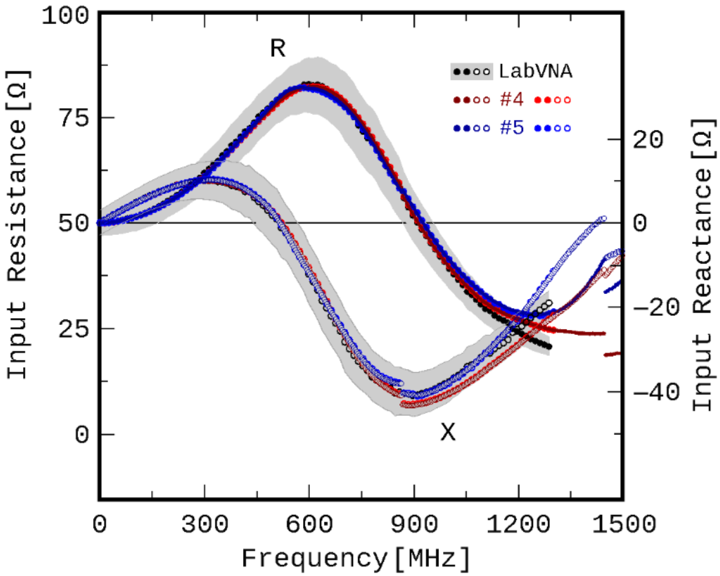

Fig. 19: Impedance of #4, #5 H4 in full band

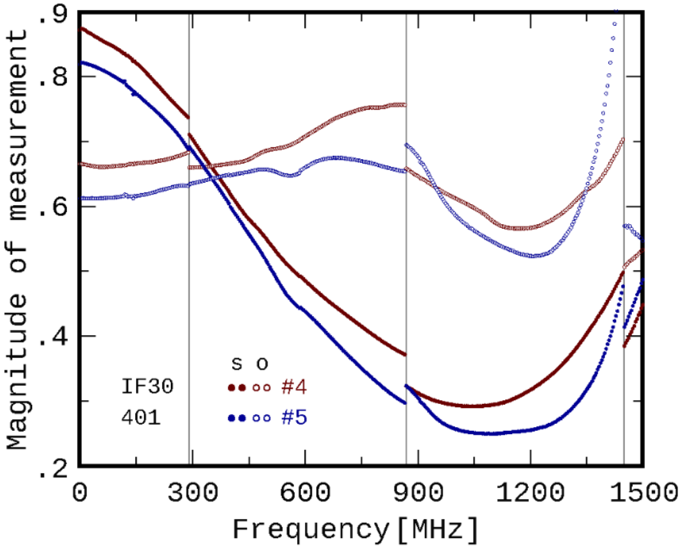

Fig. 20: Magnitude of s, o measurements in full band

Tab. 1: "Jumps" - Discontinuities in frequency bands

f [MHz]	#po	Band 1 [MHz]	Band 2 [MHz]	Band 3 [MHz]
2 - 1302	101	288 - 301	860 - 873	-
2 - 1302	401	288 - 294.5	869.75 - 873	-
0.05 - 1500	401	288.79 - 292.54	866.27 - 870.02	1447.50 - 1451.25
288 - 301	101	289.95 - 290.08		
860 - 873	101		869.88 - 870.01	
1445 - 1450	101			1450.0 - 1450.1
Approximately		290	870	1450

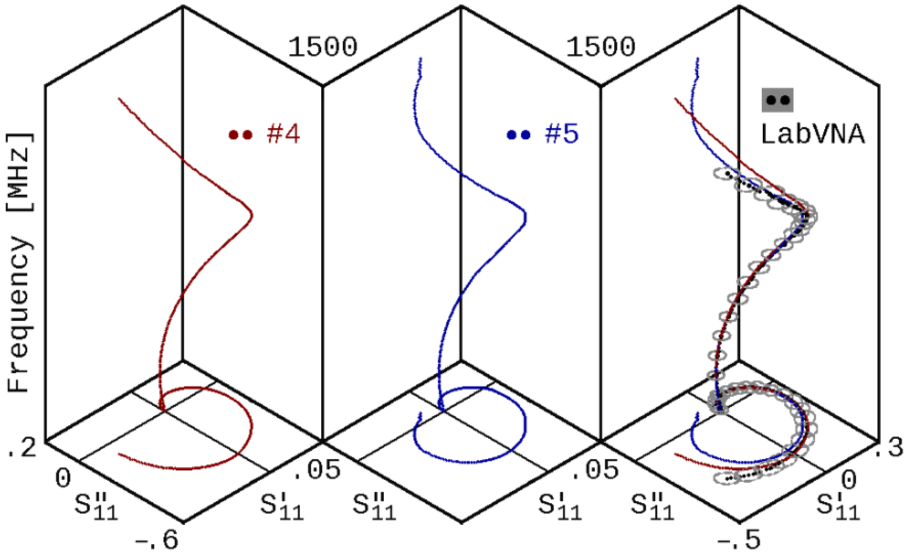

Fig. 21: S_{11} for #4, #5 H4 in full band after shift

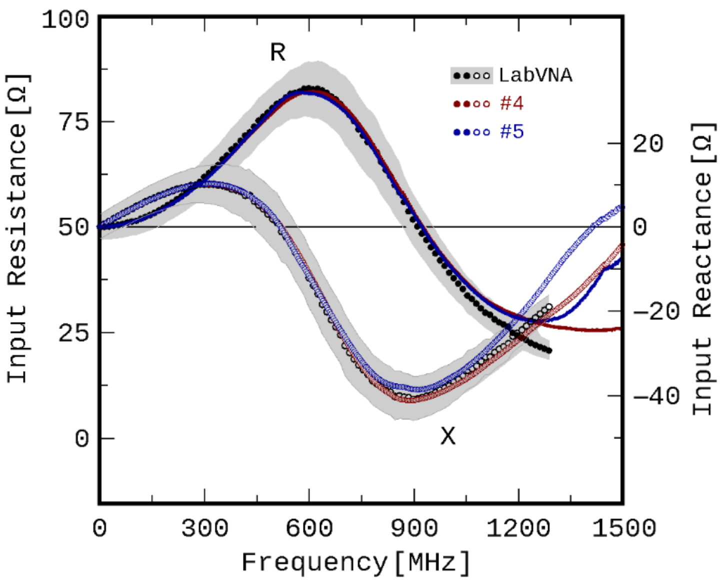

Fig. 22: Impedance of #4, #5 H4 in full band, after shift

D,M,R

Fig 23 shows the intermediate quantities D, M, R (Directivity, source Match and Reflection tracking error) of our LabVNA in 3D and 2D, repeated here from [3] for the sake of completeness and to better highlight the difference of these quantities in the two different measurement systems LabVNA and NanoVNA. Fig. 24 and Fig. 25 shows D, M, R of the three initial models of NanoVNA and of the two tested H4-NanoVNA models, respectively. Finally, the D, M, R in full band are given in Fig. 26. As has been already pointed out in [3] the difference between LabVNA and NanoVNA did not affect the result for the reflection coefficient and impedance. From these figures it is also obvious that there is a similarity between all the tested NanoVNAs. Further discussion for this matter will be follow in a future work.

Conclusion

Three different NanoVNAs of the initial model were measured and there is essentially no significant difference in their behavior. On the contrary, regarding the two H4 models that we tested, a deviation has been observed not only in the size of the "jumps" that appear and are now significant, especially at higher frequencies but also to their measurement results, at those frequencies. Thus, #5 presented smaller jumps but seems to be further away from the measurement with the LabVNA for frequencies above 900 MHz than #4. In general, up to 1300 MHz we conclude that the impedance results can be considered as acceptable while it is remarkable that up to 900 MHz all the NanoVNAs exhibit almost the same behavior and a very good agreement with our LabVNA measurements.

The extended measurements in full band 0.05 to 1500 MHz proved to be possible and stable only when we set the IF Bandwidth to the lowest value of 30 Hz, that is, when an increased time interval was given to the NanoVNA to stabilize the measured value. We have to repeat here that in our LabVNA we used the CW mode to take the measurements and not the sweep mode, in order to gain as much stability -that is accuracy- as possible. In NanoVNAs we have not yet try this mode. Thus, the comparisons conditions are not exactly equivalent even in the case of the H4 models where we succeeded in taking measurements in the 2 - 1302MHz range with a step of 13 MHz, just like in our LabVNA.

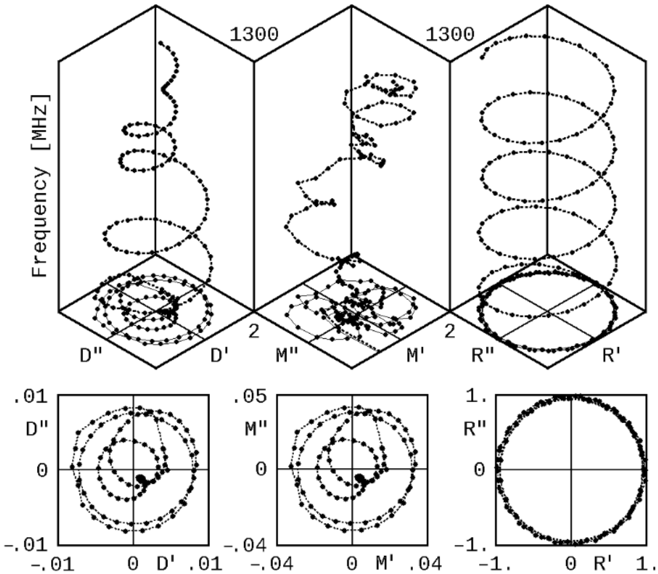

Fig. 23: D, M, R for LabVNA

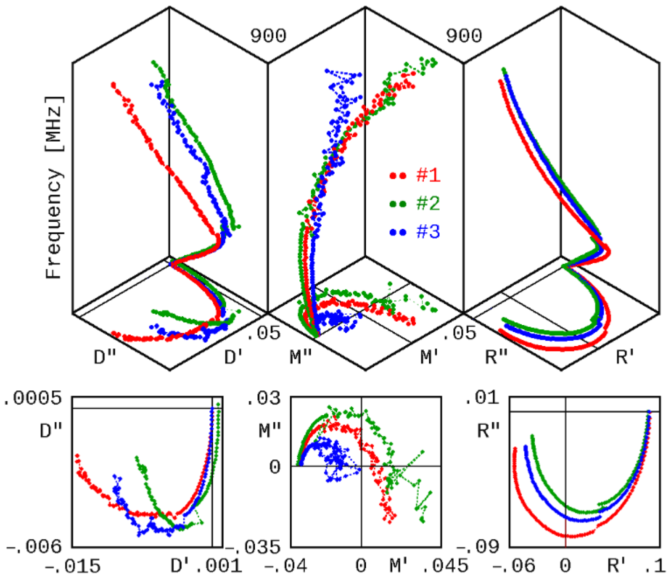

Fig. 24: D, M, R of #1, #2, #3 NanoVNAs initial model

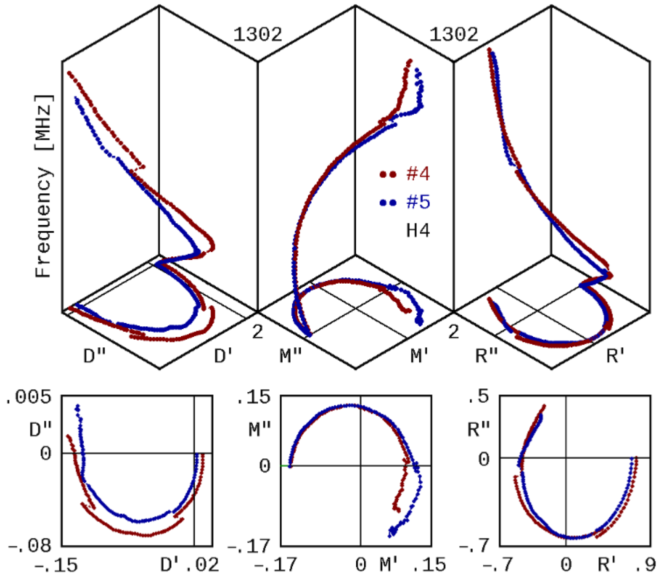

Fig. 25: D, M, R for #4, #5 H4 NanoVNA model

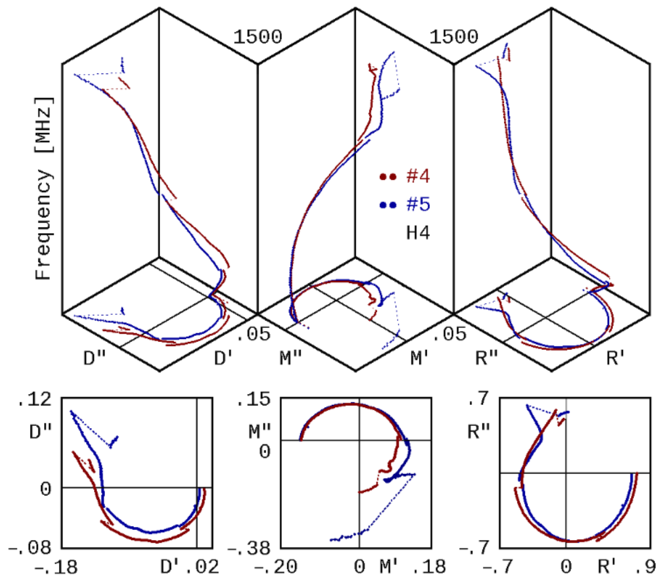

Fig. 26: D, M, R for #4, #5 H4 NanoVNA model in full band

In Tab. 1, some comparisons are given for the bands where the discontinuities - jumps appeared, which also shows the possibility of reducing the width of the jump band and even to determine one frequency where the jump occurs: 290 MHz, 870 MHz and 1450 MHz. We proposed a simple way to deal with the "jump" problem, introducing only a shift-transfer on the results which proved to be adequate for this convenient, closed, passive load of nominal value 50-Ohm, while perhaps these jumps add an extra twist-rotation to the complex measured values. We decided to leave for the future the observations on the presented intermediate quantities of D, M, R and the search for analogies between the two totally different generations of vector measurement systems, LabVNA and NanoVNA for either the original model or the more sophisticated H4 model.

References

[1] "NanoVNA - Very tiny handheld Vector Network Analyzer" "https://github.com/DiSlord/NanoVNA-D"

[2] "NanoVNA User Guide" "https://cho45-github-io.translate.goog/NanoVNA-manual/?_x_tr_sl=ja&_x_tr_tl=en&_x_tr_hl=de"

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