nanoVNA Calibration Standards

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1. Introduction

The nanoVNA is an inexpensive and very popular vector network analyzer (figure 1). I purchased the AURSINC nanoVNA-H4, which is one of many implementations of the nanoVNA platform. According to the Amazon listing, the -H4 has a 4 in (100 mm), 480x320 pixel TFT display and a 1950 mAh rechargeable battery. Its native frequency range is advertised as 10 kHz to 300 MHz with measurements up to 1500 MHz by using harmonics. The nanoVNA has some limitations, such as being capable of only 101 measurement points, but it is hard to beat the price at less than 100 USD.

Figure 1 ~ nanoVNA-H4 and measurement accessories supplied with it. These include two RG-316, 150 mm long coaxial jumper cables with SMA male connectors, SMA male Open, Short and Load calibration standards, and an SMA female barrel connector. It also included a couple USB cables and a Quick Start Guide (not shown). Note the guitar pick on the lanyard to be used as a stylus. I prefer a soft-tip stylus and added the one shown above the unit. The calibration standards have an identical outward appearance so I color-coded them with fingernail polish for easy identification: Blue = Load; Red = Short; and White = Open. The SMA barrel connector, seen to the left of the Load, is not strictly part of the calibration standards but is necessary for Thru calibration and when using the standards with cables or devices that have male connectors. I also marked the two coaxial jumper cables red and green for identification. Image © 2021 W. Reeve

The nanoVNA assumes that all calibration standards are ideal. It has no provisions for entering the electrical characteristics (capacitance, inductance, resistance), and no such data are provided or available for the nanoVNA. The nanoVNA does have a Port Extension feature for entering delay.

Because of the low cost and lack of calibration features, I was quite skeptical about the quality of the supplied calibration standards and decided to measure their reflection coefficient (S11 scattering parameter) with a professional instrument. I report the measurements here. I also compare measurements of the nanoVNA jumper cables to similar measurements with precision test cables. This article is focused on the calibration standards and does not discuss the performance of the nanoVNA itself. Readers should note that, because of there are many nanoVNA versions, there also may be many versions of the calibration standards. The measurements and other information provided in this article may or may not apply to other versions.

2. Measurements Setup

I used a Keysight FieldFox N9917A Microwave Analyzer in *Network Analyzer* mode for all measurements. The FieldFox was setup for 50 kHz to 1500 MHz frequency range and 1001 measurement points. I set markers at 1000 MHz (arbitrary) and 1420 MHz (corresponding to the 21.1 cm wavelength of neutral hydrogen emissions). All measurements involved reflection coefficients displayed in dB. My discussions use the equivalent return loss, where Return loss (dB) = |Reflection coefficient (dB)|.

For FieldFox calibration I used an HP 85033D 3.5 mm Calibration Kit and a type N-M to SMA-F adapter to adapt the FieldFox connector to the SMA connectors on the nanoVNA calibration standards and jumper cables. Unlike the nanoVNA calibration standards, the HP Calibration Kit is fully characterized. Its characteristics are stored on the FieldFox and recalled when needed. The adapter was part of the FieldFox calibration and all measurements. Because the nanoVNA calibration standards are male gender, I used the SMA female barrel connector (coupler) supplied with the unit to connect the standards to the coaxial jumper cables

The nanoVNA barrel connector does not appear to be special in any way, and serious users of the nanoVNA should consider replacing it with one of higher quality (figure 2). The connector does not have flats for a wrench so it is impossible to properly torque connections to it. Where the barrel connector was required, I only could make the connections finger-tight. Its characteristics (whatever they are) are included in the measurements discussed below.

Figure 2 ~ nanoVNA SMA barrel connector (upper-right) alongside a high-quality connector. The brass nanoVNA connector has no flats for a wrench and cannot be properly torqued. The RF Industries model RSA-3404 nickel-plated brass connector shown next to it has flats for a 5.5 mm wrench. I made all connections involving the brass barrel connector finger-tight. Image © 2021 W. Reeve

3. Calibration Standards and Cable Measurements

In this section I discuss the measured return loss for each standard, the two nanoVNA jumper cables alone, and the two jumper cables with the Load standard connected.

The three calibration standards showed very good results throughout the measurement frequency range (figure 3). The return loss of the Open and Short are very close to zero, as expected. The return loss of the Load is nearly 44 dB at 1420 MHz (equivalent to a VSWR of 1.013:1) and better than 41 dB throughout the entire measurement frequency range. The two jumper cables showed no unusual behavior when measured alone (figure 4) but, when connected to the Load, they markedly reduced the return loss of the Load from 44 dB to 20 dB at 1420 MHz (figure 5). The measurements of the cable and Load combination also showed some resonant effects that were not obvious when the cables were measured alone.

The nominal attenuation of RG-316 cable at 1420 MHz is 1.03 dB/m so, for a 150 mm long cable without connectors, the 1-way attenuation would be near 0.15 dB. With total reflection at an open end, the return loss would be double the 1-way attenuation or 0.3 dB. Connectorized cables will show slightly higher attenuation due to the connectors, particularly at higher frequencies. The measured return loss was 0.43 and 0.42 for the open-circuited cables, well within expectations when the connectors and instrument accuracy are taken into account.

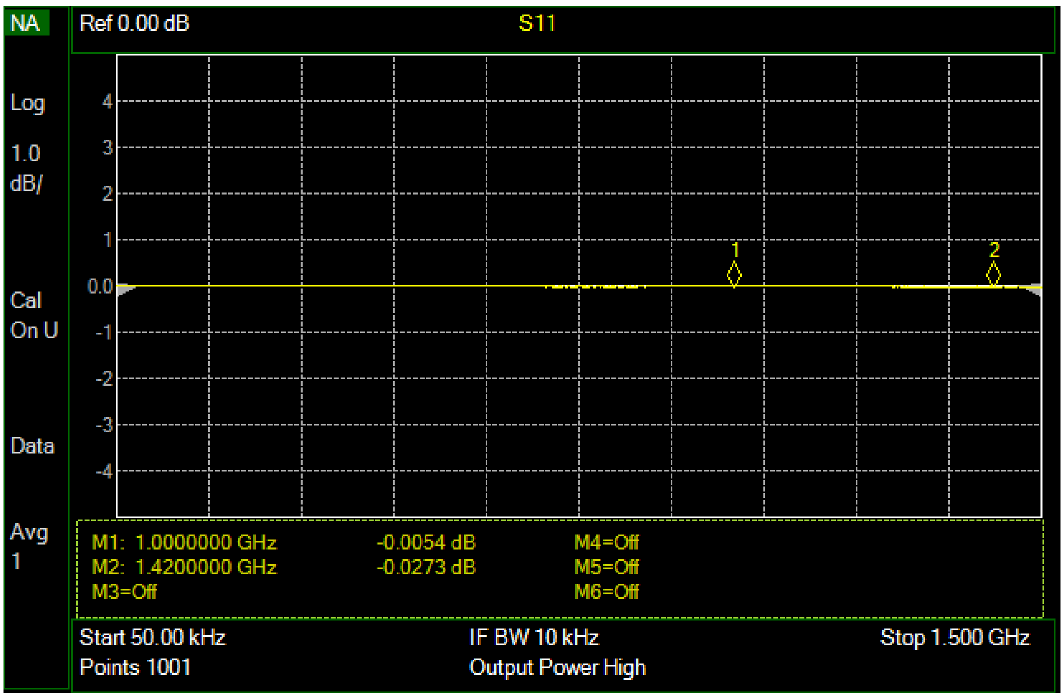

Figure 3.a ~ nanoVNA Open standard. Vertical scale is 1 dB/div with the reference (at center) set to 0.0 dB. These measurements are for direct connection of the Open standard to the FieldFox port adapter.

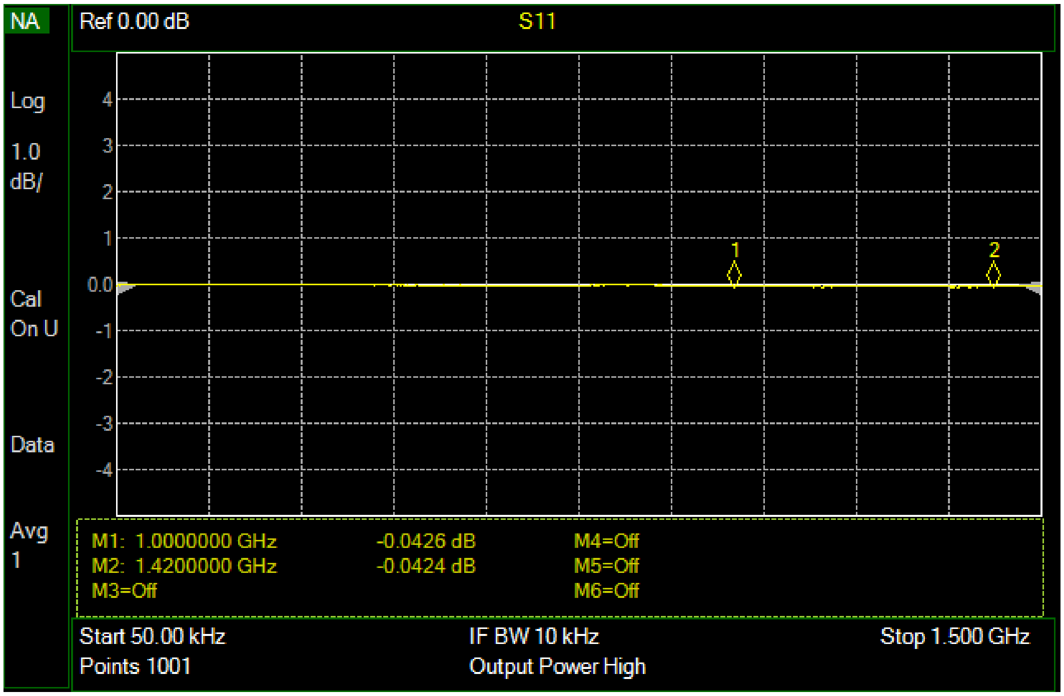

Figure 3.b ~ nanoVNA Short standard. Vertical scale is 1 dB/div with the reference (at center) set to 0.0 dB. These measurements are for direct connection of the Short standard to the FieldFox port adapter.

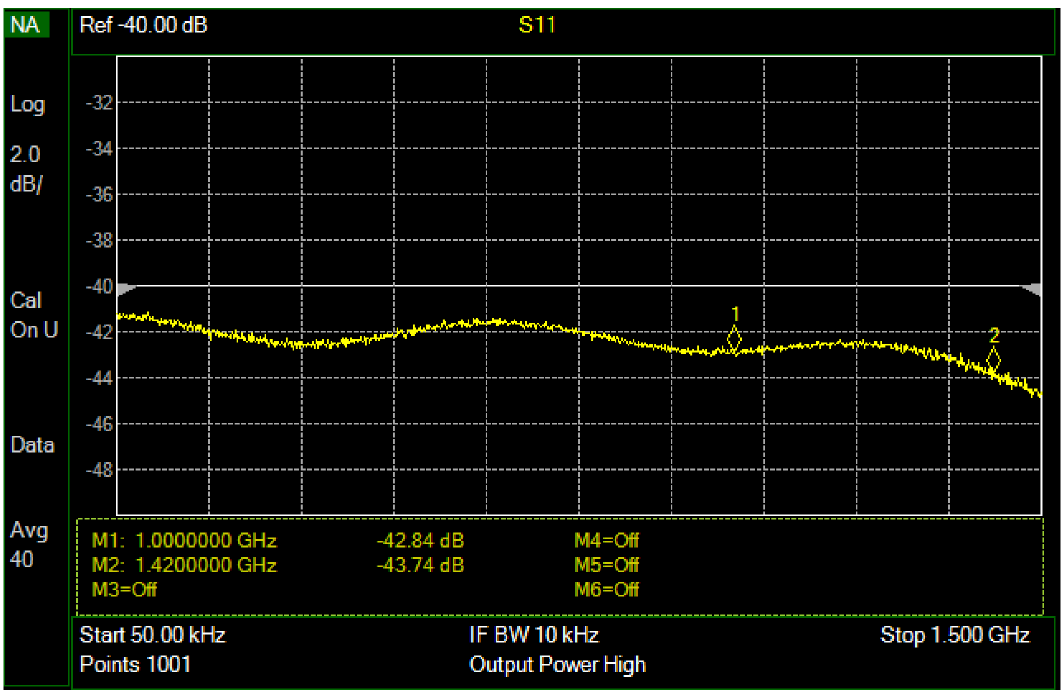

Figure 3.c ~ nanoVNA Load standard. Vertical scale is 2 dB/div with the reference (at center) set to –40.0 dB.. These measurements are for direct connection of the Load standard to the FieldFox port adapter.

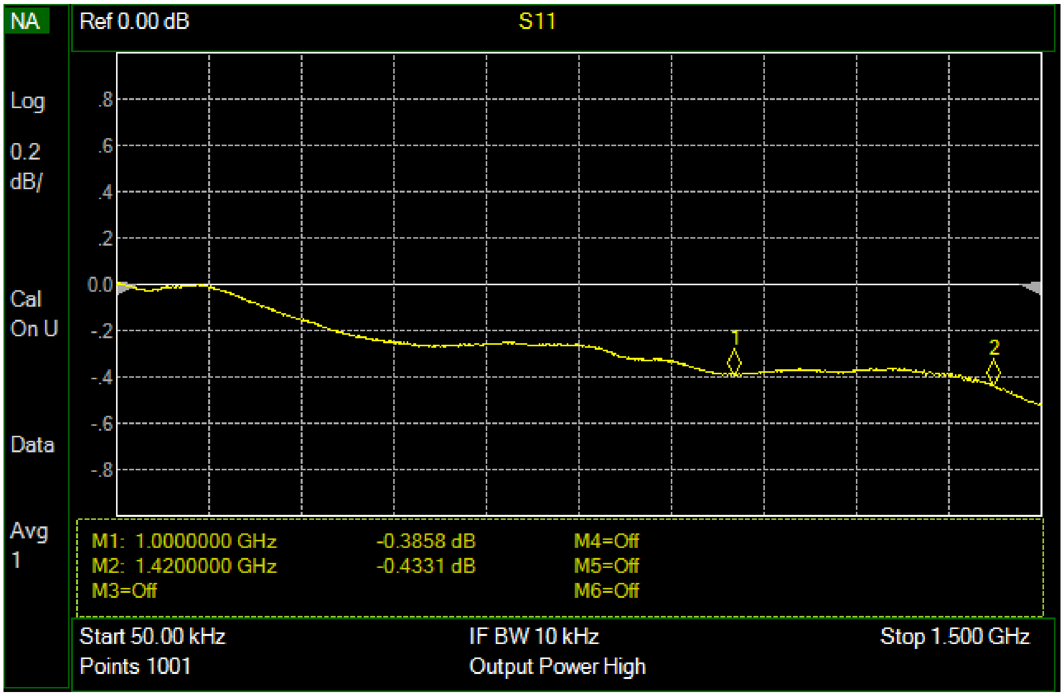

Figure 4.a ~ nanoVNA Red coaxial jumper cable alone, no termination and no barrel connector. Vertical scale is 2 dB/div with the reference (at center) set to 0.0 dB.

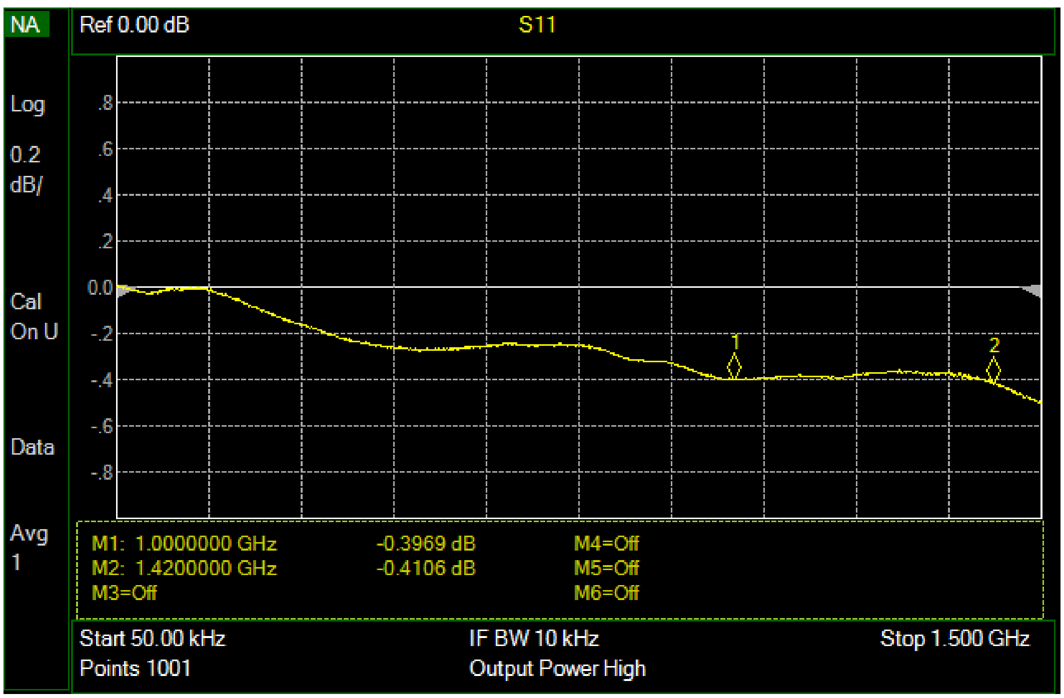

Figure 4.b ~ nanoVNA Green coaxial jumper cable alone, no termination and no barrel connector. Vertical scale is 2 dB/div with the reference (at center) set to 0.0 dB.

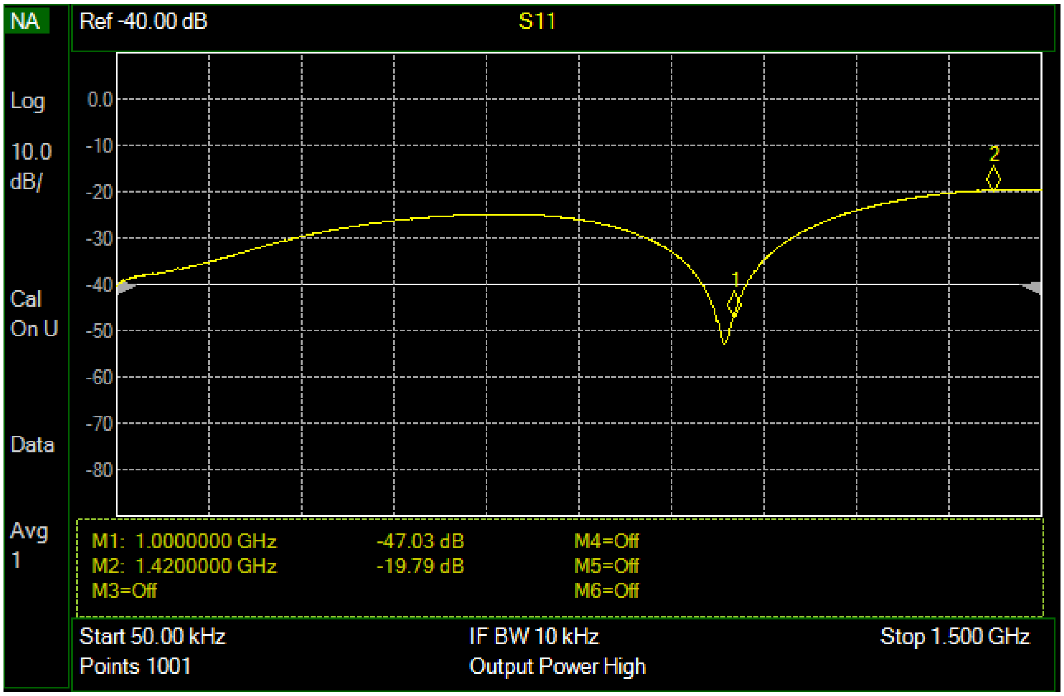

Figure 5.a ~ nanoVNA Red coaxial jumper cable with barrel connector and Load standard. Vertical scale is 10 dB/div with the reference (at center) set to –40.0 dB.

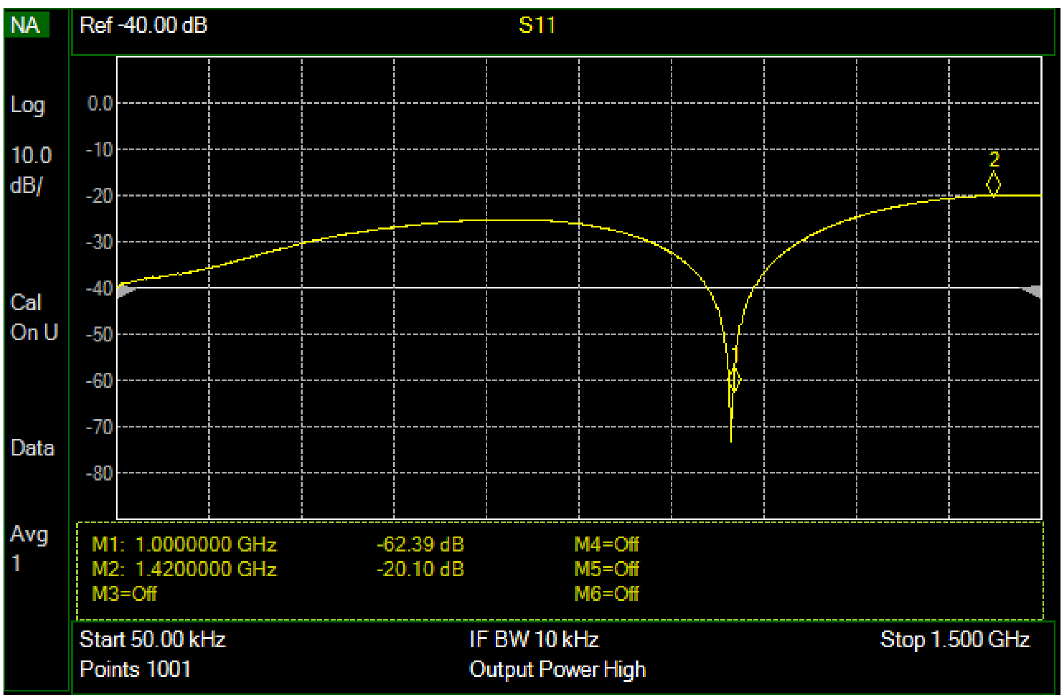

Figure 5.b ~ nanoVNA Green coaxial jumper cable with barrel connector and Load standard. Vertical scale is 10 dB/div with the reference (at center) set to –40.0 dB.

RG-316 cable has a PTFE dielectric with a nominal velocity factor of 0.69 to 0.7. Therefore, the wavelength at 1420 MHz in the cables would be 146 to 148 mm, which coincidentally is close to the physical cable lengths. When terminated with the Load, both cables showed a resonance dip just below the 1000 MHz markers, one cable about 20 dB deeper than the other. This difference could be due to measurement resolution, which is about 1.5 MHz.

The resonance effects and return loss degradations caused by the cables call into question their usefulness with the nanoVNA. For example, if the measured return loss of a very good Load standard (44 dB in the case of the nanoVNA Load) in combination with the cable is 20 dB, no measurement of a device will ever be better than 20 dB no matter what its actual return loss is. It should be noted that 20 dB return loss corresponds to a VSWR of 1.22:1 and is not that bad. It is the degradation from 44 to 20 dB that is of concern. It is good practice to include any jumper or test cables in the calibration, and this is done in the next section..

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4. Comparison with Precision Test Cables

I performed additional measurements with the nanoVNA coaxial jumper cables and several precision test cables. The test cables were Pasternack PE300.24 (24 in length) and Gore 0KR01R71024.0 (24 in length) (figure 6). The Pasternack cables have a straight SMA-M connector on each end. The Gore cables have a straight SMA-M connector on one end and a right-angle SMA-M connector on the other. For the measurements with the Gore cables, I connected the straight connector to the FieldFox port (through the adapter) and the right-angle connector to the nanoVNA Load standard.

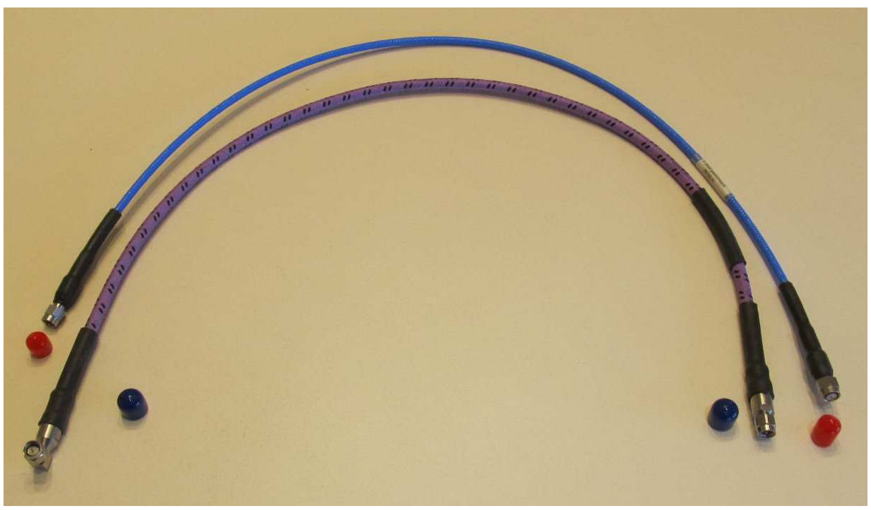

Figure 6 ~ Precision test cables with protective caps removed. The upper cable is a Pasternack PE300-24 and the lower cable is a Gore. The Gore cable has a tough, braided fabric protective cover over the jacket. Its right-angle connector is visible in the lower-left corner.

First, for comparison with figure 5 above, I measured the nanoVNA Load standard return loss when connected to the precision test cables (figure 7). For these measurements, the calibration plane was at the adapter on the FieldFox as with all previous measurements. The precision test cables showed ripple in their reflection coefficient traces, but this is common and indicates imperfect impedance matching. The variations due to ripple were on the order of 10 dB for the Pasternack cables and 20 dB for the Gore cables. Note that these precision cables show a much different response than the nanoVNA jumper cables, partly because they are longer.

The test cables reduced the measured return loss of the Load from 44 dB to 34 dB (Pasternack) and 29 dB (Gore with right-angle connector) at 1420 MHz – neither as severe as the shorter RG-316 cables supplied with the nanoVNA. I was expecting the right-angle connectors on the Gore cables to degrade the Load measurements, and this apparently was the case. Compared to the Pasternack test cables, the Gore cables showed lower return loss at 1420 MHz by about 5 dB.

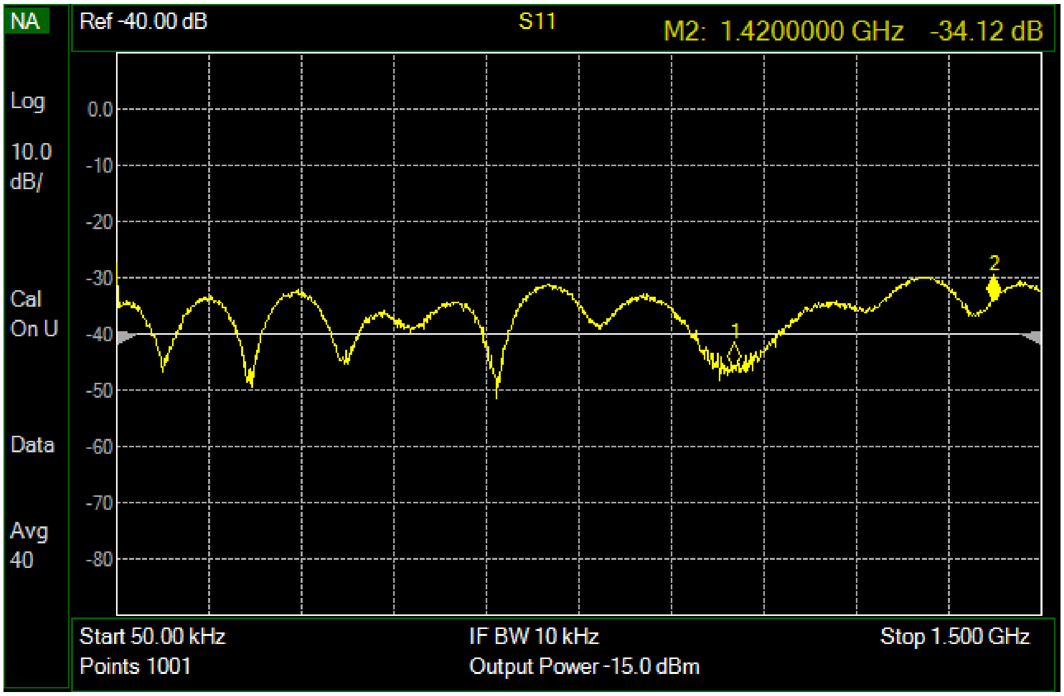

Figure 7.a ~ Pasternack PE300.24 test cable and Load standard with barrel connector, typical of four cables. Vertical scale is 10 dB/div with the reference (at center) set to –40.0 dB.

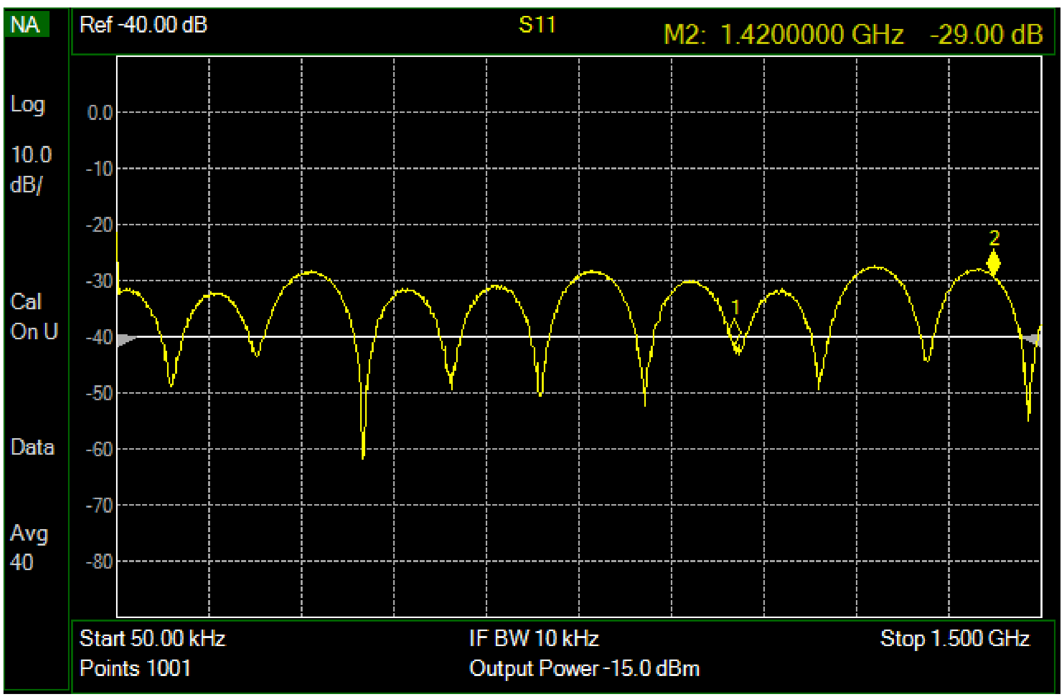

Figure 7.b ~ Gore 0KR01R71024.0 test cable and Load standard with barrel connector, typical of two cables. Vertical scale is 10 dB/div with the reference (at center) set to –40.0 dB.

I then moved the calibration plane to the end of the cable and barrel connector by recalibrating the FieldFox with the HP 85033D Calibration Kit at that position. Three calibrations were made, first using the nanoVNA jumper cables, then a Pasternack cable and, finally, a Gore cable. These calibrations included the SMA barrel connector because it is required for connecting all of the nanoVNA calibration standards to the cables. After each calibration, I again measured the return loss of the Load standard.

This set of measurements yielded better results, as expected (figure 8). In these measurements, the cable and barrel connector characteristics were embedded in the calibration so, ideally, they have no effect, and the Load standard would measure as if it was connected directly to the instrument. However, in practical measurements, especially at frequencies in the GHz range, any movement of the test cables during and after calibration can affect the results. Precision test cables generally are less susceptible to this effect, but I noticed the RG-316 jumper cables supplied with the nanoVNA showed considerable differences when moved around - I could easily change the return loss by 10 dB by moving and bending (but not kinking) the cable.

The measurement results show return losses more in line with those shown previously in figure 3.c. Curiously, the return loss is a few dB higher with one of the nanoVNA jumper cables than either the Load alone or the Load with the precision test cables. These differences are easily explained by the comments above about cable movement during and after calibration affecting the measurements. The precision test cables showed more consistent results.

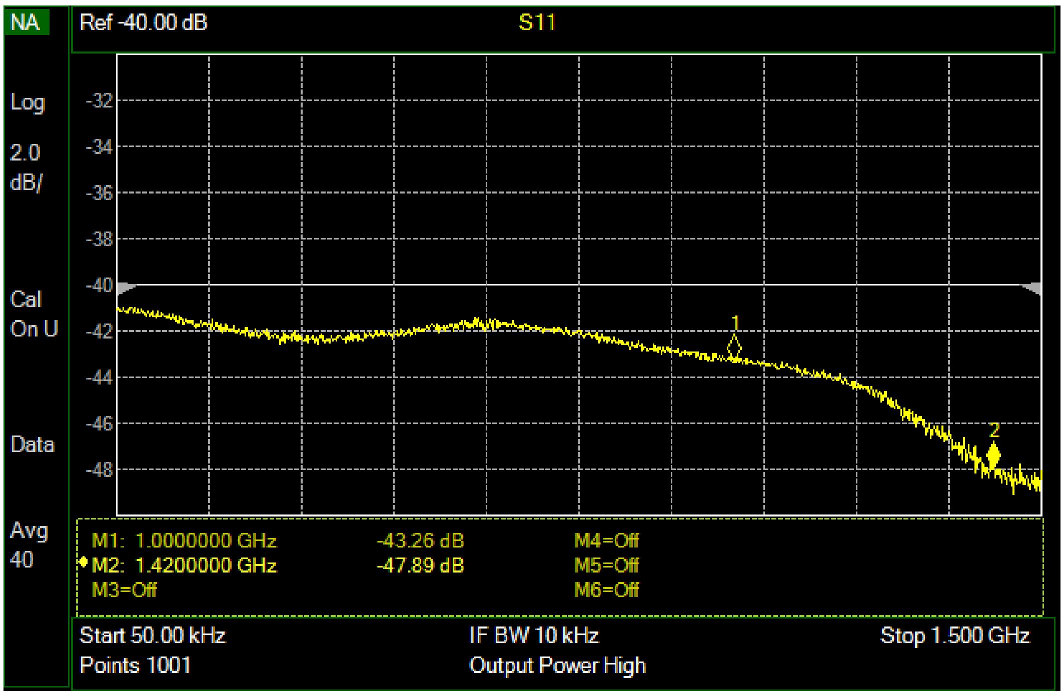

Figure 8.a.1 ~ Return loss of the Load standard on the Red nanoVNA coaxial jumper cable. The barrel connector was included in the FieldFox calibration. Vertical scale is 2 dB/div with the reference (at center) set to –40.0 dB. Note that the resonance effect seen in figure 5 is not present because the calibration plane has been moved to the end of the barrel connector on the cable.

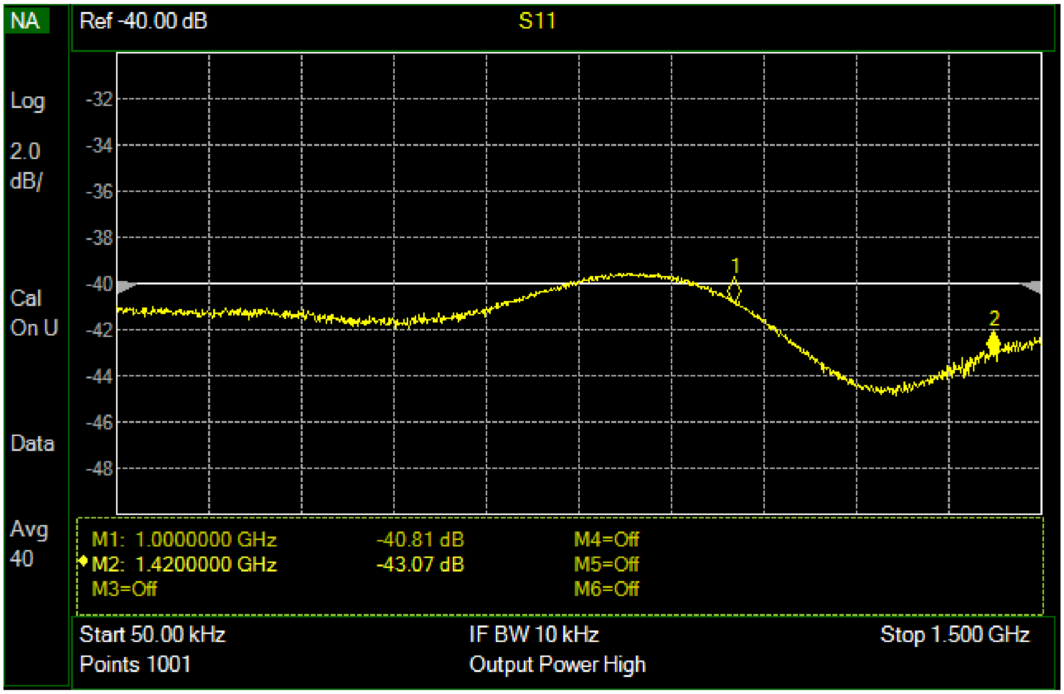

Figure 8.a.2 ~ Return loss of the Load standard on the Green nanoVNA coaxial jumper cable. The barrel connector was included in the FieldFox calibration. Vertical scale is 2 dB/div with the reference (at center) set to –40.0 dB. Note that the resonance effect seen in figure 5 is not present because the calibration plane has been moved to the end of the barrel connector on the cable.

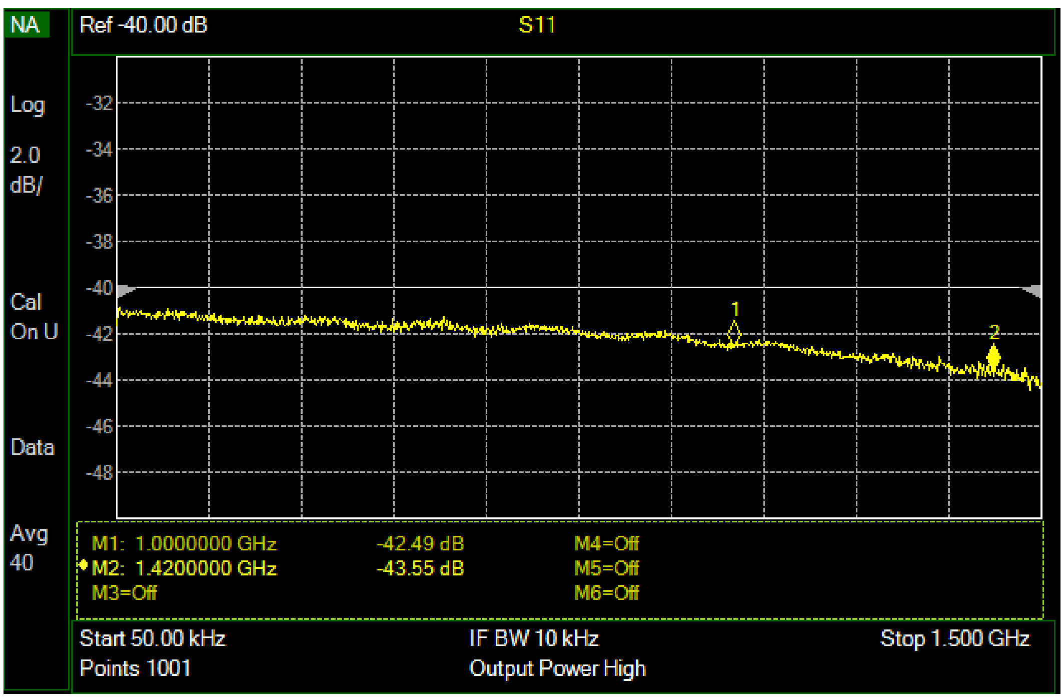

Figure 8.b ~ Return loss of the Load standard connected to one of four Pasternack test cables. Vertical scale is 2 dB/div with the reference (at center) set to –40.0 dB. Note that the ripple seen in figure 7 is not present because the calibration plane has been moved to the end of the barrel connector on the cable.

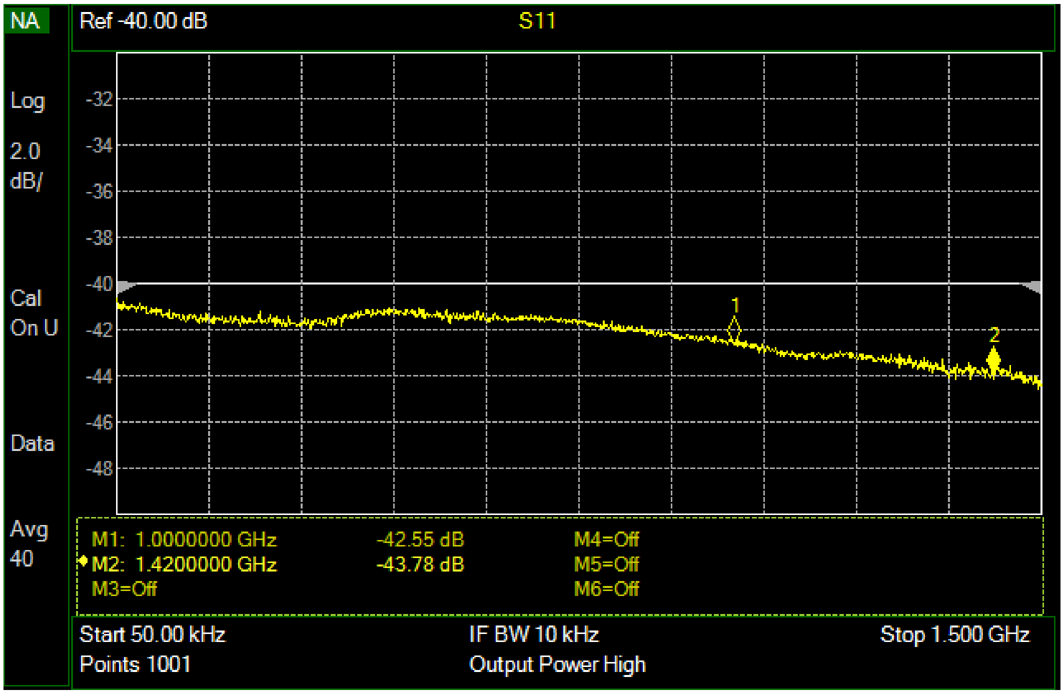

Figure 8.c ~ Return loss of the Load standard connected to one of two Gore test cables. Vertical scale is 2 dB/div with the reference (at center) set to –40.0 dB. Note that the ripple seen in figure 7 is not present because the calibration plane has been moved to the end of the barrel connector on the cable.

5. Conclusions

The measurements eliminated my skepticism of the nanoVNA calibration standards but not of the test cables. The calibration standards by themselves looked very good but the supplied coaxial jumper cables do not have comparable performance and are not useful for repeatable measurements. Test cables normally are connected to a VNA during calibration and their effects are *calibrated out*. Doing this significantly improved the measurements as expected, but any movement of the jumper cables affected the measurements especially at higher frequencies.

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