MASSACHUSETTS INSTITUTE OF TECHNOLOGY
HAYSTACK OBSERVATORY
WESTFORD, MASSACHUSETTS 01886

September 12, 2012

Telephone: 781-981-5400
Fax: 781-981-0590

To: EDGES Group

From: Alan E.E. Rogers

Subject: Calibration and temperature corrections for high accuracy VNA measurements

The method of VNA calibration described in Memo 90 was tested on a hand held VNA (Agilent FieldFox N9923A) for high accuracy S11 measurements in the 50 to 200 MHz range. In addition to the imperfect calibration load correction described in memo 90 corrections are needed to correct the effect of changes in the temperature of the VNA from time of calibration. In order to make these corrections the S11 of an open, short and load at 30 and 42 °C is measured from which are then used to derive temperature coefficients for the directivity ($e00$) mismatch ($e11$) and tracking ($e10$). For the following coefficients were derived at 100 MHz (for example):

Complex Vector	Magnitude/K	Phase (deg)
$\Delta e00$	6.1×10^{-4}	65
$\Delta e11$	3.6×10^{-4}	-92
$\Delta e10$	4.3×10^{-4}	152

These coefficients can then be used to update the coefficients measured at the reference temperature

$$e00' = \Gamma_{load}$$

$$e11' = \left(2e00' - \Gamma_{open} - \Gamma_{short}\right) / \left(\Gamma_{short} - \Gamma_{open}\right)$$

$$e10' = \left(\Gamma_{open} - e00'\right)\left(1 - e11'\right)$$

$$e00 = e00' + \Delta e00\left(T - T_{ref}\right)$$

$$e11 = e11' + \Delta e11\left(T - T_{ref}\right)$$

$$e10 = e10' + \Delta e10\left(T - T_{ref}\right)$$

Which are then used to calculated the corrected reflection coefficient

$$\Gamma_{corr} = \left(\Gamma_{obs} - e00\right) / \left(e10 - e00\, e11 + \Gamma_{obs} e11\right)$$

In practice the VNA has a large thermal mass and the internal temperatures (RFI, SB1, SB2, Batt) change slowly so the best procedure is to calibrate within a few minutes of a critical S11 measurement rather than rely on making a correction for a temperature which differs from that of the calibration. Another reason for always calibrating just before measurement is that the internal temperatures do not always track together so that the temperature coefficients of directivity, mismatch and tracking are also a function of the internal temperature distribution which depends on the VNA orientation and air circulation in the vicinity of the VNA.

To compare the expected accuracy of several VNAs a 7 dB attenuator of male port resistance 74.3±0.1 ohms was measured by 3 different VNAs which were SOL calibrated with load whose resistance was 50.0±0.05 ohms. The results were as follows:

VNA	Freq (MHz)	Amplitude (dB)	Phase (deg)
85047A/8753C	50	-14.18	-3.1
85047A/8753C	100	-14.19	-6.2
85047A/8753C	150	-14.19	-9.3
85047A/8753C	200	-14.18	-12.4
FieldFox N9923A	50	-14.17	-3.1
FieldFox N9923A	100	-14.17	-6.2
FieldFox N9923A	150	-14.17	-9.3
FieldFox N9923A	200	-14.18	-12.4
N5222A	50	-14.15	-3.0
N5222A	100	-14.16	-6.0
N5222A	150	-14.16	-9.0
N5222A	200	-14.17	-12.0

Figure 1 shows measurements for the 7 dB attenuator with the N5222A and Field Fox.

The thick were taken within a few minutes of the calibration when the room was at 24 °C. The lower curve is from the N5222A and while it is slightly nosier then the FieldFox because an output power of 0 dBm was chosen compared with 10 dBm for the FieldFox the variation with frequency is well under 0.005 dB peak to peak. 16 hours later the FieldFox had drifted by more than 0.02 dB/°C while the N5222A had drifted by about -0.003 dB/°C or about the same as measurements made with 85047A/8753C. In all cases the change of phase with temperature was under 0.1°/°C. These results emphasize that the FieldFox can only be used in a very stable temperature environment after being in that environment for several hours and then measurements need to be made within a few minutes of calibration. It is doubtful that the FieldFox could achieve an accuracy of 0.01 dB for measurements of the S11 of an antenna in the field. However if the 850471/8753C or N5222A were placed in a dugout close to the edge of the ground plane and allow to stabilize the ground temperature it was probably result in a respectability at the 0.005 dB level. Tests of other VNAs are still in progress and precise levels of absolute accuracy have yet to be determined.

Comments

The calculated reflection coefficient from the resistance is -14.18±0.02 dB. At present the resistance measurement accuracy is limited by the Fluke handheld but far more accurate ohm meters are available. From the reasonable agreement between units we might expect S11 accuracy at the ±0.02 dB and ± 0.5 degrees of phase when reflection coefficients are in the range of 0 to -15 dB. A measurement of the male port of the attenuator with the N5222A using the electronic ECAL Agilent N4433A gave a value of -14.13 dB at 100 MHz which is clearly in error by about 0.04 dB but is within the specified accuracy of 0.1 dB. The value using the ECAL can be corrected using the method described in memo #90 when this is done a value of -14.19 dB is obtained.

It is also noted that if care is taken not to bend the connecting cable between calibrations and DUT measurements the cable imperfections are removed by the calibration. A test was made using 75Ω of about 6 ns in electrical length and found to have less than 0.02 dB and 0.1 degrees effect on the measurement of the 7 dB attenuator.

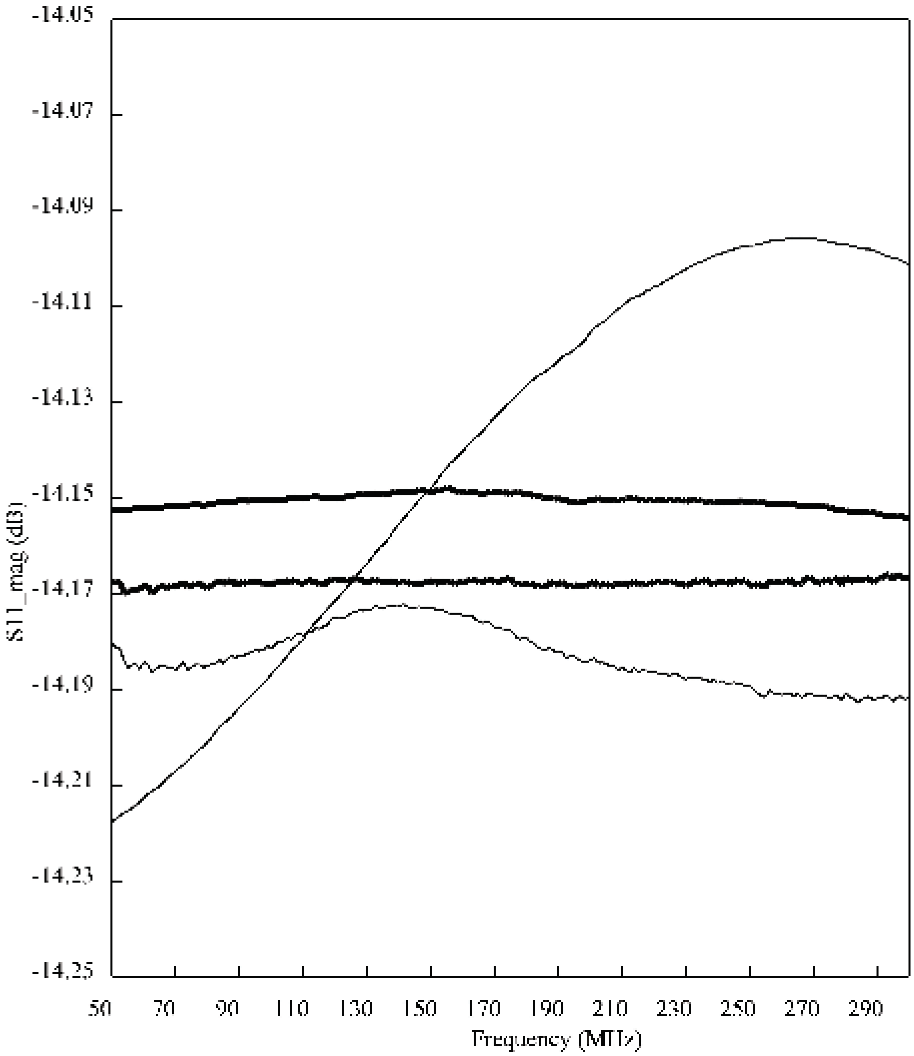

Figure 1. Lower curves are N5222A upper curves are N9923A at 24C thin curves after 16h and room at 21C.