Automatic, Calibrated and Accurate Measurement of S-Parameters in Climatic Chamber

Oscar Monerris Belda, Elena Diaz Caballero, Jesú Ruiz Garnica, and Vicente E. Boria, *Senior Member, IEEE*

***Abstract*—When measuring RF or microwave devices under a temperature profile inside a climatic chamber, one of the main problems lies in the impossibility to have the network analyzer calibrated for all the temperatures measured along the profile. Typically, the calibration is performed just at room temperature, assuming that there is going to be an error in the rest of the measured temperatures. That error will be higher the further we are from room conditions. In this work, we present a systematic procedure for accurately measuring the S-parameters of a device at different temperatures. It applies a calibration algorithm using the S-parameters of the device under test (DUT) and of the calibration standards measured at the different temperatures of interest along the temperature profile.**

***Index Terms*—Climatic chamber, RF and microwave devices, systematic measurement, temperature calibration.**

I. Introduction

PERFORMING the measurement of the scattering parameters using a Vector Network Analyzer (VNA) is a common task carried out thousands of times a day in RF/microwave laboratories. Prior to any accurate measurement, a calibration process is performed using some mathematical techniques, such as the Thru-Reflect-Line (TRL) [1]or Short-Open-Line-Termination (SOLT) [2], for correcting the deviations appeared in the measurements done by the network analyzer. Those deviations are due to non-idealities in the VNA itself and the cables, probes or connectors used for measuring the device under test (DUT). This calibration process is always done at room temperature and, typically, the DUT is also kept at room temperature during the measurement process.

However, in some special cases, such as outdoor equipment and satellite elements, the DUTs must be tested under different temperatures emulating the conditions that are going to suffer under real operation, which might have a major impact on the electric performance of the device. Such is the impact of temperature on the electric performance of the device that several patents exists describing temperature compensating techniques for microwave filters [3].

When performing thermal VNA measurements, it is a common practice to assume that ambient temperature calibration stands valid at any other temperature. In literature, although in the framework of a different application, we can find a procedure for calibrating the measurement of complex permittivity of solids at different temperatures up to $1000°C$ [4], but the improvements made by that calibration compared with the one performed at room temperature are not discussed. This work demonstrates that the mentioned assumption is not valid, since it leads to errors in the measurements that are more significant the more different the test temperature is from the room one.

In this letter, an automatic and accurate procedure is proposed for measuring and calibrating devices at different temperatures using a climatic chamber -hereinafter the *temperature calibration –*. Then two microwave filters have been measured, comparing the results using the temperature calibration procedure and the common procedure at room temperature, analyzing the error this last one would introduce in the measurement of S-parameters and giving some conclusions.

II. Measuring and Calibrating at Different Temperatures

For space applications, components must be tested under different temperatures emulating the operating conditions in orbit. One of the main tests to be made is measuring the response of the device at the full temperature range –from approx. $-100°C$ to $150°C$– covering the typical operation conditions. In order to do so, the device is measured inside a climatic chamber, which applies a temperature profile so that the component can be measured at different temperatures.

When measuring scattering parameters at different temperatures along a temperature profile, a calibration should be performed at each temperature of interest where the VNA will take a measurement, so that the actual conditions of the measuring system at that specific temperature can be considered. However, this is not feasible since, for calibrating the VNA at each temperature, it would be necessary to break the temperature profile in order to connect the standards.

This is the reason why the traditional way of doing -hereinafter referred to as the *traditional calibration*– consists of calibrating just at room temperature, that is to perform only one initial measurement of the calibration standards at room temperature, and then applying that calibration correction in the VNA for all the temperatures of interest. In this case, some errors in the measurements should be assumed, since the VNA would be correcting the DUT measurement that is being performed, for instance, at $100°C$, using the data of the calibration standards

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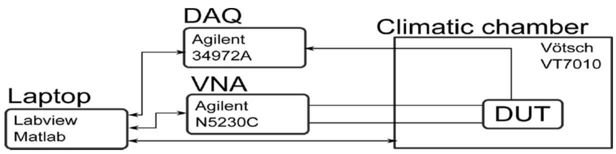

Fig. 1. Test setup diagram.

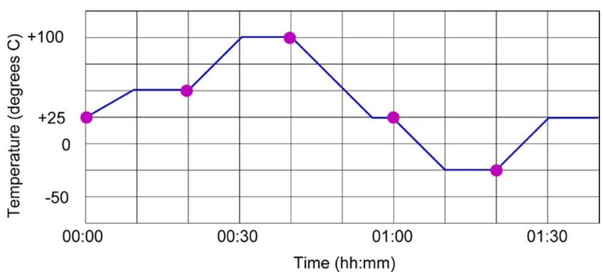

Fig. 2. Example of temperature profile (line) and VNA measurements (dots).

acquired at room temperature $(25^\circ\mathrm{C})$ [5], [6]. The best approximation that can be found in the literature is the application of some incomplete correction, which can include, for example, the thermal effect in the cables [7].

In this work, in order to be able to calibrate using the data of the calibration standards at the adequate temperature, the calibration is externally performed after taking all the acquisitions along the temperature profile. Hence the approach is: *a*) to set up an arbitrary user-defined temperature profile and the measuring points; *b*) to run the temperature profile for each calibration standard, measuring at the specified points and storing the acquired data; *c*) to run the temperature profile for the DUT, measuring at the specified points and storing the acquired data, without performing any calibration with the VNA; and *d*) to externally perform a calibration at each temperature of interest by using the corresponding stored measurements of the calibration standards and the DUT.

The external calibration (step *d*) is done by a Matlab routine that has been implemented for performing the appropriate corrections at each different temperature. In particular, a TRL calibration [1]has been used since the calibration standards usually have a better thermal stability than the SOLT ones.

But first, it is necessary to measure the calibration standards (step *b*) –in TRL they are a thru, a reflect and a line, and they must be appropriate for the technology of the device under test- and the DUT (step *c*) at different points along a temperature profile. For this purpose, a Labview software, which is detailed below, has been developed so that those measurements can be automatically performed inside a climatic chamber.

III. Automatic Measurements Along a Temperature Profile

An automatic routine has been implemented using Labview to control a climatic chamber and a VNA for carrying out a user-defined temperature profile. In Fig. 1, the test set-up can be observed, where a Data Acquisition (DAQ) unit is used in order to measure the temperature on the DUT and standards using thermocouples during the temperature profile.

The same temperature profile should be applied for measuring all the calibration standards and the DUT. It is also necessary to include some dwell time in the profile to allow thermal stabilization before taking a measurement at a certain temperature. A temperature profile example is shown in Fig. 2.

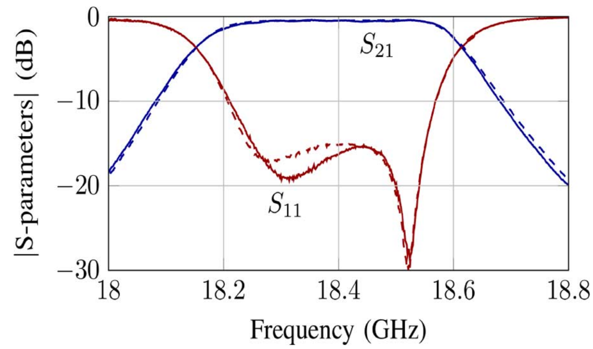

Fig. 3. Validation of the TRL temperature calibration at room temperature: comparative of the temperature calibration (solid) and the traditional VNA calibration (dashed).

IV. Validation Results

In order to demonstrate the improved results given by this new technique, two microwave filters have been characterized at several temperatures. Two completely different waveguide microwave filters have been used for this purpose, since temperature changes alter the resonance frequency and the couplings in different ways. The first DUT is a bandpass filter with inductive metal posts in WR-42 standard waveguide. The second DUT in a smooth profile lowpass filter [8]in WR-75.

The climatic chamber is able to provide a temperature range from $-70^\circ\mathrm{C}$ to $180^\circ\mathrm{C}$. Nevertheless, given that the used RF interface cables[1] are only rated to $-55^\circ\mathrm{C}$ to $120^\circ\mathrm{C}$, the temperature span has been reduced.

In this section, first the TRL temperature calibration is going to be validated at room temperature, and then both DUTs -and their respective appropriate TRL standards- are going to be measured at several temperatures and the results compared with typical VNA calibration.

In order to prove the correct performance of the developed TRL temperature calibration, the WR-42 bandpass filter has been used. First, the temperature calibration has been applied after measuring all the standards and the DUT at room temperature $(25^\circ\mathrm{C})$, obtaining the data in solid lines in Fig. 3. Then, the traditional calibration using the VNA routine has been applied for measuring the DUT, obtaining the data in dashed lines in Fig. 3. It can be observed that both calibration procedures obtain the same result, thus validating the new calibration procedure.

After setting the appropriate temperature profile, the same WR-42 bandpass filter has been measured at several temperatures. Fig. 4 shows the comparison between the S-parameters obtained at $25^\circ\mathrm{C}$ and $100^\circ\mathrm{C}$ using the temperature calibration. A frequency shift can be observed in the response at $100^\circ\mathrm{C}$, which makes sense since the filter dimensions are slightly bigger due to the temperature increment, thus shifting the bandpass filter response to lower frequencies.

The second filter is a WR-75 lowpass filter having a continuous profile. In Fig. 5, it can be seen that the frequency shift is smaller than in Fig. 4 (even if the temperature increment is

[1]Gore™ TVAC qualified precision coaxial cable rated up to 50 GHz.

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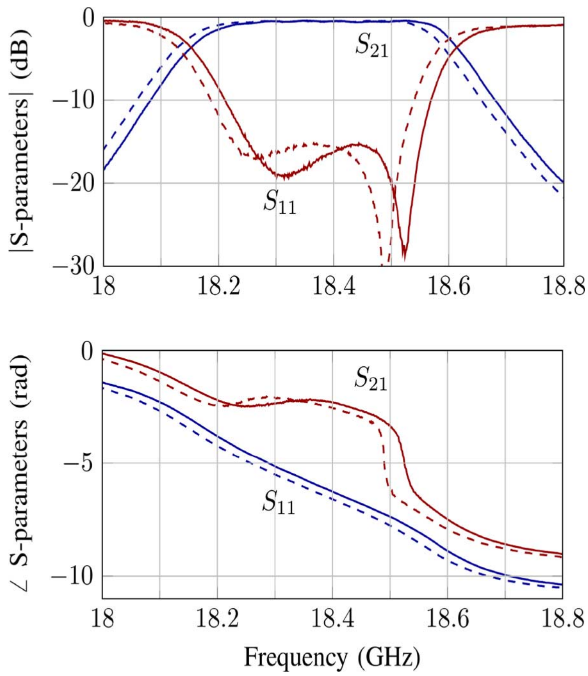


Fig. 4. Measured S-parameters -amplitude and phase- of the WR-42 bandpass filter at 25° C (solid) and 100° C (dashed) using the temperature calibration.

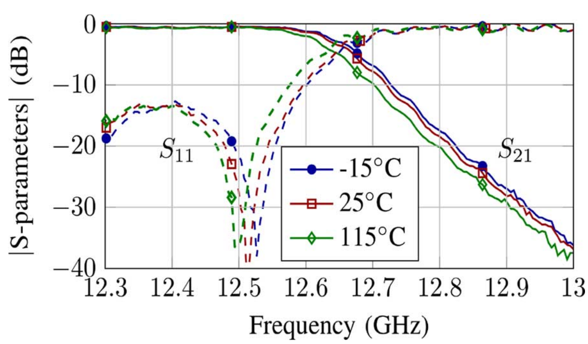
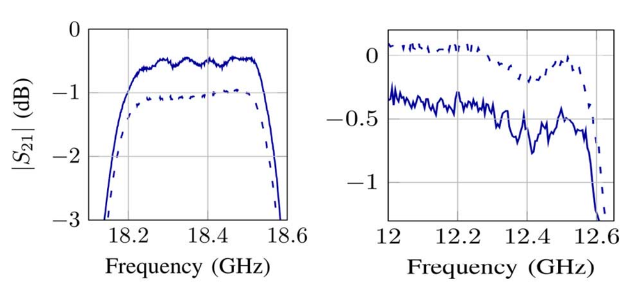


Fig. 5. Measured S-parameters of the WR-75 lowpass filter at several temperatures using the temperature calibration.



(a) (b)

Fig. 6. Details of the improvements due to the proposed temperature calibration (solid) compared to the traditional calibration (dashed). (a) WR42 filter at 100° C. (b) WR75 filter at −15° C.

almost twice as the increment considered in Fig. 4) due to this filter topology being less sensitive to thermal effects [8].

Some details over the improvements observed in the measurements using the temperature calibration compared to the traditional calibration are shown in Fig. 6. In that figure we see how the traditional calibration, being unable to consider the actual conditions -in cables, connectors, etc.– for each temperature, yields errors in the insertion losses or in the bandwidth (bandwidth shrinking and widening at 100°C and −15°C, respectively). Note that those errors could lead to inconsistent results such as the observed positive values for S_{21} (dB) in Fig. 6(b), which could be even more positive at lower temperatures.

In particular, assuming that the temperature calibration is correct, performing measurements along a temperature profile from −55°C to 120°C for several waveguide filters, and using the setup in Fig. 1 and aluminum alloy calkits[2] for all of them, we have analyzed the error introduced by using a room temperature calibration along the whole thermal range. For instance, the average error introduced in the insertion losses can be approximated by a straight line function whose slope is ≈ 0.55 dB/(100°C) for this particular setup.

V. Conclusion

An automatic and accurate procedure has been proposed for measuring the S-parameters of a microwave component at different temperatures along a temperature profile. The accuracy of the measurements are guaranteed since the calibration is performed at each temperature of interest instead of simply assuming that the performance of the setup does not change due to temperature changes.

An analysis over experimental results shows the error introduced in the measurements if the traditional VNA calibration at room temperature was used at other temperatures.

Acknowledgment

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[2]Linear thermal expansion coefficient of aluminum alloy $\approx 24 \cdot 10^{-6}$m/(m ·° C).