S-PARAMETER MEASUREMENT OF SMT COMPONENTS USING THE LA19-13-03 VNA

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1.   Introduction

Having accurate s-parameters of surface mount technology (SMT) devices can be very useful for the designer. It allows accurate system modelling thereby reducing rework and design effort.

Of course, obtaining the s-parameters of an SMT component is not straight forward as the device needs to be mounted on a test board and the effects of the board need to be removed from the measurements.

There are several ways of measuring the s-parameters of an SMT device. Here we describe three as follows:

- Port extension
- De-embedding
- Calibration on board (the subject of this application note)

Port extension is the simplest approach. The VNA is calibrated as usual at the ends of the test cables. The jig is connected and the measurement planes extended to the mounting pads of the SMT device. The disadvantage is that effects of mismatches associated with, say the coaxial to microstrip connectors are not removed. Also, any losses associated with the microstrip lines connecting the SMT device are difficult to remove accurately from the measurements.

De-Embedding requires that each half of the test jig is characterised separately as a 2 port network. The SMT component is then measured in the jig. The jig information is then used to mathematically remove the effects of the jig from the measurement. This approach can yield good results but a lot of effort is required to characterise the jig accurately.

Calibration on board provides calibration Standards on the test jig. It uses the conventional SOLT (Short, Open, Load and Through) calibration approach. This approach requires a more complex test jig but has the advantage that, provided the Standards are good, the test jig effects are automatically removed.

In this note we describe a calibration on board test jig designed on low cost FR4 material for use with LA Techniques' LA19-13-03 VNA. The jig is capable of good results up to 6 GHz.

2. SMT Example device

The device chosen for this application note is the Mini-Circuits LFCN-2500 filter. This is a dc to 2.5 GHz low pass filter housed in a 1206 size package. It has a -3dB point at 3 GHz and a maximum attenuation of around 40 dB at 4 GHz.

3. Test Jig

Figure 1 shows a photo of the jig used for the LFCN-2500 filter. Apart from the device to be tested, the jig includes the following elements.

- Through line
- Short Standard
- Open Standard
- Load Standard

So, the jig includes all the components necessary to perform a SOLT calibration with a measurement plane at the SMT device's pads.
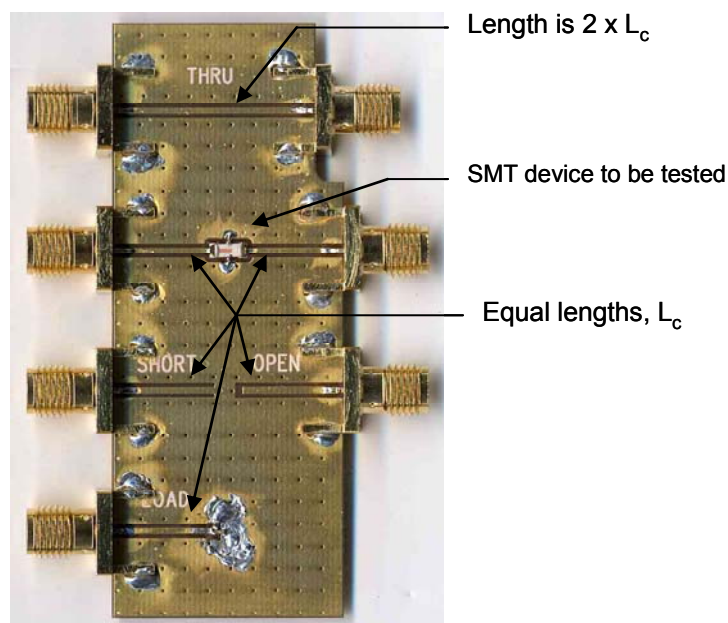

Figure 1. The FR4 test jig contains the SOLT Standards

The test jig was designed for the LFCN-2500 filter. Of course, the same approach described here can be used to design a test jig capable of accommodating several different types of components.

Figure 2 shows the layer build of the test jig. The board uses 4 layers and has an overall finished thickness of 1.6mm. This arrangement results in a rugged jig able to accommodate widely available edge launch SMA connectors. Also, the resulting 50 Ω microstrip width is 0.67 mm wide, consistent with the size of component to be tested.
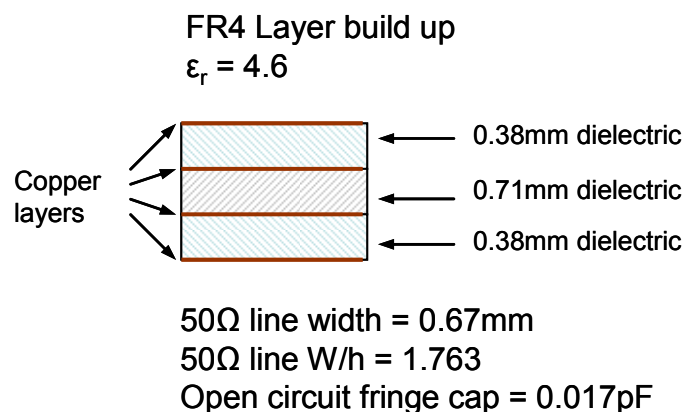
FR4 Layer build up
$\varepsilon_r = 4.6$

Copper layers

0.38mm dielectric
0.71mm dielectric
0.38mm dielectric

50Ω line width = 0.67mm
50Ω line W/h = 1.763
Open circuit fringe cap = 0.017pF

Figure 2. The FR4 test jig layer build

Apart from the microstrip lines on the top layer, all 4 layers of the test jig are all grounded copper with closely spaced interconnecting vias as shown in Fig.1.

The Standards

It is critically important that the Open, Short and Load Standards are connected using identical microstrip line lengths. In addition, the Through Standard must be a microstrip line equal to twice the length of the line connecting the other Standards as shown in   Fig. 1. Note that the outline of the jig board has been modified to ensure that the Through line is the correct length.

The Open circuit is modelled by a simple fringe capacitance value of 0.017 pF. This was derived using the width to height ratio of the microstrip to dielectric [Microstrip Lines and Slotlines, K.C. Gupta et al., second edition, Artech House 1996].

The Short circuit is assumed to be a perfect, that is, no inductance to ground.

The 50 Ω load is the most difficult Standard to implement well. It requires some testing and re-working to arrive at an optimum arrangement. A reasonable target is to achieve around 30 dB of return loss, measured at the jig connector.

Figure 3 shows the final arrangement used for the 50 Ω load. This uses two 100 Ω resistors connected in parallel. The best return loss was achieved with the mounting arrangement shown.
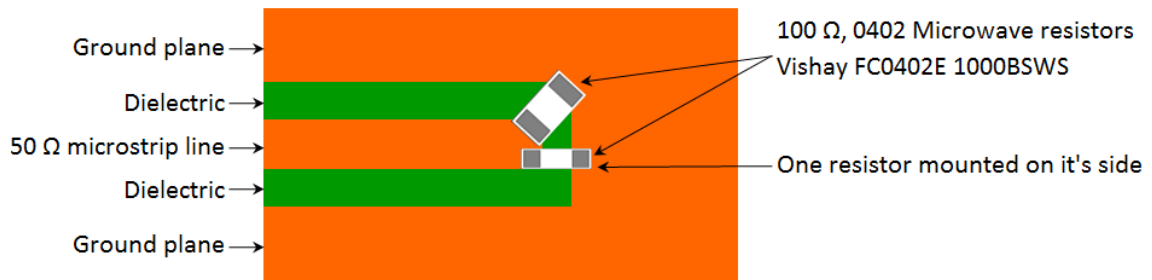
Figure 3. The 50 Ω load Standard

Figure 4 shows the measured return loss of the 50 Ω load. The plot shown has had the effect of the edge connector removed. As can be seen, the load achieves a very good return loss of better than 35 dB up to 6 GHz.
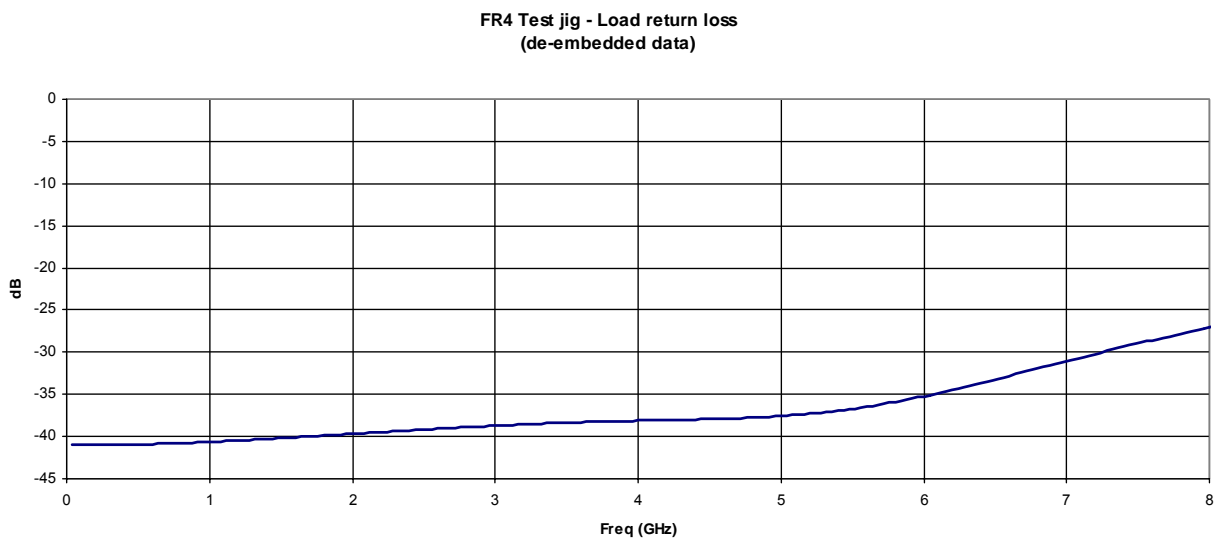

Figure 4. Measured (de-embedded) 50 Ω load Standard return loss

4.   Calibrating the LA19-13-03 VNA

Creating the calibration Kit

Having built the test jig, we now proceed to calibrate the VNA. The first step is to define the calibration kit. That is, define the SOLT Standards built on the test jig that we are going to use.

From the Tools menu select Calibration Kit and then the Cal Kit Editor. This will bring up the form shown in Fig. 5. Using this editor, create a new kit (New Kit button), enter a suitable name, enter the Open Standard fringe capacitance (17.0 for C0 in this example) and select Use ideal Thru model option as shown. The Thru length is 0 mm. Click save to save the calibration kit file to hard disk.
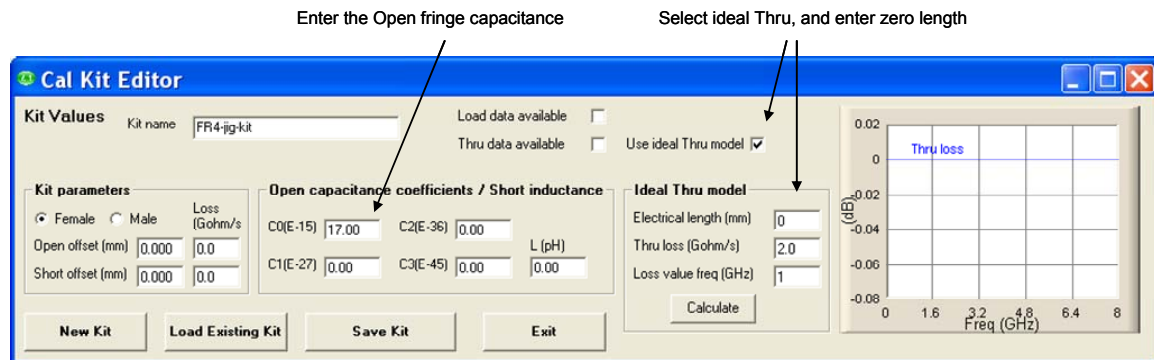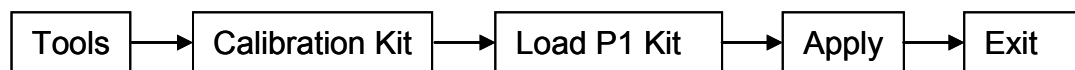

Figure 5. Select Calibration Kit editor from the Tools menu

Calibration of the VNA

Load the test jig calibration kit created previously using the Tools menu as shown.

Once the kit is loaded, open the calibration form (see Fig. 6) to set the frequency sweep limits, the number of points and test power level.

Once the frequency limits and number of sweep points have been set, select the Non-insertable DUT option. The actual calibration can now begin.

Connect each Standard in turn to the ports of the VNA as shown in Fig. 7. Note that the Open and Short are measured in only two steps. One step measures the Open connected to port 1 and the Short connected to port 2. The other step is the reverse, that is, the Short connected to port 1 and the Open connected to port 2.

In our case, the Isolation step can be skipped as the instrument software makes sufficient isolation measurements during the Load measurement step.

Once all Standards have been measured, click on Apply Cal. The software will compute the VNA error terms and automatically close the calibration window. We are now ready to measure the SMT device mounted on the test jig.
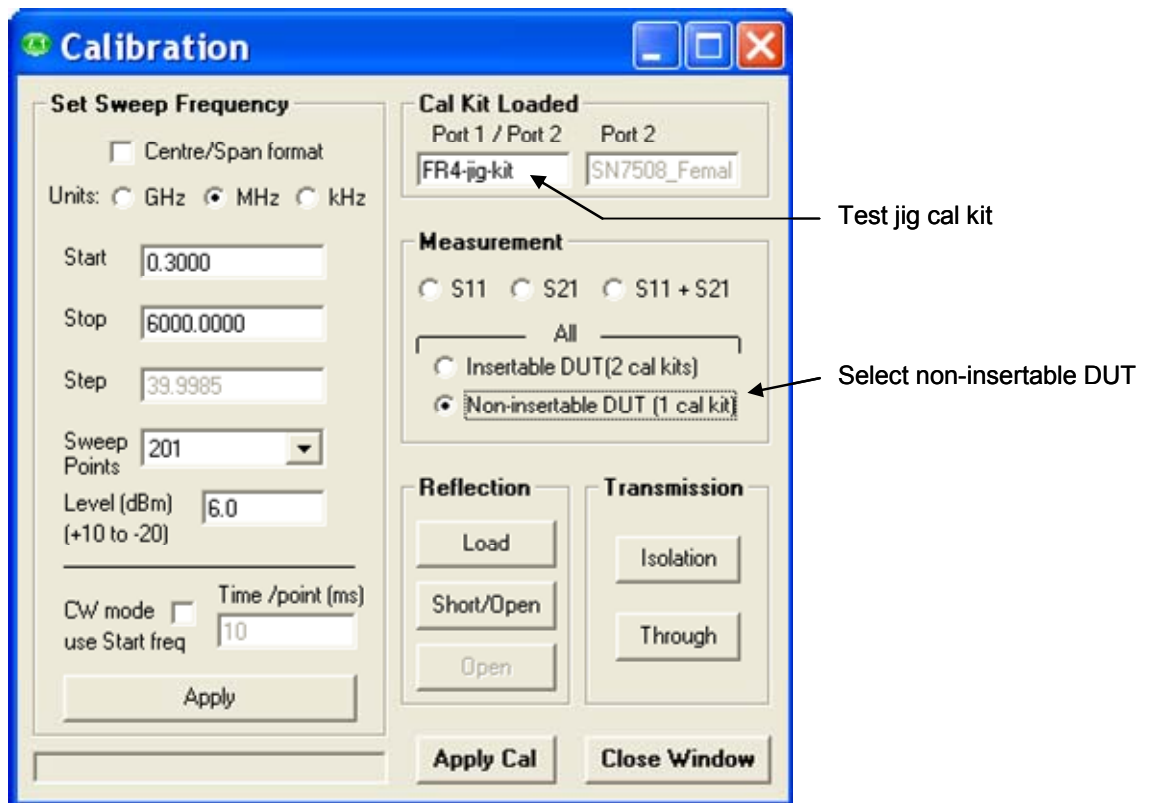
Figure 6. The calibration window used to calibrate the VNA

Figure 7. Measuring the test jig with the LA19-13-03

Perform the calibrated measurement

Connect the DUT on the test jig to the VNA. Click on the Start button to start the measurement sweep. The instrument will then show the s-parameters of the DUT. In our example, the s-parameters of the LFCN-2500 low pass filter.

The results can be saved as a graphics files (as shown in Fig. 8) or as a data file in a format that can later be used by a circuit simulator.
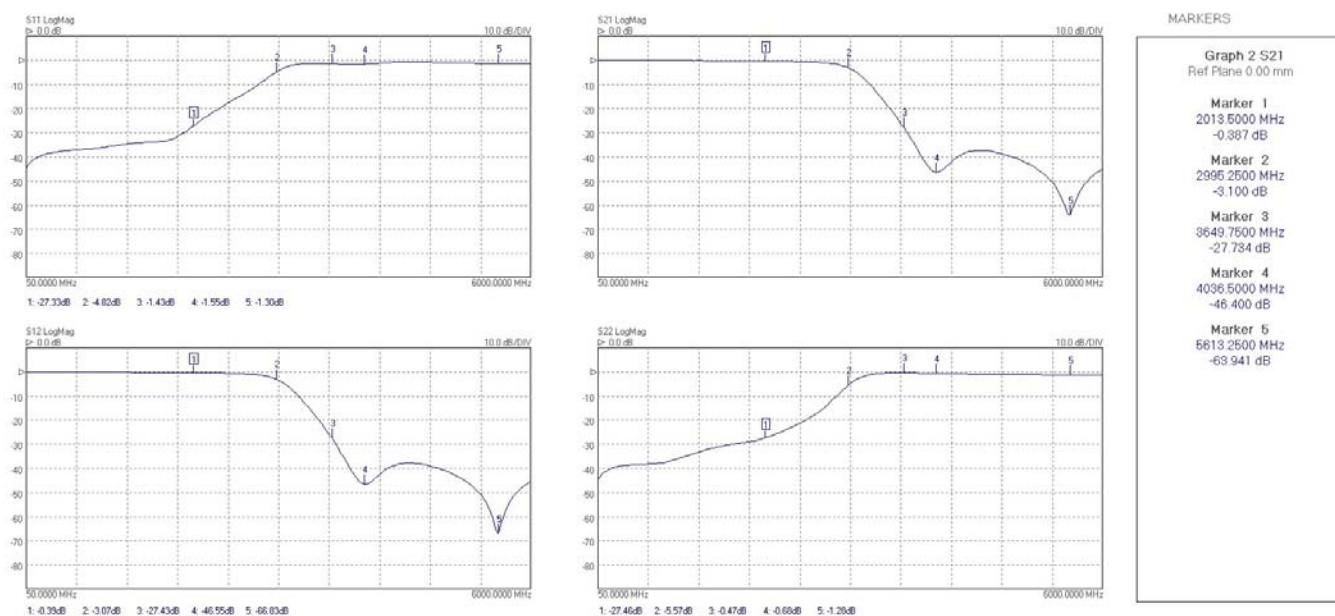

Figure 8. Measured s-parameters of the LFCN-2500 filter

5.   Conclusions

This note has described a possible method for measuring SMT devices using the LA19-13-03 VNA. The technique incorporates calibration Standards on a low cost FR4 test jig allowing good results to be obtained up to 6 GHz. The main advantage of the technique over for example, port extension, is that connector mismatches and line losses are calibrated out.

An example measurement of a Mini-Circuits LFCN-2500 low pass filter shows good agreement with the data sheet of the device. The measured results show a good agreement between the forward and reverse transmission coefficients (S21 and S12) as expected for such a device.

The key challenge in implementing the calibration on board technique is in implementing good calibration Standards, particularly the 50 Ω load. However, with some care it is possible to achieve good results using low cost FR4 board.