LA19-13-01 3 GHz VNA
CALIBRATION AND MEASUREMENT UNCERTAINTY

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1 INTRODUCTION

This application note covers the calibration procedure and measured uncertainty of the LA19-13-01 VNA using the optional economy calibration kits (part numbers DW96634 and DW96635) that enable the VNA to be calibrated in the 2.92 mm line size. Each kit is made up of a set of standards and two adaptors. Table 1 shows the details.

Table 1 Economy calibration kits

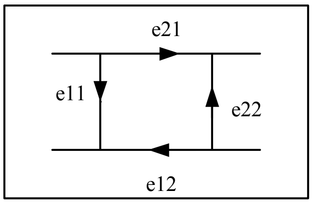
Cal Kit DW96635 used to calibrate female 2.92 mm test ports	Cal Kit DW96634 used to calibrate male 2.92 mm test ports
1 x Load standard (male) 1 x Short-circuit standard (male) 1 x Open-circuit standard (male) 1 x Load calibration data 2 x N(male) to 2.92 mm (male) adaptors	1 x Load standard (female) 1 x Short-circuit standard (female) 1 x Open-circuit standard (female) 1 x Load calibration data 2 x N(male) to 2.92 mm (female) adaptors

2 PRINCIPLE OF OPERATION

Reflection measurement using a non-perfect VNA system can be represented as shown in Fig. 2.1. In this, the system is represented by an ideal measurement system to which the device under test (DUT) is connected through an 'error' network. The latter represents the imperfections associated with the system.

The errors are as follows:

e11: Directivity error
e22: Source match error
e21, e12: Frequency tracking error


e21
e11
e22
e12

3 USING THE CALIBRATION KIT

3.1 Selecting which cal kit to use

Selection between the available kits largely depends on the connectors found on the DUT. Figures 3.1 and 3.2 show some possible arrangements. Note that the arrangement shown on the right hand side of both diagrams is likely to be the optimum arrangement for measuring both S11 and S21. This is because the mismatch associated with the test cable is removed and the DUT is directly loaded with port 2 of the VNA, which should present a small reflection coefficient. In cases where the DUT has both connectors of the same sex, then additional adaptors are likely to be required.

Male kit

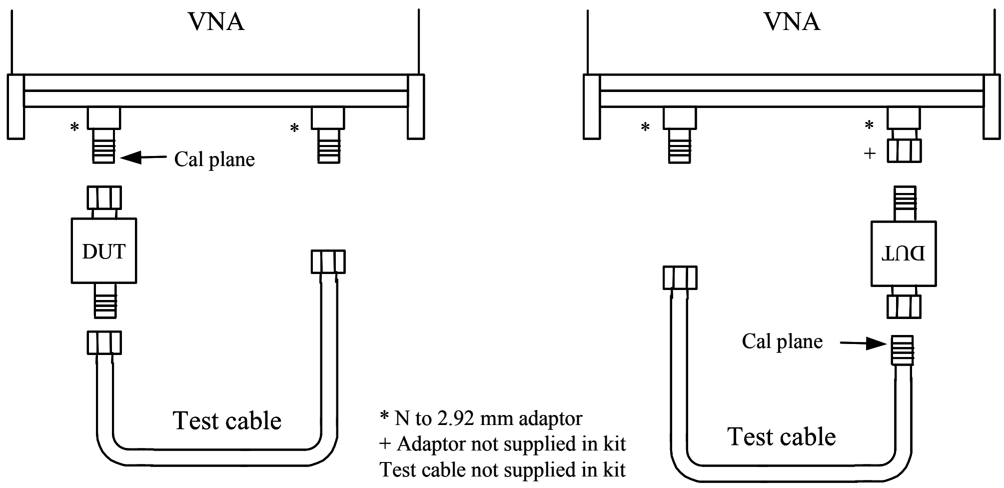


Figure 3.1: Possible DUT arrangements when using the male kit. For best performance use a test cable with 2.92 mm connectors.

Female kit

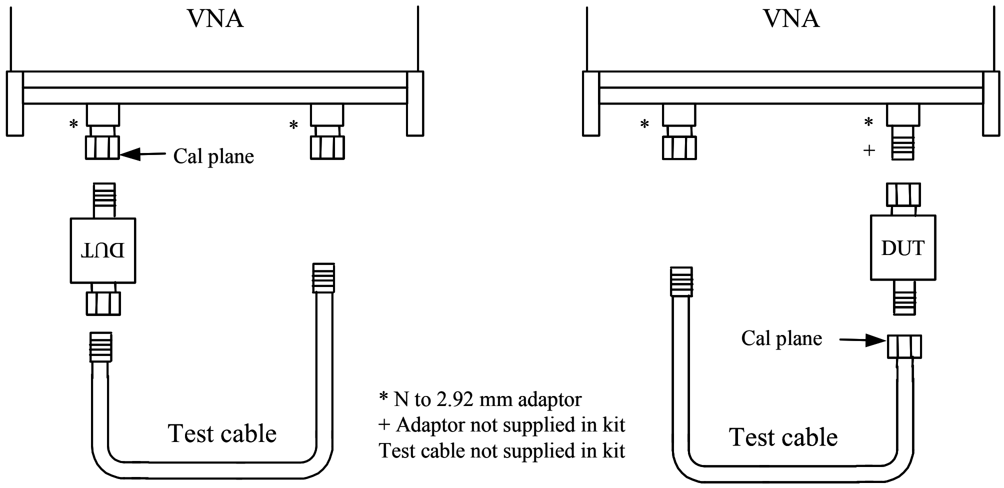


Figure 3.2: Possible DUT arrangements when using the female kit. For best performance use a test cable with 2.92 mm connectors.

3.2 The cal kit parameters window

The calibration kits are supplied with measured data as described in the previous section. The calibration kit parameters window (Fig. 3.3) displays the various values associated with the kit including an indication that reflection coefficient data for the matched load is available. Note that the reflection coefficient data is supplied in the format shown in Fig. 3.4. Bear this in mind if the need arises to create a new kit.

In the following sections, loading the kit and calibrating the instrument are described.

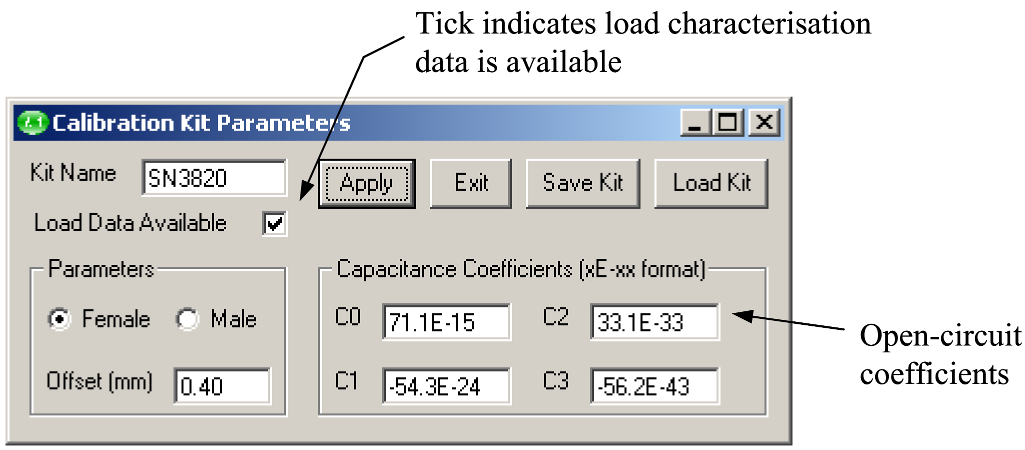


Figure 3.3: The calibration kit window shows the kit parameters

Frequency (MHz)	S11 (real)	S11 (imaginary)
3	-1.7265E-03	7.7777E-05
32.97	-1.6588E-03	3.3093E-04
62.94	-1.4761E-03	5.9003E-04
92.91	-1.4653E-03	1.0253E-03
122.88	-1.3841E-03	1.2608E-03
152.85	-1.1924E-03	1.5800E-03
182.82	-1.0884E-03	1.9085E-03
212.79	-8.7216E-04	2.1355E-03
242.76	-7.0326E-04	2.4109E-03
272.73	-5.7006E-04	2.6790E-03

There must be 101 data lines. Typically these should cover the band 3 MHz – 3 GHz. **No empty or comment lines are allowed at any point.**

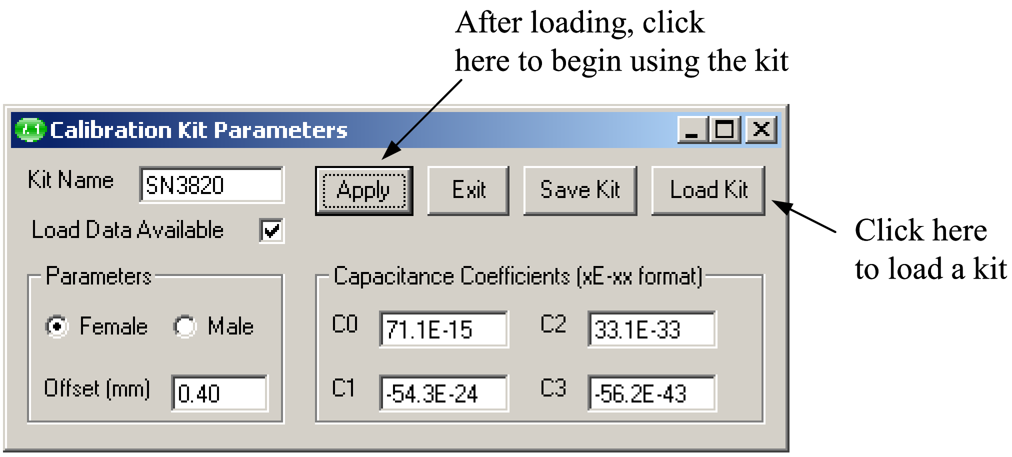


Figure 3.5: Calibration kit parameters window

The chosen calibration kit is now loaded and ready for use.

3.4 Calibrating

The Calibration window (Fig. 3.6) is used to set up and carry out the calibration of the VNA. This is displayed by clicking on the Calibration button on the main window. The steps in performing a calibration are as follows:

Setting the frequency sweep

- Set the frequency sweep characteristics (start and stop frequency and number of points)
- Select the desired test port power level (the instrument is specified with its default setting of 0 dBm)
- Click the Apply button above the progress bar to program the synthesisers

Performing the calibration

- Select the measurement required (S11, S21 or both)
- Click on each standard button and follow the instructions
- When all standards have been done click on the Apply Cal button
- Click on the Close Window button

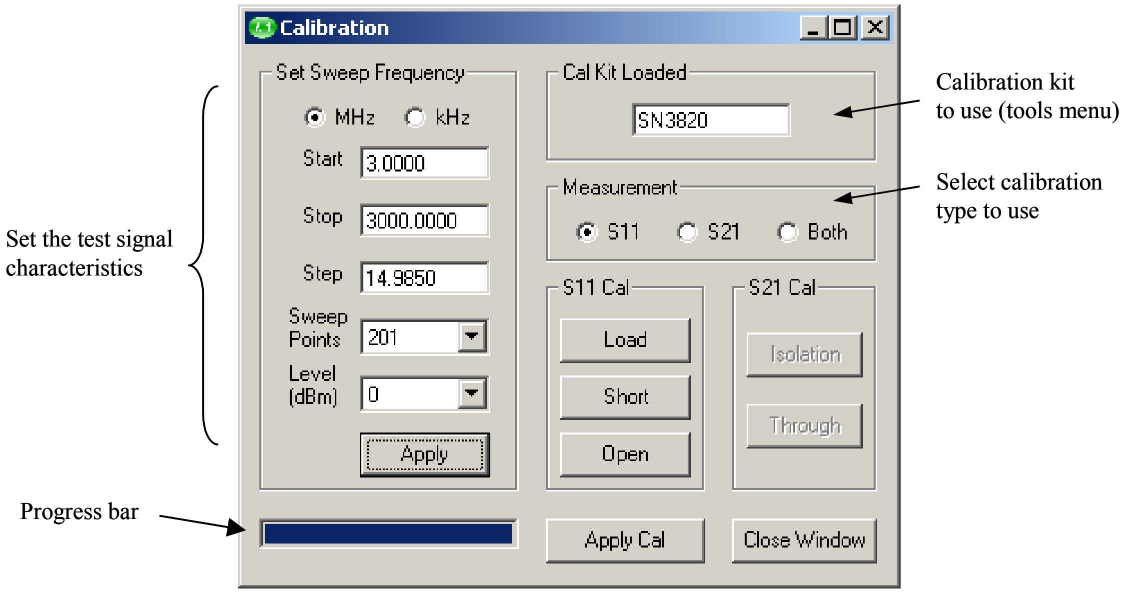


Figure 3.6: Setting up the calibration (click on the Calibration button)

3.5 Re-creating the cal kit

If the calibration kit file is accidentally corrupted or deleted, it then becomes necessary to re-create the kit, the following alternative procedures may be used to restore it.

- Re-load calibration kit file from CD-ROM supplied with the kit

Or

- Open the calibration kit parameters window
- Type in the required name for the kit in the Kit Name text box
- Type in the calibration coefficients (values are given on the kit box)
- Type in the offset (value is given on the kit box)
- Select the 'female' or 'male' button (see Fig. 3.1 or Fig. 3.2, as appropriate)
- Uncheck the 'Load Data Available' box
- Check the 'Load Data Available' box
- Click Apply and follow instructions to load the Termination data
- Click Save kit to save the file to the hard disk

3.6 The cal kit file

The cal kit file is a text file holding the relevant information about the kit. If a characterised matched load (characterised from measurements) is associated with the kit, then its reflection coefficient data will be included in the file. This will take the form of 101 lines with three entries per line. The first item is the frequency (MHz) followed by the real and imaginary parts of the reflection coefficient. Figure 3.7 shows how the file may appear when displayed using a text editor.

Name of kit
Offset (distance and time)
Open-circuit coefficients

```
SN3820
False
 0.0004         1.334256E-12                  7.11E-14     -5.43E-23      3.31E-32     -5.62E-42
True
 3             -2.75421E-03   0.0000105
 32.970002     -2.308727E-03  0.000112
 62.94         -1.884699E-03  0.000209
 92.91         -1.481705E-03  0.000302
 122.88        -1.099326E-03  0.00039
 152.85        -7.3714E-04    0.000473
 182.82        -3.94729E-04   0.000553
 212.79        -7.16728E-05   0.000629
                  ⋮
 2760.239872    1.158948E-03  0.0115
 2790.210048    1.388509E-03  0.0119
 2820.179968    1.635251E-03  0.0123
 2850.149888    1.899593E-03  0.0127
 2880.120064    2.181954E-03  0.0131
 2910.089984    2.482756E-03  0.0136
 2940.06016     2.802417E-03  0.014
 2970.03008     3.141359E-03  0.0145
 3000           0.0035        0.015
EOF
```

Termination data

Figure 3.7: The kit file is a text file that can be viewed with any text editor

4 MEASURED PERFORMANCE

In the following sections measured values of the LA19-13-01 VNA's directivity, effective test port match and linearity are given. These were obtained in accordance with conventional guidelines [1] relating to VNA uncertainty evaluation. The measured values are used to estimate the reflection and transmission uncertainty of the instrument when calibrated with LA Techniques' economy calibration kits.[1] Unless otherwise stated, the measurements have been taken with 128 averages.

4.1 Directivity

The LA19-13-01 effective directivity was measured using a 150 mm precision, unsupported 50 Ω air line. Representative graphical results are shown for the measured residual directivity and test port match in Figs 4.1 and 4.2, respectively. A total of four calibration kits were tested and the results are shown in Table 2.

Table 2: Residual directivity and test port match after calibration with kits evaluated

Residual error term	Male standards kits		Female standards kits	
	S/N 3748	S/N 3817	S/N 3819	S/N 3820
Directivity (dB)	-51	-51	-45	-47
Test Port Match (dB)	-41	-43	-43	-40

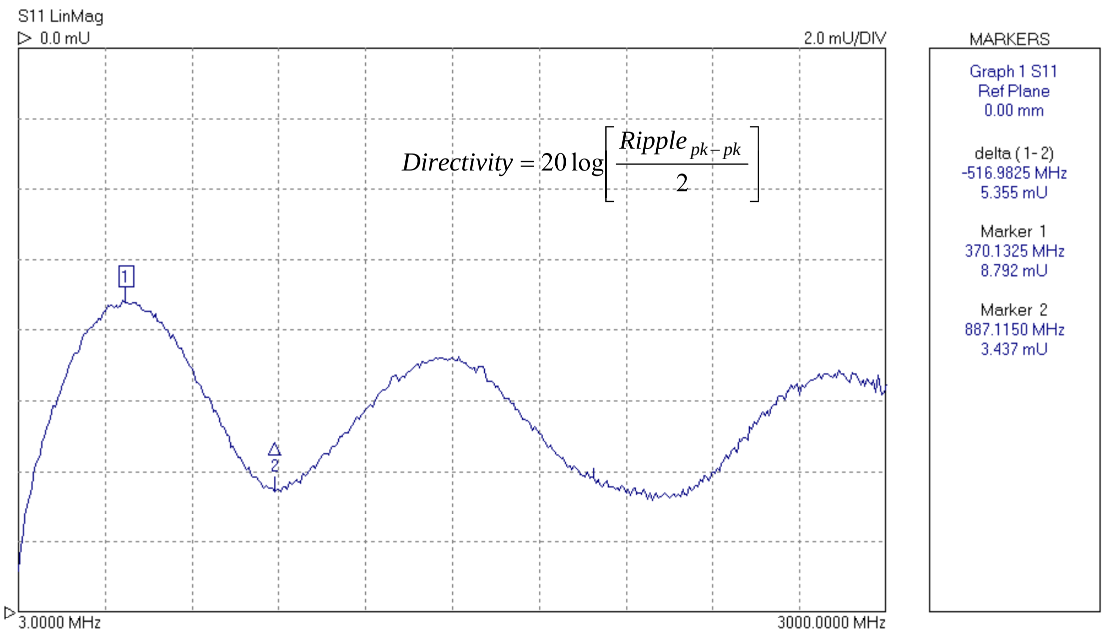


Figure 4.1: Measured residual directivity of better than -50 dB for the kits containing the male standards.

[1] These measured values were obtained from the kits that were tested. Subsequent uncertainties are estimated on the basis that other kits will have similar properties.

4.2 Test Port Match

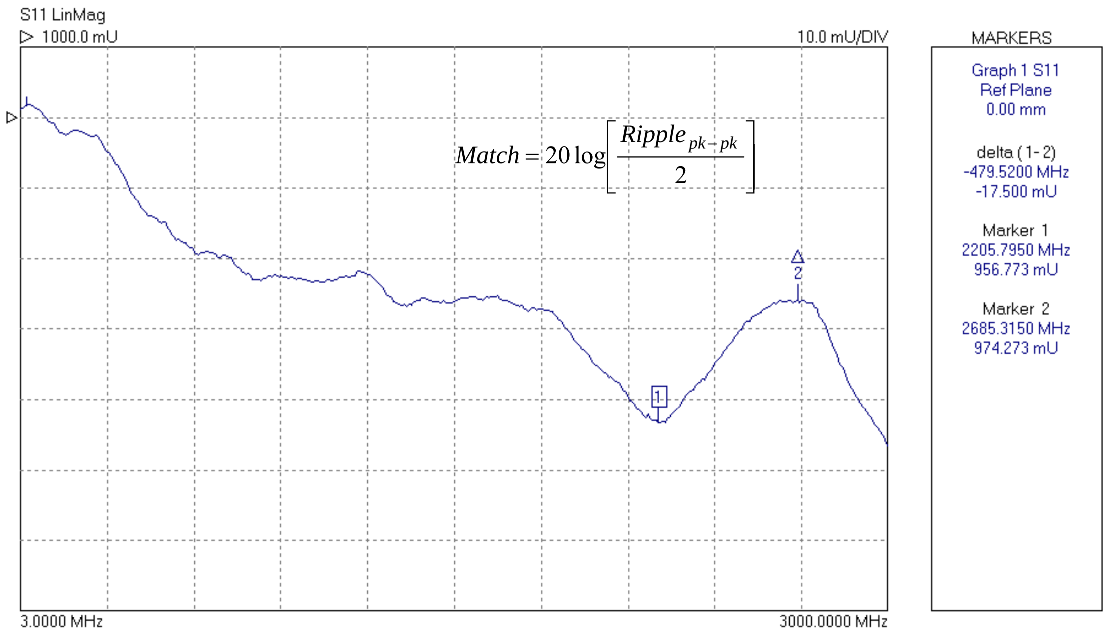


Figure 4.2: Measured residual test port match of better than -40 dB in all cases tested.

4.3 Linearity

Linearity was assessed by comparison with a step attenuator calibrated by the National Physical Laboratory[2]. The method for determining linearity is that given in [1], using results obtained over the range 10 dB to 50 dB, inclusive. Results are only given up to 2 GHz as the attenuator was not calibrated beyond this frequency.

Table 3: Measured VNA linearity

Frequency	Maximum observed non-linearity (dB/dB)
5 MHz	0.003 2
20 MHz	0.001 8
100 MHz	0.000 9
500 MHz	0.001 6
2 GHz	0.000 9

This shows that the linearity is significantly better than 0.002 dB/dB at most frequencies.

4.4 Reflection Uncertainty

The estimated reflection uncertainty [1] based on the measured results presented so far is shown in Figs. 4.3 (return loss uncertainty) and 4.4 (reflection phase uncertainty). It is assumed that the DUT has S12=0.

[2] This attenuator consists of two Type-N step attenuators connected in series (HP8494G and HP8496G) calibrated over a 90 dB dynamic range.

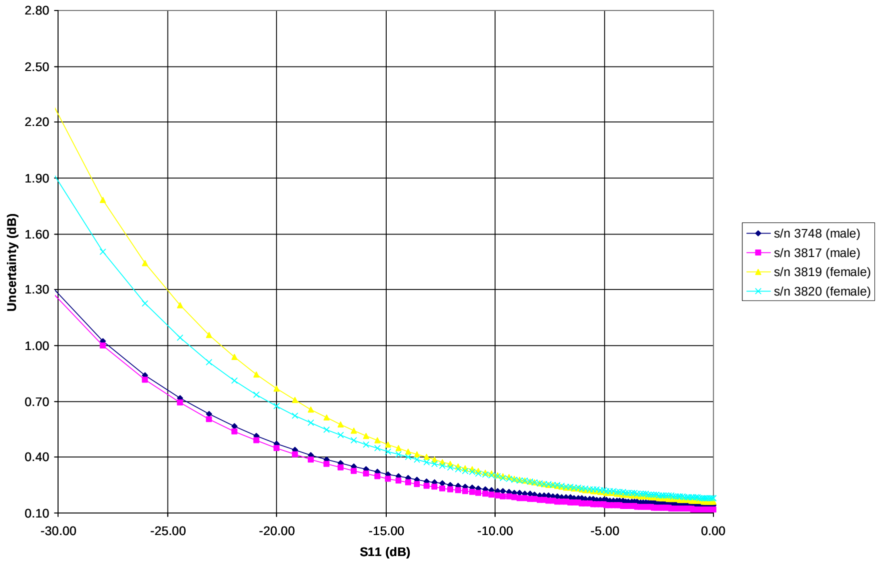


Figure 4.3: Estimated return loss uncertainty

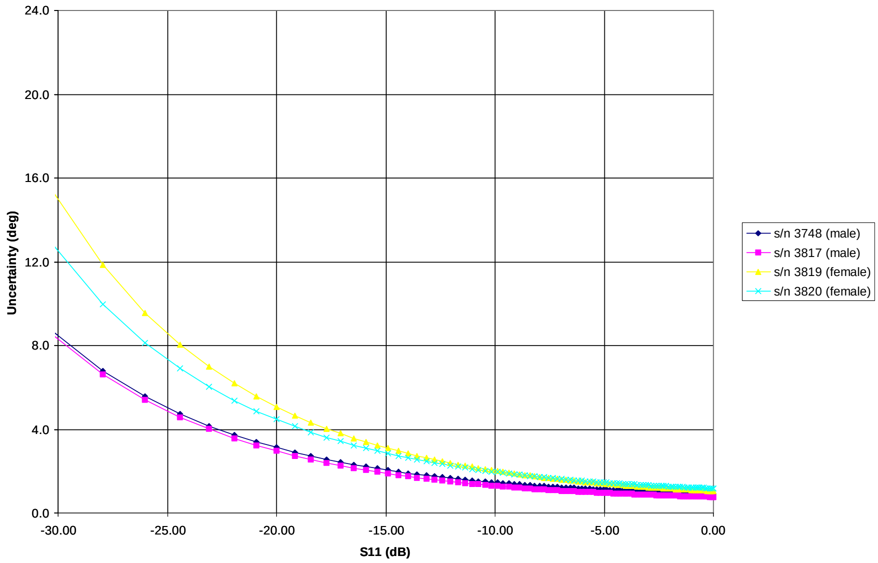


Figure 4.4: Estimated reflection phase uncertainty

4.5 Transmission Uncertainty

The transmission uncertainty for devices with low attenuation (i.e. linear |S21.S12| product close to unity) is generally dominated by the error introduced by the load match [2]. This term cannot be corrected without a full 12-terms correction. On the other hand, for devices with high values attenuation (i.e. linear |S21.S12| product close to zero), the error introduced by the instrument's crosstalk and noise floor become dominant.

The estimated uncertainties, using the measured results presented so far, are shown in Figs. 4.5 (magnitude uncertainty) and 4.6 (phase uncertainty). The phase uncertainty was estimated from the magnitude value and its uncertainty. In the graphs shown, the reflection coefficients (S11 and S22) of the DUT are assumed to be either 0 (i.e. perfect) or 0.32 (i.e. a return loss of-10 dB). Further, it is assumed that the DUT is reciprocal, that is, S21=S12. The estimate uses the approach described in [2] but does not include external factors such as cable flexing, connector repeatability or changes in ambient conditions, etc. A load match return loss of -29 dB and a crosstalk value of -83 dB were used in the calculations. These are the measured worst-case values across the full bandwidth of the VNA.

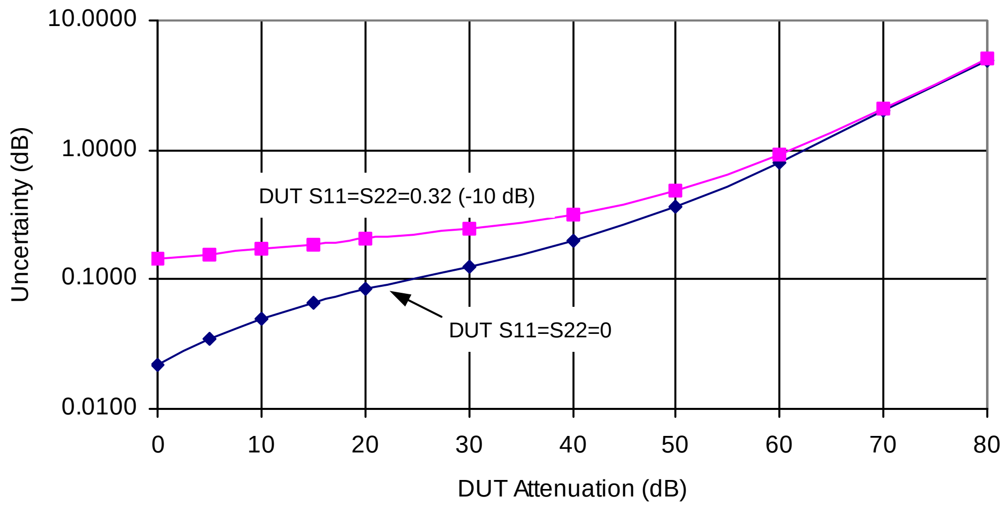


Figure 4.5: Estimated transmission uncertainty (DUT S21=S12=-Attenuation)

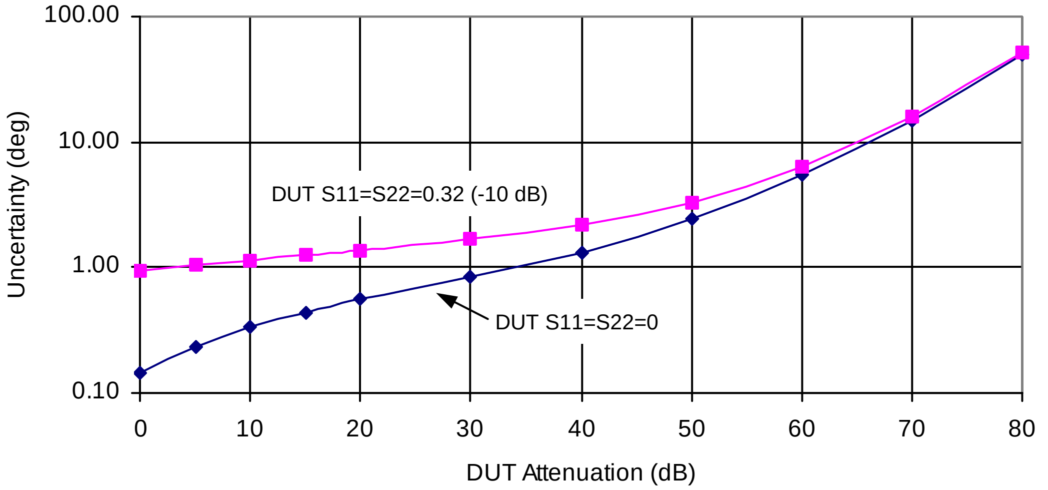


Figure 4.6: Estimated transmission phase uncertainty (DUT S21=S12=-Attenuation)

5 CARE OF THE CALIBRATION KITS

In order to maintain the performance of the instrument, it is important that the calibration kits are treated with care. Use the following guidelines when using the kits. Further information can be found in [3].

- Check the **pin depth** of the connectors: If possible, check that the pin depth is within the range 0" to -0.005" (i.e. –5 thou). A suitable gauge to check 2.92 mm connectors is required for this.
- Do not **over torque** the connectors: Always use a suitable torque spanner (set to provide a torque of between 5 lb.in and 9 lb.in). Never use pliers or an adjustable wrench.
- Do not subject the kit components to **mechanical shock**: Handle the kit components with care. Do not drop them.
- Regularly **clean the connectors**: Routinely inspect and carefully clean the connectors. It is recommended that a cotton swab damped in isopropyl alcohol is used to gently clean the connectors. Do not put lateral pressure on the centre conductor. Ensure that no material has been left behind in the connector after cleaning.

6 CONCLUSIONS

The economy calibration kits for use with LA19-13-01 VNA can provide excellent measurement results for most applications. Measured results demonstrate a residual directivity of better than -45 dB, a residual test port match of at least -40 dB, a linearity of generally better than 0.002 dB/dB, a worst-case load match of -29 dB and worst-case crosstalk of -83 dB.

7 REFERENCES

[1] EA Guidelines on the Evaluation of Vector Network Analysers (VNA), European co-operation for Accreditation, EA-10/12, May 2000.

[2] Applying Error Correction to Network Analyser Measurements, Agilent application note AN 1287-3.

[3] “ANAMET connector guide – using coaxial connectors in measurement”, downloadable free from www.npl.co.uk/anamet/connector_guide.html

