ME1000 RF Circuit Design

Lab 1

Calibration with Spectrum Analyzer

Objectives

i) To perform scalar offset calibration with a spectrum analyzer (SA)
ii) To verify the signal purity of a signal generator (SG)
iii) To determine the losses contributed by the cables, connectors, and PCB traces

Equipments ~~requiredRequired~~

i) Agilent N9320B 3 GHz RF Spectrum Analyzer
ii) Agilent N9310A RF Signal Generator

Accessories ~~required~~Required

i) TRM standard calibration kit
ii) 2 × SMA(m)-to-SMA(m) coaxial cable

1. Introduction

1.1 The Need for Scalar Offset Calibrations

A typical frequency domain measurement of a device-under-test (DUT) is shown in Figure 1~~Figure 1~~. When measuring the frequency response of a DUT, you will collect the power transferred from a SG to a SA via the DUT. To ensure that the data collected represents the actual response of the DUT only — and not portions related to the cables, connectors, and the losses within the measurement equipment itself — it is necessary to measure the total path loss of the interconnections from the equipment to the input and output terminals of the DUT.

In principle, the actual effect of the DUT is the measured value minus the losses due to the interconnections on both ends of the DUT. The process of accounting for the effect of the interconnection during a measurement is called *Calibration*. Since we are only interested in power measurement, the calibration process described here is known as *Scalar Offset Calibration*, and it is usually performed at various frequency of interest.

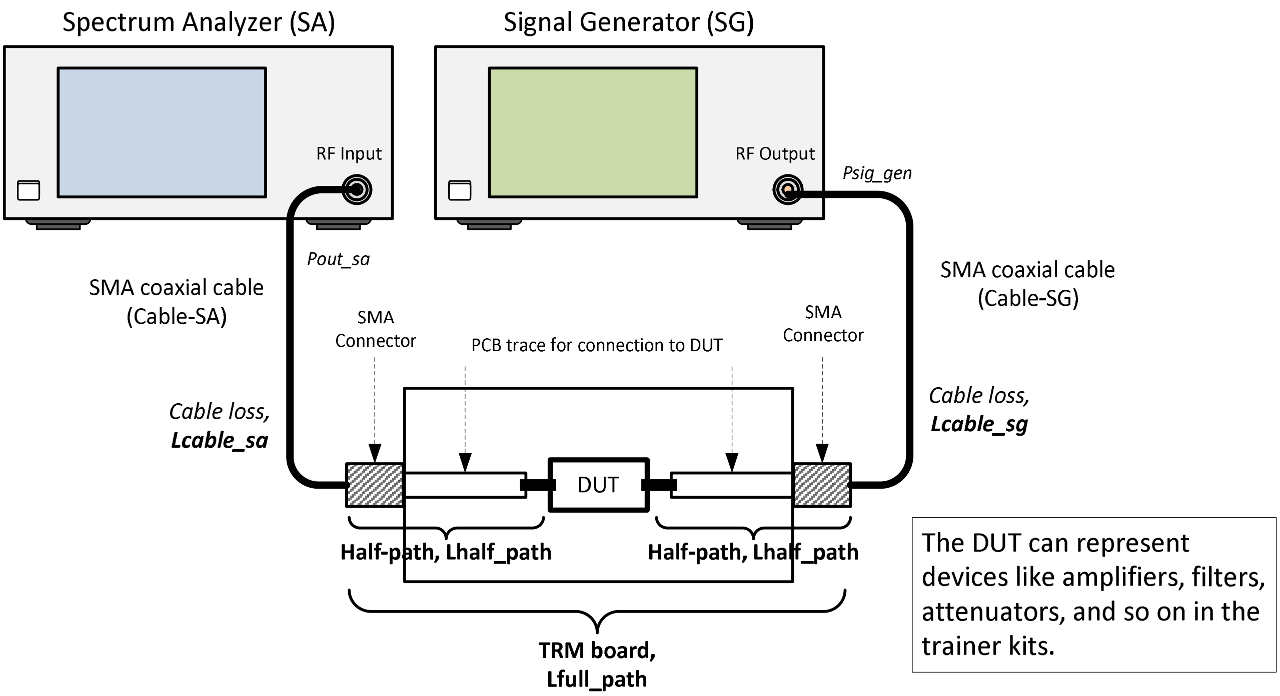

Figure 1 – The Need to Calibrate Scalar Offset of Cables, Connectors, and PCB Trace Losses

2. SG Verification and Calibration of Loss Contributed by the Cable

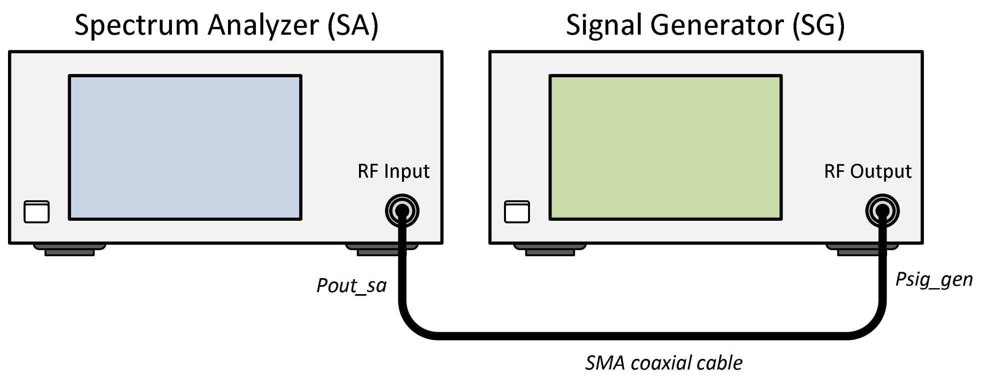

Figure 2 – SG Verification and SMA Coaxial Cable Loss Calibration

Important:

Excessive input power levels can damage the SA. The threshold for damage is different for various models. The input setting can be as low as 20 dBm (0.1 W or 3.2 V [1] in a 50 Ω load). Observe the caution notice on the front panel of the equipment.

[1] We are referring to the time-averaged power, $P = \frac{|V|^2}{2R}$ where R = 50 Ω.

First, we must investigate whether the SG we use is a perfectly linear device by connecting the SG directly to the SA as shown in Figure 2.

1. Use the following settings for the SG:

   CW frequency: 868 MHz
   Power level: –40 dBm (to be increased in 10 dB steps until 0 dBm)

N9310A setting:	**[ ]** - Hardkey; **{ }** - Softkey
Preset to default settings:	**[Preset]**
Frequency:	**[Frequency]** > **[868]** > **{MHZ}**
Amplitude:	**[Amplitude]** > **[+/–]** > **[40]** > **{dBm}**
Turn Off Mod:	**[Mod On/Off]**
Turn On RF Out:	**[RF On/Off]**

2. Use the following settings for the SA:

   Preset the SA to its default settings.
   Resolution bandwidth: 100 kHz
   Input attenuation: 10 dB (or auto)

N9320B setting:	**[ ]** - Hardkey; **{ }** - Softkey
Preset to default settings:	**[Preset/System]** > **{Preset}**
Span:	**[SPAN]** > **{FULL SPAN}**
Attenuation:	**[AMPLITUDE]** > **{Attenuation}** > **[10]** > **{dB}**
RBW:	**[BW/Avg]** > **{Res BW}** > **{100}** > **{KHZ}**

Exercises

a) What are the frequencies that appear in the SA when signal power is –40 dBm?

Frequency = __________ MHz, __________ MHz, and __________ MHz

Note:
Use marker function Peak Search if necessary.

b) Increase the power level by 10 dB each step until 0 dBm and note the different frequencies displayed. Are there any other frequencies that appear during this power increase?

YES, they are __________ MHz and __________ MHz or
NO, no other frequencies have appeared.

c) Explain why there is more than a single frequency component at the measured output.
d) Explain the difference between the measured and the expected output power level when the input power level is at 0 dBm.
e) Fill in the table below:

Input Power from Signal Generator, *Psig_gen* (dBm)	**Fundamental Power (dBm)**	**2nd Harmonic Power (dBm)**	**3rd Harmonic Power (dBm)**
−40			
−30			
−20			
−10			
0			

We can calibrate the cable losses before measuring any DUT by using the same setup as shown in Figure 2.

3. Use the following settings to determine the loss contribute by the cable:

SG settings
CW frequency: 868 MHz
Power: −25 dBm

N9310A setting:	**[ ]** - Hardkey; **{ }** - Softkey
Frequency:	**[Frequency]** > **[868]** > **{MHZ}**
Amplitude:	**[Amplitude]** > **[+/–]** > **[25]** > **{dBm}**

SA settings
Centre frequency: 868 MHz
Span: 10 MHz (approximately 1% of centre frequency)
Input Attenuation: 10 dB (or auto)
RBW: 100 kHz (or auto)
Averaging: On

N9320B setting:	**[ ]** - Hardkey; **{ }** - Softkey
Center frequency:	**[FREQUENCY]** > **[868]** > **{MHZ}**
Span:	**[SPAN]** > **[10]** > **{MHZ}**
Attenuation:	**[AMPLITUDE]** > **{Attenuation}** > **[10]** > **{dB}**
RBW:	**[BW/Avg]** > **{Res BW}** > **{100}** > **{KHZ}**
Averaging:	**[BW/Avg]** > **{Average}**

Exercises

a) What is the frequency and power display on the SA when the input power level is −25 dBm?

Frequency = __________ MHz

Power level = __________ dBm

Note:
Use the marker function if necessary.

b) Fill in the table below to determine the cable loss for various test signals. You should change the frequency and power level settings on the SG, as well as the center frequency and span settings on the SA. Use a span setting approximately 1% of the centerre frequency.

SG Frequency, *fsig_gen* (MHz)	SG Power Level, *Psig_gen* (dBm)	SA Measured Peak Frequency, *fsa* (MHz)	SA Measured Output Power, *Psa* (dBm)	Loss Contributed by Cable, *Lcable* = *Psig_gen* – *Psa* (dB)
50	−25			
50	−20			
50	−15			
50	−10			
50	−5			
100	−25			
100	−10			
500	−15			
500	−10			
818	−25			
818	−20			
818	−15			
818	−10			
818	−5			
818	0			
868	−25			
868	−20			
868	−18			
868	−15			
868	−13			
868	−10			
868	−8			
868	−5			
868	0			
1000	−15			
1736	−15			
1736	−5			
2604	−15			
2604	−5			

c) Does the cable loss remain the same for different input frequencies?

d) By how much does the SA measured signal power level drop at 50 MHz and 868 MHz when the SG power level setting is reduced by 10 dB?

3. Path Loss Calibration

The total path loss in a frequency response measurement consists of two parts: the input path loss and the output path loss. Each path loss is in turn due to the coaxial cable and connector losses, and the loss from the copper trace on the printed circuit board (PCB) that leads to the DUT terminals. We can measure the path loss with the use of a calibration structure called the TRM (Through-Reflect-Match) board.

- Input path loss: Cable-SG loss and half of the loss from the TRM board (PCB traces and connectors).
- Output path loss: Cable-SA loss and half of the loss from the TRM board.

Assumption: The input and output paths of the TRM board are identical.

Since both input and output path loss consists of two parts, these two parts can be determined individually from the following procedures and summed up to give us the total path loss.

3.1.1. Procedures

1. Measure the cable loss from the Cable-SG, *Lcable_sg* and Cable-SA, *Lcable_sa*.
2. Measure the loss from the TRM board (through path).

3.1.2. Equipment Setup

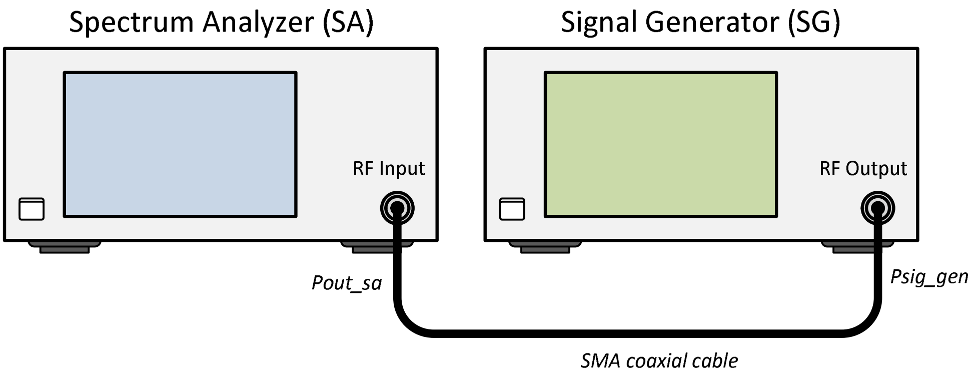

Figure 3 – SMA coaxial cable loss measurement setup

We can measure the cable losses by using the setup shown in Figure 3.

1. Connect the SMA coaxial cable used for connecting the SG as shown in Figure 3. This cable will be referred to as Cable-SG. Label this cable for identification.
2. Use the following settings the for SG and SA:

SG settings
CW frequency: Frequency of interest
Power: −25 dBm

N9310A setting:	**[ ]** - Hardkey; **{ }** - Softkey
Frequency:	**[Frequency]** > **[868]** > **{MHZ}**
Amplitude:	**[Amplitude]** > **[+/–]** > **[25]** > **{dBm}**

SA settings

Centre frequency:	Frequency of interest
Span:	10 MHz
Input attenuation:	10 dB (or auto)
RBW:	100 kHz (or auto)
Averaging:	On

N9320B setting:	**[ ]** - Hardkey; **{ }** - Softkey
Center frequency:	**[FREQUENCY]** > **[868]** > **{MHZ}**
Span:	**[SPAN]** > **[10]** > **{MHZ}**
Attenuation:	**[AMPLITUDE]** > **{Attenuation}** > **[10]** > **{dB}**
RBW:	**[BW/Avg]** > **{Res BW}** > **{100}** > **{KHZ}**
Averaging:	**[BW/Avg]** > **{Average}**

Note:

50 MHz and 868 MHz are required for the other labs to compensate for the losses.

Cable loss = SA reading – SG amplitude setting

Since it is a loss, omit the negative sign of the final answer for the equation above.

1. Make the measurements and record the losses for Cable-SG in Table 1:

Table 1 – Path Loss Calibration Data

Frequency (MHz)	Cable-SG Loss, *Lcable_sg*	Cable-SA Loss, *Lcable_sa*
50		
818		
868		
750		
800		
850		
900		
950		
1000		
1050		
1100		
1150		
1200		
1250		
1300		
1350		
1400		

2. Connect the SMA coaxial cable used for connecting the SA as shown in Figure 3. This cable will be referred to as Cable-SA. Label this cable for identification.
3. Make the measurements and record the losses for Cable-SA in Table 1.

4. Losses Contributed by Connector and PCB Trace

5. Losses Contributed by Connector and PCB Trace

Using a TRM board that represents the copper traces on the trainer board, we can measure the loss up until the DUT end.

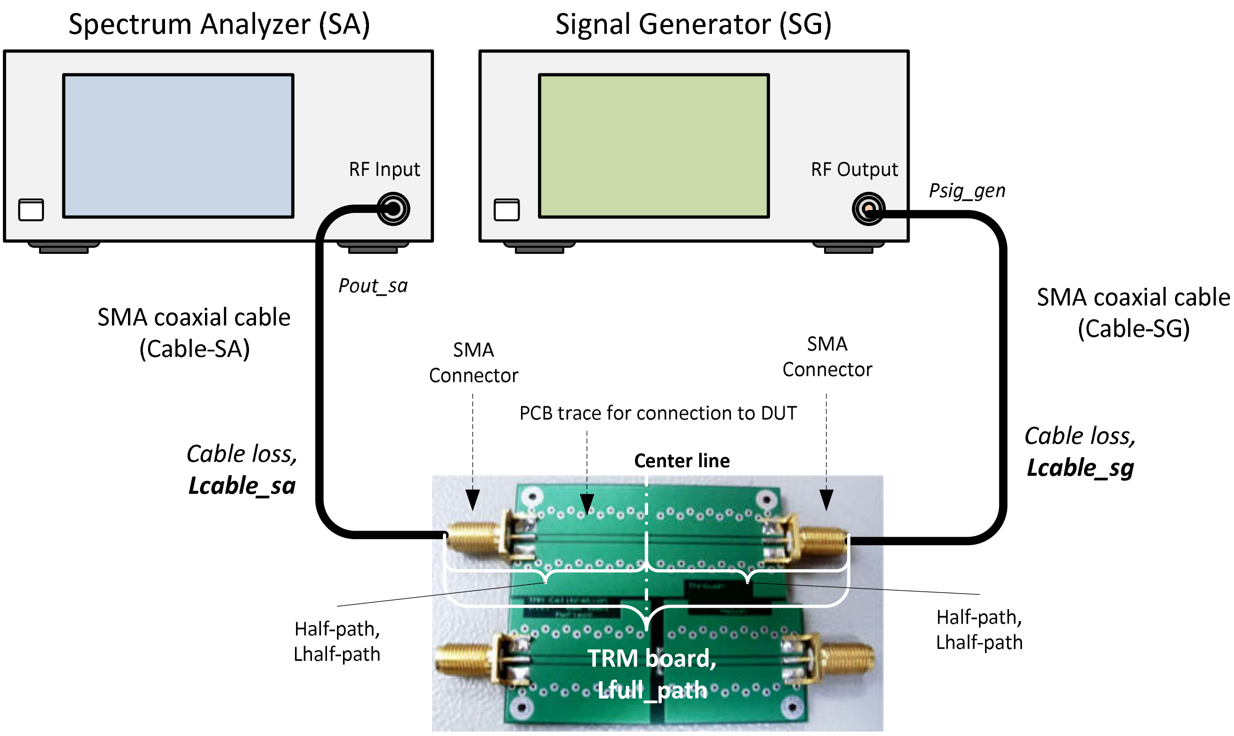

Figure 4 – SMA Connector and PCB Trace Loss Calibration

1. Make the connection as shown in Figure 4.
2. The measurements from this connection are the total loss contributed by the Cable-SG, Cable-SA, and the full through path of the TRM board.
   a. *Lfull_path* = Measured signal amplitude – SG amplitude setting − (*Lcable_sg* + *Lcable_sa*)
   b. *Lhalf_path* = 0.5 * *Lfull_path*

   Assumption: The input and output path losses are equal.

   Note:
   The cable losses are of positive values as taken from Table 1. Omit the negative sign for the *Lfull_path* at the end of calculation.

3. Make the measurements and record the losses for the TRM through loss under the Measured Power at the SA column in Table 2.
4. Calculate the *Lfull_path* and *Lhalf_path* and record it in Table 2.

5. Calculate the total input and output path loss as shown below :
   a. Total input path loss, *Linput-path* = *Lcable-sg* + *Lhalf-path*
   b. Total output path loss, *Loutput-path* = *Lcable-sa* + *Lhalf-path*

Table 2 – Input and Output Path Loss Calibration Data

Frequency (MHz)	Cable-SG Loss, *Lcable_sg*	Cable-SA Loss, *Lcable_sa*	Measured Power at SA	TRM Through Loss, *Lfull_path*	TRM Through Loss, *Lhalf_path*	Total Input Path Loss, *Linput _path*	Total Output Path Loss, *Loutput _path*
50							
818							
868							
750							
800							
850							
900							
950							
1000							
1050							
1100							
1150							
1200							
1250							
1300							
1350							
1400							

References

[1] Presentation slides, "*A Seminar on RF Measurement – Spectrum Analysis Basics,*" Agilent Technologies, 2001
[2] Thomas H. Lee, "*Planar Microwave Engineering,*" Cambridge University Press, 2004