Effect of Error in *Open* and *Short* Standards on Measurement of Attenuator

Raul Monsalve

SESE, Arizona State University

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Description

If a calibration is performed forcing the VNA to believe that the *open* or *short* behave exactly as stated by their fiducial models, and they do not, an error will be introduced to the measurement of the device under test.

This report provides an estimation of the impact of error in the model of the *open* and *short* standards that belong to the Agilent 85033E calibration kit, on the measurement of an attenuator with reflection coefficient of $\sim$ -15 dB.

The estimation is obtained from simulations. Realistic errors in the model of the *open* and *short* are obtained from the uncertainty reported by Agilent.

Standard Calibration Certificate

Certificate Of Calibration

Certificate No: 85033EMY3920577620130607

Manufacturer: Agilent Technologies
Model No: 85033E
Options Installed With Specifications: 400

Description: 3.5mm Standard Calibration Kit
Serial No: MY39205776

Date of Calibration: 07-JUN-2013
Temperature: (23 ± 0.5) °C
Procedure: MTA-T0107, MTA-T0126, MTA-T0127, MTA-T0128

Humidity: (20 to 55) % RH

This certifies that the above product was calibrated in compliance with a quality system registered to ISO 9001:2008, using applicable Agilent Technologies' procedures.

As Received: Factory tested - No incoming data available.

As Shipped Conditions: At the completion of the calibration, measured values were IN-SPECIFICATION at the points tested.

These calibration procedures and test points are those recommended in a procedure developed by Agilent.

Figure: 1. Main part of the certificate of calibration. This kind of certificate is included by default every time a new Agilent kit is bought. It basically states that the standards are IN SPECIFICATION. As clarified by an Agilent engineer, this implies that their reflection coefficient meets the specifications indicated in the manual of the cal kit, shown in the next figure.

Normal Uncertainties

Table 2-4 Electrical Specifications for 3.5 mm Devices

Device	Specification	Frequency (GHz)
Broadband Loads (-m- and -f-)	Return Loss ≥46 dB (ρ ≤0.005)	DC to ≤2
	Return Loss ≥44 dB (ρ ≤0.006)	>2 to ≤3
	Return Loss ≥38 dB (ρ ≤0.013)	>3 to ≤9
Offset Opens[a] (-m- and -f-)	±0.55 ° from Nominal	DC to ≤2
	±0.65 ° from Nominal	>2 to ≤3
	±0.85 ° from Nominal	>3 to ≤6
	±1.00 ° from Nominal	>6 to ≤9
Offset Shorts[a] (-m- and -f-)	±0.48 ° from Nominal	DC to ≤2
	±0.50 ° from Nominal	>2 to ≤3
	±0.55 ° from Nominal	>3 to ≤6
	±0.65 ° from Nominal	>6 to ≤9

a. The specifications for the opens and shorts are given as allowed deviation from the nominal model as defined in the standard definitions.

Figure: 2. Focusing on the *open* and *short*, their phase below 2 GHz is known with an uncertainty of $\pm$ 0.55° and $\pm$ 0.48° respectively. These correspond to $\pm$ 2σ deviations from the models produced with the equations of Application Note 1287-11. The Agilent engineer stated that only phase uncertainties are necessary to quote since physically, the dominant uncertainty is that in the physical length, instead of the loss.

Error in Phase of Open: Before Correction

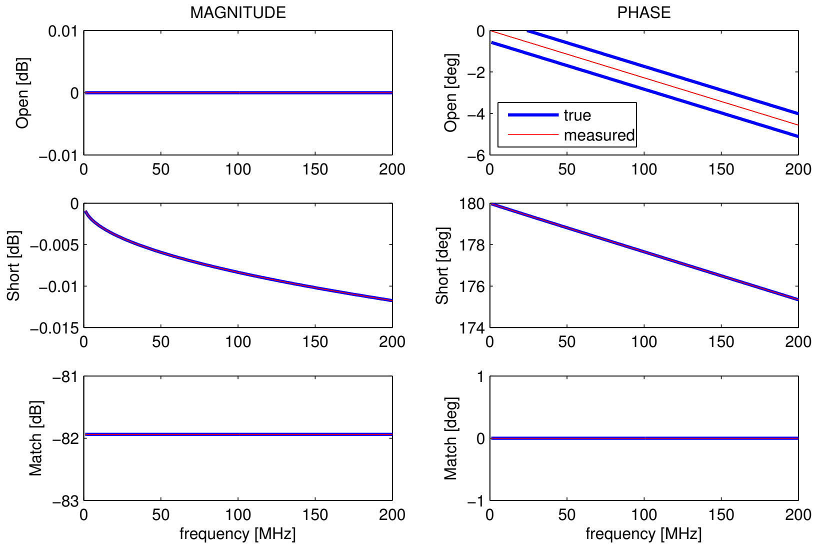

Figure: 3. Data simulated with equations of App Note 1287-11, and the fiducial parameters of the standards. A resistance value of 50.008 Ω was used for the *match* for better visualization in dB scale. Here, the measured phase of the *open* corresponds to the fiducial model (red line). However, the true value is $\pm$ 0.55° away (two blue lines shown simultaneously). The measurement of the other standards matches their true value (lines overlap).

Error in Phase of Open: Corrected

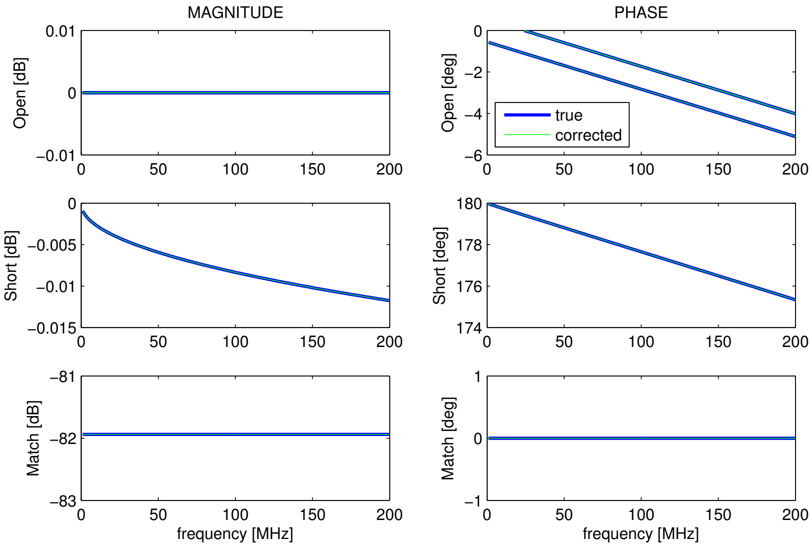

Figure: 4. The S-parameters of the difference between true and measured standards is computed, and then used to correct the scale of the VNA. Here, the *open*, *short*, and *match* are re-measured after correction (green lines). They all match their expectation. Two cases are shown in parallel, where the phase of the *open* is *fiducial* $\pm$ 0.55°. The correction is successful in both cases.

Error in Phase of Open: Propagation to Attenuator

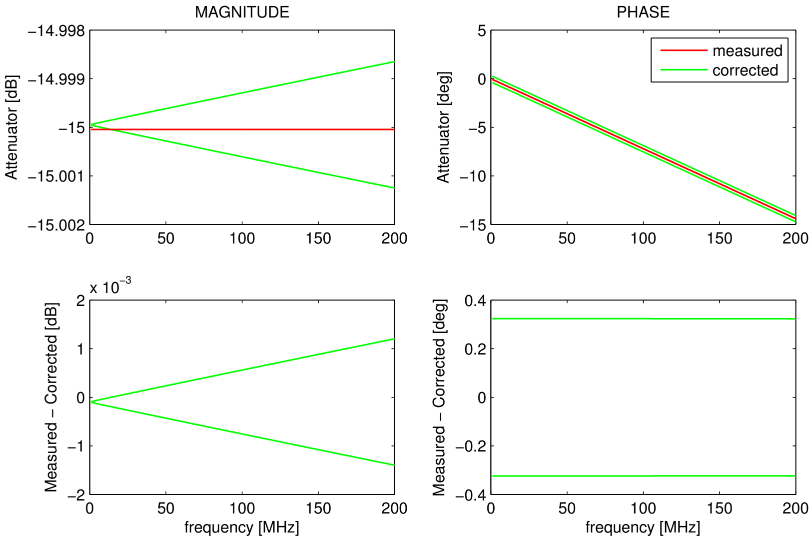

Figure: 5. TOP: The red lines represent a simulated attenuator, before correcting the scale of the VNA. The green lines represent the corrected response of the attenuator. They are obtained after forcing the VNA to use the true values of the standards (previous figure), and in particular, the phase of the *open*. BOTTOM: Distance between the attenuator measurement (with incorrect VNA scale) and the true value (corrected scale).

Error in Phase of Short: Before Correction

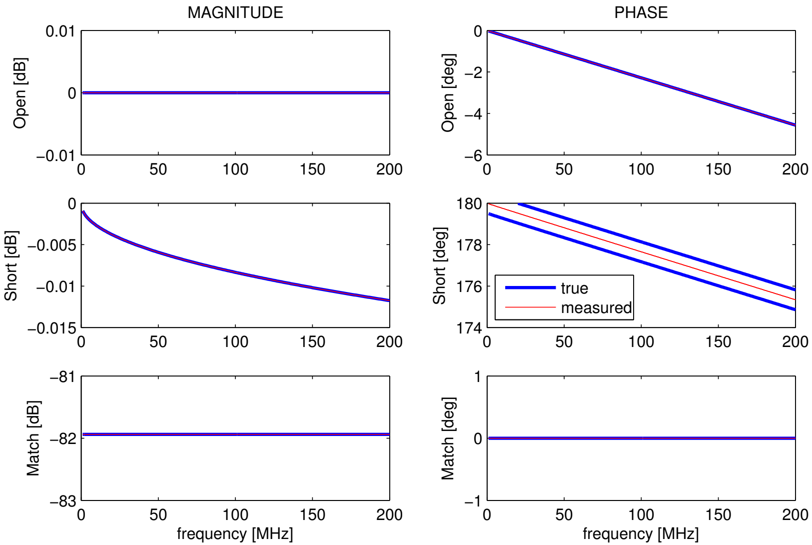

Figure: 6. Simulation of error in phase of *short*. This exercise is equivalent to the one with the *open*. Here, the measured phase of the *short* corresponds to the fiducial model (red line). However, the true value is $\pm$ 0.48° away (two blue lines shown simultaneously). The measurement of the other standards matches their true value (lines overlap).

Error in Phase of Short: Corrected

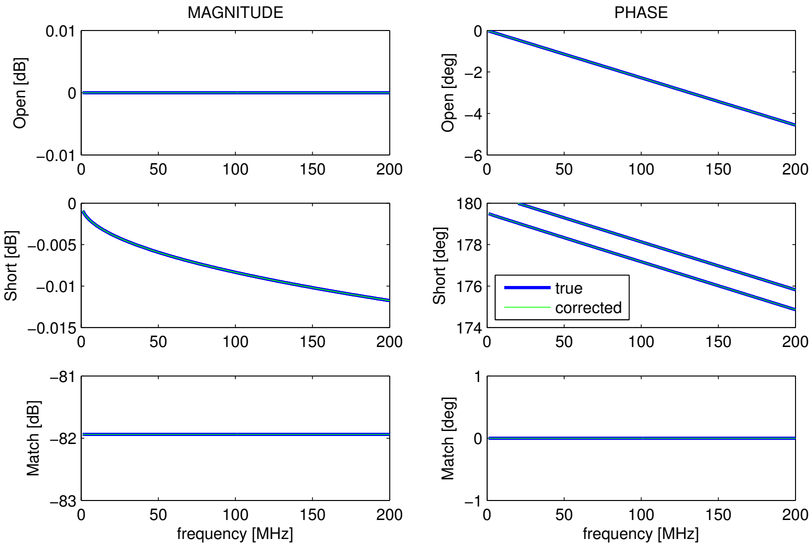

Figure: 7. The S-parameters of the difference between true and measured standards is computed, and then used to correct the scale of the VNA. Here, the *open*, *short*, and *match* are re-measured after correction (green lines). They all match their expectation. Two cases are shown in parallel, where the phase of the *short* is *fiducial* $\pm$ 0.48°. The correction is successful in both cases.

Error in Phase of Short: Propagation to Attenuator

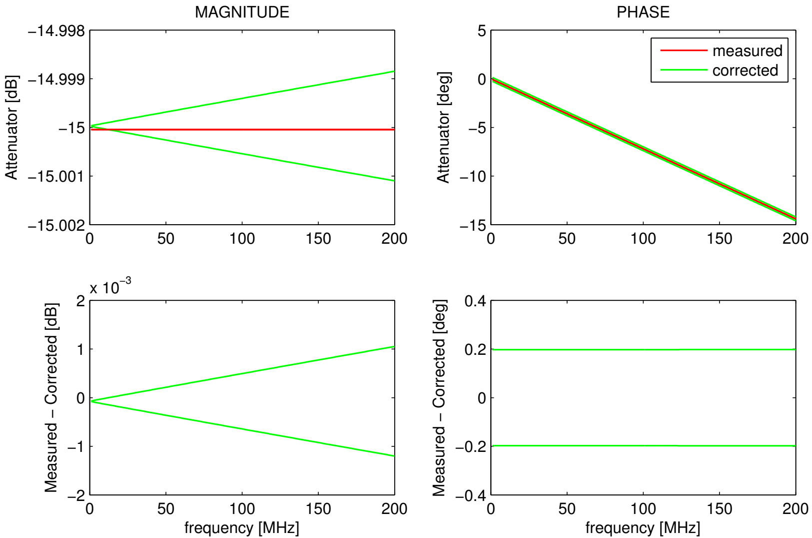

Figure: 8. TOP: The red lines represent a simulated attenuator, before correcting the scale of the VNA. The green lines represent the corrected response of the attenuator. They are obtained after forcing the VNA to use the true values of the standards (previous figure), and in particular, the phase of the *short*. BOTTOM: Distance between the attenuator measurement (with incorrect VNA scale) and the true value (corrected scale).

More Strict Certification: ISO/IEC 17025:2005

It is possible to request an additional certification from Agilent for the calibration kit. It is called ISO/IEC 17025:2005 certification. The practical benefits of this option is that data specific to the calibration kit are provided, along with more stringent uncertainties.

People from Agilent were kind enough to send me a sample of a report included as part of the ISO/IEC 17025:2005 certification.

Figure 11 summarizes the results of error propagation for both, the normal phase uncertainty provided in the manual, and the smaller uncertainty presented in the next two tables corresponding to the optional ISO/IEC 17025:2005 certification.

ISO 17025 Certification: Sample for Phase of Open

Measurement Report

ISO/IEC 17025:2005

Certificate No: 85033EOpt1A7MY3920502220111102

Kit Model No: 85033E Opt 1A7 **Kit Serial No: MY39205022**
Part Model No: 85033-60019
Part Serial No: 55972
Device Description: OPEN-F 3.5 9GHZ
Test Description: Modelled Phase
Measurement Units: Degrees (Scalar)
Test Date: 21-NOV-2011
Model Revision: B.03.00

Freq(GHz)	Model Data	Min Spec	Measured	Max Spec	+/- Uncert	Status
0.045	-1.0280	-0.5500	-0.0096	0.5500	0.0954	Pass
0.050	-1.1420	-0.5500	-0.0050	0.5500	0.0953	Pass
0.130	-2.9680	-0.5500	0.0162	0.5500	0.0945	Pass
0.250	-5.7080	-0.5500	-0.0135	0.5500	0.0942	Pass
0.500	-11.4150	-0.5500	0.0559	0.5500	0.0941	Pass
1.000	-22.8260	-0.5500	0.0914	0.5500	0.0939	Pass
>1.800	-41.0790	-0.5500	0.1899	0.5500	0.0940	Pass
2.000	-45.6410	-0.5500	0.1768	0.5500	0.0939	Pass
>2.600	-59.3280	-0.6500	0.2276	0.6500	0.0951	Pass
3.000	-68.4520	-0.6500	0.1872	0.6500	0.0951	Pass
>4.000	-91.2620	-0.8500	0.2224	0.8500	0.0952	Pass
5.000	-114.0740	-0.8500	0.1930	0.8500	0.0953	Pass
6.000	-136.8890	-0.8500	0.1707	0.8500	0.0953	Pass
>6.100	-139.1700	-1.0000	0.1622	1.0000	0.0953	Pass
7.000	-159.7060	-1.0000	0.1448	1.0000	0.0953	Pass
8.000	177.4740	-1.0000	0.1334	1.0000	0.0954	Pass
9.000	154.6520	-1.0000	0.1089	1.0000	0.1018	Pass

Figure: 9. Phase of the *open*. This table provides the phase for the fiducial model (Model Data), the normal uncertainties (Min/Max Spec), a more accurate measurement of phase with respect to the model (Measured), and smaller $\pm 2\sigma$ uncertainties ($\pm$ Uncert).

ISO 17025 Certification: Sample for Phase of Short

Measurement Report

ISO/IEC 17025:2005

Certificate No: 85033EOpt1A7MY3920502220111102

Kit Model No: 85033E Opt 1A7 **Kit Serial No: MY39205022**
Part Model No: 85033-60021
Part Serial No: 55854
Device Description: SHORT-F 3.5 9GHZ
Test Description: Modelled Phase
Measurement Units: Degrees (Scalar)
Test Date: 17-NOV-2011
Model Revision: B.03.00

Freq(GHz)	Model Data	Min Spec	Measured	Max Spec	+/- Uncert	Status
0.045	178.9320	-0.4800	0.0279	0.4800	0.0863	Pass
0.050	178.8160	-0.4800	0.0144	0.4800	0.0862	Pass
0.130	176.9590	-0.4800	0.0353	0.4800	0.0855	Pass
>0.150	176.4970	-0.4800	0.0486	0.4800	0.0854	Pass
0.250	174.1850	-0.4800	0.0174	0.4800	0.0852	Pass
0.500	168.4220	-0.4800	0.0119	0.4800	0.0851	Pass
1.000	156.9170	-0.4800	-0.0316	0.4800	0.0850	Pass
2.000	133.9450	-0.4800	-0.0304	0.4800	0.0851	Pass
>3.000	111.0030	-0.5000	-0.0825	0.5000	0.0852	Pass
>4.000	88.0830	-0.5500	-0.0870	0.5500	0.0853	Pass
5.000	65.1800	-0.5500	-0.0164	0.5500	0.0853	Pass
6.000	42.2890	-0.5500	0.0365	0.5500	0.0853	Pass
7.000	19.4060	-0.6500	0.0798	0.6500	0.0853	Pass
8.000	-3.4750	-0.6500	0.1617	0.6500	0.0852	Pass
>9.000	-26.3570	-0.6500	0.2247	0.6500	0.0853	Pass

Figure: 10. Phase of the *short*. This table provides the phase for the fiducial model (Model Data), the normal uncertainties (Min/Max Spec), a more accurate measurement of phase with respect to the model (Measured), and smaller $\pm 2\sigma$ uncertainties ($\pm$ Uncert).

Summary

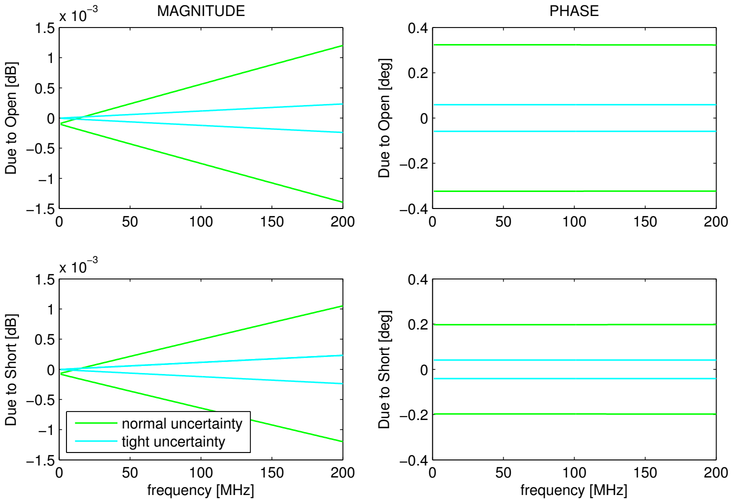

Figure: 11. The GREEN lines of this figure correspond to the same information presented at the bottom of figures 5 and 8. They represent the error in the measurement of the attenuator, due to unaccounted errors in the *open* and *short* (separately) allowed by the uncertainties provided in the manual of the cal kit. The CYAN lines present equivalent information, but now limiting the error in the phase of the *open* and *short* to the uncertainty limits provided by a typical ISO 17025 certification. A common $\pm 2\sigma$ error value of $\pm 0.1^\circ$ was used in the analysis for the *open* and *short*, instead of $\pm 0.55^\circ$ and $\pm 0.48^\circ$.

Conclusion

The uncertainty in the model of the *open* and *short* of the Agilent 85033E cal kit was propagated to the measurement of an attenuator, using simulated data.

Only phase uncertainties are provided. In the sample report of the optional ISO 17025 certification, the ($\pm$ 2σ) uncertainties are reduced from $\sim \pm$ 0.5° to $\sim \pm$ 0.1°.

The effect of these uncertainties on the attenuator at $\sim$ -15 dB is small. Using the default uncertainties, the possible error introduced by one of the two standards at a time is $\sim \pm$ 0.0013 dB in magnitude and $\pm$ 0.3° in phase (worst case scenario at 200 MHz). If the ISO 17025 uncertainty is used, the error range decreases to $\pm$ 0.00025 dB and $\pm$ 0.05°.