Calibration Check **Tom Clupper 12/5/2021**

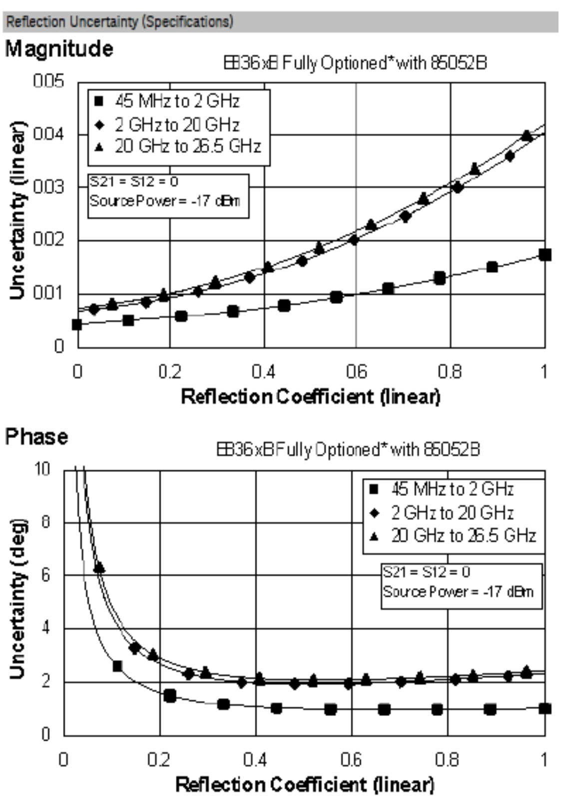
Experiment to compare the S-parameters measured on various VNA's using a few standard devices using the same port adapter, test cable and calibration kit (85052B) with a standard full 2-port SOLT calibration.

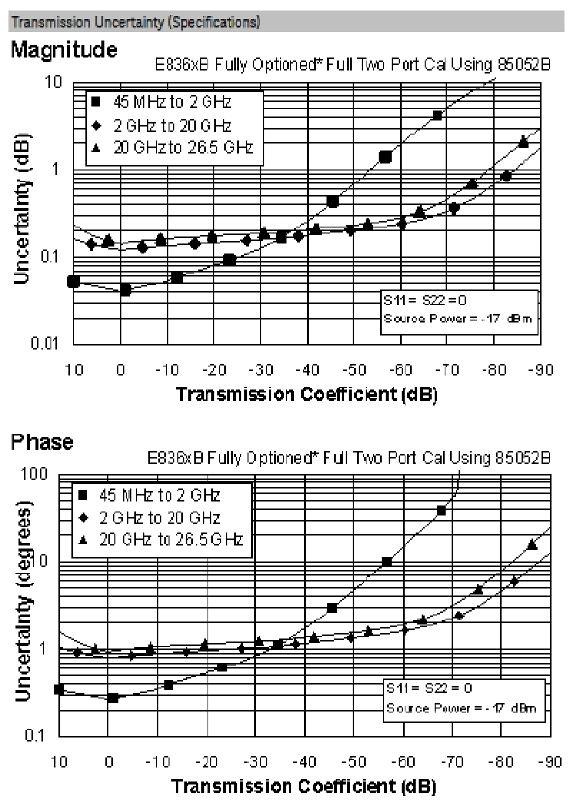
For the standards, I used a 7mm airline and 7mm Beatty standard each terminated with 7mm-3.5mm adapters. The reason for this is so the "innards" of the coax standards do not change between connections. The adapters keep the center conductor of the airlines captivated and the response of the standards unchanged between VNAs. So, basically there is a "low-reflection" standard and a "high-reflection" standard. The exact response is not critical as long as it does not change over time. Notice, that the standards were designed to be insertable (3.5mm-socket to 3.5mm-pin). This was done so that a "zero-thru" calibration could be done.

The same calibration coefficients and technique were used on the VNAs (well, the ones that could support it). For instance, the 8720ES does not support inductance correction of the short standard, so the E8364C coefficients definitions were changed to the same ones on the 8720ES. I also used a number of SMA-pin to SMA-socket attenuators (50dB, 10dB, 20dB, 30dB, 40dB) to examine dynamic range.

Reference VNA: **Keysight E8364C** VNA (Firmware Revision=A.09.42.22):

Test setup: {VNA-2.4mmNMD-p} {2.4mmNMD-s<>3.5mm-s} {85052-60013 3.5mm-p<>3.5mm-s} {Port 1} {DUT} {Port 2} {GBD01D010240:3.5mm-p<>3.5mm-p} {3.5mm-s<>2.4mmNMD-s} {VNA-2.4mmNMD-p}





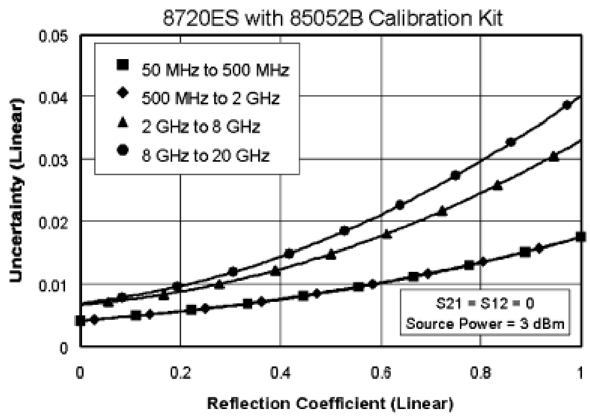
The above graphs show the expected uncertainty of the E8364C for the main measurements parameters. So, to compare S-parameter files, it makes sense to focus on Magnitude S11, dB S21, and angle S21. For low reflection devices the S11 Mag uncertainty should be less than 0.01 and for the Beatty standard it should be less than 0.02. For S21 dB, the uncertainty should be better than 0.2dB and the phase uncertainty should be better than 1 degree.

<u>First VNA to compare:</u> Keysight 8720ES VNA (Firmware Revision=7.74):

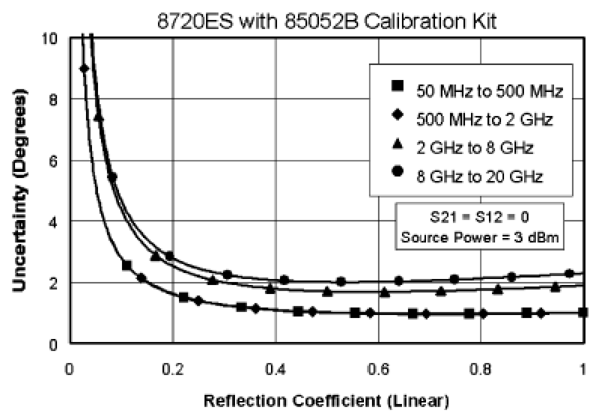
Test setup: {VNA-3.5mmNMD-p} {MMC8021A2: 3.5mm-s<>3.5mm-s} {85052-60013; SN30973: 3.5mm-p<>3.5mm-s} {Port 1} {DUT} {Port 2} {GBD01D010240:3.5mm-p<>3.5mm-p} {MMC8021A2: 3.5mm-s<>3.5mm-s} {VNA-3.5mmNMD-p}

Measurement uncertainty

Reflection measurements

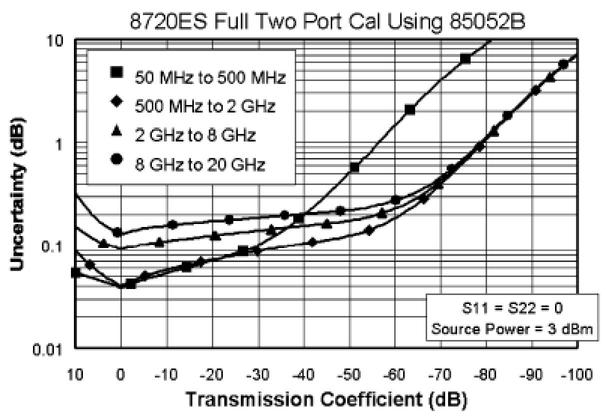


Magnitude

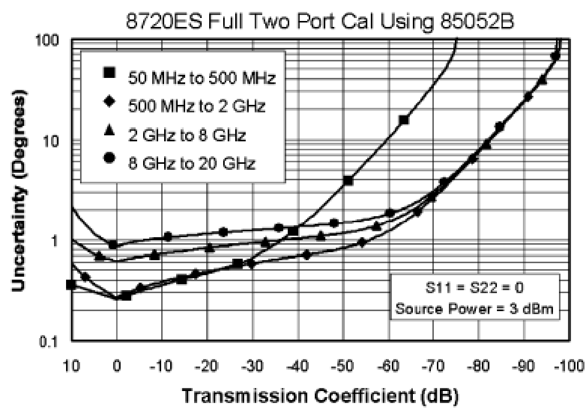


Phase

Transmission measurements



Magnitude



Phase

The above graphs show the expected uncertainty of the 8720ES for the main measurements parameters. So, to compare S-parameter files, it makes sense to focus on Magnitude S11, dB S21, and angle S21. For low reflection devices the S11 Mag uncertainty should be less than 0.01 and for the Beatty standard it should be less than 0.02. For S21 dB, the uncertainty should be better than 0.2dB and the phase uncertainty should be better than 1 degree.

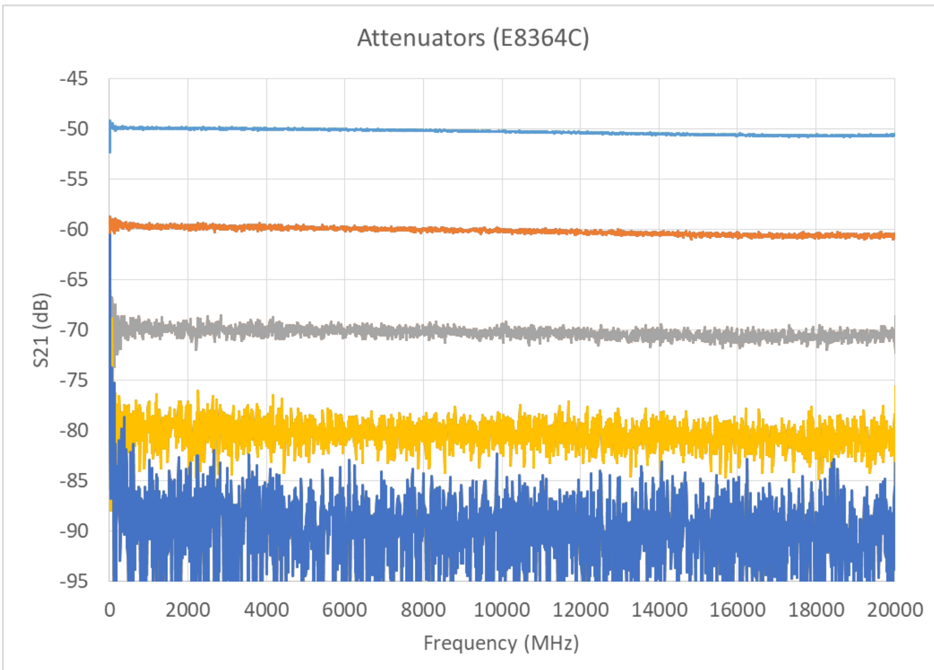
<u>Second VNA to compare:</u> nanoVNA V2 4GHz (https://nanorfe.com/)

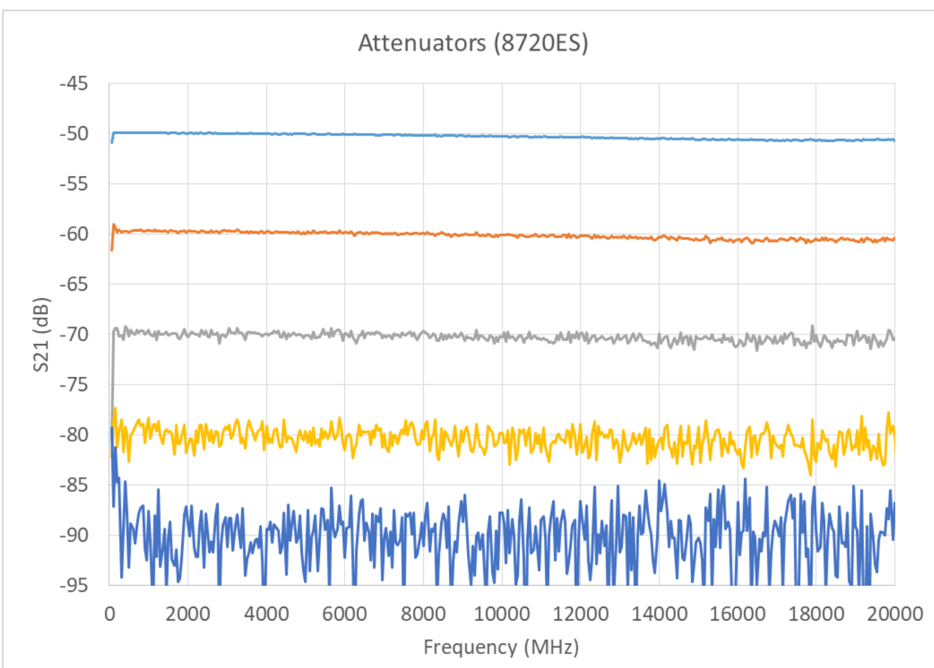
Test setup: The nanoVNA has its own calibration standards and cable and uses basic calibration techniques. Port 1 is an SMA-socket connector on the box. Port 2 has an SMA-socket that uses an included SMA-pin to SMA-pin test cable to provide the needed SMA-pin for port 2 through measurements.

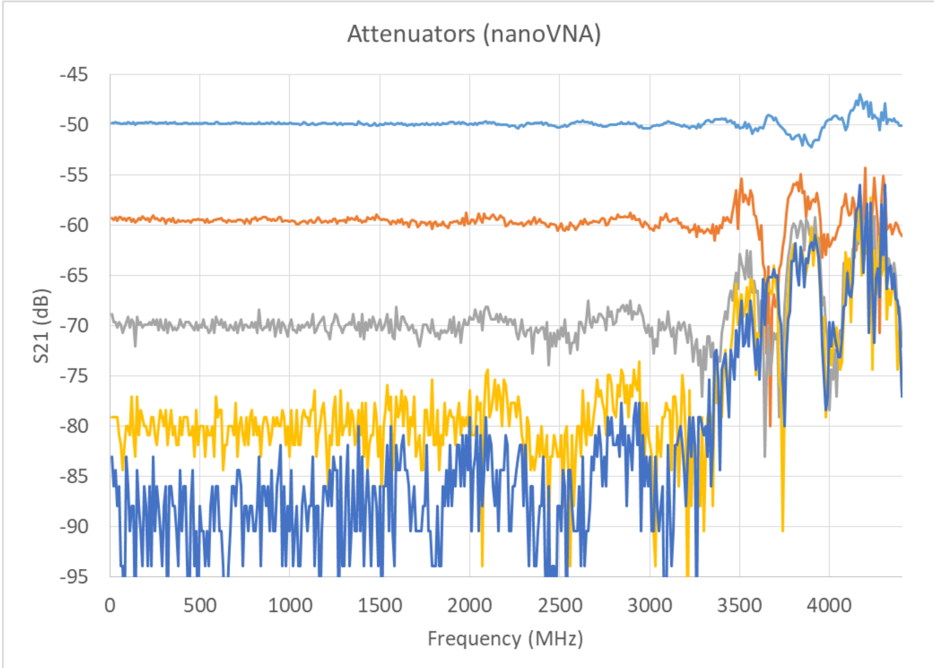
Some notes about the tests:

- The attenuators were used to examine the dynamic range by measuring S21 dB of 50dB, 60db, 70dB, 80dB, and 90dB values
- The frequency range for the E8364C was 10 MHz to 20.05 GHz, using 10 MHz steps
- The frequency range for the 8720ES was 50 MHz to 20.05 GHz, using 50 MHz steps
- The frequency range for the nanoVNA was 10 MHz to 4400 MHz, using 10 MHz steps
- The measurements were made using an IF bandwidth of 100Hz (when available)
- One of the comparisons was using an Ecal module (N4691-60004) vs. the 85052B cal kit (as the reference data) on the E8364C VNA

Results for the attenuators:







Observation:

It looks like the dynamic range tracks pretty well between the E8364C and the 8720ES. You would need to use a lower IF bandwidth and enable averaging to get any type of improvement. The nanoVNA, on the other hand, is only practically usable to about 2 GHz for higher dynamic range measurements.

Results from Airline (low reflection) and Beatty (high reflection) standards:

Summary table for Airline Standard:

	Average Max S11 mag Spec	Peak delta S11 mag measured	Average max S21 dB Spec	Peak delta S21 dB measured	Average Max S21 ang deg Spec	Peak delta S21 ang deg measured
8720ES	0.01	0.006	0.2	0.095	1	0.39
nanoVNA		0.017		0.45		2.91

Summary table for Beatty standard:

	Average Max S11 mag Spec	Peak delta S11 mag measured	Average max S21 dB Spec	Peak delta S21 dB measured	Average Max S21 ang deg Spec	Peak delta S21 ang deg measured
8720ES	0.02	0.0048	0.2	0.082	1	0.66
nanoVNA		0.019		1.62		10.67

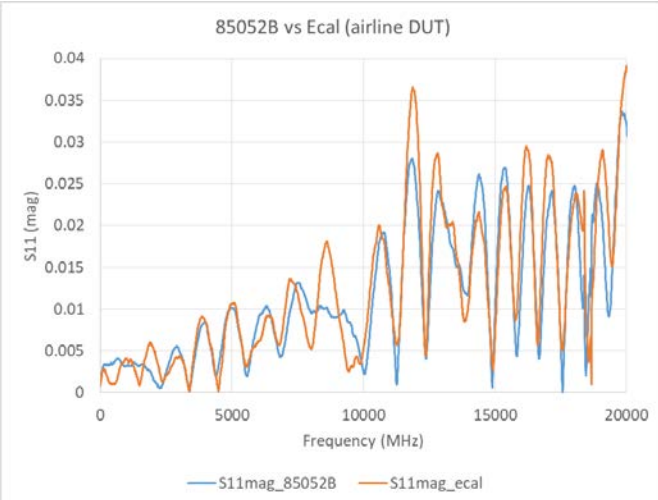
Observation:

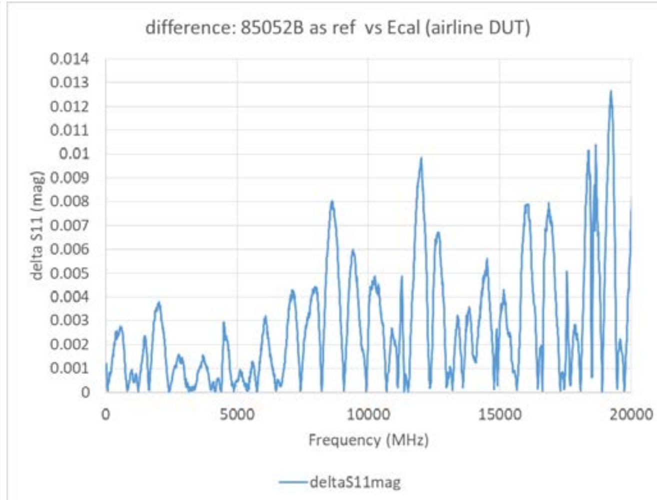
If you assume that the E8364C using the 85052B cal kit produces a reasonable “golden standard” set of S-parameter data for the standards, then you can see that the 8720ES produces S-parameter data well within the uncertainty of the stated uncertainty range. However, even though there is no specific uncertainty specs for the nanoVNA, it is apparent that it really does not produce accurate S-parameter data above about 2 GHz (particularly for through measurements). I believe improved accuracy could be achieved by using better calibration standards and techniques. I will explore this in a later experiment.

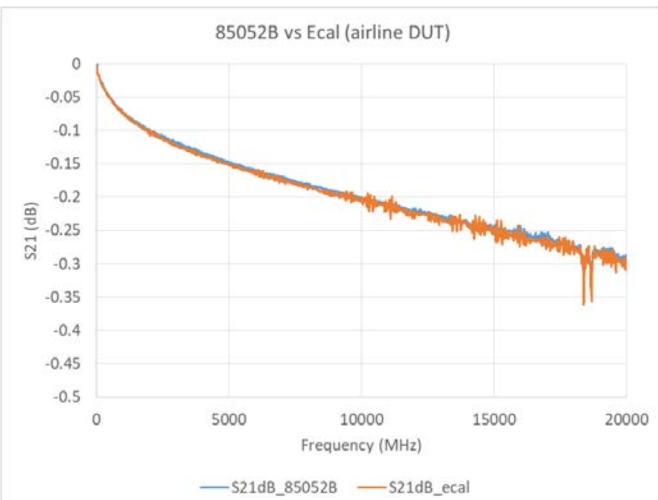
Results comparing the Ecal module to the 85052B cal kit (using it as the reference) for the E8364C:

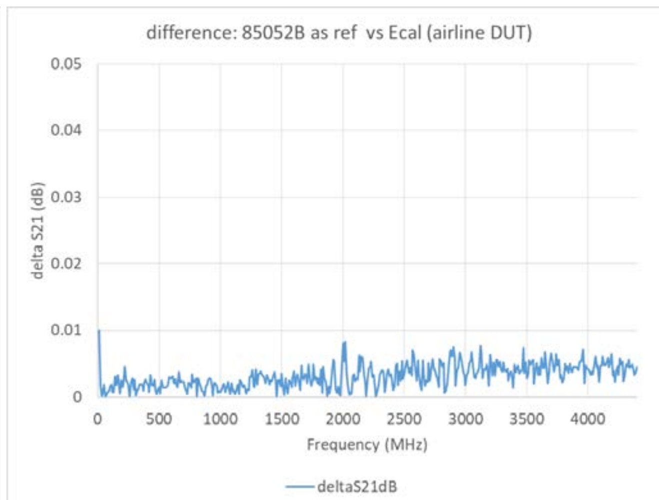
NOTE: Plot on right is just the magnitude difference of the traces on the left

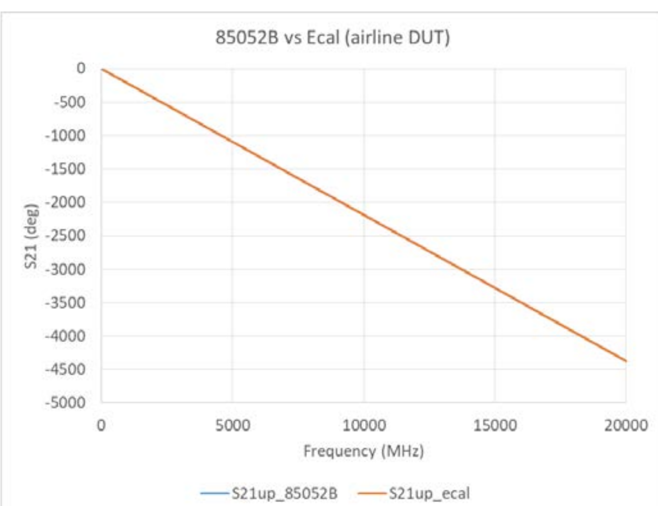
Airline Standard:

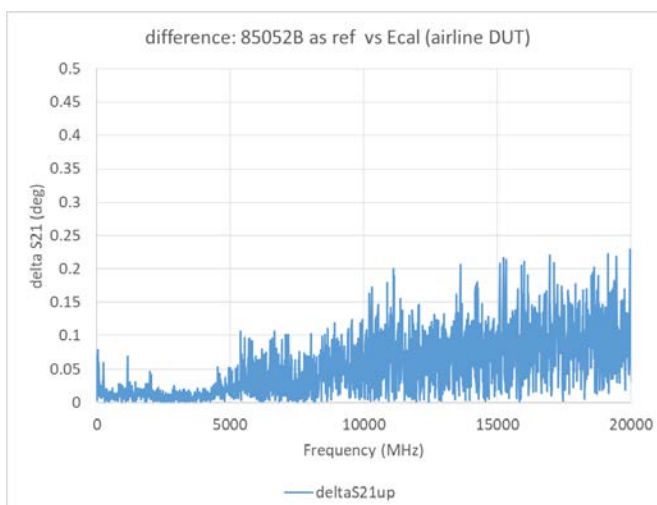




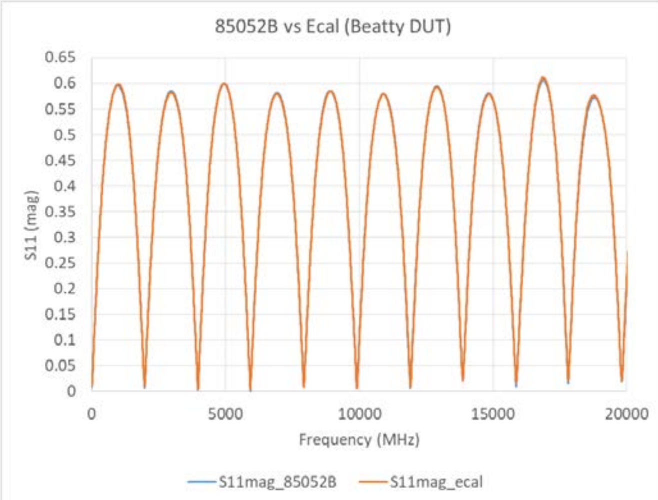


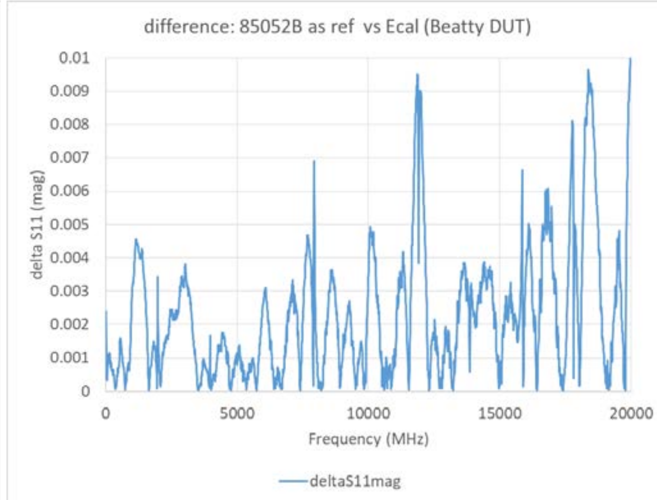


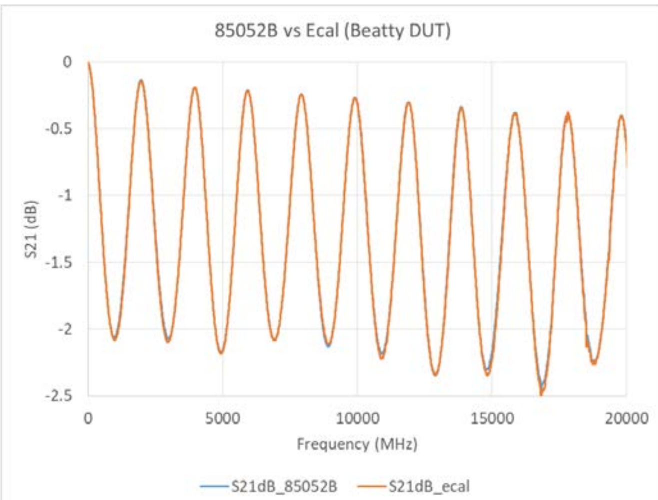


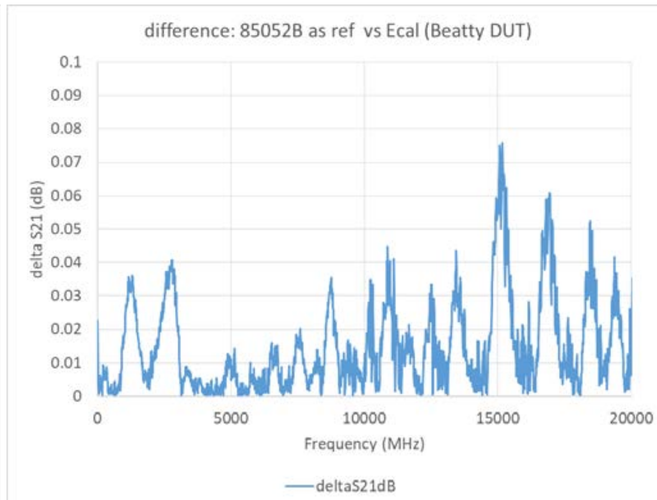


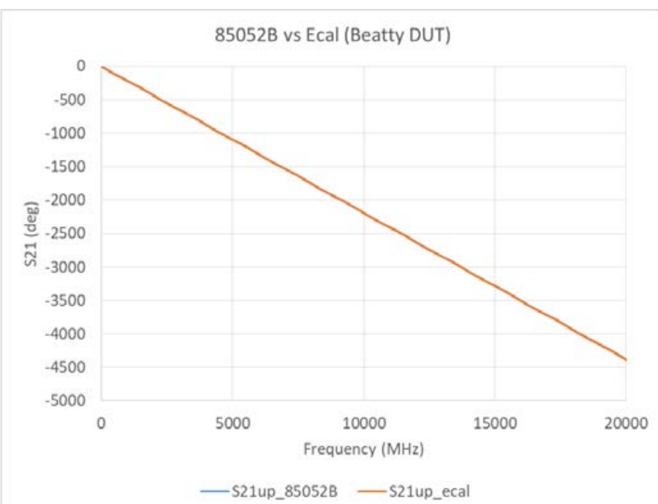
Beatty standard:

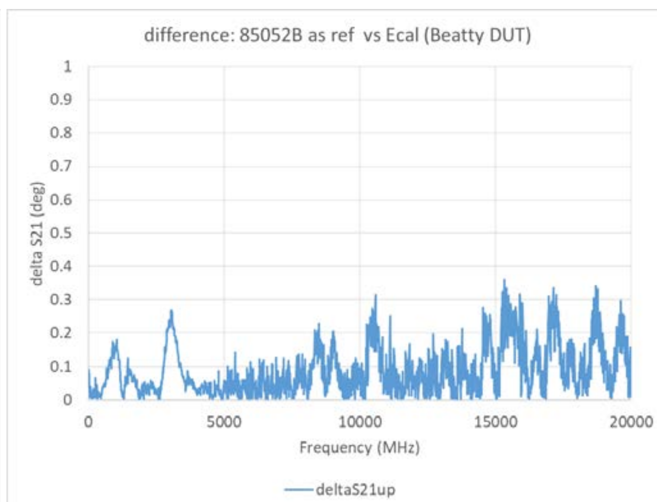








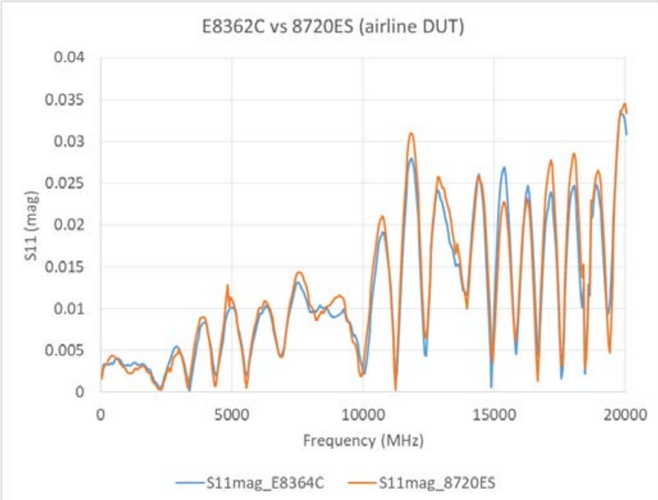


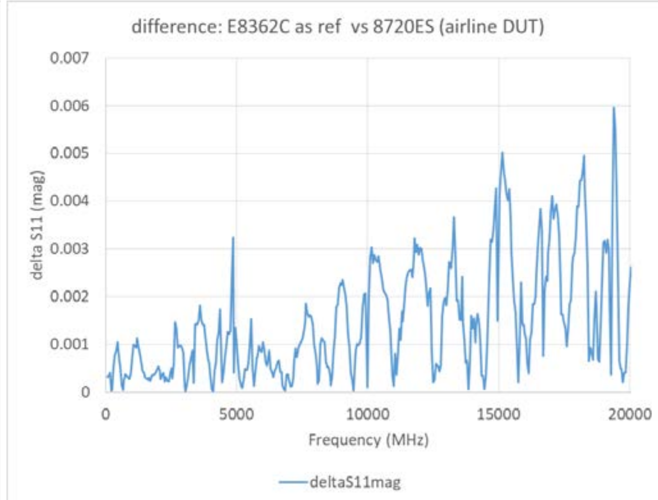


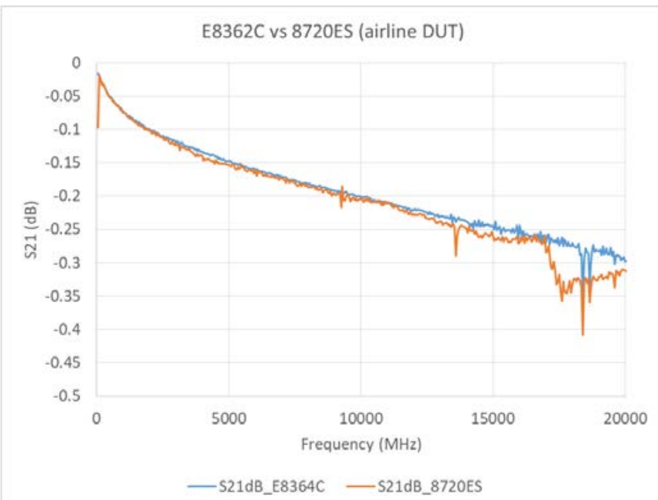
Results comparing the 8720ES to the E8364C as the reference (using the 85052B cal kit on both):

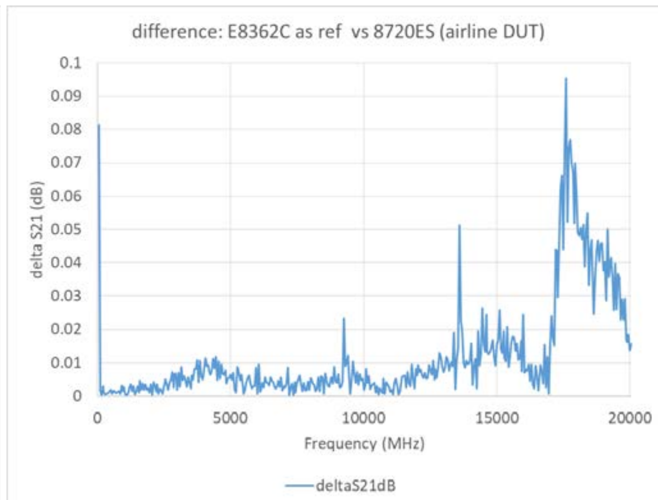
NOTE: Plot on right is just the magnitude difference of the traces on the left

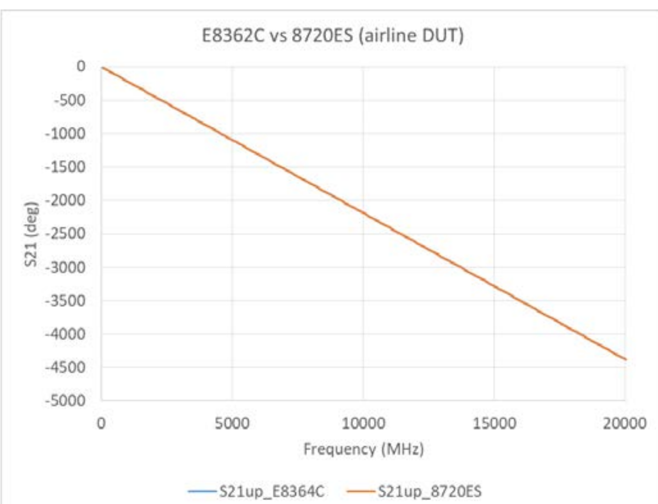
Airline Standard:

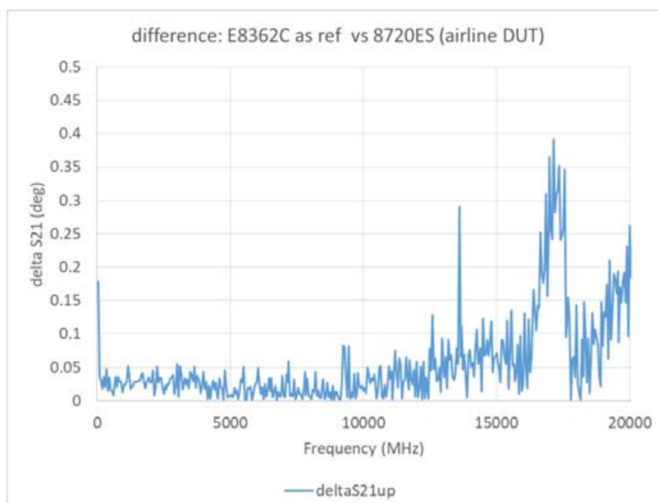




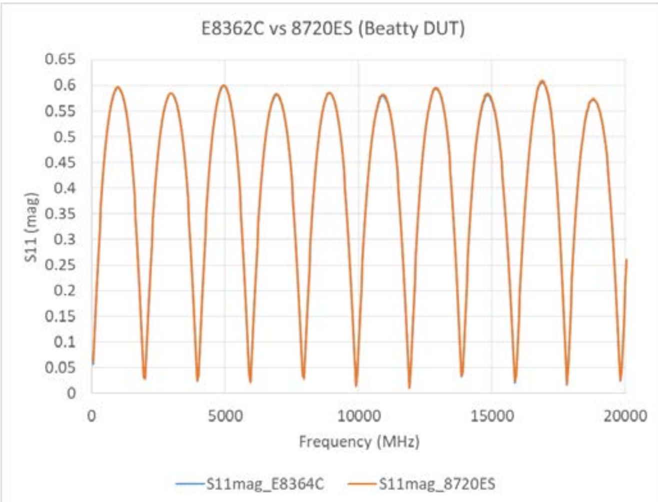


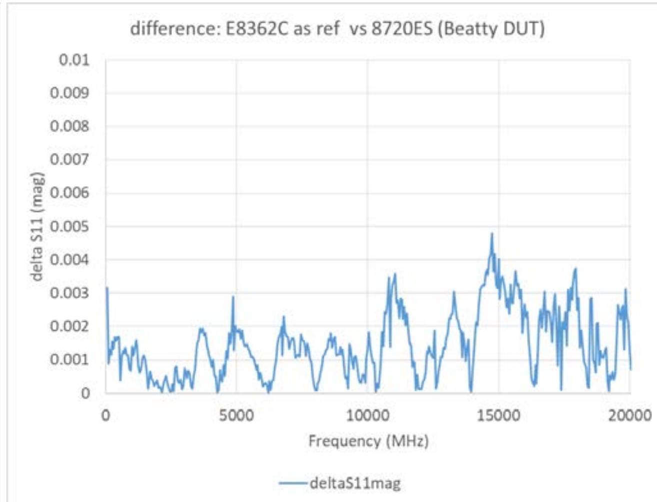


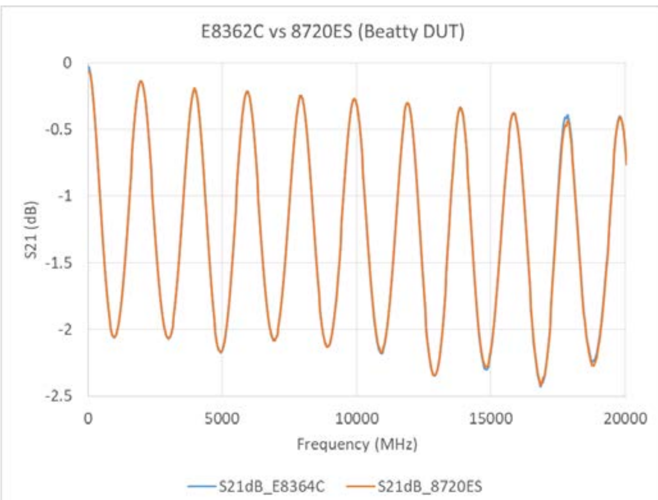


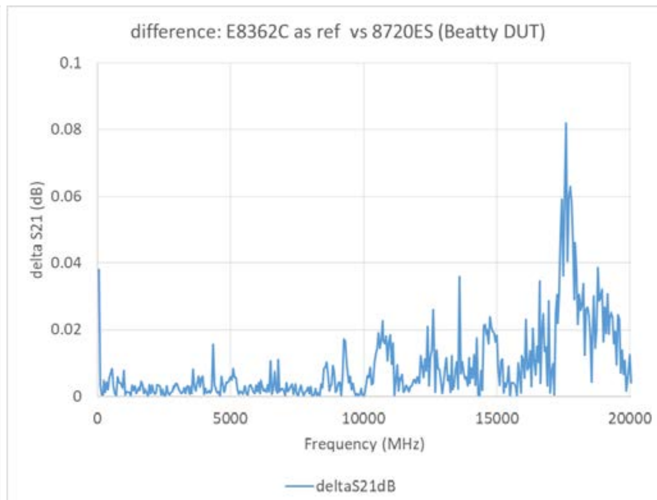


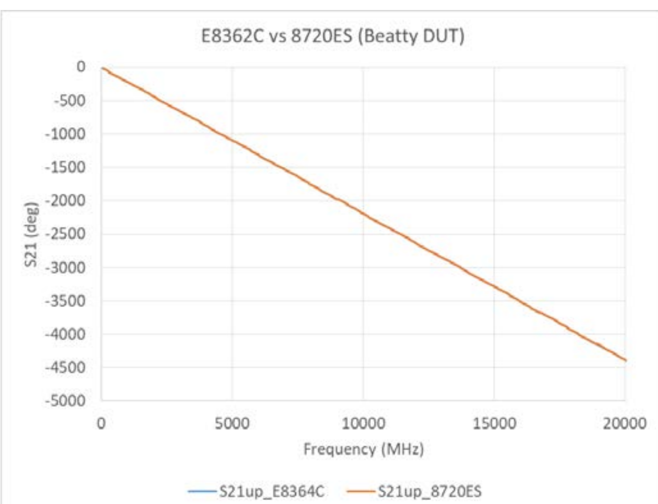
Beatty standard:

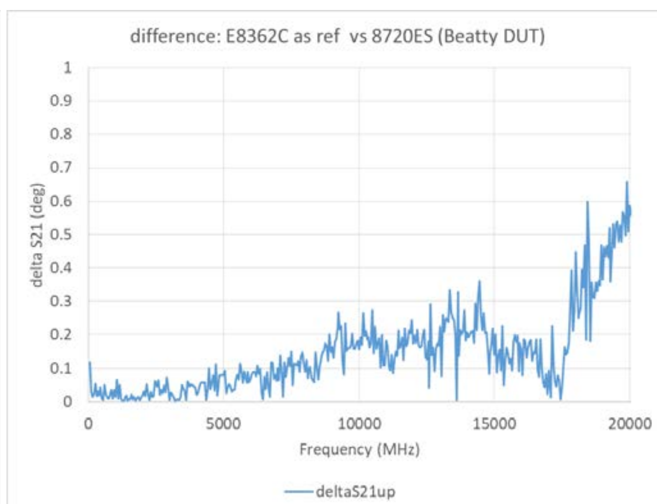








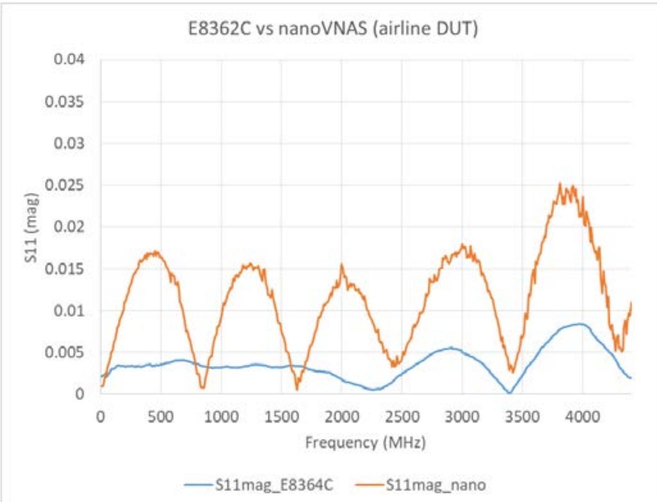


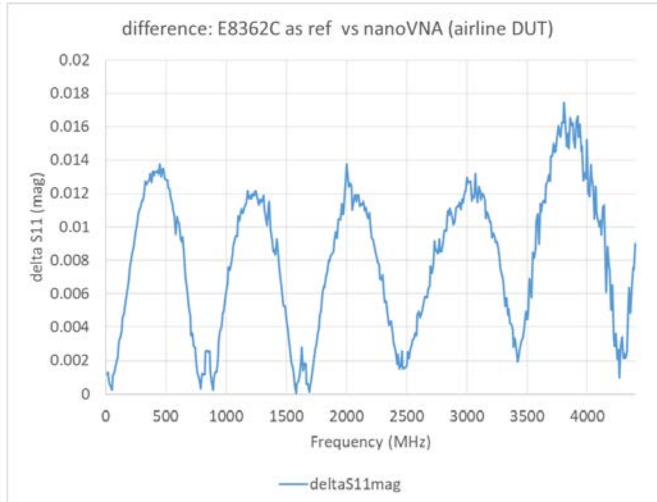


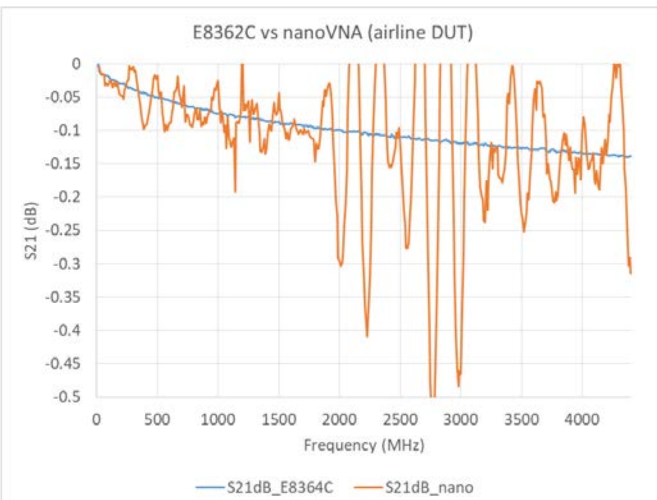
Results comparing the nanoVNA to the E8364C as the reference:

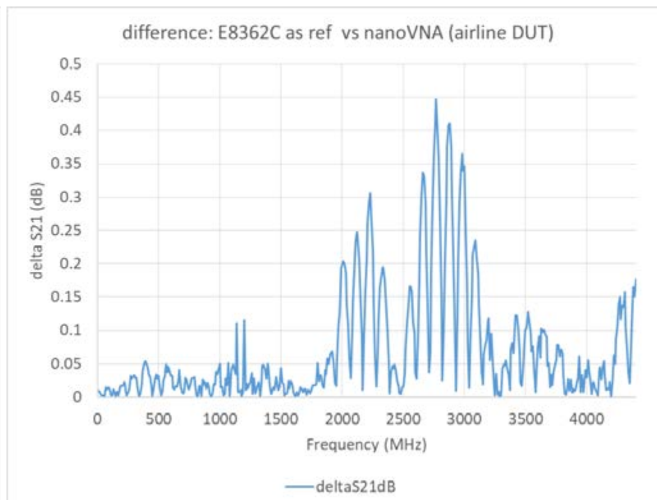
NOTE: Plot on right is just the magnitude difference of the traces on the left

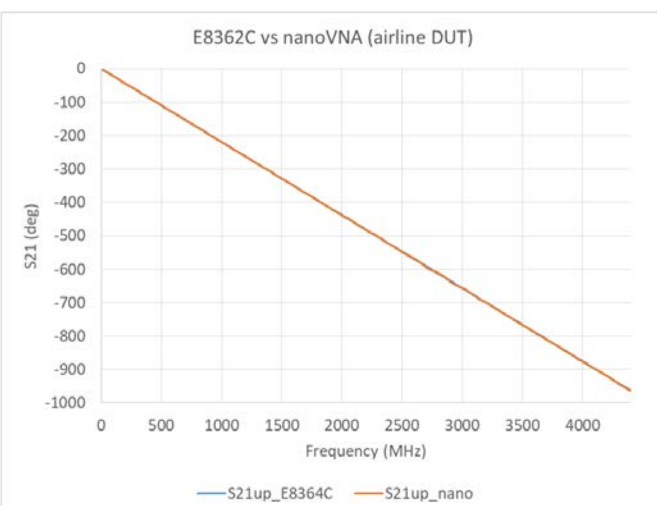
Airline Standard:

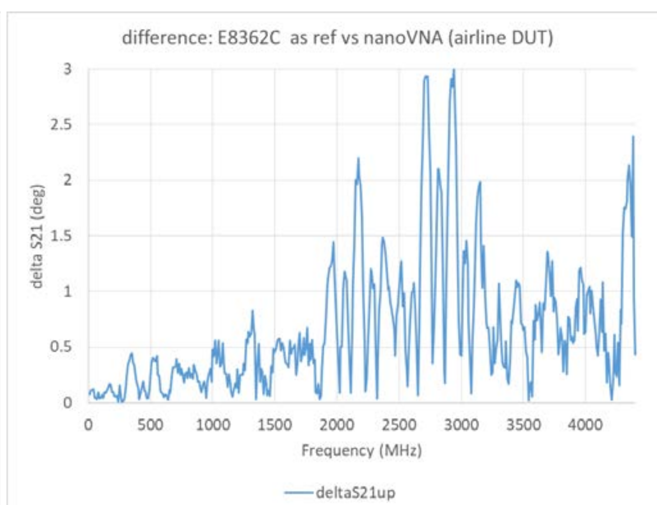












Beatty standard: