Introduction

The intent of this paper is to explain the validity of measuring and reporting the scattering parameters of vector network analyzer calibration kits to a frequency above DC (i.e. 45 MHz or 10 MHz), even though the components are specified down to DC.

Traceability

The measurement traceability for vector network analyzer calibration kit at Keysight Technologies is established via a measurement calibration method called TRL calibration. TRL stands for Thru-Reflect-Line. The TRL calibration method is a full two port correction algorithm that uses air dielectric coaxial transmission lines, a flush thru connection, and offset or flush short circuits as the primary standards. The system needs to be solved for 7 unknowns. The coaxial transmission lines and the flush thru connection provide 6 of the known quantities, the short circuits on both ports provide the seventh.

The calibration artifacts are mechanically very stable and can be dimensionally characterized by measuring the diameters of the center and outer conductor, along with the overall length of the transmission lines and offset short circuits. In the case of a flush short circuit, the flatness can be mechanically measured. Thereby making the scattering parameters traceable to dimensional measurements and physical constants in nature.

The ratio of diameters of the coaxial transmission line determines the characteristic impedance of the lines. For most calibration kits this is set to 50 ohms. The system impedance of the measurement system is also 50 ohms. The propagation constant of the transmission line is determined during the error correction term computation that establishes the calibration. Therefore, the total propagation delay of each transmission line does not need to be known a- priory.

The uncertainty of this method is dependent on the fact that the transmission lines:

1. Are 50 ohms impedance
2. Have small reflections from each end
3. Are of low loss
4. Have short circuits on both ports that behave identically
5. Flush thru connection has no loss and zero reflection.

These uncertainties can be kept very small due to high precision mechanical manufacturing and precision dimensional metrology capabilities at Keysight Technologies. TRL calibration has a low frequency coverage limitation due to the length of longest line in use. Operating coaxial transmission lines much beyond 30 cm becomes impractical. The longest airline that is employed at Keysight in the Type N connector style is 12.5 cm. This limits the practical lowest operating frequency to 200 Mhz. In some other connector styles the lowest TRL operating frequency is 250 Mhz.

Working Standard

The working standards are an open circuit, load circuit and a short circuit. These three circuits are characterized by a combination of dimensional metrology and measurements on a system that is calibrated by the TRL calibration described above. For each circuit, a point by point table of scattering parameters vs. frequency with associated uncertainties is established. This scattering parameter table is then used in another calibration correction algorithm to calibrate a production vector network analyzer system. As stated above the lowest frequency that can be measured with the TRL methodology is 200 Mhz. The remaining lower frequency information down to DC for the working standards is established through interpolation and curve fitting.

A short circuit and an open circuit are simple mechanical devices, which have predictable scattering parameter response based on EM theory [1]. A short circuit can be assumed to have a complex reflection coefficient of -1+0j at DC and likewise an open circuit can be assumed to have a reflection coefficient of +1+0j. The load circuit can be measured for DC resistance, which is close to 50 ohms. With this information and the scattering parameter measurements at higher microwave frequencies the remaining frequency table can be interpolated based on EM theory.[1]

Production Measurements

A vector network analyzer system is calibrated using the working standard as described above. This working standard has a full frequency point by point scattering parameter table that is used in a correction algorithm.

Production devices are measured with this calibrated system to determine if they are in or out of specification. These systems are usually microwave systems, with a starting frequency of 10 or 45 MHz depending on model.

The argument was made in the previous section "Working standard," that these simple mechanical devices have a predictable scattering parameter behavior. The same argument can be made for the production open, short and load devices. Therefore, if these devices are measured at 45 MHz and found to be in specification and the low frequency or DC response is known or easily predictable than it is unlikely that these parts will be out of specification between DC and 45 MHz. It is therefore unnecessary to make any additional measurements or report any additional data at those intermediate frequencies.

Conclusion

Traceability of scattering parameters in a coaxial system is established through TRL calibration which relies only on air dielectric coaxial transmission lines and short circuits. These are dimensionally stable and well characterized. The TRL calibration algorithm has very little need for a-priory characteristics. The lowest calibration frequency is typically 200 or 250 MHz. Direct scattering parameter traceability through measurements using any method at very low frequencies becomes impractical due to the required physical length of the longest transmission line. Short and open circuits are simple mechanical devices, which have a well understood scattering parameter behavior [1]. A load circuit can be measured for DC resistance. The intermediate scattering parameter response between this low frequency point and 200 MHz is based on interpolation. If production devices are found to be in specification at 45 MHz it is unlikely that these devices will be out of specification at a lower frequency.

1. An interpolation scheme for precision intermediate frequency reflection coefficients measurements. Nick Ridler et al. IEEE transactions on instrumentation and measurement. Vol 52. No. 1, February 2003.

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