Monoblock RF Filter Testing
SMA, In-Fixture Calibration and the UDCK

Introduction

Factory testing needs to be accurate and quick. While the most accurate (and universally available) calibration method is the end-of-cable 3.5 mm Air Precision Connector (APC) 2-port cal, see Fig 1, it is also the most expensive in the cost of standards and the time it takes to remove and install the fixture from the cables to do the calibration. Volume manufacturing also requires the flexibility to rapidly move from one product to another. Clearly, other calibration methods must be used.

The High Model Mix Solution

For low volume manufacturing we have chosen to use relatively inexpensive SMA standards, see Fig. 2. 3.5 mm APC standards individually cost $500 to $1,000. Individual SMA "standards" can be obtained for $20 to $100. These "standards" are commercial parts meant for termination of co-ax lines and other RF devices. They are not standardized and so they vary from manufacturer to manufacturer.

Figure 1 3.5 mm APC Standards

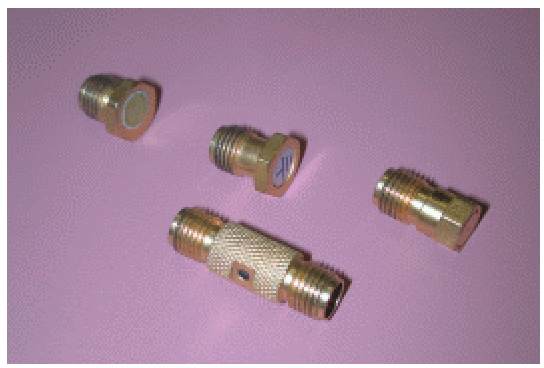

Figure 2 SMA Standards

To compensate for the lack of standardization, we have chosen to use only certain manufacturers as the source for the parts. The SMA "standards" used are similar to the VNA cal kits in that a set of Open, Short, Load and Thru terminations are required for the 2-port calibration. And like any controlled manufacturing process there is a regular (once-a-month) recall of the standards from the factory floor to be replaced with a new set. The recalled standards are each given a thorough visual inspection for damage or wear as well as a RF electrical test to make sure that they are within SPC control limits. They are in turn reassembled into qualified kits and inventoried for the next factory user.

Standards are matched with an electrical definition for the termination type in the calibration process of a VNA. This method allows the VNA user to do a calibration on different kinds of cable connectors and/or fixture types. Each analyzer comes with a selection of standard types that are defined by the connector type. Older VNA types like the Hp8753C came with a "sexless" precision connector the 7mm APC. This cal kit type as well as the 3.5mm, N 50 Ω, N 75 Ω, and USER KIT are selectable in the Cal Kit Menu on the VNA. To have the analyzer correctly compensate for the electrical differences in the standards, it is essential that the correct cal kit definitions be selected before the calibration process. Even though the VNA indicates "CAL" it may be a very poor cal.

SMA does not appear in the Cal Kit Menu. The only option available is to define electrical parameters for the SMA standard types and save them as a USER KIT. When we have used standard definitions this way we refer to them as User Defined Cal Kits or UDCK for short.

As mentioned before, SMA standards are not precision standards. The variations in mechanical dimensions, material types etc restrict their use to a range of frequencies up to about 6 GHz where the definitions are reasonably accurate. However, when correctly defined, SMA calibration accuracy can approach that of 3.5 mm standards.

The High Volume Solution

It would be convenient to not have to remove the cables from the fixtures for a few reasons. Flexing the cables while connecting them to standards and then reconnecting the cables causes Gage Repeatability and Reproducibility errors (GR&R) as well as wear and tear on both the cable and fixture connectors.   A duplex filter calibration requires three separate calibrations for the three combinations of ports (and a verification of each) and so the process takes a lot of time.

A calibration can be done in the fixture without removing the cables but this requires standards that have to some how fit into the fixture. To do this requires that sets of standards be made exactly the same size as a Monoblock filter, be durable enough to be repeat ably inserted in the fixture and to be reproducible to a very high RF electrical standard.

The standards CTS has developed, see Fig. 3, are made from a material with a much lower dielectric constant than used for filters so that block resonances are outside the normal pass and rejection bands for the filter. The blocks are precision lapped (±0.025 mm) on all six surfaces to the shape of the filter. Various co-planar artworks are developed for the I/O pads, and top surfaces for the 50-ohm load, and thru standards. For duplexer Monoblocks, three different thrus must be made corresponding to the three different port sets, S21, S31 and S32. The silver thickness applied to the dielectric block is SPC controlled and the artwork is applied to the standards using a high accuracy laser to control trace widths, gaps and penetration depths.

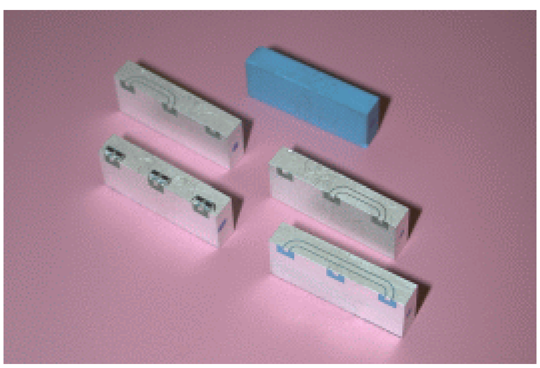

Figure 3 CTS In-Fixture Standards

The RF electrical characteristics are verified using a 20 GHz TDR VNA calibrated with 3.5 mm APC standards. The artwork is adjusted to achieve the best possible compromise for reflections from the fixture to the pad and pad to trace transitions, resistor terminations and thru impedance match. Once the design has been optimized the UDCK values must be derived.

Each of the standards in a kit has a unique RF electrical model. The models we use vary depending on the type of standard. A third order capacitance model, Loss, Delay and Zo, defines an OPEN standard. For a SHORT standard only the Delay is defined. For a LOAD standard Zo is defined. And finally the THRUs have Loss, Delay and Zo defined. These values for each of the Monoblock Filters we manufacture are stored in our database and are downloaded into the VNA at the same time as the test spec parameters. The parameters are available world wide so that each of our factories has access to the same standards models.

As with all manufactured products there is a variation in the measured values. Even with precision control of the standards manufacturing process, a range of values will be produced. To allow each of our factories to verify that the standards are within tolerance, the standards must be measured against another more accurate standard. We select the best of each type of standard from the first batch of standards to become the “Golden Standards”. The Golden Standards are used with the UDCK definitions to calibrate the VNA used to qualify the standards before they are released to our factories. The qualifying VNA is used in TDR mode to verify that each standard is within ± 4.0 mU of the Golden Standard. Our factories also use the Golden Standards to re-qualify the in-fixture standards in the same way as the SMA standards are managed.

Test Accuracy

CTS maintains a high customer expectation of RF measurement accuracy. Realistically it is difficult to measure a Monoblock RF Filter to a high precision. A S-parameter reading of -1.23785 dB for insertion loss on a VNA looks very accurate but it is only really accurate to the nearest tenth at best. For this reason we state that the accuracy of our spec values for filters is 0.10 dB for insertion loss, 1.0 dB for return loss and 1.0 dB for stop bands.

In the figures below we have compared the measurements for a CER0171A Monoblock Filter using all three methods of calibration. The most accurate calibration, 3.5 mm APC and the SMA cal both do not compensate for the fixture loss and match. The In-fixture cal method removes both the fixture loss and the match error during the calibration.

Fig. 4 shows the overlay of all four S-parameters for each of the three calibrations. At this scale the transmission traces are essentially the same. The forward and reverse transmission S-parameters also match indicating a good calibration.

The return loss traces show the most deviation. The two lowest traces are the In-Fixture measurements. As mentioned before, it is expected that the In-Fixture measurements will be different from the 3.5 mm or SMA cals that were calibrated at the fixture connector. Also some error will be present from fixture match contamination of the standards during TDR measurement.

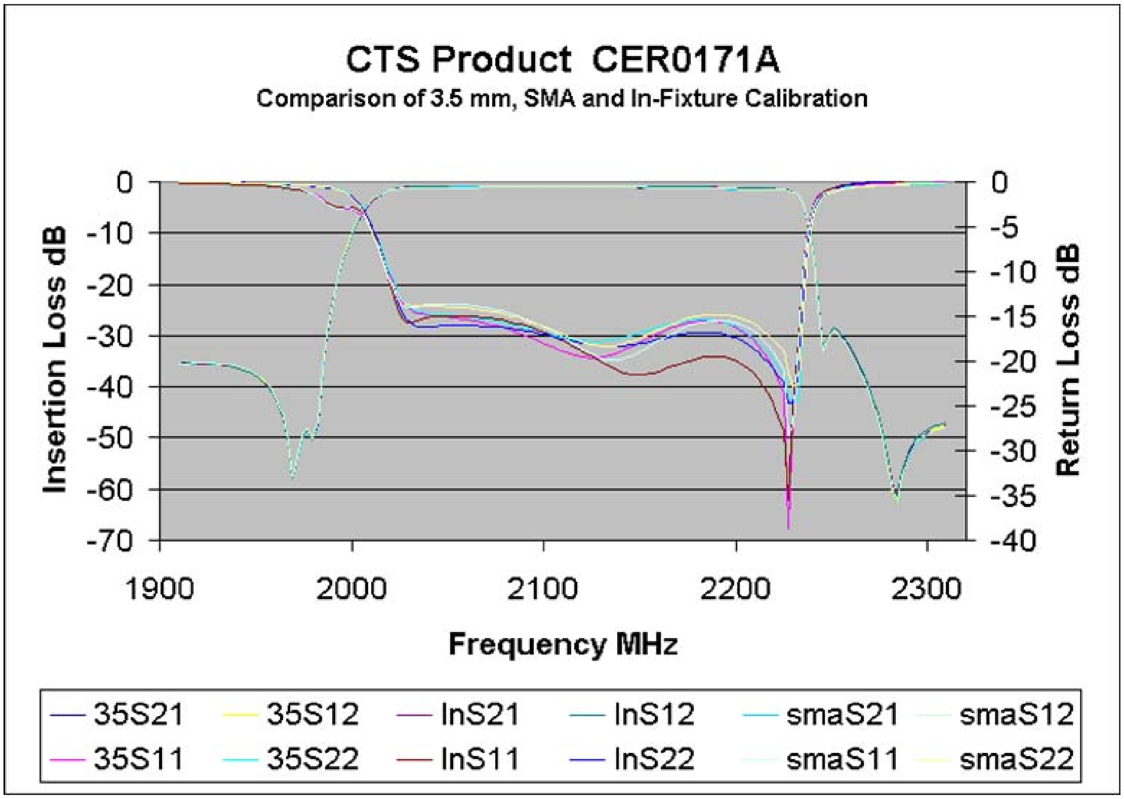

Figure 4 CTS CER0171A Monoblock Filter Calibration Comparisons

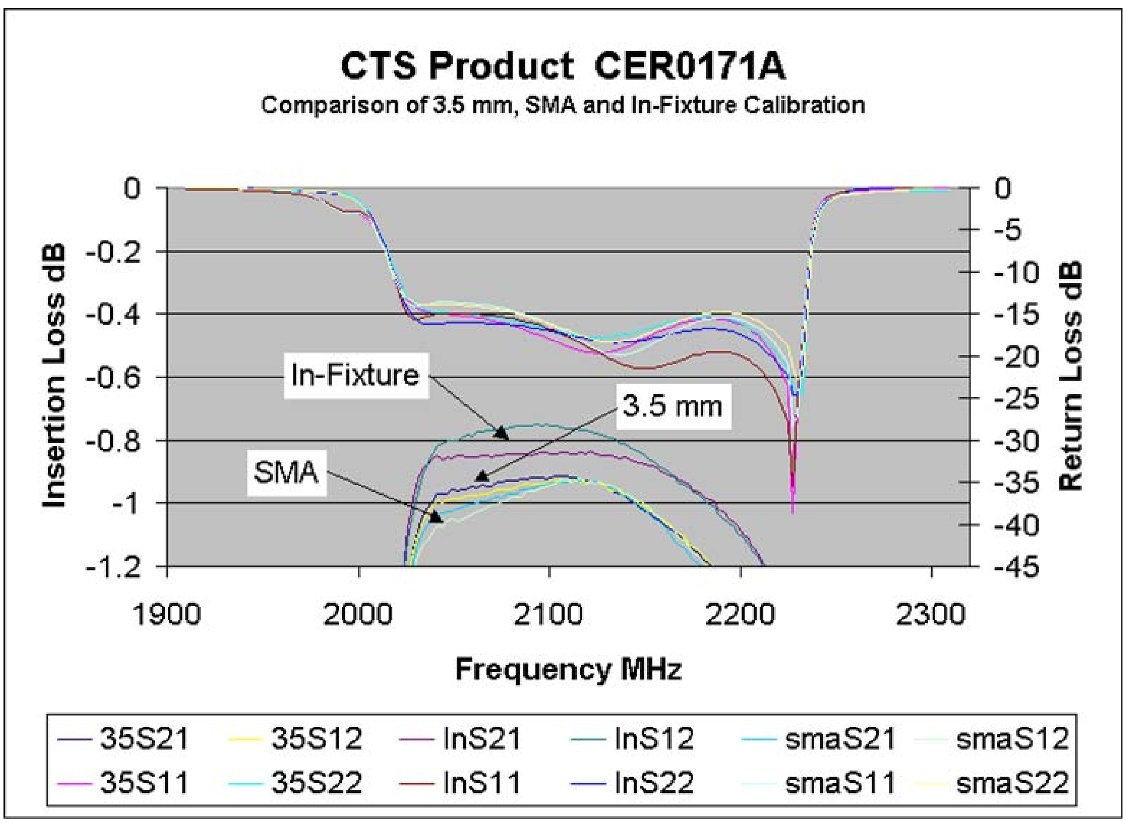

Figure 5 CTS CER0171A expanded Insertion Loss Region

In Fig. 5 the transmission S-parameters have been greatly expanded to show the IL differenced due to the cal type. The In-Fixture cal for forward and reverse is shifted up from the SMA and 3.5 mm cals by about 0.08 dB. This is due to the fixture loss. The forward and reverse traces are separated indicating some calibration error. As would be expected the 3.5 mm cal traces have the tightest grouping. The SMA cal traces are also closely grouped and are very close to the 3.5 mm group.

Conclusion

Accurate Monoblock RF test measurement requires that all elements of the test system be managed. Fixture Gage Reproducibly and Repeatability, calibration methods, calibration standards, and cable stability all contribute to the validity of the measurements. CTS has attempted to balance the accuracy of measurement with the cost of testing and will continue to incorporate new methods and technology into the measurement process to improve measurement capabilities.

We have shown the typical errors expected in the measurement and calibration process and indicated the difficulty in obtaining valid data in a production environment.

Bibliography

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