Benefits of Reduced Insertion Loss for mmW Over Temperature Wafer Test

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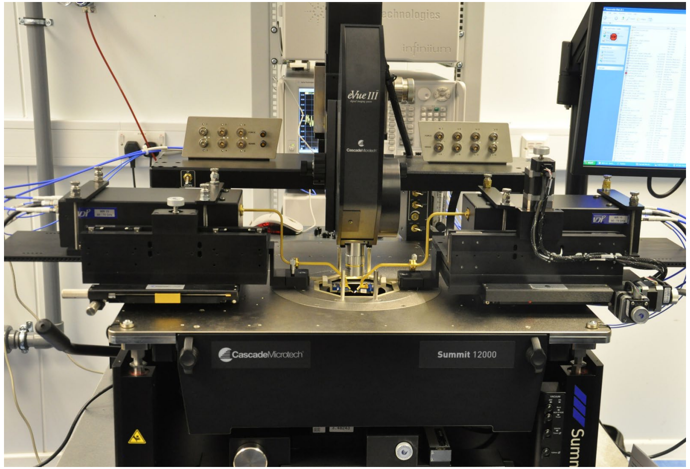
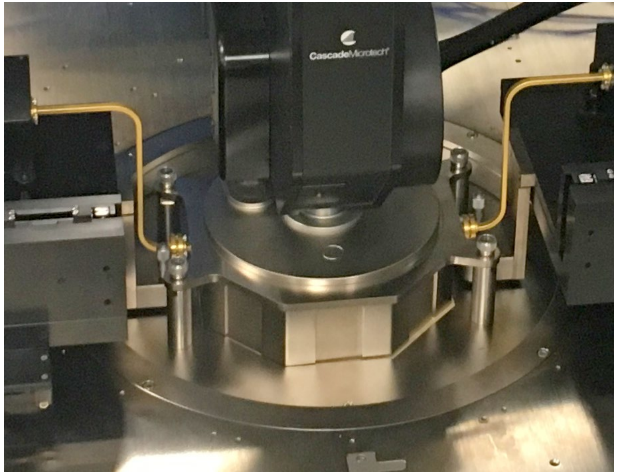
FormFactor

Conventional arrangement for waveguide over temperature wafer probing

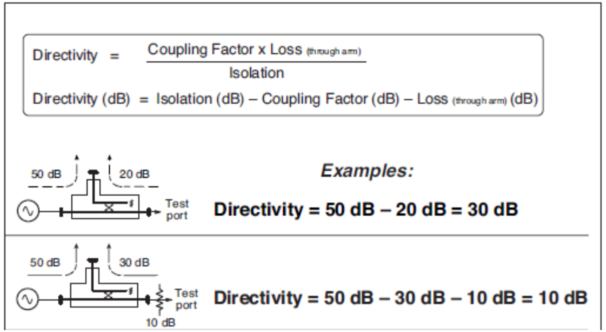
- Large heavier extenders warrant large positioners
- Probe tips at the thermal chuck and inside microchamber enclosure
- Positioners are tall meaning we used tall probes and tall waveguide S bends





Why shorten path to the probe?

- Raw directivity of system is degraded by up to **2x** Insertion loss between test port and probe tip
- For T geometry probe at 330 GHz insertion loss is 2.9 dB and guide insertion loss approx. 5.8 dB (approximately double probe dB loss)
- Reflected signal from ISS Short will be attenuated by 11.6 dB compared to a directly connected probe assuming 8" path length
- Degraded directivity = Increased drift



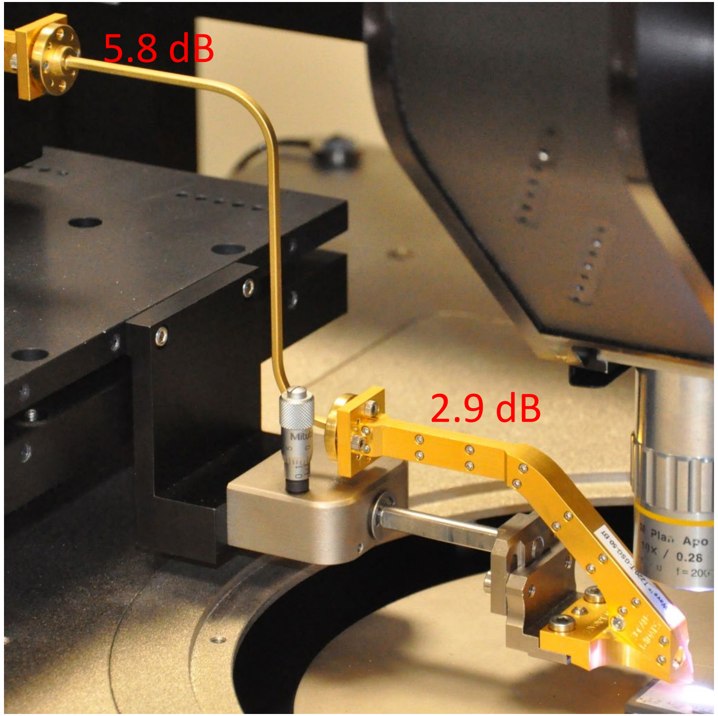
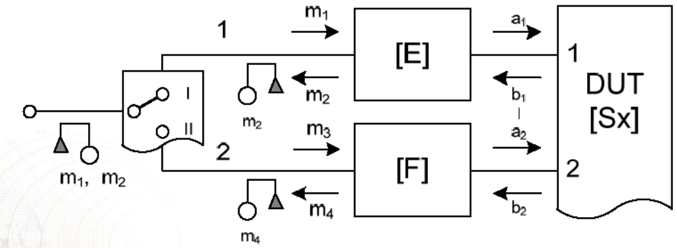


Image shown is with T-Wave "T" geometry probe

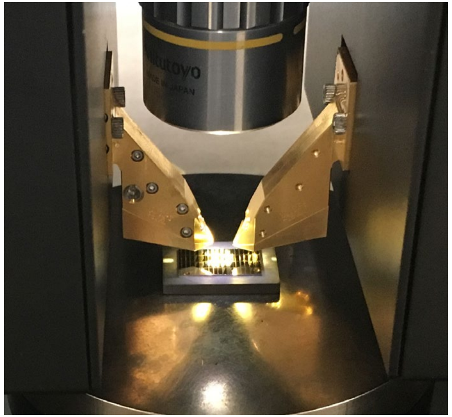
Why is system stability important?

- Vector network analysers have systemic errors
- Calibration routines regardless of method aim to characterise these errors to produce accurate corrected data
- If systemic error changes, corrected data is no longer valid and corrected data will now have a difference between what it would have been when calibration was new.
- Reduced directivity and increase path length make instrument more sensitive to small changes in system due to environment, predominantly temperature and vibration driven
- Reduction of loss and path length should improve directivity and changes due material expansion
- The less sensitive a system is to environmental changes the less time wasted in frequent recalibration and less tendency to except data that is “reasonably” good
- Calibration standards will last much longer as less cal cycles needed

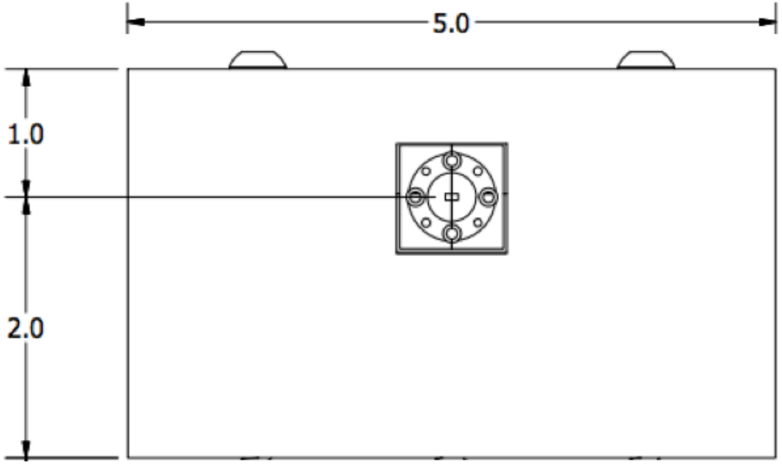


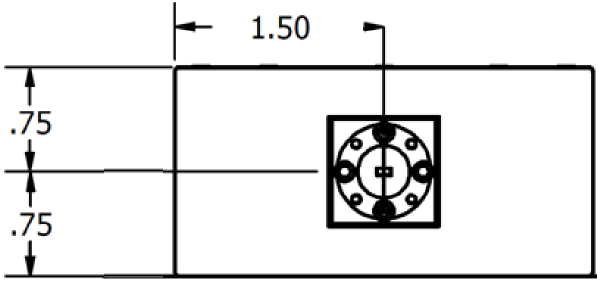
Semi-automatic – raised chuck solution

- Highest Frequency supported by our probes
- Allows probes to connect directly to extender which gives best performance
- Raising probes limits usable chuck diameter and no access to thermal chuck



Virginia Diodes Mini Modules

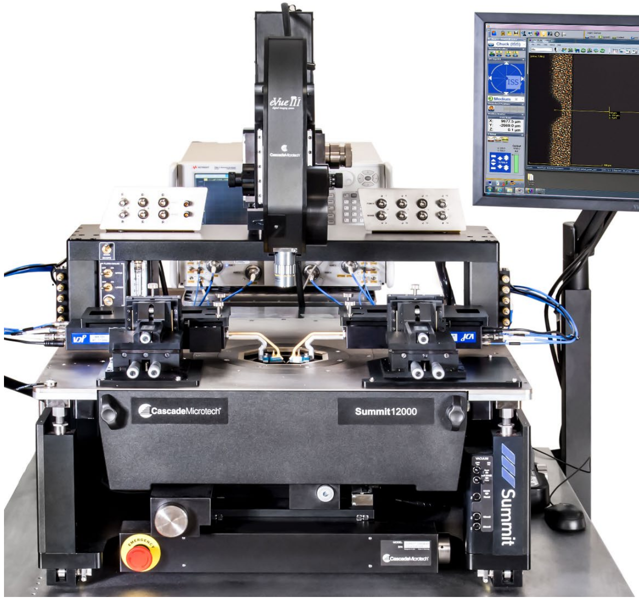


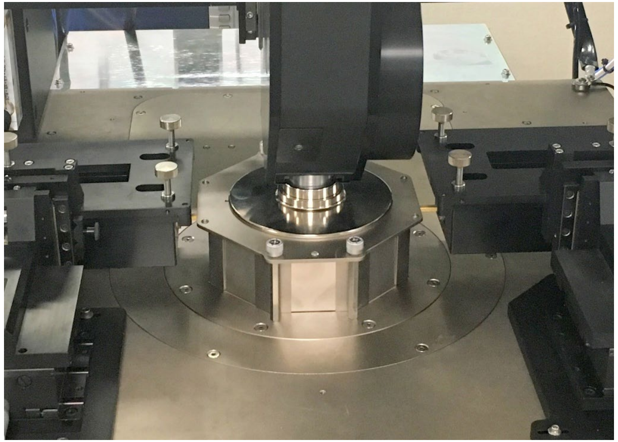


- Less mass 1.8 Kg compared to 4 Kg
- ¼ Volume of standard
- Overall length varies with band slightly but cross section is the same
- No fans below 110 GHz
- Attenuator is removable if desired

Standard-Size to Mini Module size comparison

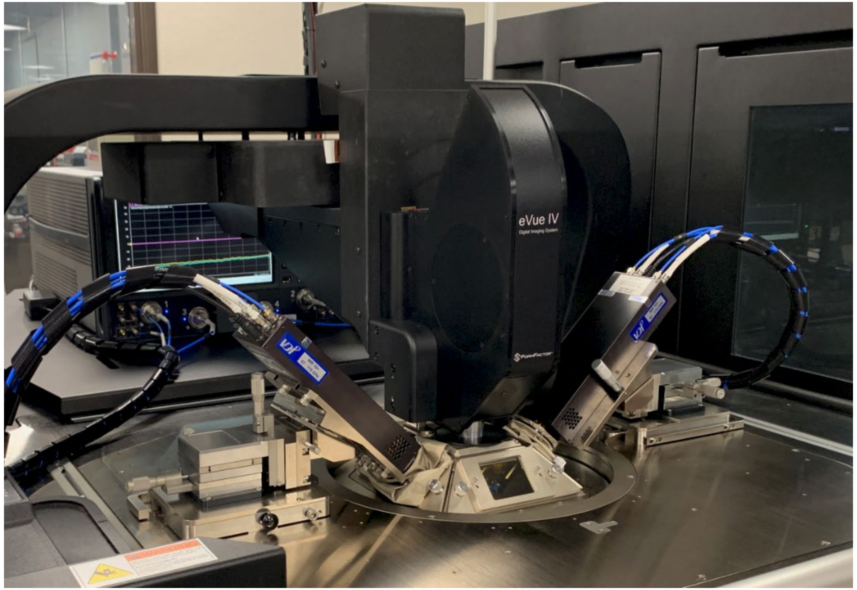
Semi-automatic, thermal – manual positioner bands from 50-330GHz

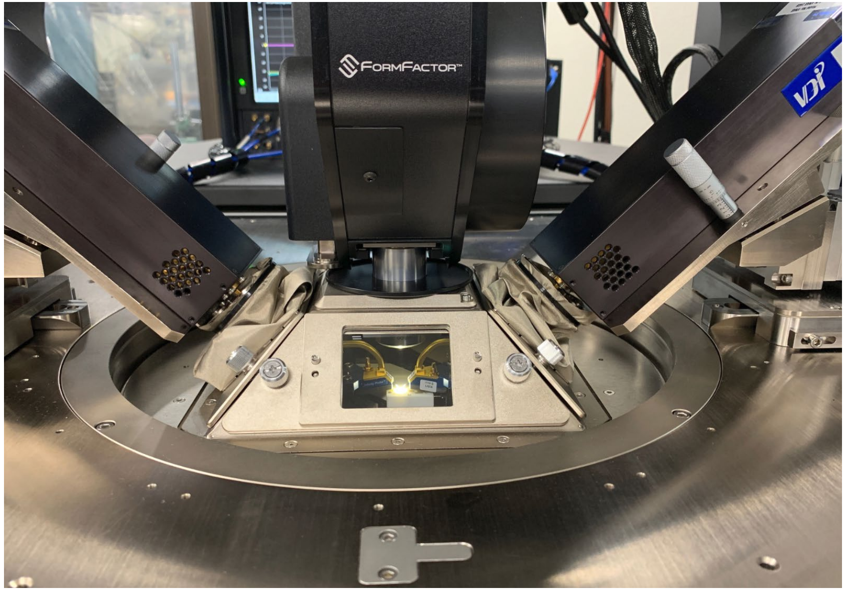




- This arrangement makes use of Tall geometry probes and small form factor of the Virginia diodes **mini modules**
- Probes connected directly to extender
- Reliant on shallow 14mm Chuck to platen height of Summit 12000
- Other stations in our ranges are deeper to improve thermal stability but which prevents use of this approach

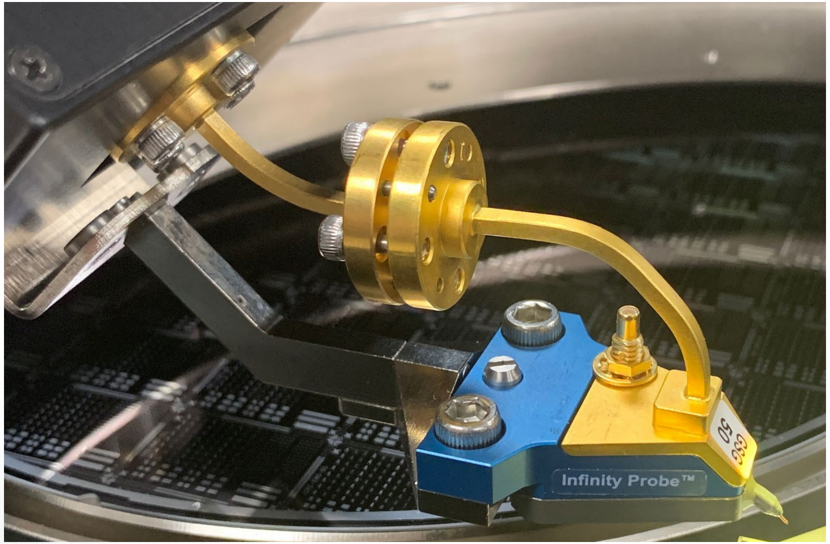
Angled extender allows minimal path length

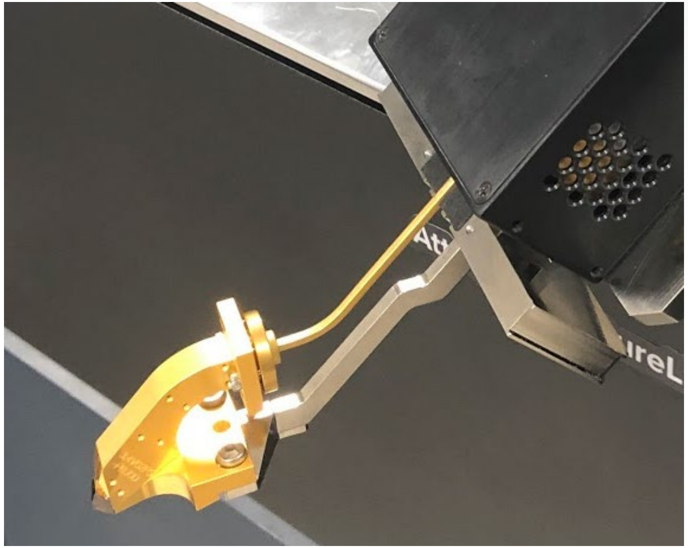




- Allows over temperature test with minimal loss
- Angled extender used new RF tophat designed originally to allow for short 120 GHz coaxial cables
- S Geometry probe for minimal insertion loss and very short waveguides to change angle
- Same RF tophat as used with N5291A (125 GHz coaxial)

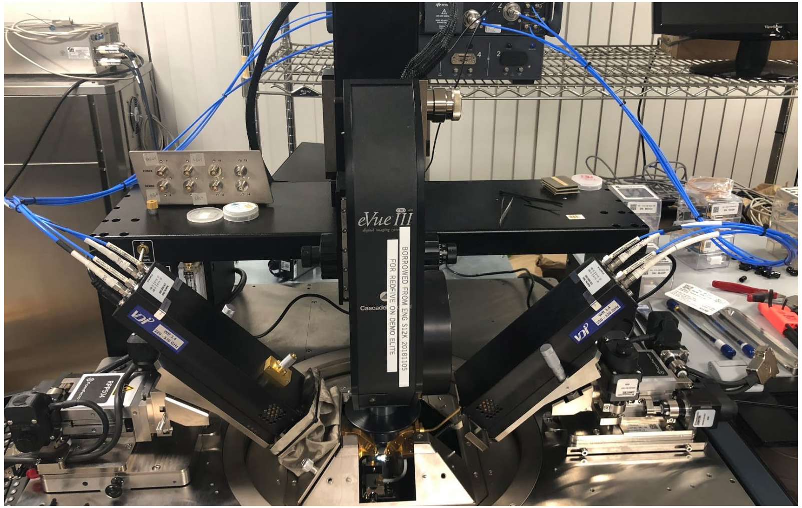
Angled extender allows minimal path length

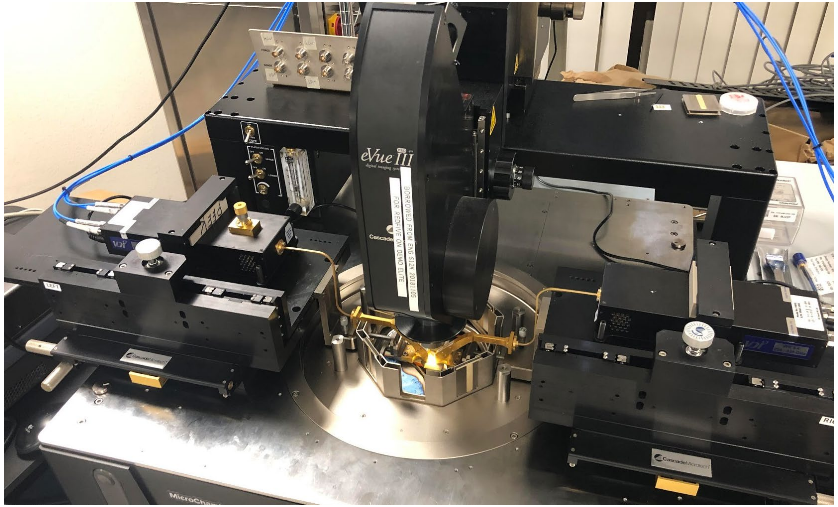




- Non chambered (left) and Chambered versions (right) available
- Non chambered version still capable of hot thermal measurements but has even shorter waveguide extension
- T-Wave / ACP and Infinity all supported for all implementations

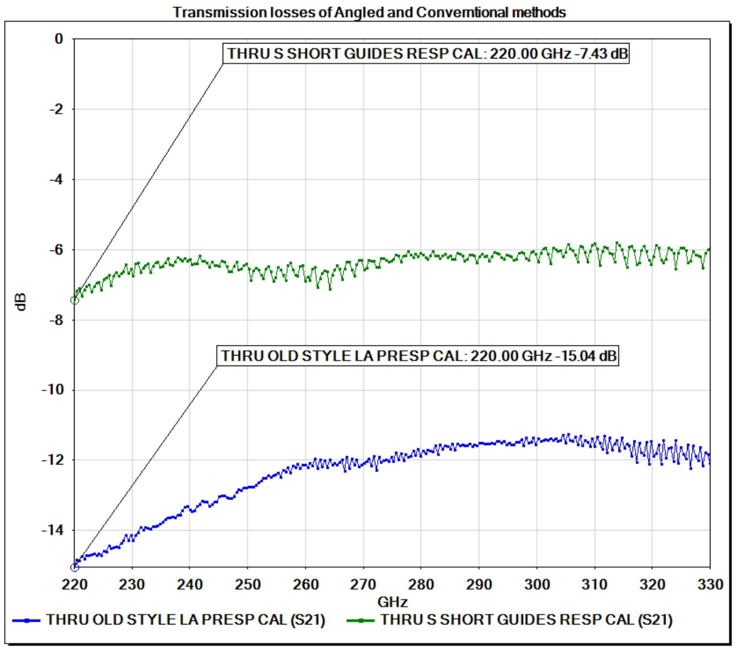
Experimental performance comparison – path loss

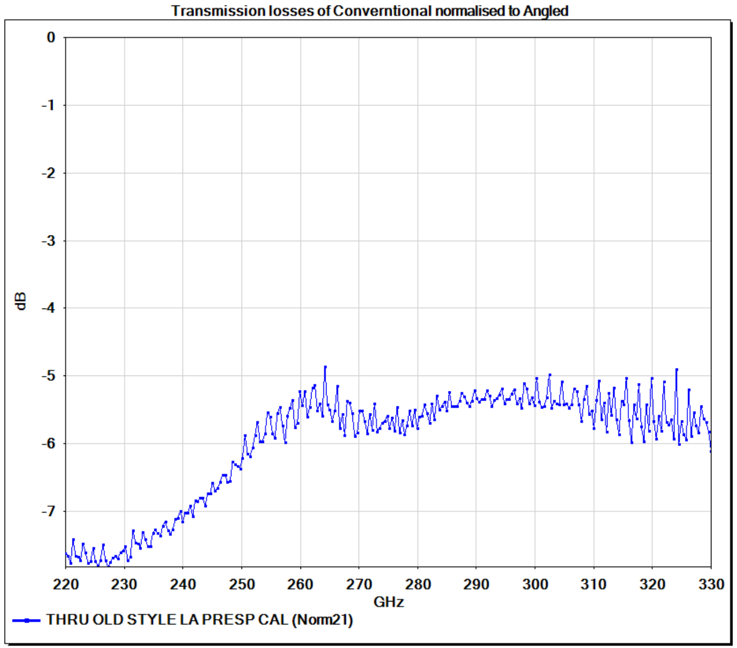




- Setup on left has angled extenders, S Geometry T-Wave probes and Short waveguide extensions
- Setup on right has conventional Large area positioners, T Geometry T-Wave wave probes and typical extensions
- Response cal done (not full as wg shim can't be used on extender without port saver section in place)

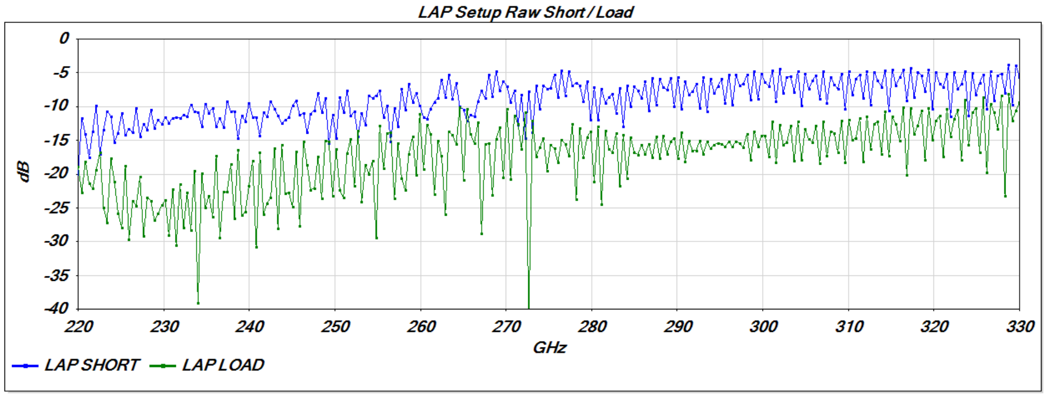
Path loss flange to flange – using response cal

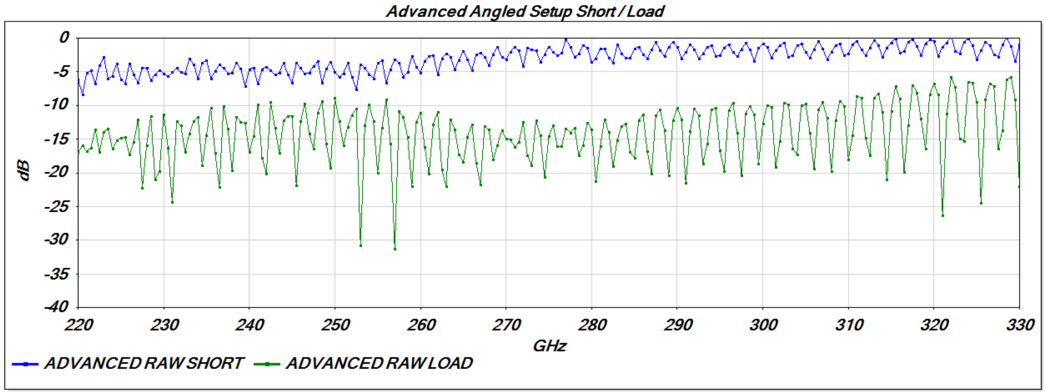




- Low frequency is around -7.5 dB insertion loss compared to -15 approx.
- Improvement of around -7.5 dB at cutoff

Load compared to short- raw absolute

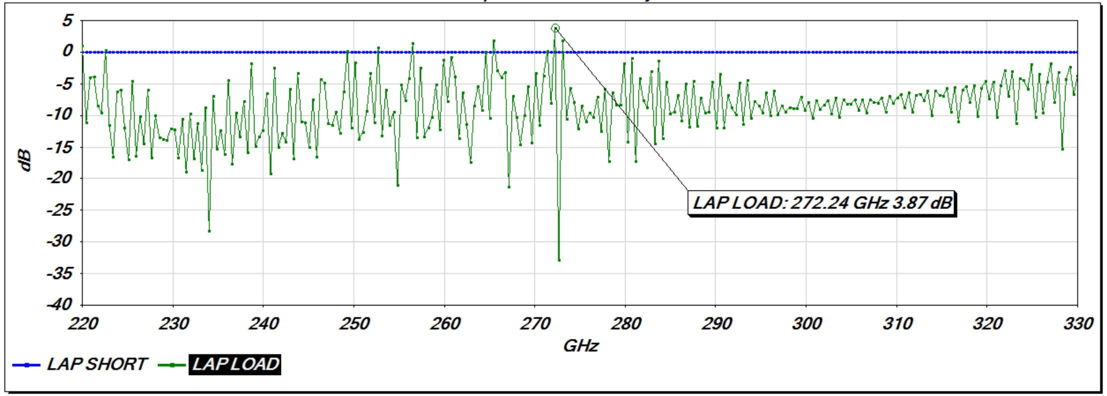




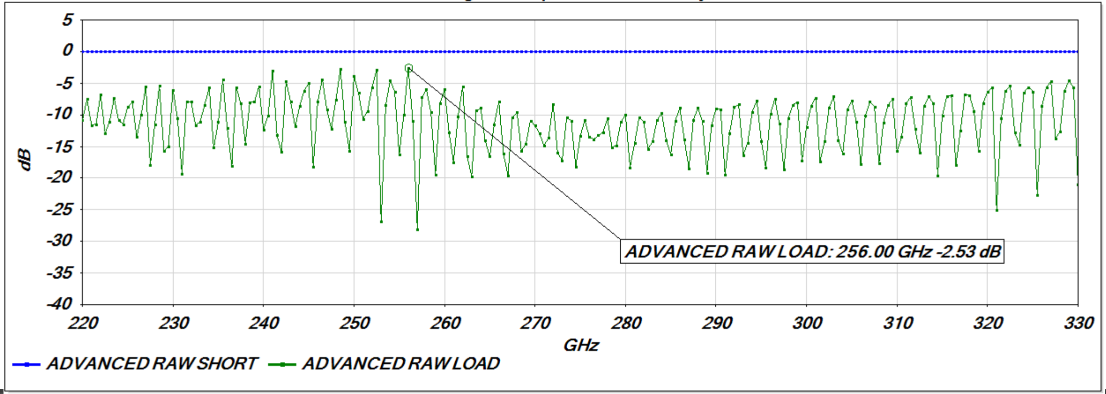
- The larger the separation from Load w.r.t Short the better
- Top is conventional Bottom is Angled

Load normalised by short

LAP Setup Load normalised by Short

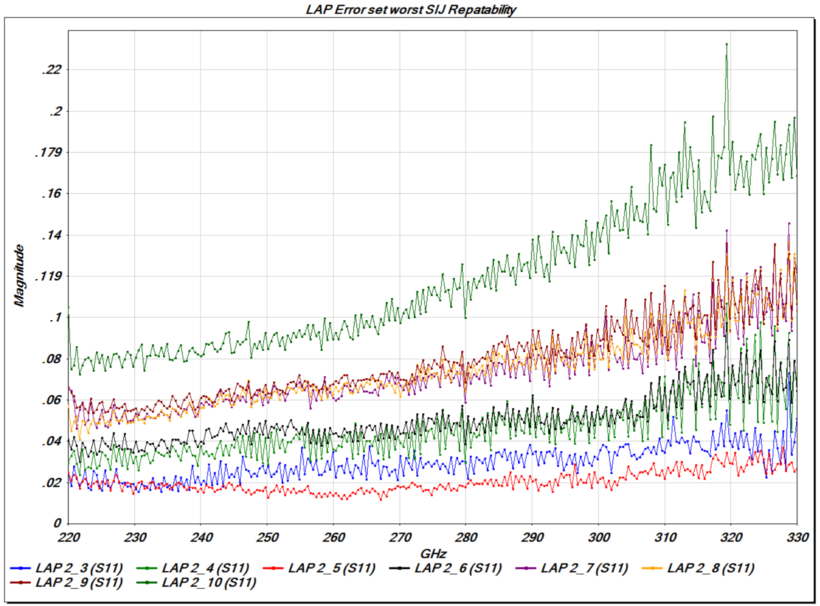


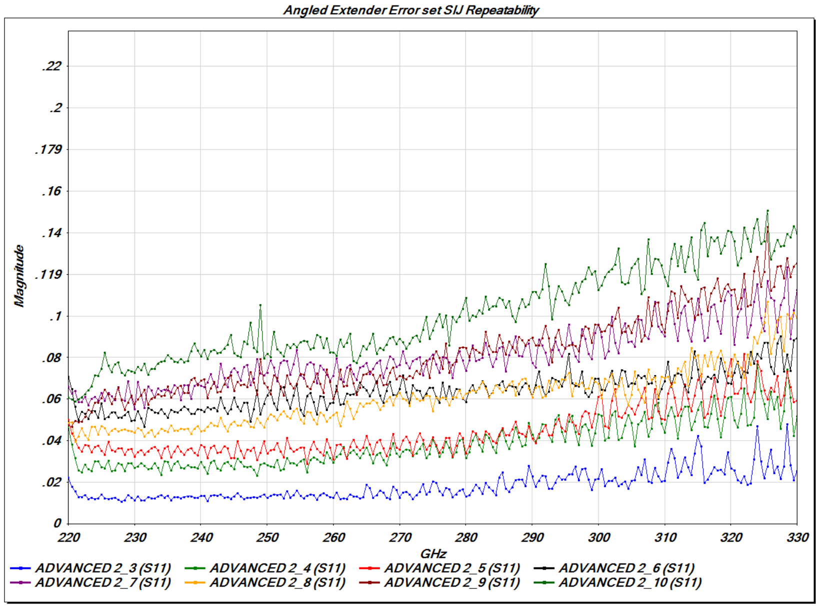
Advanced Angled Setup Load normalised by Short



- Worst case for LAP load actually have +3.87 dB w.r.t Short
- Angled case worst case -2.53 dB
- In general around 5 dB better off

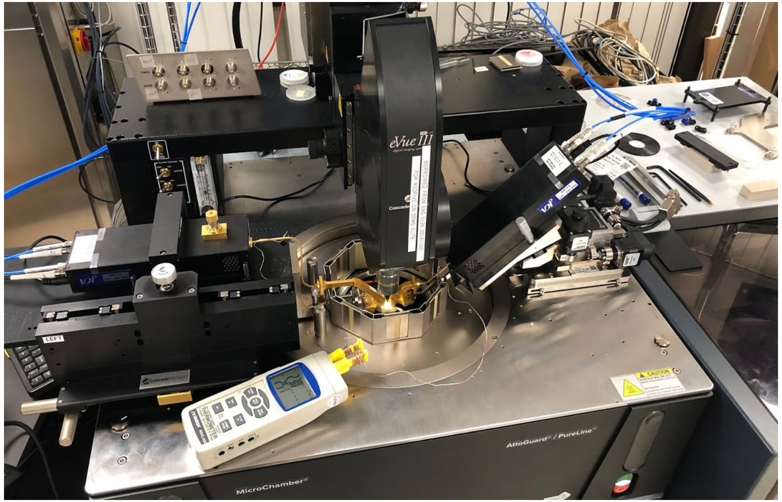
Error set repeatability – LAP left / Angled right

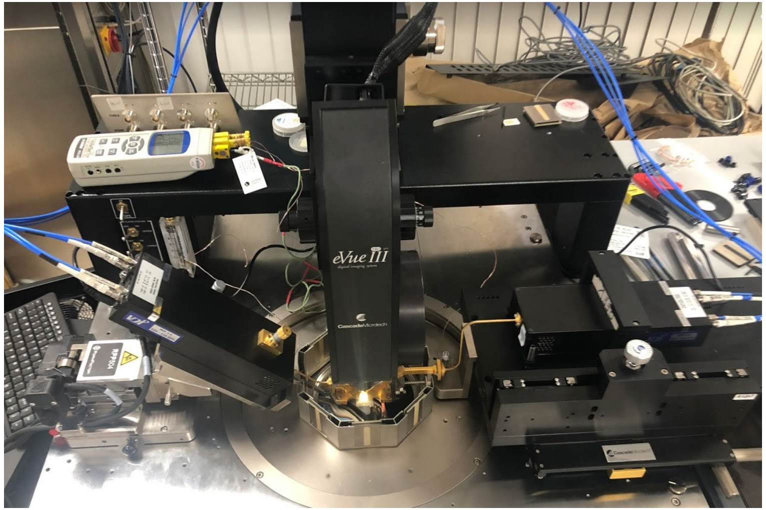




- 10 Calibrations done one after the other without probe movements (hence LRRM)
- In general error set resulting from LRRM has comparable differences other than outlier seen on 10th cycles

Drift improvements

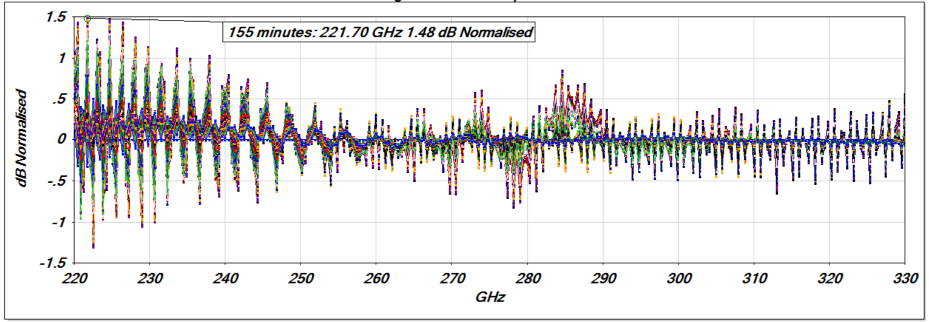




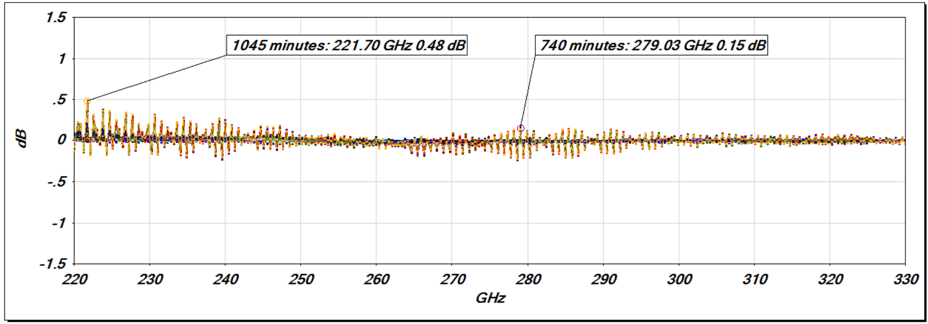
- Experiment done to see if drift is better for reduce path case
- First case is Long path setup left using Tall geometry and Angled Right short geometry
- Second case is with sides swapped Angled left, Long path right
- Calibrated Open measurements taken every five minutes and normalised to first

Drift comparison - magnitude

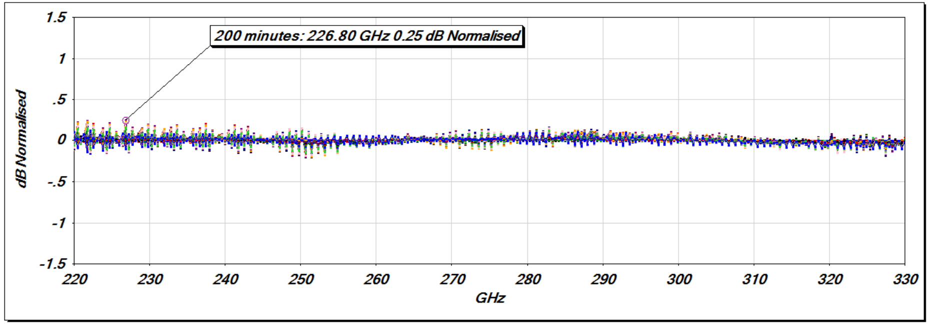
Conventional Waveguide Probe Setup - Attenuator head Port1



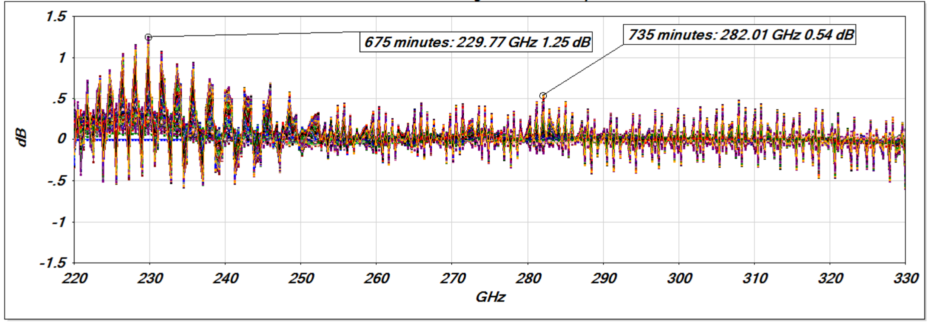
FormFactor's advanced mmW and THz solution



FormFactor's advanced mmW and THz solution - No attenuator Port2

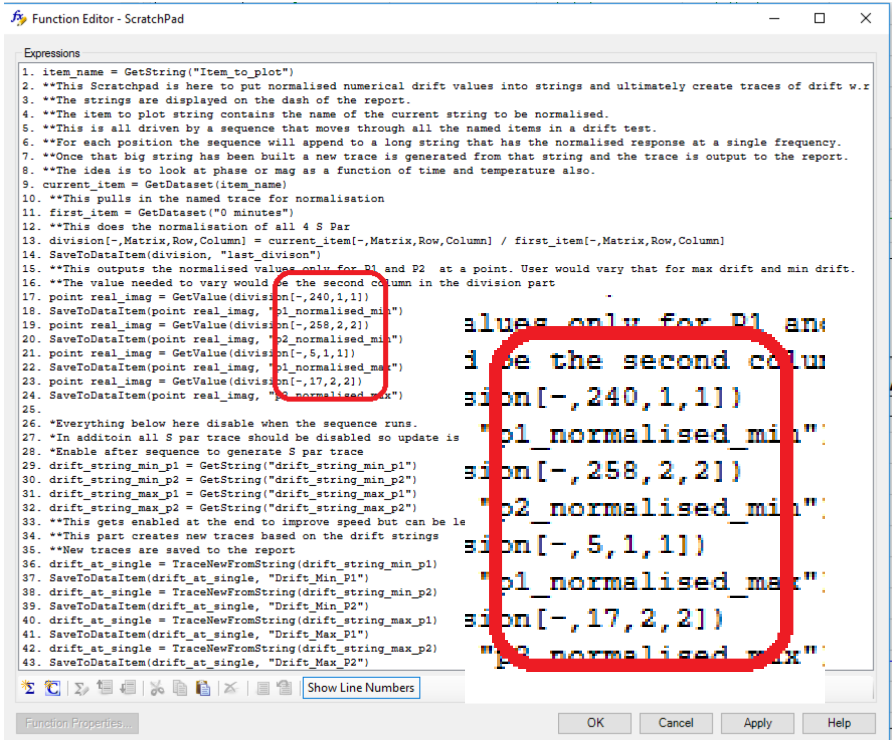


Conventional Waveguide Probe Setup



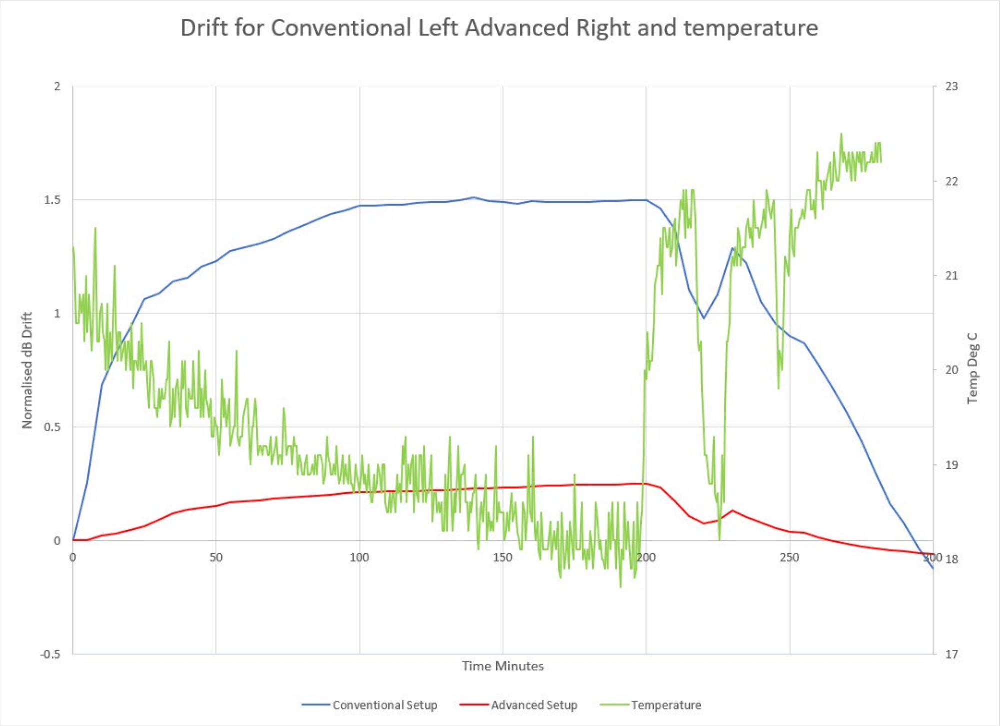
- Heavy drift characteristics clearly follows the setup
- Both setups left overnight

Max drift at single frequency – scratch and sequence combined



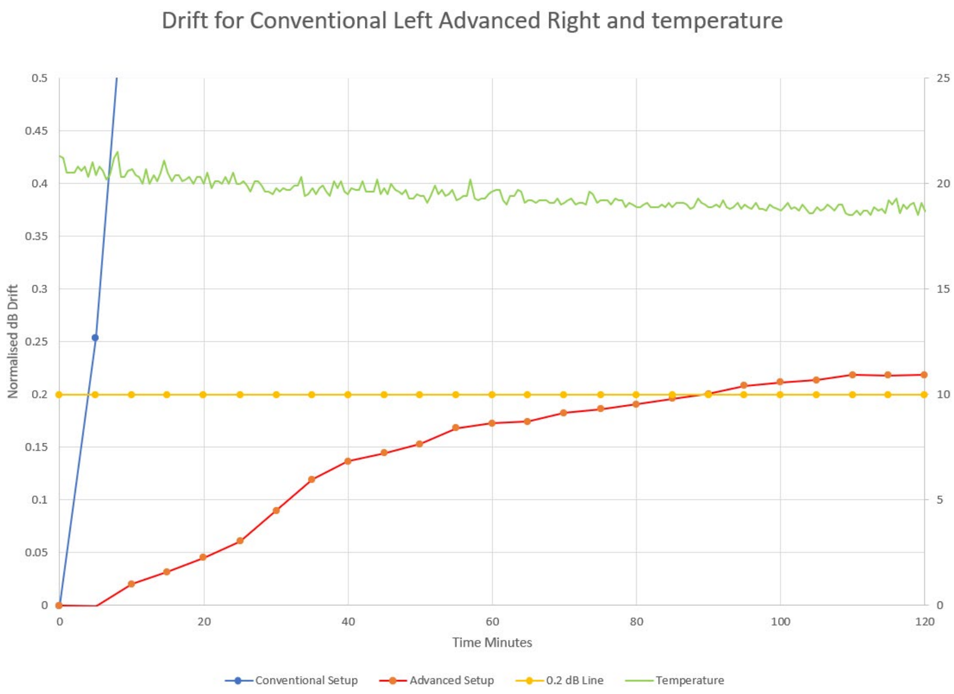
- Scratchpad is used to normalise a given point (240,258,5,17) from trace selected by the name in the report toolbar variable w.r.t start point. This is done for max and min of S11 and S22
- Sequence takes normalised point and adds it along with the Time value to a single string in the form of Time,Real, Imag, Time, Real, Imag.....
- Long String is used to create a new trace. Once for S11 Min, S22 Min, S11 Max, S22 Max
- Sequence is used to iterated toolbar variable to all the times

Drift as a function of temperature



- Thermometer batteries fail after five hours
- Previous graph used to assess point of maximum drift
- Red trace advanced angled, blue trace conventional, green temperature
- Drift characteristics follow room temperature

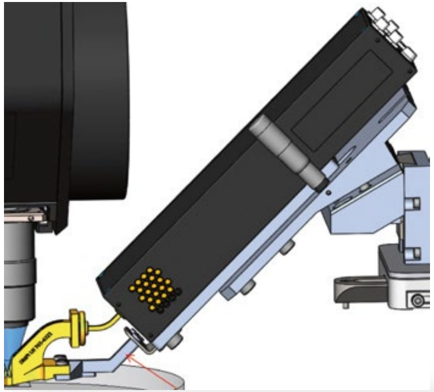
Drift comparison – time to recalibration



- Zooming into the data
- If a tight 0.2 Db window is selected this is 90 minutes in comparison to just four

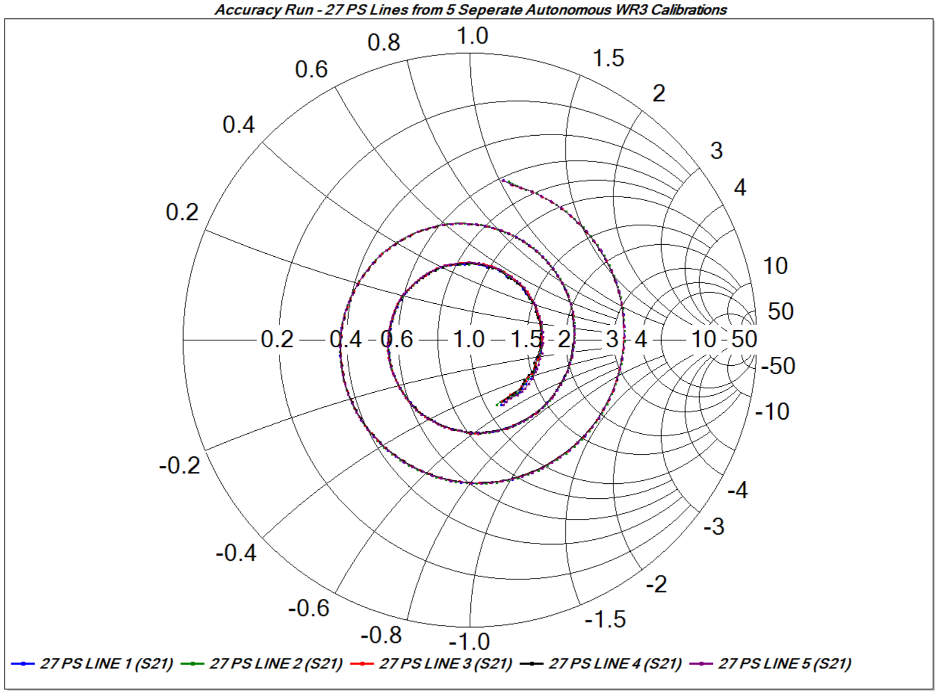
Autonomous RF – Now tested to 325 GHz ……

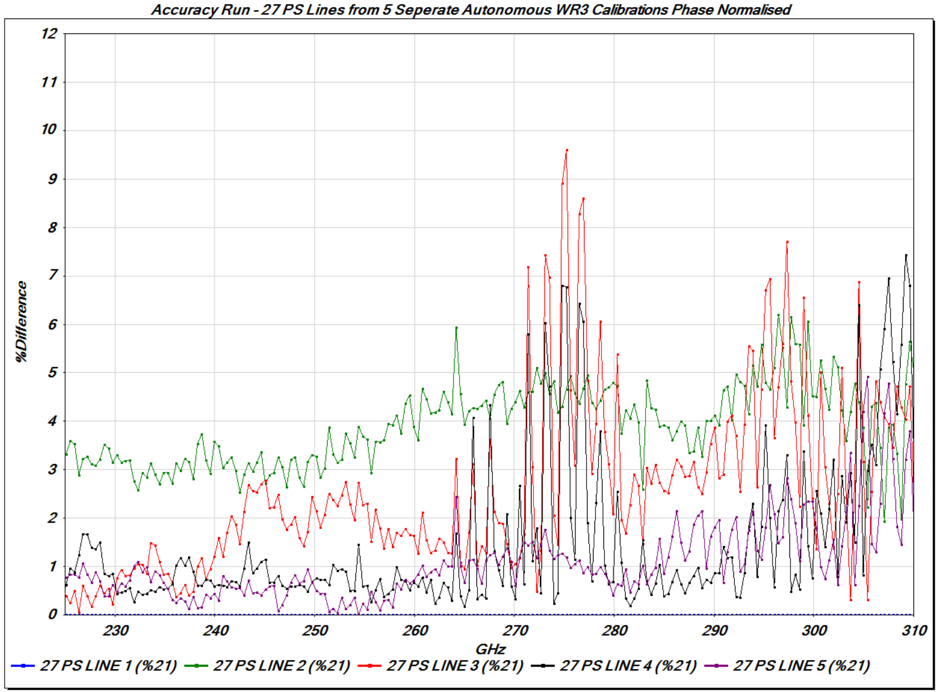
- True Automatic, hands free calibration
- Setup of Calibration for MLTRL requires no expert placement, all automatic including all lines
- Monitors calibration drift, re-calibrates automatically
- Full management of system expansion and RF stability
- Full thermal automatic calibration
- Save time & increase data accuracy
- Corrects "thermally induced" probe electrical errors



Autonomous RF System training with MLTRL Video

Autonomous MLTRL measurement repeatability





- 27 PS Lines corrected from their own MLTRL calibrations x5 using angled frequency extenders

Conclusion

- Mini modules from Virginia diodes allow a paradigm shift for on wafer probing
- Angled approach allows for vastly reduced insertion loss and still allows for on wafer probing throughout the temperature range
- Reduced loss demonstrably improves system drift
- Use of motorised angled arrangement in conjunction with Autonomous RF software allows for fully autonomous MLTRL testing in the WR3 band