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Continuous S-parameter measurements to 500 GHz

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Virginia Diodes
Keysight Technologies

Goals

- To show full band measurements from 200 MHz to 500 GHz is readily achievable on formfactor platforms with automatic MLTRL calibration and LRRM to 330 GHz
- To highlight capabilities and compromise areas when N5291A is stretched upward to 130 GHz and WR5.1 minis downwards to 130 GHz
- To show measurements carried out between one substrate used for calibration and another for measurement
- To show measurements of a range of standards including offset shorts
- To test tophat operation and take measurements at 125C
- To demonstrate data processing capabilities of Wincal XE software and show some approaches to assist probe placement
- Inspired by 2017 ARFTG Paper by Dr Sia

Minimizing Discontinuities in Wafer-Level Sub-THz Measurements up to 750 GHz for Device Modelling Applications

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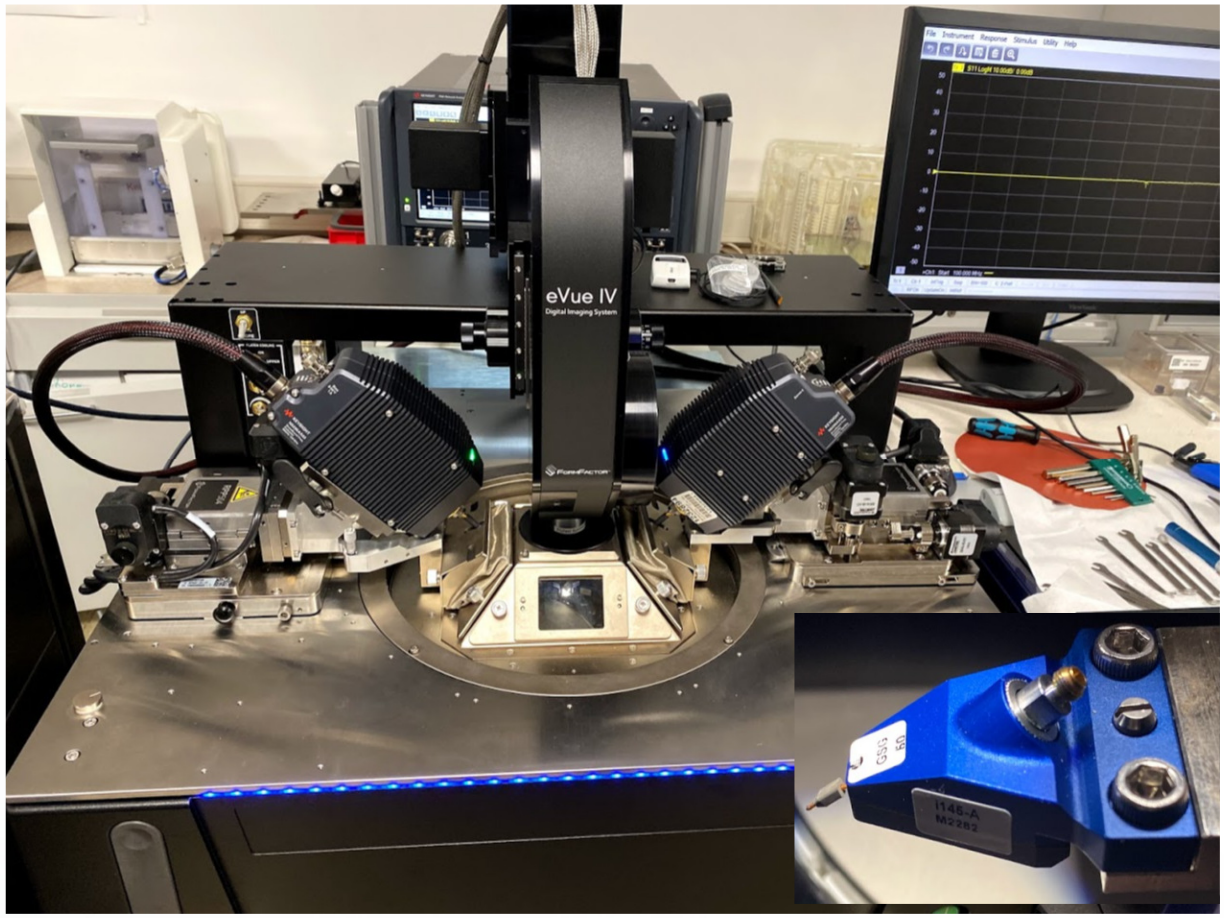
Test Setup – Coaxial setup



- N5291A 120 GHz VNA
- 10 cm cables with integral 0.8 to 1mm adaptor
- 2 X i145-GSG-50 Infinity probes with 0.8mm connectors
- Tophat in use for these measurements but cables for non-tophat use would be identical
- Summit 200 Wafer prober – It has a loader but we didn't use this

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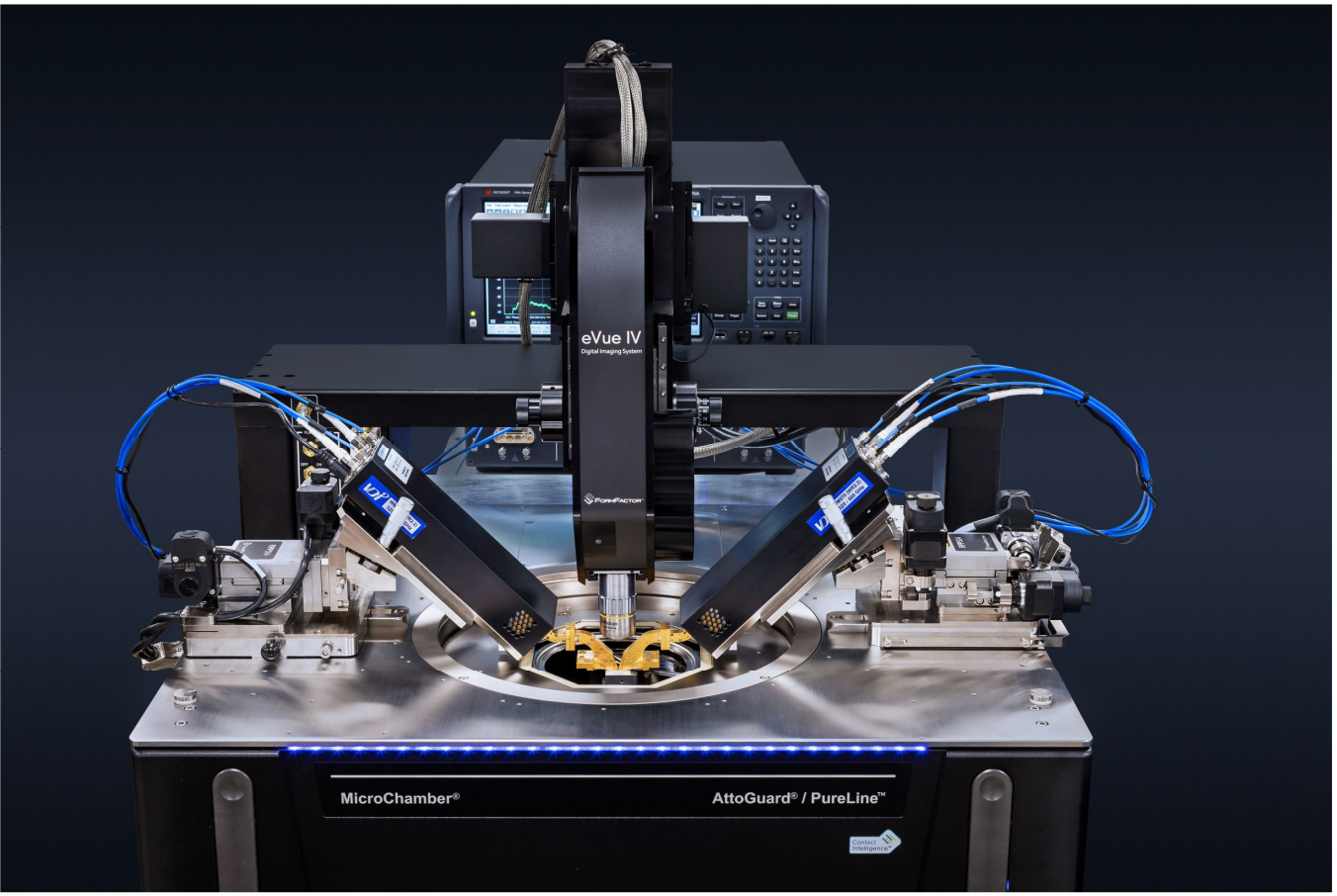
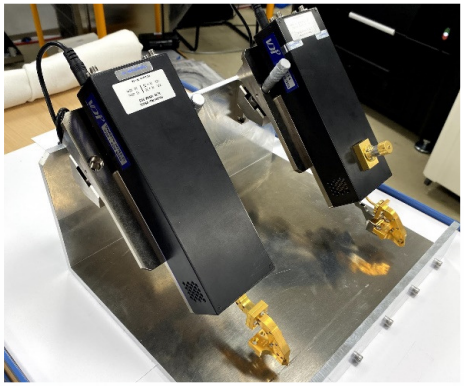
Test Setup – Waveguide setup



- All extenders used kindly loaned by Virginia diodes, VNX-Mini modules
- Probes loaned by Dominion Micro probe
- For this setup we remove the VDI fitted port saves which is 2” long and replace this with inclined short port saver from Formfactor
- Parking fixture used to allow populated arms to reach temperature equilibrium prior to testing



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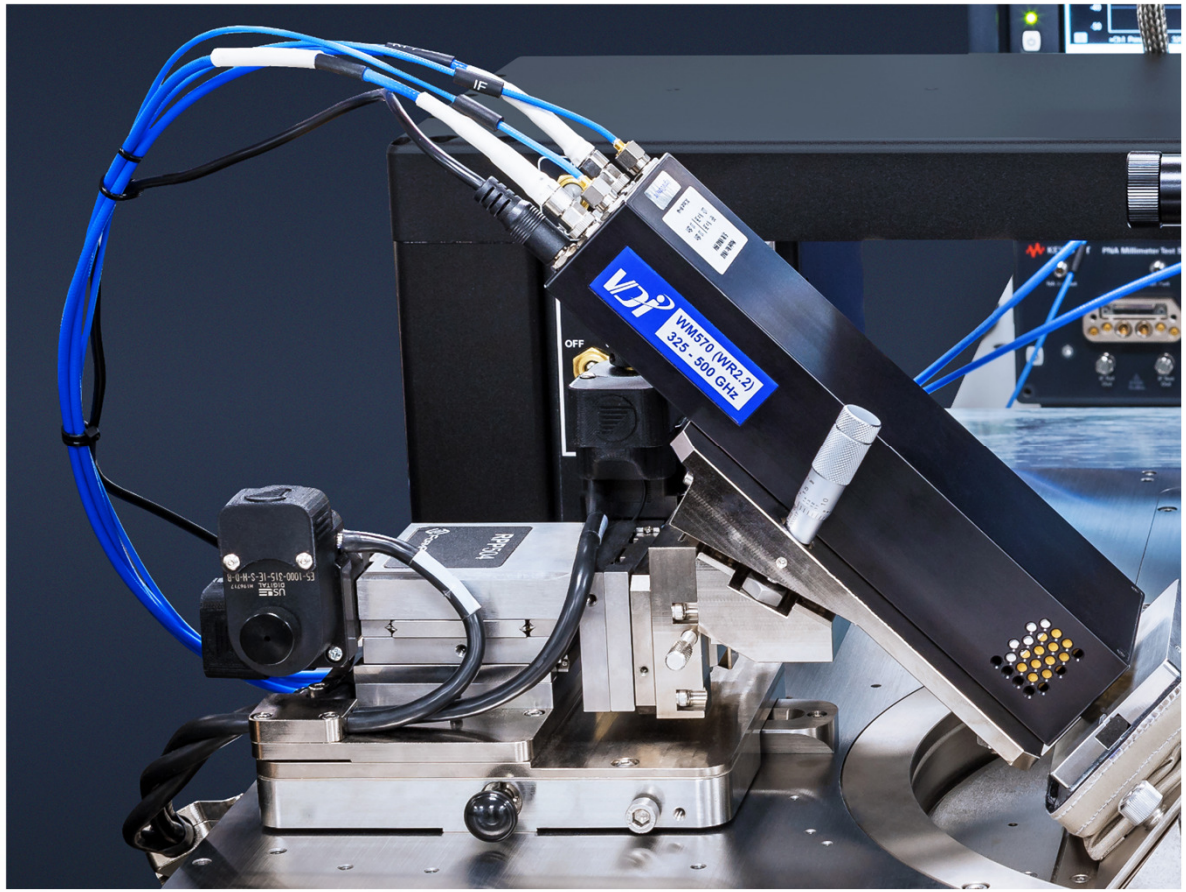
Programmable positioners to aid testing and calibration



- Motorised position allows testing and calibration to be automated with sub micron resolution
- Used for MLTRL calibration and standard measurements
- Probe arms all extender and probe to be planarized as an assembly
- Compact and easy to install

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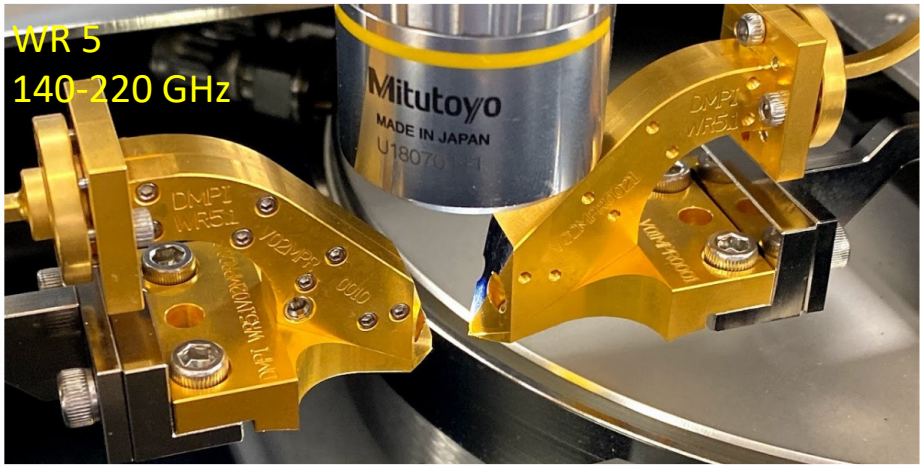
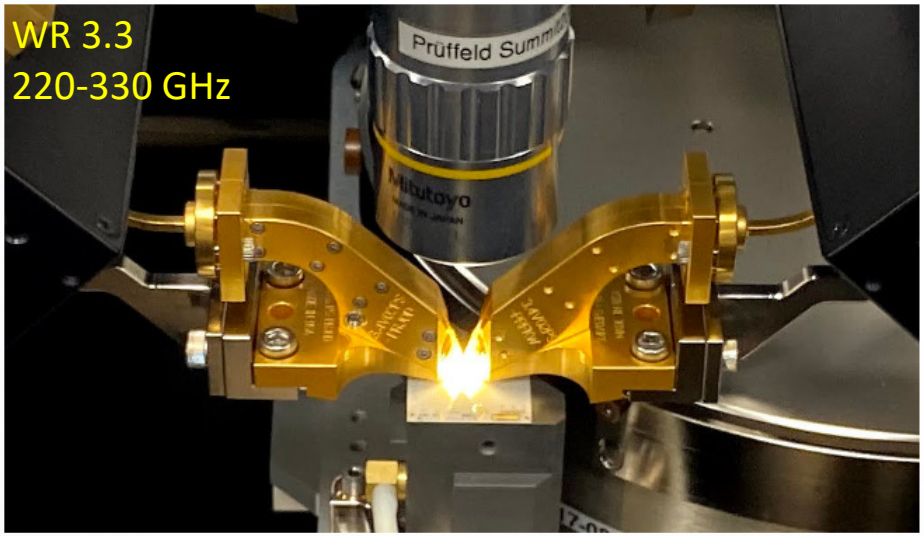
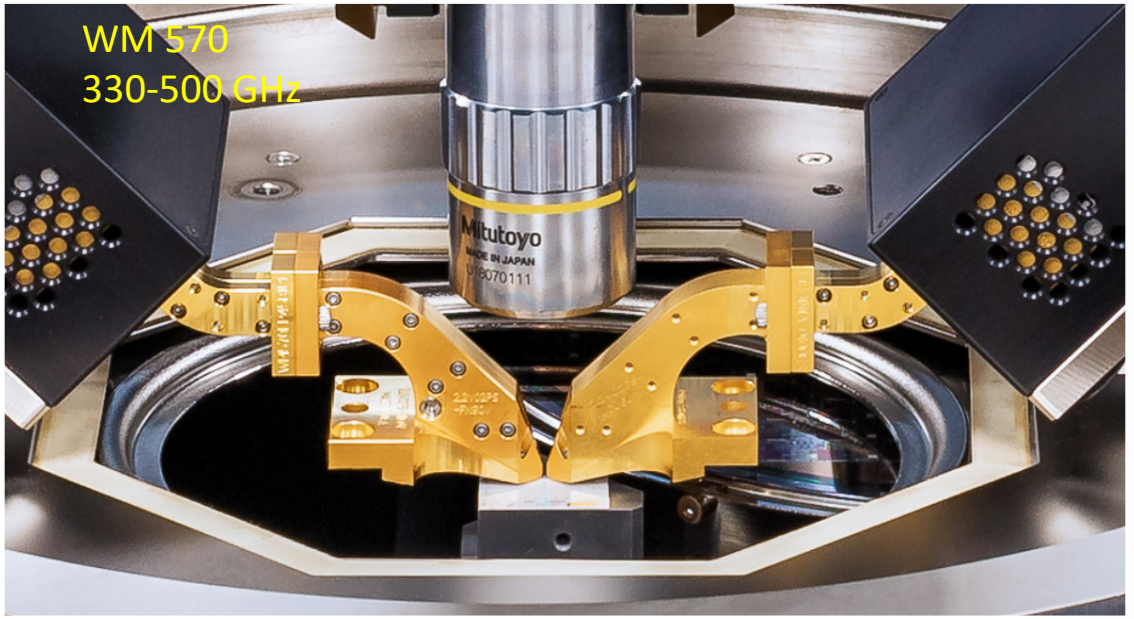
Test Setup – Waveguide setup, WR5,WR3.3,WM570







- S-Geometry probes used along with Short port savers to modify launch angle
- Probes loaned by DMPI for this work
- 2 x T220-S-GSG-50 plus 184-424 port saver
- 2 x T330-S-GSG-50 plus 184-426 port saver
- 2 x T500-S-GSG-50 plus 185-639 port saver

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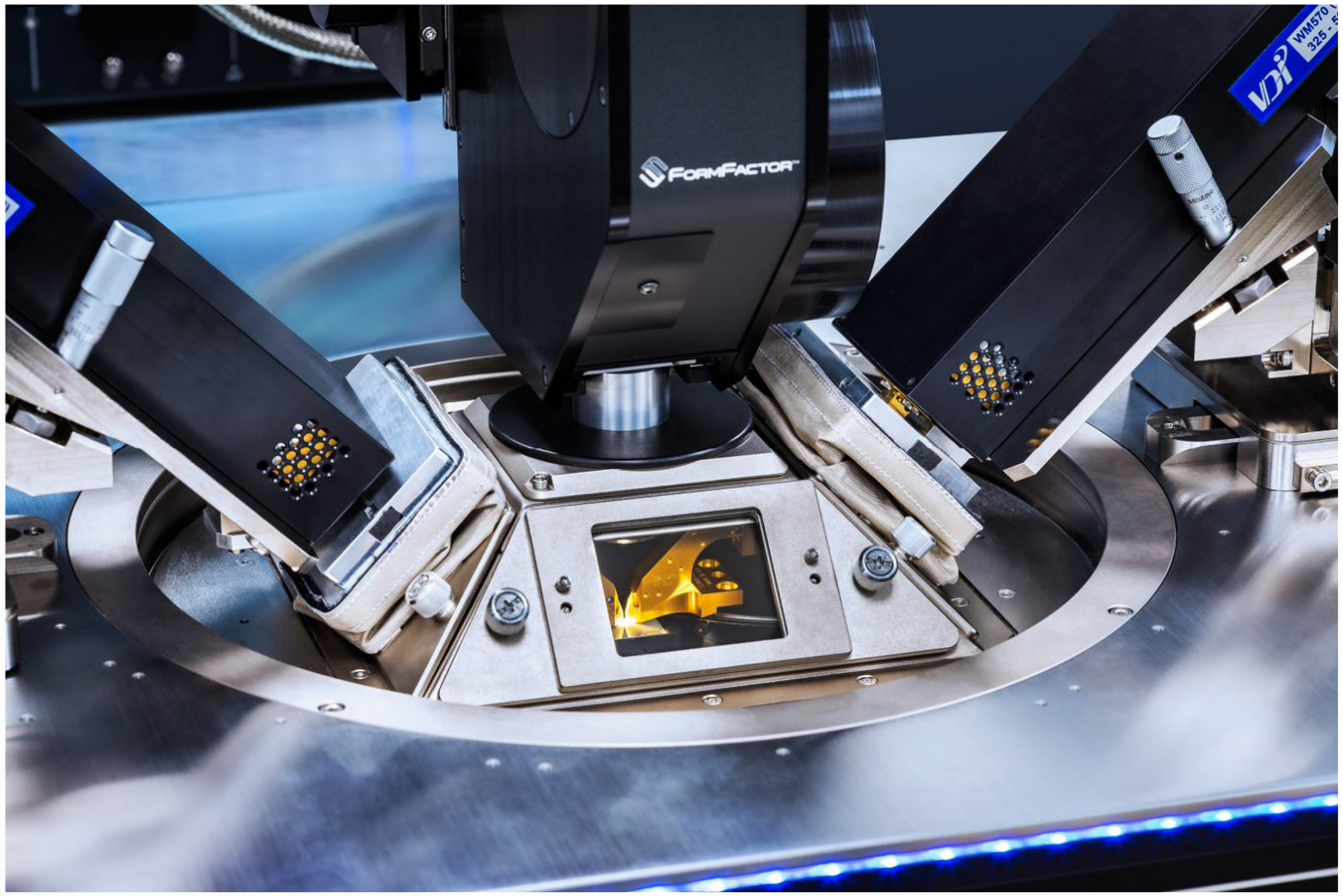
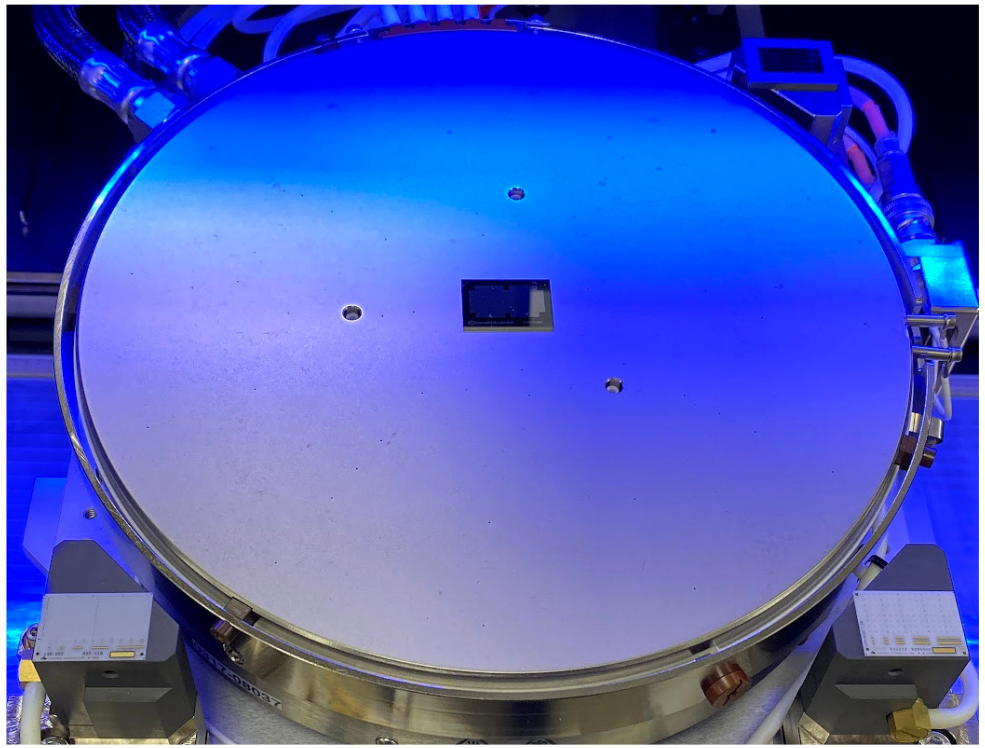
Side evaluation – Setting up for 500 GHz Tophat and 125C thermal



- Measurements were done using WM570 extenders and T500 probes but not used in single data trace
- Calibration was done at 500 GHz on wafer chuck with absorber using 172-886
- S Geometry probe used and port savers

Test setup

172-886 ISS



138-356
CAL ISS

138-356 REF

- All measurements carried out on RF absorbing material – Front 2 chucks were native, rear Steel with 116-344 absorber
- For Co-axial, WR 5, WR3.4 and WM570 MLTRL calibrations are done on 138-356
- LRRM used to 330 GHz
- MLTRL Calibration and measurement also carried out on 172-886

Test setup Stimulus

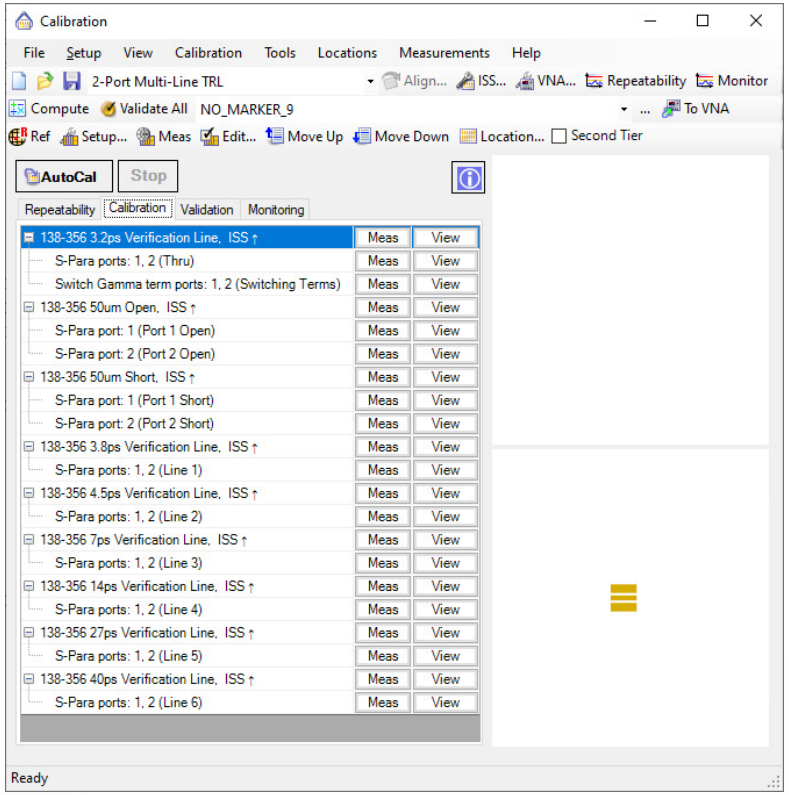
BAND	FREQUENCY RANGE MEASURED	COMMENT
1MM N5291A	200MHz to 130 GHz IN 200MHz Steps	This is 10 GHz higher than the advertised upper frequency but in practice works well and used routinely
WR5.1	130 to 220 GHz in 200MHz steps	The lower end really is stretched here, 10 GHz below official lower end in cut-off region
WR3.3	220 to 325 GHz in 200 MHz steps	
WRM570 (WR2.2)	325 to 500 GHz in 200 MHz steps	

- Power was set to maximum for the waveguide bands and -7 dBm for coaxial
- Generally 50 Hz IF Bandwidth is used
- Optionally we could have added WR6 Band to cover the 120 GHz to 140 Band gap also but this was not done for logistical reasons

Iss used – 138-356 used for Calibration and as measurement standard

Verification Lines		
ID	ps	um
K1	0.5	135
K2	0.5	135
K3	0.5	135
K4	0.5	135
K5	1.1	215
K6	1.4	250
K7	1.9	315
K8	2.3	365
K9	2.7	420
K10	3.2	485
K11	3.8	570
K12	4.5	655

ID	ps	um
L1	1	200
L2	3	450
L3	7	900
L4	14	1800
L5	27	3500
L6	40	5250



- Dimensions shows are line end to line end
- 130 um per pico second
- Electrical length is end to end minus 70 um (ie K1 is 65 um tip to tip)
- Used for both LRRM on 50 um SOLT standards and also MLTRL on Lines
- For the thru the 3.2 ps line standard has been used
- Calibrations were automated with Wincal
- More standards used than required as empirically DMPI found this improves propagation constant accuracy. It also provided useful additional data.
- Wincal allows full auto MLTRL for 138-356 and 172-886

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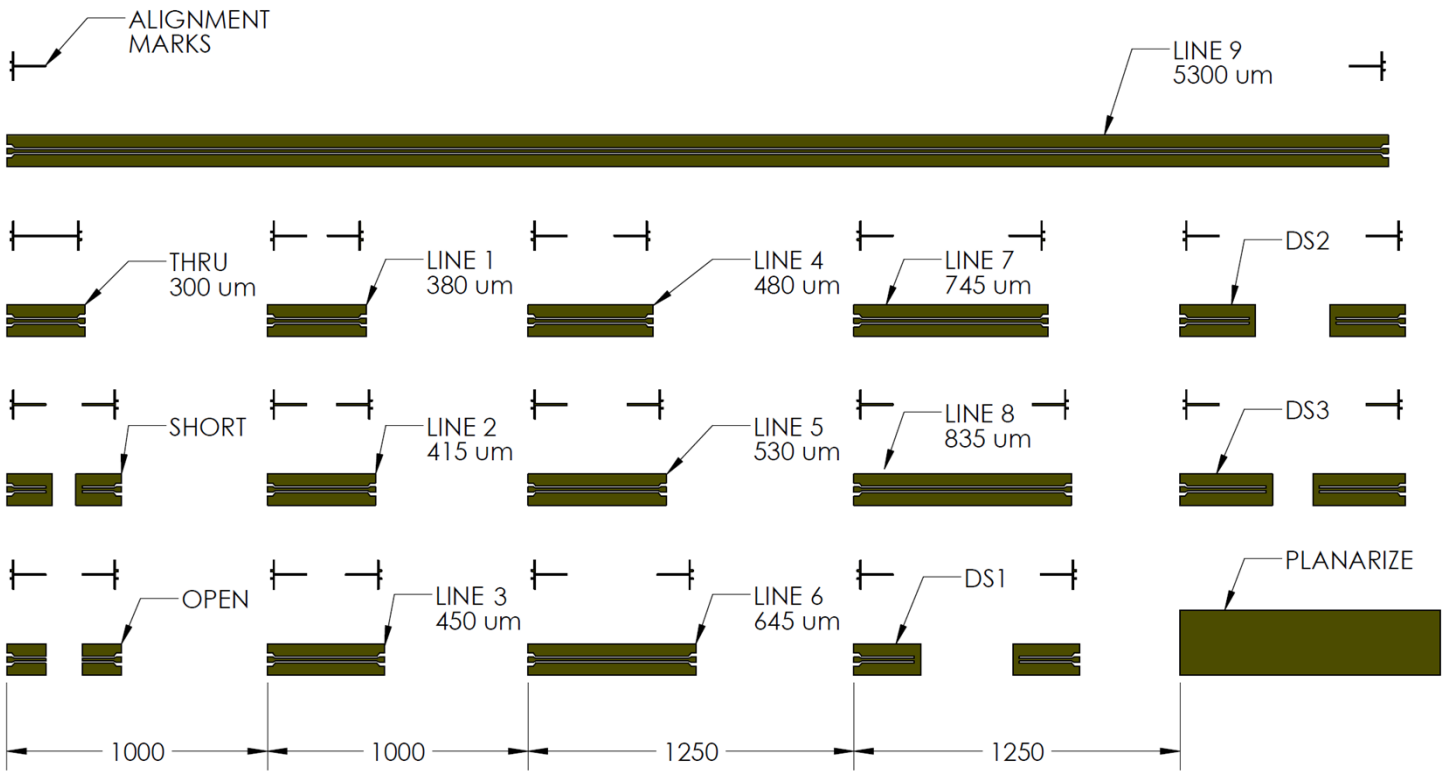
Iss used – 172-886 used for Calibration and as measurement standard



- Dimensions shows are line end to line end
- Electrical length is 45 um shorter than indicated
- 124 um per pS
- Offset shorts are handy reflect standards here
- All standards have named marker guides above them to aid manual placement if needed

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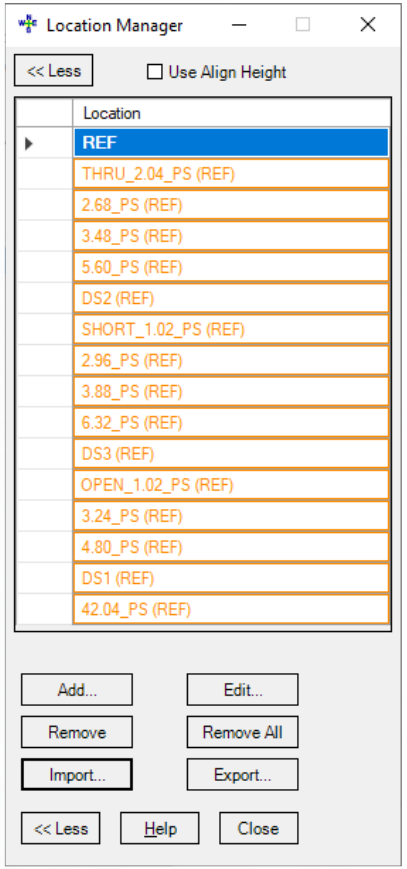
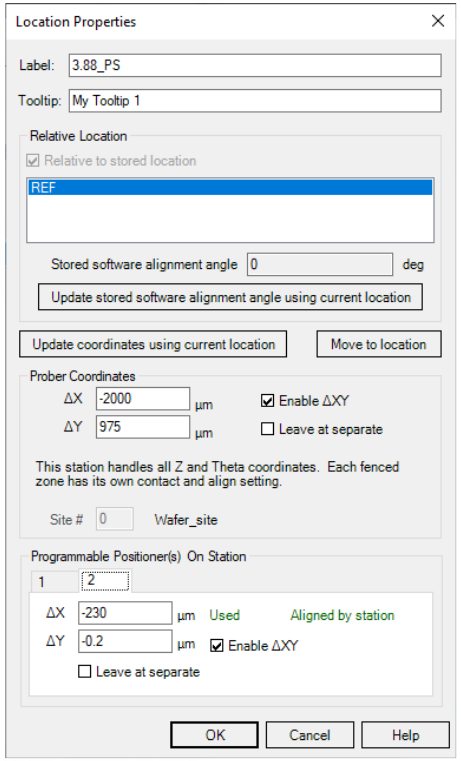
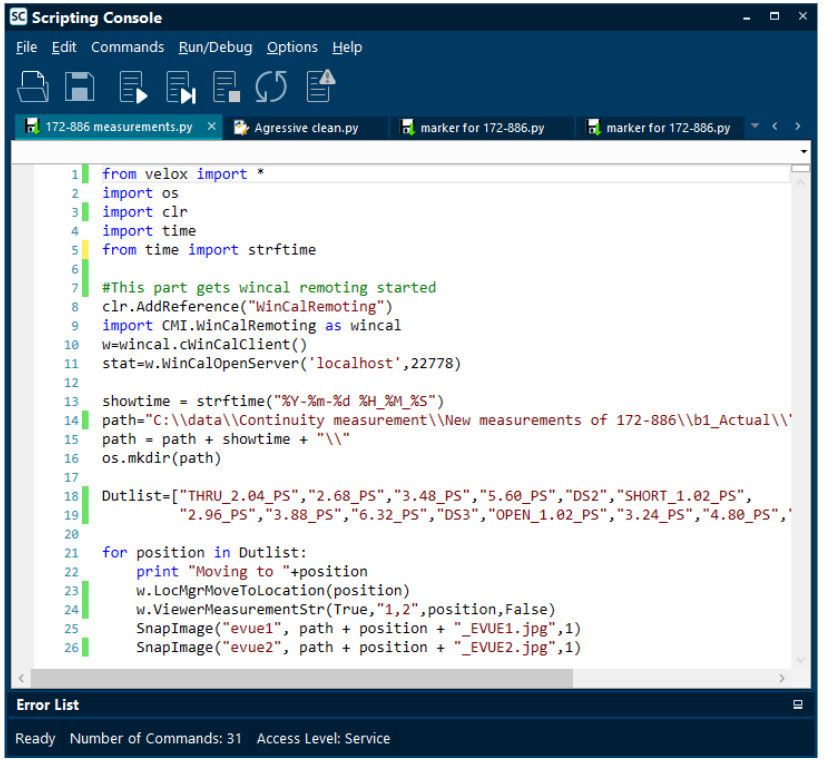
Data acquisition







- Location manager is a simple and efficient means of storing Chuck and positioner locations for measurement
- Python connects to Wincal from Velox scripting console and controls movement to DUT location, measurement with Wincal and recording of photos just for additional info

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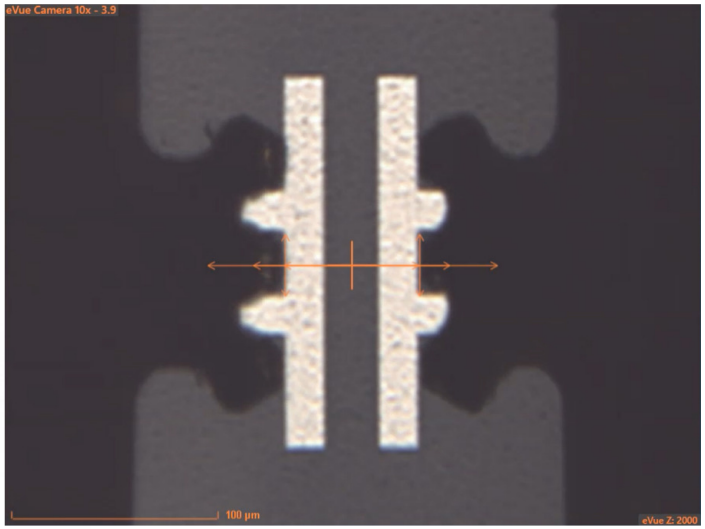
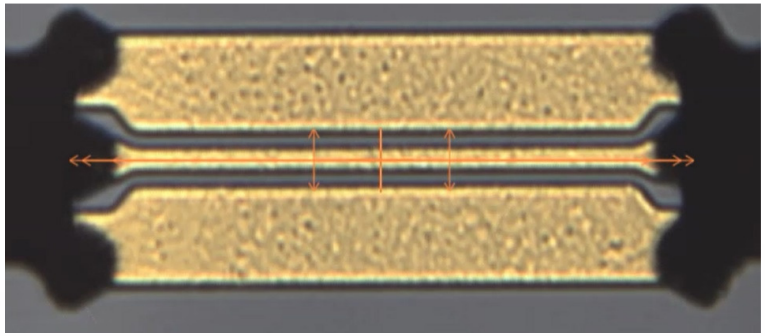
Probe alignment using markers



- Alignment marks help ensure that scrub is repeatable
- Useful to check stepping set is correct as markers can be configured for the different standards
- Now available in Velox both for Semi-Auto and manual stations



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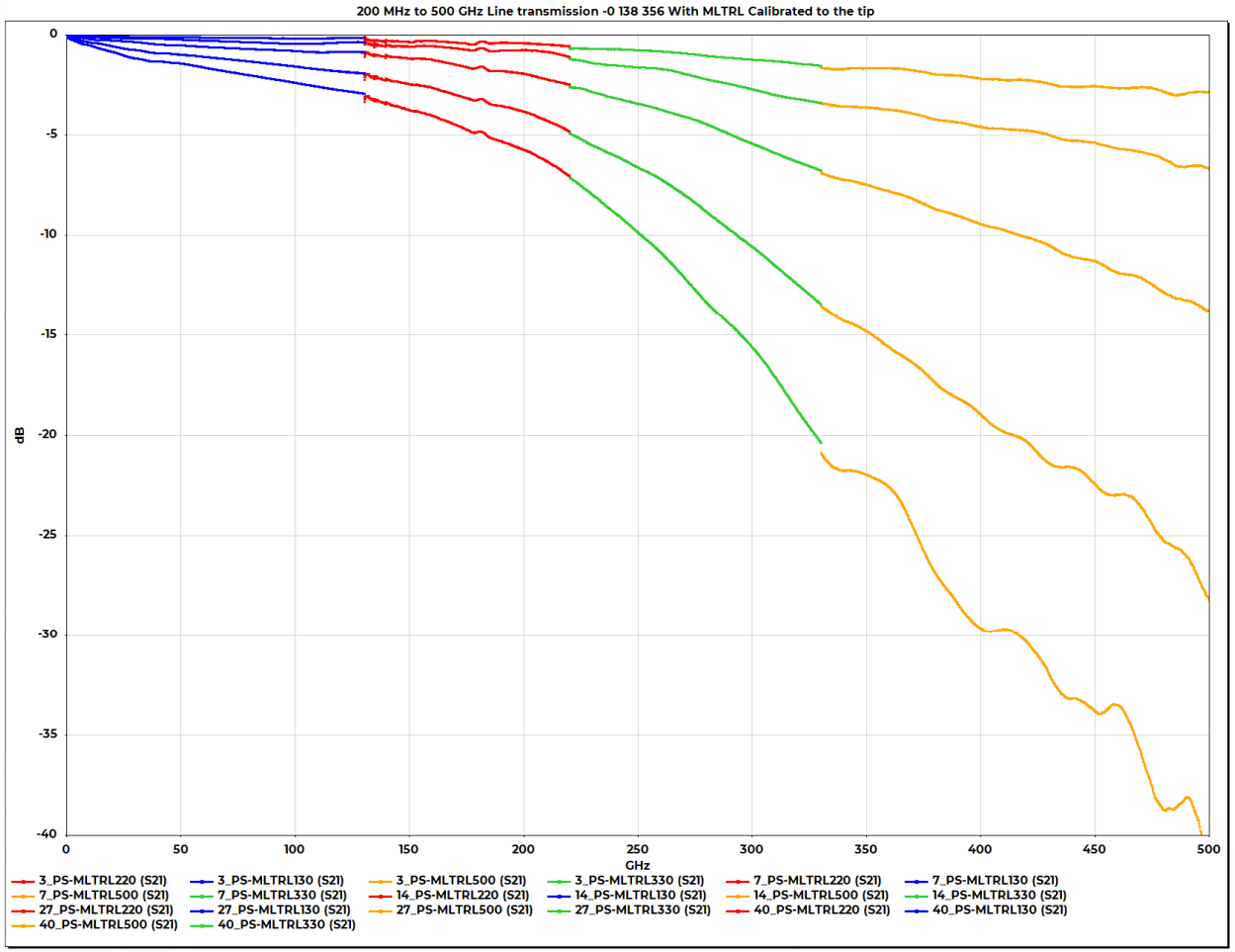
Data acquisition run on 172-886

Results – MLTRL Reference to tip 138-356, Calibration taken from different 138-356



- 3,4.5,7,14,27,40 PS Transmission lines shown here
- No modification of line Capacitance per unit length

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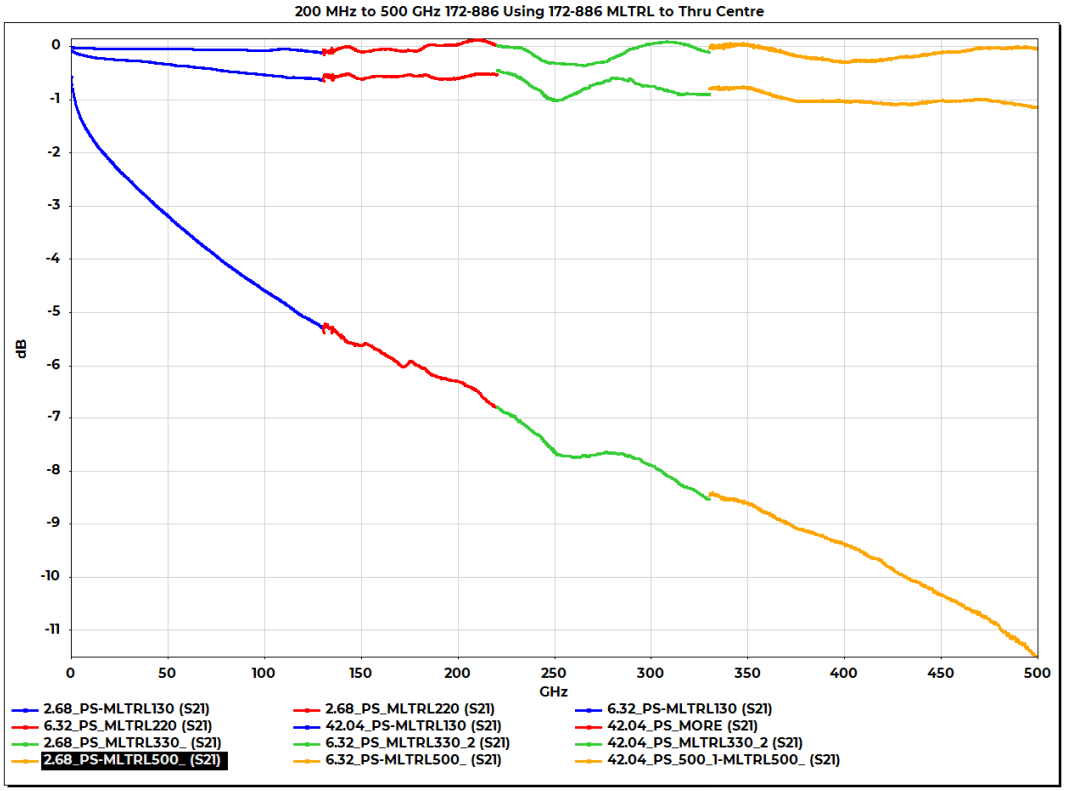
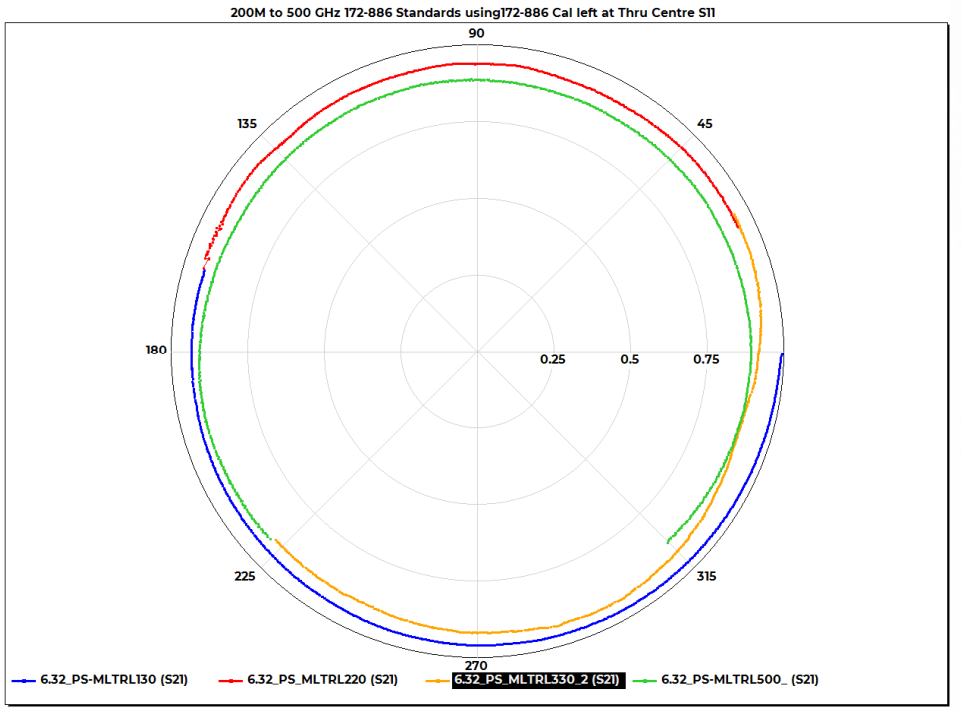
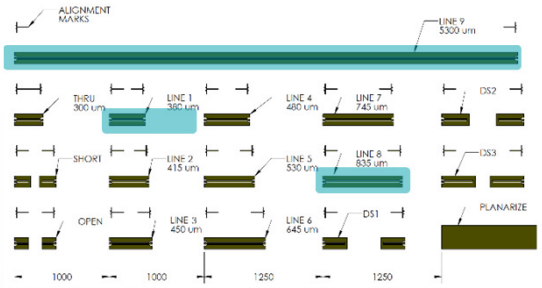
Results – 172-886 Calibrated with 172-886 MLTRL

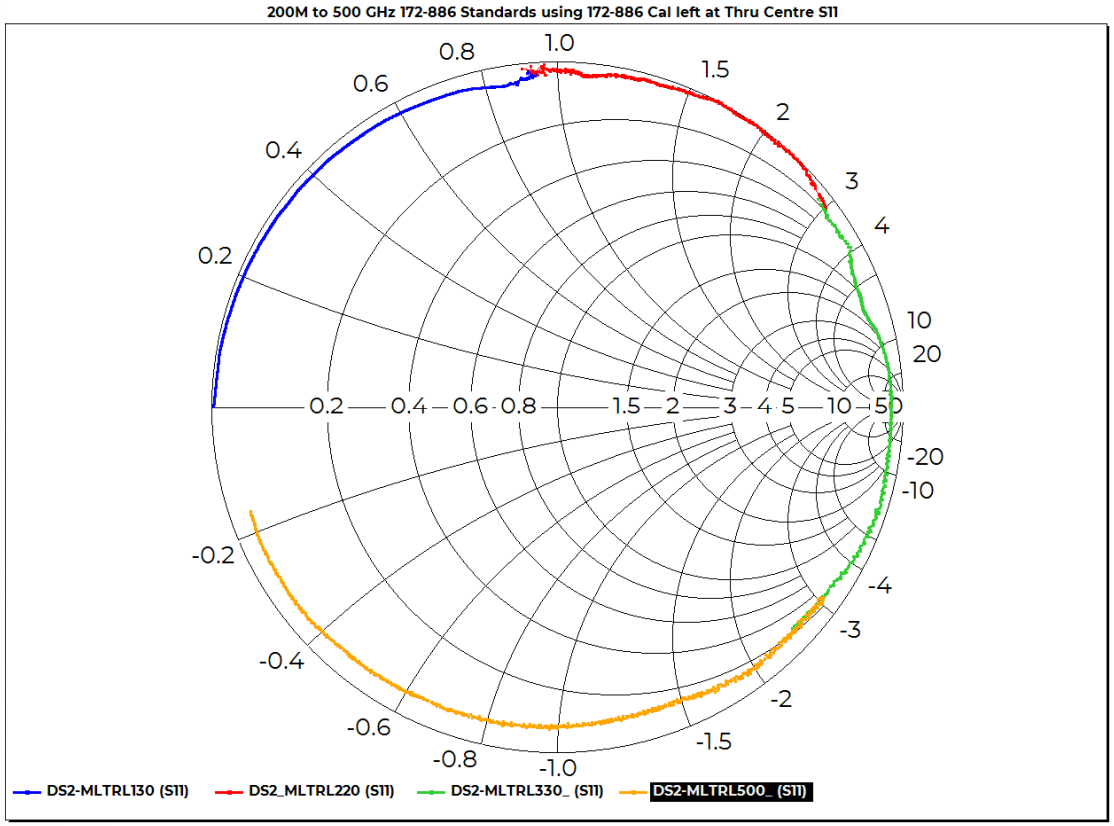


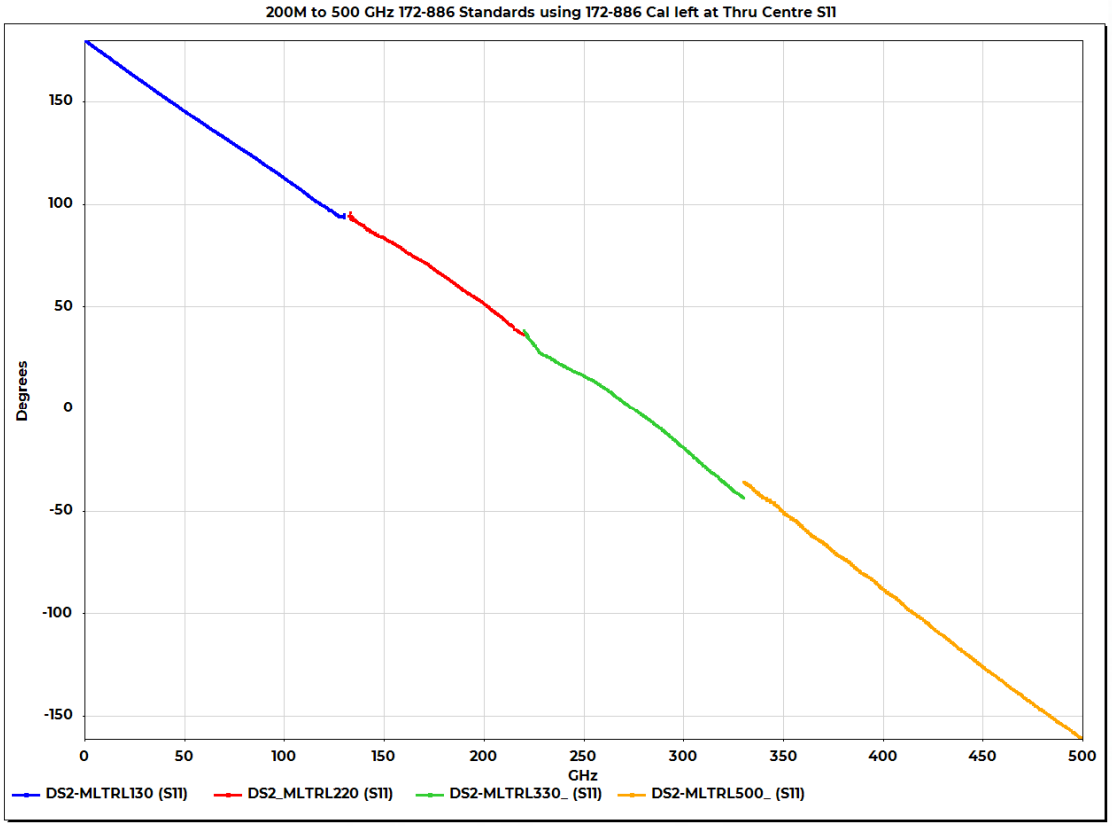


- Note large difference in line length from 6.32 pS to 42.05 pS



Results – Offset Short Reflect DS2 172-886 Calibrated with 172-886 MLTRL





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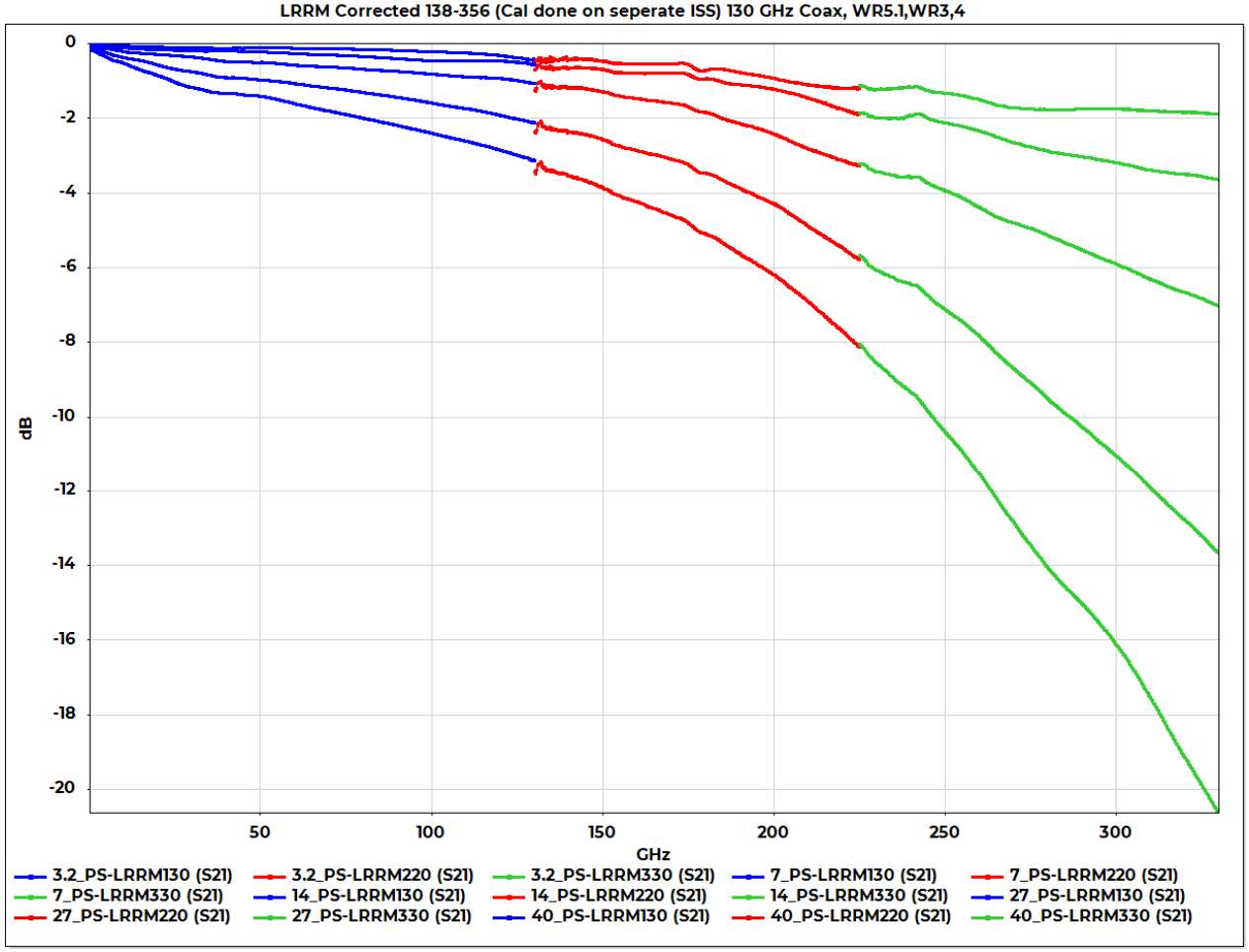
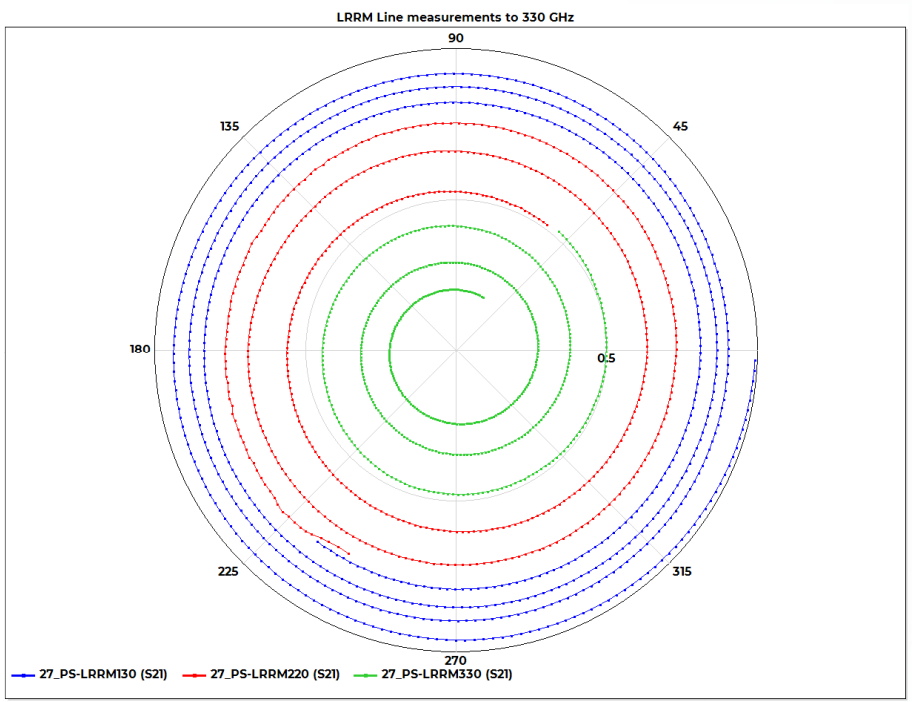
LRRM to 330 GHz - Transmission





- Lrrm is not really recommended above 220 GHz..but transmission isn't bad

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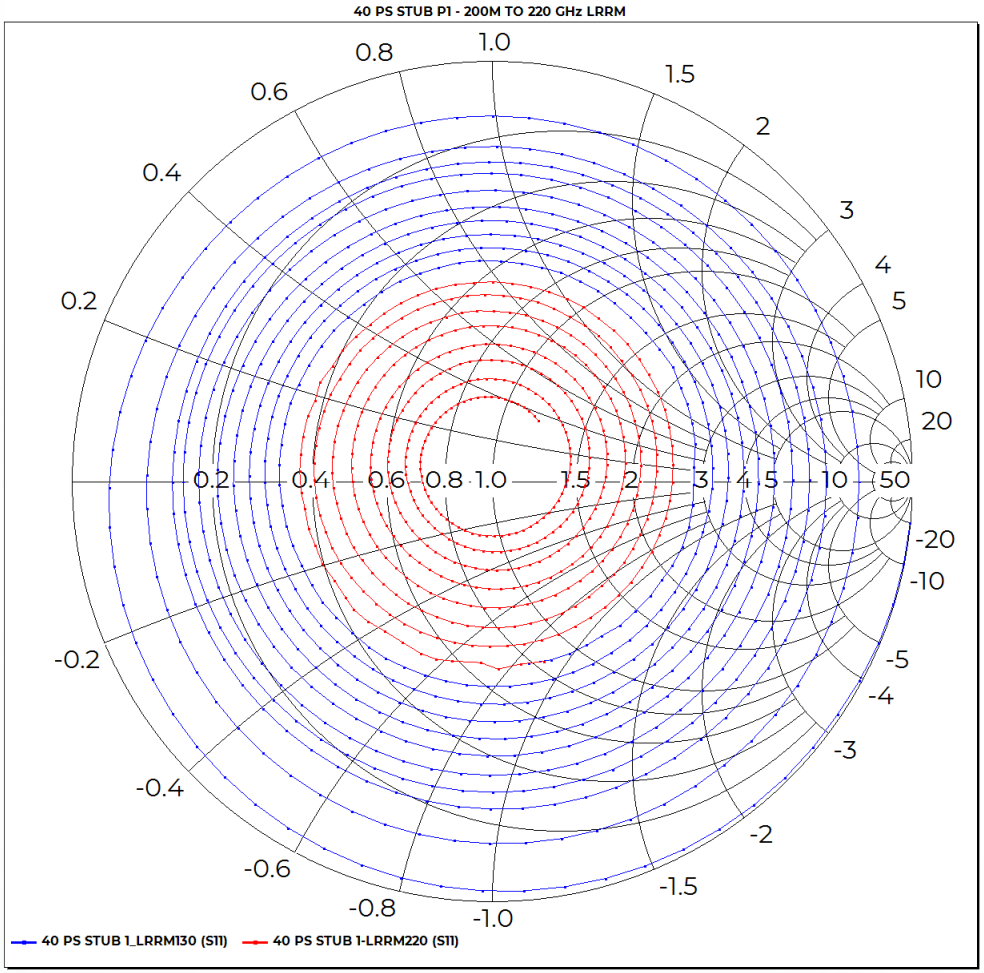
LRRM Stub response to WR5



- Stub was 40 PS and Dynamic range becomes a problem along with WR3 LRRM calibration

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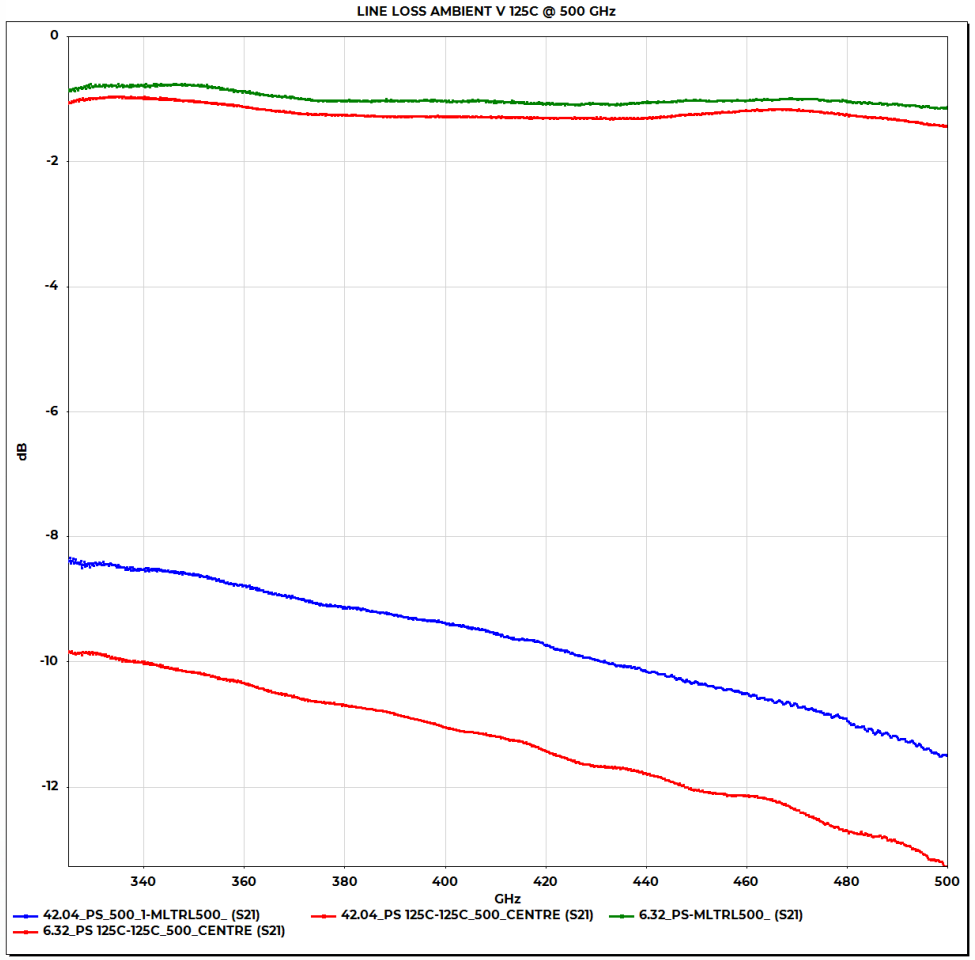
500 GHz Thermal measurements



- MLTRL Was done with the 172-886 on an absorber on main calibration chuck
- Calibration and line measurements done with Chuck at 125C

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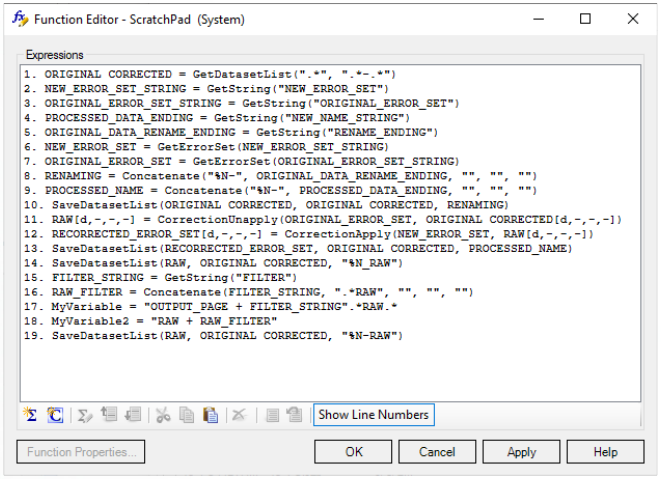
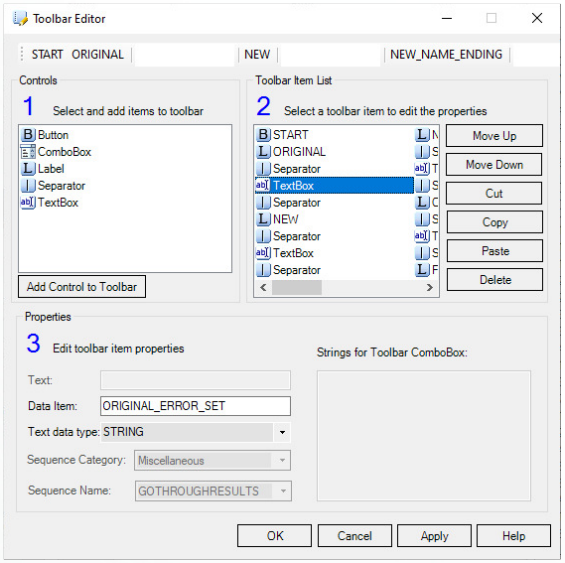
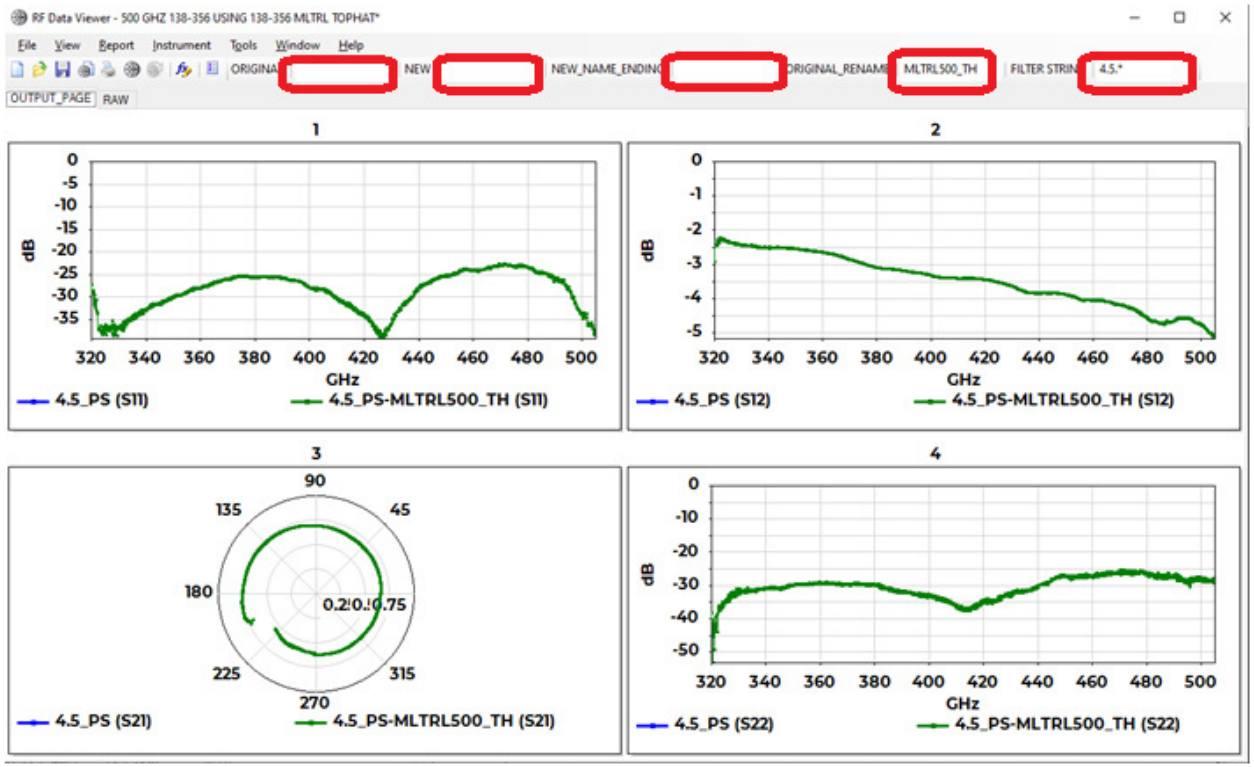
Analysis practical – Using Wincal as generic re-correction and display tool







- Wincal can be used to dynamically recorrect data sets with different calibrations and display specific data quickly
- Useful if MLTRL and LRRM are done sequentially

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Conclusions

- Measurements from 200 MHz (and lower) through to 500 GHz are achievable with just 4 bands skipping WR6 using N5291A although compromises are made
- Good agreement over a range of different standards
- Automatic MLTRL works effectively
- Thermal measurements to 500 GHz are possible