

Continuous S-parameter measurements to 500 GHz

Gavin Fisher – Centre of Expertise With kind assistance from Maria Muehlig Dominion Microprobe 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

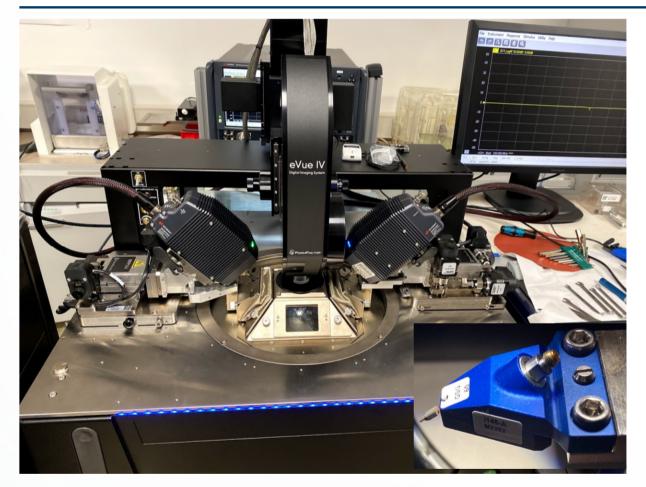
Minimizing Discontinuities in Wafer-Level Sub-THz Measurements up to 750 GHz for Device Modelling Applications

Choon Beng Sia

Cascade Microtech Inc. (A FormFactor Company) 26 Woodlands Loop, Level 7, Singapore 738317

FORMFACTOR

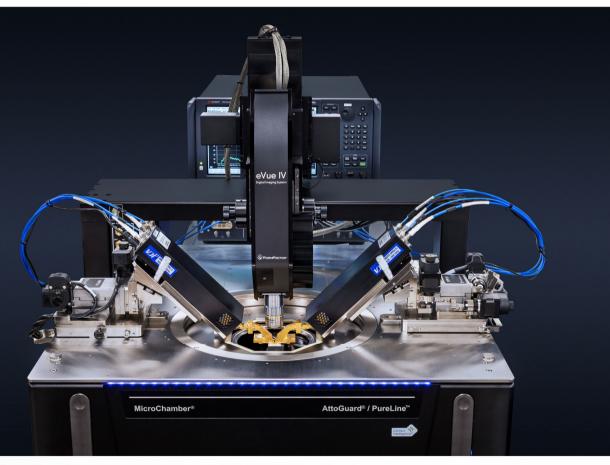
Test Setup – Coaxial setup



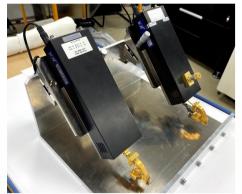
- N5291A 120 GHz VNA
- 10 cm cables with integral 0.8 to 1mm adaptor
- 2 X i145-GSG-50 Infinity probes with 0.8mm connectors
- Tophat in use for these measurements but cables for non-tophat use would be identical
- Summit 200 Wafer prober It has a loader but we didn't use this



Test Setup – Waveguide setup

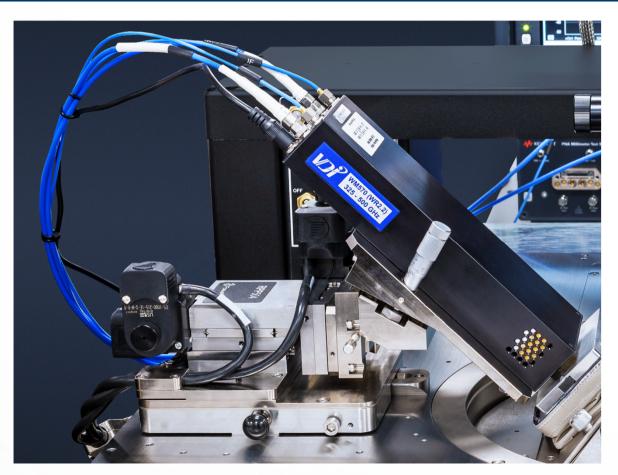


- All extenders used kindly loaned by Virginia diodes, VNX-Mini modules
- Probes loaned by Dominion Micro probe
- For this setup we remove the VDI fitted port saves which is 2" long and replace this with inclined short port saver from Formfactor
- Parking fixture used to allow populated arms to reach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



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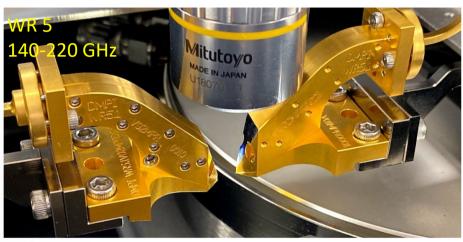
Programmable positioners to aid testing and calibration



- 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







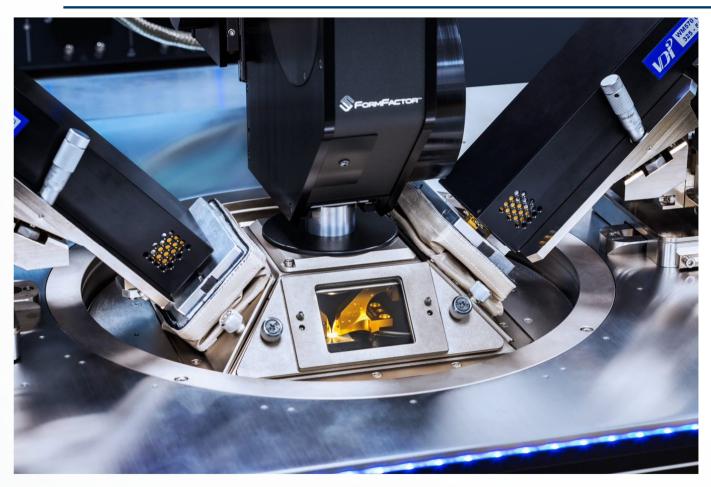
- S-Geometry probes used along with Short port savers to modify launch angle
- Probes loaned by DMPI for this work

6

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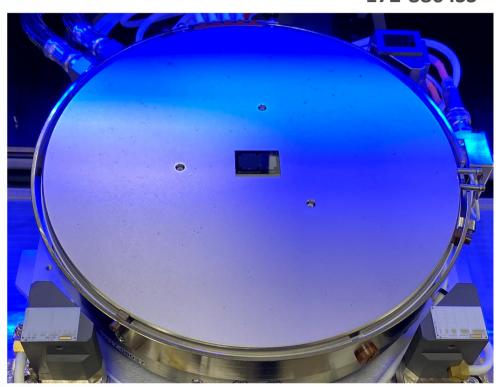
Side evaluation – Setting up for 500 GHz Tophat and 125C thermal



- 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

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Test setup



138-356 CAL ISS 172-886 ISS

- 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

FORMFACTOR

138-356 REF

Test setup Stimulus

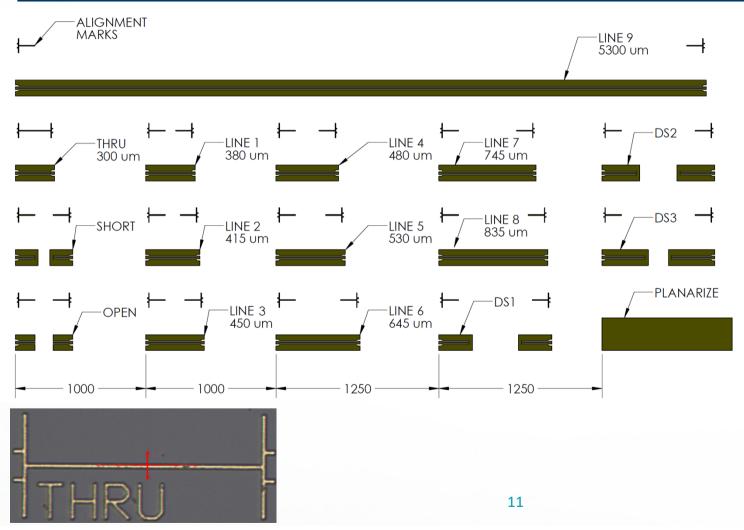
BAND	FREQUENCY RANGE MEASURED	COMMENT
1MM N5291A	200MHz to 130 GHz IN 200MHz Steps	This is 10 GHz higher than the advertised upper frequency but in practice works well and used routinely
WR5.1	130 to 220 GHz in 200MHz steps	The lower end really is stretched here, 10 GHz below official lower end in cut-off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

Verif	fication	Lines		1	v	L .	
ID	ps	um		Ŧ	ĸ	-	
K1	0.5	135		-		-	
K2	0.5	135					
					L		
K3	0.5	135					
K4	0.5	135	Calibration			– 🗆 🗙	
K5	1.1	215	File Setup View Calibration Tools Loca	tions Measurement	ts Help		 Dimensions shows are line end to line end
K6		250	📄 🦻 📕 2-Port Multi-Line TRL	🝷 🞯 Align 🔏 l	SS 着 VNA 📐 Rep	peatability 🔄 Monitor	
	1.4		INO MARKER 9			🚝 To VNA	 130 um per pico second
K7	1.9	315	🕵 Ref 🔏 Setup 🕲 Meas 🗹 Edit 📜 Move Up	Move Down 📰 I	Location 🗌 Second T	ïer	130 dill per pico second
K8	2.3	365			1		
K9	2.7	420	MutoCal Stop	\bigcirc			 Electrical length is end to end minus 70 um (ie K1 is 65 ur
K10	3.2	485	Repeatability Calibration Validation Monitoring				
			■ 138-356 3.2ps Verification Line, ISS ↑	Meas View			to tip)
K11	3.8	570	S-Para ports: 1, 2 (Thru)	Meas View			
K12	4.5	655	Switch Gamma term ports: 1, 2 (Switching Terms)	Meas View			
			□ 138-356 50um Open, ISS ↑	Meas View			 Used for both LRRM on 50 um SOLT standards and also M
			S-Para port: 1 (Port 1 Open) S-Para port: 2 (Port 2 Open)	Meas View Meas View			
ID	ps	um	□ 138-356 50um Short. ISS ↑	Meas View			on Lines
L1	1	200	S-Para port: 1 (Port 1 Short)	Meas View			
L2	2	450	S-Para port: 2 (Port 2 Short)	Meas View			. For the thrusthe 2.2 we live standard has been used
	5		□ 138-356 3.8ps Verification Line, ISS ↑	Meas View			 For the thru the 3.2 ps line standard has been used
L3	7	900	S-Para ports: 1, 2 (Line 1)	Meas View			
L4	14	1800	□ 138-356 4.5ps Verification Line, ISS ↑	Meas View			Colibrations were suterested with Minsel
			S-Para ports: 1, 2 (Line 2)	Meas View		_	 Calibrations were automated with Wincal
L5	27	3500	□ 138-356 7ps Verification Line, ISS ↑	Meas View			
L6	40	5250	S-Para ports: 1, 2 (Line 3)	Meas View			NAME at a she walk was at the second survive of an example in a literal the DNAD! f
20	10	5250	□ 138-356 14ps Verification Line, ISS ↑	Meas View	-		 More standards used than required as empirically DMPI features
			S-Para ports: 1, 2 (Line 4)	Meas View	-	-	
			□ 138-356 27ps Verification Line, ISS ↑	Meas View			this improves propagation constant accuracy. It also provi
			S-Para ports: 1, 2 (Line 5)	Meas View			
			□ 138-356 40ps Verification Line, ISS ↑	Meas View			useful additional data.
			S-Para ports: 1, 2 (Line 6)	Meas View			
							• Wincal allows full auto MLTRL for 138-356 and 172-886
			Ready			.::	

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

FORMFACTOR

<< Less Use Align Height Location REF 1HRU_2.04_PS (REF) 2.68_PS (REF) 3.48_PS (REF) 5.60_PS (REF) DS2 (REF) SHORT_1.02_PS (REF) 2.96_PS (REF) 3.88_PS (REF) 6.32_PS (REF) DS3 (REF) OPEN_1.02_PS (REF) 3.24_PS (REF) 4.80 PS (REF)	🃲 Location Manager 🛛 🗆 🗙						
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3.24_PS (REF)		DS3 (REF)					
		OPEN_1.02_PS (REF)					
4.80 PS (REF)		3.24_PS (REF)					
		4.80_PS (REF)					
DS1 (REF)		DS1 (REF)					
42.04_PS (REF)		42.04_PS (REF)					

Edit.. Remove All

Export...

Close

<u>H</u>elp

Add..

Remove Import.

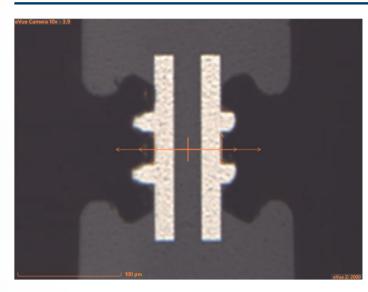
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Data acquisition

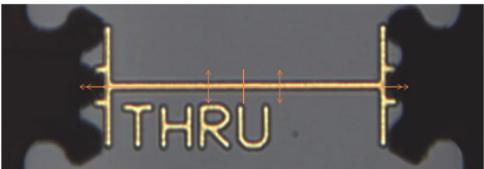
Location Properties X	SG Scripting Console _ 🗆 ×
	<u>F</u> ile <u>E</u> dit Commands <u>R</u> un/Debug <u>O</u> ptions <u>H</u> elp
Label: 3.88_PS	
Tooltip: My Tooltip 1	
Relative Location	📅 172-886 measurements.py 🗙 🍄 Agressive clean.py 🛛 🥫 marker for 172-886.py 🗧 marker for 172-886.py
✓ Relative to stored location	
REF	1 from velox import *
	2 import os 3 import clr
	4 import time
	5 from time import strftime
Stored software alignment angle 0 deg	6
Update stored software alignment angle using current location	7 #This part gets wincal remoting started
opulate stored software angriment angle daning current location	<pre>8 clr.AddReference("WinCalRemoting")</pre>
	9 import CMI.WinCalRemoting as wincal
Update coordinates using current location Move to location	<pre>10 w=wincal.cWinCalClient() 11 stat=w.WinCalOpenServer('localhost',22778)</pre>
Prober Coordinates	12
ΔX -2000 μm I Enable ΔXY	13 showtime = strftime("%Y-%m-%d %H %M %S")
	14 path="C:\\data\\Continuity measurement\\New measurements of 172-886\\b1_Actual\\'
ΔY 975 μm Leave at separate	<pre>15 path = path + showtime + "\\"</pre>
This station handles all Z and Theta coordinates. Each fenced	16 os.mkdir(path)
zone has its own contact and align setting.	17
	18 Dutlist=["THRU_2.04_PS","2.68_PS","3.48_PS","5.60_PS","DS2","SHORT_1.02_PS",
Site # 0 Wafer_site	19 "2.96_PS", "3.88_PS", "6.32_PS", "DS3", "OPEN_1.02_PS", "3.24_PS", "4.80_PS", '
	20 21 for position in Dutlist:
Programmable Positioner(s) On Station	22 print "Moving to "+position
1 2	23 w.LocMgrMoveToLocation(position)
ΔX -230 μm Used Aligned by station	<pre>24 w.ViewerMeasurementStr(True, "1,2", position, False)</pre>
	<pre>25 SnapImage("evue1", path + position + "_EVUE1.jpg",1)</pre>
ΔY -0.2 μm 🗹 Enable ΔXY	<pre>26 SnapImage("evue2", path + position + "_EVUE2.jpg",1)</pre>
Leave at separate	×
·	
	Error List
OK Cancel Help	Ready Number of Commands: 31 Access Level: Service

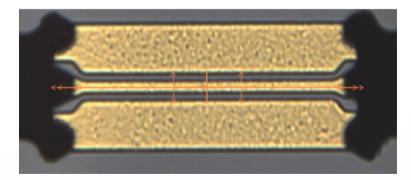
- Location manager is a simple and efficient means of storing Chuck and positioner locations for measurement ٠
- Python connects to Wincal from Velox scripting console and controls movement to DUT location, • measurement with Wincal and recording of photos just for additional info

Probe alignment using markers



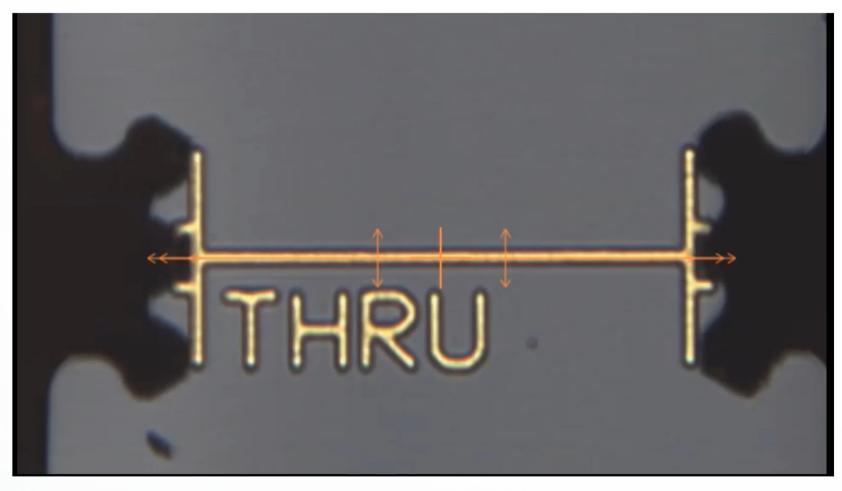
- Alignment marks help ensure that scrub is repeatable
- Useful to check stepping set is correct as markers can be configured for the different standards
- Now available in Velox both for Semi-Auto and manual stations



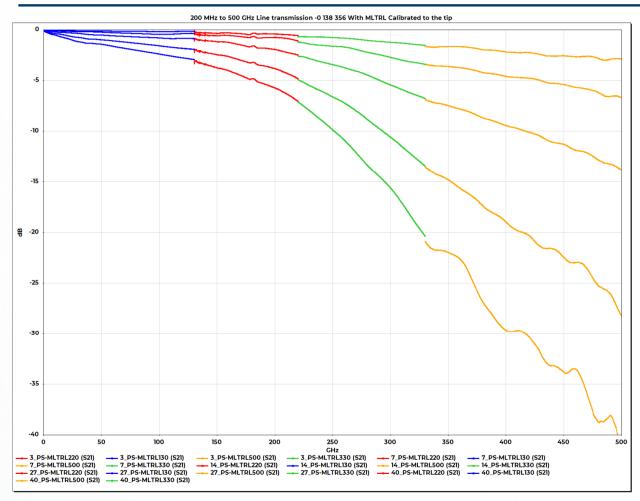




Data acquisition run on 172-886



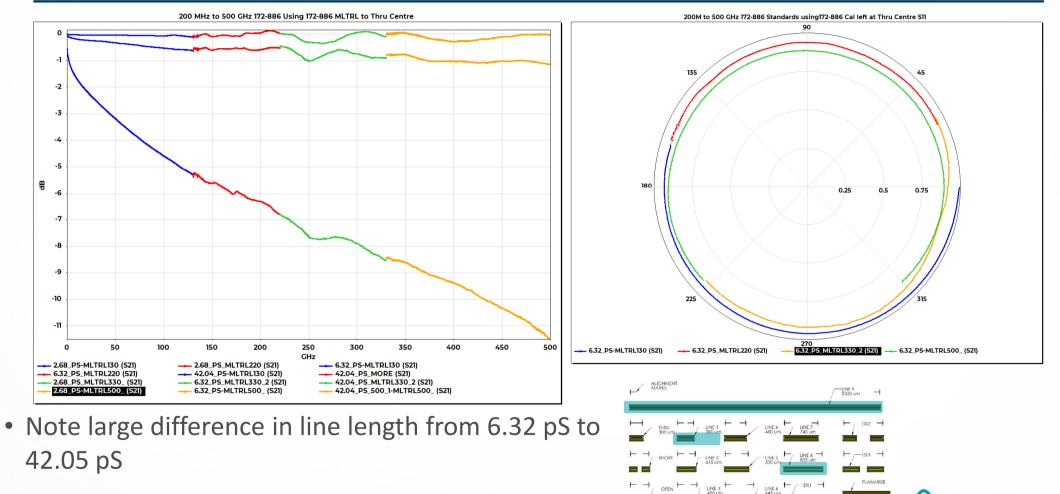
Results – MLTRL Reference to tip 138-356, Calibration taken from different 138-356



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

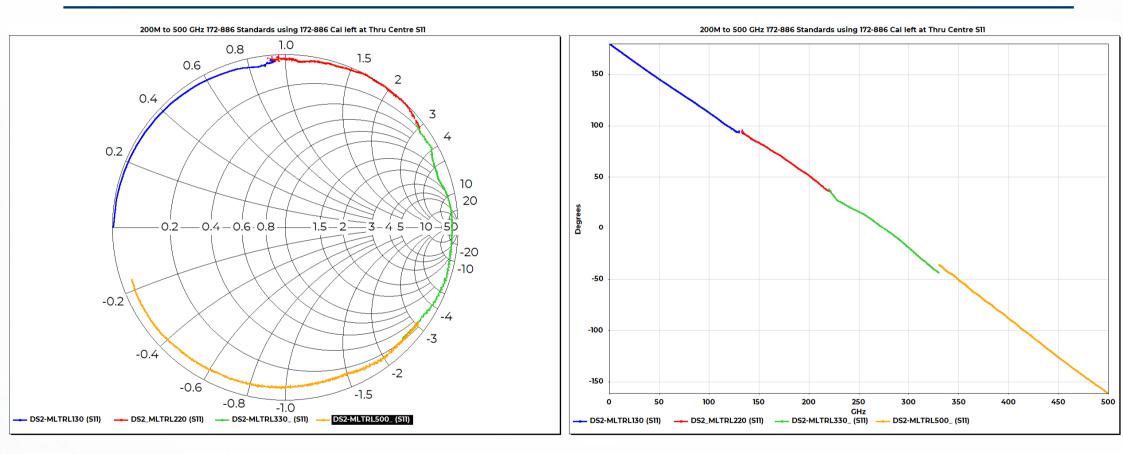


Results – 172-886 Calibrated with 172-886 MLTRL

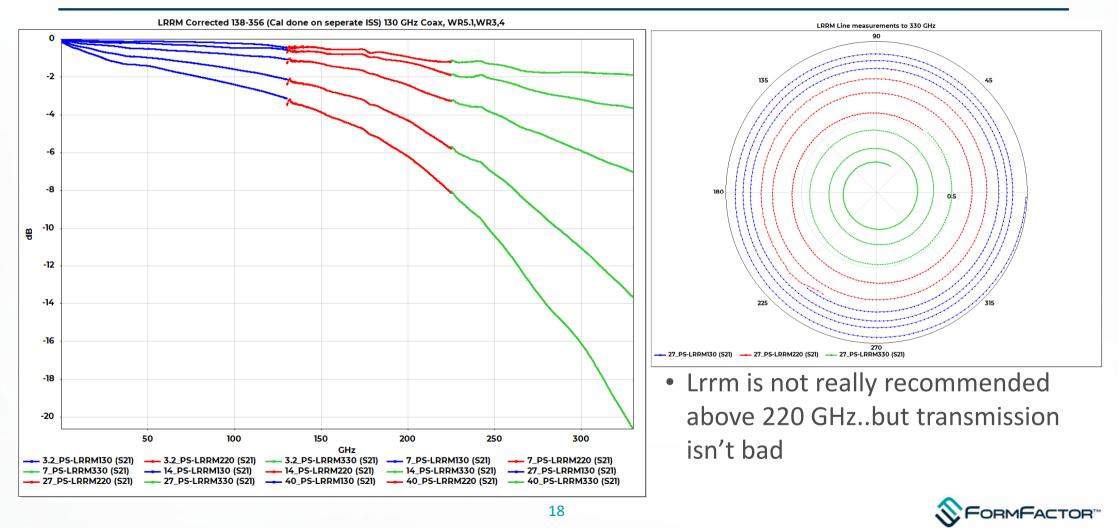


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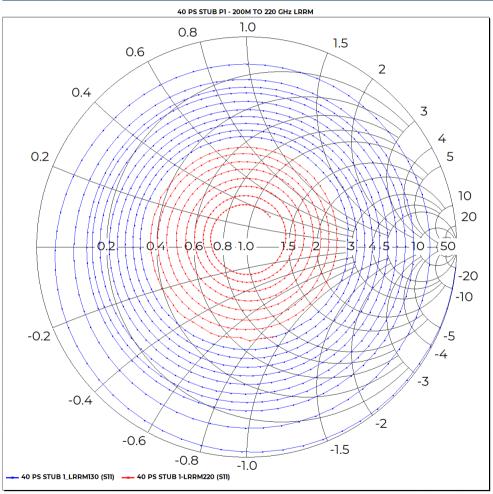
Results – Offset Short Reflect DS2 172-886 Calibrated with 172-886 MLTRL



LRRM to 330 GHz - Transmission



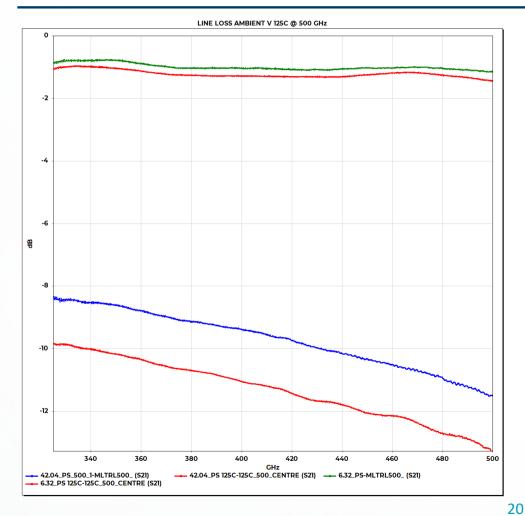
LRRM Stub response to WR5



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



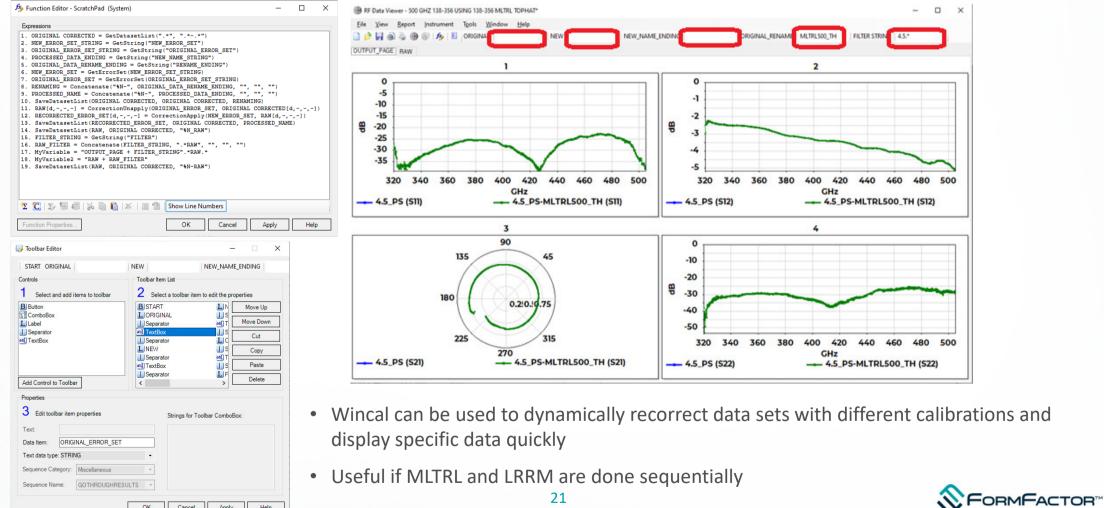
500 GHz Thermal measurements



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



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



OK

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Help

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

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