Pin Savers : Enabling ATE testing 81GHz mmWave RFCOM SoC Device

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Texas Instruments

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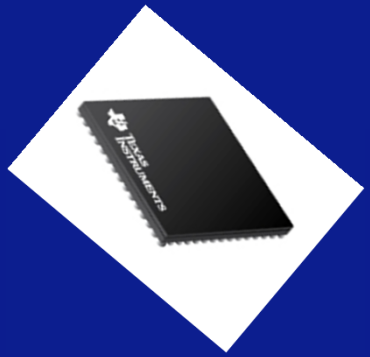
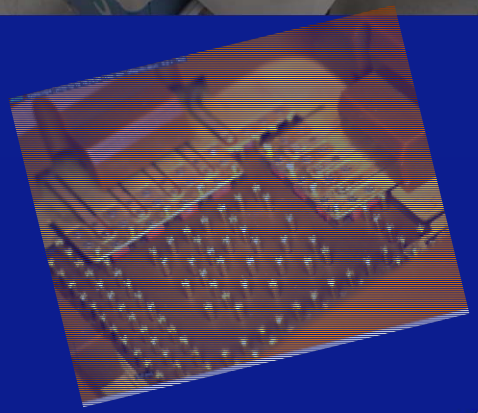




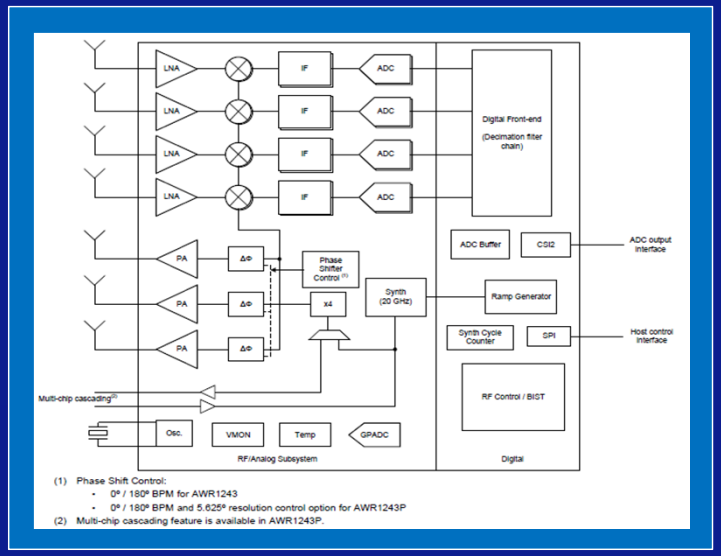
TI Automotive 76-81GHz mm-Wave Radar SoC

AWR1243 is 1st TI's Radar RFCOM SoC device, key features are:

1. Integrated 3 Tx & 4 Rx (from 76GHz to 81GHz), Synth/ADC with integrated DSP+MCU
2. FCBGA package for lower cost PCB assembly
3. ASIL-B capable Safety device (targeting 0 DPPM)

Main challenges:

1) Socket solution for 76-81GHz
2) 0.65mm FCBGA
3) Test Cell solution backward compatible with existing TI tester platforms for better utilization
4) Test Cell solutions easily scalable for high pin-count SOC devices (as Radar IC) to support high volume production
5) Handler & Socket are completely new developments - require verification/qualification to release to production floor



AWR1243 Block Diagram from Datasheet

TI 76-81GHz mm-Wave ATE Production Tester Solution Definition

Device Datasheet

over recommended operating conditions and with run time calibrations enabled(unless otherwise noted)

PARAMETER			MIN	TYP	MAX	UNIT
Receiver	Noise figure	76 to 77 GHz		14		dB
		77 to 81 GHz		15		
	1-dB compression point (Out Of Band)(1)			–8		dBm
	Maximum gain			48		dB
	Gain range			24		dB
	Gain step size			2		dB
	Image Rejection Ratio (IMRR)			30		dB
	IF bandwidth(2)				15	MHz
	A2D sampling rate (real)				37.5	Msps
	A2D sampling rate (complex)				18.75	Msps
	A2D resolution			12		Bits
	Return loss (S11)			<–10		dB
	Gain mismatch variation (over temperature)			±0.5		dB
	Phase mismatch variation (over temperature)			±3		°
	In-band IIP2	RX gain = 30dB IF = 1.5, 2 MHz at –12 dBFS		16		dBm
	Out-of-band IIP2	RX gain = 24dB IF = 10 kHz at -10dBm, 1.9 MHz at -30 dBm		24		dBm
	Idle Channel Spurs			–90		dBFS
Transmitter	Output power			12		dBm
	Amplitude noise			–145		dBc/Hz
Clock subsystem	Frequency range		76		81	GHz
	Ramp rate				100	MHz/µs
	Phase noise at 1-MHz offset	76 to 77 GHz		–95		dBc/Hz
		77 to 81 GHz		–93		
20 GHz SYNC OUT signal (FM_CW_CLKOUT and FM_CW_SYNCOUT)(3)	Frequency range		19		20.25	GHz
	Output Power			7		dBm
	Return loss			–10		dB
	Impedance			50		Ω
20 GHz SYNC IN signal (FM_CW_SYNCIN)(4)(3)	Frequency range		19		20.25	GHz
	Input Power			1		dBm
	Return loss			–10		dB
	Impedance			50		Ω

Test Requirements

ATE Vendor Capability Comparison

	ATE Vendor A	ATE Vendor B	ATE Vendor C
60-90GHz Power Mea. Ports	✓	✓	✓
60-90GHz Phase Noise Measurement	✓	✓	✗
60-90GHz Source	✓	✓	✓
Manufacturing Compatibility & Readiness	✗	✓	✓
Multi-site Capability	✗	✓	✓
Backward Compability with Existing Platfroms	✗	✓	✓
De-embedding & Calibration	✓	✓	✓

Data Collected in 2014

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TI 76-81GHz mm-Wave ATE Production Socket Solution Definition

Main challenges:

1.Membrane solution

- ✓ Meets the electrical requirement
- ❖ not available for large pitch (0.65mm)
- ❖ Can not support +/- 50um BGA ball height variation (max +/-25um)

2.Socket solution compatible to TI existing ATE testers and handlers infrastructure

BGA Socket Solution Comparisons

	Wafer-Probe	Socket Vendor A	Socket Vendor B	Socket Vendor C
Solution Type	Membrane	Leadframe+pogo	Pogo	Interposer + PCB
Package Pitch	NA	0.65mm	~0.3mm - 0.8mm	~0.5mm
Ball Height Variation	+/-25um	+/-50um	+/-50um	+/-50um
Frequency Range	~100GHz	~81GHz	~40GHz	~60GHz
RF Insertion Loss	✓	✓	✕	✕
RF Return Loss@-10dB	✓	✓	✓	✓
Contact Life(Insertions)	Yes (<=1M)	Yes (<=1M, leadframe unknown)	NA	NA
Tri-temp Qualified	✓	✓ (DOE Planned)	NA	NA
De-embedding	✓	✓	✕	✓
Overall Cost	✕	✓	✓	✓
Cost of Repair/Replacement	✕	✓	✓	✓

Data Collected in 2014

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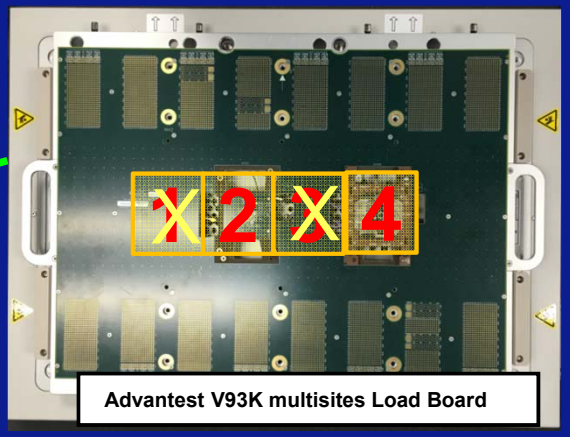
Advantest V93K/UDI (Universal Device Interface) ATE Board Stack-up

UDI add-on requires:

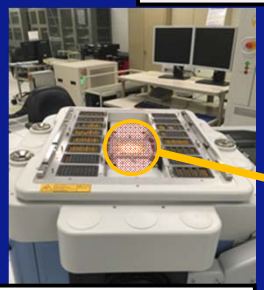
1. V93K + PSRF

2. Waterline & power upgrade module

mm-Wave UDI

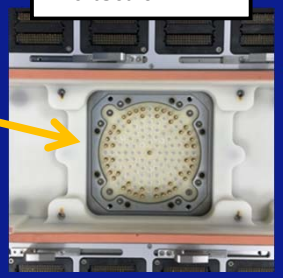


Advantest V93K multisites Load Board



Std V93K "S" Test-head

PortScale RF

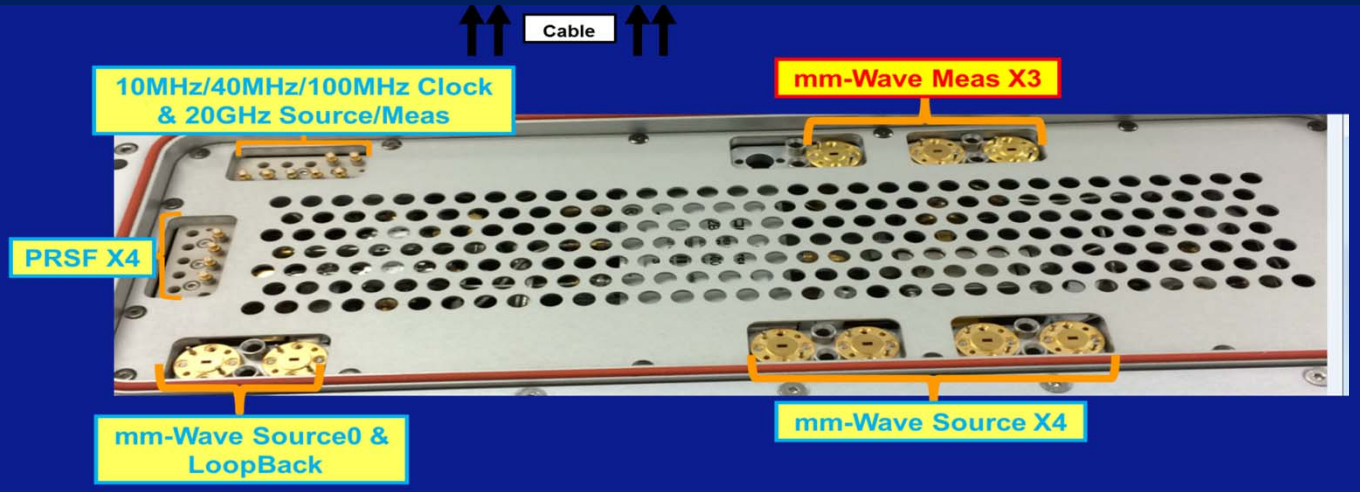


- **Socket is compatible to TI compliance**
- **UDI support multi-sites**

TI 76-81GHz mm-Wave UDI & ATE Board Interface

To complete a 81GHz mmWave Test Cell, we added the following hardware to TI Standard V93k configuration:

1. mm-Wave extension UDI to existing V93K PSRF
2. ATE Load Board mate to UDI as one single unit
3. ATE load-board attaches to UDI using blind-mate connection (WR12 wave-guide & SMP RF ports)

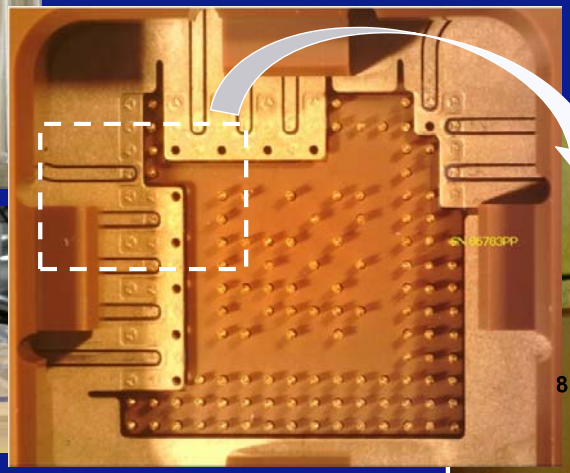


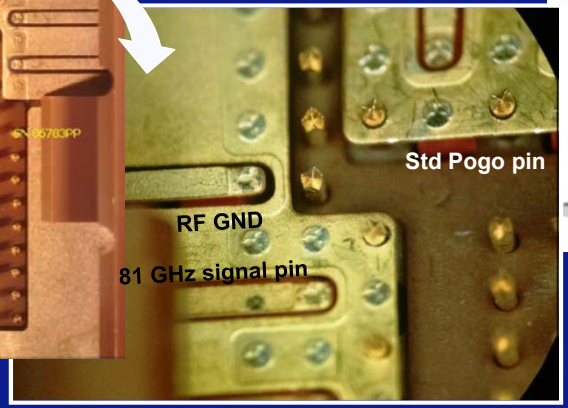
TI 76-81GHz mm-Wave Socket Configuration

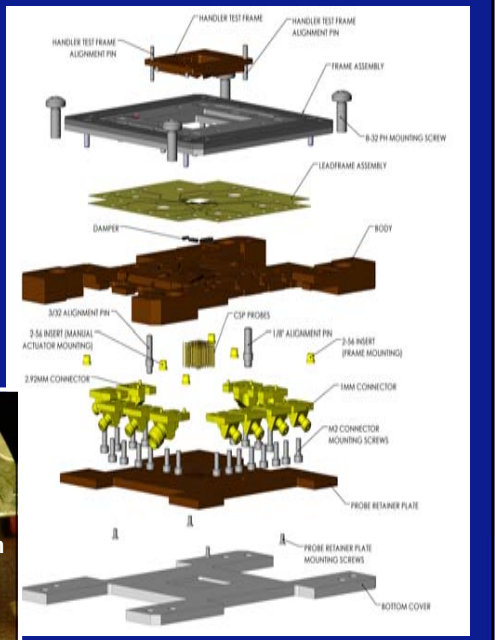
Socket designed to perform across wide-band of 60-90GHz;
Socket mechanical structure includes:

- Pogo pins used for Digital/Power pins
- Lead-frame CPW(GSG) traces for mm-Wave signals
- 1mm & 2.92 RF connectors

Pogo pins with lead-frame traces







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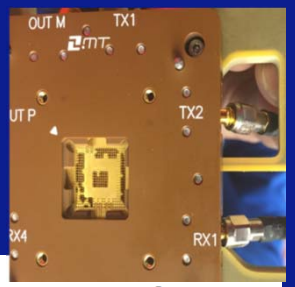
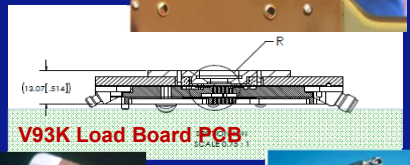
TI 76-81GHz mm-Wave Socket/UDI Connections

Top-side Socket View

Hand-test Lid

Socket W/O Hand-test Lid





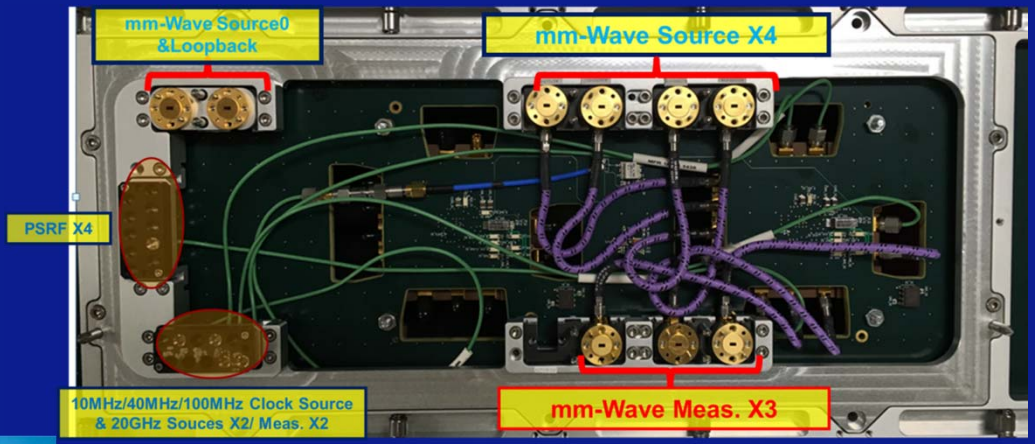
holes for 1mm & 2.92 connectors

Side View

1mm cable

WR12-1mm Adapter

Fully Configured Board Bottom-Side

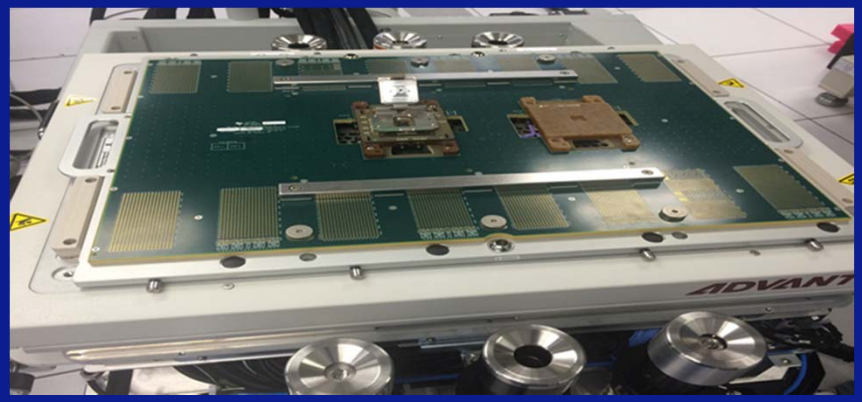


Side View

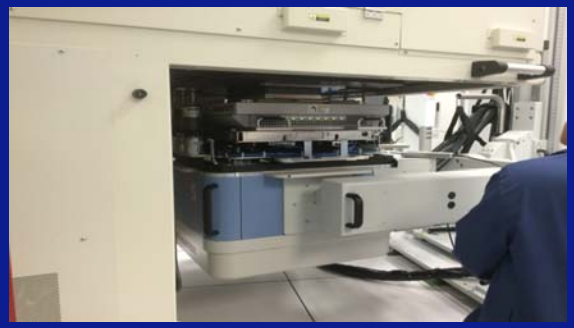
V93K UDI Test Cell Development Challenges

Tester Docking Plane vs UDI Docking Plane

ATE Load Board on UDI



Handler Docking

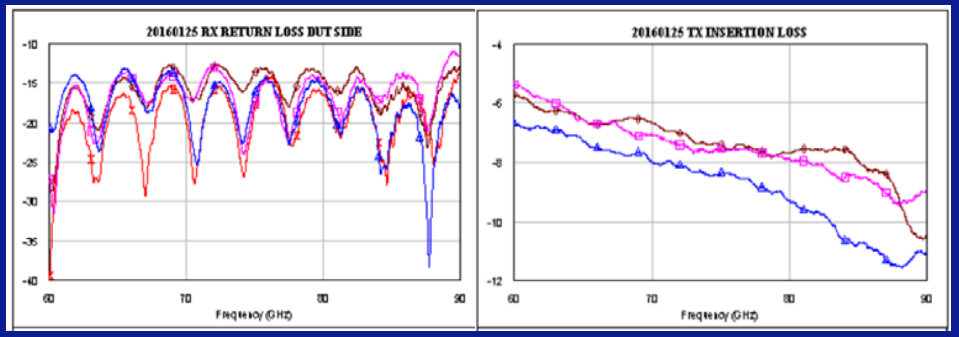


ATE Test Cell & Socket Verification

UDI Standalone Evaluation Summary

Modules	Items/Parameters Name		Units	mmWave UDI Design Spec	Summary
Band Output (GHz)	Power Range			Values	
High Band Source 1 (76 - 81Ghz @ 1Ghz Step)	Power Range		dBm	-45 to +15 dBm	
	Step		dBm	0.1db	
High Band Source 2 (76 - 81Ghz @ 1Ghz Step)	Power Range		dBm	-45 to +15 dBm	
	Step		dB	0.1db	
High Band Source 3 (76 - 81Ghz @ 1Ghz Step)	Power Range		dBm	-45 to +15 dBm	
	Step		dB	0.1db	
High Band Source 4 (76 - 81Ghz @ 1Ghz Step)	Power Range		dBm	-45 to +15 dBm	
	Step		dB	0.1db	
High Band Source 0 (76 - 81Ghz @ 1Ghz Step)	Power Range		dBm	-45 to +15 dBm	
	Step		dB	0.1db	
	Accuracy		dB	+/- 0.5 dB	
	Phase noise	@10KHz	dBc	-85	
		@100KHz	dBc	-86	
		@1MHz	dBc	-106	
		@10MHz	dBc	-126	
High Band Mixer 1 (76 - 81Ghz @ 1Ghz Step)	P1dB		dBm	+10	
	Accuracy		dB	+/0.5	
	Dynamic Range		dB	60	
	Phase noise	@10KHz	dBc	-93	
		@100KHz	dBc	-98	
		@1MHz	dBc	-105	
		@10MHz	dBc	-126	
High Band Mixer 2 (76 - 81Ghz @ 1Ghz Step)	P1dB		dBm	+10	
	Accuracy		dB	+/0.5	
	Dynamic Range		dB	60	
	Phase noise	@10KHz	dBc	-93	
		@100KHz	dBc	-98	
		@1MHz	dBc	-105	
		@10MHz	dBc	-126	
High Band Mixer 3 (76 - 81Ghz @ 1Ghz Step)	P1dB		dBm	+10	
	Accuracy		dB	+/0.5	
	Dynamic Range		dB	60	
	Phase noise	@10KHz	dBc	-93	
		@100KHz	dBc	-98	
		@1MHz	dBc	-105	
		@10MHz	dBc	-126	

81GHz mmWave Socket S-parameter Measurements using VNA



Verification Completion Status	Parameter	Description	Expected Target Value	Units	Measured (Room Temp) Unit 1 ATE	Unit 2 ATE	Unit 2 Bench	Unit 3 ATE	Unit 3 Bench	Unit 4 ATE	Unit 5 ATE	Delta (ATE - Bench)	Delta (ATE - Bench)
100%	TX PA Power	Max. Output power (dBm)	9	dBm	8.30	8.27	7.37	8.41	7.35	8.89	8.62	0.90	1.06
100%	TX Phase Noise	10kHz offset	-70	dBc/Hz	-59.83	-61	-59	-60.59	-58	-59.44	-67.2	-2	-2.59
		1MHz offset	-94	dBc/Hz	-98.09	-96.77	-95.5	-96.75	-94.4	-96.33	-96.35	-1.27	-2.35
		10MHz offset	-115	dBc/Hz	-118.5	-118.1	-120	-117.1	-119.8	-118.5	-118	1.9	2.7
100%	RX Noise Figure	5MHz offset (IF BW = Default)	16	dB	17.84	17.5	18.09	18.24	18.86	18.16	18.72	-0.586	-0.62
		1MHz offset (IF BW = Default)	16	dB	20.34	17.58	20.06	17.95	19.89	18.28	18.21	-2.476	-1.93

Procedure:
1) Use TC2 silicon with V93k 81Ghz & TC2 socket to measure above parameters
2) Sample 5 units for initial data collection
3) Perform repeatability & reproducibility study across all pamaters in the table above
4) Perform bench correlation (soldered down) on minimum of 2units

- Results show good correlation between same unit socket in ATE & solder-down EVM
- Hand-test solution demonstrates workable solution
  - Integration with production handler and tri-temp evaluation will be next step

ATE / Socket Hand Test Results

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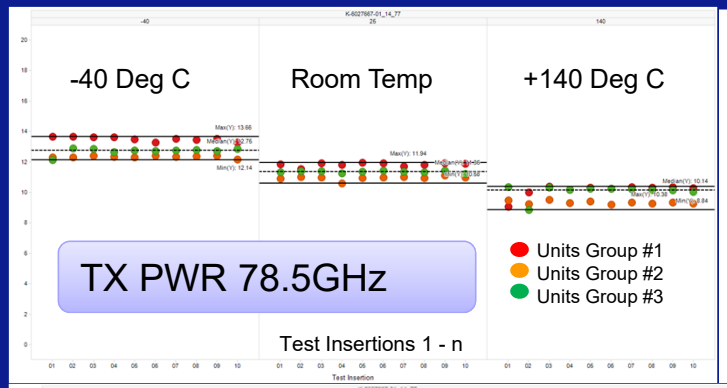
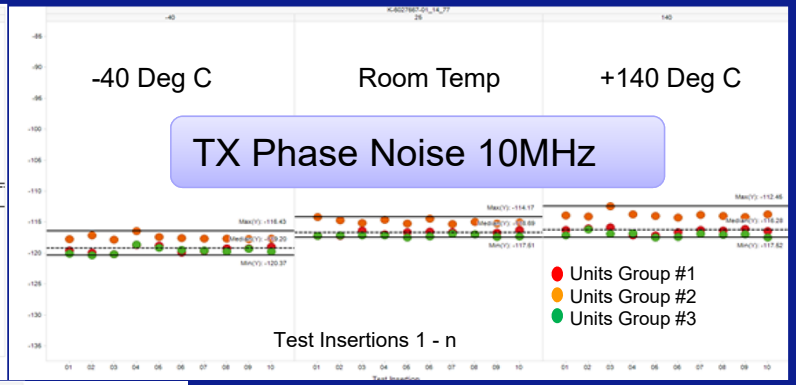
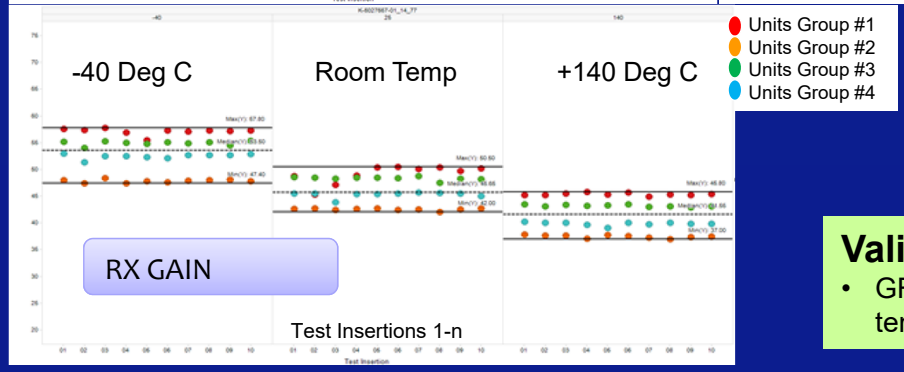
Handler Qualification Study (Tri-temp RF GR&R Data)







Setup Description

- ATE w/ UDI, Socket and Handler
- 10 units, 10 separate runs per temperature
- 3 temperatures (-40C, 25C, 140C)

Validation Result:

- GR&R shows stable RF performance across temperatures and multiple insertions

81GHz Test Cell Handler Qualification Study Plan

81GHz Functional Contactor checklist using TC2 Socket & Device

Socket Aging & Electrical Performance Check with TC2 Device

Index	Item description	Inspection Criteria	Status/Measured Value	Comments
1	RF Pin response characteristic (TC2 socket)	Measure Tx/Rx RF parameters (PA Power, PN, NF) per spec @ targeted OT at room temp	Completed	
		Measure Tx/Rx RF parameters (PA Power, PN, NF) per spec @ targeted OT- 50um at room temp	Completed	Max OT is OT - 30um; fails beyond this
		Measure Tx/Rx RF parameters (PA Power, PN, NF) per spec @ targeted OT + 50um at room temp	Completed	Max OT is OT + 30um; fails beyond this
		Initiate Socket Aging study (in 50k, 100k, 200k, 300k, 400k, 500k steps)	Completed	500k insertion study done - rolloff seen at ~200k-300k insertions; socket sent back to Norwood for VNA testing.
		Measure Tx/Rx RF parameters (PA Power, PN, NF) per spec room temp for each aging step		

81GHz Functional Contactor checklist using AR12 ES1 Socket & Device

General Socket checks

Index	Item description	Inspection Criteria	Status/Measured Value	Comments
1	Review Xcerra OQC checklist	Pass vendor OQC spec	Completed	Vendor OQC spec received
2	General visual inspection	Check socket for visual mechanical defects & general cleanliness		VM check done
3	Adjustable hardstop	Record min and max hardstop position		Mechanical fit verified
4	Overall mechanical check	Mechanical fit on loadboard and nest		1st touch @45deg; Test position @90deg verified on 1 MA
	Handler Kit Integration Checkout			
5	Form Fit and basic function check	Preliminary assembled kit check to minimize damage risk to ES1 contactor. Run small number of dummy parts thru the handler at room temp	Completed	Shim & GRR study for the handler; Several findings leading to change in default shim height as well as FAF design
6	System reproducibility (Shim & GRR study for the handler)	Run 10u thru ~~5~~ 10 handler cycles and compare device datalog on RF response @ ~~room temp~~ tri-temp	Completed	**Study conclusion:** Hand-test FAF @10.45 Handler FAF @10.5
	Handler Kit Integration Checkout for Production Readiness			
7	Mechanical System performance check (No Jamming, realible Cres @tri-temp)	Run ~100u AR12 ES1 rejects & daisy chains at tri-temp. Measure critical performance on Conty / CRES, handler jam rate, document any mechanical issues, LL, and fixes	Completed	
	Electrical performance check of the handler and +/-5C tolerance requirement at -40C and 140C	Run 1500 units at each temp (-40C, 30C, 140C). 1. Run full flow V93k Rev08 (PM, TRIM, Digital, RF) 2. Collect data from on-board temp sensors and on-chip temp sensors on temperature values as seen at DUT & DIB 3. Do 100% VM on all units to check for damage (cosmetic or physical on the surface of the units) 4. Measure & monitor - board temperature on UDI side, UDI case temperatures, humidity at the DIB/UDI i/f, critical parameter distributions & performance, etc.	Completed	
	Mechanical System performance check (LF & contact realiablity verification @tri-temp)	**Control Run:** Run live ES1 samples interleaved with Daisy Chain samples to validate full flow at 140C worst-case ~~tri-temp~~ for production reliability checkout up to ~~100k~~ 50k(10% of 1M) insertions . Measure RF parameters, CRES, measure & monitor - board temperature on UDI side, UDI case temperatures, humidity at the DIB/UDI i/f, etc.	Completed	

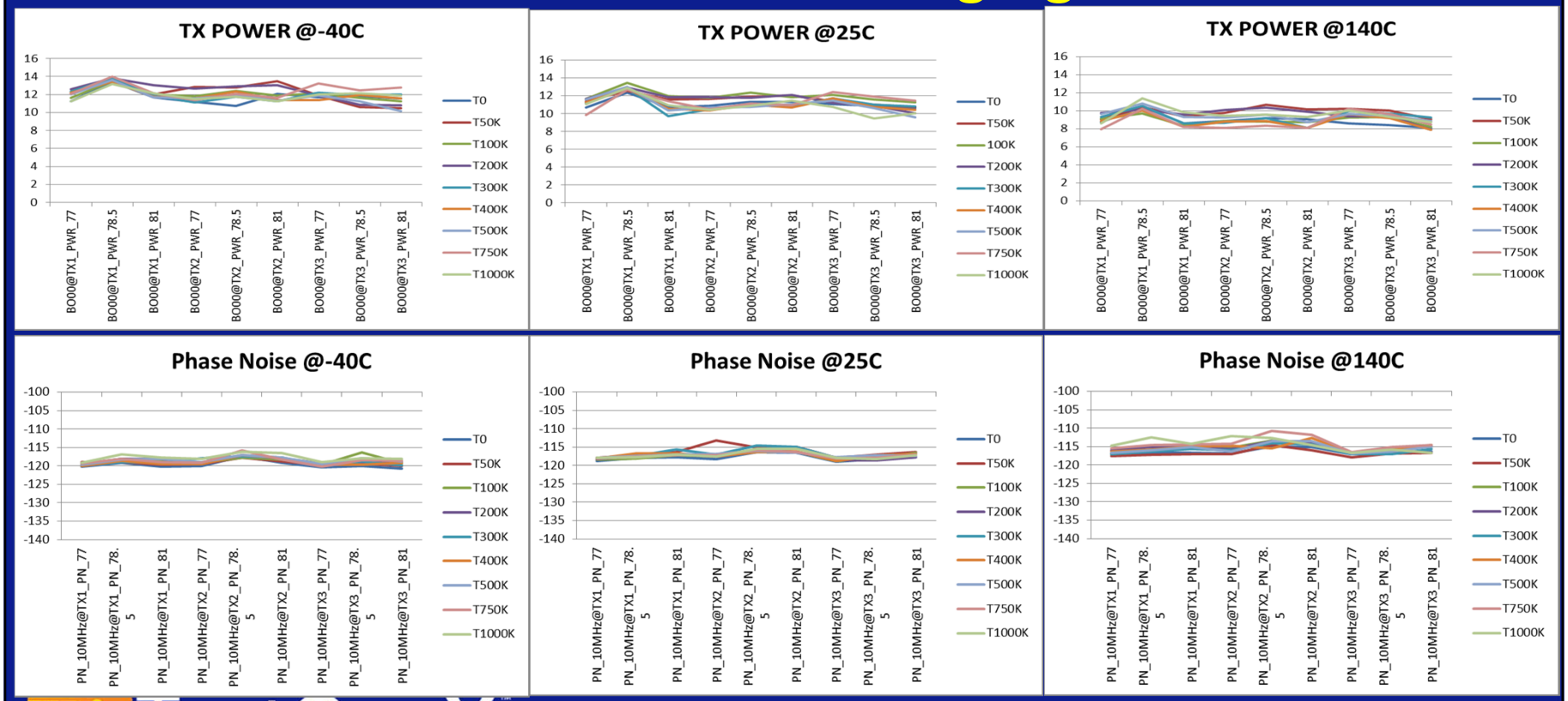
1. Early learning with prototype design
   a. Operational mechanical margin
   b. Tri-temp
   c. Over-travel characterization
   d. Lifetime aging study
2. Design learning cycle
3. Electrical characteristic evaluation
4. Full system integration evaluation
5. GRR and reliability prove out
6. Production environment emulation and performance evaluation

81GHz Socket Qualification Study

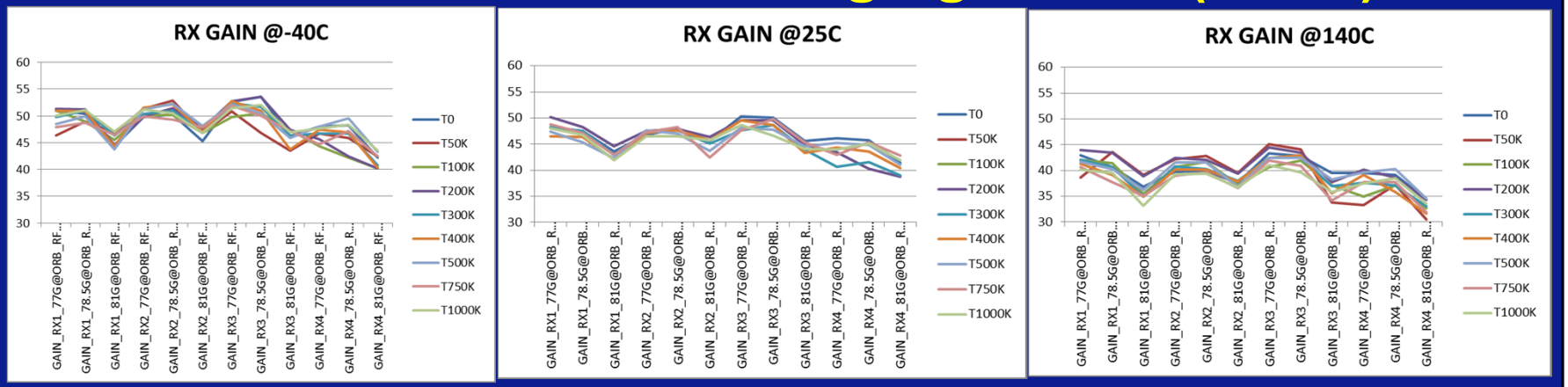
Socket Aging & Electrical Performance Check with Production Socket and Device				
Index	Item description	Inspection Criteria	Status/Measured Value	Comments
1	RF Pin response characteristic (ES1 socket)	Measure Tx/Rx RF parameters (PA Power, PN, NF) per spec @ targeted OT at tri-temp	Completed	Test-list and criteria of parameters to be observed and measured aligned with MAKE & Xcerra
		Measure Tx/Rx RF parameters (PA Power, PN, NF) per spec @ minimum OT - at tri-temp	Completed	
		Measure Tx/Rx RF parameters (PA Power, PN, NF) per spec @ Maximum OT at tri-temp	Completed	
		Initiate Socket Aging study	Completed	No signs of RF performance degredation through 500k aging
		Measure Tx/Rx RF parameters (all "working" Rx / Tx) per spec room temp for each aging step		

- **Socket Qualification Study Plan:**
  - Age up to **1M insertions** in steps of 100k
  - Cycle **across temperature** extremes → -50C and 150C
- **Data Collection & Measurements:**
  - Measure **Insertion Loss & Return Loss** at Tzero and T+ (discrete steps) using VNA **(Owner: Cohu)**
    - Tzero, 200K, 400K, 600K, 800K, 1M
  - Measure & Record plunging **force** on lead-frame at following discrete steps: **(Owner: Cohu)**
    - Tzero, 50K, 100K, 200K, 300K, 400K, 500K, 600K, 800K, 1M
  - **Clean Socket** at following discrete steps: **(Owner: Cohu)**
    - Tzero, 200K, 400K, 600K, 800K, 1M
  - Measure **RF performance @tri-temp using bench golden units** (Owner: TI)

AR1243 Socket 1Million Aging Result



AR1243 Socket 1Million Aging Result (Cont.)



Summary / Observation:

- **RF performance** looks very **stable** after 1Million aging of the socket at tri-temp
- Key RF Parameters show performance **equivalent to TimeZero**
- **No** signs of **degradation or roll-off** in performance observed **up to 1000k** insertions on the socket
- Socket health (pin / LF) looks very stable thus far up to 1000k aging

Parameters Reviewed:

- Tx Output Power, Phase Noise
- Rx Gain

Summary / Wrap Up

- This joint Test Cell development journey took us > 2 years to release in TI production site in 2Q/2017.
- Tested over 200K units (in total) with expected yield through 4Q/2018.
- Methodical & systematic approach that is well planned and executed is the key to the success
- Looking for more success stories from the industry on the mmWave testing capability and technology advances that bring lower cost to user like us
- Special thanks to supplier and all internal TI support teams,

  TI: Edison Estacio, Dien Ho and Jonathan Hsu

  Cohu/Xcerra: Jason Mroczkowski, Nadia Steckler and Mike Hanks

  Advantest: Daniel Lam, Jim Kempf and Roger McAleenan

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