

5G Wafer Test and the New Age of Parallelism



Daniel Bock, Ph.D. Choon Beng Sia, Ph.D. FormFactor, Inc.

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Overview

- 5G What do you know now?
- What Probing Technology can you use at these frequencies?
- What should you think about for probe head inductance (or everything you know is wrong)?
- What are some of the Figures Of Merit (FOM) important for 5G probe cards?

What is 5G?

- Communication Network for 4th
 Industrial Revolution
 - 5G RF, Optical, High Speed Digital
- Extremely Fast Data Rates
 - 10Gbps (5G) vs 100Mbps (4G)
- Ultra Low Latency
 - 1ms (5G) vs 50ms (4G)
- Huge No. of Connections
 - 100 billion (5G) vs 1000 (4G)
- Higher Energy Efficiency
 - Always Stay Connected
- Connect Everyone, Everything

5G NETWORK ARCHITECTURE



Daniel Bock

Sources: https://www.quora.com/What-is-5G-Will-5G-technology-bring-new-dimensions-to-wireless; http://www.emfexplained.info/?ID=25916; https://en.wikipedia.org/wiki/Fourth_Industrial_Revolution

What does 5G Production Test Require?

•What we know 5G components testing will require:

- -New test equipment for the higher frequencies and more channels
- -Time of test as low as possible with high throughput and multi-site capability on the probe card
- High accuracy is needed to validate performance with high measurement repeatability to verify modulation



What does this mean for Probe Cards?

- The net result is that any probe card technology needs to be capable in the test environment
- Including:
 - Signal integrity
 - Multi-Site Capability
 - High channel count capable in arrays (RF lines are not in the periphery)
 - Lowest cost of test possible for the use case

Pyramid, Katana-RF, Pyrana & ePyrana

Comparison:



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Probe Residual Inductance (L_r)

 When looking at probe head inductance, people confuse the definition of the time delay and the residual inductance





compensated with capacitance

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How to Calculate the L_r?

- Looking at the voltage drop due to the inductance from the two sides of the probe head was done to estimate L_r
 - The definition of voltage drop for inductance goes as

• $\Delta V = -Lr \frac{dI}{dt}$

 Within Microwave Office, voltage probes were used to measure the ΔV across a probe head S-parameter model and then calculate the residual inductance

Residual Inductance Estimates

 Based on available data, the residual inductance of various probe head technologies is:

	L _r (pH)	Uncompensated length (μm)
Needle Card with Epoxy ring (1)	10,000-20,000	>10,000
Vertical	~1,000	2,900
Pyrana/Katana	500	2,800
ePyrana	50	225
Pyramid	40	50

• The residual inductance is an important FOM that dictates the maximum operational bandwidth of each probe head technology

Ref 1: http://www.accuprobe.com/services.php SWTest June 2-5, 2019

What Type of Tests does 5G Require?

•5G components testing, the industry hasn't agreed upon what are the best wafer test measurements:



Modified from: http://www.5gsummit.org/hawaii/docs/slides/Panel-slides.pdf

What RF Figure of Merit quantifies the quality of your device?



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Daniel Bock Reference: https://www.pinterest.com/michigantech/engineer-and-scientist-humor/

First Test Method: S-Parameters

- S-parameter FOM includes: measurement accuracy and repeatability of S-parameter measurements
 - There a multiple ways to do RF calibration. Two of the simpler methods that can be used in a full production environment were evaluated
 - 1-port SOL
 - Automatic Fixture Removal (AFR)
 - We compared the absolute value of the measurements and repeatability for IL and RL



What is the difference between SOL and AFR?

- Both methods can be used to generate 2-port S-parameters for the Probe Card
 - SOL: generates 2-port parameters based on Short-Open-Load measurements
 - Accepted to have good accuracy for characterizing a probe card

$$\begin{pmatrix} S_{11} \\ S_{22} \\ \mathbf{\Delta S} \end{pmatrix} = \begin{pmatrix} 1 & M_s \cdot \Gamma_s & \Gamma_s \\ 1 & M_o \cdot \Gamma_o & \Gamma_o \\ 1 & M_L \cdot \Gamma_L & \Gamma_L \end{pmatrix}^{-1} \cdot \begin{pmatrix} M_{1s} \\ M_{1o} \\ M_{1c} \end{pmatrix}$$

- AFR: uses 1 port measurements in order to isolate the performance of only the probe card and then generates representative 2-port parameters of the device
 - Note: AFR can be done three different ways:
 - Use Short only, Open only, and Short-Open combined

Comparison of the RF Measurements

- AFR is able to get some of the 'basic' features of the probe card performance
 - However, it does lose some of the more detailed variations in performance for IL
 - Larger difference in RL, with AFR calculating better than actual performance



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Return Loss

RF Repeatability of SOL

- One key consideration post calibration is what is the measurement standard deviation from touchdown to touchdown
 - These measurements are done with a single SOL calibration, and then remeasuring the standards 10 times each
 - Each plot is the std dev of the measurements (Blue = Pyramid; Red = ePyrana)







Repeatability of AFR

• AFR, in comparison, has similar repeatability

- This indicates that the cal method doesn't necessarily dictate the repeatability
 - Blue = Pyramid; Red = ePyrana







Calibration and IL-RL difference

- It has been accepted that as the RL-IL difference gets smaller, measurements get worse
 - Characterization work has generally maintained that the difference between IL and RL should be more than 10 dB
 - For production, it can operate much closer in difference
 - Our measurements found a point were repeatability began to degrade suddenly



RF Measurement FOM

- At 37 GHz, the IL and RL difference just reached the critical point of about 3 dB difference (or 50%)
 - It appears to be that an important FOM for probe cards is that IL-RL difference should be > 3 dB
 - Pyramid meets this out to 81 Ghz
 - ePyrana is good in 45 GHz



Next Test Method: Eye Diagrams

- Eye Diagram FOM includes: the eye amplitude, jitter, and all characteristics that differentiate 0 and 1s
 - For example TIAs, CDRs





Eye Diagram Test

- A digital signal (pseudo-random bit stream) through the probe head S-parameters
- A representative signal with the following characteristics was generated:
 - Data Rate: 28 Gbps
 - Rise Time/Fall Time: 10 ps
 - V_high : 1.5 V
 - V_low: 0.0 V



Eye Diagram Comparison

- The Eyes are different, with the biggest difference being the eye in ePyrana being smaller than that in Pyramid
 - A reduction in eye size of about 14% with ePyrana compared to Pyramid
 - Pyrana was also simulated, with a 40% reduction in the eye





Eye Diagram FOM

- Pyramid maintains the best amplitude because of its lowest loss
- ePyrana will generally be good enough, with only a 14% reduction
- Pyrana has the largest reduction in the eye, with about 40% smaller eye

Next Test Method: Modulated Signals

Modulated Signal FOM: EVM

- 5G will primarily use QAM type of signal modulation and you need to be able to recover the bits
 - The more symbol definitions (like QAM126 vs QAM256), the more bits that can be encoded in each symbol, but the required accuracy of the measurement goes up, which is quantified as Error Vector Magnitude (EVM)





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Constellation GIF: By Chris Watts - Own work, CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=15781908

What is EVM?

 EVM is a measure of the how the signal is distorted from the proper magnitude-phase location on the constellation diagram



*Total number of chips varies by Architecture



Figure 1. Understanding the EVM calculation

What is the required EVM for 5G?

- The governing body for the requirements in 5G (3GPP) has released direction on what the EVM requirements look like
 - This is the EVM for the total system, where the higher bit-encoding requires lower EVM

Table 3. 3GPP TS 38.101-1 EVM requirements for different 5G modulation schemes

Modulation scheme for PDSCH	Required EVM	
QPSK	17.5 %	
16QAM	12.5 %	
64QAM	8 %	
256QAM	3.5 %	

5G NR Radio Specification for the System; Rev. 15



EVM FOM

 We then looked at what is the EVM for the FFI's three RF probe card technologies



16-QAM



	Pyramid	Pyrana	ePryana	3GPP
16-QAM	3.1	8.7	4	12.5%
64-QAM	2.7	7.7	3.5	8%
256-QAM	2.56	7.2	3.3	3.5%

EVM % of the three different probe heads vs QAM

Summary

• We have discussed:

- A new probe head FOM for L_r
- What are the appropriate FOM for the different types of tests to evaluate the capability of probe cards for:
 - S-parameters
 - Eye Diagrams
 - Constellation diagrams

Questions

