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Device Packaging Conference,
WeKoPa Resort 2020

A New Level of Connectivity- 5G Package Considerations

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CRD
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Topics to Cover

- **Spectrum Overview**
- **Mobile Infrastructure**
- **5G Phone Architecture & Package Options (Sub6Ghz & mmWave)**
- **Summary**

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Trends Moving Forward – Power and Performance Drivers!!

Captain Kirk Says to Engineering……

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5G Introduction

Data Capacity

Response Time

Density

- **The International Telecommunication Union (ITU) has put forth three major performance indicator for 5G.**
  - 1) Greater than 10Gbps peak data rates (vs. 1Gbps in 4G) for enhanced mobile broadband (eMBB)
  - 2) Less than 1ms latency (vs. 10ms in 4G) for ultra-reliable low-latency communications (uRLLC)
  - 3) Greater than 1mn connections per km^2 (vs. 100K in 4G) for massive machine-type communication (mMTC)

Source: Skyworks

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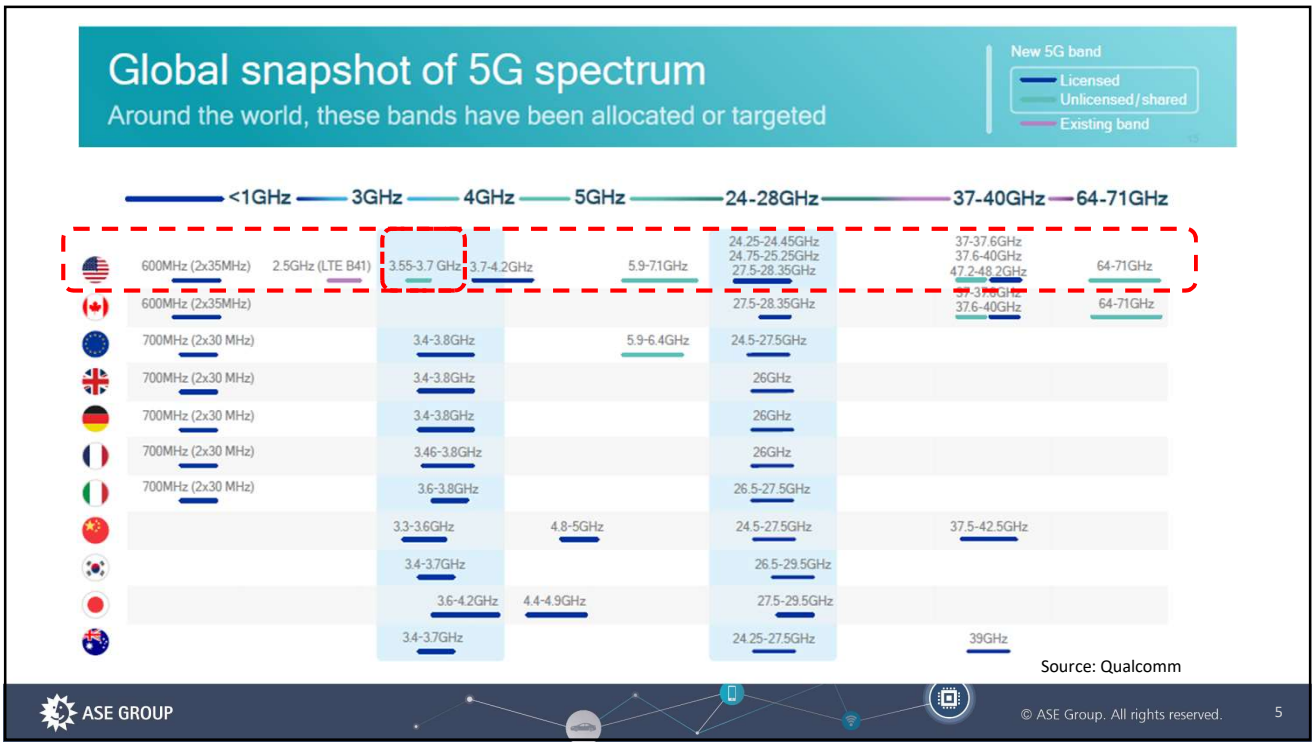

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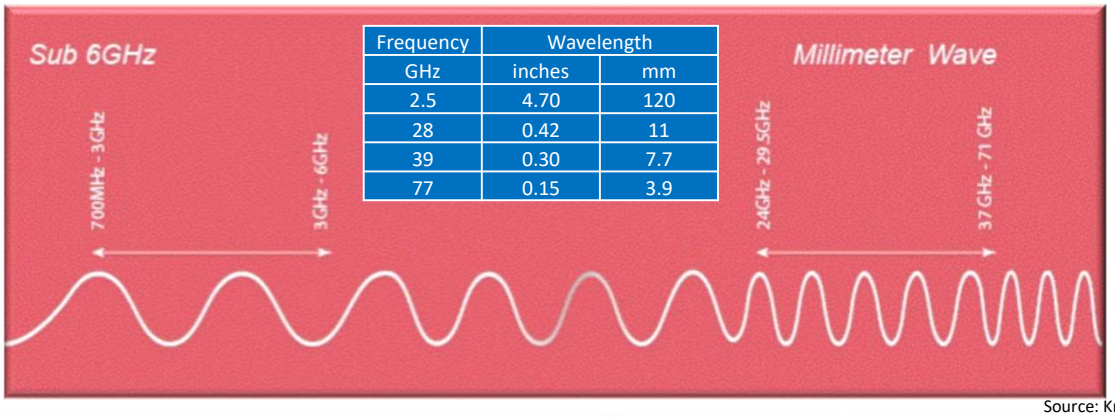
5G Latest Status

- **S. Korea and U.S. launched 5G commercial services last Dec, while most regions will start after 2020 and onwards.**
- **U.S. spectrum auctions for 5G operations are mostly in mmWave bands (>24GHz) while others are mostly operated at sub-6GHz spectrum** (Must prepare for both spectrums). **Jan 27th 2020- US Releases Sub6 Band 3.5Ghz.**



Frequency	Wavelength	
GHz	inches	mm
2.5	4.70	120
28	0.42	11
39	0.30	7.7
77	0.15	3.9

Source: Knowles

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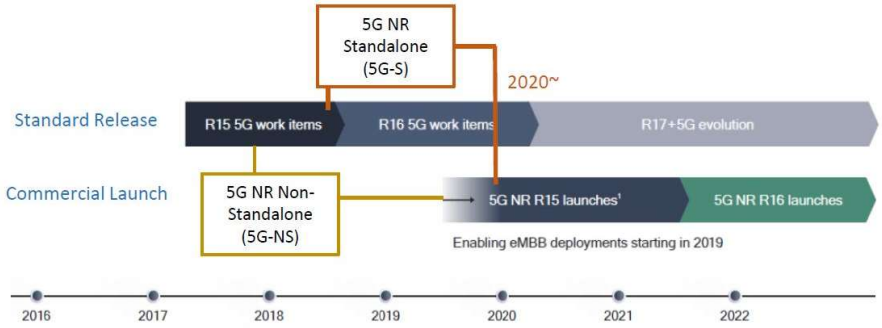
5G Standard

Near-term

- 5G NR Non-Standalone (5G-NS) allows 4G-LTE (both LTE radio and LTE core) to act as an anchor for the 5G network, and therefore 5G-NS acts as an overlay on an existing 4G network.

True 5G Features

- 5G-Standalone (5G-S) brings a new end-to-end infrastructure, facilitating the ability to deploy 5G independently, without the need for LTE radio/core.



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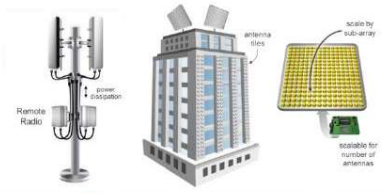
5G Challenges

mmWave

- mmWave spectrum does have some major downsides. The waves can only travel in straight lines, and for very short distances (200-1000 feet).
- The signal tends to bounce off walls and windows of buildings rather than penetrate them and can be absorbed by plants and rain.
- To solve this problem, the industry plans to utilize small cells for dense cities.
- mmWave hardware and test is more expensive than sub-6Ghz.

Sub-6GHz

- Crowded space below 4GHz due to previous cell generations.
- Overlap close proximity of frequency bands.
- Key enabler for tight spectrum segments is filter capability and effectiveness.
- More band drive more co-existence filter/product needs.



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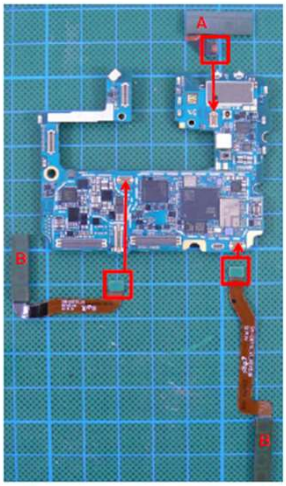
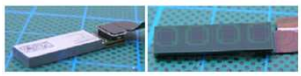
MM Wave vs Sub 6Ghz





GOOGLE SPLAT CHART FOR 28GHZ VS 3.5GHZ COVERAGE IN LOS ANGELES

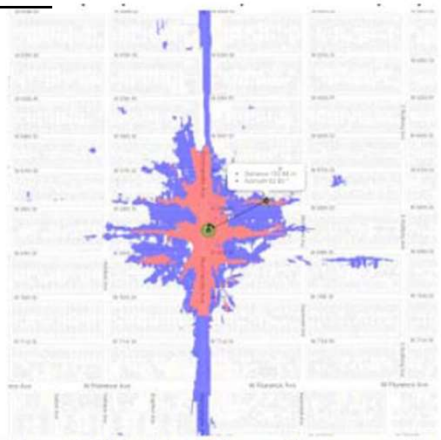


Figure 1: "Splat" chart with mmWave propagation

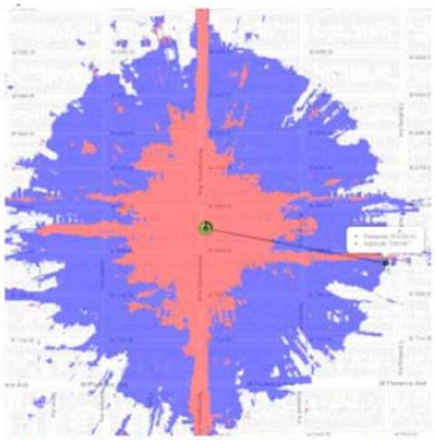


Figure 2: "Splat" chart with sub-6 propagation

NOTE: Blue is 100Mbps, Red is 1Gbps

Some service providers have no choice but to use mmWave early on, simply because that is the frequency they currently have available. Prime examples are some US providers, especially Verizon.

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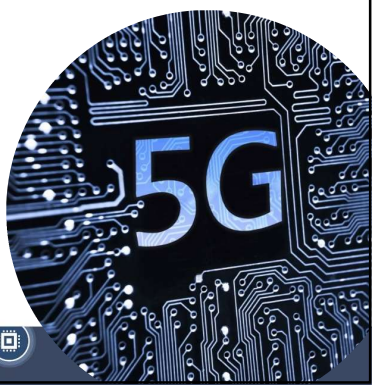
Mobile Infrastructure



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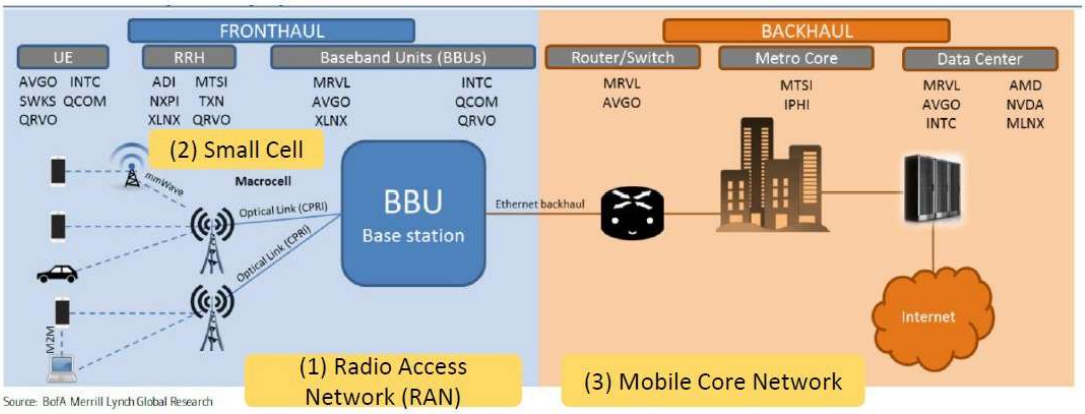
Mobile Infrastructure

Mobile Infra Hardware = (1) + (2) + (3)



Note: UE= User Equipment, RRH = Remote Radio Head, BBU = Baseband Units

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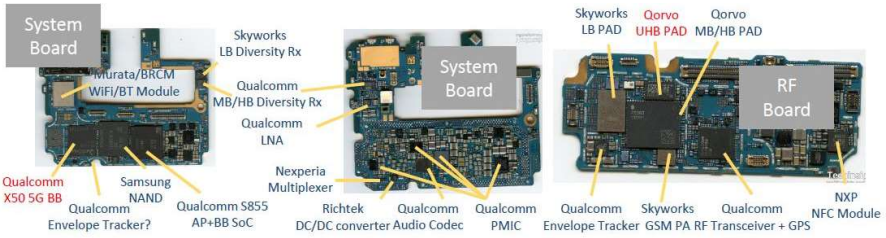
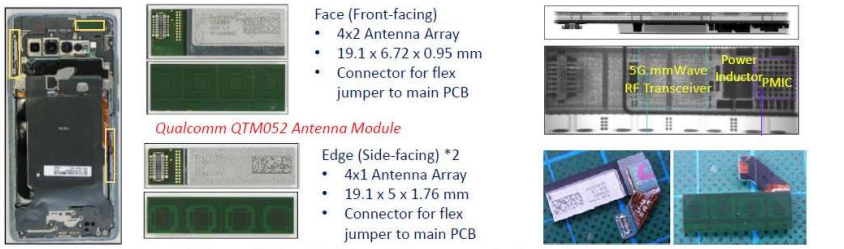
User Equipment (UE)

Mobile Phone Example

- Each Generation Becomes more Modular- SiP
- RF Board Separate
- Multiple mmWave Modules for Coverage
- FC, SiP, FOWLP, WLP , Embedded

Samsung GS10 5G (mmWave)





Source: Techinsights

Substrate design: 5-2-5 layers (5 for antenna signal route and 5 for antenna structure)

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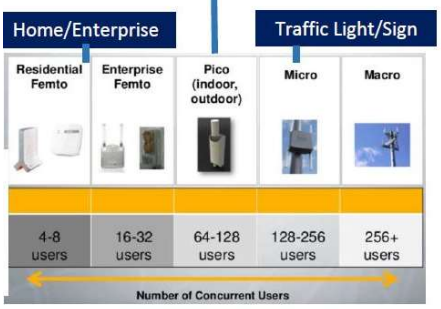
SMALL CELL

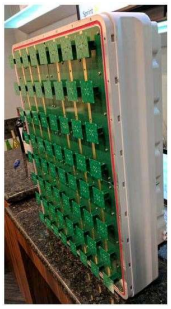
Shopping mall, office, train station



WiGig

- RF Package Requirement
  Freq Dependent <6Ghz, >6Ghz
- Modules, POP, FC, QFN,AOP/AIP

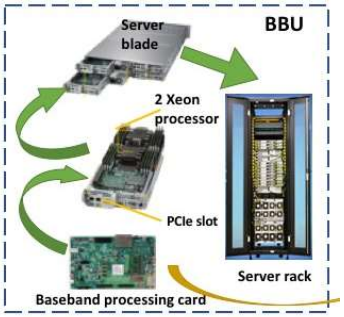
REMOTE RADIO UNIT (RRU)

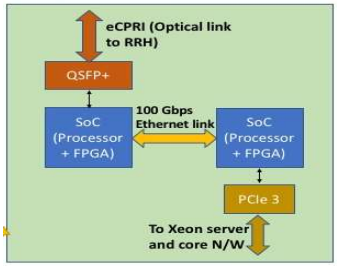


Nokia
8x8 TX/RX
3.5Ghz
1200Watt

- Receiver/Transceiver
- PA (Massive MIMO)
- Digital FE (FPGA)
- Array Module & Small Antenna Pkg

BASEBAND UNIT (BBU)-Base Station





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BACKHAUL

Internet

ROUTER SWITCH

- Switch IC's
- FCBGA and FOCoS
- Thermal Key/Pwr Mgmt
- FCMCM

METRO CORE

- Optical/SiPh Modules
- FC/High Thermal
- Long Haul
- Short Haul

DATA CENTER

- 2.5D,FOCoS, Chiplets
- Adv. FCBGA-Thermal
- Optical/SiPh
- Power Mgmt

28nm→ 16/14nm → 10nm → 7nm →5nm
Larger package size (>65x65mm)
Higher power/thermal (>400W)

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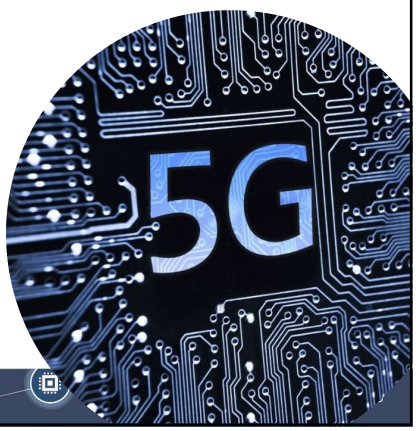
5G Phone Architecture



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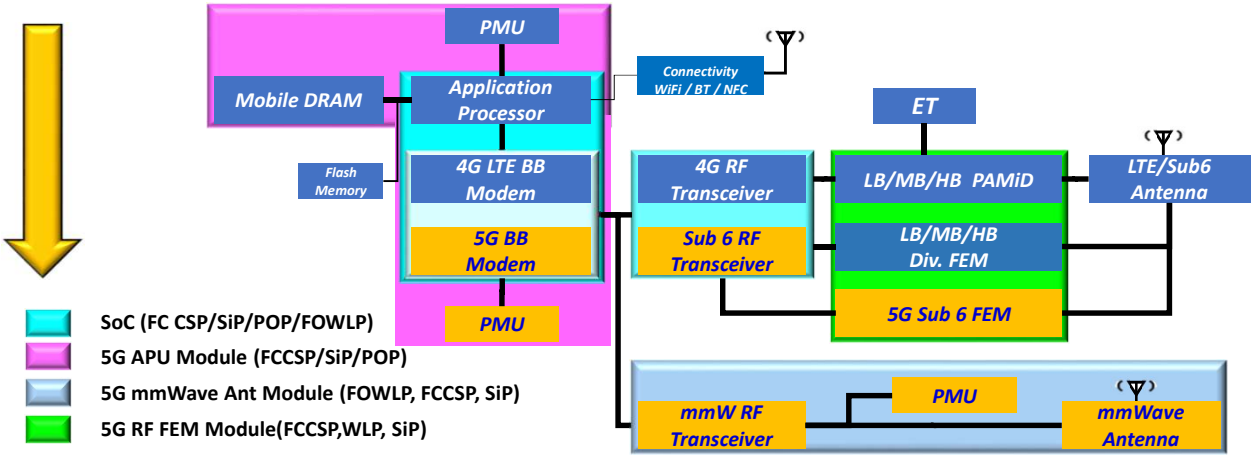
5G Phone System Architecture



- For sub-6GHz 5G, the additional RF path will be broadly similar to the current RF FE and the industry has much experience in designing and packaging these components.
- Initially, these will be additional components, but soon the legacy 2G/3G/4G functions and 5G functions will be co-packaged in highly integrated RF modules.

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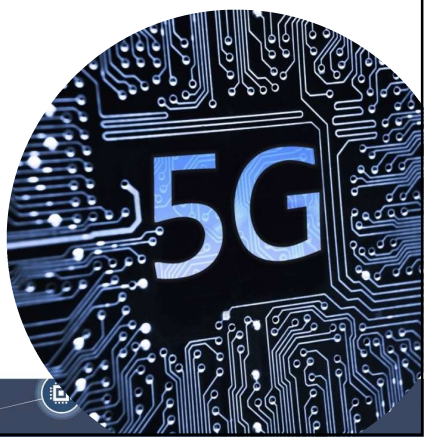
5G Package Options (RF Focus)



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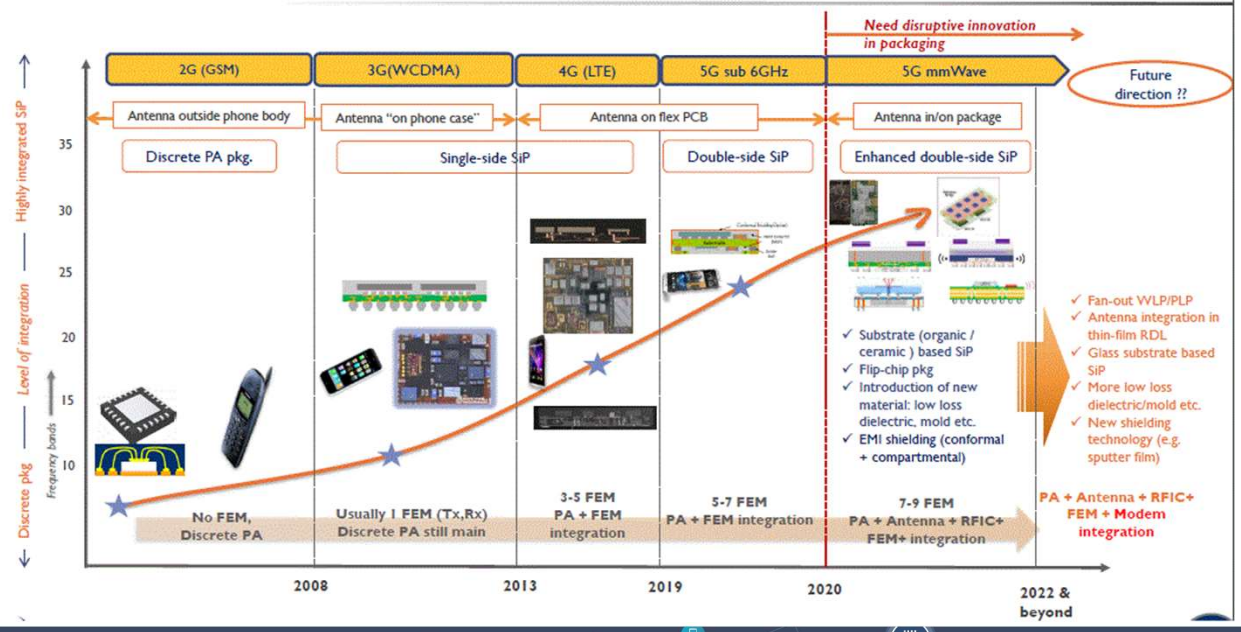
MOBILE RF FEM PACKAGE TREND

Source-:Yole



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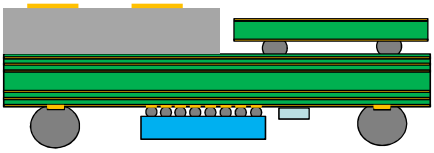
AiP (Antenna In Package) Assembly Technology- mmWave

Low Dk/Df Material
- Substrate
- EMC

Dimension control
- Z-height gap control
- X,Y shift control

Warpage control
- Material selection
- Structure design

Antenna architecture
- One piece
- Proximity stacking
- Hybrid



Connector integration
- High Frequency
- Low Loss Interconnect
- System Level Testing

Thermal
- Thermal simulation/design capability
- Bottom side thermal path

Reliability
- Thermal stress (pre-con/TCT/HAST/HTST)
- Board-level (Drop/TCT/Bending)

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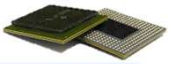
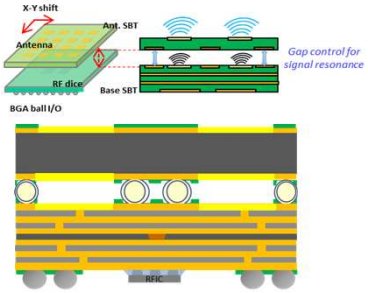
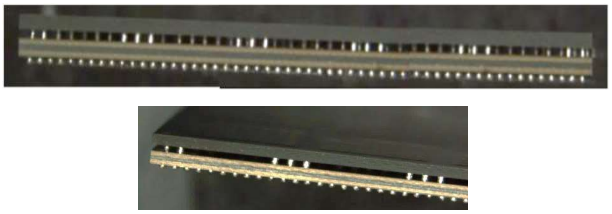
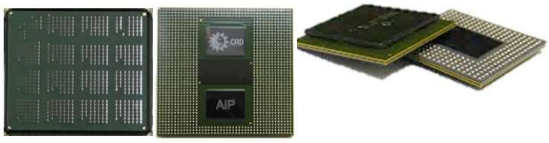
AiP – Stacked Substrate Example



Type:
- *Frequency : 28, 39, 60GHz*
- *Package size: 11mm x 11mm ~ 44x56 mm*
- *Technology*
  - *High accuracy alignment stacking*
- *Stacking capability*
  - *Gap control: +/-30um, CPK>1.33*
  - *X/Y shift: +/-30um, CPK >1.33*







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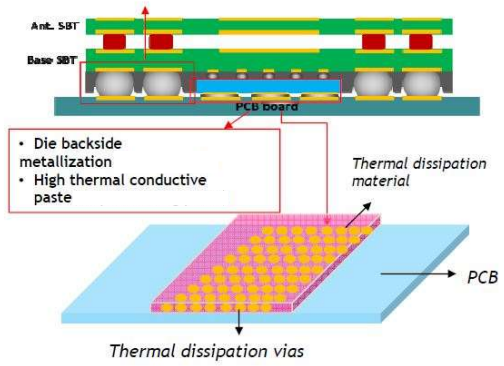
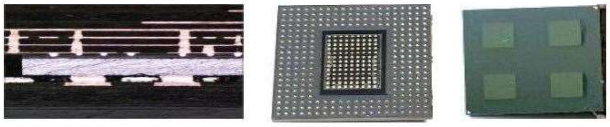
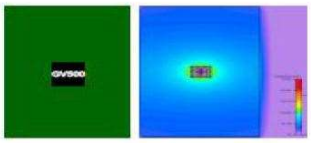
AiP – Thermal Solution Example –Stacked Substrate

- *Typical Thermal dissipation requirement*
  - *Power consumption: 2.5~3W*
  - *Ambient Temp.: 85°C*
  - *Junction Temp.: 125 °C*
- *Assembly structure & Simulation*
  - *Exposed die w/ backside metallization pad*
  - *Simulation result reach thermal requirement*
- *Thermal structure verification*







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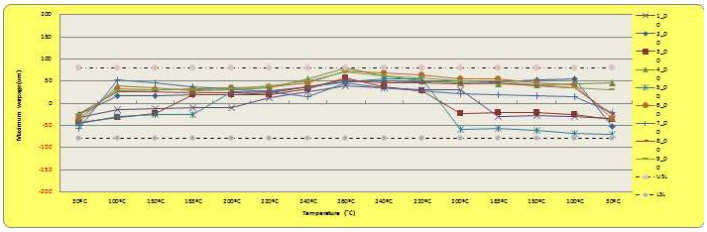
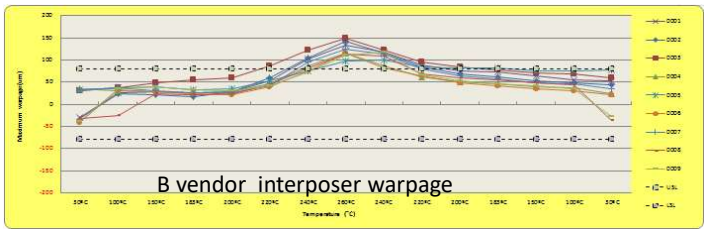
Substrate Interposer Stacking Capability

- **Key Challenge on Substrate Interposer**
  - **Hi-temp warp need to control within 75um and have better performance**



A Vendor interposer Warpage



B vendor interposer warpage

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mmWave Models for Characterization – High Freq Material/Roughness

Material Model

Permittivity : Djordjević-Sarkar Model

$$\varepsilon_r(\omega) = \varepsilon'_\infty + \frac{\Delta\varepsilon'}{m_2 - m_1}\frac{\ln\frac{\omega_2 + j\omega}{\omega_1 + j\omega}}{\ln(10)} - j\frac{\sigma}{\omega\varepsilon_0}$$

Permeability : Lorentzian Model

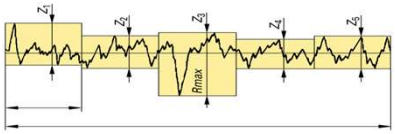
$$\mu_{FMR}(f) = 1 + \frac{\mu_s}{1 + i\frac{f}{f_a} - \left(\frac{f}{f_r}\right)^2}$$

Where

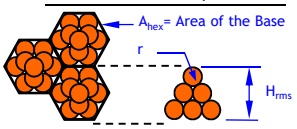
$\mu_s = M_s/H_a$
$f_a = \gamma H_a/\alpha$
M_s : Saturation magnetization
H_a : Anisotropy field
γ : Gyromagnetic ratio
α : Damping factor

Roughness Model

Ten-point mean Roughness (Rz)



11 uniform size spheres



$$H_{rms} \cong \frac{R_z}{2\sqrt{3}} \qquad r = \frac{H_{rms}}{2\left(\frac{2}{3}\sqrt{6}+1\right)} \qquad SR = 5.346$$

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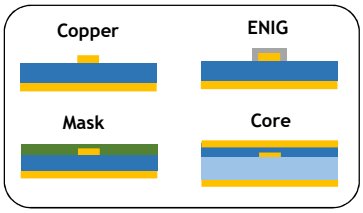
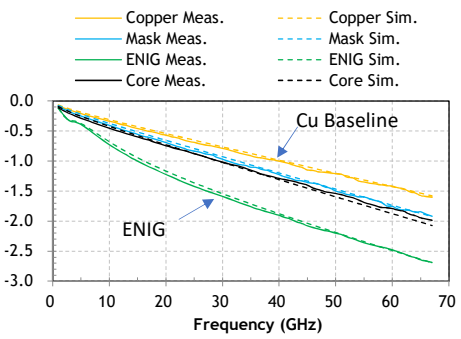
Dk & Df Extraction with HS Transmission Lines

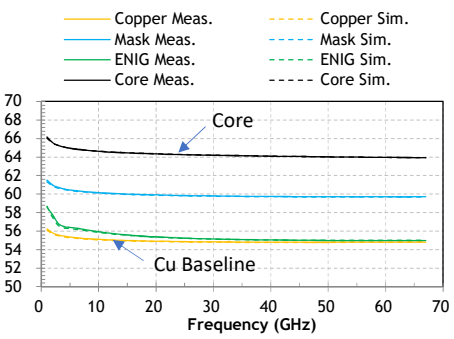


Material		Mask	Prepreg	Core
Vender		Vendor A	Vendor B	
Nominal Thickness (um)		20	40	100
Dk at 1GHz	Extracted	3.55	3.60	3.60
	Vendor	3.3	3.29	3.52
Df at 1GHz	Extracted	0.010	0.0050	0.0050
	Vendor	0.011	0.0029	0.0028

Loss (dB/cm)



Delay (ps/cm)



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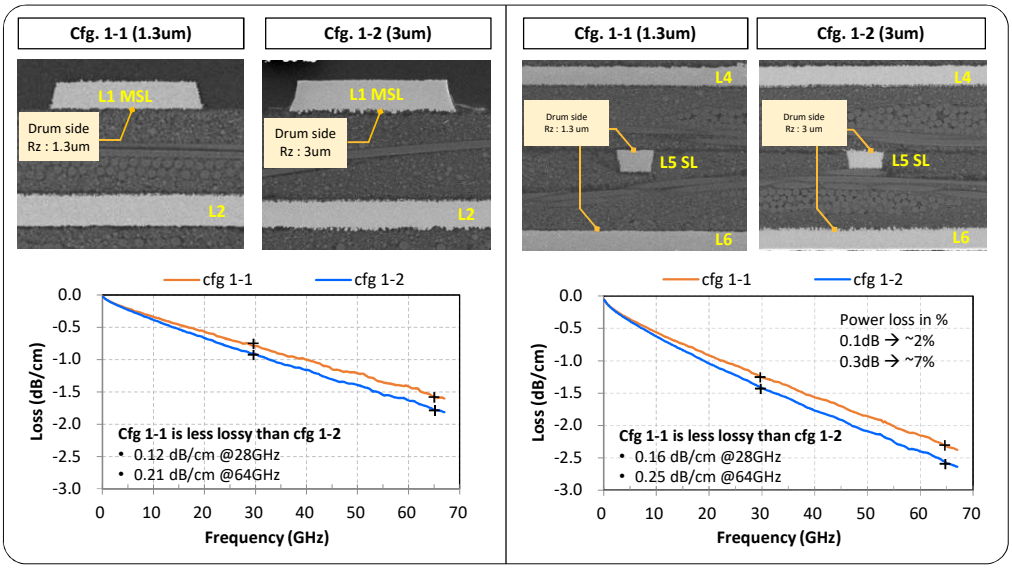
Roughness Effect



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Summary

- The RF frequency **spectrum is a key driver** for user end equipment and infrastructure. The US is a leader in the mmWave spectrum but behind in the sub 6Ghz which will be the heavy lifter for wide coverage.
- mmWave **spectrum limitations** include short transmission length, low penetration rates and line of sight requirements while sub 6Ghz main limitations center around limited bandwidth range which drives freq coexistence filter needs.
- Several **key packaging platforms** enable the complete mobile infrastructure including advanced SiP, FoCoS, Fan-Out, Flip Chip, 2.5D and Embedded Technologies.
- For mmWave frequencies, **key performance drivers** for single, double and SiP module type package solutions include low loss material selection, line transmission material roughness (skin effect), and transmission length.

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