ADVANCED RF SYSTEM-IN-PACKAGE FOR CELLPHONES 2019

Market & Technology report - March 2019

5G is pushing innovation for RF front-end SiP.

WHAT'S NEW

- Compared to Yole Développement's 2017 RF SiP report (where only a PAMiD module forecast was covered), this year's report extends the RF front-end SiP scope to include all RF front-end SiP for cellular and connectivity functions in cell phones:
  > Cellular:
    - PAMiD
    - PAM
    - Rx DM
    - ASM
    - Antennaplexers
    - LMM
    - MMMB PA
    - mmW FEM
  > Connectivity
    - WiFi FEM
    - WiGig FEM
- Packaging trends for wafer-level packaging and SiP
- Interconnect trends for various components in RF SiP
- RF front-end SiP forecast in revenue, wafers, and units by: cell phone category/type, cellular and Wi-Fi standards, and various types of RF front-end SiPs
- Antenna-in-package (AiP) trends for 5G mmWave application
- Substrate trends for 5G
- RF SiP assembly: detailed supply chain for various players, including substrate supply chain
- Packaging roadmap and challenges for 5G sub-6 Ghz and mmWave applications

2019 MARKS THE BEGINNING OF 5G IMPLEMENTATION FOR MOBILE

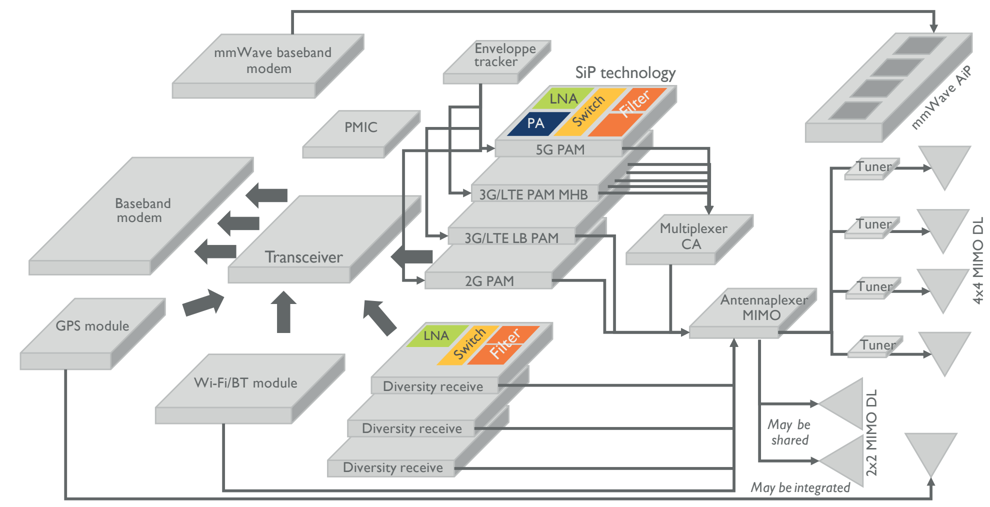
5G has arrived, and various key smartphone OEMs have recently announced the phones that will support 5G cellular and connectivity. 5G will totally redefine how the radio frequency (RF) front-end interacts in-between the network and the modem. The new RF bands (sub-6 GHz and mm-wave, as defined in 3GPP release 15) pose big challenges for the industry.

LTE (Long Term Evolution) evolution has led to complex architecture in today's mobile phones, mostly due to carrier aggregation. Meanwhile, RF's board area and available antenna space have been reduced, leading to a densification trend that sees more handset OEMs adopting power amplifier modules and implementing new techniques, i.e. antenna-sharing between LTE and WiFi.

In the low-frequency band, the inclusion of the 600 MHz band will pose new challenges for low-band antenna design and antenna tuners. 5G will add even more complexity, with new radio bands released in ultra-high frequencies (N77, N78, N79). Band re-farming (early bands are N41, N71, N28, and N66, with more to come) with dual connectivity will also contribute to increasing constraint on the front-end. More densification in front-end modules will be required to enable new band integration, because without tight integration, 5G NR in the mmWave spectrum can't deliver the multi-gigabit speeds that are 5G's key USP.

A 5G handset requires 4X4 MIMO implementation, which will add a significant number of RF streams in the handset. Combined with carrier aggregation requirements, this will lead to more complex specifications for antenna tuners and multiplexers.

2018-2024 RF front-end structure for the 5G mobile



(Yole Développement, March 2019)

5G WILL BRING MORE PACKAGING BUSINESS FOR OSATS

The RF SiP packaging market can be divided into two segments: 1st-level packaging of various RF components like filters, switches, and amplifiers at die/wafer level (which includes RDL, RSV, and/or bumping steps); and 2nd-level SiP packaging, which is performed at the SMT level where various components are assembled on SiP substrate along with passives. In 2018, the total RF front-end module SiP market (including 1st and 2nd level) was $3.3B, and is expected to grow at an 11.3% $CAGR_{2018-2023}$, reaching $5.3B in 2023.

Wafer-level packaging constituted 9% of the total RF SiP assembly market in 2018. This new Yole Développement report investigates in detail the SiP market for various RF front-end modules in the mobile biz: PAMiD (power amplifier module with integrated duplexer), PAM (power amplifier module), Rx DM (receive diversity module), ASM (switchplexer; antenna switch module), antennaplexers (multiplexer), LMM (low noise amplifier - multiplexer module), MMMB PA (multi-mode, multi-band power amplifier), and mmW front-end modules. By 2023, PAMiD SiP assembly will account for 39% of the RF SiP market's total revenue.

The RF front-end module, covering cellular and connectivity, is included in this report, and a SiP market forecast breakdown is provided via various air standards and smartphone categories. By

KEY FEATURES

Market overview

- Drivers and dynamics for 5G varieties: 5G mmWave and 5G sub-6 GHz
- Disruptions and opportunities thereof
- Focus on various SiP architectures in cell phones' RF front-end
- Focus on cellular and connectivity RF front-end modules
- Market forecast including wafer-level and SiP-level revenue
- RF front-end SiP forecast in revenue, wafers, and units by:
  - Cell phone category/type
  - Cellular and Wi-Fi standards
  - Various types of RF front-end SiPs
- Interconnect trends forecast for RF SiP

Technology trends and forecasts

- RF front-end multi-die system-in-package challenges and technology requirements for 5G sub-6 GHz and 5G mmWave (>24 GHz) bands
- 5G SiP packaging roadmaps for smartphone front-end
- Packaging trends for cellular and connectivity modules
- Antenna-in-package (AiP) trends for 5G mmWave
- Substrate trends for 5G mmWave
- Shielding trends
- RF SiP revenue, wafer, and unit forecasts

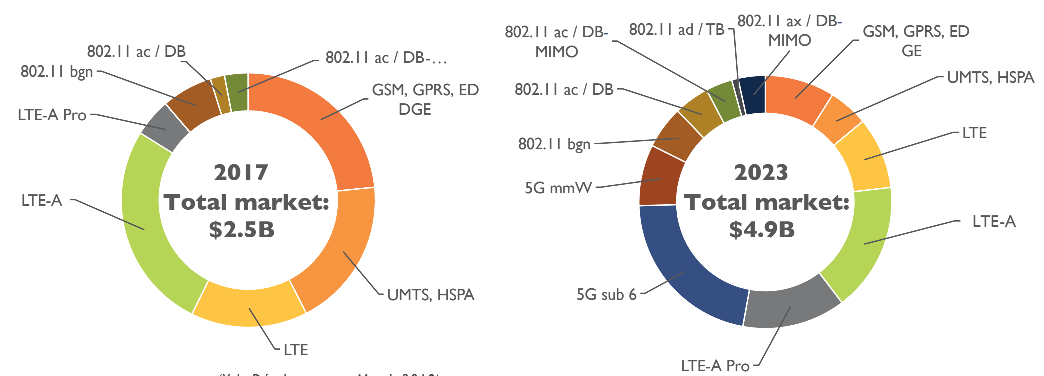
Supply chain analysis

- Supply chain changes in the new 5G era
- RF SiP assembly - Detailed supply chain for various players
- Current RF SiP manufacturers - Strategies and outlook
- New entries and supply chain disruptions for mmWave packaging
- Substrate supply chain

2023, the RF front-end SiP market for cellular and connectivity will constitute 82% and 18% of the total SiP market, respectively. By cellular air standards, front-end modules supporting 5G (sub-6GHz and mmWave) will account for 28% of the total RF SiP market in 2023. High-end smartphone contributes 43% RF FEM SiP assembly market, followed by low-end smartphone (35%) and luxury smartphone (13%).

The RF front-end SiP supply chain for 4G is led by a few IDMs like Qorvo, Broadcom (Avago), Skyworks Solutions, and Murata, which outsource part of SiP assembly to OSATs. Qualcomm emerged as a serious RF front-end player for 5G solutions, especially 5G mmWave (with multiple wins at various mobile OEMs), and is expected to maintain its dominance in the future. In fact, Qualcomm is the only player providing complete solutions for 5G including modem, antenna module, and application processors. Qualcomm, being fabless, outsources all of its SiP assembly, which results in more business opportunities for OSATs. Also, IDMs are focusing more on RF front-end solutions for 5G sub-6Ghz, which also require packaging innovations like closer placement of components, double-sided mounting, conformal/ compartmental shielding, high-accuracy and high-speed SMT, etc. This requires investment in new tools & processes. We believe the burden of high investment in assembly technology will motivate firms to outsource more to OSATs.

RF FEM SiP assembly market by cellular & connectivity air standards



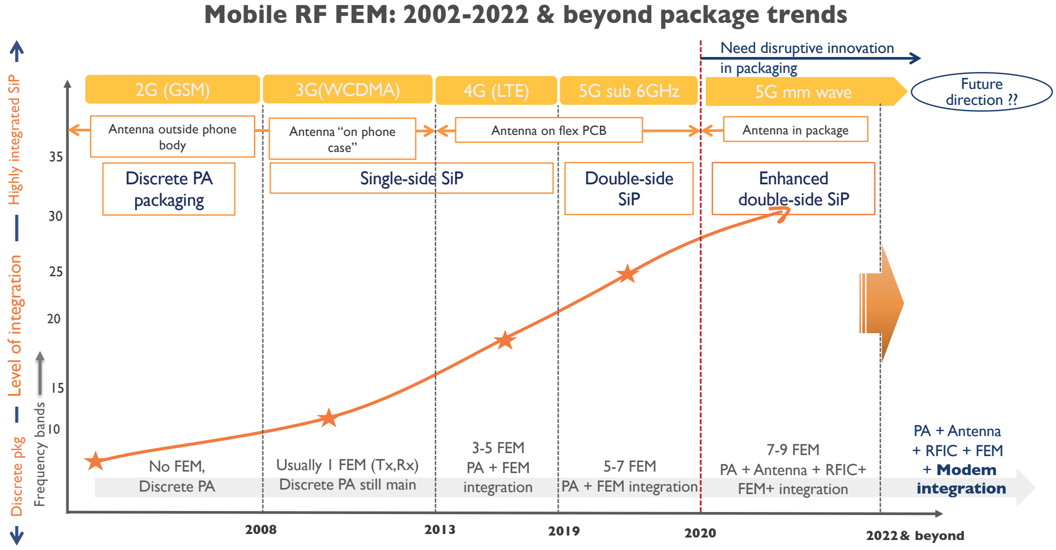
(Yole Développement, March 2019)

5G IS PUSHING INNOVATION IN PACKAGING FOR RF FRONT-END

4G LTE in smartphones uses multi-die system-in-packages for FEM, as well as for filter banks and diversity receive modules. System-in-packages bring needed form factor reduction, shorter signal paths, and lower losses. 4G LTE FEM today comprise 10 - 15 dies, utilizing flip-chip balls or Cu pillars to connect to the organic substrate (up to 8 organic or 18 ceramic layers), whereas some power amplifiers still use wire bonds. 5G sub -6 GHz products are expected to utilize modifications of existing flip-chip SiPs (i.e. double-sided FC package substrate) with a similar bill of materials: incremental innovation. 5G mmWave frequencies bring disruptive packaging with the entry of new architectures: fan-out WLP and glass substrate interposers competing with advanced organic substrate flip-chip packages with new low-loss dielectrics.

Antenna technology and placement is one of the most critical challenges for 5G semiconductor systems. At mmWave frequencies, long paths from semiconductor packages to antennas represent high losses, making it desirable to integrate the antenna into the SiP. Higher frequencies require smaller antennas (mm instead of cm), which from a footprint point of view would be easier to integrate into SiPs. However, today a single antenna must work with a number of frequency bands,

Mobile RF FEM: 2002-2022 & beyond package trends



(Yole Développement, March 2019)

which complicates antenna form and attached circuitry. Various packaging solutions with different architectures are proposed for integrating antenna elements with RF components for 5G mobile communication. Because of the cost and mature supply chain, laminate substrate-based flip-chip is first to be adopted for antenna-in-package (AiP). Fan-out WLP/PLP is a promising solution for AiP integration because of its high signal performance, low-loss, and reduced form factor, but it requires double-sided RDL. Outside of a few players, the technology is still not ready at OSATS for HVM.

Furthermore, shielding of circuitry from antenna radiation is needed, while at the same time ensuring the antenna is not blocked and can achieve clear reception/transmission. Along with laminates, ceramic and glass have also emerged as choice package substrate materials. To choose package substrate material for 5G mm wave, compromises must be made between electrical properties, cost, processability, and supply-chain readiness. Because of the cost & material/ assembly supply chain readiness, organic laminate will be adopted first (with limited ceramic adoption), followed by ceramic and glass.

OBJECTIVES OF THE REPORT

Advanced RF SiP for Cellphones 2019 is an updated version of the Advanced RF SiP for Cellphones 2017 report. The objectives of this new report are as follows:

- Discuss drivers and dynamics for 5G varieties: 5G mmWave and 5G sub-6 GHz, and investigate the disruptions and opportunities thereof
- Focus on various SiP architectures in the RF front-end of cellphones, for both cellular and connectivity
- RF front-end SiP market forecast in revenue, wafers, and units by:
  - Cell phone category/type
  - By cellular and Wi-Fi standards
  - By various types of RF front-end SiPs
- Interconnects trends forecast for RF SiP
- Analyze various developing RF SiP architectures for sub-6 GHz and mmWave frequencies, advantages and suitability thereof
- RF front-end multi-die SiP roadmap, challenges, and technology requirements for 5G sub-6 GHz and 5G mmWave (>24 GHz) bands, including antenna-in-package (AiP) trends
- Analyze supply chain changes and opportunities for 5G in smartphones, focusing on RF SiP manufacturing and assembly, including package substrate

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