

ADVANCED RF SYSTEM-IN-PACKAGE FOR CELL PHONES 2017

Market & Technology report - October 2017

The transition from 4G to 5G requires disruptive packaging innovation. 5G mmWave, 5G sub 6 GHz - which packaging architectures can rise to the occasion?

KEY FEATURES OF THE REPORT

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Market overview

- Drivers and dynamics for 5G flavors: 5G mmWave and 5G sub 6 GHz
- Disruptions and opportunities thereof
- Focus on FEM and PAM architectures in RF front-end of cellphones
- RF front end SiP forecast (revenue, wafers, units)

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
- RF SiP revenue, wafer and unit forecasts

Supply chain analysis

- Supply chain changes in the new 5G era
- Strategies and outlook of current RF SiP manufacturers
- New entries and supply chain disruptions for mmWave packaging

5G – THE DISRUPTION IS AROUND THE CORNER!

The 5th generation of cellular networks is anticipated to arrive in the timeframe of the next 2-5 years, enabling Gbps data rates and a plethora of new applications and services. One of the key drivers for developing such speed is high resolution video demand (4K, 8K etc.) over mobile devices. Furthermore, future applications such as mobile driven augmented and virtual reality would benefit greatly from such technical capabilities. In addition, certain amounts of data generated by the Internet of Things end devices will need to be transmitted over the cellular network as well. Global mobile data traffic is growing at an astonishing rate, with >40% CAGR predicted from 2017-2022.

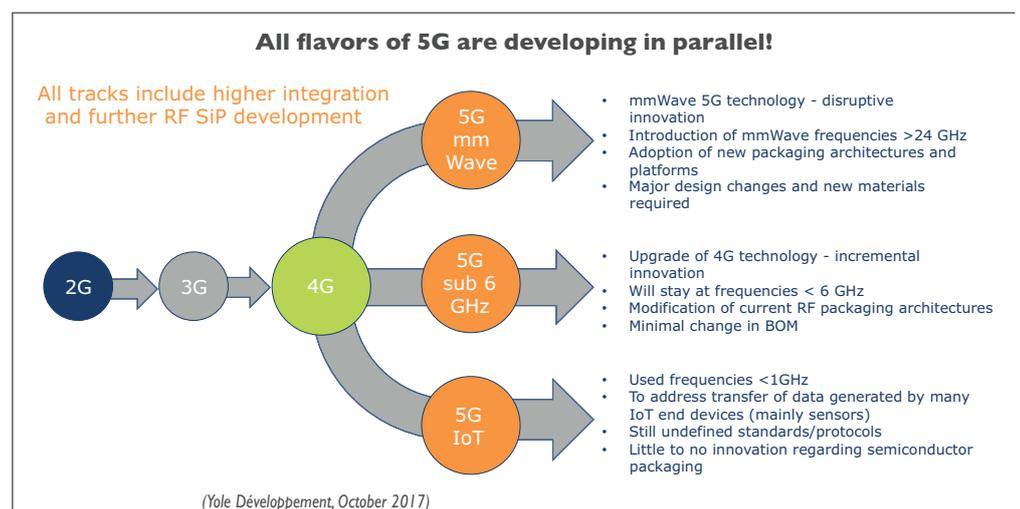
While some parts of 5G might be available as soon as 2019, in reality, there are many uncertainties which keep the global community in discussion:

- Accuracy of future projected data demands and market growth
- Growth of applications and services which would require 5G networks
- Justification of financial investment in infrastructure required
- Allocation of appropriate frequency bands
- Technology readiness
- Competition from advanced WiFi (i.e. WiGiG)
- Capabilities of ongoing 4G innovation

The fundamental motivation for developing 5G networks is the assumption that much higher data rates will be needed, than current 4G allows. The speed of 5G adoption will highly depend on market demand and status of RF

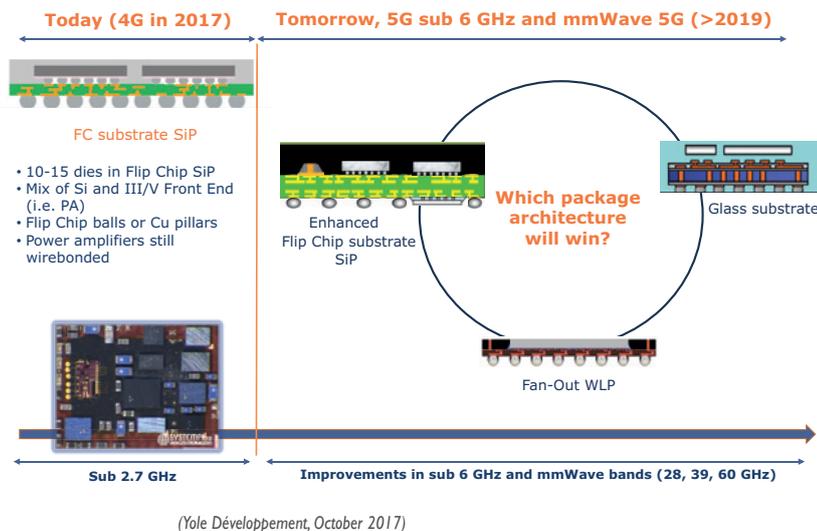
semiconductor technology quality. While the step from 3G to 4G was more incremental, 5G is considered a disruptive step, both from financial and technology viewpoint. 5G has 3 aspects: mmWave, sub 6GHz and sub 1 GHz (5G Internet-of-Thing - IoT). Highest frequency 5G targets mmWave frequency bands, in the range from 28 GHz to 60 GHz and even in some cases up to 80 GHz. This requires significant technology overhaul and installation of a large number of smaller local cells to assure signal quality. Meanwhile, significant efforts are being allocated to improve current 4G technology in the sub 6 GHz bands, towards 100 Mbit/s and beyond. The semiconductor industry, from front end to assembly and test is under heavy pressure to innovate at a very fast pace while maintaining desired quality and reliability.

RF front end modules today are utilizing complex System-in-Package (SiP) architectures with 10-15 dies (switches, filters, power amplifiers) included and several types of interconnects (wire bond, flip chip, Cu pillars) in a single package. Future smartphone connectivity relies on SiP innovation with SiP packaging revenue expected to grow >10% CAGR 2017 to 2022, more than the overall fast growing advanced packaging sector with CAGR 2017-2022 of 7%. Overall RF front end component market for smartphones is expected to grow from 12.3 \$B in 2017 to 22.8 \$B in 2022, with a CAGR of 13%. Advanced multi die SiP packaging holds a large set of key technologies to address all flavors of 5G requirements with the ability to enable or slow down the 5G market!



NEW DESIGNS FOR CHALLENGING 5G REQUIREMENTS

More and disruptive SiP architectures expected in 5G mmWave



Accomplishing Gbps wireless datarates on the cellular network requires operation of devices at GHz frequencies. While allocation of frequency bands is still in discussion, mmWave bands around 28 GHz, 39 GHz and 60 GHz come most into discussion. Meanwhile 5G below 6GHz is targeting expansion to 3.5 GHz and 4.5 GHz. Although 5G below 6 GHz also requires semiconductor packaging innovation, it can be considered mostly incremental. However, the 5G mmWave domain is opening completely new sets of requirements that requires considerable technology disruptions. At mmWave frequencies signal path length becomes particularly critical and any design imperfection is transformed into considerable signal losses and deteriorated device performance. Today, RF SiPs,

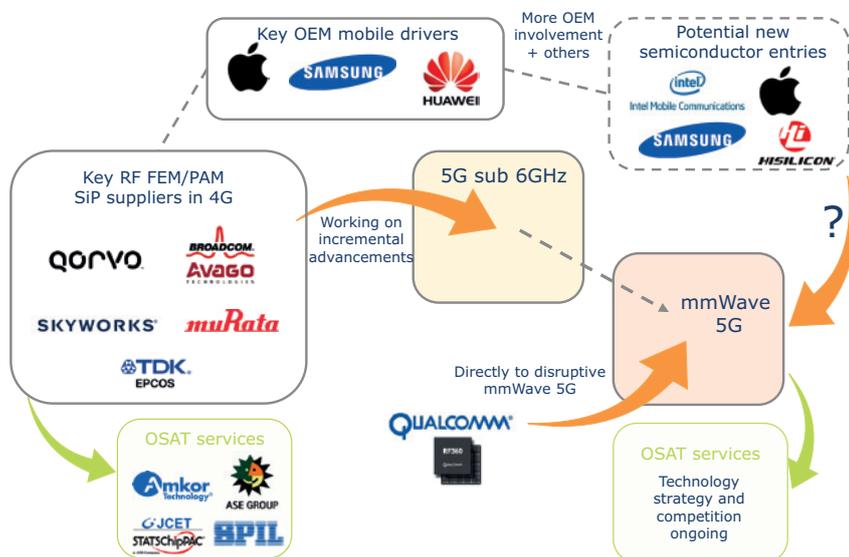
namely FEMiD and PAMiD are rather complex and contain 10-15 heterogeneous dies (Si based, III/V, MEMS etc.) with mixed wirebonding, flip chip ball or Cu pillar interconnects attaching to organic package substrates with up to 7 metal layers. Future 5G sub 6 GHz and especially 5G mmWave will require even denser integration of dies in order to minimize signal paths and keep losses under control.

Finding new innovative substrate/RDL solutions will directly impact the performance and success of a product. On top of that, integration of the antenna within the SiP is more a need than an option, bringing a set of additional challenges from placement options, processing, shielding etc. Future RF packaging innovation in cellphones is being performed on several levels and in parallel for 5G sub 6GHz and 5G mmWave, however the real packaging disruption is expected on mmWave frequencies >24 GHz. Some of the future RF packaging quests are search for low loss materials, antenna integration, possible integration of dies in front end, overhaul in packaging architectures and exploration of shielding options – all in order to develop new generations of 5G RF SiPs. Investigated packaging platforms for 5G so far include advanced Flip Chip substrate solutions, Fan-Out WLP and glass interposers.

What are the requirements and challenges in 5G packaging? How does that reflect on RF packaging architectures and materials? What are the advantages and limitations of developing RF packaging architectures? How will the dies and interconnects change at higher frequencies? Is there a better fit for lower and higher mmWave 5G bands? Which RF packaging architectures will win? Take a look into the full report for an in depth analysis providing answers to these questions.

5G BRINGS BOTH COMPLEXITY AND NEW BUSINESS OPPORTUNITIES

Supply chain to get more complex with Qualcomm 5G push and potential new entries



The SiP supply chain in the smartphone RF front end (FEM/PAM) in today's 4G technology is clearly led by 5 IDMs: Qorvo, Broadcom (Avago), Skyworks, Murata and TDK Epcos. Part of their production is outsourced to top OSATs: ASE, Amkor, JCET Group and SPIL. The future brings diversified strategies on which markets to target first. Today's IDMs are more focusing on 5G sub 6 GHz solutions while Qualcomm is attempting to skip a step directly focusing on promoting and developing mmWave 5G technologies while working on establishing a 5G mmWave supply chain in order to ensure early leadership. Various packaging technology options and market uncertainties leave OSATs to make difficult choices on targeted customers, markets and packaging architectures to qualify and offer, in order to motivate IDMs for further outsourcing.

With 5G mmWave, 5G sub 6 GHz and 5G IoT developing in parallel, what are the strategies of each RF SiP manufacturer and their long term

outlook? Can Qualcomm outpace the competitors by being first to develop 5G mmWave technologies or are the timelines premature? How are OSATs responding and is outsourcing expected to increase or decrease at mmWave frequencies? With specific technology changes at 5G mmWave, doors are open for other fabless and IDM to enter the competition at RF front end. Why are they considered as potential new entries and how can the supply chain? This report aims to provide answers to these diverse and challenging questions.

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OBJECTIVES OF THE REPORT

- Translate 5G market drivers to semiconductor packaging dynamics
- Summarize multi die packaging (SiP) technology challenges and requirements for RF Front-End in smartphones
- Analyze various developing RF SiP architectures for sub 6 GHz and mmWave frequencies, advantages and suitability thereof
- Analyze supply chain changes and opportunities for 5G in smartphones



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