5G’s impact on the RF Front-End Industry

RF SiP China 2018

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- Power Electronics
- Batteries & Energy Management

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OUTLINE OF THE PRESENTATION

- 5G market drivers
- 5G frequency allocation
- 5G impact on technology evolution
- Consequence on packaging technology
- Market forecast, supply chain and market share
Increasing data rate for mobile phones is supported by a move into the high frequency bands, firstly in the sub 6GHz regime, but also to mmWave wide bands.

5G use cases extend far beyond mobile phone, from IoT to autonomous vehicle, creating new challenges for the network in terms of data rate and latency agility.
FOCUS ON MOBILE: HIGH QUALITY VIDEO AND REAL TIME APPLICATIONS

- Cellular communication is a 30 year old industry
- It took at least 10 years between each cellular generation
- However, this new generation of 5G is expected to be introduced faster than any other generation, at least 2 years in advance, and we expect to see 5G mobile devices by mid 2019
CROWDED SPECTRUM FOR MOBILE APPLICATION

The RF spectrum is crowded, especially for LTE. Carrier aggregation helped for LTE-A and LTE-A Pro, but new spectrum will be required.

LTE mobile generation occupies a large portion of the available spectrum in the 400 MHz – 4GHz radio band (roughly 40%) compared to other mobile generation (GSM, UMTS, CDMA)

Source Niviuk
Network densification is needed to reduce the number of users per base station. Spectral efficiency is improved with high modulation order and more and more with MIMO technology which adds spatial streams. Data rate improvement is supported by bandwidth improvement brought by carrier aggregation technology or wider frequency bands.

\[
C = \frac{m}{n} \cdot \frac{\text{BW}}{\log_2(1 + \frac{S}{N+1})}
\]

Source 5G America
New Radio bands sub 6 GHz bring more than 2 GHz of spectrum mostly in the ultra high band regime.

### Broad bands

- **Ultra High Band**: 42, 43, 48
- **High Band**: 1, 4, 7, 30, 38, 39, 40, 41, 66
- **Mid Band**: 2, 3, 9, 21, 25
- **Low Band**: 5, 6, 8, 11, 12, 13, 17, 18, 19, 20, 26, 28, 29, 71
- **N77, N78, N79**

### Band refarming

- Early band: N41, N71, N28, N66
- Broad bands: LTE, NR

### LTE / 5G NR bandwidth comparison (MHz)

- **LTE**:
  - Low Band: 265
  - Mid Band: 315
  - High Band: 250
  - UHB: 210
- **NR**:
  - Low Band: 550
  - Mid Band: 244
  - High Band: 170
  - UHB: 178
Ultra high band adoption with wide bandwidth is expected worldwide through band N77, N78, N79.

Source: Qorvo modified by Yole

- 100 MHz @ 4.8 GHz
- + 190 MHz @ 2.6 GHz
- 100 MHz @ 3.5 GHz
- 100 MHz @ 3.5 GHz
Mm-wave roll out will happen first in the USA and Korea. Later in 2020 for Japan and rest of the world.

- Band N257 is main band for 5G mm-wave roll out in USA, Korea and Japan
- Europe, China, Rest of the World focus on band N258 later in 2020
- First mm-wave antenna module to support band N257, N261 and upcoming N260
Next Flagship Handset Release

5G handset devices expected to happen in 2019.

- **SAMSUNG**
  - LTE-A Pro
  - 1.2 Gbps
  - 5-6 CC
  - 4x4 MIMO

- **SONY**
  - 1st End to End Radio
  - 3 PAMiD
  - 3 DRx

- **Qualcomm**
  - iPhone XS
  - Not 5G
  - 1.2 Gbps
  - 5-6 CC
  - 4x4 MIMO

- **amsung**
  - S10
  - Expected 5G

- **HUAWEI**
  - Mate 30
  - Expected 5G

- **ONEPLUS**
  - OnePlus 7
  - Expected 5G

- **Outsiders**
  - Mi Mix 3
  - Vivo Nex S
  - Z3 + 5G mod

- **High runner**
  - Samsung
  - Huawei
  - OnePlus

Q1-18 | Q2-18 | Q3-18 | Q4-18 | Q1-19 | Q2-19 | Q3-19 | Q4-19
---|---|---|---|---|---|---|---
5G impact on RF Front-End module and connectivity for cell phones | www.yole.fr | ©2018
North America shows the highest LTE adoption rate followed by North East Asia, particularly China.

5G penetration rate is expected to follow the same trend.
Despite a slow down in mobile market growth, RF Front-End market is still expected to increase because of complexity encountered in LTE-A Pro and 5G sub 6.
Combined carrier aggregation and MIMO technologies improve data rate and signal quality. mmWave add-on will deliver even faster throughput and ubiquitous connectivity.
Transition to 5G will be progressive with 5G NSA specifications allowing faster 5G handset design with NR bands.
In every cellular generation evolution leads to new technology and additional RF content.
RF Front-End continues to evolve. First step is merging high and mid bands, densification and continuous support for carrier aggregation. New radio bands to be integrated into ultra high band module with dual connectivity. Finally, mmWave should come on top of that beyond 2020.
ARCHITECTURE EVOLUTION FOR 5G SUB 6 GHZ

Smartphone architecture complexity will increase dramatically with 5G sub 6, with band refarming and dual connectivity, mandatory 4x4 MIMO, wider NR Ultra High Band, and even increased CA usage. While available board for RF component and antenna space continues to shrink.

- More DL CA / 4x4 MIMO → proliferation of DRxM
- More independent stream: Move from diplexer to multiplexer, good path isolation, while enabling high CA
- Integration & densification in PAMiD
- More bands, more Filters

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4x4 MIMO At least 4 antenna

- Main MB/HB
- Main LB
- Diversity MB/HB
- Diversity LB
Despite a 5.8” phone, there is less room for RF functions due to bigger battery area and new functionality such as facial ID.

RFFE area has shrunk to 320mm², connectivity area down to 160mm².
Module Integration

*Supplier are toward highly integrated solution with enhanced EMI shielding and integrated Antenna Matching IC.

Example of SystemPlus Consulting analysis showing integration on mid and high band modules into a single power amplifier module from Broadcom.

Détailler module

- 21.0 mm²
- 20 I/O Pins
- Webcast: Wireless Technology for 5Gs

Integrated Mid/High Band solution

- Same Filter Nb.
- +22 % in Area

- 85.0 mm²
- 20 I/O Pins

IPD Integration

- -52 % in I/O Nb.

Wire bonding
DIVERSITY MODULE ADOPTION

- Diversity Switch Module Adoption

*Antenna matching IC has the biggest share in the diversity switch and its integration lead to new packaging solution

Example of SystemPlus Consulting analysis showing a diversity receive module from Skyworks.

- IPD 6.5 mm²
- 7 SAW Filter 18.5 mm²
- IPD isolated from the SiP IPD represent 30% of the Component area
- EMI Shielding by Wire Bonding revealed by Laser Etching and SiP metalized
MILLIMETER WAVE DISRUPTION – WHICH PACKAGING?

Double side packaging technology already used for 60 GHz products. Does it also fit 5G 28 – 39 GHz frequency bands?

5G antenna module
~19x7mm² / ~3mm thick

28 GHz – 39 GHz

WiGig antenna module
~13x5mm² / ~1mm thick

60 GHz

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2017-2023 MARKET OUTLOOK

2017–2023 Main RF components forecast

The largest market growth is for filters for high value products. Switches and antenna tuners also show significant growth. A mmWave component segment appears in 2023.

2017 $15,087M

- Filters $4,838M
- Antenna tuners $463M
- Switches $1,440M
- PAs $246M
- LNAs $4,400M
- mmWave FEM $602M

2023 $35,167M

- Filters $15,087M CAGR +15%
- Antenna tuners $7,188M CAGR +7%
- Switches $3,361M CAGR +15%
- PAs $8,100M
- LNAs $3,361M CAGR +15%
- mmWave $22,511M CAGR +19%

CAGR = Compound Annual Growth Rate
GROWING RF CONTENT BY HANDSET

Average RFFE content value by cellphone in 2020

<table>
<thead>
<tr>
<th>2G phones</th>
<th>3G phones</th>
<th>Regional 4G phones</th>
<th>High end LTE phones</th>
<th>5G phones Sub 6 GHz</th>
<th>5G phones mmWave</th>
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<tr>
<td>$0.70</td>
<td>$2.60</td>
<td>$7.20</td>
<td>$16.35</td>
<td>2019 $32</td>
<td>2020 $38.5</td>
</tr>
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Source: Yole Développement

Rise of RF Front-End value by cellphone with increasing complexity and upcoming 5G New Radio dual connectivity. 5G sub 6 GHz Front-End extra value comes from 4x4 MIMO, dual connectivity along with high end filters. mmWave phones will include the same architecture than the sub 6 phones with at least 3 added mmWave modules (antenna arrays implementation at various locations to prevent from hand blockage effect).
SMARTPHONE MARKET SHARE IN VOLUME

Samsung and Apple lead the market. Huawei shows impressive growth QoQ, followed by Oppo and Vivo. Xiaomi surpassed Oppo for the 1st time on Q1-18 and could rank 4th in 2018.

Samsung 19%
Apple 14%
Huawei 12%
Oppo 12%
Vivo 7%
Xiaomi 7%
Others 12%

1551 Mu in 2017
Broadcom maintains a strong position in high end PA modules while Skyworks progress fast as it enters the high end market as well.

In the emerging diversity module market, Murata has the leading position with Skyworks.

**Power Amplifier Module**

- Broadcom: 31%
- Qorvo: 17%
- Skyworks: 39%
- Murata: 13%
- TDK Epcos: 0%

**Receive Diversity Module**

- Qorvo: 14%
- Skyworks: 31%
- Murata: 39%
- TDK Epcos: 16%
Historical GaAs and SiGe wafer starts should remain flat, while Ceramic material, MEMS technology, SOI and even 12" bulk silicon will enjoy a significant growth in wafer starts.
A very complex ecosystem made of internal capabilities, IP blocks and foundry service

Non exhaustive list of companies
CHALLENGE FOR RF FRONT-END

• Architecture complexity even more with additional carrier aggregation (at least 5 CC) and dual connectivity.

• Board space reduced for both RF Front-End and antennas:
  • Larger battery, new functionality (Facial recognition, ...), larger screen (move from 16:9 to 18:9)

• Increasing number of antennas to 8-10 with cellular MIMO 4x4, Wi-Fi MIMO 2x2, BT and GNSS:
  • In an even more reduced space due to screen evolution from 16:9 to 18:9

• Increasing power requirement due to antenna design constraint (smaller and broadband antenna):
  • Requiring linear class2 PA (> 26 dBm)

• Challenging multiplexing scenario, high pressure on wideband filter performance due to higher frequency bands.

• Mm-Wave antenna module packaging, integration and consumption
A complete picture thanks to Yole, System Plus and Knowmade reports.
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