Diverse RF Semiconductor Technologies Are Driving the 5G Rollout

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GLOBALFOUNDRIES®

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5G, the fifth and next generation of cellular technology, promises exponentially faster network speeds, far greater network capacity, increased responsiveness due to lower latency, reduced transmission costs per bit and greatly expanded connectivity.

It will enable a host of new paradigms and applications, including fully autonomous vehicles; more artificial intelligence at the network edge for fast, efficient local processing by mobile and other endpoint devices; a greater use of augmented/virtual reality in many areas; a tremendous expansion of the Internet of Things (IoT) and machine-to-machine communications; and other use cases yet to be imagined.

Although these exciting developments are still ahead of us, the 5G rollout that will make them possible is happening right now, faster than many predicted and gaining momentum. For example, auctions for mmWave spectrum for 5G began in late 2018 and are ongoing; the 5G technical standards-setting process is largely complete[1]; Verizon and AT&T have introduced fixed wireless services using mmWave as a precursor to mobile mmWave 5G in selected areas in the U.S, while China plans to roll out 200,000 5G base stations in 2019, and Japan, South Korea and Switzerland are also active as early adopters[2]; and a major push is on to develop the data center, networking infrastructure, customer premises equipment (CPE) and mobile systems that 5G requires.

As a result, in coming years the volume of network traffic is projected to grow exponentially. By some estimates mobile data traffic will grow at a compound annual growth rate of 31 percent through 2024, with annual global mobile data traffic reaching about 136 Exabytes per month by that year and with 5G making up ~25% of that number.[3] In addition, it's not just traffic volume that is growing but complexity, too, due to new application requirements, more users and growing user interest in activities that require the transmission and processing of large amounts of data, such as for HD video; live-streaming of sports, concerts and other events; streaming video services; and many others.

[1] *https://www.theverge.com/2018/6/15/17467734/5g-nr-standard-3gpp-standalone-finished*

[2] *https://blog.globalfoundries.com/mwc-barcelona-full-speed-ahead-5g/*

[3] *https://www.ericsson.com/en/mobility-report/reports/november-2018*

To handle all this traffic, complexity and accommodate 5G in smartphones, architectural changes are needed, and the challenge for chip designers for these applications is to create devices with optimized RF, power and performance capabilities that differentiate their products from the competition. Just as important is the ability to produce these chips at low cost in a design and manufacturing ecosystem that can get them to market quickly as 5G applications evolve, from initial designs that leverage the existing 4G/LTE architecture and the sub-6GHz bands, to designs targeting architecture amenable to mmWave frequencies.

GLOBALFOUNDRIES (GF®) offers smartphone chip designers a portfolio of innovative, proven RF technologies that are 5G-ready and have a wide range of features, capabilities and enablement that can be combined in diverse ways to create the specific attributes that a 5G application requires.

This paper will examine the contributions GLOBALFOUNDRIES' technologies are making to the 5G rollout in smartphones and other mobile devices.[4] It will start by discussing approaches to chip design for applications at sub-6GHz frequencies, which enable 5G by leveraging some of the existing 4G bands (700MHz, 2.5GHz, etc.) and also frequency bands between 3.3GHz and 5GHz.

Chip development in this frequency range typically consists of design "tweaks" and not total redesigns. As a result, the first generation of 5G smartphones will be based primarily on sub-6GHz 5G implementations.

Then, the paper will discuss 5G implementations in the millimeter-wave (mmWave) band at frequencies above 24GHz. These enable extremely high rates of data transmission but require multiple antennae working together as phased arrays to extend the mmWave reach.

Finally, there will be a discussion of Wi-Fi front-end modules, as Wi-Fi capability is included today in a wide range of devices that will interact with 5G systems (for example, smartphones, tablets, laptops, desktops, wearables and routers).

[4] *GF technologies are also making significant contributions to 5G infrastructure. To learn more about this topic, visit globalfoundries.com*

1) Sub-6GHz 5G Implementations: GF's 8SW RF SOI Technology

In RF circuit design, the RF front-end module (FEM) typically comprises everything between the antenna and the RF transceiver (a transmitter/receiver). This includes the switches, filters and low-noise amplifiers (LNAs) needed to process signals received from the antenna, along with the power amplifiers (PA) that amplify the transmitted signal to the antenna through the filters and switches.

For sub-6GHz cellular architectures, the FEM is hybrid, meaning that multiple technologies are used because they bring unique advantages to each of the elements shown in Figure 1. GaAs is used for the PA while RF SOI is used for switches, with either SiGe or RF SOI used for the LNAs.

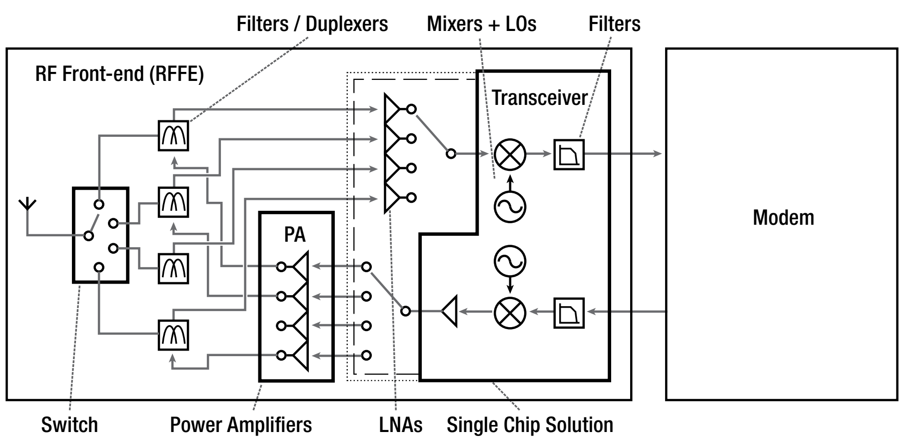


Figure 1: Sub-6GHz Smartphone Cellular Front End and Transceiver

Note: LNAs are part of the front end in most of the current tier 1 smartphone designs

GF's 8SW RF SOI technology is the industry's first fully qualified high-volume RF SOI foundry solution manufactured on 300mm wafers. It is optimized to deliver best-in-class performance for LNAs, switches and tuners in FEMs designed for use in high-end 4G-LTE and sub-6 GHz 5G applications.

Built on a trap-rich, high-resistivity substrate with all-copper interconnects, optimized metal stacks and MIM capacitors, GF's 8SW technology delivers industry-leading on-resistance and off-capacitance for high isolation and greatly reduced insertion loss (IL) and harmonics. Reduced insertion loss is a key requirement both for smartphone original equipment manufacturers (OEMs) and cellular network operators, because lower IL results in a much stronger signal, which translates to fewer dropped calls/dropped connections and higher data speeds, particularly at the cell edge.

Switches made with GF's 8SW RF SOI technology also offer higher isolation and linearity than other offerings in the industry, leading to higher receiver sensitivities and less interference, which again translates into fewer dropped calls/connections/cross talk and, as a result, a better user experience.

2) Sub-6GHz 5G Implementations: GF's 12LP FinFET Technology

Sub-6GHz cellular smartphone architectures typically use a standalone transceiver, and until very recently these transceivers were built on 28nm bulk CMOS technology. However, we are now seeing a migration to higher-performance FinFET technology to enable 5G systems to handle more digital content, and to take advantage of lower power for the analog circuits.

GF's 12LP FinFET foundry technology is an excellent process choice for sub-6GHz cellular transceiver designs. It is a 12nm version of GF's established, mature 14LPP FinFET technology. The 12LP FinFET process provides industry-leading F_t/F_{max} and noise figure performance for exceptional RF performance, and combines it with superior power efficiency.

3) mmWave 5G Implementations: GF's 45RFSOI Technology for FEM-Centric Designs

5G architectures in the mmWave bands are evolving, and so front-end module designs will vary by customer. GLOBALFOUNDRIES has industry-leading solutions for all design approaches and works closely with customers to help them choose the one that works best for their requirements.

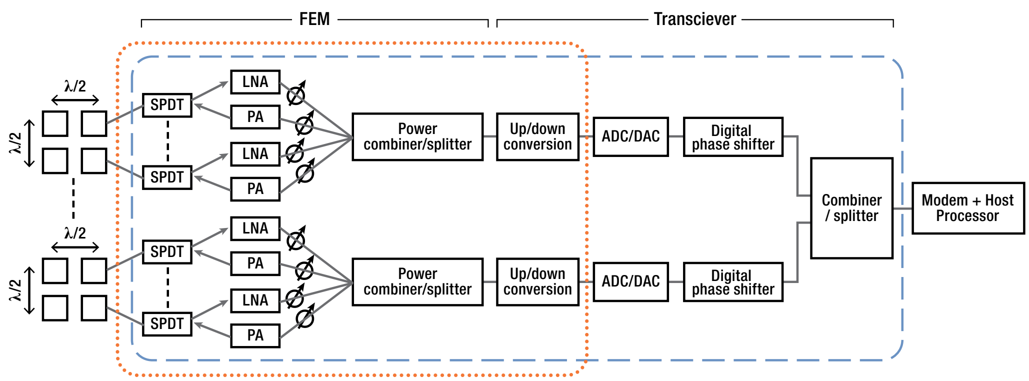


Figure 2: 5G mmWave Cellular Front End and Transceiver Schematics

One FEM-centric design option is a partial integration approach (dotted box in Figure 2) in which the mmWave PA, LNA, switches, phase shifters and power combiners/splitters are integrated and, in some cases, the RF/mmWave up/down converters are as well. These converters transform mmWaves from/to an intermediate frequency (IF) that lies above 6GHz but far below the mmWave level. Typically it is within the 7–12GHz range. This is called a "High IF" architecture, and it takes advantage of lower interconnect losses between the FEM and transceiver at IF frequencies, versus mmWave frequencies. The IF frequency is chosen so as to not interfere with other sub-6GHz signals in the same handset.

An alternative partial integration approach keeps the PA discrete instead of integrating it with the other FEM elements (LNA, switch, phase shifters and power combiners/splitters).

Another FEM-centric design option is a fully integrated approach (dashed box in Figure 2) that integrates the entire subsystem, including the transceiver, and which stops at the modem interface.

Customers taking a FEM-centric approach to mmWave architectures will require high RF performance along with very high PA capability. GF's 45RFSOI process is an excellent choice for these applications. By adding RF-centric enhancements that build on the inherent advantages of GF's proven, 45nm partially depleted silicon-on-insulator (PD-SOI) technology, the 45RFSOI process offers best-in-class mmWave FEM performance. Benefits include:

- High-resistivity substrate for high-linearity switches, LNAs and low-loss interconnects at mmWave frequencies
- High f_t/f_{max} (290/410 GHz) and stacking capability for PAs, with higher maximum output power (P_{sat}) and power gain, and higher efficiency, high-power-tolerant switches offering low insertion loss (0.65dB[5])
- Optimized low-loss back-end-of-line (BEOL) fabrication, enabling low noise-figure (NF) LNAs (1.3 dB[5]) and low-loss interconnects, along with passive components like phase shifters and power splitters/combiners

The higher P_{sat} and lower NF achievable with GF's 45RFSOI process results in an increased power-added efficiency (PAE) for the PA, and a reduced number of antenna array elements required for a given equivalent isotropic radiated power (EIRP) output. This translates to less battery power drain and better thermal management. PA power efficiency and thermal management are critical not only because battery life is a key requirement for mobile devices, but also because fans or heatsinks can't be used in increasingly thin, lightweight mobile devices. In addition, fewer required array elements make for a smaller antenna module and, consequently, lower packaging costs.

GF's 45RFSOI technology is also well-suited for integrated FEMs in mmWave 5G small cells, as it offers the unique capability to design chips with P_{sat} of up to 23dBm at max >40% efficiency.

[5] *Demonstrated in GF reference designs*

4) mmWave 5G Implementations: GF's 22FDX® Technology for Fully Integrated Architectures

GF's 22FDX process is the industry's only technology that enables a fully integrated 5G mmWave radio solution (PAs + LNAs + switch + transceiver, and even including data converters) at the power efficiency and performance levels required for thin and light smartphones, tablets and laptops.

Power amplifiers built with 22FDX technology demonstrate 34% transmit power savings, 14% total power savings, 10% battery life increase and less heat compared to bulk CMOS. In addition, 22FDX allows for full integration of the PAs and does not require PA power combiners, leading to smaller devices and higher efficiency.

In LNA performance, 22FDX delivers a ~30% better noise figure than bulk CMOS, which leads to better signal reach and fewer dropped calls. This difference is estimated to lead to a ~6% gain in distance coverage.

In addition, 22FDX delivers a minimum of 50% better switch performance than bulk CMOS, also resulting in a stronger signal and fewer dropped calls. This equates to an increase in sensitivity of 0.85dB, which is quite significant when put into context: designers typically compete over just a few tenths of a dB of insertion loss difference.

Today, GF's 22FDX process can address transmit power levels up to 20dBm P_{sat}. For applications that operate below this power level, the PA can be integrated in 22FDX with the rest of the FEM module.

5) mmWave 5G Implementations: SiGe for Higher P_{sat}

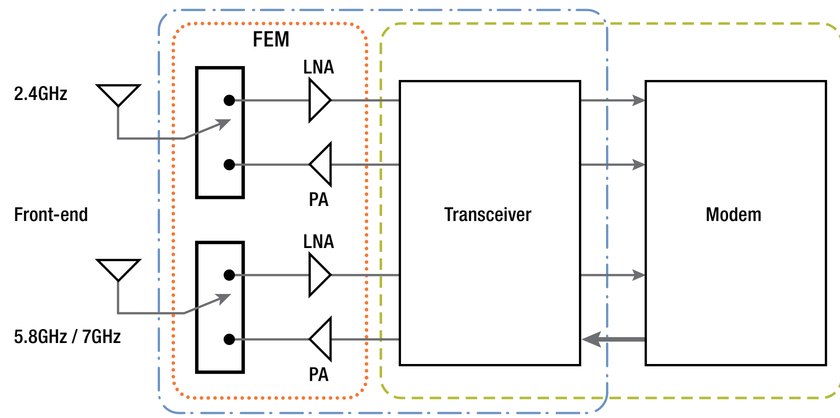
For applications targeting higher P_{sat} (>23dBm) the PA will need to be separate, and in these cases GF offers high-performance SiGe (130nm or 90nm BiCMOS) for integrated or discrete PA devices. The higher P_{sat} of SiGe (silicon germanium) makes it an ideal technology for mmWave 5G infrastructure (for example, small cells and backhaul FEMs).

6) Wi-Fi Radio

The capabilities of Wi-Fi front-ends have increased over the years to meet the increasing performance requirements specified in the technical standards for Wi-Fi equipment (for example, 802.11 a/b/g/n/ac). The latest Wi-Fi standard is 802.11ax, which covers both 2.4 & 5.8GHz as well as an emerging 6GHz band, up to the 7.125GHz frequency range.

As shown in Figure 3, Wi-Fi radio architectures vary. They may include a standalone FEM and transceiver or an integrated FEM and transceiver, and sometimes integration of the modem.

Figure 3: Wi-Fi Module Schematics for 2x2 MIMO



Note: In a 2x2 MIMO configuration, there is a duplication of FEM for each band

A standalone Wi-Fi FEM can either be an integrated module with switch + PA + LNA (small dotted box in Figure 3), or just the switch + LNA with a separate discrete PA. GF's 8SW technology is designed to deliver a best-in-class solution for a Wi-Fi switch + LNA, offering the same performance advantages as mentioned earlier for a cellular switch. In addition, 8SW is optimized to provide industry leading low-noise, high-gain and high-linearity benefits in an RF SOI-based LNA.

For high-performance discrete PAs, some designers choose GaAs (gallium arsenide). However, designers generally are moving toward the integrated approach, and GF's SiGe BiCMOS power amplifier technology helps them strike the optimum balance between performance, integration and cost efficiency. GF's SiGe PA technologies are built on a silicon base which offers integration advantages over gallium-arsenide alternatives for smaller modules at similar performance. All SiGe PA offerings feature production-proven through-silicon vias (TSVs), which enable low-cost packaging solutions.

Both the GF 22FDX and 12LP processes can enable the integration of FEM and transceiver (dot dash box in Figure 3). If the modem is included as part of a system-on-a-chip as shown by the combination of all the boxes in the figure (FEM + transceiver + modem), then GF's 12LP offers a unique combination of superior RF performance along with the logic, power, performance and scaling advantages of FinFET technology.

If integration of the PA is a challenge, a hybrid PA may be the right solution, using either SiGe or GaAs depending on the power requirements.

Conclusion

GLOBALFOUNDRIES offers a wide range of differentiated RF technologies that are helping to enable our clients' innovations, our ecosystem partners' success and strong growth for the entire 5G industry.

Whether for sub-6GHz or mmWave 5G applications, or state-of-the-art Wi-Fi radios, these diverse technologies bring specific benefits to 5G solutions, helping designers create devices that offer optimized 5G performance along with the required balance of power, performance, RF capability and application-specific features. Learn more at *globalfoundries.com*

GLOBALFOUNDRIES®
2600 Great America Way, Santa Clara, CA 95054 USA
Tel: +1 408-462-3900 globalfoundries.com/contact-us