5G Wireless and the New Imperative for Denser, Faster, Multifunction Devices

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Abstract— **Parallel advancements in GaN, MMICs, RF SOCs – and also optical networking technologies – are converging to increase design and cost efficiencies**

I. Introduction

The advent of 5G has spurred a rethinking of wireless infrastructure, from semiconductors to basestation system architectures to network topologies.

At the semiconductor level, the mainstream commercialization of GaN on Si has opened the door to improved RF power density, space savings and energy efficiency, at affordable cost structures on par with LDMOS, and far below GaN on SiC. In parallel, the use case for GaN has expanded beyond discrete transistors for high-power RF applications. The economies of scale achieved with GaN's propagation into commercial 4G LTE wireless infrastructure has enabled GaN's migration into the MMICs market, where it's helping system designers achieve higher levels of functionality and device integration for next-generation 5G systems.

Meanwhile, the evolution of RF SOCs with integrated RF, analog and digital circuitry has unlocked huge gains in data processing speed across a very wide frequency range, leveraging advanced direct sampling capabilities. At the board level, this eliminates the need for discrete data converters tied to very specific frequency plans, enabling smaller system footprints with digital flexibility and increased IO.

At the network node level, 5G data throughput requirements invite a fresh look at the optical transport technologies tasked with offloading and routing the 5G data deluge. By taking a holistic view of the network from basestation to network fiber optics – from RF to Light, if you will – system designers can gain a better understanding of the challenges and opportunities that arise when these technologies intersect.

Here we'll assess the benefits of GaN on Si for integrated, multifunction MMICs, as well as the benefits of RF systems on chips (SOCs), and advanced optical technology architectures affecting the evolution of 5G wireless infrastructure.

II. IINNOVATION IN GaN AND MMICs

The sheer density of massive MIMO antenna configurations – scaling as high as 256+ transmit and receive elements in a single 5G basestation – puts a premium value on available PCB space, particularly at higher frequencies. To meet this challenge, multifunction MMICs are supplanting discrete ICs and single-function MMICs in 5G basestation designs.

In addition to the space savings benefits that multifunction integration helps to drive, costs are lowered through a reduction in individual die packaging, design complexity, testing, and assembly labor. Reductions in the number of interfaces improve overall mechanical reliability.

Against this backdrop, GaN on Si's successful penetration into the commercial semiconductor marketplace comes at a fortuitous time. Its scalability to 8 and 12 inch silicon wafers is enabling cost efficiencies that are well out of reach for GaN on SiC, at power densities that can't be achieved with LDMOS – upward of 4X to 6X more power per unit area.

Bridging the gap between these two key attributes, GaN on Si is further distinguished by its ability to integrate increased functionality at the silicon level, yielding additional space optimization for ultra compact MMICs. Its silicon substrate supports homogenous integration of GaN devices and CMOS-based devices on a single chip – a capability that GaN on SiC can't provide due to the inherent process limitations. This opens the door to multifunction, digitally-assisted RF MMICs that can incorporate on-chip digital control and calibration, on-chip power distribution networks, and more.

III. RF SOC PROCESSING EFFICIENCY

For 5G basestation infrastructure, the integration benefits and reductions in hardware content enabled with GaN on Si-based multifunction MMICs are further complemented by the recent commercial-market emergence of RF SOCs. Integrating multi-giga sample RF data converters for high speed data processing across a very wide frequency range, RF SOCs streamline the data pipeline and provide a scalable pathway for increasing RF channel-count.

With conventional super heterodyne receiver architectures, signals have to be down converted to baseband signals, which requires a mixer and additional circuitry. A 2.6 GHz RF signal (4G LTE) would need to be down converted into the MHz frequency range, where a conventional ADC could sample at a lower speed.

In order to place all of the frequency content in the first Nyquist band, you need to sample at 3X the radio frequency. A 2.6 GHz signal would need to be sampled at almost 8 giga samples per second to achieve this, far outstripping the capability of conventional ADCs sampling at much lower rates – typically 3 giga samples per second, in the 400 MHz frequency range.

A new generation of RF SOCs is overcoming this obstacle, providing the ability to sample signals at up to 56 giga samples per second – this enables direct RF sampling at very high RF frequencies, with the option to down sample. This digital sampling capability eliminates the need for a conventional superhet receiver and discrete data converters, while also eliminating the exciter technology needed for superhet sampling.

RF SOCs can pack a very large number of channels into a very small footprint. Functionally, from four to sixteen channels can be fit into an IC that's approximately 12mm X 12mm, versus requiring multiple circuit cards to do the same thing – this is analogous to the footprint reductions and IO gains achieved via the evolution from rotary phone to mobile smartphone. And with a defined pathway toward RF CMOS technology at 7nm spacing, channel density will only continue to grow, and power optimization will continue to improve.

Going forward, RF SOCs will enable signals that are increasingly free of distortion – ambiguities and imperfections that previously weren't correctable will be readily correctable. At the system level, here again we see how the benefits of multifunction integration and reduced component count can drive significant space, power and cost savings for affordable 5G infrastructure.

IV. FROM RF TO LIGHT

Wireless network operators and hyperscale datacenter operators share a common imperative on the pathway to 5G – they need to move data as quickly and cost efficiently as possible. As parallel advancements in RF and optical technologies begin to intersect and integrate, we'll gain a clearer perspective of how innovations in one technology domain can affect the evolution of the other.

The faster data processing and throughput speeds achieved at the RF basestation are likewise mirrored in the transition from 100G to 400G optical transceiver modules, particularly in the datacenter where port density must continue to increase to keep pace with insatiable data demands.

The broader trend toward higher levels of integration and reduced component count is a key factor in the evolution to 400G modules, where the emergence of the single lambda (aka single wavelength) PAM-4 modulation scheme is transforming module architectures. For 100G transceivers, single lambda PAM-4 technology can reduce the number of lasers to one, and eliminates the need for optical multiplexing. For 400G implementations, only four optical assemblies are needed, representing a major opportunity for datacenter operators to reduce their cost with an extremely compact and energy efficient module. This innovation in the hyperscale datacenter will emanate outward to wireless network nodes in the not too distant future.

At the semiconductor level, accelerating advancements in silicon photonics technology will transform the composition of next generation, multifunction MMICs, leveraging established CMOS processes to generate thousands of optical components at a time on wafer substrates leveraging commercial-scale manufacturing techniques. With newfound ability to integrate GaN-based RF devices together with optical devices on a single silicon die – at extremely attractive cost structures – the resulting reduction in interfaces between RF and optical componentry will make it that much easier to push cleaner, faster signals through the network.

In the meantime, continued advancements in GaN on Si technology, multifunction MMICs and RF SOCs will propel the RF and microwaves industry toward the realization of more elegant, integrated, and cost effective wireless system infrastructure on the path to 5G connectivity.