Semiconductor Innovation: Enabling Mobile Connectivity

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Abstract

Four decades of advancements in wireless technology have taken us from brick-sized cellular phones to palm-sized mobile devices that do much more than just make phone calls. Compound semiconductor technology has played a pivotal role in delivering both space and power saving enhancements, particularly in the radio section of the handset. This progress, along with key design and packaging advances, has driven critical improvements in signal quality and talk time, while opening board space for circuitry that delivers additional functionality including Web browsing, music downloads, navigation, camera capability, games, payments, and even digital door keys and identity credentials. Even though the size of the RF section is shrinking to make room for IC content that performs these functions, the RF content is growing at a faster rate than shipments of the handset units themselves. Meanwhile, ongoing RF innovations have also created opportunities to embed wireless functionality into many other types of mobile devices. This paper looks at key advances in RF amplifier, module and subsystem technology, including design, manufacturing and packaging innovations, which are fueling new opportunities and propelling wireless innovation beyond the handset.

INTRODUCTION

The first portable cellular handset was thick and heavy, and significantly larger than today's cell phones. It was only capable of making a phone call, had an average talk time of 60 minutes, took almost 19 hours to recharge and weighed 2.5 pounds. It was single frequency and required as many as 10 square inches of board space for the system's radio section alone.

It was essentially useless -- unless its inventors could dramatically reduce the phone's size and power consumption, and ensure it could be used anywhere. The key was making the cell phone's electronics smaller and more efficient, which would require a more dense proliferation of cellular towers to reduce signal transmission distances, and a methodology for passing connections from one cell tower to the next.

Contrast this to where we are today. Smart phones not only make voice calls, they serve as a camera, music player, GPS navigator, portable device to stream content and much more. We use our phones for social networking, particularly as the mobile Internet has now become a part of our daily lives. And with the advent of cloud applications, we are moving to the seamless sharing of content, enabling us to access our music, video and other content whenever and wherever, regardless of whether we are using our phone, tablet, or other mobile platform. Further, these devices are light weight and portable, with smart phones weighing less than four ounces and taking a mere three hours to recharge. And by comparison, today's least expensive 2G phones have ten times the RF complexity and do substantially more in a much smaller footprint.

Perhaps even more amazing is that the wireless technology that has made modern smart phones possible is now also becoming more and more ubiquitous. Bluetooth, HSPA, Wi-Fi to GPS, LTE and ZigBee® technologies are being embedded into a growing range of new devices from televisions and tablets to media players, and set top boxes, in addition to smart phones.

At the same time, the RF content is increasing even while the total available board space is decreasing as more and more functionality is added. In fact, RF TAM is expected to grow at an approximately 17 percent compounded annual growth rate – more than three times faster than the total growth of high-end LTE smart phones, and 30 percent faster than that of mid-tier smart phones. (see Fig. 1).

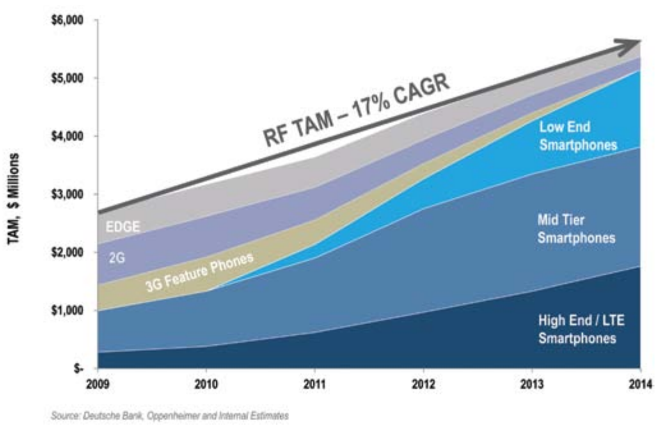

Fig. 1: Growth of RF TAM

While the typical feature phone previously consumed less than $1 of semiconductor content, today's smart phones require up to $10 of multi-mode functionality, including a GPRS/EDGE PA, four WCDMA bands, an antenna switch and WLAN module, and various LTE bands. With the transition from 3G to 4G, each will need approximately three times more content than today's phones in order to support multiple standards and modes of operation.

MAKING IT POSSIBLE: SIZE AND INTEGRATION ADVANCES IN CS TECHNOLOGY

The only way to shrink cell phone size while adding features was to integrate more functions onto each die, and more dice into each package. Compound semiconductor technology, new silicon architectures, and stacked-die packaging techniques have played major roles in making these improvements possible. As the industry moved from rudimentary GaAs MESFET PAs to GaAs HBT technology, and on to InGaP, BiFET and BiHEMT technology with Si and SOI switching and control circuitry, there have been increasing levels of integration and performance improvements.

Early phones required up to 50 discrete components for the radio functionality alone. The first discrete PAs were soon replaced by PA modules, followed by integrated transmit front-end modules, and eventually by today's SIP radio solutions that integrate the PA, switches, RF ICs, and filters in a GaAs MMIC-based laminate package.

SIP solutions have shrunk as well, as the industry migrated from 2G to 3G. Early SIPs were simple, 2-layer circuit boards with relatively low component density, and have since evolved to 6- and 8-layer substrates with embedded high-density passive components and dimensions 20 times smaller than their predecessors.

For instance, CDMA PAs in 1995 required over a dozen components in a ceramic package with metal lid that occupied 20 x 12 mm of space. By 2003, the single-band WCDMA PA function was compressed into a 3x3 mm footprint (see Fig. 2) and today the dual-band WCDMA or LTE PA takes up only a 3x4 mm area. The PA combined with a SAW or BAW duplexer has been reduced from 5x8 mm in 2007 to 3.2x4.1 mm today. During the same time, the GSM PA shrank from 6x8 mm to 3.5x5 mm and the transmit FEM – from 8x8 mm to 5x6 mm in size. Interestingly, these patterns follow Moore's Law – straight line on a semi-logarithmic scale, signifying the benefits of technology and innovation. Meanwhile, the number of throws in the front-end switch of the Tx-FEM or ASM has increased from four to 12 and MMMB PAs are supporting larger and larger numbers of bands. Today's MMMB PAs can support up to 17 bands and are adding multiple new features and capabilities, such as advanced MIPI control, envelope tracking, carrier aggregation, and LTE-Advanced. Meanwhile, pins or terminals per component have also dramatically increased.

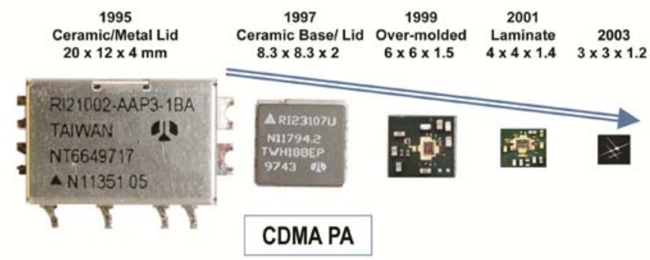

Fig. 2: Evolution of WCDMA PAs

Convergence will continue as handsets migrate to 4G technology, and there are important functional partitioning decisions to make. As highly integrated FEMs migrate to 4G solutions, they have the potential to deliver improved performance along with better power efficiency than is possible if switch and filtering functions are realized as discrete components on the phone board.

Ongoing size and integration improvements in the PA section of the phone will continue to require a challenging combination of design, process and packaging technology. Contrary to conventional wisdom, this section of the phone has followed an integration path nearly as impressive as the primarily digital, easier-to-integrate baseband section. According to research conducted by Prismark Partners, the handset's baseband section has shrunk from 20 square centimeters for early 3G smart phones to 5 square centimeters today, or 16 percent annually over the 8-year period since 3G phones were launched. Meanwhile, the 3G handset's PA footprint shrank 13 percent. When evaluated on a per-band basis, the size reduction is an even more impressive 20 percent. (see Fig. 3).

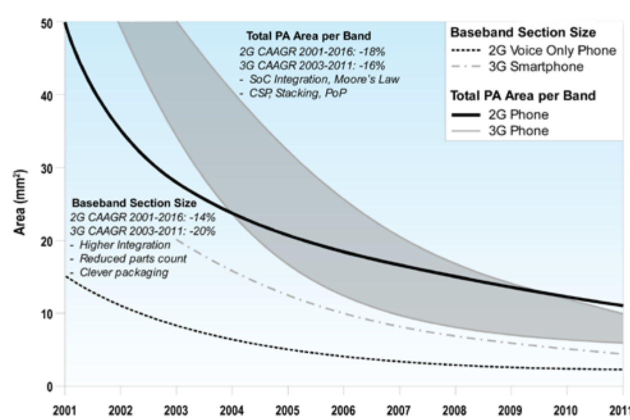

Fig. 3: Size reduction in baseband and PA sections

Plus, integration advances in the RF front-end and PA section have been achieved while accommodating far more mixed-signal analog and digital complexity than has been required in the generally all-digital baseband section. Accommodating this complexity has given today's smart phones the critical ability to support more and more bands while still shrinking phone size and adding functions. At the same time, PA costs have steadily decreased. Today's PAs, for instance, can provide MMMB functionality with integrated filtering and switching over 15 bands of 2.5G, 3G and 4G modulation support for the same or lower cost as compared to a simple 2G PA less than five years ago.

IMPROVING POWER SAVINGS AND TALK TIME

Process, design and packaging advances have also enabled critical increases in power efficiency, which drives improved talk time. GaAs HBT process technology developments have been particularly important for improving PAE. While there was a period when many thought silicon PAs would eventually dominate, HBT PAs have continued to deliver superior performance at lower cost, particularly as the complexity of the front-end architecture continues to increase. There have been improvements in power dissipation of approximately 100mW per year over the last few years (see Fig. 4).

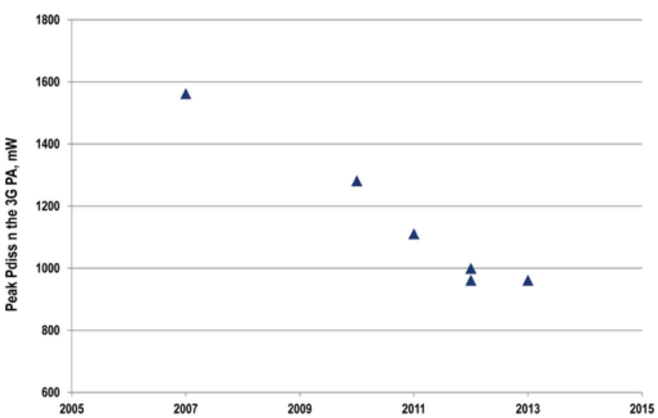

Fig. 4: Improvements in Peak Power Dissipation

Ongoing PAE improvements are critical, since PAs and associated components still consume a significant percentage of system power. Conventional, narrow band techniques for improving PAE cannot span more than a single band. New technologies, including envelope tracking, are now being explored that improve PAE without compromising bandwidth.

Envelope tracking enables the voltage supplied to the final RF stage power transistor to be changed dynamically, and synchronized with the RF signal passing through the device. The supply voltage is reduced from its maximum value and allowed to track the signal envelope, with lower dissipated energy (see Fig. 5). An envelope tracking amplifier operates at its optimum efficiency at all envelope levels, greatly improving efficiency whe operating with envelope varying signals. Envelope tracking is expected to deliver 200 to 500mW in battery power savings, or more, along with 20 to 30 percent less dissipated power, lower heat dissipation, and improved 3G/4G coverage per base station since less back-off will be required.

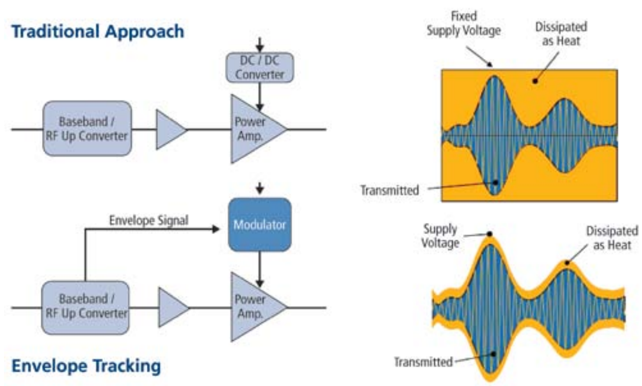

Fig. 5: Envelope Tracking

BEYOND THE HANDSET

Wireless semiconductor technology advances are also now moving beyond the handset and mobile computing devices into new applications including smart energy, the wirelessly connected home, medical equipment, infrastructure platforms, and military and automotive systems. In the military space, a growing variety of defense and homeland security systems need RF/microwave solutions for applications including radio communications, radars, electronic surveillance, and electronic countermeasures. There also is significant demand for components including varactor diodes and switches in heart monitors, pacemakers, patient monitors, medical wireless telemetry systems and MRI scanners.

Skyworks estimates that the TAM for high-performance analog products used in these mobile connectivity applications will grow at a 37 percent compounded annual rate to nearly $1 billion by 2014. The TAM for all high-performance analog solutions used in mobile connectivity, the wireless infrastructure, and smart energy and GPS applications is expected to reach more than $2.5 billion by 2014.

A New Model for a Rapidly Growing Market

Mobile device volumes are expected to continue to grow and drive significant demand for underlying RF solutions. It is anticipated that smart phone growth will continue to eclipse overall feature phone growth by a factor of almost seven. Similarly, as tablets maintain a projected 91 percent growth pace, the associated RF content is expected to grow 126 percent. At the same time, the number of devices per person is also increasing. Market growth will only accelerate as each user adopts more devices. Whereas most mobile users in 1990 only carried a single device, today's average is significantly higher – and growing – with the advent of new wireless hardware platforms and consumer products.

To support this growing demand, infrastructure upgrades and the development of new base stations will be needed to support anticipated traffic. Smart phones may only represent 20 percent or less of total worldwide phone shipments, but they drive 80 percent or more of the mobile traffic. A typical server can only support 10 smart phones, so there is a critical need to very quickly upgrade today's mobile infrastructure.

Meanwhile, 4G demand is only just beginning. Today's approximately 936 million 4G connections are expected to grow to nearly 5 billion connections by 2016, including 3.8 billion HSPA connections and 661 million LTE connections. This proliferation of 4G is expected to further increase RF complexity and content, which will require continuing advances in compound semiconductor technology.

Against this backdrop, the industry's system design model has changed dramatically. Few handset manufacturers and smart phone providers now have in-house RF or digital teams. Instead, they focus on industrial design, marketing, and user interface and software developments, and increasingly rely on semiconductor manufacturers to deliver the core hardware technology. The latest solutions deliver unprecedented complexity, integrating up to 10 front-ends that have been optimized for performance and power efficiency, and yet they can be delivered as drop-in solutions that impose no requirements on the manufacturer match components or perform other tasks to make all of these functions work together.

Conclusions

No one could have predicted 10 years ago where the industry would be today. Moving forward, there is ample RF technology headroom to meet growing demand for comprehensive "world" phones with the highest possible data download performance. The first Motorola flip-phone cost $1,500 and today would be considered virtually useless. Since then, the industry has evolved to a new development model, and a much faster RF innovation cycle is now being driven by RF design specialists rather than the traditional handset OEMs. The next 10 years of innovation should be at least as impressive as the last, if not more.

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Acronyms

ASM: Antenna Switch Module
BAW: Bulk Acoustic Wave
BiFET: Bipolar Field Effect Transistor
BiHEMT: Bipolar High Electron Mobility Transistor
CDMA: Code Division Multiple Access
EDGE: Enhanced Data GSM Environment
FEM: Front-End Module
GaAs: Gallium Arsenide
GPRS: General Packet Radio Services
GPS: Global Positioning System
GSM: Global System for Mobile Communications
HBT: Heterojunction Bipolar Transistor
HSPA: High Speed Packet Access
InGaP: Indium Gallium Phosphide
LTE: Long Term Evolution
MESFET: Metal Semiconductor Field Effect Transistor
MIPI: Mobile Industry Processor Interface
MMIC: Monolithic Microwave Integrated Circuit
MMMB: Multi-Mode Multi-Band
MRI: Magnetic Resonance Imaging
mW: Milliwatt
PAE: Power Added Efficiency
RF: Radio Frequency
SAW: Surface Acoustic Wave
Si: Silicon
SIP: System in Package
SOI: Silicon on Insulator
TAM: Total Available Market
Tx-FEM: Transmit Front-end Module
WCDMA: Wideband Code-Division Multiple Access
WLAN: Wireless Local Area Network