GLOSSARY OF ACRONYMS

BiCMOS — Bipolar Complementary Metal-oxide Semiconductor

CCK — Complementary Code Keying (RF modulation)

CMOS — Complementary Metal Oxide Semiconductor

COT — Customer-Owned Tooling

E911 — Enhanced

f_T – Transistor Peak Frequency

GaAs — Gallium Arsenide

GPS — Global Positioning System

GSM — Global System for Mobile Communications (formerly Groupe Speciale Mobile)

HBT — Heterojunction Bipolar Transistor

IC — Integrated Circuit

IDM — Integrated Device Manufacturer

LDMOS — Laterally Diffused Metal-Oxide Semiconductor

LNA — Low-Noise Amplifier

MAC — Media Access Layer

PA — Power Amplifier

SiGe — Silicon Germanium

SoC — System-on-Chip

SRAM — Static Random Access Memory

VCO — Voltage-Controlled Oscillator

VLNA — Very Low Noise Amplifier

WLAN — Wireless Local Area Network

FEATURED TECHNOLOGY |

SiGe BiCMOS Plays a Growing Role in the Mobile Platform

| Lower costs and advancements in SiGe BiCMOS offer significant benefits to the wireless community.

| By Paul Kempf

The dominance of SiGe BiCMOS in RF transceivers for mobile platforms is evident when looking inside most of today's leading cellular phones. Today's situation developed despite the relatively limited access to SiGe BiCMOS at the beginning of the design cycle for the chips in current phones, which commenced about 24 to 36 months ago. Now, with the much broader access to, lower costs associated with and continued design advantages of pure-play foundry technology that is well-suited to common radio architectures, there are good indicators of continued growth for SiGe BiCMOS in cell phones and other mobile platforms.

This article explores the performance and economic benefits that translate into the leading position that SiGe BiCMOS currently holds in the RF portion of the handset. It outlines the growth prospects for SiGe BiCMOS as part of the revolution in functionality that is bringing WLAN, GPS, Bluetooth, TV, audio and much more to the mobile platform.

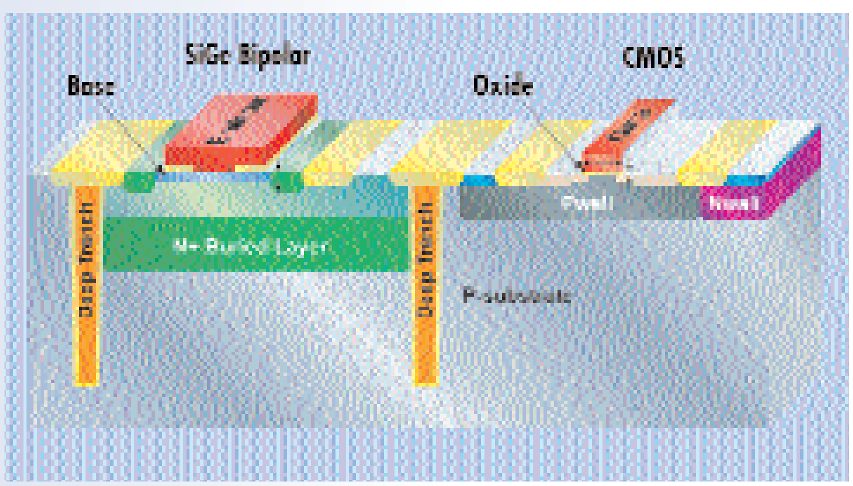

Figure 1. Scaling of SiGe bipolar emitter width and base thickness has improved small and large signal performance with each new generation. Similar scaling of CMOS gate length and oxide thickness has improved transistor speed at the cost of dynamic range.

Technology Tailored for the Cell Phone

Volume production of SiGe BiCMOS was driven by the wireless transceiver as SiGe BiCMOS offered a path to integration of VLNAs, low power frequency synthesizers, and high-quality passive components for the integration of VCOs. Despite fairly low RF operating ranges (below 2 GHz) relative to the f_T of greater than 60 GHz, each generation of SiGe BiCMOS has offered reduced power consumption, higher breakdown voltage and lower noise figure. Continued lateral and vertical scaling of SiGe technology has provided better small-signal performance for low voltage operation, but has also offered enhanced large-signal performance for more efficient RF drivers and power amplifiers. This is in stark contrast to the lower voltages and more fragile gate oxides that result from similar scaling of each new generation of CMOS technology, making it more difficult to design real-world RF circuits with each new generation of CMOS.

The evolution of the RF transceiver from a set of chips tailored for each function, implemented in a variety of processes, such as GaAs and silicon bipolar or BiCMOS technologies, to the single, small-form-factor, low power, low cost SiGe BiCMOS chip has been the result of evolving process technology optimized to perform the transceiver function. This optimization has included integration of bipolar transistors with CMOS for low power digital control and frequency synthesizers, isolation techniques such as triple-well and deep-trench that allow receive and transmit paths to be on the same die, high-density linear capacitors for reduced die size, thick inductor metal for compact on-chip filters and varactors for automatic frequency calibration. (See Figure 1.)

The known solutions for analog scaling provide an opportunity for significant die size reduction using SiGe BiCMOS technology vs. industry-standard CMOS technology. This die size savings can either be translated into smaller package and board space, or lower total cost, depending on the level of analog and digital integration. Product yield improve-

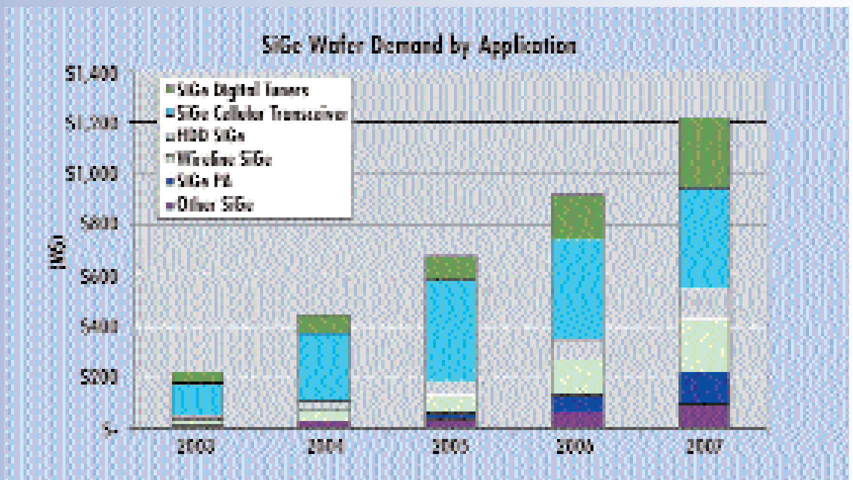

Figure 2. The market growth of SiGe BiCMOS is projected to be largely a result of applications in mobile platforms (*source: ABI Research, Semico, Jazz*).

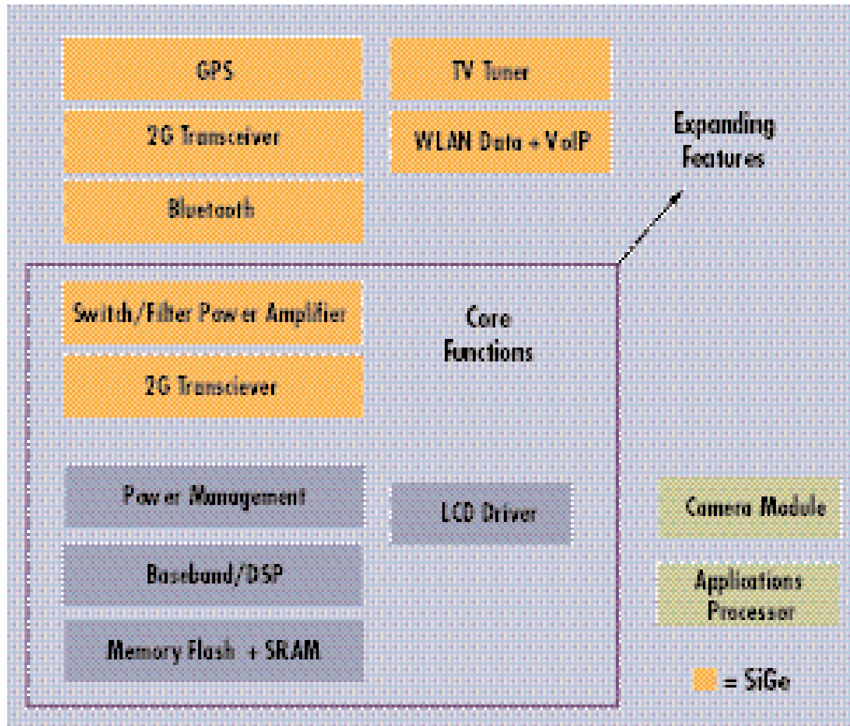

Figure 3. Growing list of features poised to join cell phone functionality in the mobile platform.

ments can be realized in conjunction with mixed-signal integration because of fewer interfaces between ICs, but can be negatively affected by the yield loss in more parametrically sensitive analog and RF circuit blocks that would otherwise contribute little to defect-driven yield of a large digital SoC.

Winning Performance and Die Cost

Die cost of a SiGe BiCMOS RF chip, as influenced by die size and the overall complexity that determines wafer price, has remained competitive versus standard CMOS because of the applications focus that results in meeting system specifications with small die size in a technology node that lags a comparable CMOS implementation by two generations. The extra process steps required in a SiGe BiCMOS process, with line-widths generally lagging state-of-the-art lithography by two generations, are less expensive than the standard CMOS process using the most advanced lithography.

In addition to the performance and die cost advantages that have promoted the growth of SiGe BiCMOS for RF transceivers, much lower product development costs are realized because of the exponentially increasing cost of masks for each CMOS generation. Shorter time-to-market for SiGe BiCMOS products has been demonstrated because of the maturity of device modeling, design platform and manufacturing capability that is possible when using well-established process modules and fab equipment. Product development cost and time-to-market are key factors for the funding of start-up companies and for the prioritization of product development activities at established fabless companies. Lower costs and more predictable development timelines enable entry of new suppliers and promote risk-taking in the introduction of new product functionality and architecture. This explains why most new RF applications are first realized in a SiGe BiCMOS implementation even in cases such as Bluetooth, where a CMOS implementation may become standard later in a product cycle.

Maturing Foundry Supplier Base

The largest SiGe BiCMOS suppliers are a mixture of diversified semiconductor suppliers, electronics systems companies and pure-play wafer foundries for which providing foundry services for their end-customers represents a significant part of their total SiGe BiCMOS volume. To a varying extent, the COT model has dominated SiGe RF design, so the quality of device models and the design platform has been the defining attribute that has resulted in successful SiGe BiCMOS RF products. This is an obstacle for performing RF CMOS design at fabless companies and IDMs, which have been compelled to invest in their own modeling and design infrastructure to enable RF products in advanced CMOS. Maturation of SiGe BiCMOS manufacturing capability has resulted from the scaling of capacity and process deployment at a growing number of suppliers, resulting in a SiGe BiCMOS market approaching $1 billion in wafer sales, as shown in Figure 2.

Unlike standard CMOS wafer manufacturing, which resided in-house at IDMs and eventually migrated to the foundry model through outsourcing, it is more likely that the pure-play foundry industry will become the largest SiGe BiCMOS wafer supplier more quickly because of the availability of foundry processes relatively early in the design cycle for SiGe BiCMOS applications and designs. With foundries as the dominant supplier, the cost-competitiveness and flexible capacity that is expected of pure-play foundries has become characteristic of the SiGe BiCMOS market as well, supporting the continued growth in existing and new applications.

Enabling New Functionality: WLAN, GPS, TV, Video and Audio

A primary reason for continued growth of SiGe in the mobile platform is the number of different RF interfaces that are expected to radically expand functionality and improve the user experience, as shown in Figure 3.

Bluetooth has been growing as an embedded function that has become the standard for wireless headsets and for connection to automotive hands-free devices. Highly integrated SoC solutions lead the Bluetooth market, driving advanced RF CMOS technology to achieve low cost systems that include significant amounts of embedded memory in the form of SRAM and Flash, a standard processor, as well as mixed-signal and RF circuits. Because of the extremely short range required for wireless personal area networks such as Bluetooth, it is virtually the only cell phone function in which an embedded CMOS PA can provide adequate power to achieve the 10 m range that users expect.

WLAN has some similarities to Bluetooth in terms of the basic building blocks required to assemble the system: high-density logic, SRAM, processor, data converters, RF and PA capability. The much more challenging WLAN 802.11a/b/g standards at 2.4 GHz and 5.8 GHz result in RF implementations that consume a higher percentage of the die area in an advanced CMOS SoC and require separate SiGe BiCMOS PAs to provide 17 to 23 dBm of output power. SiGe BiCMOS power amplifiers incorporate sophisticated power control on the same die and can be packaged with the primarily digital SoC, or delivered in a separate module with front-end filters and switches.

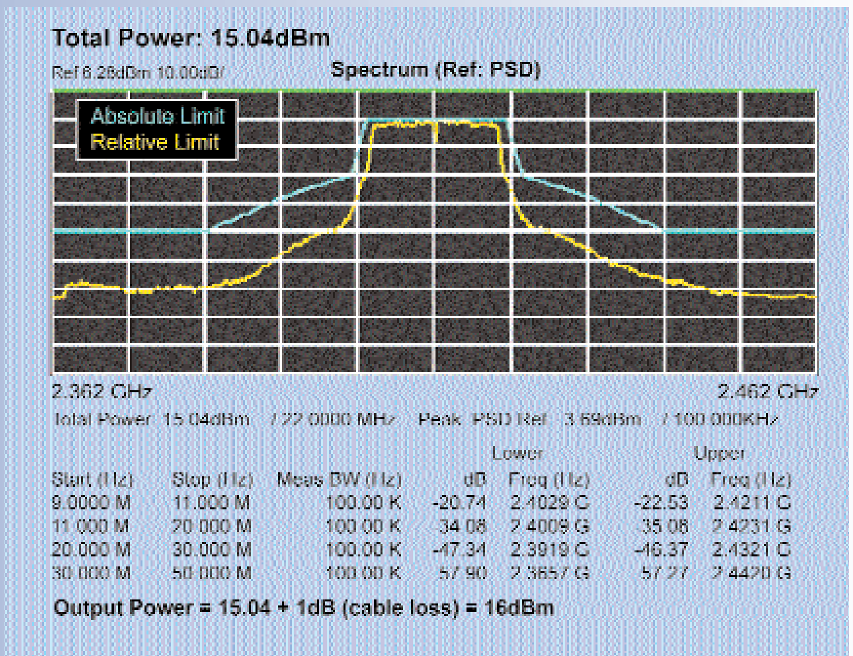

Figure 4. Example of a WLAN product that uses SiGe BiCMOS to integrate power amplifiers in the radio chip, providing power out of 16 dBm at the antenna for 54 Mb/s OFDM (shown) and 20 dBm for 11 Mb/s CCK (*source: Airoha Technology*).

A new trend has been the integration of multiple PAs with a separate multi-standard WLAN radio in SiGe BiCMOS to cost-optimize the bill-of-materials. (See example in Figure 4.) This new approach results in a simpler baseband/MAC chip, and ultimately in a smaller overall footprint, by using readily available stacked-die packaging of the first chip, the CMOS baseband/MAC with the second chip, the SiGe BiCMOS radio and integrated PAs. The evolution of WLAN to the 802.11n standard is yet another driver of SiGe BiCMOS technology, as the need for multiple-channel radios and power amplifiers to meet the requirements of the higher 802.11n data rate results in more RF content. Although 802.11n is positioned to be the next WLAN technology, it is likely that low power consumption requirements will initially exclude its use in the cell phone.

A transition from analog to digital TV in consumer and wireless applications, and the increasing deployment of mobile television broadcasts for handheld devices, is driving the growth of the multi-standard silicon TV tuner market. The recent trend, which replaces the traditional "can" tuner with a silicon-based tuner for better performance and lower cost, is in line with the anticipated adoption of mobile TV for cellular phones and other consumer electronics products.

Digital TV broadcasts require a receiver that can pick up a signal inside or outside a building, requiring high dynamic and tunable range plus mobility for a handheld. The inherent dynamic range, low noise, low power, isolation and good sensitivity characteristics of SiGe BiCMOS are a natural fit, and consequently multiple RF tuner designs are driving explosive growth in the number of designs in SiGe BiCMOS today.

Integration of additional functions, such as TV, GPS (for E911), video, digital audio and FM radio with the cell phone has created a new market opportunity that has affirmed the concept of the mobile platform with functions far beyond voice communications and messaging. Each of these new functions introduces a new frequency band, from which a number of new RF design issues arise. Some chips on the market combine two or more RF functions in a single SiGe BiCMOS device, but none are sophisticated enough to support the multitude of simultaneous frequency bands. (See Table 1.) The digital corollary to the proliferation of RF interfaces is the evolution of custom applications processors for back-end processing for embedded cameras, digital video, digital audio and other functions to process the multiple incoming signals.

Table 1. Allocated Frequency Spectrum for some of the New Functions in the Mobile Platform

Function	Frequency (MHz)	
GSM 400	450 — 467	478 — 496
GSM 850	824 — 849	869 — 894
GSM 900	880 — 915	925 — 960
GSM 1800	1710 — 1785	1805 — 1880
GSM 1900	1850 — 1910	1930 — 1990
3G	1920 — 1980	2110 — 2170
	1900 — 1920	2010 — 2025
	1980 — 2010	2170 — 2200
CDMA	1930 — 1990	
	1805 — 1870	
	869 — 894	
WLAN	2400 —2497	
	5150 — 5875	
DVB-H	1670 — 1675	
DAB	1452 — 1492	
FM	88 — 108	
GPS	1575	

SiGe Growth in Established Functions

And what of the growth of SiGe in the standard cell phone radio functions related to the power amplifier and transceiver?

The PA is a large-signal component that operates at high power density and must have good thermal characteristics. It normally consists of two gain stages and a high power output stage with inter-stage matching and has been implemented in GaAs HBT and silicon LDMOS for mainstream cell phones (>1 W power output). Stand-alone SiGe BiCMOS products have been announced for higher-power cellular PAs, and the potentials for integration of power control, input voltage protection and the PAs to support multiple standards have made this an area of active product development.

Products that bring together the most demanding radio components — the PA, power control, transmit/receive switch, and lowpass filter — into a single package have successfully ramped up because of the savings in subsystem design, test and assembly effort for the system manufacturer. These analog components, as well as the surrounding voltage regulators, battery charger, oscillators and channel select filters, could be targeted for integration if it were not for the heterogeneous technologies used for these applications.

Integration of the LNA, receive path, VCO, synthesizer and transmit path into a single chip took years of industry effort to become established as the norm for GSM. Highly integrated transceivers have lowered system cost. The growing number of other analog components needed to support multiband phones creates motivation for a silicon-based technology that can provide a path toward integration of the analog subsystem.

Growing use of SiGe BiCMOS in the cell phone makes it a prime candidate for further analog integration as the overall system functions mature and drive the need for fewer components. Attention to the integration and scaling requirements for analog and RF circuit components provides a cost reduction without trading off dynamic range, reliability, linearity, matching and other parameters that are essential to analog integration.

Summary

SiGe BiCMOS is the dominant technology in RF chips for cell phones. The challenges of bringing robust products to market for entirely new cell phone functions, such as WLAN, GPS, TV, video and audio has resulted in the continued choice of SiGe BiCMOS as the technology that can provide a low power and low cost solution with a time-to-market in line with the ever-changing requirements of the mobile platform.

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