SiGe Extends Its Reach:
Power Amplifiers Supply Wireless and Cellular Applications

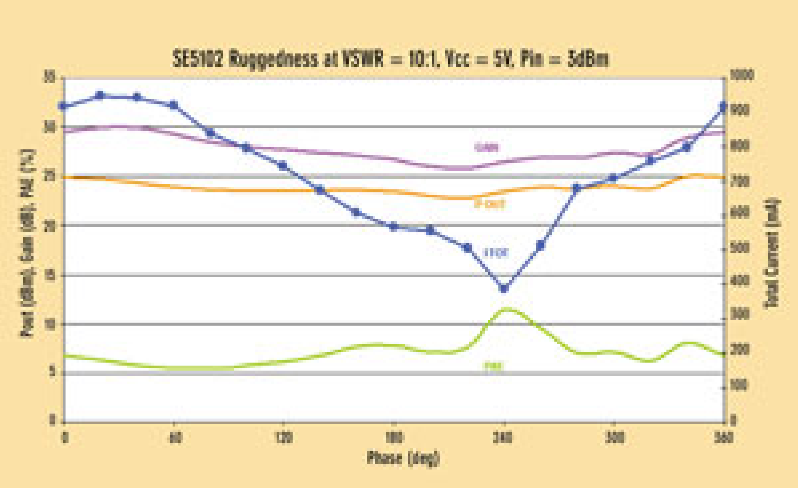
New engineering techniques allow SiGe to be used in high-power amplifiers for CDMA, GSM, and WLAN applications; enable the next generation of integration.

By Jerry Loraine and Steve Kovacic, SiGe Semiconductor
Silicon germanium (SiGe) has grown from a promising technology to a leading-edge solution for current and next-generation mobile devices, including cellular, wireless local area network (WLAN), and Bluetooth. Since its introduction in the 1980s, SiGe has been a material of great interest for those pursuing low-cost high-frequency applications that require performance beyond that of standard silicon. In wireless applications, the technology has been largely accepted for use in downcoverters, low-noise amplifiers (LNAs), preamplifiers, and WLAN power amplifiers (PAs).

Now SiGe can be used for high-power amplifier applications, such as handsets compliant to the Code Division Multiple Access (CDMA) and Global System for Mobile Communications (GSM) specifications. And, its ability to integrate more circuits positions the material well for future integration of the PA with the RF circuitry.

SiGe Advantages

Two factors have been largely responsible for driving down the cost of handset design: integration and the use of low-cost, integration-friendly technologies such as SiGe.



A SiGe PA is able to withstand VSWR of 10:1 across all phases at a peak input power of +35 dBm and Vcc of +5 VDC.
SiGe's list of advantages is impressive. As a &quotyounger brother&quot of silicon, it offers the integration, yield, and cost benefits associated with silicon processing, but it also features the speed benefits of Class III-V semiconductors such as gallium arsenide (GaAs) and indium phosphide (InP). The process can be used to integrate high-quality passive components by increasing the metal and dielectric layer stack to reduce parasitic capacitance and inductance. In addition, the germanium profile can be used to engineer device behavior over temperature. SiGe BiCMOS technology is compatible with virtually all innovations in the silicon VLSI industry including SOI and trench isolation.

Whereas ordinary silicon chips operate at frequencies up to a few GHz, SiGe has been demonstrated at operating frequencies up to 350 GHz[ii] with current speeds reaching 2 to 4 times that achieved with ordinary silicon.[iii] Additional significant advantages over III-V bipolar transistors include reduced noise, power efficiency, and better heat dissipation. In fact, the thermal conductivity of the silicon substrate is 3X that of GaAs.

Its numerous advantages have allowed SiGe to enable lower-cost, high-performance products in WLAN, cable telephony, and optical applications. Now, recent technological developments in the areas of breakdown voltage and the integration of high-performance passive components are allowing SiGe to make inroads into a traditional GaAs stronghold-the cellular power amplifier.

Breakdown Voltage

A cellular PA must handle VSWR of 10:1 at high voltage and deliver signals of +28 dBm (CDMA) to +35dBm (GSM). Traditionally, cellular PAs have been implemented in GaAs because it offers high breakdown voltages. However, the attractiveness of GaAs in this application is limited, due to its higher cost and its inability to integrate with the rest of the radio circuitry. This is especially true in the case of multi-mode cellular phones, which require multiple PAs. This further increases the handset bill of materials (BOM) because the type of integration achieved with low-cost silicon-based processes is not available.

To manufacture a silicon germanium PA to meet demanding cellular specifications, a mainstream silicon germanium process with an f_T of 30 GHz, similar to those used in InGaP processes was implemented. This process was specifically selected for its breakdown voltage, linear performance and efficiency at cellular power levels, and its support of integration.

In order to ensure reliability at high power output levels, silicon germanium's breakdown voltage of +5.5 VDC had to be improved. Designers developed proprietary circuits, techniques, and transistors that allow high power PAs to be produced with breakdown voltages that can reliably serve 10:1 VSWR, all phases, at full power, and supply voltages of +5 V (CDMA) and +4.5 V (GSM).

Low breakdown voltage and the concomitant reliability concerns, is the reason that RF CMOS, another silicon-based technology, cannot realize an RF PA in a size-, space-, cost-, or power-efficient way (see Table 1). For example, in order to be fast enough to operate efficiently, the RF CMOS chip must run at a much higher current, requiring a larger transistor, which makes the die size larger. Bigger transistors also make the device less power efficient. These trade-offs make RF CMOS a poor choice for high efficiency PAs as required in cellular applications.

Table 1.
A Comparison of SiGe BiCMOS, RF CMOS, and InGaP/GaAs Implementations for a Cellular Front End

Parameter	SiGe BiCMOS Low-V/High-V	0.25 um RF CMOS	InGaP/GaAs HBT
Wafer Size	8"	8"	80 80 4 - 6^{2}
FT (GHz)	80/32	35	46
Fmax (GHz)	80/55	50	67
Vbe/Vth	0.8	0.5	1.3
Bvceo/BVds	>2.5 / >6.5	<2.5	>10
Bvcbo	> 8 / >15	N/A	>15
Current Density (mA/um2)	3/0.6	0.25	0.5
PNPs	Yes	Yes	No
FETs (# 0.25 mm)	Yes	Yes	No
Environmental Issues?	No	No	Yes

Integrating Passives

Traditionally, passive components in SiGe did not have as high a performance as in GaAs; this was especially true of inductors, a key component in a radio design. In the new process, integrating high-performance passives was achieved by integrating thick copper and thick aluminum top layers. Since SiGe allows up to five layers of interconnect, it is possible to "stack" passive components on the chip. High quality factor (Q) inductors can be realized in these top layers, and the resulting device is technically superior to those manufactured using III-V semiconductor materials.

Cellular Applications

Due to these engineering advances, SiGe now has the higher breakdown voltage required to deliver the PA efficiency and linearity for GSM-EDGE/CDMA as well as the latest WLAN applications (including 802.11g).

As a result, designers can take full advantage of SiGe in terms of its cost-effective, high component integration, low noise, and high frequency characteristics in their battery-operated designs. In addition, when the digital circuit needs to interface with analog, SiGe BiCMOS has the voltage headroom and noise performance required. (A diminishing supply voltage in RF CMOS, for instance, limits its ability to interface to high dynamic range analog inputs.)

Cost is a primary advantage of SiGe when comparing it to the III-IV semiconductors typically used in cellular PA applications. A SiGe mainstream process runs on 200 mm (8-in wafers), and is on the industry roadmap to 300 mm. GaAs, on the other hand, is manufactured on 4 to 6-in. wafers, with the yield and processing cost disadvantages associated with a smaller wafer size.

The latest deposition tools such as batch ultra-high vacuum chemical vapor deposition (UHVCVD) and single wafer tools reliably deposit high-quality SiGe on 200-mm wafers, allowing epitaxial growth of a SiGe base layer within a silicon fab or foundry.

High integration is another major advantage of using SiGe because designers can integrate more control circuitry around the PA. The result is a solution with a smaller footprint than one in a III-V material, which would require the PA chip plus a CMOS control chip. SiGe is able to integrate both functions into one chip, and has the potential to integrate more of the radio functionality.

PAs require control circuitry to satisfy regulatory requirements for RF output power control or to simply turn the PA on/off. This control circuitry is also being used to improve the efficiency of the PA over a wide RF output power range. For instance, output power varies depending on the handset's distance from the base station, and, in order to maximize talk time, designers need to optimize the performance of the PA over the entire power range instead of just at maximum output power. Integrated control circuits allow them to do this.

Some time in the near future, it is likely that designers will want to integrate the RF circuits-either into the CMOS circuitry or into the PA chip. By using SiGe, designers will be able to integrate the RF circuits with the PA without sacrificing PA efficiency, which would reduce battery life of the cellular phone. This is important because it is likely to be smaller and more cost effective than integrating all the radio, including the PA, into the CMOS circuitry.

For instance, in order to improve the handset talk time and enable more features, CMOS geometry is expected to shrink to 90 nm and less, and it will become too expensive in mask charges to develop the radio circuits in CMOS. SiGe is a good way forward for high performance, highly-integrated radio front ends that integrate the PA, control circuitry, and the RF circuits.

Other Applications

Improvements made to the SiGe manufacturing and design process for the cellular market benefit other communications applications as well, including those in the WLAN and optical markets.

In future product generations, digital circuits for WLANs will most likely be absorbed into the communications processor. This will create a need for a stand alone radio, and SiGe BiCMOS is well suited to offer a cost-effective, low power solution. For Bluetooth, SiGe could be used to produce very low-noise, low-power radios. And, in the optical communications market, SiGe allows more integration of control circuits and optical networking interface circuits, which allows placement of very low noise amplifiers and all of the control circuits very close to the optical components.

Moving Forward

SiGe BiCMOS is now extremely well positioned for the future of wireless technology. It offers the breakdown voltage and integration capability to meet the PA and radio circuit requirements of current cellular, WLAN, and Bluetooth applications. Furthermore, it is the most promising technology for allowing the anticipated integration requirements of the future.

Jerry Loraine is the Chief Technology Officer and Vice President, Business Development of SiGe Semiconductor. Steve Kovacic is the Director R&D and IP Management for SiGe Semiconductor. For more information visit www.sige.com.
Editor's Note: For a list of references, please email kpotts@reedbusiness.com.