SiGe Technology Makes Practical Advances

This novel device technology is making major strides in RF and digital integrated circuits for high-frequency, high-speed communications systems.

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SILICON germanium (SiGe) is a semiconductor technology made for wireless applications. It offers the high-speed, high-frequency performance needed for wireless systems, and it provides the potential for integrating analog, RF, and digital functions on a single integrated circuit (IC). Plus, it is based on low-cost Si wafers. Admittedly, it requires more process steps than conventional Si bipolar technologies. But this is a semiconductor process that is gaining acceptance among wireless designers and is bound to make its mark on analog and digital architectures in the years to come.

In a little more than a year, numerous firms have introduced commercial ICs based on SiGe, including TEMIC Semiconductors (Heilbronn, Germany) with last year's announcement of the model U7004B IC for cordless Digital European Cordless Telecommunications (DECT) applications at 2.4 GHz. Integrating a low-noise amplifier (LNA), power amplifier (PA), and transmit/receiver (Tx/Rx) switch driver, the SiGe IC draws 350-mA typical current from a single +3-VDC supply and achieves a typical noise figure (NF) of 2 dB.

Shortly thereafter, SiGe Microsystems (Ottawa, Ontario, Canada) unveiled several amplifier products (see sidebar on p. 124) and Maxim Integrated Products (Sunnyvale, CA) introduced its first SiGe products, a line of downconverter mixers and LNAs for cellular and personal-communications-services (PCS) applications (see *Microwaves & RF*, February 1999, p. 140). Maxim's MAX2680, MAX2681, and MAX2682 downconverter mixers cover a wide range of applications from 400 to 2500 MHz with various NFs and dynamic ranges. The firm's MAX2640 LNA offers more than 15-dB gain and 0.9-dB NF at 900 MHz. The MAX2641 LNA features 14.4-dB gain and 1.3-dB NF at 1900 MHz.

More recently, such firms as Applied Micro Circuits Corp. (San Diego, CA), Intersil/Harris (Melbourne, FL), and Stanford Microdevices (Sunnyvale, CA) have demonstrated the commercial possibilities for digital and RF products based on SiGe. Applied Micro Circuits Corp., for example, last month launched the S3057 IC, a multirate serialization/deserialization interface IC for Synchronous Optical Network (SONET)/synchronous-digital-hierarchy (SDH) and Gigabit Ethernet OC-48 applications at 2.488 Gb/s. The low-jitter IC consumes only 1.5-W power from a single +3.3-VDC sup-

WIRELESS WONDERS?

A new website, http://www.wirelesswonders.com, will be offering an extensive listing of products based on wireless technology. While it may be too soon to find silicon-germanium (SiGe) devices in these products, other advanced technologies, including GaAs heterojunction bipolar transistors (HBTs) and bipolar-complementary-metal-oxide-semiconductor (BiCMOS) integrated circuits (ICs) commonly support a wide range of wireless products, from door chimes to sophisticated medical equipment.

Each year, literally thousands of new products are introduced with some form of wireless technology. Some are simple devices. Others are elaborate systems. In addition to learning about wireless products, visitors to http://www.wirelesswonders.com can first nominate their favorite wireless products of 1999 for top wireless products. Once nominations are accepted, voting for top wireless products begins on the site from December 1, 1999 to January 31, 2000. All entries will be eligible to win one of the seven wireless wonders of the world for 1999, with the drawing to be held at the Wireless Symposium & Exhibition/ Portable By Design Conference in February at the San Jose Convention Center (San Jose, CA).●●

ply while working with a reference clock at 155.52 MHz.

Intersil has been converting its successful PRISM line of wireless local-area-network (WLAN) ICs to SiGe bipolar-complementary metal-oxide semiconductor (BiCMOS) as part of the development of the PRISM II chip set. The model HFA3983 SiGe monolithic PA is only one of five ICs aimed at WLAN applications in the 2.4-GHz industrial-scientific-medical (ISM) band. It integrates a 30-dB PA circuit, a logarithmic power-detection function with 15-dB dynamic range, and CMOS-level-compatible power up/down function. The SiGe amplifier features two cascaded low-voltage single-supply stages that combine for +18-dBm typical output power for the direct-sequence, spread-spectrum (DSSS) signals found in WLAN systems. The typical power gain is 30 dB. At the rated output power, the logarithmic detector is accurate within 1 dB. The slope of the detector is 100 mV/dB over its 15-dB dynamic range. The amplifier is designed to work with the PRISM HFA3861 baseband processor and the HFA3783 in-phase/quadrature (I/Q) modulator/demodulator. Similar to many companies entering commercial wireless markets with SiGe ICs, the HFA3983 is fabricated at the SiGe foundry owned and operated by IBM (Hopewell Junction, NY).

General-purpose amplifiers and LNAs in the SGA series from Stanford Microdevices (Sunnyvale, CA) offer low-cost solutions for a variety of wireless applications from DC to 5 GHz. Based on an SiGe heterojunction-bipolar-transistor (HBT) process with 1-μm emitters and f_T of 65 GHz, the amplifier line includes the model SGA-64, which is rated for +20-dBm output power at 1-dB compression from DC to 1.8 GHz. The monolithic microwave IC (MMIC) achieves more than 19-dB gain at 1 GHz and more than 16-dB gain at 2 GHz, as well as drawing 75 mA from a +5.2-VDC supply.

IBM is undoubtedly the single strongest force behind the development and acceptance of SiGe in today's markets. Many firms involved in wireless design and development rely on IBM's Hopewell Junction foundry, which is just north of New York City. RF Micro Devices (Greensboro, NC), for example, has signed an agreement with IBM to use the process to develop SiGe RF building blocks. Partners for IBM's SiGe technology have included Hughes Electronics (Malibu, CA) and Nortel Technology (Ottawa, Ontario, Canada). Also, Philsar Electronics, Inc. (Nepean, Ontario, Canada) has signed a licensing agreement with IBM and plans to use the technology to design low-power-radio ICs. And for some time, IBM has strongly backed the SiGe device developments of CommQuest Technologies (Encinitas, CA) and National Semiconductor (Santa Clara, CA), to name a few.

Despite its many partnerships, IBM has also developed several SiGe products of its own, including SiGe discrete devices and ICs. The company's model IBM43RF1111 SiGe LNA, for example, is ideal for cellular and PCS applications. It offers 17-dB gain at 900 MHz and 11-dB gain at 1900 MHz, with a GaAs-like NF of only 1.4 dB at 900 MHz. The unconditionally stable amplifier achieves an input third-order intercept point (IP3) of +8 dBm and draws only 7.5-mA current from a single supply of +2.7 to +3.3 VDC.

Last year, the company reported on the potential of SiGe BiCMOS for creating very-large-scale-integration (VLSI) application-specific ICs (ASICs).[1] Intended to validate design library elements with the SiGe process, the 8.06 × 8.06-mm ASIC may represent the forerunner of a single-chip radio for wireless applications. The ASIC was fabricated with a double-polysilicon self-aligned SiGe BiCMOS process capable of transition frequency (f_T) of 50 GHz at a breakdown voltage of +3.4 VDC and f_T) of 28 GHz at a breakdown voltage of +5.7 VDC.

Earlier this year, the firm also presented work on a transceiver IC for use at 5.2 GHz.[2] Formed with 0.5-μm SiGe BiCMOS technology, the transceiver consists of several mixers, several stages of IF amplification, an RF LNA, and RF driver amplifier. Tests were performed on wafer using a probe from Cascade Microtech (Hillsboro, OR). Designed for operation at 5.2 GHz, the IC achieves a 3-dB bandwidth of 7 GHz, with 11.7-dB downconversion gain, 7.5-dB NF, an input third-order intercept performance of –11.2 dBm, and amplitude imbalance of 0.33 dB across a 300-MHz intermediate-frequency (IF) bandwidth. The transceiver also offers 14.7-dB upconversion gain and output 1-dB compression point of –23 dBm. Using a single +3.3-VDC supply, the IC consumes 122-mW power for the receiver and 114-mW power for the transmitter.

The SiGe story began around 1986 when IBM developed the ultra-high-vacuum/chemical-vapor-deposition (UHV/CVD) processing capability to produce uniform SiGe heterostructures with greater speed than other wafer-processing techniques, such as molecular beam epitaxy (MBE). Although the firm fabricated the first SiGe HBT in 1987 using MBE, the switch to the more efficient UHV/CVD processing approach was made shortly thereafter. In 1993, tremendous publicity was generated by the announcement of a joint effort on the part of IBM and Analog Devices (Wilmington, MA) to produce a 12-b, 1.2-GSamples/s digital-to-analog converter (DAC). Unfortunately, the joint effort by the two firms did not survive the low breakdown voltages and limited yields of the process at that time.

SiGe processes essentially build on established semiconductor process approaches such as Si CMOS, by depositing a thin layer of Ge on top of the Si substrate. Depending on the device characteristics of a particular process, the Ge layer is often graded in thickness, to control parasitic capacitances and inductances and optimize high-frequency performance. The resulting compound semiconductor material has a carrier mobility that is two to three times that of standard Si, while maintaining the relatively low cost of standard Si CMOS processing and materials. The high carrier mobility is of particular benefit to certain types of transistor structures, notably HBTs. Deep trenches are formed in the SiGe materials to achieve the isolation needed for high-quality passive components, such as capacitors. Even compared to GaAs, the proponents of SiGe processing, such as IBM, promise lower-voltage/lower-power operation, less low-frequency noise, improved third-order intercept performance, and tremendous potential for integration of analog and digital functions. Yet, supporters of GaAs claim that the cost differential between GaAs and SiGe is not that great due to the additional processing steps required to create SiGe ICs, and that GaAs is still a better substrate for forming high-performance passive circuit elements.

If the papers at the upcoming 45th Annual IEEE International Elec-

WHAT'S IN A NAME?

No firm could be more closely linked to SiGe technology than one with the name SiGe Microsystems, Inc. (Ottawa, Ontario, Canada). The company, one of the first to announce commercial SiGe products, already supports numerous industries with circuits of varying complexity. The first product, a differential Global Positioning System (GPS) receiver, operates at 1.5 GHz.

More recently, the firm announced the model PA2425 monolithic SiGe power amplifier (PA) for use in the 2.4-GHz industrial-scientific-medical (ISM) band. Ideal for applications in IEEE 802.11 wireless local-area networks (WLANs), Bluetooth systems, and HomeRF products, the high-efficiency PA delivers +25-dBm typical output power (+24-dBm minimum output power) from 2400 to 2500 MHz with 45-percent power-added efficiency (PAE) in Class AB mode. The amplifier exhibits gain variations of typically ∓0.5 dB across the full operating band. The reverse isolation is typically 32 dB, while second, third, and fourth harmonics are –40 dBc.

Supplied in an eight-lead plastic-small-outline-package (PSOP) housings, the amplifier's SiGe structure and heatslug die pad provide high thermal conductivity and resulting low junction temperatures. The effective thermal dissipation enables the amplifier to operate at a 100-percent duty cycle while drawing only 220 mA from a single +3.3-VDC supply. The integrated circuit (IC) includes bias control and power-down functions. SiGe Microsystems, Inc., 1500 Montreal Rd., M50 IPF, Ottawa, Ontario K1A OR6, Canada; (613) 748-1334, FAX: (613) 748-1635, Internet: http://www.sige.com. ●●

tron Devices Meeting (December 5-8, 1999, Washington Hilton and Towers, Washington, DC) are any indication, SiGe technology promises to become an even greater threat for GaAs and conventional Si processes in the years to come. G. Freeman, D. Ahlgren, and co-workers from IBM Microelectronics will offer insights into the next generation of SiGe devices with a presentation at IEDM on a 0.18-µm SiGe process that is BiCMOS and ASIC compatible. Capable of producing HBTs with f_T performance of 90 GHz at a breakdown voltage of +2.3 VDC, lower-frequency performance is possible at 25 GHz for a breakdown voltage of +5.5 VDC.

Also, a report from Katsuyoshi Washio and associates from the Central Research Laboratories of Hitachi Ltd. (Tokyo, Japan) details a 0.2-µm self-aligned SiGe HBT capable of 6.7-ps emitter-coupled-logic (ECL) gate delays and maximum frequency of oscillation (f_{max}) of 107 GHz. Compatible with standard Si BiCMOS, the new process promises to support high-speed data-communications systems operating in excess of 10 Gb/s. To reduce parasitic capacitance across devices, shallow-trench and deep trench isolations were used.

A paper to be given by K.E. Ehwald and colleagues from the Institute for Semiconductor Physics (Frankfurt, Germany) in conjunction with researchers from Motorola, Inc. (Mesa, AZ) explains how only four additional mask layers are needed to add SiGe:C HBTs to a standard 0.25-µm CMOS process without changes in the CMOS process flow. The resulting BiCMOS process yields peak HBT transition frequency (f_T) of 55 GHz and f_{max} of 90 GHz at a breakdown voltage of +3.3 VDC.

Finally, C.A. King and fellow researchers from Bell Laboratories/Lucent Technologies (Murray Hill, NJ) will offer a technique for lowering the cost of SiGe processing. Their solution is a low-cost graded SiGe-base BiCMOS technology with Lucent's existing 0.25-µm CMOS process at the core. The modified, low-cost process requires the addition of only four lithography levels to the existing process, and results in self-aligned SiGe transistors with peak f_T of 51 GHz and peak f_{max} of 53 GHz at a breakdown voltage of approximately +2.5 VDC.

Several years ago, mention of SiGe technology brought raised eyebrows and much skepticism about its practical application in either high-frequency analog or high-speed digital circuits. Today, the technology boasts a growing list of commercial products, manufacturers, as well as believers in its future for high-frequency, high-speed products (see sidebar on p. 121). ●●

References

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