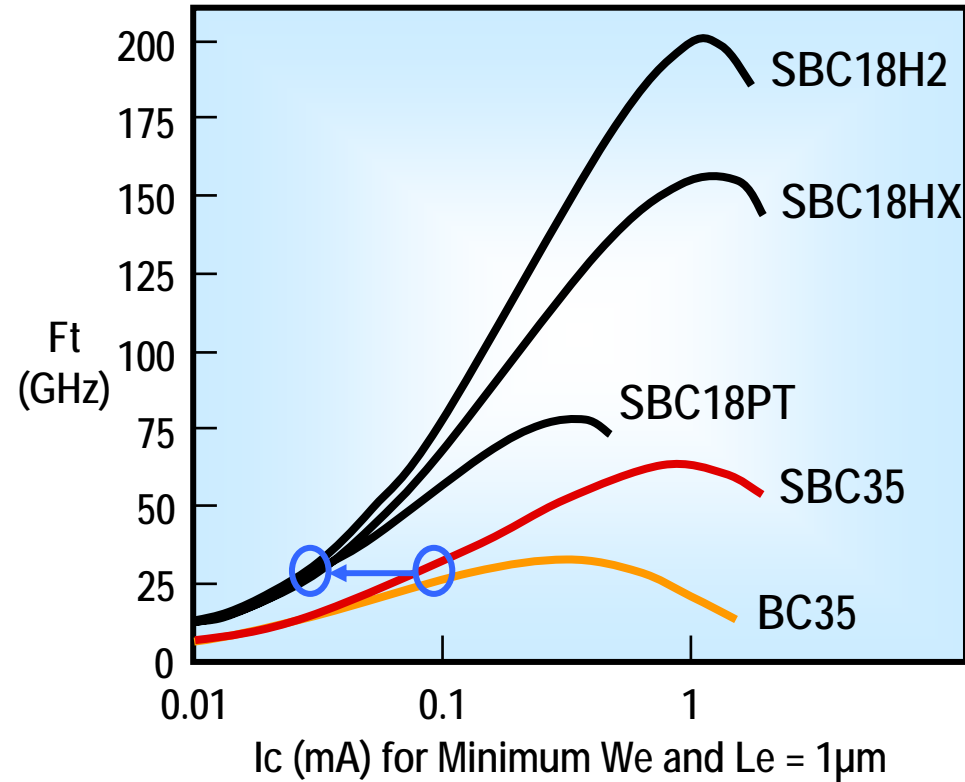
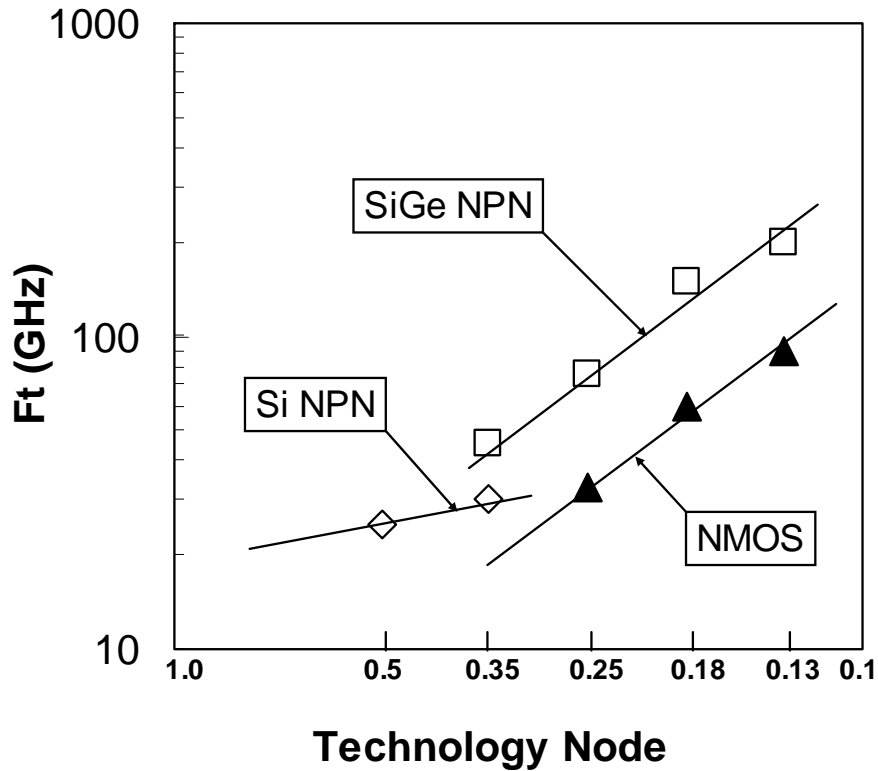


SiGe BiCMOS for Communication ICs

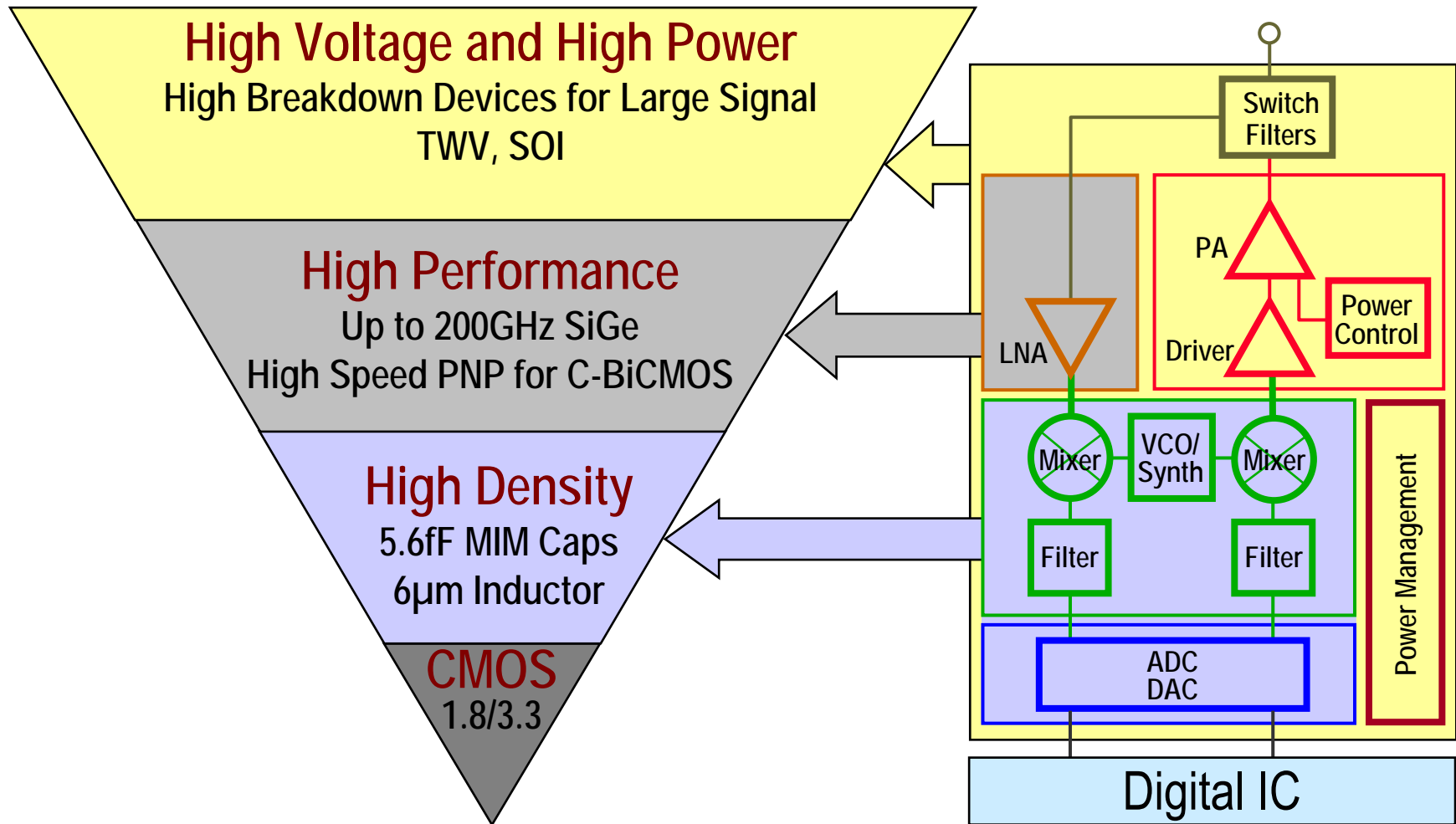
Marco Racanelli
August 5th, 2008

SiGe BiCMOS Evolution



SiGe Remains 2-3 Technology Nodes ahead of CMOS in Performance

SiGe BiCMOS Platform for Analog Integration



SiGe is Combined with CMOS and Advanced Passives for Analog System Integration

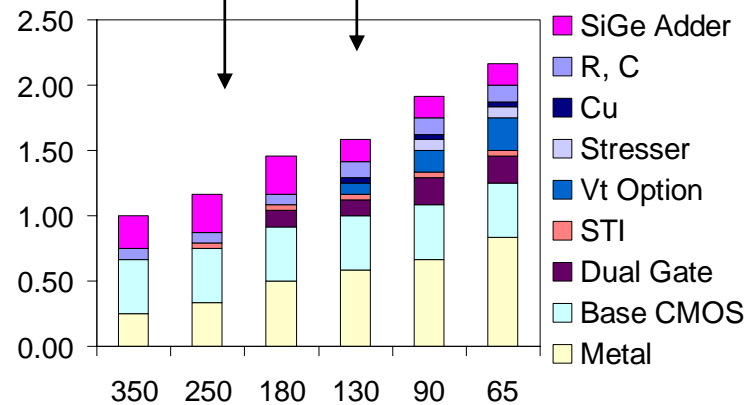
SiGe Integration Roadmap



Most popular foundry node today

Most advanced foundry node today

Normalized Layer Count



Technology Node (nm)

SiGe is a Lower Cost-Adder in More Advanced CMOS Nodes

SiGe Performance Roadmap

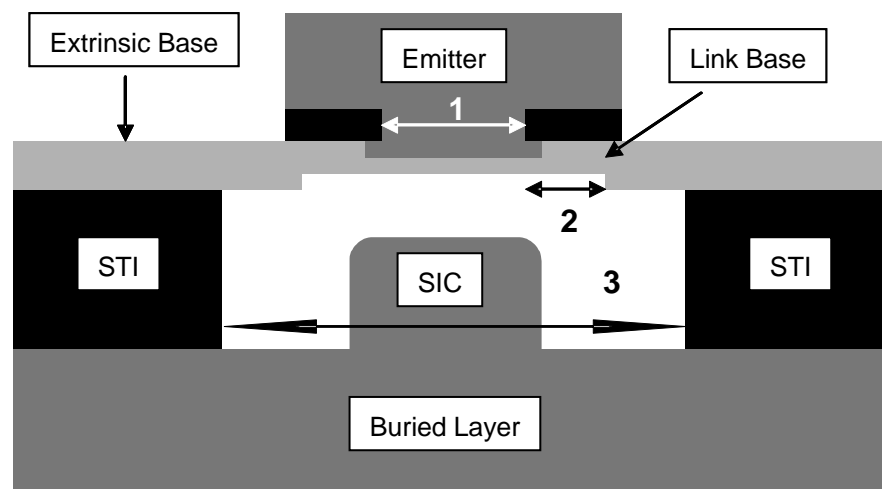


1. Lithography Scaling (lateral):

- Emitter width (1)
 - Base Resistance
 - Power Consumption
- Base Link / Active Width (2,3)
 - Base Resistance
 - Collector Capacitance

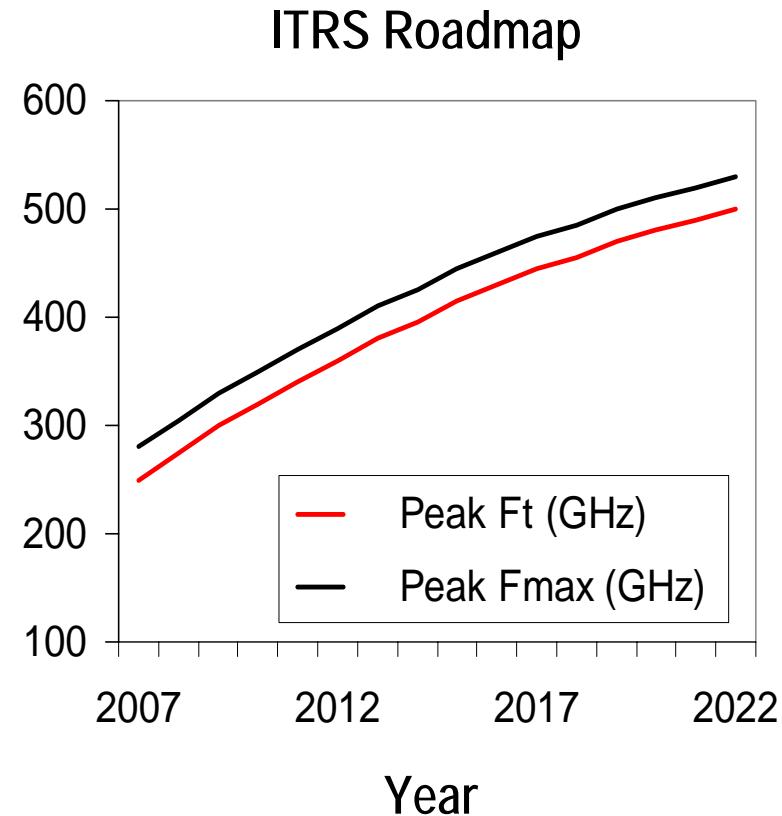
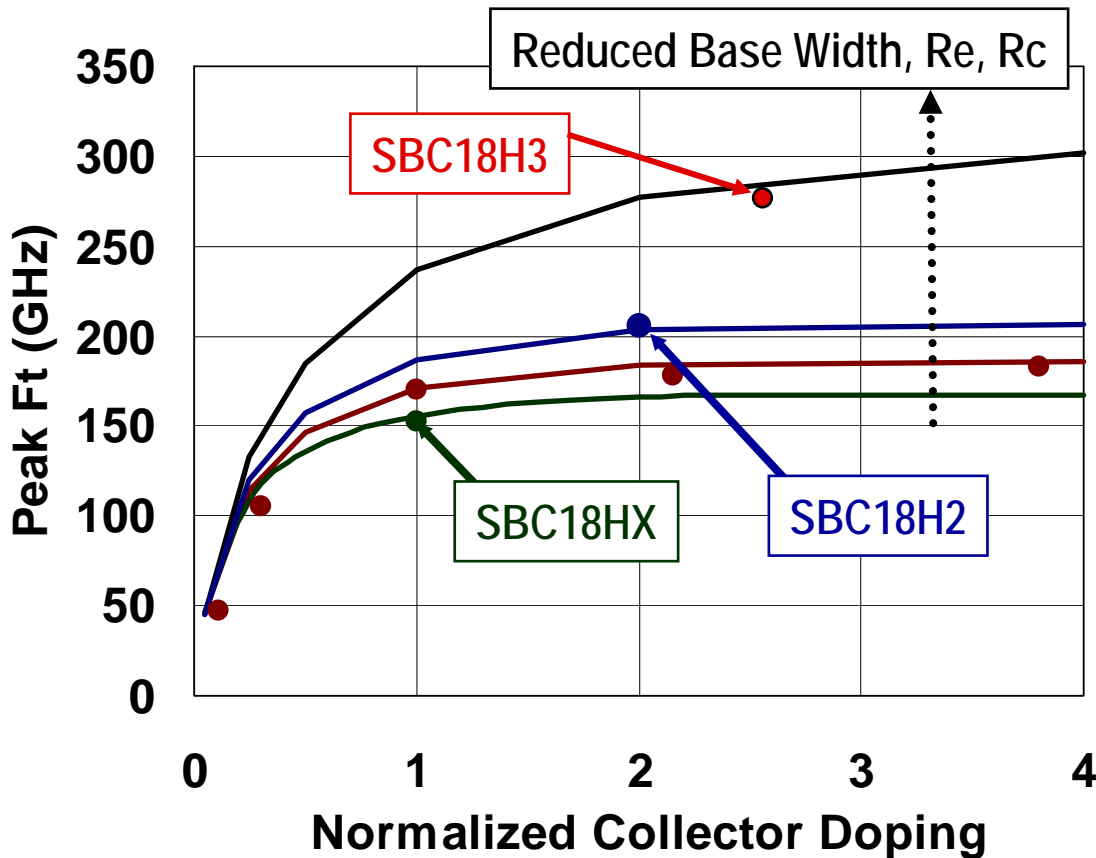
2. Vertical Scaling

- Emitter/Base/Collector profile
 - Trade off R_b/C_{bc} for higher τ_f

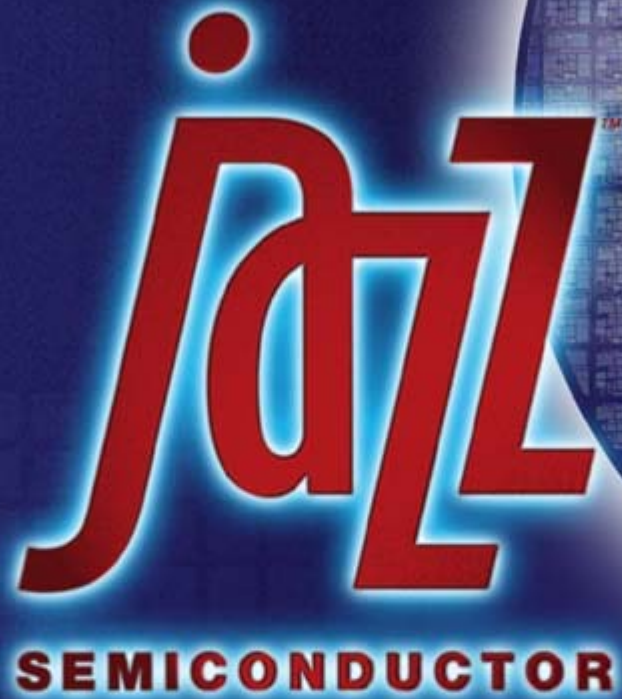


Lithography advances continue to improve SiGe device performance

SiGe Performance: Vertical Scaling



Lower R_b , R_c from lateral scaling can be traded for higher Ft through vertical scaling continuing to achieve both high Ft and high Fmax



Applications

Benefits of SiGe over CMOS for High Speed Analog

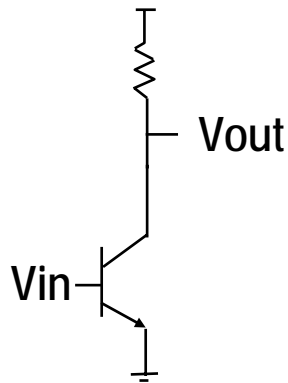


- Performance (F_t/F_{max}) that is superior by 2-3 generations
 - 0.18 μ m SiGe (200GHz) is comparable to 65nm CMOS (~200GHz)
 - Leads to lower mask/wafer cost vs. CMOS for same F_t
 - F_t/F_{max} can be traded off for lower power consumption
- Low 1/f Noise and HF Noise
 - 1/f noise is orders of magnitude lower than CMOS
 - HF noise more easily matched to simultaneously deliver high gain (better LNA)
- Better dynamic range and high voltage handling capability
 - 200GHz still supports >5V operation on the collector (vs. ~1V for 65nm CMOS)
 - 30GHz can support 20V for Power Amplifier applications (vs. 3.3V for CMOS)

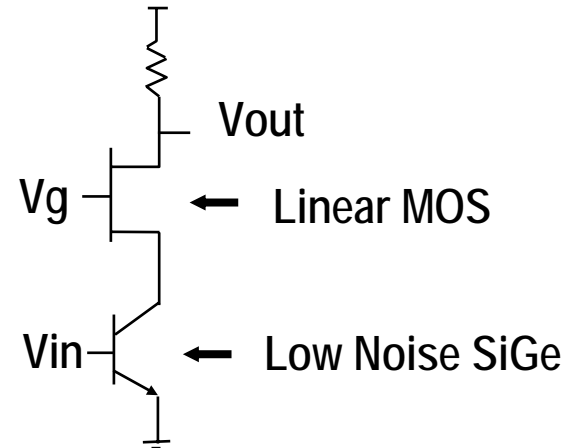
SiGe for Low-Noise-Amplifiers



Low NF, high Rn, Ga, at low current with good linearity make SiGe superior to MOS for LNA



SBC18 Low NF PCS LNA



SBC18 Low Power PCS LNA

	Process Technology	Gain dB	Ic mA	Power mW	NF dB	IIP3 dBm
Low NF PCS LNA*	SBC18	16.2	2.75	8.3	0.99	12.6
Low Power PCS LNA**	SBC18	16	1.40	3	1.67	-6

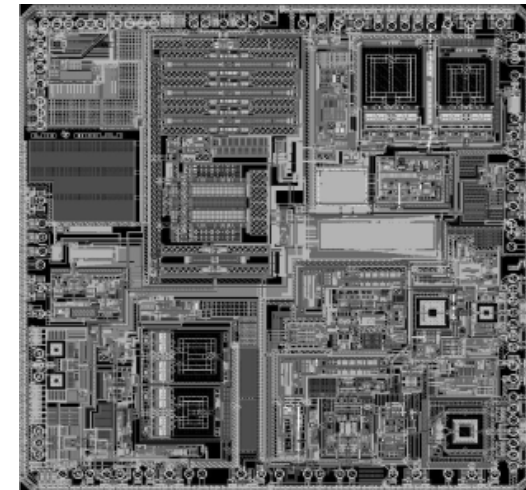
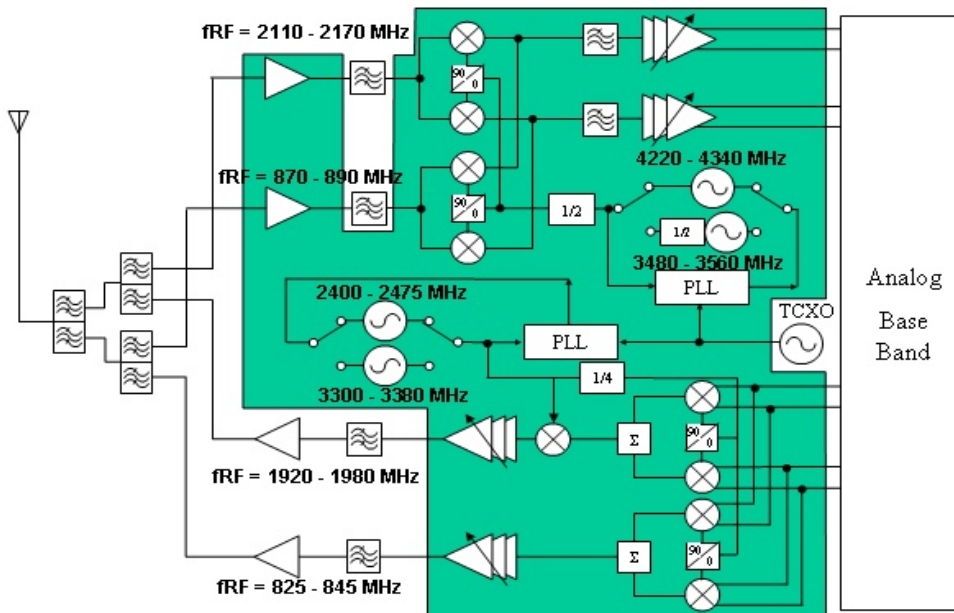
* P. Ye et al., 2002 RFIC Symp, Skyworks Solutions

** P. Ma et al., 2003 RFIC Symp

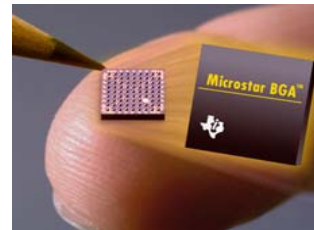


SiGe high levels of integration for RF Transceivers

Alhambra TRF6302 Dual Band WCDMA Transceiver



- < 3cm² single-sided PCB total radio area
- 6mm x 6mm u^{*}Jr. (120GQZ) BGA CSP
- 28mA RX, @ 2.8V supply
- 54mA TX @ 6dBm Pout

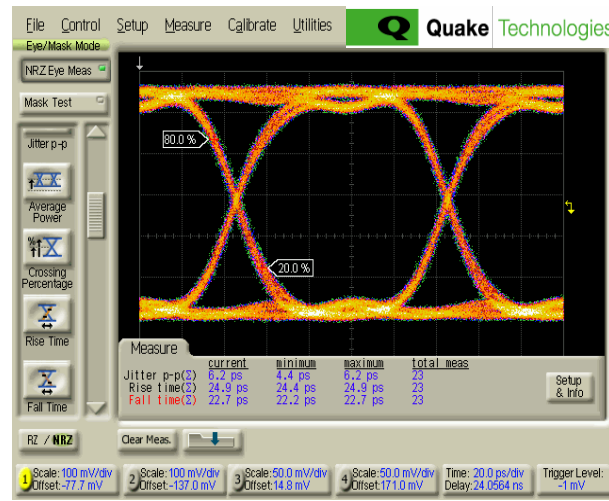


RF 800/2000 MHz WCDMA	Component Count
Front End Module	1
PAM	1
Alhambra (RF IC)	1
Resistors	5
Inductors	9
Capacitors	30
TCXO	1
LDO's	2
SAW's	4
RF DUAL BAND	54

And High-Speed Wireline Transceivers



Low Power - 1.9W 10.7 Gb/s Low Jitter SerDes

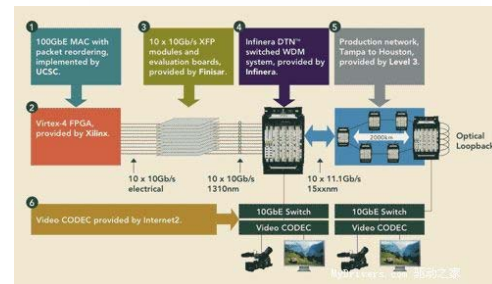


Cost Effective 0.35um SiGe for FTx Components

0.18um SiGe for High-Speed Emerging Markets



Phyworks leverages Jazz Semiconductor's 0.35 and 0.18 Micron SiGe BiCMOS Process Technologies to maintain Competitive Edge

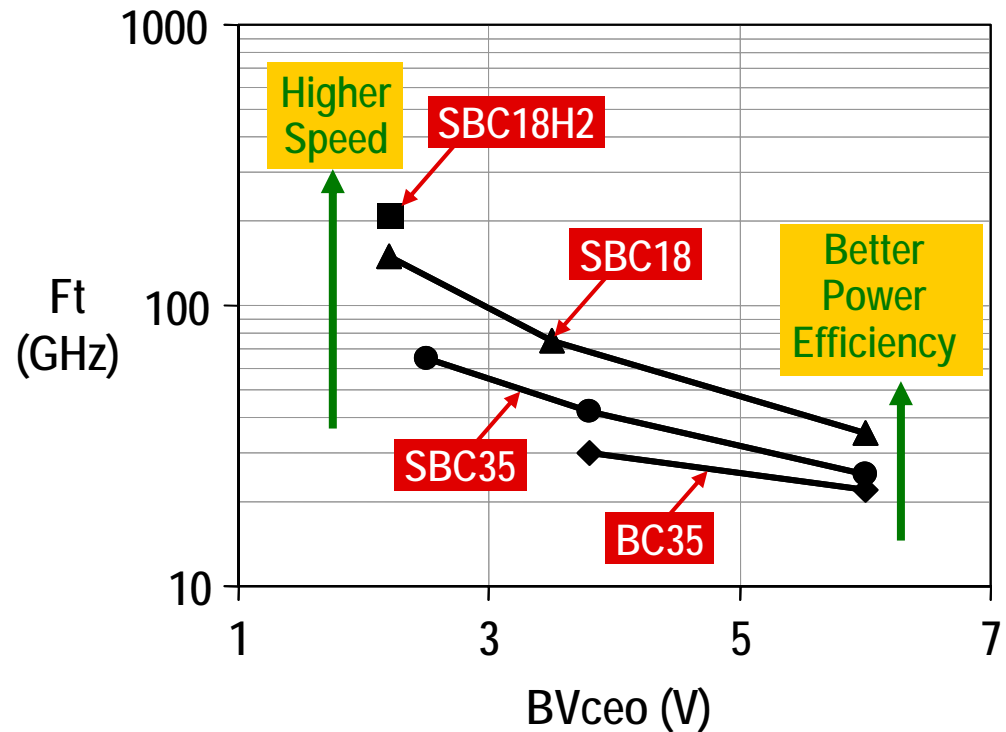
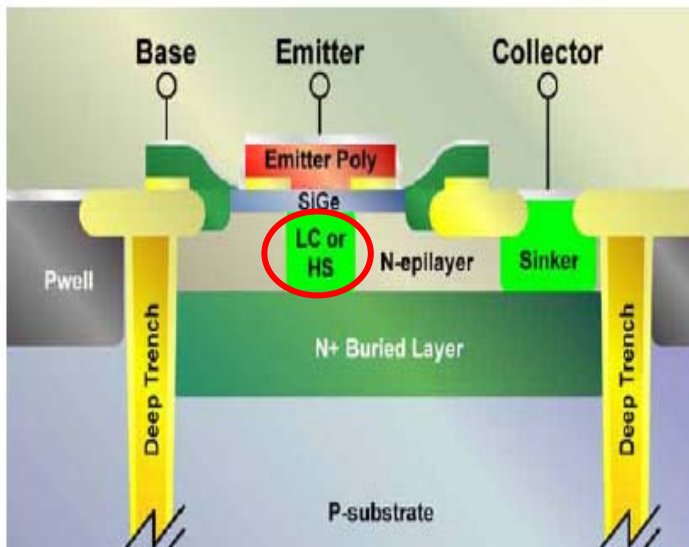


0.18-MICRON SiGe BiCMOS PROCESS TO DELIVER THE FIRST 100 Gb/s ICs FOR OPTICAL NETWORKS

SiGe for Power Amplifiers

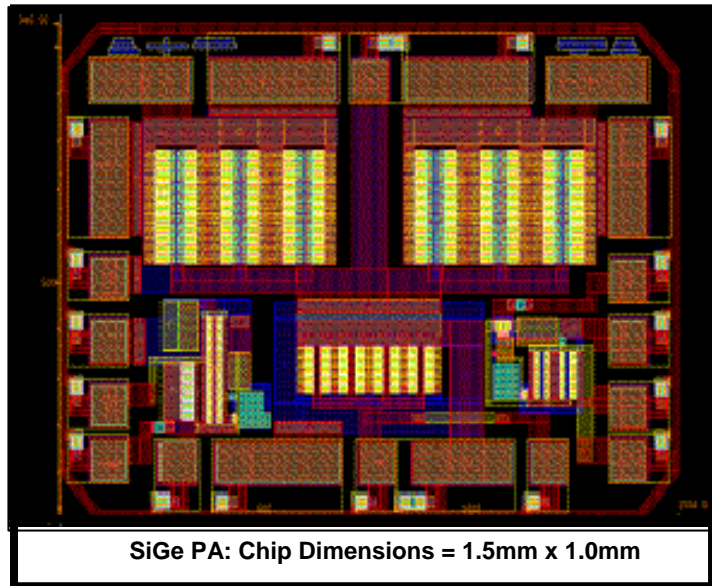


Collector implant modulates speed / breakdown tradeoff



Each new SiGe generation improves speed vs. breakdown improving PA performance

High Power PA Examples: 0.35um SiGe



836.5MHz Pout=28dBm	PAE (%)	ACPR1 (dBc)	ACPR2 (dBc)	Pgain (dB)
SiGe	43	-47	-55	30.4
GaAs	45	-47	-56	29.4

1.88GHz Pout=28dB	PAE (%)	ACPR1 (dBc)	ACPR2 (dBc)	Pgain (dB)
SiGe	32.5	-47	-57.5	22.4
GaAs	41.0	-47	-59.7	27.0

Ruggedness	PIN (dBm)	VCC at PA Failure (V)	PA Survives (V)
SiGe	6.3	4.4	4.3
GaAs	1.4	4.1	4.0

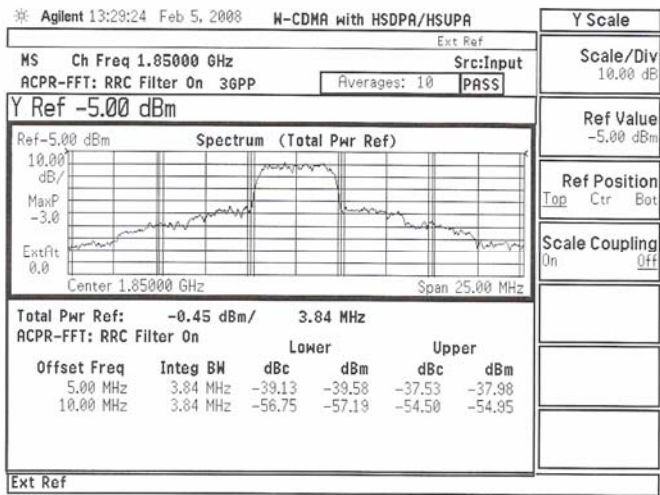
0.35um SiGe competitive at 800MHz but lagging GaAs at 2GHz

* Keith Nellis and Peter Zampardi, 2003 BCTM, Skyworks Solutions

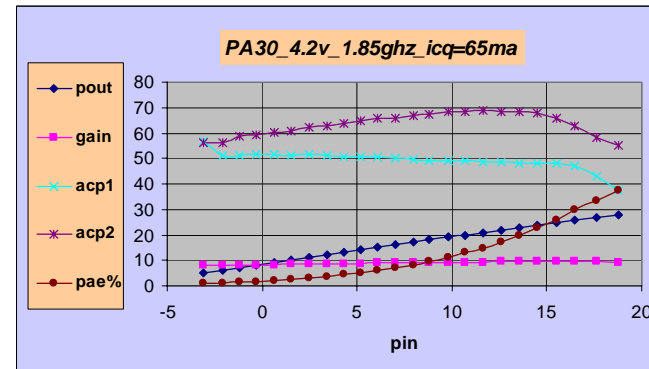
High Power PA Examples: 0.18um SiGe



WCDMA Compliant



1.85GHz, PAE=39%, Pout=28dBm



Ruggedness

- VCC = 4.8v,
- PO=28dbm CW.
- 10:1 VSWR
- Room Temp

NO DAMAGE

0.18um SiGe competitive with GaAs for WCDMA PA applications

Silicon Radio Platform SOI for Antenna Switch Integration

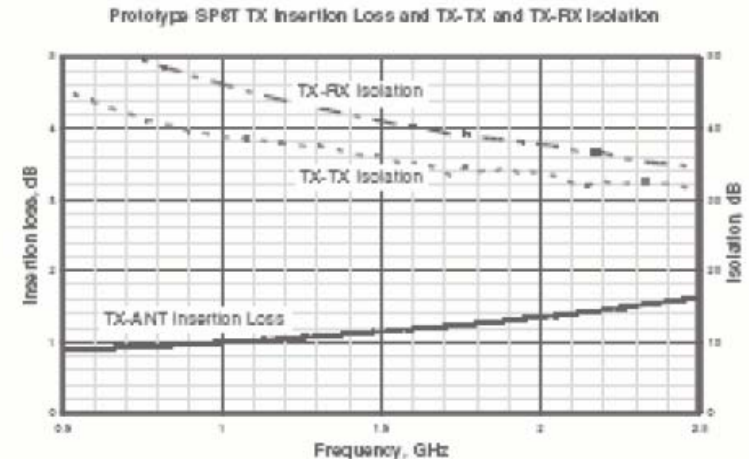
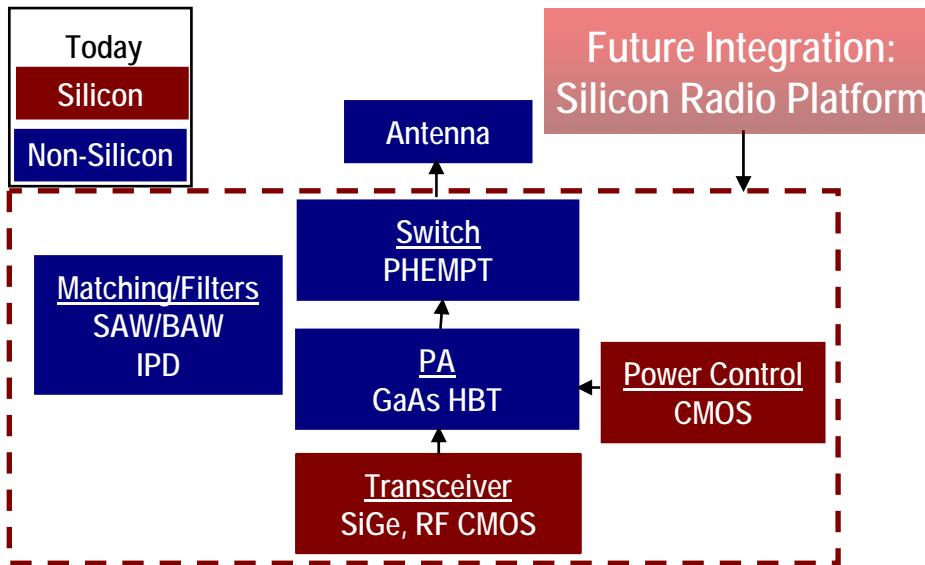


Fig. 9. Measured SP6T insertion loss and isolation characteristics of the prototype SP6T switch. Insertion loss is measured using an RF probe technique calibrated close to the die. Isolation measurement include approximately 1dB of board losses..

Measured Data on Silicon-SOI Switch*

IL <1dB (900 MHz)

IL <1.2dB (2 GHz)

* RFMD, 2007 MTT

Enable Complete Integration of PA + Switch + Control (+ Transceiver) on a Single Die

SiGe for mmWave Emerging Applications

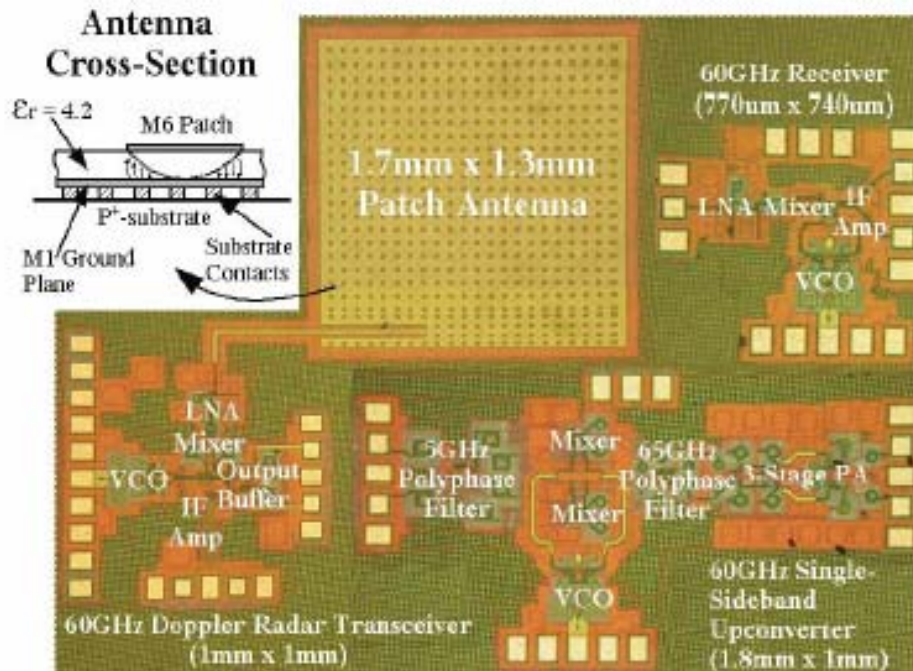


- New applications emerging in the 10GHz to 100GHz band
 - 24GHz radar
 - 77GHz collision avoidance
 - 60GHz WLAN
 - 100GHz imaging
 - 40Gb + Optical Networks
- 0.18um SiGe offers significant benefit over 65nm CMOS
 - Lower noise
 - Better large signal performance
 - Better passive elements
 - Lower cost

mmWave Example: 60GHz WLAN



60GHz WLAN TxRx with Integrated Antenna In 0.18um SiGe



Performance

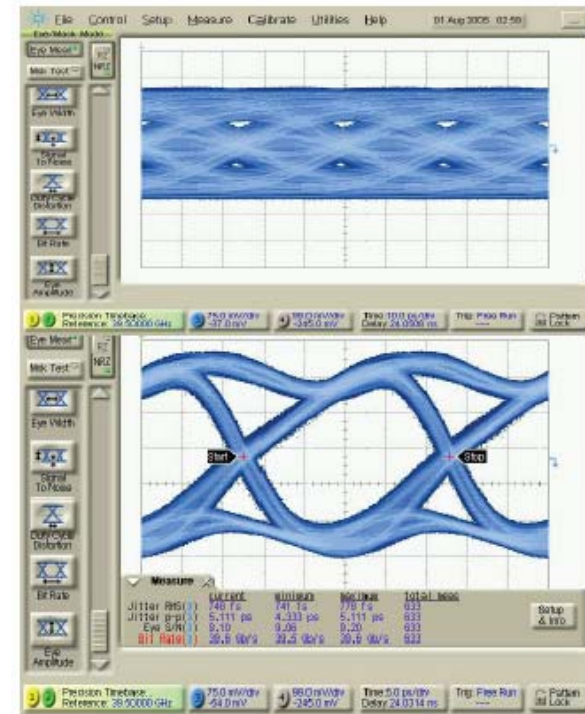
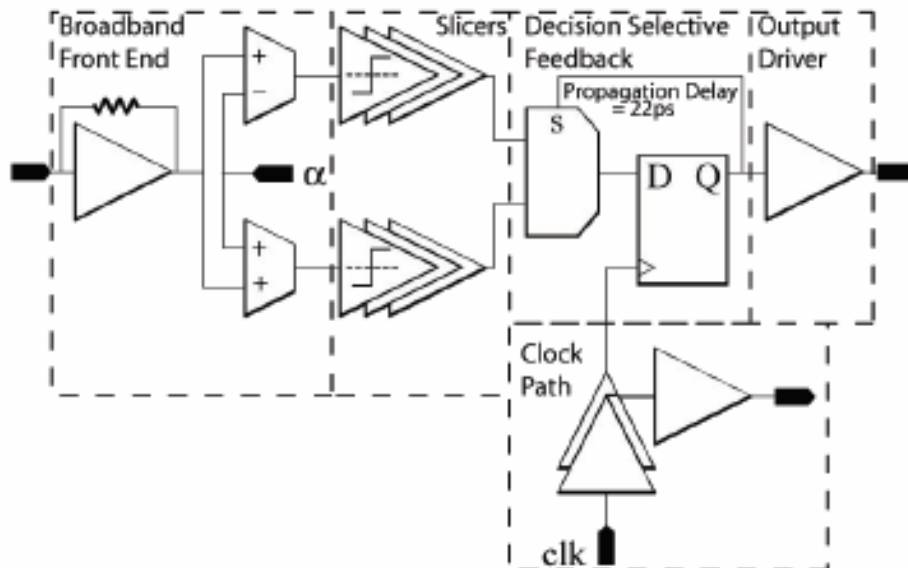
Supply Voltage	3.3V
Conversion gain	20dB
Noise Figure	12dB
Image Rejection	45dB

S.P. Voinigescu, T. Chalvatzis, K.H.K. Yau, A. Hazneci, A. Garg, S. Sharahmian, T. Yao, M. Gordon, T.O. Dickson, E. Laskin, S.T. Nicolson, A.C. Carusone, L. Tchoketch, O. Yuryevich, G. Ng, B. Lai, and P. Liu, "SiGe BiCMOS for Analog, High Speed Digital and Millimetre-Wave Applications Beyond 50GHz", BCTM Proc., Sept. 2006.

mmWave Example: 40Gb/s Communications



40Gb/s Equalizer In 0.18um SiGe

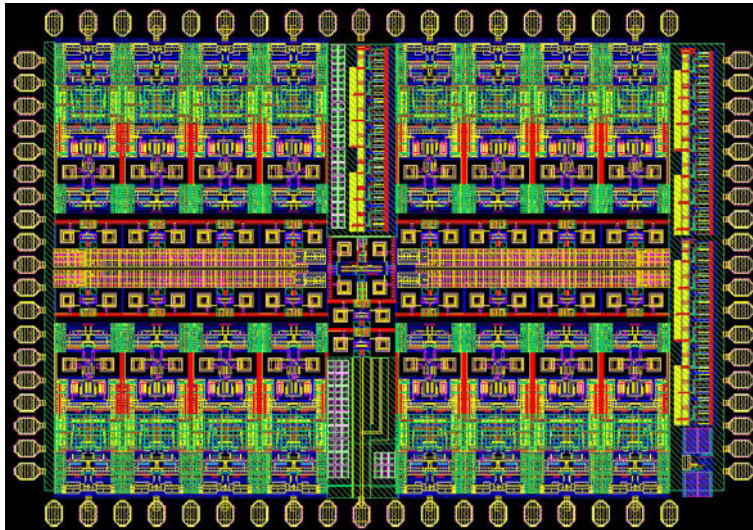


S.P. Voinigescu, T. Chalvatzis, K.H.K. Yau, A. Hazneci, A. Garg, S. Sharahmian, T. Yao, M. Gordon, T.O. Dickson, E. Laskin, S.T. Nicolson, A.C. Carusone, L. Tchoketch, O. Yuryevich, G. Ng, B. Lai, and P. Liu, "SiGe BiCMOS for Analog, High Speed Digital and Millimetre-Wave Applications Beyond 50GHz", BCTM Proc., Sept. 2006.

mmWave Examples: Phased Array



Phased Array Receiver in 0.18um SiGe



Beamformer-on-a-chip

Frequency	40-50 GHz
Channels	16
Die Size	3.2x2.6 mm ²

K. Koh and G. M. Rebeiz, "An X- and Ku-Band 8-Element Linear Phased Array Receiver,"
IEEE Custom Integrated Circuits Conference, pp. 761-764, San Jose, September 2007.
DARPA Press Announcement

Summary



- **SiGe BiCMOS offers advantages over CMOS for high speed analog**
 - Performance that is 2-3 generations ahead of CMOS
 - Continued performance roadmap (200-300GHz today)
 - Power, noise, high voltage handling advantage
 - CMOS offers better digital density and power
- **SiGe has been a high-volume technology for 7-10 years**
 - Largest markets: Wireless and wireline transceivers, TV tuners, HDD pre-amp
- **New markets emerging for SiGe**
 - Power amplifiers displacing GaAs components
 - Already happening for low-power and underway for cellular
 - mmWave applications pushing analog performance
 - 24/77GHz radar, 60GHz WLAN, 40Gb/s optical communications