2006
International Technology Roadmap for Semiconductors

Radio Frequency and Analog/Mixed-Signal Technologies for Wireless Communications Working Group

ITRS Public Conference
July 12
San Francisco, CA

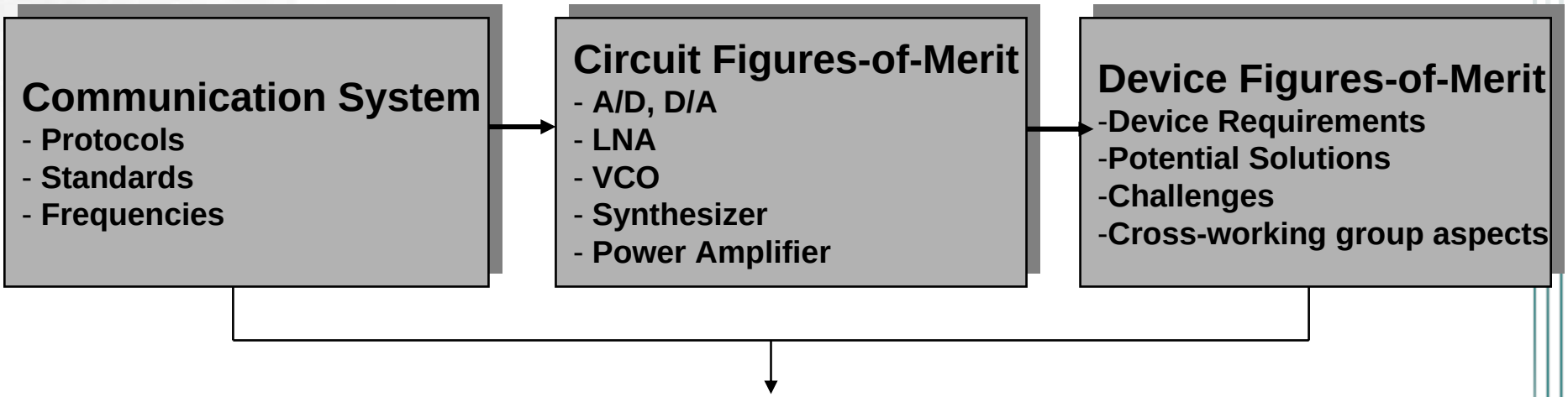
Objectives

- Use wireless IC as system / technology driver for ITRS
- Address intersection of Si-based technologies with III-V compound semiconductors and other potential technologies (MEMS, BAW, Passives, ..)
- Present technical challenges and requirements for AMS & RF IC technologies in wireless 0.8-100GHz applications such as cellular phones, WLAN/WPAN, automotive radar, phased array systems and other emerging standards
- Chapter divided into 5 sub-groups
  - CMOS for RF and AMS
  - Bipolar for RF and AMS
  - Passives for RF&AMS and PA
  - Power Amplifiers
  - Millimeter Wave

0.8-10 GHz Systems

→ 10-100 GHz Systems

Working Strategy



Technology Roadmap for Devices :

Material systems : Si, SiGe, GaAS, InP, SiC, GaN

Device structures : MOSFET, LDMOS, HBT, MESFET, PHEMT, MHEMT, on-chip passives

XTWG

2006 Organization

Chair :	**Margaret Huang, Freescale**	**27 Members /last year 34**
Co-chairs :	**Bin Zhao, Skyworks**	**16 US, 6 Europe, 5 AP**
	Jan-Erik Mueller, Infineon	
Editor :	**Herbert Bennett, NIST**	

• **Subgroup (1) : CMOS (11)**	**Peter Cotrell, IBM**
• **Subgroup (2) : Bipolar (6)**	**Marco Racanelli, Jazz**
• **Subgroup (3) : Passives (5)**	**Sam Shichijo, TI**
• **Subgroup (4) : PA & power management (4)**	**P. Zampardi, Skyworks**
	Chuck Weitzel, Freescale
• **Subgroup (5) : Millimeter Wave System (5)**	**Tony Immorlica, BAE Systems**

2006 Organization

Herbert Bennett	NIST
Doug Coolbaugh	IBM
Julio Costa	RFMD
Peter Cottrell	IBM
Stefaan Decoutere	IMEC
Erwin Hijzen	Philips
Digh Hisamoto	Hitachi
W. Margaret Huang	Freescale
Anthony Immorlica	BAE Systems
Snezana Jenei	Infineon
Jay John	Freescale
Alvin Joseph	IBM
Takahiro Kamei	Oki
Tom Kazior	Raytheon
Yukihiro Kiyota	Sony
Sebastian Liau	ITRI Taiwan
Jan-Erik Mueller	Infineon
Hansu Oh	Samsung
Marco Racanelli	JAZZ
Bernard Sautreuil	STM
Sam Shichijo	TI
Chuck Weitzel	Freescale
Geoffrey Yeap	Qualcomm
Bin Zhao	Skyworks
Peter Zampardi	Skyworks
Herbert Zirath	Chalmers U
John Zolper	DARPA

2006 New members

2006 Requirement Tables Updates

- **No major updates plan**
- **CMOS**
  - **No wireless specific updates**
  - **Dependent on PIDS LSTP CMOS**
- **Bipolar**
  - **update the Jc at peak HF device Ft to reflect recent data**
- **Passives**
  - **clarify voltage and temperature for the capacitor leakages**
- **mm-Wave**
  - **InP HBT**
  - **GaN**

2006 Updates for mm-wave

- **InP HBTs**
  - **Predictions on target and solutions in hand**
    - **f_t/f_{max} 400/450 GHz demonstrated**
  - **Addresses market needs in Digital Synthesizers, A/D converters, mixed signal**

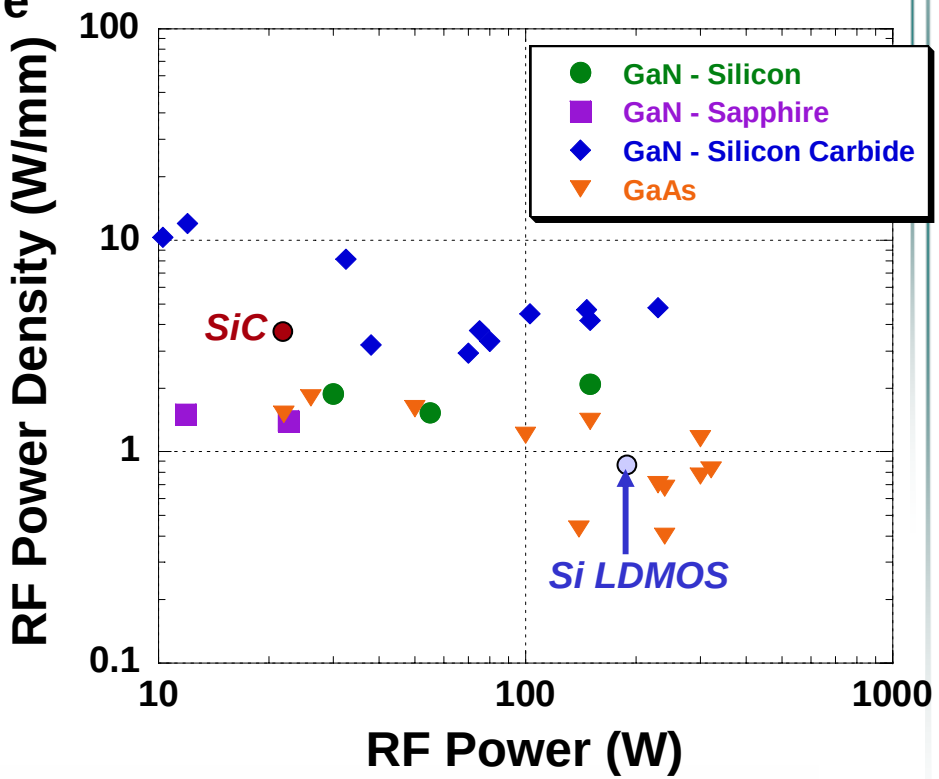
- **GaN HEMTs**
  - **Significant [up to 10X] power density advantage over all other technologies**
    - **Record power densities at 40 GHz of 10W/mm with 40 Volts drain bias***
  - **Challenges for commercialization for mm-wave**
    - **Stability, leakage current at shorter gate lengths, and reliability**
    - **Cost and maturity of substrates and fabrication processes**
    - **Thermal management**
  - **Significant progress since 2005, but commercialization will lag predictions by several years. No volume markets to drive earlier results.**

GaN Ref:
T. Palacios et al, High Power AlGaN/GaN HEMTs for Ka-Band Applications IEEE Elec Dev lett, V26, No.11, Nov 2005
P. Schuh et al, 20W GaN HPAs for Next Generation X-Band T/R Modules, 2006 IEEE MTT-S Symposium, paper WE3B-06, June 2006

GaN HFET for Base Station Power Amplifiers

- GaN offers significantly higher RF power densities than GaAs
  - Lower loss matching, especially very large devices
  - Higher operating voltage, 48 V
  - Higher operating temperature possible
  - Optimize packaging to maximize advantage
  - Look for overall system advantage
- Challenges for commercialization
  - Device DC and RF stability
  - Device reliability
  - Cost Cost Cost

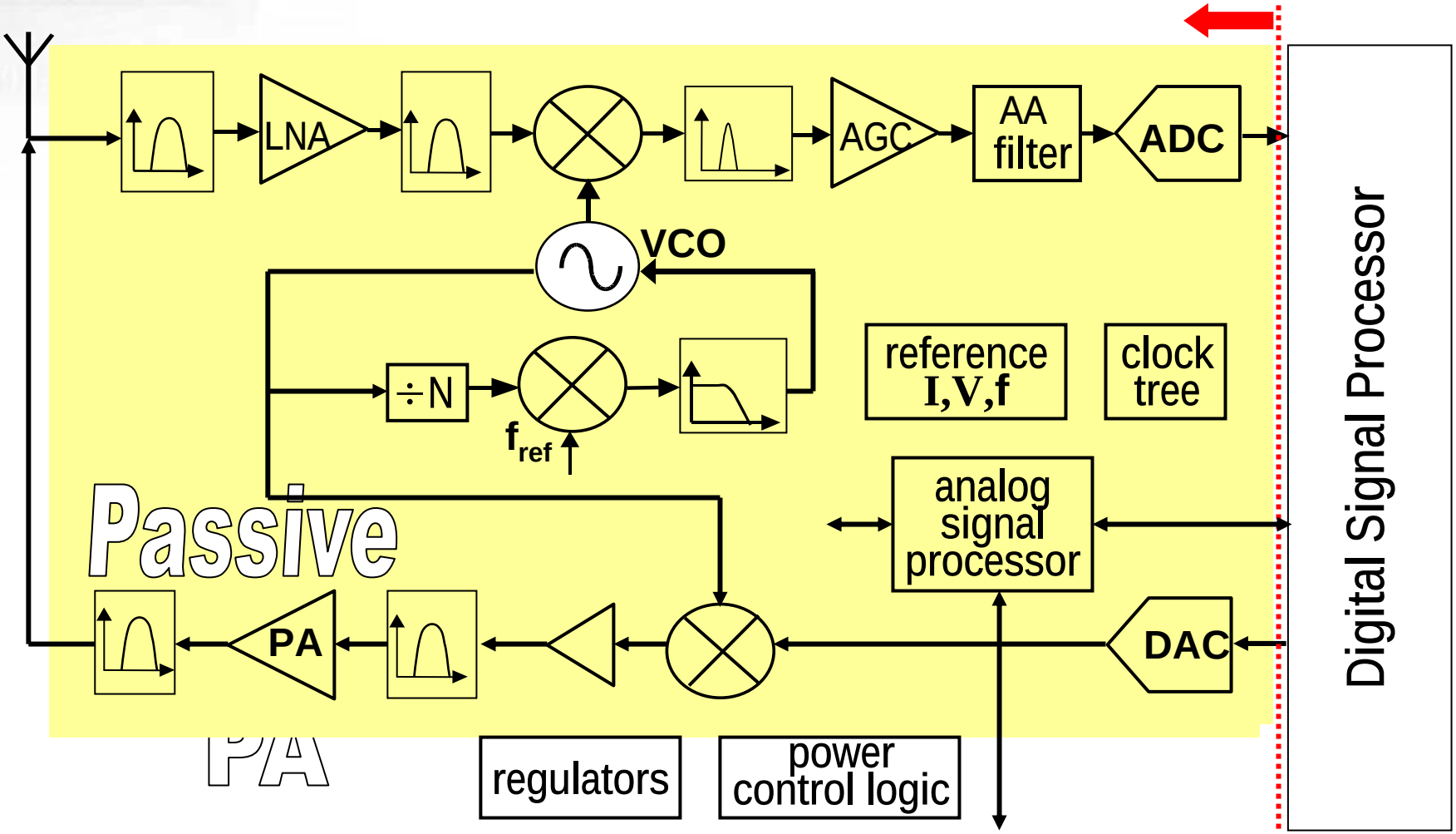
GaN-GaAs Power > 10 W



Power densities on SiC substrates 3-4 times those of best GaAs power FET's

Ref: C. Weitzel 2006 IMS

Basic mobile communication system



Cross-TWG Focus - Design

- **Software Define Radio (SDR) impact on analog/RF CMOS requirements**
  - **Address growing market multi-band, mutli mode, portable applications**
  - **ALL digital radio:**
    - **ADC performance (sample rate, resolution, power consumption)**
    - **Transmit solution (power out, linearity & efficiency)**
    - **Cost (size, time-to-market)**
  - **Hybrid with RF/Analog front end**
    - **wideband LNA**
    - **multiple PAs + switch**
    - **Single PA with matching and switch network (linearity & efficiency)**
  - **Device roadmap alone does not enable SDR**
  - **Propose Design TWG address all digital radio requirements**
  - **Wireless propose adding filters and switches tables to address Hybrid SDR**
    - **Exploring expansion of scope to include new semiconductor devices (eg. MEMs, SOS) and relevant figure(s) of merit for existing elements**

ADC Ref:
A. Abidi 2006 RFIC 12b, 10GS/s over 800MHz to 5.5GHz band

Cross-TWG Focus - Assy&Pkg

- Wireless focus on functional requirement, packaging focus on how to provide it
- Initial focus on <10GHz Front End Module (PA, switch, filter drive requirements)
- Assembly
  - Wireless to provide Front End Module /Single Package Radio Assembly requirements
    - e.g. Laminate Requirements: surface mount component, Die mounting technology, # routing layers, Design Rule Mismatch between Semi and Laminate (flip-chip bump size&pitch), thermal management (power density), cost
  - Wireless to determine need for stacked Die for Radio Front End
  - Wireless to provide Switch & Filter assembly requirements
- Components and Embedded Components
  - Generic PA and on-chip passive spec (current Wireless tables)
  - Wireless to provide off-chip Passives requirements (Assy&Pkg table)
    - T-Lines, Inductors, Caps, R's, Vias, Couplers/Detectors, Current&Voltage ratings under mismatch, tolerance, model (Design TWG?)
  - Discussion for roadmap coverage:
    - SMT, Passive Chips, Embedded Components (substrate)

Difficult Challenges (1)

- **Signal isolation – challenge to both technologists and EDA tool providers, discuss but not roadmap due to difficulty with setting figure of merit**
- **CAD solution for Integrated Radio SiP design (chip, passive, component, package, tool compatibility, model accuracies, isolation)**
- **Optimizing analog/RF CMOS devices with scaled technologies and scaled power supply: voltage gain, mismatch, 1/f noise, leakage and breakdown**
- **Fundamental changes in CMOS device structure to FDSOI or Dual-Gate device may lead to the need of separate process/chip to support conventional precision analog/RF devices**

Difficult Challenges (2)

- **Cost and performance tradeoff of integrating passive devices in scaled CMOS (additional processing steps, silicon area, need of new material)**
  - **High density integrated passive device scaling; Q-factor and inductance for inductors, high tuning range and Q varactors, matching and linearity for capacitors, precision resistor**
- **Predictability of battery technology roadmap and impact on PA and power management roadmap**
- **Compound semiconductor substrate quality & availability, esp for SiC used for GaN**
- **High power density of emerging GaN technologies demand new approaches to thermal management at both chip and package level**

Publications

• H. S. Bennett, R. Brederlow, J. Costa, P. Cottrell, W. M. Huang, A. A. Immorlica Jr., J-E Mueller, M. Racanelli, H. Shichijo, C. E. Weitzel, B. Zhao, "Radio-Frequency and Analog Mixed-Signal Circuits and Devices for Wireless Communications", IEEE Circuits and Devices Magazine, Nov. 2004, pp. 38-51.

• H. S. Bennett, R. Brederlow, J. Costa, P. Cottrell, W. M. Huang, A. A. Immorlica Jr., J-E Mueller, M. Racanelli, H. Shichijo, C. E. Weitzel, B. Zhao, "The Compound Semiconductor Roadmap Embedded in the ITRS:Implications for the MANTECH Community", Mantech, April 2005, New Orleans.

• C. E. Weitzel, "Will GaAs Survive Wireless PAs?," Mantech, April 2005, New Orleans.

• H. S. Bennett, J. Costa, A. A. Immorlica Jr., and C.E. Weitzel, "Opportunities And Challenges For Indium Phosphide And Related Materials: International Technology Roadmap For Semiconductors Perspective," International Conference on InP and Related Materials (IPRM), May 2005, Glasgow.

• H. S. Bennett, R. Brederlow, J. Costa, P. Cottrell, W. M. Huang, A. A. Immorlica Jr., J-E Mueller, M. Racanelli, H. Shichijo, C. E. Weitzel, B. Zhao, "Device and Technology Evolution for Si-Based RF Integrated Circuits", IEEE Trans. On Electron Dev., July 2005, pp. 1235-1258.

• S. Decoutere, W. M. Huang, H. S. Bennett, J. Costa, P. Cottrell, A. A. Immorlica Jr., J-E Mueller, M. Racanelli, H. Shichijo, C. E. Weitzel, B. Zhao, "Process Issues and ITRS Relationship", SEMI Europe Standards Autumn Conference - Standard Electronics Manufacturing Initiatives for Wireless Communication Devices, Oct. 2005, Leuven.

Published Cont'd

- J-E Mueller, "ITRS Roadmap for Wireless Technologies", GMM Workshop Germany 2006
- W. M. Huang, H. S. Bennett, J. Costa, P. Cottrell, A. A. Immorlica Jr., J-E Mueller, M. Racanelli, H. Shichijo, C. E. Weitzel, B. Zhao, "RF, Analog and Mixed Signal Technologies for Communication ICs - An ITRS Perspective", BCTM 2006.
- B. Zhao, H. S. Bennett, J. Costa, P. Cottrell, W. M. Huang, A. A. Immorlica Jr., J-E Mueller, M. Racanelli, H. Shichijo, and C. E. Weitzel, "Future Perspective of Analog/Mixed-Signal and RF Integrated Circuit Technologies", ICSICT 2006.