2006
International Technology Roadmap for Semiconductors

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

ITRS Public Conference
Dec 5 2006
Hsin Chu, Taiwan

Wireless ITWG Scope

- Use wireless IC as technology driver
- Roadmap technical requirements, challenges and potential solutions for RF and AMS IC technologies in wireless applications such as cellular phones, WLAN, WPAN, automotive radar, phased array systems and other emerging standards
- Address intersection of silicon with III-V compound semiconductors and other potential technologies (MEMS, BAW, ..)

Wireless Communication Application Spectrum

InP-HBT, HEMT GaaS MEHMT

GaAs-HBT, PHEMT

SiGe–HBT, BiCMOS

GaN-HEMT

Si–RF CMOS

SiC -MESFET

Roadmap mm-Wave Tables

0.8 GHz	2 GHz			5 GHz		10 GHz	28 GHz	77 GHz	94 GHz
GSM CDMA ISM	PDC GPS SAT Radio	DCS PCS DECT CDMA	WLAN 802.11b/g Bluetooth ZigBee	SAT TV	WLAN 802.11a	SAT TV WLAN Hyperlink UWB	LMDS WLAN	AUTO RADAR	All Weather Landing

Applications drive Noise Figure, Power, Power Added Efficiency, Linearity and Cost

Circuit Functions of a Typical Wireless Communication System

Showing ITRS Wireless Roadmap Technology Partition

LNA
VCO
RF Transceiver
÷N
f_{ref}
PA
AGC
AA filter
ADC
AMS
reference I,V,f
clock tree
analog signal processor
DAC
Digital Signal Processor
PA&PM
regulators
power control logic

CMOS
Bipolar
Passives
Power Amplifier

Wireless ITWG Methodology

Communication System
- Protocols/Standards
- Frequencies 0.8 – 100GHz
- Architecture

Circuit Figures-of-Merit
- Dynamic Range, Bandwidth
- Gain, Noise Figure, Linearity
- Phase Noise
- Output Power, Gain, PAE
- Power Consumption

Device Figures-of-Merit
- Mismatch, Gain
- f_T & f_{MAX}
- NFmin & 1/f noise
- Breakdown
- Quality factor, linearity
- Power density, PAE
- COST

Wireless Roadmap

2006 Wireless ITWG Organization

Chair:	W. Margaret Huang	Freescale
Co-Chairs:	Bin Zhao	Skyworks
	Jan-Erik Mueller	Infineon

Name	Affiliation
Herbert Bennett	NIST
Doug Coolbaugh	IBM
Julio Costa	RFMD
Peter Cottrell	IBM
Stefaan Decoutere	IMEC
Erwin Hijzen	Philips
Digh Hisamoto	Hitachi
Anthony Immorlica	BAE Systems
Snezana Jenei	Infineon
Jay John	Freescale
Alvin Joseph	IBM
Takahiro Kamei	Oki
Tom Kazior	Raytheon
Yukihiro Kiyota	Sony
Minh Le	Consultant
Sebastian Liau	ITRI Taiwan
Hansu Oh	Samsung
Marco Racanelli	Jazz
Bernard Sautreuil	ST Micro
Sam Shichijo	TI
Chuck Weitzel	Freescale
Geoffrey Yeap	Qualcomm
Peter Zampardi	Skyworks
Herbert Zirath	Chalmers U
John Zolper	DARPA

2006 New members

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

Wireless Roadmap Highlights

- CMOS
  - Performance Analog CMOS
    - Base on Logic Low STandby Power (LSTP) CMOS roadmap with 1 year lag (Supply Voltage, Tox, Gate length)
    - Added RF AMS parameters: Gm/Gds, 1/f noise, Vt matching, Ft/Fmax. Noise Fig
  - Precision Analog CMOS
    - Thick gate oxide CMOS
- Bipolar
  - 3 Separate Bipolar devices:
    - RF – “typical” low-cost bipolar device for <10GHz wireless transceiver
    - High Speed – mm-Wave applications
    - High Voltage – power amplifier applications

Wireless Roadmap Highlights

- On-Chip Passives
  - 3 applications: Analog, RF and Power Amplifier
  - Devices include: Capacitors, Resistors, Inductors, Varactors
- Power Amplifier
  - Handset and Base station
  - Handset : HBT & FET, IIIV and Si
  - Base Station: Cellular and emerging WiMAX
    Required relatively high RF power, LDMOS & IIIV FET
- mm-Wave
  - Dominates by IIIV (GaAs MESFET, GaAs PHEMT, InP HEMT, GaAs MHEMT, GaN HEMT, InP HBT), plus SiGe HBT
  - Low noise amplifier and power devices

2006 Requirement Tables Updates

- No major updates from 2005 Roadmap
- CMOS
  - No wireless specific updates
- 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

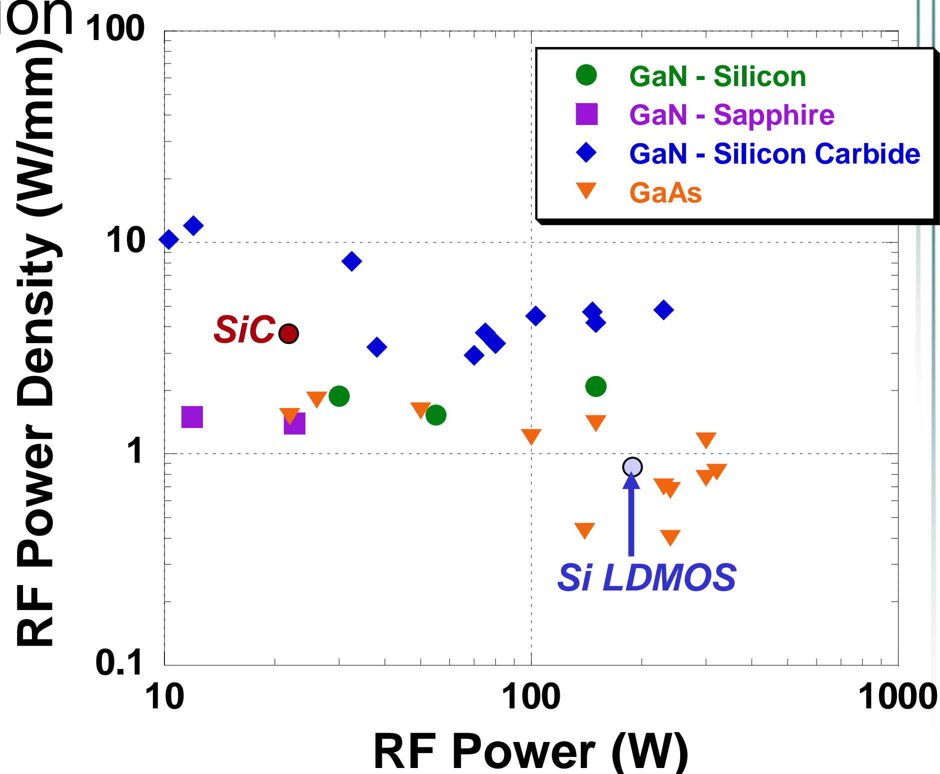
2006 Updates for mm-wave

- 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 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
  - Thermal management
  - Cost Cost Cost



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

Ref : C. Weitzel IMS Workshop 2006

Cross-TWG Focus
Software Defined Radio (SDR)

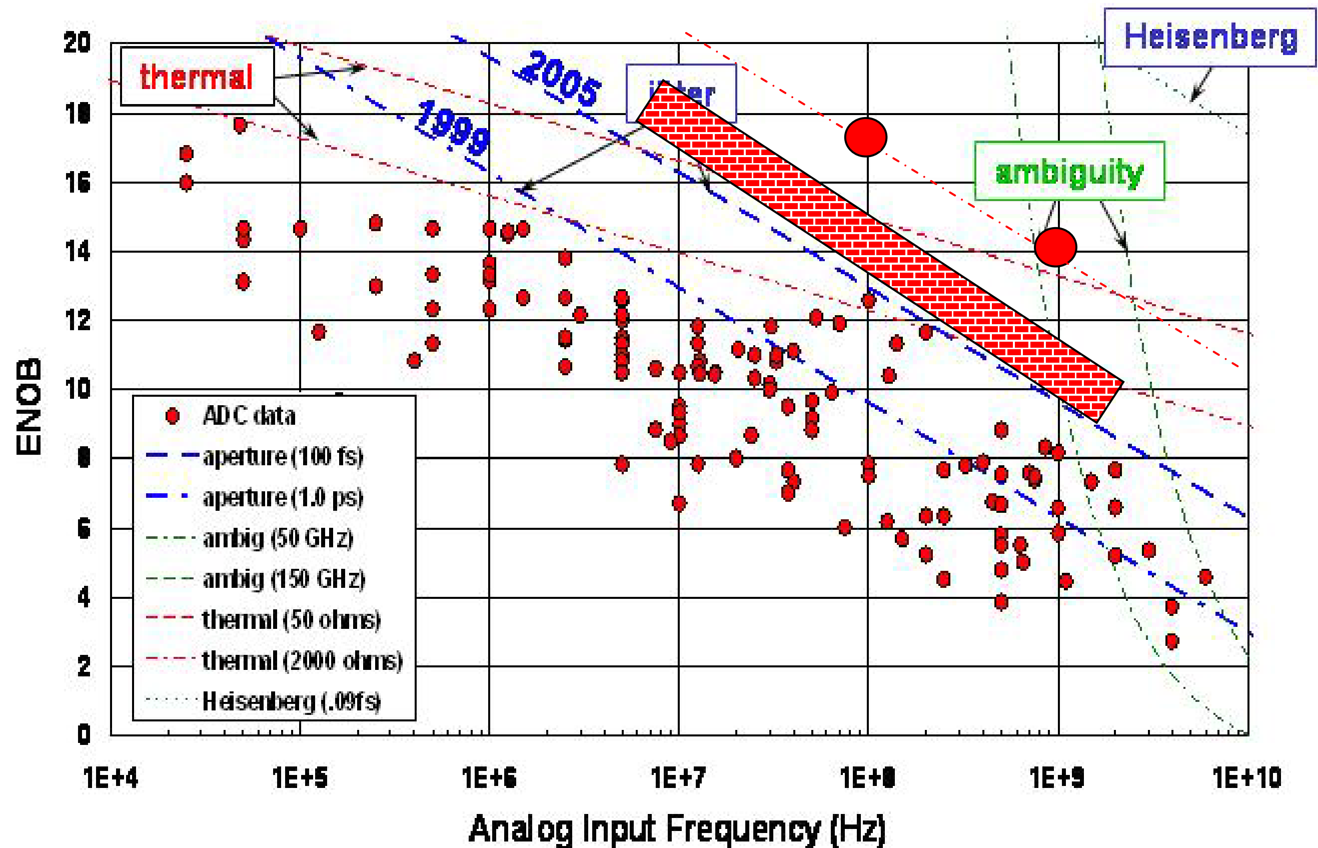
- Address multi-band, multi-mode, portable applications
- Digital radio:
  - ADC performance (sample rate, resolution, power consumption)
  - Transmit solution (power out, linearity & efficiency)
  - Cost (size, time-to-market)
- Hybrid with RF/Analog front end:
  - Wideband LNA
  - Multiple PAs + switch
  - Single PA with matching and switch network (linearity & efficiency)
- Present device roadmap alone does not enable SDR; needs to:
  - Address digital radio design requirements
  - Address module assembly and embedded passives requirements
  - Add filter and switch (MEMS) requirements for hybrid approach (2007)

Analog-to-Digital Converter Technology

- Needed for all-digital receivers at reasonable power consumption

Drivers in Handset Application:

- IF Frequency
- ⇒ Sample Rate
- Dynamic Range
- ⇒Resolution
- Power consumption



Adapted from R. H. Walden, 310-336-2755, The Aerospace Corporation, 2005

SiP Module System Integration

Silicon CMOS or BiCMOS Transceiver

III-V or Silicon PA

Embedded Passives

PM

dig chassis

TX

FG

RX

Single Chip Radio

Ref: W.M. Huang, RFIC Workshop 2005

Cross-TWG Focus - Assy&Pkg

- Wireless focus on functional requirement,
- Assy&Pkg focus on how to provide solution
- Initial focus on <10GHz Front End Module (PA, switch, filter drive)
- Assembly
  - Wireless to provide Front End Module /SiP 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)

Wireless Working Group Key Considerations

Traditional Roadmap Drivers:

- Cost (scaling, die size, part count)
- Power Consumption
- Chip Functionality

Non-traditional Roadmap Drivers:

- Government regulations determining system spectrum and specifications
- Standards and protocols drive frequencies, power and performance
- Production Volume – specialty foundries and captive applications

Cost / Performance Drives Integration:

- Multi-band Multi-mode system applications (SiP Functionality)
- RF modules, embedded passives, filter and T/R switch integration (MEMS)
- Signal Isolation
- Analog Shrink (power supply, area, design innovations)

Challenges and Trends

Radio Integration:

- Performance and cost trade off for SoC vs SiP solution
- Signal isolation - challenge to technologists, designers and EDA tool providers
- CAD solution for Integrated Radio SiP design (chip, passive, component, package, tool compatibility, model accuracies)

Device Technology:

- Optimizing analog/RF CMOS devices with scaled technologies. Fundamental changes in CMOS device structure device may lead to the need of separate process/chip to support conventional precision analog/RF devices
- Cost and performance tradeoff of integrating passive devices
- Predictability of battery technology and its impact on PA roadmap
- Compound semiconductor substrate quality, reliability, new thermal management

Design:

- Design approach for PA ruggedness
- Digitizing analog functions, Software Define Radio (SDR)

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.
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- J-E Mueller, "ITRS Roadmap for Wireless Technologies", GMM Workshop Germany 2006
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