ITRS CHAPTER: RF and A/MS Technologies for Wireless Communications*+

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Summary: State of Wireless Technologies 2010 - ITRS Perspective

Radio frequency (RF) and analog mixed-signal (AMS) technologies serve the very rapidly growing wireless communications market and represent essential and critical technologies for the success of many semiconductor manufacturers. Communications products are becoming key drivers of volume manufacturing. Consumer products now account for over half of the demand for semiconductors.[1] The requirements for wireless transceiver ICs are technology drivers that contribute substantially to the recent ITRS More-than-Moore thrusts.

Scope

Figure 1 shows the circuit functions of a typical mobile communication system with operating or carrier frequencies of the wireless systems between 0.8 GHz and 10 GHz. The four basic circuit functions shown therein are power management (PM), power amplifier (PA), RF transceiver and, AMS, which interfaces with the digital signal processor (DSP).

As shown in Figure 2, wireless and mobile communications cover a very wide spectrum of applications including radio and TV broadcasting, cellular phones (GSM, GPRS, EDGE, CDMA, 3GPP), wireless cables and wireless local area networks (Bluetooth, Wi-Fi, ZigBee), broadband wireless access (UWB, WiMAX), global position system (GPS), phased array RF systems, RFID and smart handheld devices. The impact of wireless and mobile communications on our daily lives has been significant, as they empower us to communicate voice, data, image and video to anywhere at anytime. In future years, it is expected that the frequency axis in Figure 2 will lose its significance in defining the boundaries among technologies for some of the applications listed therein.

This 2010 ITRS RF and A/MS Chapter Update considers the four circuit functions (PM, PA, RF transceiver and AMS highlighted in Figure 1) that drive RF and analog technology needs and has sections addressing applications for frequencies less than 10 GHz and for mm-wave frequencies. The RF and A/MS ITWG has five technology subgroups. Four of the subgroups cover applications below 10 GHz: CMOS, bipolar, passives, power amplifiers (PAs) and MEMs. The fifth subgroup on mm-wave applications focuses on power and low-noise requirements of both III-V compound semiconductor and silicon-based devices used in transceiver ICs.

Some portions of the RF and A/MS Technology Roadmap pertain more to prototype capabilities rather than the usual CMOS volume production of most of the other ITRS Chapters. Production implies applications and markets. But, emerging mm-wave connectivity and imaging applications that are part of the RF and A/MS ITWG currently lag technology capabilities.

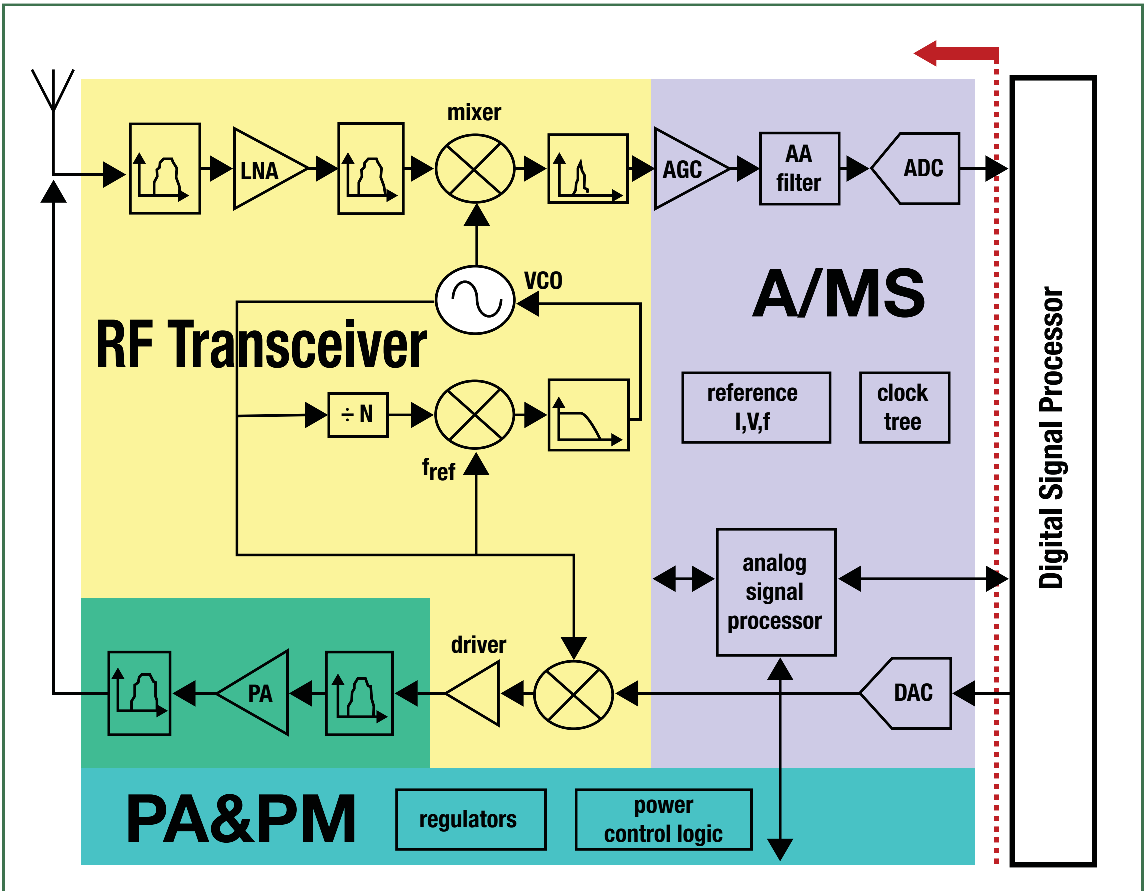

Figure 1. Circuit Functions

What Is New in the 2010 ITRS Chapter on RF and A/MS Technologies for Wireless Communications?

For CMOS, the 2010 technology requirements tables continue the link of performance-RF to LSTP CMOS with a one-year lag, and mm-wave CMOS to HP CMOS with a two-year lag as reflected in the 2009 table. Three adjustments were made for 2010; matching is dramatically lowered to reflect published data for high-κ/metal-gate technologies, f_{MAX} was lowered to better reflect recent publications, and the fact the analog-friendly FETs are now commonly available is reflected in the Precision Analog table.

For bipolar, only the figures of the HS PNP transistor, newly introduced in 2009, have been updated. BV_{CEO} reduction is delayed at the expense of a slower increase in f_T over time in order to better fit to the key applications that are more BV_{CEO}-driven than f_T-driven today. f_T and f_{MAX} colors have been updated for the HS PNP and PA NPN bipolar transistors in agreement with published data. The key driving forces for the bipolar roadmap continue to include speed, power consumption, noise and breakdown voltages.

For passive devices, the density and leakage for the on-chip MOS capacitor lag one year behind those for CMOS active devices as shown in the 2010 tables. Inductors with Q factor values of 35 are expected to be manufactured at high volumes in 2012 accordingly.[2,3]

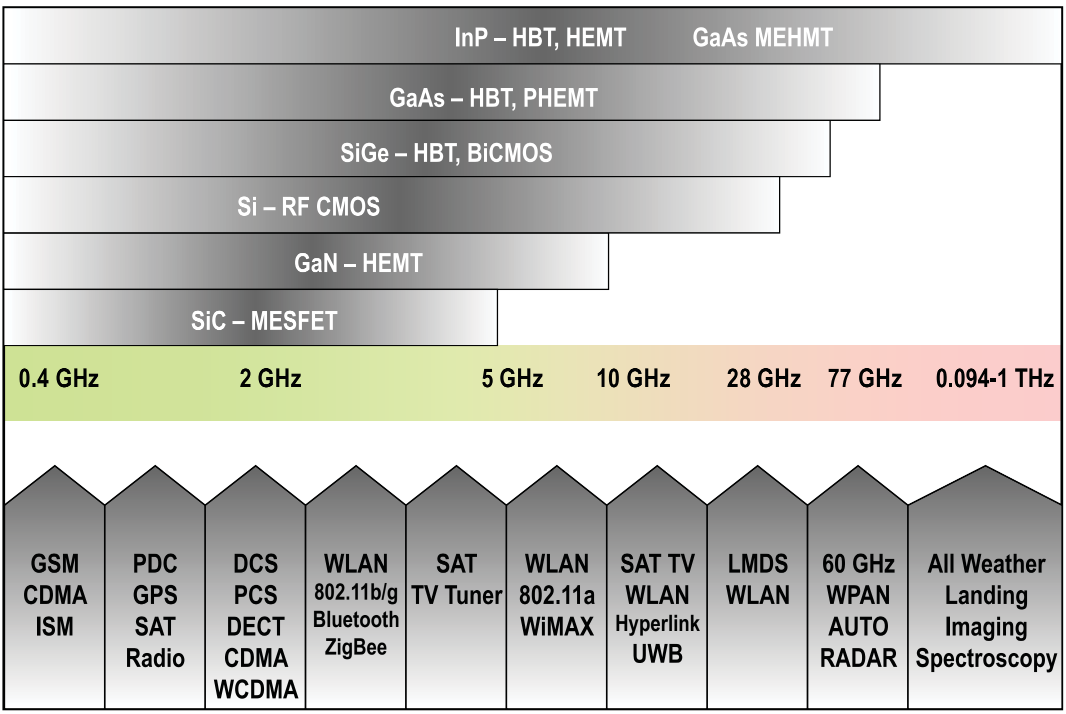

Figure 2. Wireless Applications and Spectrum

However, the technology of 3D IC interposer is expected to enable higher Q factors in the near future. RF capacitors with densities near 1.5 fF/μm^2 are now available from some vendors of III-V compound semiconductor PAs. In the table for off-chip inorganic substrate capacitors, the leakage current density tends to be in the range of nA, which is reflected in the reliability data of some publications.[4] In the table on potential solutions for 0.4 GHz to 10 GHz applications, materials for thinner layers with higher dielectric constants used in decoupling capacitors would require one more year of R&D activities. And, high-μ materials needed in inductors with high Q factors greater than 35 for use in analog or power devices and circuits would require two more years of R&D activities.[3]

For power amplifiers, Handset Devices - The battery requirements are expected to remain at current levels for at least few more years. The MEMS adoption seems to be happening more slowly than expected, but remains an active area of development. It is also likely to be going directly toward an integrated solution. Base-Station Devices - The tables show that 48V LDMOS is likely to be introduced into the cellular infrastructure market in 2011. This introduction is primarily due to increased demand for higher-power parts for Doherty PAs, and, due to the possibility that for the longer term it may serve as an envelope-tracking or drain modulation solution to achieve higher efficiencies than can be achieved with Doherty PAs alone. In addition, the increased focus on efficiency is reflected in both the drain efficiency at 1 dB compression and peak drain efficiency. The goals for high-efficiency architecture and drain efficiency have increased for both LDMOS and GaN.

For MEMS, we have no changes to the 2009 Tables in that edition of the ITRS. Because MEMs is a very broad and diverse area, we are having ongoing discussions with other ITRS Working Groups and with the iNEMI MEMS Working Group about the optimum way in which to do technology roadmaps for MEMs.

For millimeter wave applications, we have assumed "production" implies that at least one company offers products with "data sheets" or that the technology is available for custom designs from one or more companies as a foundry service. The RF and A/MS "production" differs from the overall ITRS definition of production; namely, two companes reach production within three months of each other. The main changes in the technology requirements table from 2009 are manifested as a delay in the trend to smaller critical dimensions in HBT and HEMT technologies. Because InP HBTs are not moving as fast as predicted to smaller dimensions, increases in f_t and f_{MAX} are slowing down. For GaN HEMTs, technology challenges of maintaining breakdown voltage are delaying shrinking gate lengths. Nevertheless, we still predict that GaAs and InP will begin to be replaced by GaN as early as 2012 and 2014, respectively, for new applications. Power MHEMT is also likely to eventually be replaced by GaN HEMTs. As predicted in 2009, LN MHEMT at 70 nm is now available. However, continued progress in shrinking dimensions and higher-frequency performance will be driven by market applications. Volume markets will be very cost sensitive, and SiGe and RF CMOS will be utilized in applications where their performance is adequate, resulting in possible further delay in transitioning III-V R&D advances into production.

2010 RF and A/MS Trends

More than Moore

Collaborations with iNEMI are ongoing to generate a matrix of applications for wireless technologies that cover emerging technologies such as ultralow power, medical sensors and devices, security, MEMS and the like.

Electronic systems can have many types of semiconductor components comprising several materials types (Si, SiGe, GaAs, InP, etc.) and different transistor device types (HEMT, HBT, BiCMOS, etc.). As these different semiconductor materials and device types are not usually compatible in their fabrication processes, they cannot be inherently fabricated together in a conventional batch process. As a result, there can be significant performance and cost penalties associated with interconnecting these devices at the next level of assembly, the stacked-package, printed wiring board or module level. In addition, each semiconductor component or integrated circuit is usually placed in its own package for practical purposes, which tends to drive up power dissipation and can complicate the design and fabrication of the circuit board on which the chips are placed, especially for RF and millimeter-wave circuits. The physical placement of chips can have a great effect on performance.

"Heterogeneous" and "polylithic integration" are general terms used to describe the physical process of bringing multiple disparate materials and devices closer together. New methods and advances in fabrication and integration processes now enable some disparate semiconductors to be heterogeneously combined to result in the highest-performing and most effective complete integrated systems-on-chip. This capability will let electronic system and integrated circuit designers use the best type of material for implementing the circuit functions. The optimal choice of any particular heterogeneous integration technology will depend on the specifics of the various materials involved and the requirements of the integrated circuit and application (thermal considerations, power, number of connections, RF performance, and noise), the expected volume, and the risks and costs.

Broadband

The ecosystem of LTE, WiMAX and IMS for 3G, 4G and beyond-4G mobile broadband continues to include more users and to offer more applications each year. Some forecasters expect that manufacturers will ship more than 1 billion mobile handsets worldwide in 2010 and that future networks will deliver seamless performance for multiple generations of mobile devices. This rapid deployment of broadband wireless communication systems now affects over 3 billion global users and enables significant economic and societal applications that span transportation, multimedia and cooperative communications, localization and tracking of smart devices, video streaming, networking, cognitive radio, telemedicine (diagnostic and monitoring health care support), quality health care at lower cost, emergency response, and security. Many nations have goals to provide quality wireless services that will greatly diminish the isolation of the poor. These include eliminating households without wireless or wired connections.

Network Optimization

To meet these large ecosystem demands for rich content, reduced energy consumption and the lowest possible cost per bit, wireless manufacturers and network providers strive to develop technologies designed to reduce interference, stimulate cooperative communication among heterogeneous networks and promote energy savings. Their goal is to create innovative wireless technologies that optimize spectrum usage and establish new operating parameters for collaborative wireless and wired networks. Manufacturers want to offer wireless systems with ever-increasing figures of merit such as higher speeds and higher quality of services at lower costs. Users want cheap and highly functional wireless services anytime and anywhere.

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Acronyms

AMS	Analog/mixed-signal
BiCMOS	Bipolar complementary metal oxide semiconductor
CDMA	Code division multiple access
CMOS	Complementary metal oxide semiconductor
DAC	Digital-to-analog converter
EDGE	Enhanced data rates for GSM evolution
f_{MAX}	Unity power gain maximum frequency of oscillation (f_{MAX})
f_T	Maximum transit or cutoff frequency (f_T) at unity current gain
GPRS	General packet radio service
GSM	Global system for mobile
HBT	Heterojunction bipolar transistor
HEMT	High-electron mobility transistor
HP	High performance
HS	High speed
IC	Integrated circuit
ISM	Industrial, scientific and medical (radio bands)
iNEMI	International electronics manufacturing initiative
ISM	Industrial, scientific and medical (radio bands)
LDMOS	Laterally diffused metal oxide semiconductor
LN	Low noise
LSTP	Low standby power
LTE	Long-term evolution
MEMS	Microelectromechanical system
MHEMT	Metamorphic high-electron mobility transistor
MOS	Metal oxide semiconductor
PA	Power amplifier
PM	Power management
RF	Radio frequency
RFID	Radio frequency identification
UWB	Ultra-wideband
Wi-Fi	Trade name for IEEE 802.11 wireless technologies
WiMAX	Worldwide interoperability for microwave
3GPP	Third-generational partnership project
κ	Dielectric constant

Endnotes

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4. M. Zelner, et al. “Reliability of BST Thin Film Capacitors,” in proceedings of the 3rd International Conference on Integrity, Reliability, and Failure, Porto, Portugal, July 20-24, 2009, Paper Ref: S0310_P0565, 2009.

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Jack Pekarik

Jack Pekarik joined IBM in 1985 and received his Ph.D. in EE from UC Santa Barbara in 1993 while on leave. He has worked on technology for bipolar, DRAM & CMOS in bulk and SOI, compact modeling and manufacturing, and now works on SiGe BiCMOS in Burlington, Vt. Dr. Pekarik is the chairman of the ITRS TWG on RF and A/MS Technologies for Wireless Communications.

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