Research Needs for
Analog and Mixed-Signal (AMS) Devices

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Scope and Challenges

Emphasized in the ITRS *Executive Summary* [1], as scaling is being driven towards the limit, Functional Diversification is becoming an important aspect of scaling. This diversification mainly calls for integration of different functions and technologies on a single chip. Analog and mixed-signal devices and technologies are a big part of the enablers.

This document is prepared for the generation and reference of the Call-for-White-Papers in the Device Sciences AMS Thrust. Within the program structure of SRC–GRC, this Thrust only deals with technology-related research. Other AMS-related works but focusing on circuit design or compact modeling are included in their respective thrusts, but tied together by the AMS cross-cut.

According to the Roadmap of the chapter *Radio Frequency and Analog/Mixed-Signal Technologies for Wireless Communications*, this discipline can be divided into following areas [2], with their respective challenges listed below:

- RF and AMS CMOS—Device scaling, in particular high-performance logic scaling, generally makes the analog characteristics worse. These issues include mismatch, channel strain causing mismatch and $1/f$ noise, floating-body effects of SOI and FinFET structures, standby power (off current), parasitic resistance and capacitance, etc.
- RF and AMS Bipolar Devices—Wireless applications continue to push the frequency limit. The goal is to optimize speed (f_t) while controlling punch-through and breakdown, and to control high current/power.
- On- and Off-Chip Passives for RF and Analog—Passives such as resistors, capacitors, inductors, varactors, transformers, and transmission lines often determine the overall analog performance of the circuits, and often occupy more area than the actives counterpart. Optimization and miniaturization of these embedded components in a cost-effective manner is challenging.
- Power Amplifiers—They are further divided into handset and base-station applications. Handset PAs face decreasing battery voltage and thus higher current for the same power delivery. Base-station PAs require increasing frequency operation while maintaining or improving the amplifier efficiency.
- Millimeter Wave (beyond 10 GHz)—This arena is mostly limited to compound semiconductors, namely GaAs, InP, SiC, and GaN. The continuing challenges are substrate material quality and cost, incompatibility of tools and chemicals with the mainstream Si process, and the need for thin substrates for thermal dissipation for some power devices. There is growing utilization of Si CMOS and SiGe bipolar/BiCMOS, facing some challenge of a more lossy Si substrate.

- MEMS—Applications of MEMS have been growing rapidly. These devices are now common in mobile/wireless communication and automobile systems. Examples are bulk acoustic wave (BAW) devices, resonators, capacitive switches, metal contact switches, sensors, microphones, and displays. Even though all MEMS devices share the unique feature of moving parts, MEMS technologies are extremely diverse.

Research Needs: Categories and Topics

For this Call, we have identified more specifically the topics of needs for our member companies, and expanded the topics into finer details and examples as shown in the appended table. These topics are organized into five groups. For active devices, we divide them into (1) mainstream MOSFETs, (2) other active circuit components, and (3) power devices. The last 2 groups are (4) passives and (5) others grouped as miscellaneous.

In MOSFETs, the main analog technology is similar to the ITRS low-standby power (LSTP) technology which is about 3 year behind that of the high-performance logic. Improving the analog specifications on a digital technology is an area of interest. The second group contains all other active circuit components such as diodes, varactors, bipolar transistors, ESD protection devices, and I/O devices. The next group includes power amplifiers, power diodes, and other power devices. The fourth group contains the passive devices (capacitors, inductors, transformers, resistors, etc.) as well as materials for them. The last group contains all other technology aspects such as isolation schemes, and other peripheral devices such as sensors and integrated MEMS devices.

Research Needs: Priorities

Member company representatives were asked to vote on the topics of their preference, with high priority (H) or medium priority (M). Consensus is built on the average of inputs. This methodology yields a total of 6 topics of high priority (yellow), and 10 of medium priority (blue). It is with this focus that we will call for and select proposals in these areas of research.

Contributing AMS TAB Members:

Jeff Smith (TAB Chair)	TI
Margaret Huang (TAB V-Chair)	Freescale
Rich De Souza	Freescale
Vishal Trivedi	Freescale
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Jad Rizk	Intel
Ananda Roy	Intel
Rick Wise	TI
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Reference

[1] International Technology Roadmap for Semiconductors (ITRS) 2009 Edition. "Executive Summary".

[2] International Technology Roadmap for Semiconductors (ITRS) 2009 Edition. "Radio Frequency and Analog/Mixed-Signal Technologies for Wireless Communications".

Analog and Mixed-Signal Devices: Research Needs

1. Active: MOSFET

		Priority
1a	General analog transistor performance (scaling, noise, linearity, intrinsic gain $R_{out}.g_m$)…, especially on digital technology and advanced structures (high-K, metal gate, multi-gate, FinFET)	H
1b	High-speed performance mm-wave/THz (f_t, f_{max}, parasitics, s-parameters, over temperature…)	H
1c	Ultra-low power, ultra-low leakage MOSFETs	
1d	Matching (variability)	M
1e	Reliability (degradation, hot-carrier [mm-wave large-signal], NBTI, TDDB, electromigration…)	H

2. Active: Other circuit components

2a	Peripheral components: High-Q mm-wave varactors, RF/mm-wave SOI RF switches, pin diode, Schottky diode, photodiodes, lasers	M
2b	High-performance bipolar and BiCMOS (scaling, advanced structures, f_t, f_{max}, reliability and analog performance)	M
2c	Integration and analog-performance of post-Si-era devices: e.g. carbon nanotubes and nanowires	H
2d	High-V ESD (SCR, bipolar…) and I/O devices	M
2e	Synaptic and neuronal devices for neuron electronics	

3. Actives: Power devices

3a	High-speed/high-efficiency Si-based integrated power FETs (R_{on}, power density/efficiency, high-freq for RF, high temperature, self-heating, high-voltage with high-freq). Beyond Johnson limit SOI power FET. Power/HV device integration/scaling in deep sub-µm CMOS (lithography, materials, processing, reliability…)	H
3b	UHV device (> 600 V) integration in sub-µm CMOS processes (dielectrics, interfaces, passivation, metal shielding, reliability...)	M
3c	Alternative devices for low-voltage, high-speed DC-DC convertors (SiGe, HEMT…)	
3d	GaN power device, integration, modeling, reliability…	M

4. Passives

4a	Inductor and transformer integration (especially magnetic core, …) with existing IC processing. Capacitor (high-K, high density, linearity), resistor (high/med range, precision), and their scaling	M
4b	High-performance material studies (dielectric absorption...)	
4c	mm-wave and THz on-chip filters and cavities. On-chip antenna. Resonator	
4d	Trimmable devices	

5. Miscellaneous

5a	Substrates (high-resistivity [SOI], high thermal conductivity, GaN on Si for HV…) and isolation	M
5b	Built-in self-test capabilities	H
5c	Integratable MEMS (high-precision gyroscope and accelerometer)	
5d	Sensors (bio, DNA…)	M
5e	Energy harvesting/scavenging	M