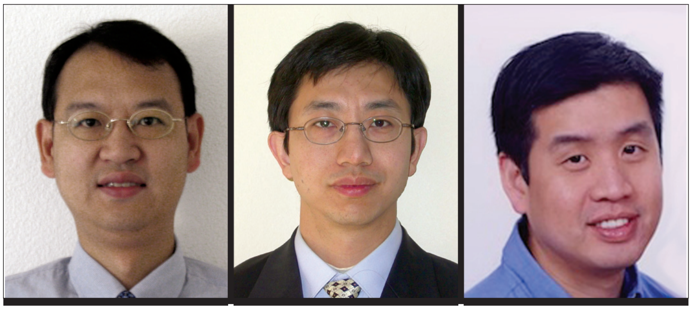
TOPICS IN INTEGRATED CIRCUITS FOR COMMUNICATIONS



Charles Chien *Zhiwei Xu* *Lew Chua-Eoan*

In this issue of the Topics in Circuits for Communications Series, we have selected three articles on integrated circuits design of next-generation mobile communication devices such as smartphones and tablets. This area is drawing significant attention from industry as well as research communities worldwide.

Just 10 years ago, a slick top-of-the-line cellular phone featured Bluetooth connectivity, second generation (2G)/2.5G cellular links with maximum transmission speeds of hundreds of kilobits per second, a whopping 0.3 Mpixels embedded camera, and a 2-in colored screen together with a QWERTY keypad. This clearly does not correctly depict the image of a smartphone today, which supports the global positioning system (GPS), IEEE 802.11n Wi-Fi, and near-field communications (NFC) in addition to Bluetooth connectivity. Moreover, a smartphone today offers substantially higher data rates of several megabits per second through the 3G/4G Long Term Evolution (LTE) cellular networks. The user interface is also greatly improved with a dramatically higher resolution camera (8–10 Mpixels) and a larger 4–5-in touch-sensitive screen.

The inflection point in the transformation of a simple feature phone to a full-fledged smartphone as we know it today occurred about six years ago. Adoption of smartphones has since then spread like wildfire, growing to a volume of 700+ million units within a short span of six years. Such broad rapid adoption leads one to ponder what made such a communication device so universally attractive. The answer lies not only in the advances we have made in the communications infrastructure and technology that enabled high data rate in excess of tens of megabits per second over wireless links, but also in the breakthroughs we have made in mobile computing and intuitive user interfaces that facilitated convenient access to multimedia contents available on the Internet right in the palm of our hands.

Circuits for next-generation mobile devices must continue to innovate, not just on wireless link performance and throughput but also on "smart" features that will sustain the growth of future mobile devices. Such "smart" features should evolve and advance together with the increasing data rate made available through advancements in LTE systems, expected to offer in a few years 1 Gb/s data rate in quasi-static environments. Two key technology drivers for continued innovations in the "smart" features lie in the need for a low-power application processor to run increasingly complex mobile applications (mobile apps), and the need for low-power embedded sensors to enable location-based services and intuitive multimodal user interfaces. Of course, the age-old challenge of harnessing sufficient capacity to support the increasing demand for high-data-rate services must still be addressed in the design of underlying radio transceivers to enable effective spectrum utilization for increased capacity and throughput.

Mobile devices have been characterized by the explosive growth of applications for communications and computing. In total, the number of mobile apps have reached in excess of 1.5 million, with 50,000 new ones being developed each month. Moreover, to date, an astounding 50+ billion apps have been downloaded onto smartphones worldwide. These mobile apps require higher processor bandwidth while delivering ultra-low power and adhering to a stringent thermal power dissipation envelope. The need for multicore architecture to address the challenge in achieving low power while delivering increased processing power was described in an article published in our series in April 2011. In this issue, the article entitled "A 32 nm 1.5 Ghz Quad-Core Processor for Mobile Applications" addresses implementation challenges in the design of a quad-core processor in 32 nm complementary metal oxide semiconductor (CMOS) intended for a wide variety of mobile applications. The mobile processor can handle unprecedented data processing throughput and multimedia performance, without sacrificing battery life and not exceeding the thermal power dissipation envelope of a mobile device.

Many mobile apps take advantage of navigation information obtained from embedded GPS in a smartphone to provide location-based services. For example, Google Maps utilizes GPS information and provides cloud-assisted navigation to a driver, essentially turning the smartphone into a personal navigation device. However, in the presence of obstructions, such as in a parking garage or shopping mall, GPS signaling can be lost. In such situations, inertial sensors embedded within smartphones enable continued navigation through dead reckoning. Furthermore, such sensors can provide information on direction, orientation, and acceleration to enable more intuitive means of interacting with the mobile device. These include automatically orienting the displayed image as the user rotates the phone or optical image stabilization to compensate for hand jitters while taking photos with the phone.

Sensors have traditionally been difficult to integrate into small form factor devices, such as a smartphone, due to mechanical constraints. However, with extensive research over the past several decades, micro-electromechanical systems (MEMS) have finally matured to enable the integration of a broad range of sensors onto a substrate that is compatible with mainstream silicon process such as CMOS technology while achieving remarkable performance. The article entitled "MEMS Inertial Sensors: A Tutorial Overview" presents a system approach to the design and integration of MEMS inertial sensors in CMOS. The author gives an overview of the physics behind mass-spring mechanical systems, defines energy metrics to compare various sensor interface designs and architecture, and also describes the fabrication process that enables the integration of sensors together with the interface circuitry to the application processor. The article concludes with an example 6-axis sensor that integrates a 3-axis gyroscope and a 3-axis accelerometer with a wide dynamic range (±2000 degree/s, and ±16g) and low noise floor (0.005 deg/s/$\sqrt{Hz}$ and 400 μg/$\sqrt{Hz}$) while consuming 3.9 mA in a low-cost plastic package.

Besides inertial sensors, MEMS offers an effective solution for radio frequency (RF) channel filtering essential to achieving high capacity and throughput in the existing as well as future cellular systems. As phones become smarter with enhanced multimedia and sensory capabilities, mobile apps will likely demand higher data rates to support multimedia-rich contents as well as, cloud-based services. This in turn requires higher bandwidth in an already congested spectrum. For instance, the Third Generation Partnership Project (3GPP) has harmonized RF bands spanning 700 to 4000 MHz for multiple standards including 2G/2.5G, 3G, and 4G LTE cellular systems. A total of 40+ bands are allocated within this frequency range, and current smartphones must typically support at least 10 bands with duplex frequency separation as low as 30 MHz and in some cases with zero guardband between neighboring bands. Furthermore, besides supporting the cellular bands, smartphones must also interoperate with GPS, Wi-Fi, and Bluetooth, which are in close proximity to the 3GPP bands. To make matters worse, the cellular radio is typically collocated with other radios for GPS, Wi-Fi, and BT in the same phone, and soon in the same chip once they are all integrated into a one-radio system on chip (SoC).

The authors of the third article, "MEMS-Based RF Channel Selection for True Software-Defined Cognitive Radio and Low-Power Sensor Communications," present a MEMS-based solution that can effectively address the problem of providing frequency isolation between transmitters that are in close proximity with the receiver both physically as well as spectrally. In particular, the article focuses on advanced MEMS technologies that could offer extremely high quality factors (e.g. > 30,000) suitable for not only existing cellular applications but also future cognitive radio and ultra-low-power sensor communication systems.

We would like to take this opportunity to thank all the authors and reviewers for their contributions to this Series. Future issues of this Series will continue to cover circuit technologies that are enabling new emerging communication systems. If readers are interested in submitting papers to this Series, please send your paper title and an abstract to any of the Series Editors for consideration.

BIOGRAPHIES

CHARLES CHIEN (charles.chien@creonexsystems.com) is president and CTO of CreoNex Systems which focuses on technology development for next generation communication systems. Previously he has held various key roles at Conexant Systems, SST Communications, and Rockwell. In his career, he has architected several key products including a CMOS/SiGe chipset for multimedia over coax (MoCA), IEEE 802.11abg WLAN RF CMOS transceiver and GaAs PA/RF switches, a wireless audio CMOS chipset for home theatre in a box, digitally assisted cellular transceivers, and low-power wireless networked sensors. He was also an assistant adjunct professor at the University of California at Los Angeles (UCLA) from 1998 to 2009. His interests focus mainly on the design of SoC solutions for wireless multimedia and networking applications. He has published in various journals and conferences, and has authored a book entitled *Digital Radio Systems on a Chip*. He received his B.S.E.E. from UC Berkeley, and his M.S. and Ph.D. from UCLA. He served as a member of the Technical Program Committee of ISSCC from 1998 to 2006.

ZHIWEI XU received B.S. and M.S. degrees from Fudan University, Shanghai, China, and his Ph.D. from UCLA, all in electrical engineering. He has held industry positions with G-Plus Inc., SST Communications, Conexant Systems, and NXP Inc., where he did development for wireless LAN and SoC solutions for proprietary wireless multimedia systems, CMOS cellular transceivers, MoCA systems, and TV tuners. He is currently with HRL Laboratories, working on software defined radios, high-speed ADC, and analog VLSI. He has published in various journals and conferences, one contribution to *The Encyclopedia of Wireless and Mobile Communications*, and five granted patents.

LEW CHUA-EOAN received his S.M. inengineering and computer science from Harvard University and his B.S. in electrical engineering from Cornell University. He has led the development of multiple DSP, RISC and Microprocessor based products and has co-authored numerous papers related to cache coherency, clocking and power control, low power, and mix-signal design. He has over 32 granted patents and has been on the Technical Program Cmmittee of the IEEE International Solid-State Circuit Conference from 2008 until 2013. He is currently senior director of engineering at Qualcomm, leading advanced research and development.