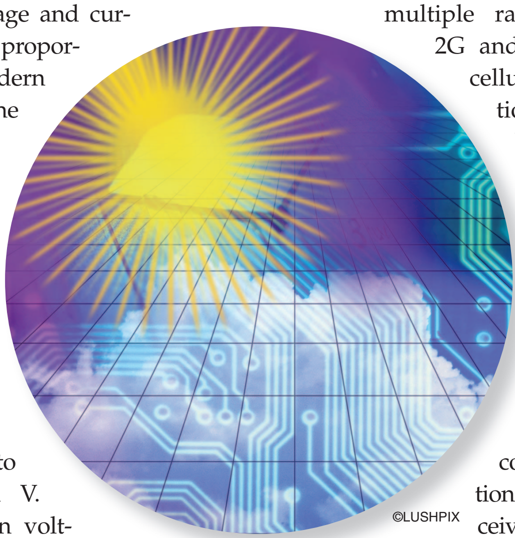
From the Guest Editors' Desk

CMOS Powers Toward System-on-Chip Integration

■ **Jeffrey S. Walling and David Allstot**

It is well known that complimentary metal-oxide-semiconductor (CMOS) has become ubiquitous in circuits for wireless applications in communications such as cellular telephony and wireless local area networks (LANs). Almost all elements of a modern radio front end and back end can be and have been integrated onto a single silicon die, allowing for significant reduction in cost in these applications. CMOS is perhaps the singular reason for the explosive growth in popularity and availability of wireless devices. It is because of this success that it is surprising that the radio frequency (RF) power amplifier (PA) that interfaces the radio's transmitter front-end circuitry to the antenna has yet to be integrated heavily into these wireless products.

Of course, the driving force behind the aforementioned integration is the scaling of the CMOS transistors minimum feature size associated with Moore's Law. One drawback for PAs integrated in CMOS technology is that, as a transistor's physical dimensions are reduced, the ability to handle large amounts of voltage and current are reduced proportionally. For a modern CMOS process, the maximum voltage that a transistor is able to process is dominated by the breakdown of the thin gate oxide of the transistor and is currently limited to approximately 1 V. This reduction in voltage has meant that CMOS PAs increasingly have to achieve high output power by operating with larger current to generate the same power.



Because of these breakdown limitations, the peak output power and efficiency of CMOS PAs has been lower than PAs integrated in III-V semiconductor technology. At the same time that these limitations in CMOS PA performance are becoming increasingly obvious, the desire to integrate the PA with the rest of the transceiver has never been greater. On most modern wireless platforms, the cost is dominated by a front-end module (FEM) that must increasingly process signals for multiple radios, including 2G and 3G radios for cellular communication, Bluetooth, WiFi and GPS.

In this issue, we offer three articles on advances in CMOS PAs that address methods that shine a light on a path towards complete integration of the transceiver. As has been the case with the evolution of the radio into CMOS technology, many of the techniques that are available today were proposed many years ago and are only now available due to the switching speed that scaling has provided.

In our first focused article, by Ali Hajimiri, a method of power combining using the distributed active transformer that enables watt-level power to be generated efficiently using standard CMOS technologies is

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transpiration" in a manuscript submitted to the Royal Society. In the presence of a thermal gradient, gas molecules exert tangential forces along the edges of a vane, which results in the rotation observed. Maxwell was again a reviewer for the manuscript; he bought Reynolds's explanation, but recommended changes to the analysis. Then, shortly before his death in November 1879, Maxwell's own detailed mathematical analysis appeared in a paper "On Stresses in Rarefied Gases Arising from Inequalities of Temperature" in the Royal Society's *Philosophical Transaction* [1]. Maxwell's paper acknowledged Reynolds's (unpublished) work but criticized Reynolds's (unpublished) mathematical treatment. Reynolds' own paper was not published until 1881. He wanted the Royal Society to publish his protest against Maxwell's questionable conduct, but after Maxwell's death, this was deemed inappropriate.

By the way, a radiometer (Nichols radiometer) based on the principle of radiation pressure was developed by Nichols and Hull in 1901 [2]. The original apparatus is at the Smithsonian. If I ever receive a replica as a gift, I promise to tell you more about it.

References

[1] P. Gibbs. (1996, July). How does a light-mill work? (updated June 1997). [Online]. Available: http://math.ucr.edu/home/baez/physics/General/LightMill/light-mill.html

[2] D. Lee. (2010, Sept. 25). A Celebration of the Legacy of Physics at Dartmouth. *Dartmouth Undergraduate J. Sci.* [Online]. Available: http://dujs.dartmouth.edu/spring-2008-10th-anniversary-edition/what-else-has-happened-a-celebration-of-the-legacy-of-physics-at-dartmouth

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highlighted. Focusing on the theme of integration in CMOS, the use of transformers is additionally leveraged for use in a power mixer that combines the functionality of an upconversion mixer with an impedance transformation that allows high output power to be achieved along with frequency translation.

The next two focused articles focus on methods that leverage CMOS strength as a switch in so-called switching amplifier topologies. Large peak-to-average ratios (PAR) are seen in modern modulation techniques in order to improve spectral efficiency, which precludes the use of switching amplifiers in traditional amplifier topologies. Two techniques that linearize a switching PA are examined. In the article by Patrick Reynaert, polar amplification in CMOS is examined. The author revisits methods to achieve high output power while examining methods using a polar coordinate system that allows the PA to simultaneously achieve high efficiency. Reynaert introduces the concept of a burst-mode RF PA, which is examined extensively in our final focused article by Jeffrey Walling and David Allstot. In this article, the authors extensively discuss encoding the envelope of the polar modulated signal as a variable pulse width to control the amplitude of the output signal. Several techniques used to implement pulse-width modulation are discussed, highlighted by an implementation of a bandpass pulse-width modulated PA.

We hope that you enjoy this issue.

President's Column *(continued from page 12)*

AdCom members will be asked to help and contribute everywhere possible and, although volunteers, will be viewed as having agreed to a contract for provision of assistance to the global microwave community. I plan to hold our AdCom, and myself, responsible for fulfilling this contract.

Our Society is very healthy, and it is my plan to utilize our resources to assist local and regional microwave activities around the world for the benefit of our membership and, indeed, to help recruit more members from the worldwide pool of non-MTT microwave engineers. A helping hand might make it possible for many to attend MTT-S events, including AdCom meetings. We will be good hosts rather than frequent visitors! I have benefitted from exposure to wonderful technical work by relatively unknown persons located in parts of the world that cannot or do not currently provide travel support to these forward-looking thinkers. It is vital to our collective scientific progress that we do not ignore potentially great work, some of which might not be fully validated experimentally due to lack of facilities. It is one of my goals to bring some of these microwave engineers into the view of the more prosperous parts of our community, using some of our available Society resources.

I am going to do my very best and hope to have the support of the entire global microwave community. Thanks to the AdCom for giving me this chance!