A History of Low Power Electronics: How It Began and Where It's Headed

James D. Meindl

Joseph M. Pettit Chair Professor of Microelectronics
Microelectronics Research Center and School of Electrical and Computer Engineering
Georgia Institute of Technology
Atlanta, Georgia

Abstract

The invention of the bipolar transistor in 1948 and the integrated circuit in 1958 as well as the announcement of CMOS logic circuits in 1963 demonstrated the critical basis for modern low power electronics. Future opportunities for low power gigascale integration will be governed by a hierarchy of physical limits whose five levels can be codified as: 1) fundamental, 2) material, 3) device, 4) circuit and 5) system. Through analysis of the attributes of a hypothetical quasi-asymptotic 10 nm *single electron* MOSFET and its local interconnection network, it is apparent that such a device would have an unaffordably large switching error rate. However, it is feasible that low power electronics may well achieve a capability within several hundred times the switching energy of the 10 nm *single electron* MOSFET.

The genesis of low power electronics can be traced to the invention of the bipolar transistor in 1947. Elimination of the suppressive requirements for several watts of filament power and several hundred volts of anode voltage in vacuum tubes in exchange for transistor operation in the tens of milliwatts range was a breakthrough of unmatched importance in low power electronics. The capability to fully exploit the superb low power assets of the bipolar transistor was provided by a second breakthrough, the invention of the integrated circuit in 1958. Although far less widely acclaimed as such, a third breakthrough of indispensable importance to modern low power digital electronics was the complementary metal-oxide-semiconductor or CMOS integrated circuit announced in 1963. Collectively, these three inventions demonstrated the critical conceptual basis for modern low power electronics[1].

The earliest and still among the most urgent demands for low power electronics stem from the stringent requirements for small size and weight, long operating life, utility and reliability of battery operated equipment such as hearing aids, implantable cardiac pacemakers, wrist watches, pocket calculators, pagers and a myriad of portable military equipment, including a helmet radio receiver used by an individual foot soldier[1]. Moreover, perhaps no segment of the electronics industry has a growth potential as explosive as that of portable products epitomized by the personal digital assistant or PDA, which has been described as a combined pocket cellular phone, pager, GPS receiver, e-mail terminal, fax, palm-top computer, address directory, notebook etc. Clearly, in the past portable products have had a profound impact on the development of low power electronics and the prospect that this influence will continue is apparent.

Although battery operated products represent a key application of low power electronics, the mainstream of the advance of microelectronics remained relatively free of serious interest in conservation of power until heat removal from a microchip became a major performance and economic issue in the early 1990's. This development brought low power electronics into the mainstream of microelectronics and is reflected in the establishment of the Low Power Electronics Conference in 1993. As we begin the era of multi-billion transistor microchips or gigascale integration(GSI), the continuing importance of low power operation as a primary requirement of virtually all electronic systems seems assured[2].

Future opportunities for low power GSI will be governed by a hierarchy of physical limits. The five levels of this hierarchy can be codified as:

1) fundamental, 2) material, 3) device, 4) circuit and 5) system[2]. To engage this hierarchy for describing the rate of progress of low power electronics as well as for

total power, where the total power is the sum of static and

performance appreciably; that is, *"keep interconnects short."* If a local interconnect is treated as a canonical distributed resistance-capacitance network, the 0-90%

by commercial tools. While an active area of academic

References

[1] J. D. Meindl, "Micropower Circuits," New York: Wiley, 1969.
[2] J. D. Meindl, "Low Power Microelectronics: Retrospect and Prospect," Proc. IEEE, Vol. 83, No. 4, April, 1995.