Perspectives in Power-Aware and Large-Area Integrated Circuits for Ubiquitous Electronics

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Abstract — **In the forthcoming ubiquitous electronics age, power-aware VLSI's and large-are electronics are of importance. If electronics does not provide low-power solutions, the power consumption of hardware will eat up the energy of the community. Large-area electronics is critically in need, since ubiquitous electronics needs to interact with people with sensors and actuators. The paper describes the recent topics in low-power VLSI systems and the possibility of large-area electronics by organic transistors.**

Keywords — **VLSI, Low-power, Large-area, Organic**

I. SUMMARY

In the coming ubiquitous IT society, low-power design is one of the key features at which the VLSI designer should aim. Otherwise, power increase will remain as one of the main obstacles to Moore's law growth. Unless VLSI power is lowered by orders of magnitude, we cannot enjoy the progress that scaling offers. This talk will cover what we now have, and what we should provide in our low-power armory to allow us to cope with ever-increasing leakage loss, as well as dynamic power. The techniques to be presented range over the system, software, circuit, and device level including interconnect and I/O issues. The novel trend is to examine cooperative approaches between levels such as software-circuit cooperation and circuit-technology cooperation. The biggest challenge that System-on-Chip designers must resolve in the future is the fact that transistors for digital and memory circuits will be more and more leaky as technology generations advance. Approaches to solving this serious problem will be described. Beyond the quest for low-power solutions lies a promising world of ubiquitous VLSI devices and products ranging from "wireless sensors and tags for everything" to "everything-you-can-do mobile terminals". (see Figs.1-22, and refer to [1-5])

Another technology of interest is large-area electronics, since ubiquitous electronics needs to interact with people with sensors and actuators. Organic electronics may be suitable for the objective. A large-area pressure sensor matrix has been fabricated on a plastic sheet for the first time, integrating high-quality organic field-effect transistors and rubbery pressure sensors. This pressure sensor demonstrates the feasibility of applying the organic transistor technology to flexible area-sensors, which opens up new applications of organic FET's including artificial skins. (see Figs. 23-25 and refer to [6-7])

ACKNOWLEDGEMENT

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REFERENCES

[1] T.Sakurai, "Perspectives on Power-Aware Electronics (Plenary Talk)," IEEE International Solid-State Circuits Conference (ISSCC), San Francisco, pp.26-29, Feb. 2003.

[2] H.Kawaguchi, K.Kanda, K.Nose, S.Hattori, D.D.Antono, D.Yamada, T.Miyazaki, K.Inagaki, T.Hiramoto, and T.Sakurai, "A 0.5-V, 400-MHz, VDD-Hopping Processor with Zero-VTH FD-SOI Technology," ISSCC, pp.108-109, Feb. 2003.

[3] K.S.Min and T.Sakurai, "Zigzag Super Cut-off CMOS (ZSCCMOS) Block Activation with Self-Adaptive Voltage Level Controller: An Alternative to Clock-Gating Scheme in Leakage Dominant Era," ISSCC, pp.400-401, Feb. 2003.

[4] K.Kanda, D.D.Antono, K.Ishida, H.Kawaguchi, T.Kuroda, and T.Sakurai, "1.27-Gbps/pin, 3mW/pin Wireless Superconnect (WSC) Interface Scheme," ISSCC, pp.186-187, Feb. 2003.

[5] D.Mizoguchi, Y.Yusof, N.Miura, T.Sakurai ,T.Kuroda, "A 1.2Gb/s/pin Wireless Superconnect Based on Inductive Inter-Chip Signaling," ISSCC, Paper#7.6, Feb. 2004.

[6] T.Someya, H.Kawaguchi, and T.Sakurai, "Cut-and-Paste Organic FET Customized ICs for Application to Artificial Skin," ISSCC, Paper #16.3, Feb. 2004.

[7] T.Someya and T.Sakurai, "Integration of Organic Field-Effect Transistors and Rubbery Pressure Sensors for Artificial Skin Applications", IEDM, p.203-207, Dec. 2003.

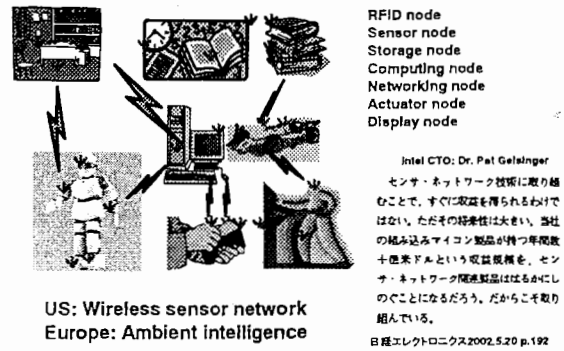


Fig.1 New infrastructure: ubiquitous electronics

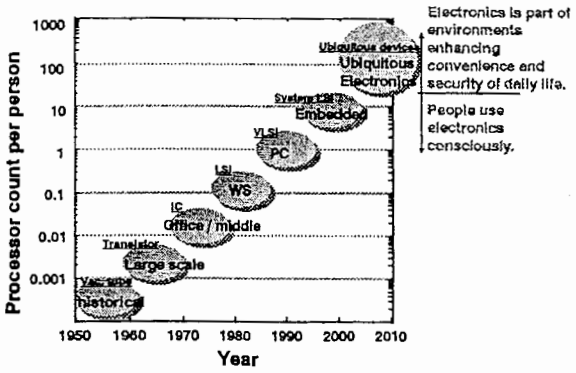


Fig.2 Ubiquitous electronics is natural extension

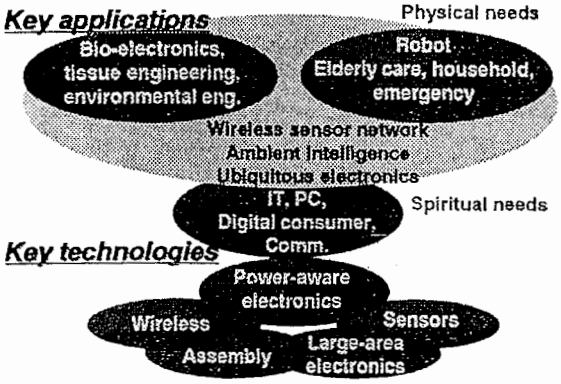


Fig.3 Ubiquitous electronics and key technologies

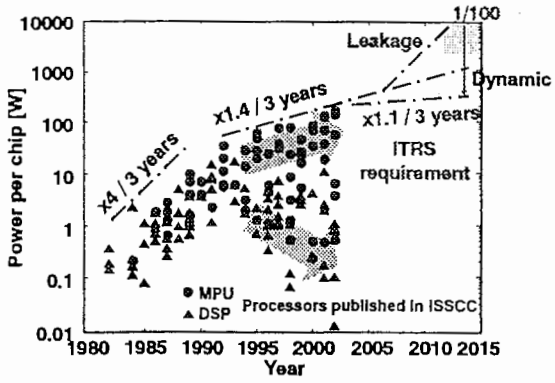


Fig.4 Trend in VLSI power consumption

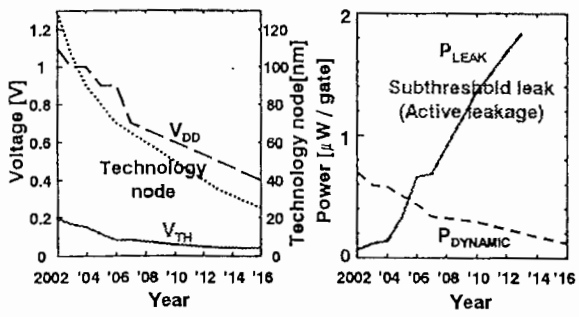


Fig.5 Active leakage makes things more challenging

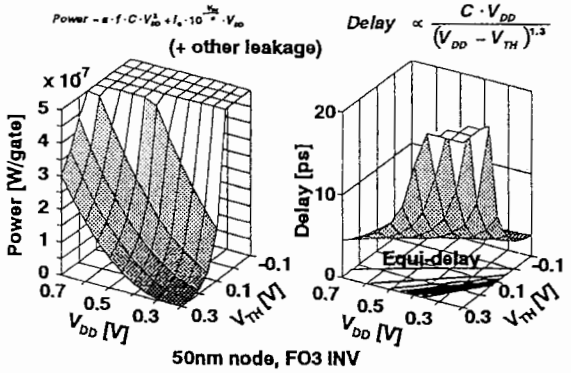


Fig.6 Trade-off between power and delay

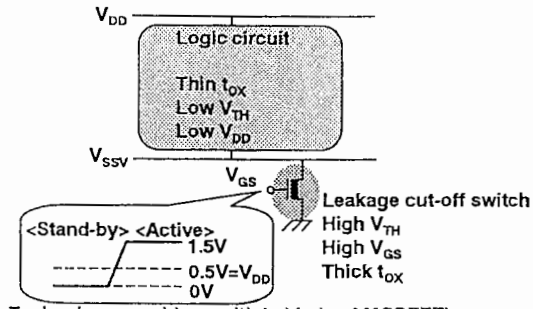
	Active	Stand-by
Multiple V_{TH}	Dual-V_{TH}	MTCMOS
Variable V_{TH}	V_{TH} hopping	VTCMOS
Multiple V_{DD}	Dual-V_{DD}	Boosted gate MOS
Variable V_{DD}	V_{DD} hopping	

Software-hardware cooperation

Technology-circuit cooperation

*) MTCMOS: Multi-Threshold CMOS
*) VTCMOS: Variable Threshold CMOS
• Multiple : spatial assignment
• Variable : temporal assignment

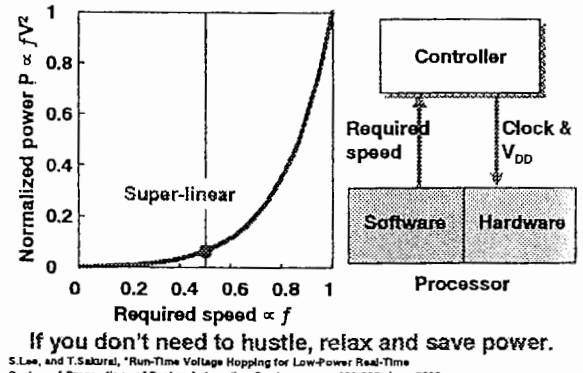
Fig.7 Controlling VDD and VTH for low power



Technology provides multiple kinds of MOSFET's and designers make use of the gift.

T. Inukai et al, CICC, May 2000

Fig.8 Stand-by leakage reduction through technology circuit cooperation



If you don't need to hustle, relax and save power.

S.Lee, and T.Sakurai, "Run-Time Voltage Hopping for Low-Power Real-Time Systems," Proceedings of Design Automation Conference, pp.806-809, June 2000

Fig.9 Dynamic power reduction through software hardware cooperation

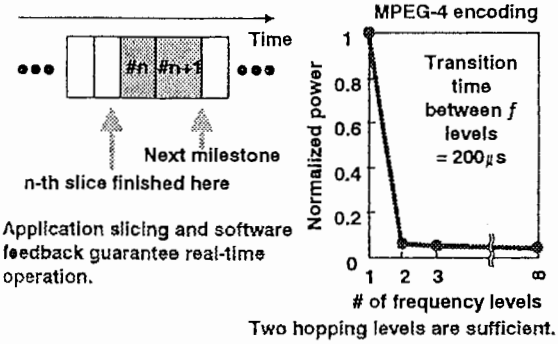


Fig.10 Applicable to real-time application VDD-hopping

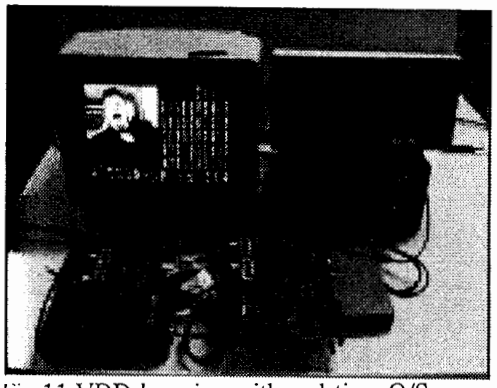


Fig.11 VDD-hopping with real-time O/S

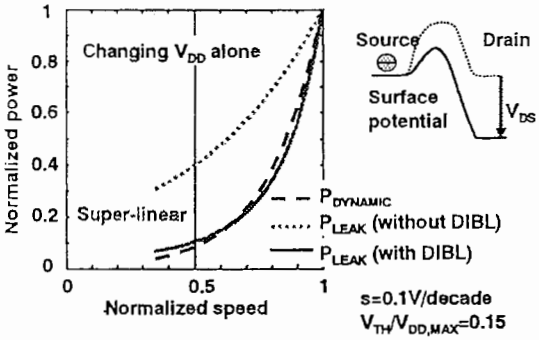
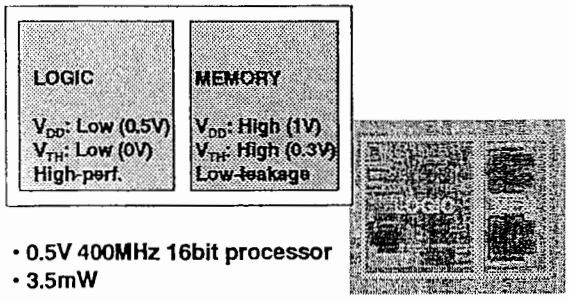
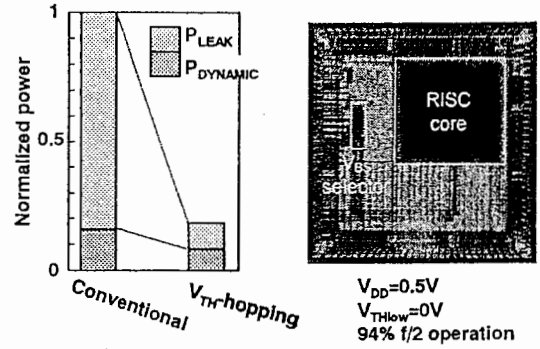


Fig.12 VDD-hopping reduces active leakage power with Drain Induced Barrier Lowering (DIBL)



H.Kawaguchi, K.Kanda, K.Nose, S.Hattori, D.D.Antono, D.Yamada, T.Miyazaki, K.Inagaki, T.Hiramoto, and T.Sakurai, "A 0.5-V, 400-MHz, VDD-Hopping Processor with Zero-VTH FD-SOI Technology," ISSCC, pp.108-109, Feb. 2003.

Fig.13 Low-voltage, low-power VDD hopping processor



V_{TH} is dynamically changed by means of back-gate bias.

K. Nose et al, JSSC, Mar. 2002

Fig.14 VTH-hopping saves 80% of active leakage

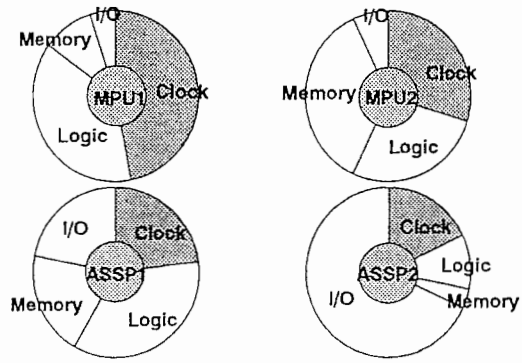
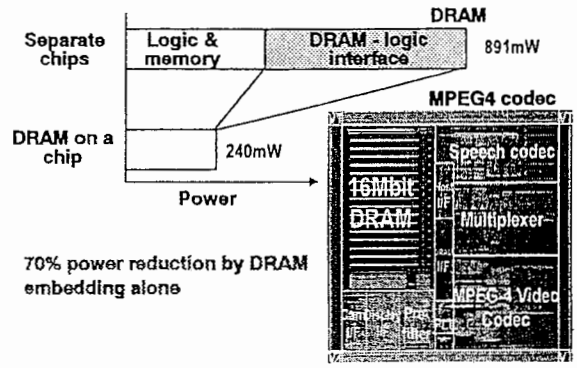
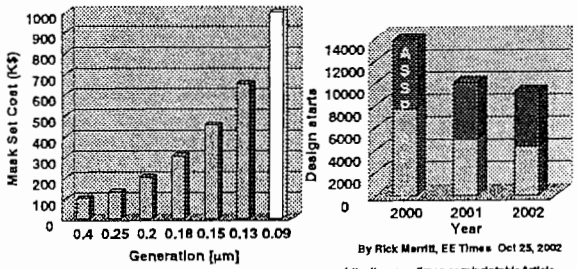


Fig.15 Power distribution is diverse



Courtesy Toshiba, ISSCC 2000

Fig.16 System-on-a-Chip reduces I/O power



By Rick Merritt, EE Times Oct 25, 2002

http://www.eetimes.com/printableArticle?doc_id=OEG20021025S0052

Source: Rahul Goyal, Intel –Nov 2001 SEMI Mtg

- NRE for a SoC is getting $5M–10M and without over $20M sales it is difficult to make a SoC. by Bryan Lewis, Gartner Dataquest
- Number of design starts is declining from 1997.
- Overhead of power and area of FPGA, and software is 40 times of SoC.

Fig.17 Exploding Non-Recurring Engineering (NRE) cost

SoC	Cell based Memory embedding	Highest performance and power efficiency	Slow TAT (3M-1Y) Huge NRE High risk in development
Quick GA	LightSpeed ChipExpress ISSP (NEC) VGPA (CMU)	QTAT (1W + 1M) Higher signal integrity	Still needs a few masks and semiconductor fab ASIC biz model (fit for giants)
FPGA	Xilinx Altera	QTAT (1day + 1M) Fully programmable in gates Established design env.	40 times more area and power and 3 times slower than SoC Still needs boards
Reconfigurable processor	DRP (NEC) IPFlex (Fujitsu invested)	10 times more area efficeint than FPGA	Killer applications? New design environments
Multi-tane processor	MeP (Toshiba) M2R (Mitsubishi)	Just need programs Multimedia oriented	New design environments No gate level parallelism
Advanced assembly	SIP Embedded Circuit Board	Good balance of QTAT (1M) and performance Combining tested chips Hybrid technology integration	Lacking EDA Known good die No standerdization of I/O

Customized in coarser granularity

Fig.18 Contenders for lower NRE

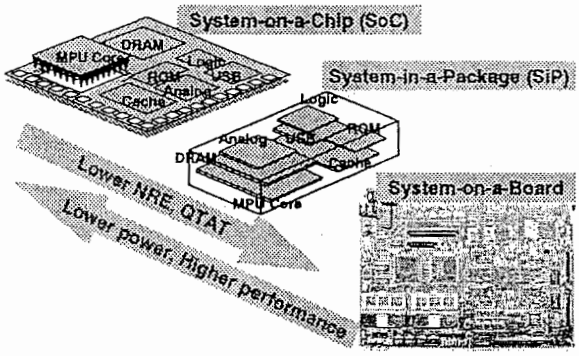


Fig.19 System-in-a-Package (SiP) will reduce NRE

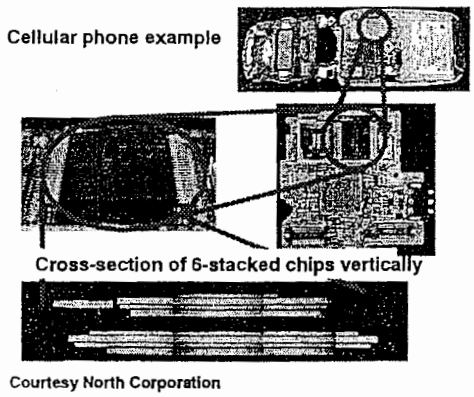


Fig.20 System-in-a-Package has come to market

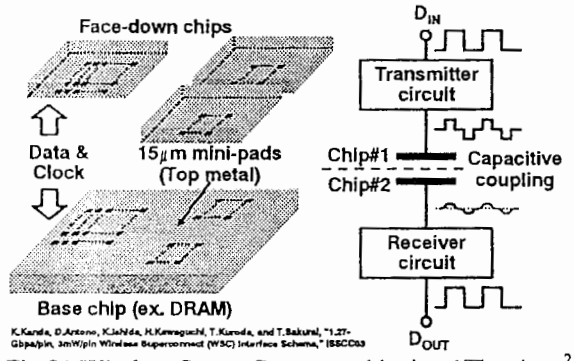


Fig.21 Wireless Super-Connect achieving 1Tbps/mm^2

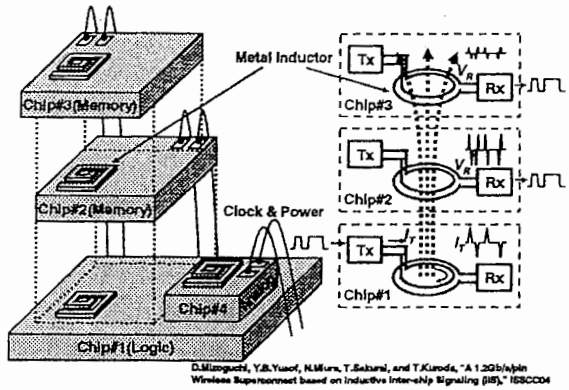


Fig.22 Inductive Wireless Super-Connect connecting multiple chips

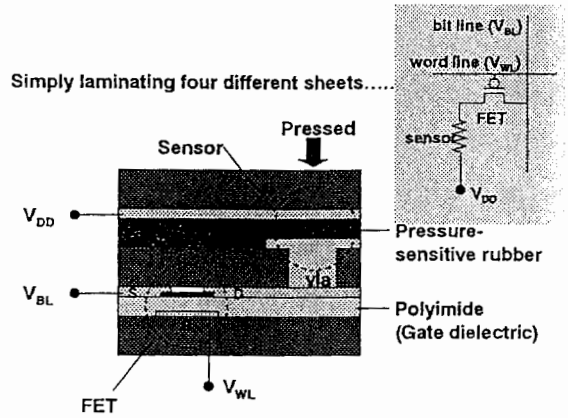


Fig.23 Integration of organic field-effect transistors and rubbery pressure sensors for artificial skin applications

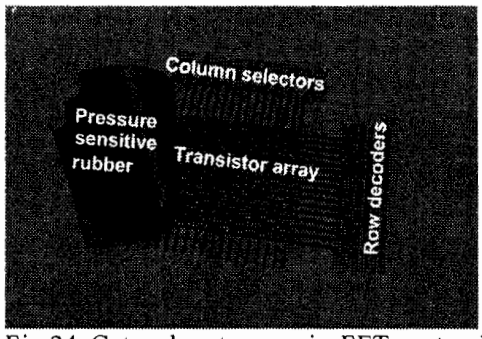
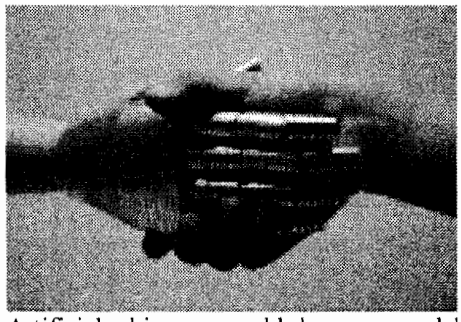


Fig.24 Cut-and-paste organic FET customized IC's and application to artificial skin



Artificial skin may add low-power delicate touch to robots