The World of Analog Micropower

Franco Maloberti
Franco.maloberti@unipv.it
Introduction
The rapid grow of digital...
Is analog died?
Complexity versus diversification...
Market and society trend...
Power and power harvesting...
Final reflection(s) ...
The first step of modern electronics

First Transistor. Bell Laboratories. December 16, 1947

William Shockley (seated)
John Bardeen (left)
Walter Brattain (right)
1958 The beginning of integrated electronics

First two Integrated Circuits
Jack Kilby. Texas Instruments
Dallas, 1958

Robert Noyce,
Fairchild
1961
Introduction

Analog Circuits
Introduction

And Digital
Introduction

The microprocessor (μp)

Moore's Law
"The number of transistors on a piece of silicon would double every couple of years"
Big changes

Courtesy Stefan Rusu Intel
Extreme high density

Microporcessor Array, 2010
1,4 billion of transistors

Test Chip 22 nm
2,9 billion di transistors
Modern times

Power consumption
Technology and Products

Telefonia mobile

Il computer

NEXT??
WILL DIGITAL DOMINATE ...

AND ANALOG FADE?
CERTAINLY NOT!

Miniaturization
Versus
Diversification
More than Moore

Miniaturization versus Diversification

Digital Domain: following Moores Law

Analog Domain:

Systems with higher value
SoC Versus SiP

Moore's Law:
- Transistor Density doubles every 18-24 months
- Valid for pure digital designs

Many analog functions do not scale

Solution:
- More than Moore's Law

Moore's Law for IC's (Pure Digital Design)

System on a chip
- Multi-Chip Module
- Chips on PCBs
- Separate encapsulated ICs for Analog and Digital
- Discrete Components: Transistors & ICS

System Integration (More Than Moore’s)
- Components on PCBs
- Surface Mount ICs for Analog and Digital
- System in Package
- Multi-Chip Module
- Chips on PCBs
- Discrete Components: Transistors & ICS
Embedded Thin-Film Components Developed for System-on-Package

**DIGITAL**
- Decoupling capacitors
- Ultra-low-loss dielectric materials
- Stable core materials
- Low-resistance global copper interconnects

**RF**
- Filters
- Switches
- Antennas
- Decoupling capacitors
- Resistors
- Inductors

**OPTOELECTRONICS**
- Semiconductor thin-film lasers/detectors
- Organic/inorganic waveguides and gratings
- Lenses and mirrors

**SENSORS**
- Nanoscale bioelectronic structures
- Resonators for sensing biological chemicals
- Liquids that emulate body fluids
Systems and 3D
SOCIETY TREND: Needs

Maslow's Hierarchy of Needs

- Physiological Needs
- Safety Needs
- Belongingness & Love Needs
- Esteem Needs
- Know & Understand
- Aesthetic Needs
- Self-Actualization
- Transcendence

Young population
Old population
Key requirements for microsystems

- **Sensors**
- **Analog processing and data conversion**
- **Low power and short range communication**
Microelectronics and quality of life

Textile sensors

Textiles capable to measure Bio-mecanical and physiological signals

- Smart materials embedded into fibers
- For multi-parameter analysis

Courtesy Prof. Danilo De Rossi Univ. Pisa
Textile for sensors

Research in material science
Electrical properties
  ➤ Metallic wires
  ➤ Conductive coating

Benefit:
✓ Low cost
Multisensor systems in a garment
✓ Wearability

Bekinox® VS is a sliver of 100% stainless steel fibres.

Courtesy Prof. Danilo De Rossi Univ. Pisa
ECG

5 signals at the same time
- Einthoven Leads: D1, D2, D3
- Precordial Leads: V2, V5

Courtesy Prof. Danilo De Rossi Univ. Pisa
Applications

Safety

Smart sensor system

Courtesy Prof. Danilo De Rossi Univ. Pisa
Applications

Antennas for communication

Courtesy Prof. Danilo De Rossi Univ. Pisa
A technology for monitoring vital parameters

- **Medical field**
  - Vital parameters
  - Sensor network
  - Wireless communication
  - With 10–20 sensors

- **Low speed < 10 kbps**

- **Safety and Wellness**
Body area network

- Sensors
- Analog and digital processing
- Micropower and Communication
Common features

- Sensors
- Analog and digital processing
- Micropower and Communication
Power harvesting

Energy Generation
- Energy Harvesting
- Energy Sources & Storage

Energy Conversion & Optimization
- Power Management

Energy Consumption
- Ultra Low-Power Systems

Energy-Autonomous System
Power harvesting

Power from ....
Power harvesting

Thermoelectric
Power harvesting

Mechanical energy
Vibration and microbes based

POWER BASICS — Microbes on the anode (in left chamber) deposit electrons (e⁻), which travel along a wire to the cathode (in right chamber). Protons (H⁺) move through a selective membrane from anode’s chamber to cathode’s chamber, where they combine with electrons and oxygen to form water.
Optical power harvesting
Optical power harvesting
### 2.1.2. Estimate of typical harvested power values

<table>
<thead>
<tr>
<th>Source</th>
<th>Source Characteristics</th>
<th>Physical Efficiency</th>
<th>Harvested Power</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Photovoltaic</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Office</td>
<td>0.1mW/cm²</td>
<td>10-24%</td>
<td>10 μW/cm²</td>
</tr>
<tr>
<td>Outdoor</td>
<td>100mW/cm²</td>
<td></td>
<td>10mW/cm²</td>
</tr>
<tr>
<td><strong>Vibration/Motion</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Human</td>
<td>0.5m@1Hz 1m/s²@50Hz 1m@5Hz 10m/s²@1kHz</td>
<td>max power is source dependent</td>
<td>4 μW/cm²</td>
</tr>
<tr>
<td>Industry</td>
<td></td>
<td></td>
<td>100 μW/cm²</td>
</tr>
<tr>
<td><strong>Thermal Energy</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Human</td>
<td>20mW/cm²</td>
<td>0.10%</td>
<td>25 μW/cm²</td>
</tr>
<tr>
<td>Industry</td>
<td>100 mW/cm²</td>
<td>3%</td>
<td>1-10mW/cm²</td>
</tr>
<tr>
<td><strong>RF</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GSM 900MHz</td>
<td>0.3-0.03 μW/cm²</td>
<td>50%</td>
<td>0.1 μW/cm²</td>
</tr>
<tr>
<td>1800MHz</td>
<td>0.1-0.01 μW/cm²</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Storing power
## Batteries

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>SUPPLIER</td>
<td>Front Technology</td>
<td>Eagle Picher</td>
<td>Varta Microbattery</td>
</tr>
<tr>
<td>SYSTEM</td>
<td>Li-LiCoO₂-secondary</td>
<td>Li MnO₂ primary (secondary prototypes)</td>
<td>Li MnO₂ primary</td>
</tr>
<tr>
<td>DIMENSIONS [mm]</td>
<td>25×25×0.15</td>
<td>6.73 × 2.37 diameter</td>
<td>29×22×0.4</td>
</tr>
<tr>
<td>PACKAGE</td>
<td>thin glass, adhesive</td>
<td>welded Ti, glass</td>
<td>Metal foil, polymer seal</td>
</tr>
<tr>
<td>CAPACITY [mAh]</td>
<td>0.7</td>
<td>2.7 (at 30 μA)</td>
<td>25</td>
</tr>
<tr>
<td>SELF DISCHARGE</td>
<td>2% / year</td>
<td>2% / year</td>
<td>-</td>
</tr>
<tr>
<td>WEIGHT [g]</td>
<td>0.19</td>
<td>0.09</td>
<td>0.65</td>
</tr>
<tr>
<td>VOLUME [cm³]</td>
<td>0.03</td>
<td>0.03</td>
<td>0.25</td>
</tr>
<tr>
<td>CYCLES</td>
<td>3500 (70%)</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>MAXIMUM TEMPERATURE</td>
<td>150 °C</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>ENERGY DENSITY [Wh/kg]</td>
<td>13</td>
<td>77</td>
<td>115</td>
</tr>
<tr>
<td>ENERGY DENSITY [Wh/l]</td>
<td>26</td>
<td>233</td>
<td>300</td>
</tr>
<tr>
<td>Chip</td>
<td>MOPS/mW</td>
<td></td>
<td></td>
</tr>
<tr>
<td>---------------------------------------------</td>
<td>---------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conventional microprocessor</td>
<td>1</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Conventional DSP core</td>
<td>45</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Low-power DSP core</td>
<td>65</td>
<td></td>
<td></td>
</tr>
<tr>
<td>CSEM MACGIC core 180 nm</td>
<td>100</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DSP + hardware accelerators</td>
<td>190</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dedicated hardware (no flexibility)</td>
<td>1900</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Upper bond (not reachable)</td>
<td>2500</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The World of Analog Micropower

The World of Systems with micro-power consumption

MULTIDISCIPLINARITY

System matters ... then, single components
Therefore

Power state-of-the-art of a single component or even the low-power of macro-functions does not make sense anymore.

Reducing the power consumption of the analog interface does not help...
HOW TO MEASURE THE POWER EFFECTIVENESS?

\[
FOM = \frac{P}{f_s \cdot 2^{ENOB}}
\]

\[
ENOB = \frac{SNDR(dB) - 1.76}{6.02}
\]
Moore than Moore is pushing Technology in a “different” direction
Don’t just focus on deep submicron technologies, other technologies and Method can be disruptive (and rewarding)
Recommendation:

Think out of the box and enjoy the world of analog micropower.
Thank you!

The pile: Invented by Alessandro Volta
Professor at University of Pavia