Area 3: Analog and Digital Electronics

Sorin P. Voinigescu

The Edward S. Rogers Sr. Department
of Electrical & Computer Engineering
UNIVERSITY OF TORONTO

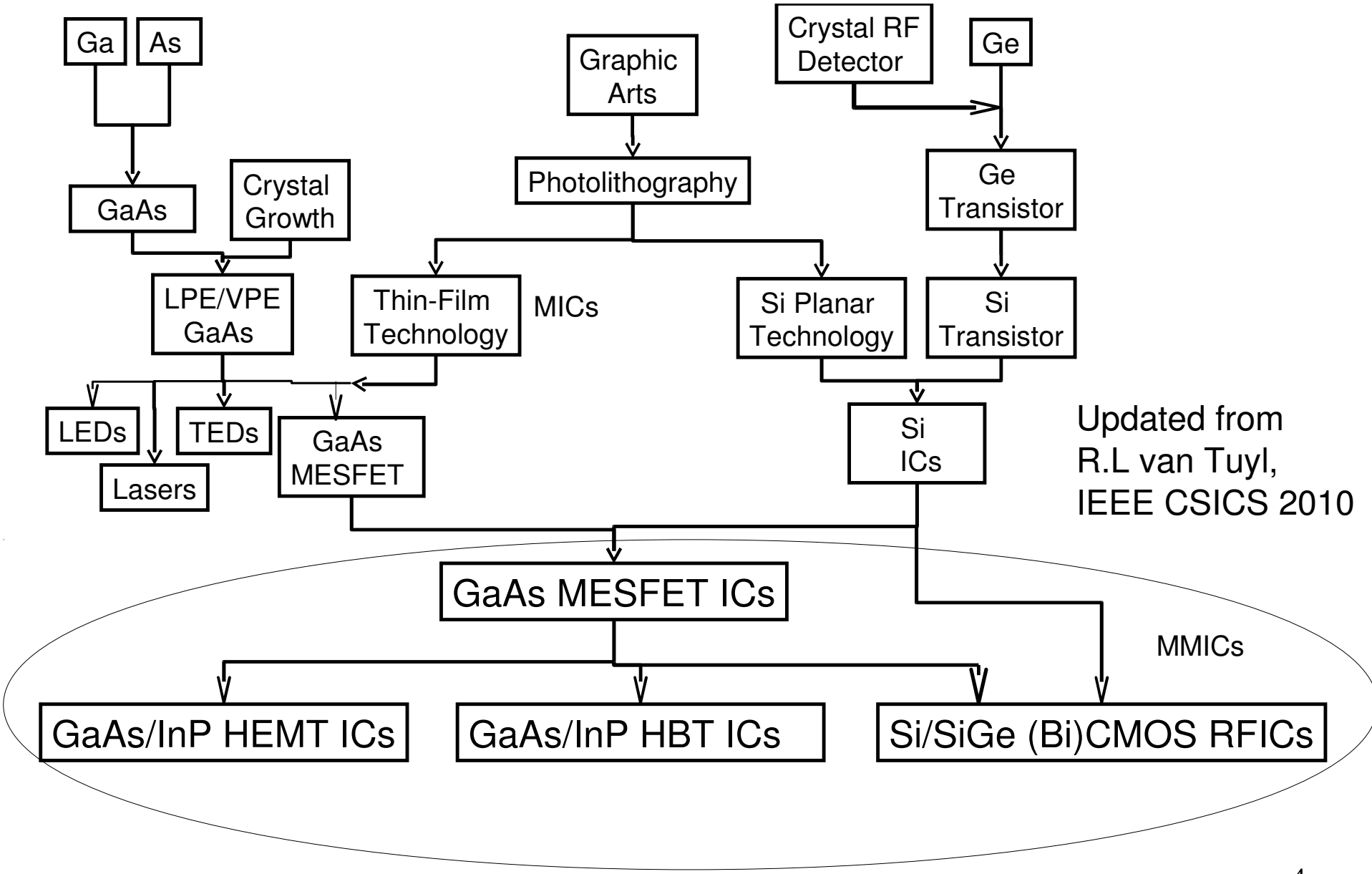
Electronic Circuits 1900-1945

- Vacuum tubes: diodes, triodes: 1900s
- RF Circuits: Oscillator, Amplifier: 1910's
- Heterodyne radio: 1920's
- Digital circuits (with vacuum tubes): 1920's
- FET patent application 1926 (Lilienfeld, Canada)
- Negative feedback amplifier: 1930's
- Microwave vacuum tubes: 1930's
- Microwave solid state (crystal) detectors 1940's

Integrated Circuits 1945-65

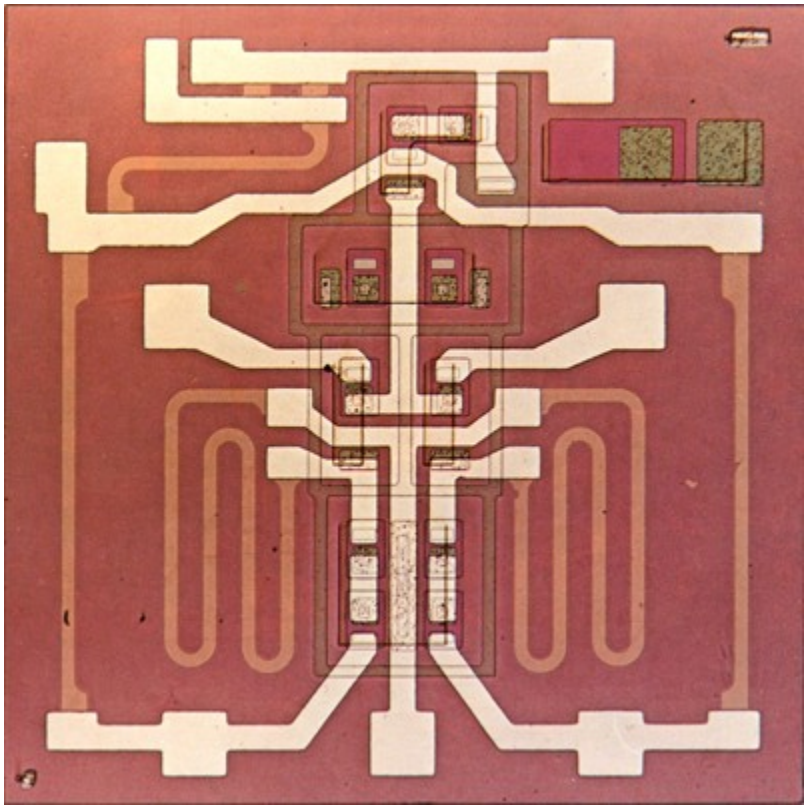
- Bipolar transistor invented 1947 (Bell Labs)
- Discrete components during 1950s
- Integrated circuit invented in 1959
  - Jack Kilby (Texas Instruments)
  - Robert Noyce (Fairchild) (then Intel)
- 1961 was first manufactured (analog) bipolar IC,
- 1960 first MOSFET fabricated
- 1965 first GaAs MESFET fabricated

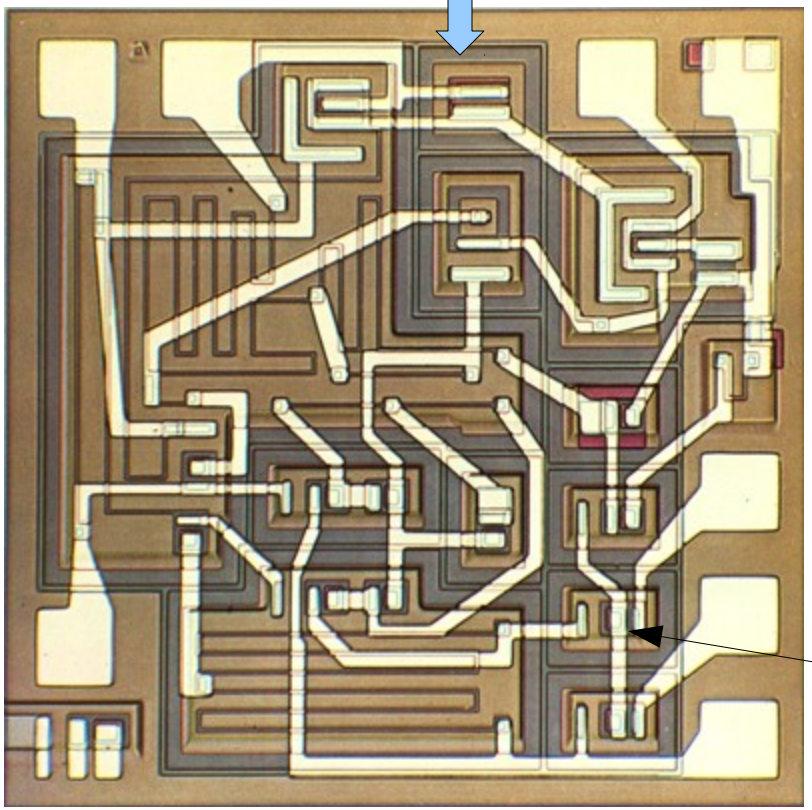
The Analog/RF/Digital IC family tree



Analog Integrated Circuits: 1960s

- Fairchild uA700 opamp
- Talbert-Widlar uA709 opamp





BJT 1963

1964 Si bipolar technology

Digital Integrated Circuits: 1970s

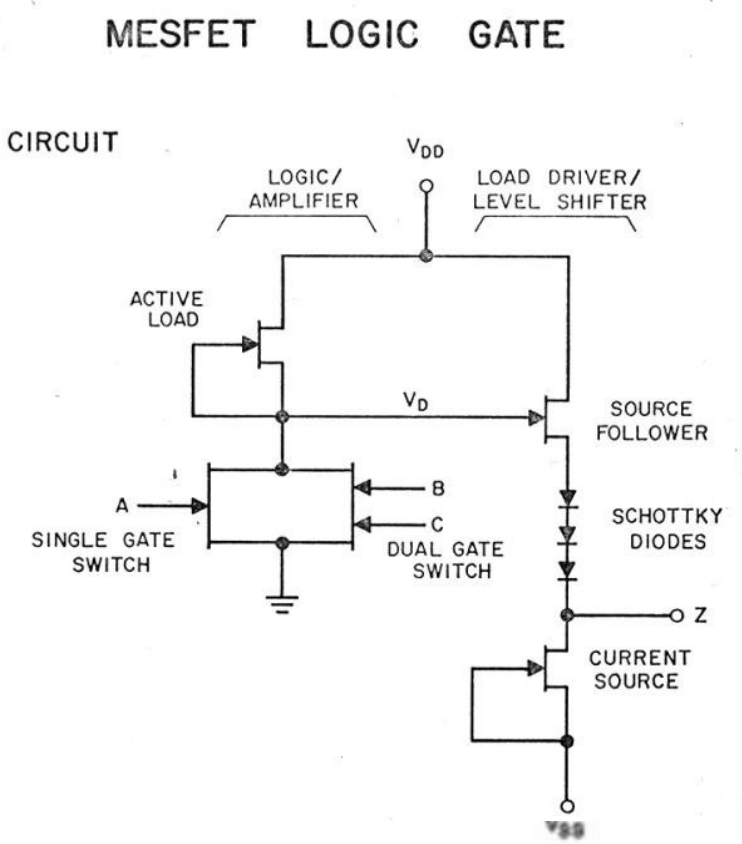
Intel® 4004 processor
Introduced 1971
Initial clock speed
108 KHz
Number of transistors
2,300
Manufacturing technology
10µ

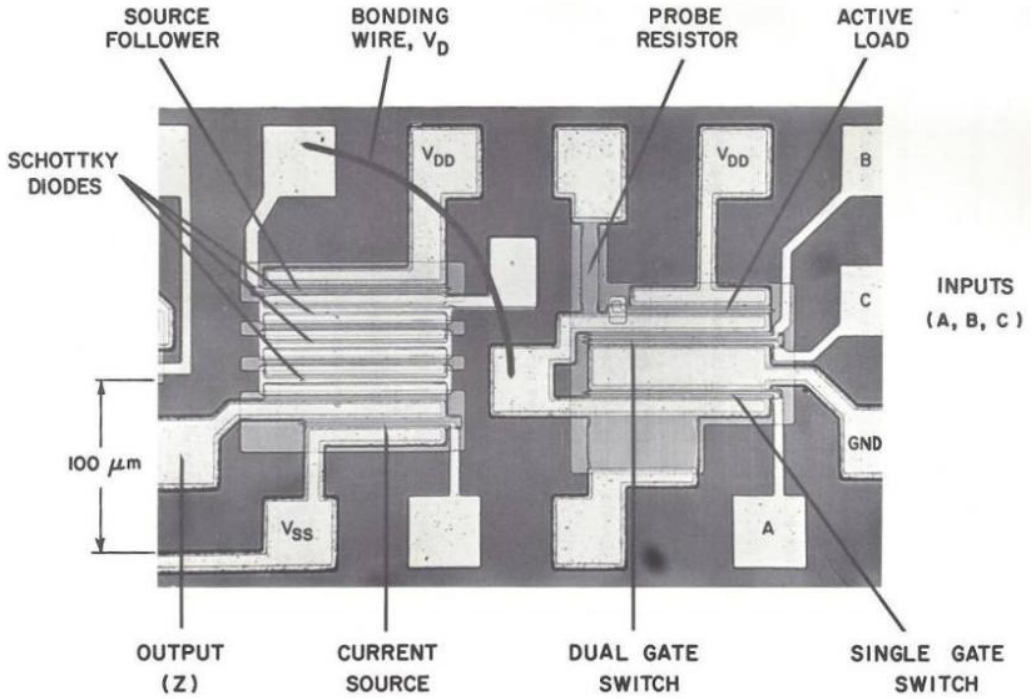
Intel® 8080 processor
Introduced 1974
Initial clock speed
2 MHz
Number of transistors
4,500
Manufacturing technology
6µ

Intel® 8088 processor
Introduced 1979
Initial clock speed
5 MHz
Number of transistors
29,000
Manufacturing technology
3µ

p-MOS only, n-MOS only, later CMOS

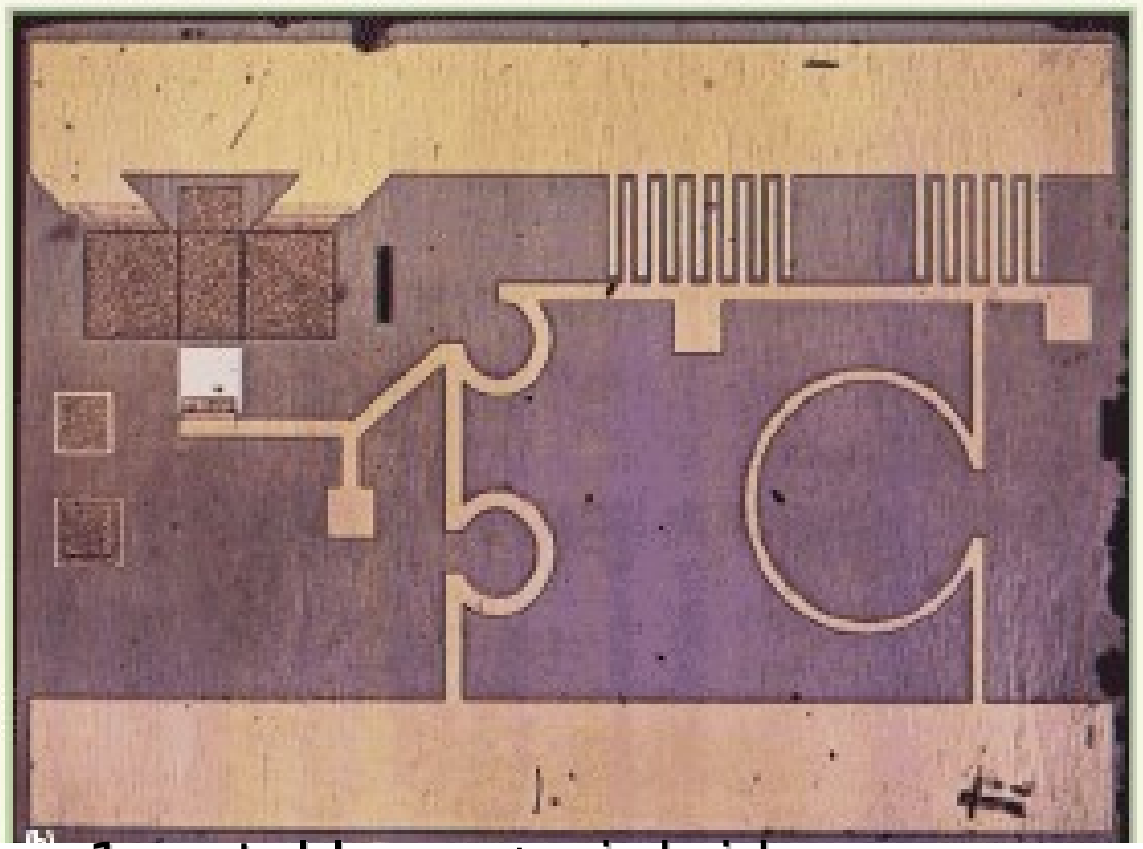
The first Gb/s Logic Gates





Hewlett Packard 1973, 1μm GaAs MESFET process

1974: First GaAs MMIC at 10 GHz



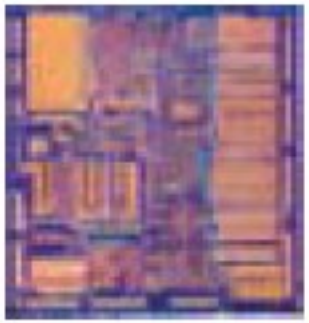
Plessey, UK
- 1μm GaAs n-channel
- MESFETs

- 1 metal layer + air bridge.
- 2 transistors
- 3 metal inductors
- MiM capacitor

MMIC=Microwave Monolithic IC

Digital Integrated Circuits: 1980s

Intel® 286 processor
Introduced 1982
Initial clock speed
6 MHz
Number of transistors
134,000
Manufacturing technology
1.5µ



Intel386™ processor
Introduced 1985
Initial clock speed
16 MHz
Number of transistors
275,000
Manufacturing technology
1.5µ

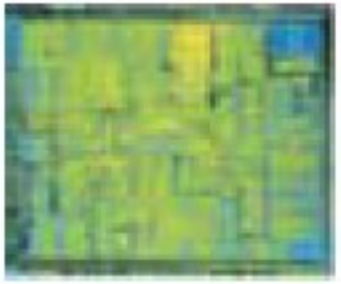
Intel486™ processor
Introduced 1989
Initial clock speed
25 MHz
Number of transistors
1,200,000
Manufacturing technology
1µ

CMOS and Si BiCMOS technologies

Digital Integrated Circuits: 1990s

Intel® Pentium® processor
Introduced 1993
Initial clock speed
66 MHz
Number of transistors
3,100,000
Manufacturing technology
0.8µ

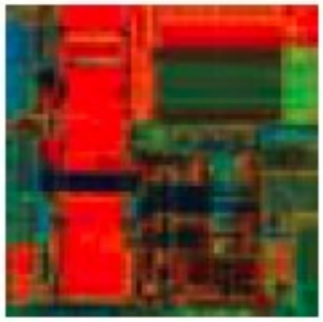
Intel® Pentium® II processor
Intel® Pentium II Xeon® processor
Introduced 1997
Initial clock speed
300 MHz
Number of transistors
7,500,000
Manufacturing technology
0.25µ



Intel® Pentium® III processor
Intel® Pentium® III Xeon® processor
Introduced 1999
Initial clock speed
500 MHz
Number of transistors
9,500,000
Manufacturing technology
0.18µ

CMOS technologies

Digital Integrated Circuits: 2000s



Intel® Itanium® 2 processor
Introduced 2002
Initial clock speed

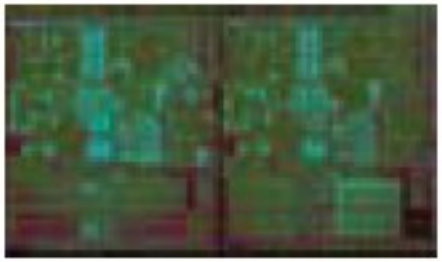
1 GHz

Number of transistors

220,000,000

Manufacturing technology

0.13µ



Intel® Pentium® D processor
Introduced 2005
Initial clock speed

3.2 GHz

Number of transistors

291,000,000

Manufacturing technology

65nm

Quad-Core Intel® Xeon® processor (Penryn)
Dual-Core Intel® Xeon® processor (Penryn)
Quad-Core Intel® Core™2 Extreme processor (Penryn)
Introduced 2007
Initial clock speed

> 3 GHz

Number of transistors

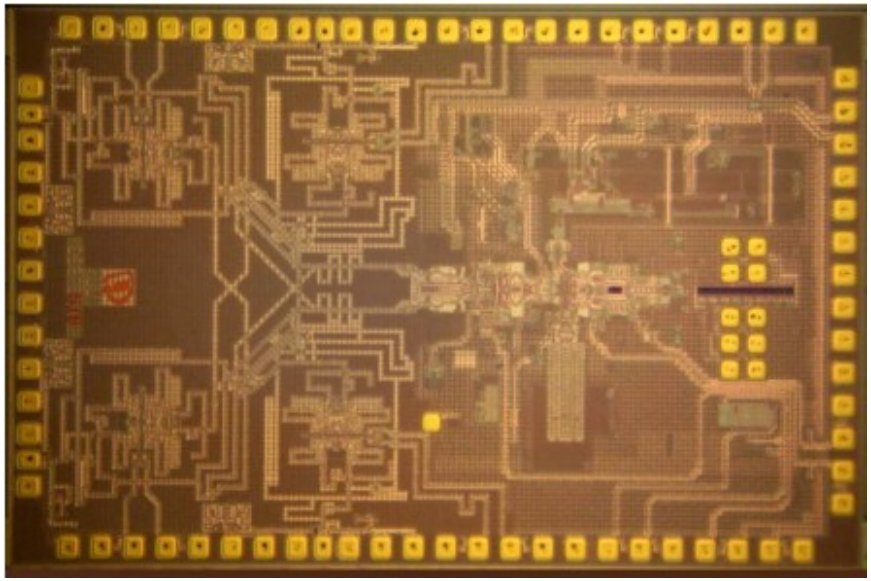
820,000,000

Manufacturing technology

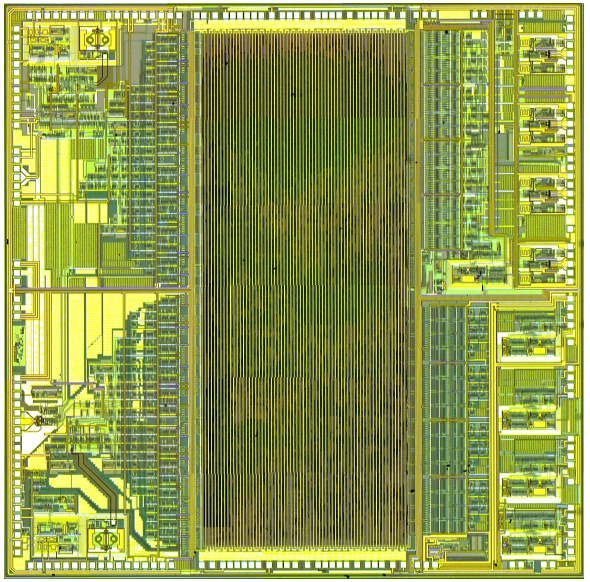
45nm

System on Chip Era Begins: 2000-2010

- Analog/Mixed-Signal/Digital and RF on the same die
  - SiGe BiCMOS
  - <=65nm CMOS



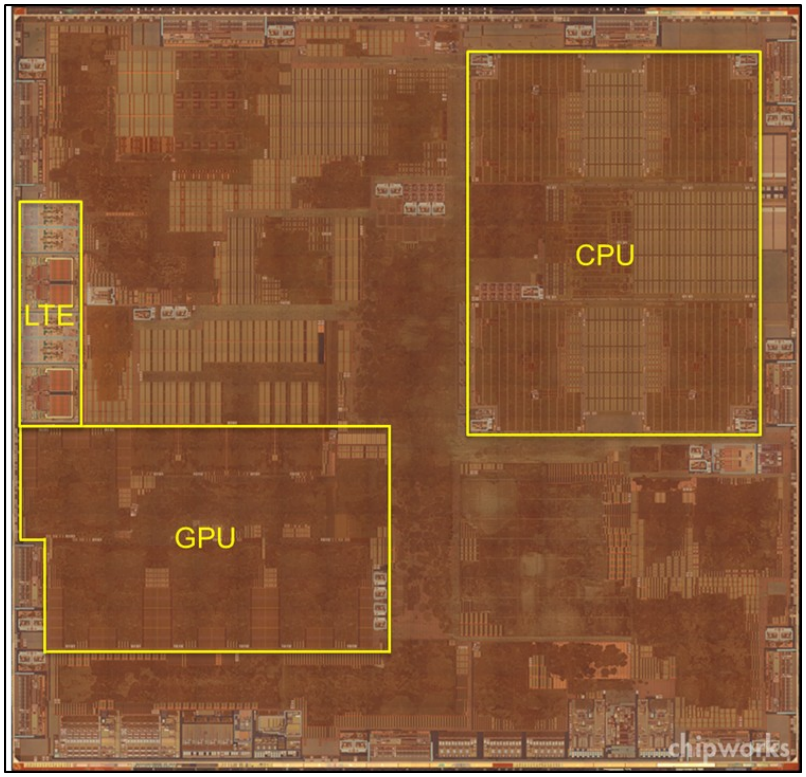
77GHz automotive radar sensor,
Infineon, 2009, 0.35µm SiGe HBT, f_T/f_{MAX}=230/250 GHz



10G Ethernet Transceiver,
Quake Technologies, 2001
0.25µm SiGe BiCMOS
f_T/f_{MAX}=70/70 GHz

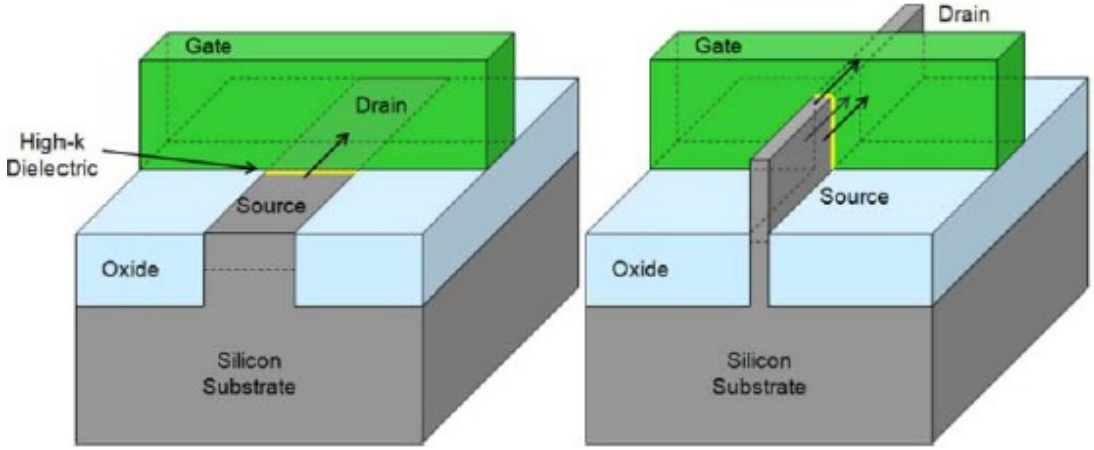
SoCs: 2010-2015

- Intel multicore processors
  - 3-4 GHz clock speed
  - >2B transistors
  - 22nm and 14nm SiGe/SiC CMOS FinFET technology
- Qualcomm RF Transceivers and multicore ARM mobile processors
  - 2-3 GHz clock speed
  - >2B transistors
  - 28nm and 22nm CMOS technology
- Broadcom 1.2Tbs Fiberoptic Transceiver
  - 40 Gb/s port speed (CML)
  - >7B transistors
  - 28nm CMOS technology

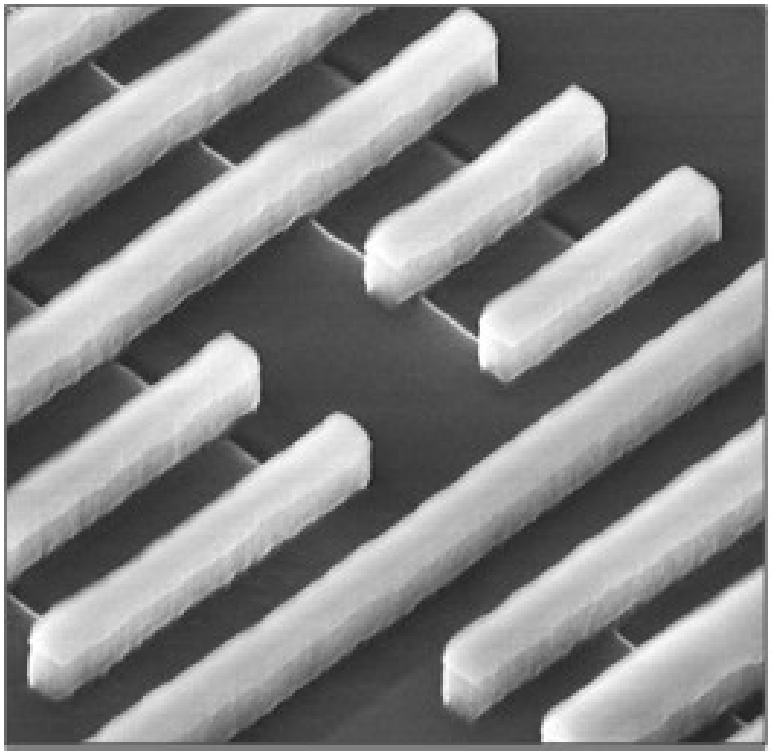


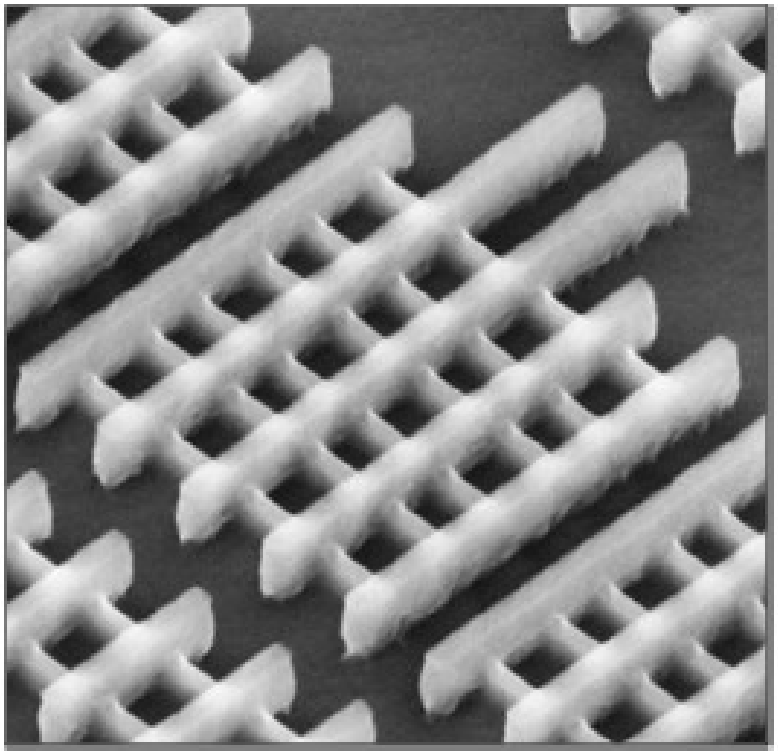
Qualcomm Snapdragon 800

32nm planar vs. 22nm FinFET CMOS ICs



Intel





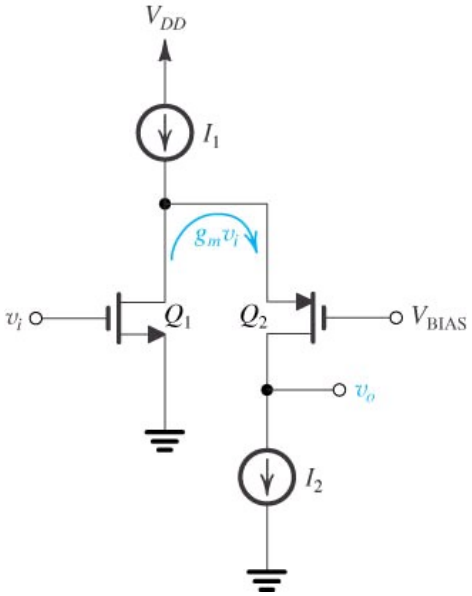
Future?
Automotive and Internet of Things Sensors That Think for Us!
The Bionic You!

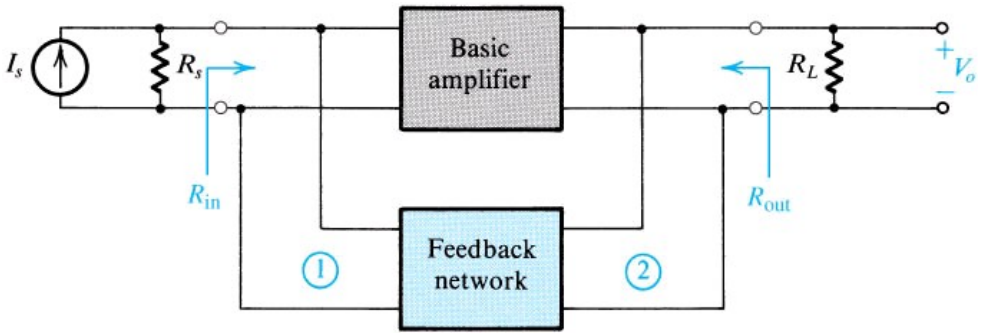
"Cars that Think", IEEE Spectrum, Oct. 2014

It's still up to you to define and steer the future!

Analog Electronics

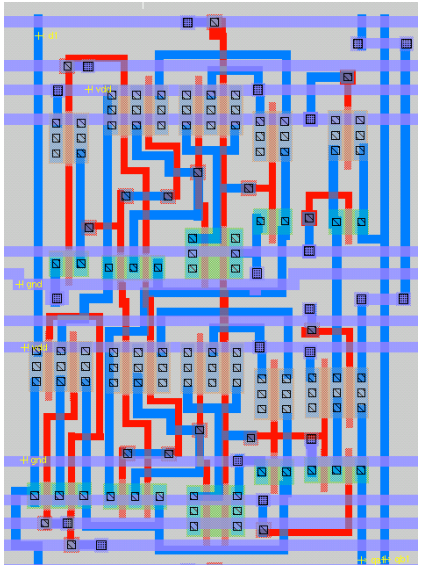
- Learn basics of analog circuit design at transistor and board level
- Much more of the world is analog than people realize
- Most integrated circuits have significant analog

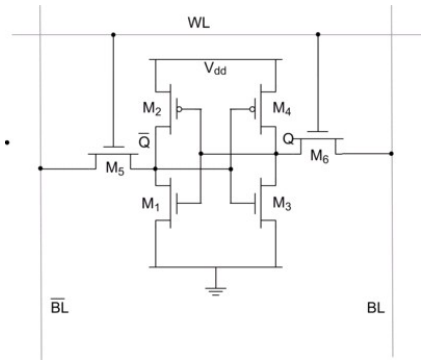


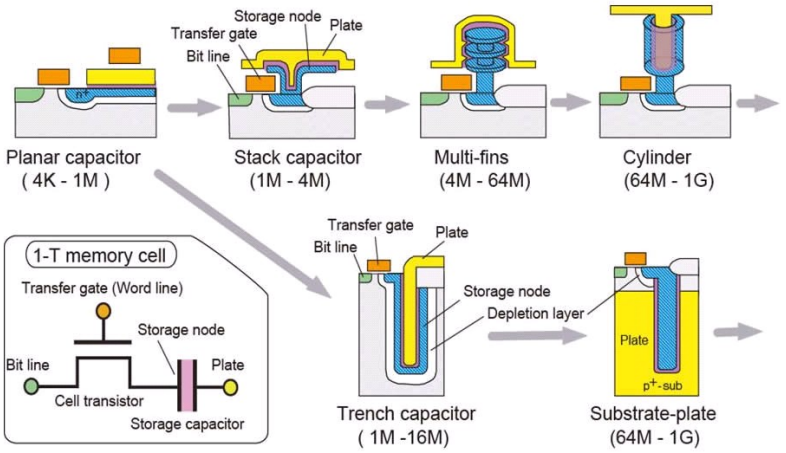


Digital Electronics

- Learn basics of digital system design at transistor and architecture levels
- Required skill for anyone thinking of hardware career







Analog Electronics

- Learn basics of analog circuit design at transistor and board level
- Much more of the world is analog than people realize
- Most integrated circuits have significant analog content

- Kernel - ECE331 Analog Electronics
  (extension of 2'nd year Introductory Electronics course)
- Depth - ECE530 Analog Integrated Circuits
  ECE512 Analog Integrated Systems
  ECE534 Integrated Circuit Engineering

Analog Electronics – Related Courses

- ECE334 Digital Electronics (kernel)
  - most integrated circuits contain both digital and analog

- ECE302 Probability & Random Processes
- ECE431 Digital Signal Processing
- ECE316 Communication Systems
  Signal processing and communications closely related

- ECE335 Introduction to Electronic Devices
- ECE524 Microwave Circuits
  - Many analog/digital circuits now operate above 3 GHz

Digital Electronics

- Learn basics of digital system design at transistor and architecture levels
- Required skill for anyone thinking of hardware career

- Kernel - ECE334 Digital Electronics
  (Transistor and gate level circuit design)
- Depth - ECE451 VLSI Systems & Design
  ECE532 Digital Systems Design
  ECE534 Integrated Circuit Engineering

Digital Electronics – Related Courses

- ECE331 Analog Electronics (kernel)
  - most integrated circuits contain both digital and analog

- ECE342 Computer Hardware
- ECE452 Computer Architecture
  Digital design at the upper architecture level

- ECE335 Introduction to Electronic Devices
  - Useful course if taking ECE534

Careers in Electronics

- **Design** — Develop new products (MASc or PhD). Design teams of 6 - 100
- **Applications** — documentation for customers about product
- **Test** — develops test methods for product
- **Sales** — sells products to customers
- **Manager** — in charge of group

Companies in Electronics

- Canada
  - PMC-Sierra, Peraso, Kapik Integration, AMD, Semtech, Ciena, Intel, Qualcomm, Analog Devices, Skyworks, InPhi
- USA
  - Qualcomm, Intel, TI, Broadcom, Apple, Qorvo, Skyworks, IBM, Freescale, Motorola, Analog Devices, Seagate, InPhi, …

Electronics – Kernel Courses

- ECE331: **Analog Electronics**
  (extension of 2'nd year analog electronics course)
  - Transistor amplifiers (inside an opamp)
  - Biasing techniques
  - Frequency response
  - Feedback analysis and stability

- ECE334: **Digital Electronics**
  (Transistor and gate level circuit design)
  - Transistor models and spice simulation
  - IC fabrication basics and layout
  - CMOS gate design and transient response
  - Latches, registers, adder cells
  - Memory design (SRAM, DRAM, ROM, FLASH)

Electronics – Depth Courses

- ECE530: Analog Integrated Circuits (analog)
  - Opamp design, comparators, A/D and D/A converters
- ECE512: Analog Integrated Systems (analog)
  - Filters, oversampling, noise in analog circuits.
- ECE451: VLSI Systems and Design (digital)
  - Complex digital systems (eg. Microprocessor)
- ECE532: Digital Systems Design (digital)
  - Hard/software interfacing, memory interfaces, ...
- ECE534: Integrated Circuit Eng. (analog or digital)
  - IC fabrication, modelling, packaging, yield, …

Analog Electronics – Related Courses

- ECE334 Digital Electronics (kernel)
  - SoCs contain both digital and analog
- ECE302 Probability & Applications
- ECE431 Digital Signal Processing
- ECE316 Communication Systems
  Signal processing and communications closely related

- ECE335 Introduction to Electronic Devices
- ECE535 Advanced Electronic Devices
- ECE422 Radio and Microwave Wireless Systems (d)

  Mobile wireless systems dominate now and in the future

Possible Analog Path

- 3rd year
  - ECE316 Communication Systems (k)
  - ECE331 Analog Electronics (k)
  - ECE335 Introduction to Electron Dev (k)
  - ECE320 Fields & Waves (k)
  - ECE302 Probability & Applications (d)
  - ECE334 Digital Electronics (k)
  - ECE311 Dynamic Systems & Control (k)
  - ECE472 Engineering Economic Analysis

Possible Analog

- 4th year
  - ECE496 Design Project
  - ECE512 Analog Integrated Systems (d)
  - ECE534 Integrated Circuit Engineering (d)
  - ECE431 Digital Signal Processing (d)
  - ECE451 VLSI Systems and Design (d)
  - ECE530 Analog Integrated Circuits (d)
  - ECE422 Radio and Microwave Wireless Systems (d)
  - ECE496 Design Project

Digital Electronics – Related Courses

- ECE342 Computer Hardware
- ECE452 Computer Architecture
  Digital design at the upper architecture level

- Any number of software courses. Digital chips these days are done with verilog/VHDL, system C, etc.
- Good digital designers are good software designers (but they can't make errors – even more rigorous testing)

Possible Digital Path

- 3rd year
  - ECE316 Communication Systems (k)
  - ECE344 Operating Systems (k)
  - ECE334 Digital Electronics (k)
  - CSC444 Software Eng I (d)
  - ECE361 Computer Networks (k)
  - ECE 342 Computer Hardware (k)
  - ECE345 Algorithms and Data Structures (k)
  - ECE472 Engineering Economic Analysis

Possible Digital Path

- 4th year
  - ECE496 Design Project
  - ECE534 Integrated Circuit Engineering (d)
  - ECE552 Computer Architecture (d)
  - ECE454 Computer Systems Programming (d)
  - ECE431 Digital Signal Processing (d)
  - ECE451 VLSI Systems and Design (d)
  - ECE532 Digital Systems Design (d)
  - ECE496 Design Project