Analog Integrated Systems Design

Lecture 01
Introduction

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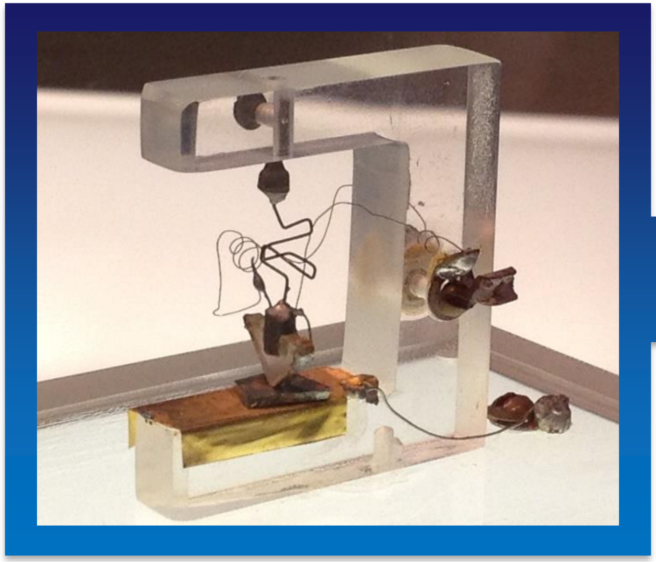
Introduction

ENIAC, U.S. Army, 1946
Size → Large hall (> $150m^2$)
Power Consumption ≈ 150kW

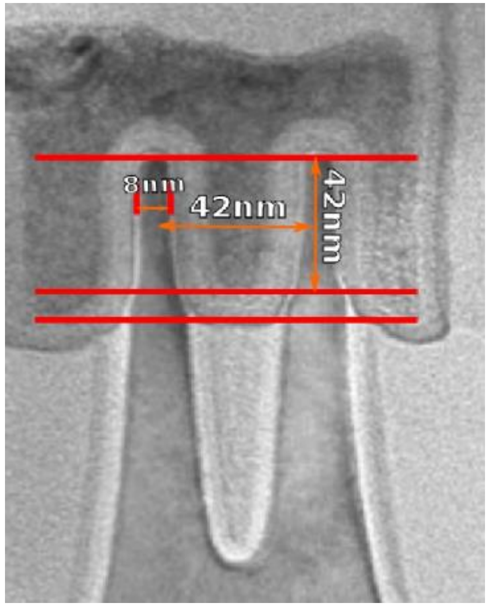
Smart phone
Size → Your pocket
Power consumption < 1W

Electronics All Around Us

Transistor Evolution

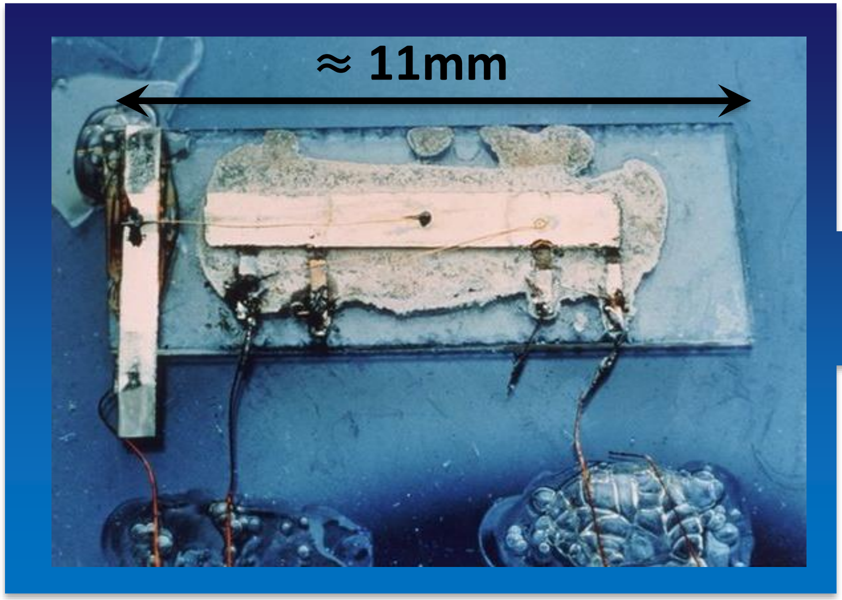


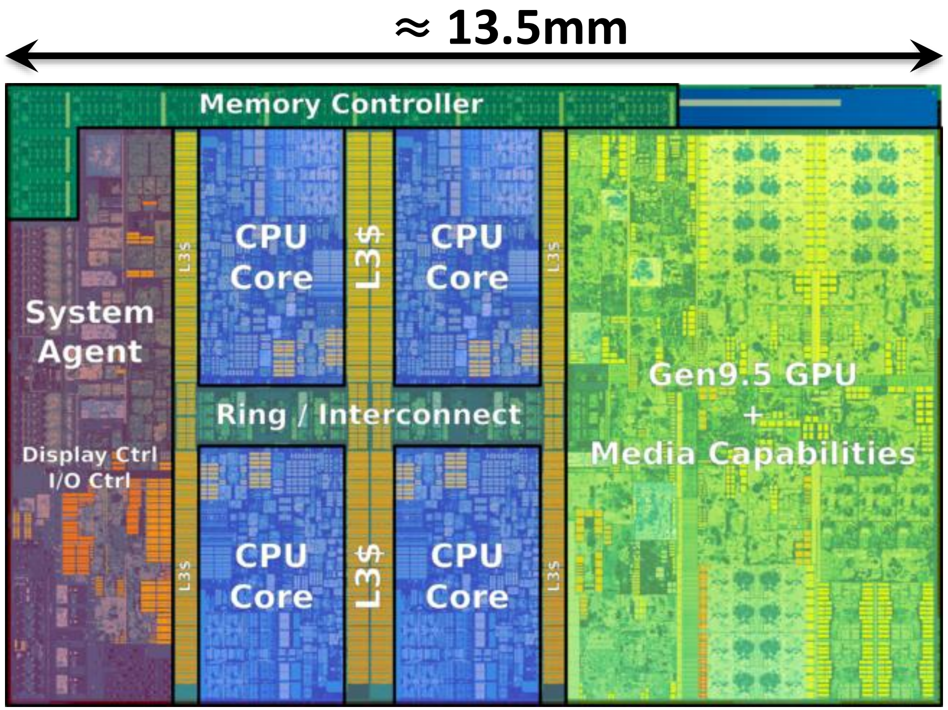
First transistor
Contacts separation ≈ 100µm
Bell Labs, 1947



Trigate Transistor
Fin width ≈ 8nm
Intel, 2015

Integrated Circuit Evolution



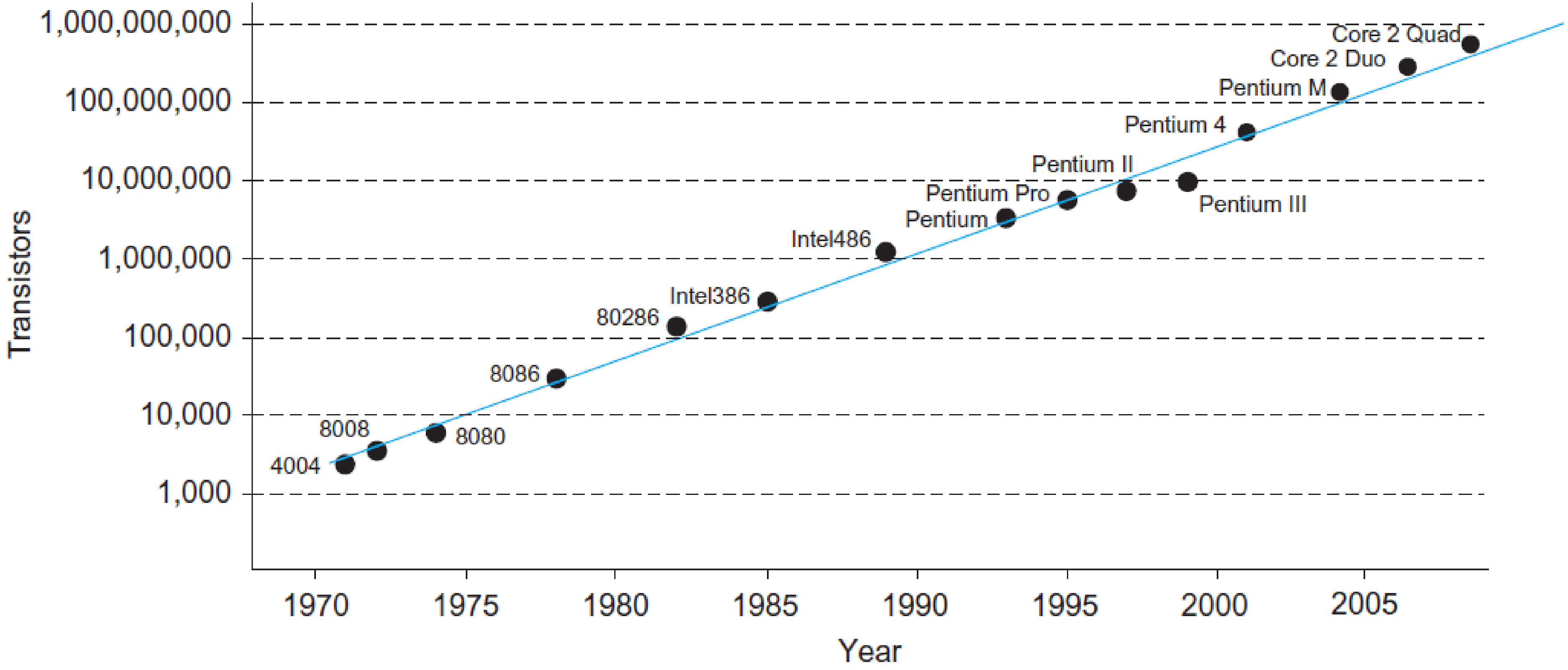


First IC
Only one transistor (+ R + C)!
Texas Instruments (TI), 1958

Quad-core CPU
$> 10^9$ transistors!
Intel, 2017

Moore's Law

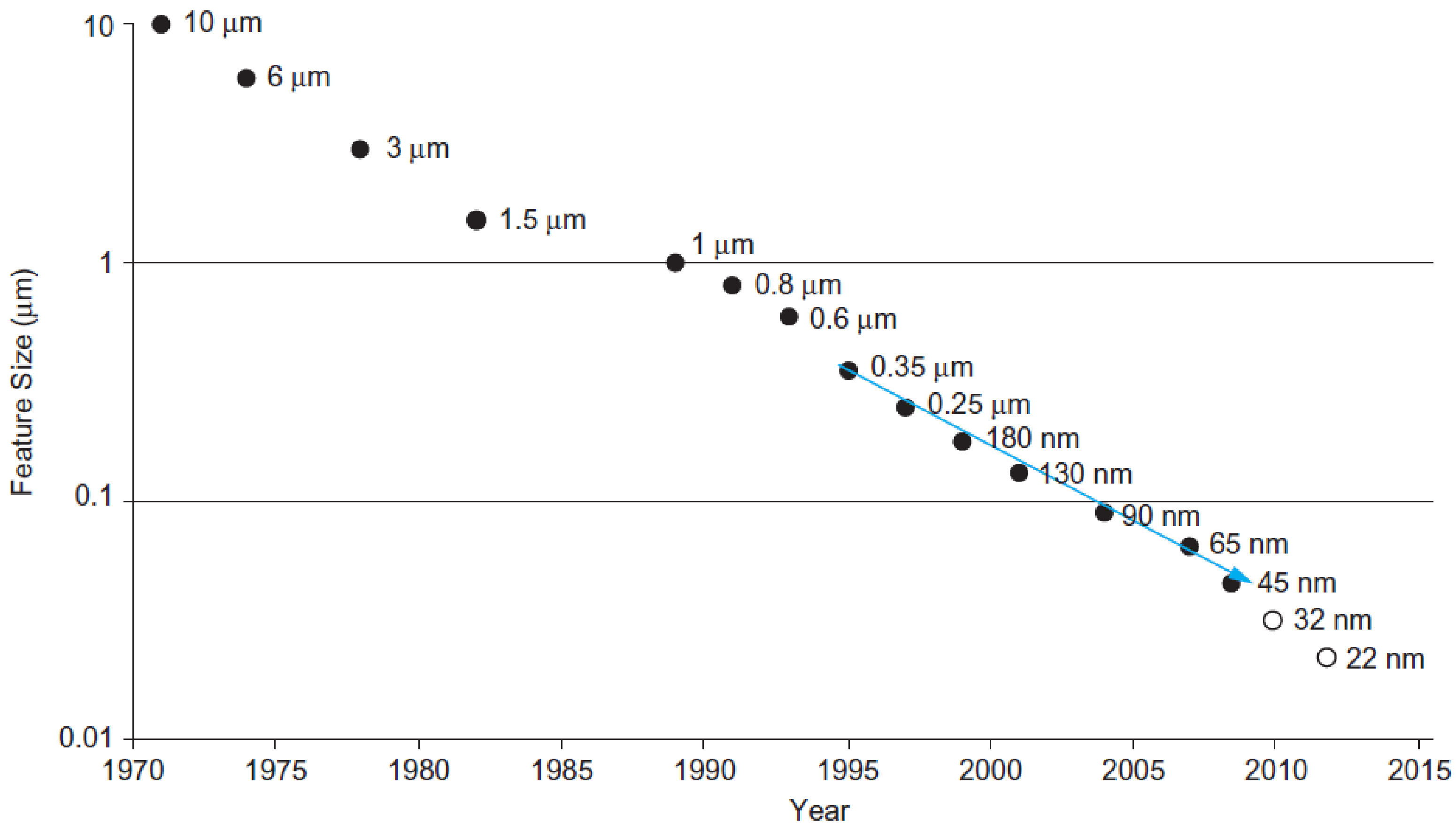
- Moore's law [1965]: Transistor count doubles every 1.5 years
- Practically: It doubled every 2-3 years since the 4004 [1970s]
- At the end of the day: It is exponential!



[Weste and Harris, 2010]

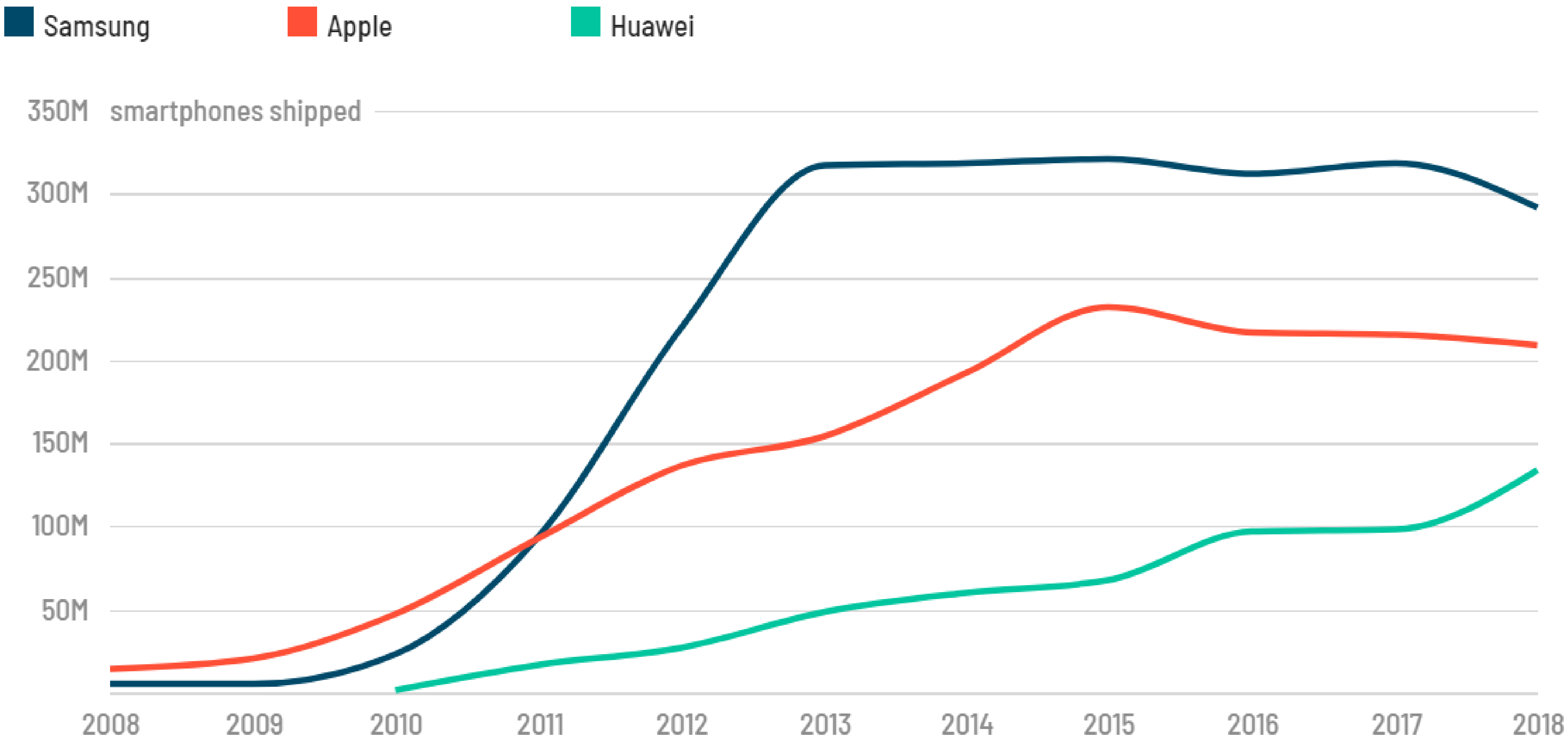
Technology Minimum Feature Size

- Minimum feature size shrinking 30% ($\approx 1/\sqrt{2}$) every 2-3 years
  - Transistor **area and cost** are reduced by a factor of **?**
- Device scaling brings new challenges in analog design



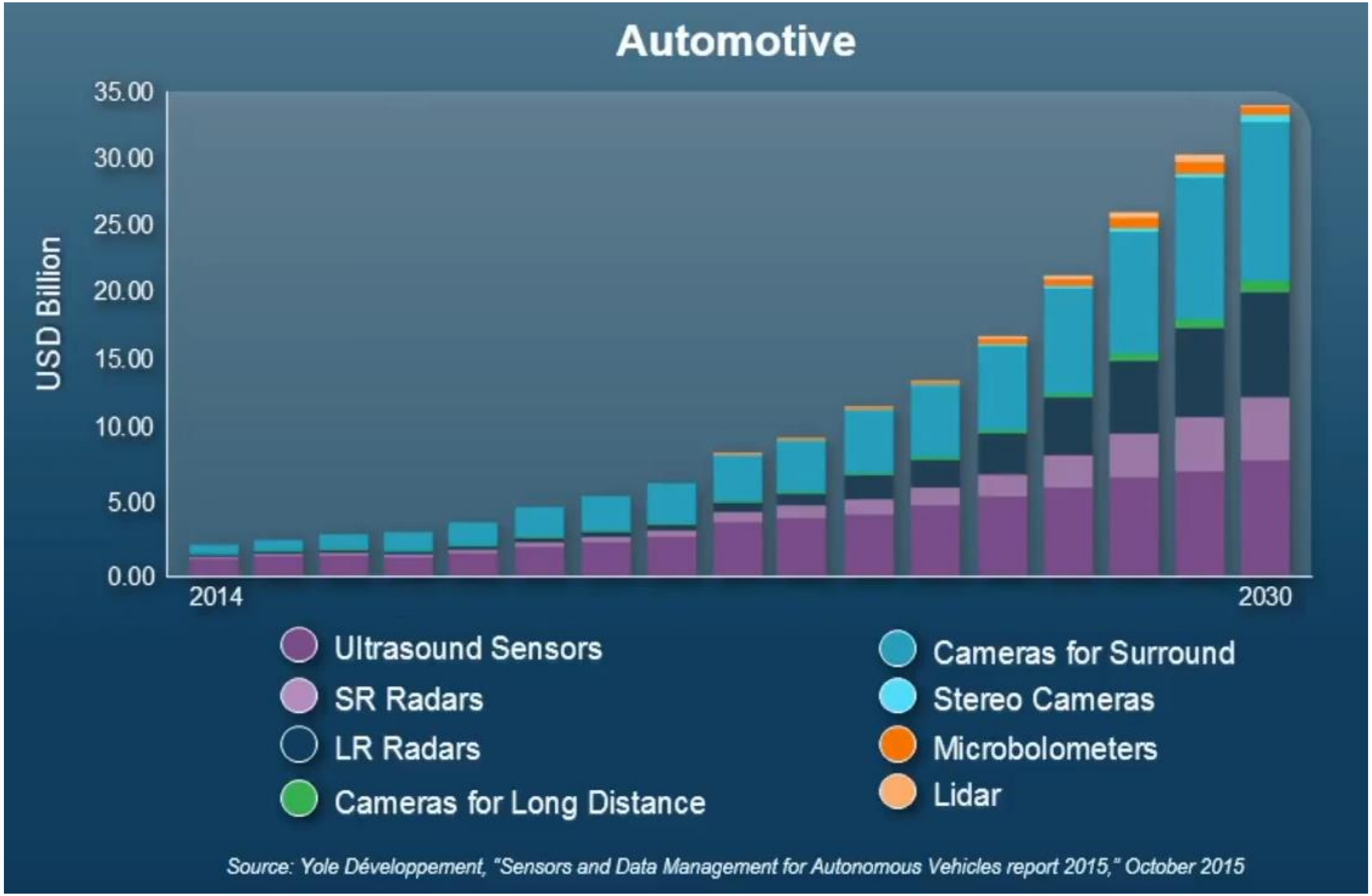
[Weste and Harris, 2010]

The Smartphone Plateau



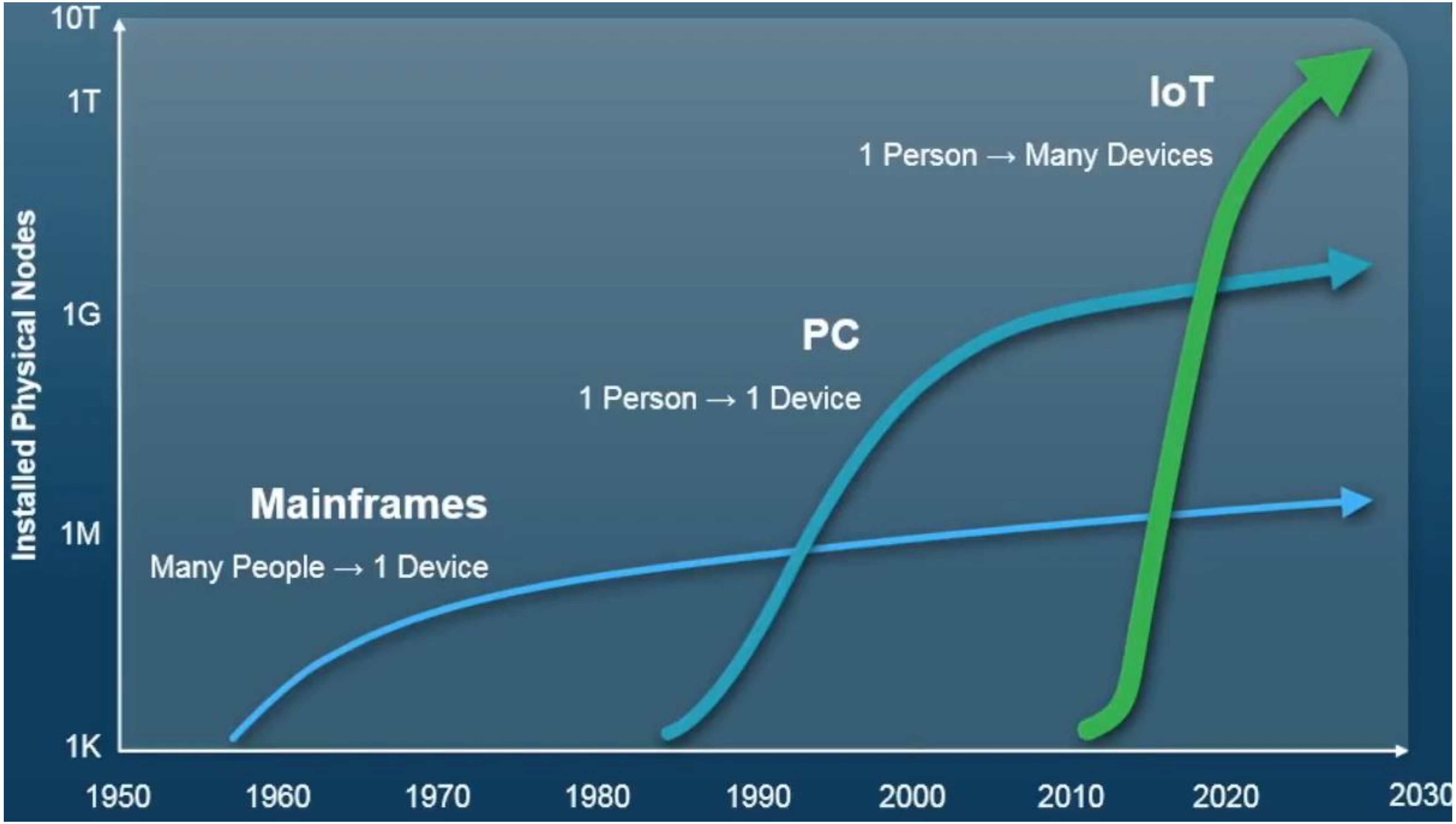
[https://edition.cnn.com/interactive/2019/09/business/samsung-headquarters-south-korea/index.html]

Growing Demand in New Applications



[Vincent Roche, ADI, ISSCC Plenary Talk, 2018]

IoT is the New Wave

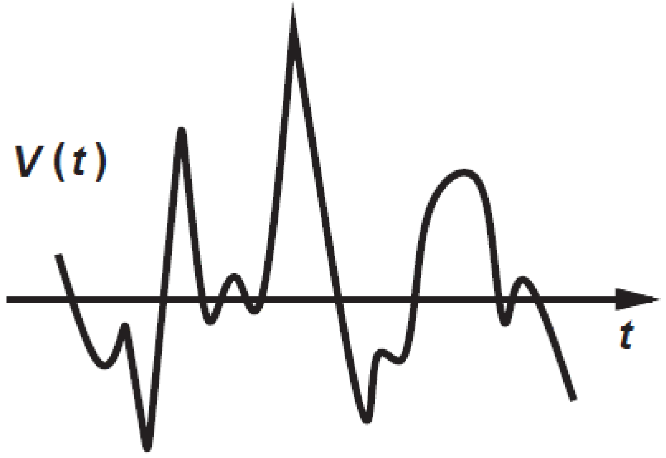


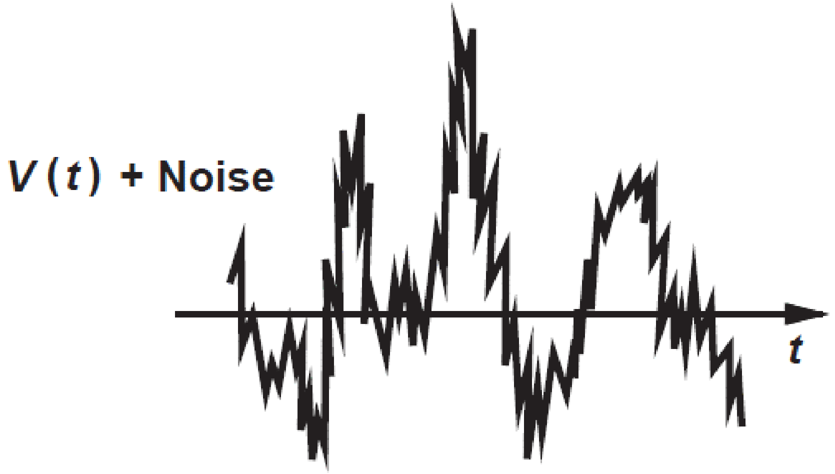
[Vincent Roche, ADI, ISSCC Plenary Talk, 2018]

IC Industry in Egypt

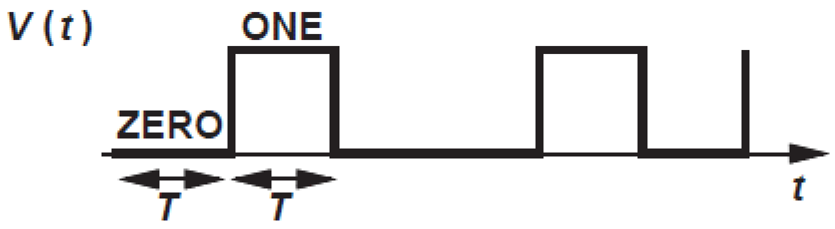
Analog vs Digital Signals

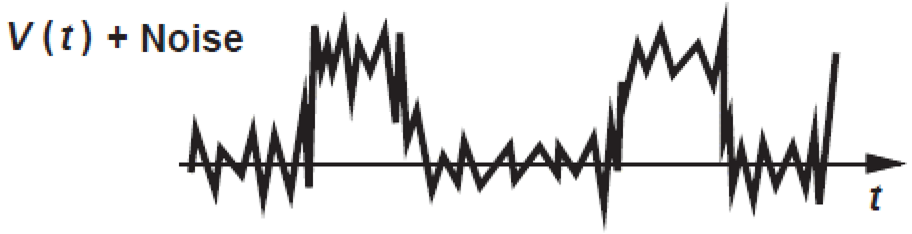
- Analog: continuous in time and amplitude





- Digital: discrete in time and amplitude





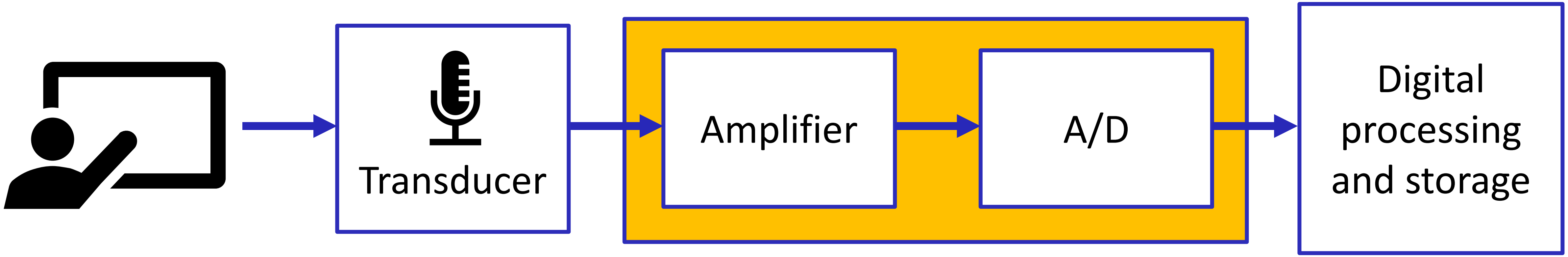
[Razavi, 2014]

Why Digital?

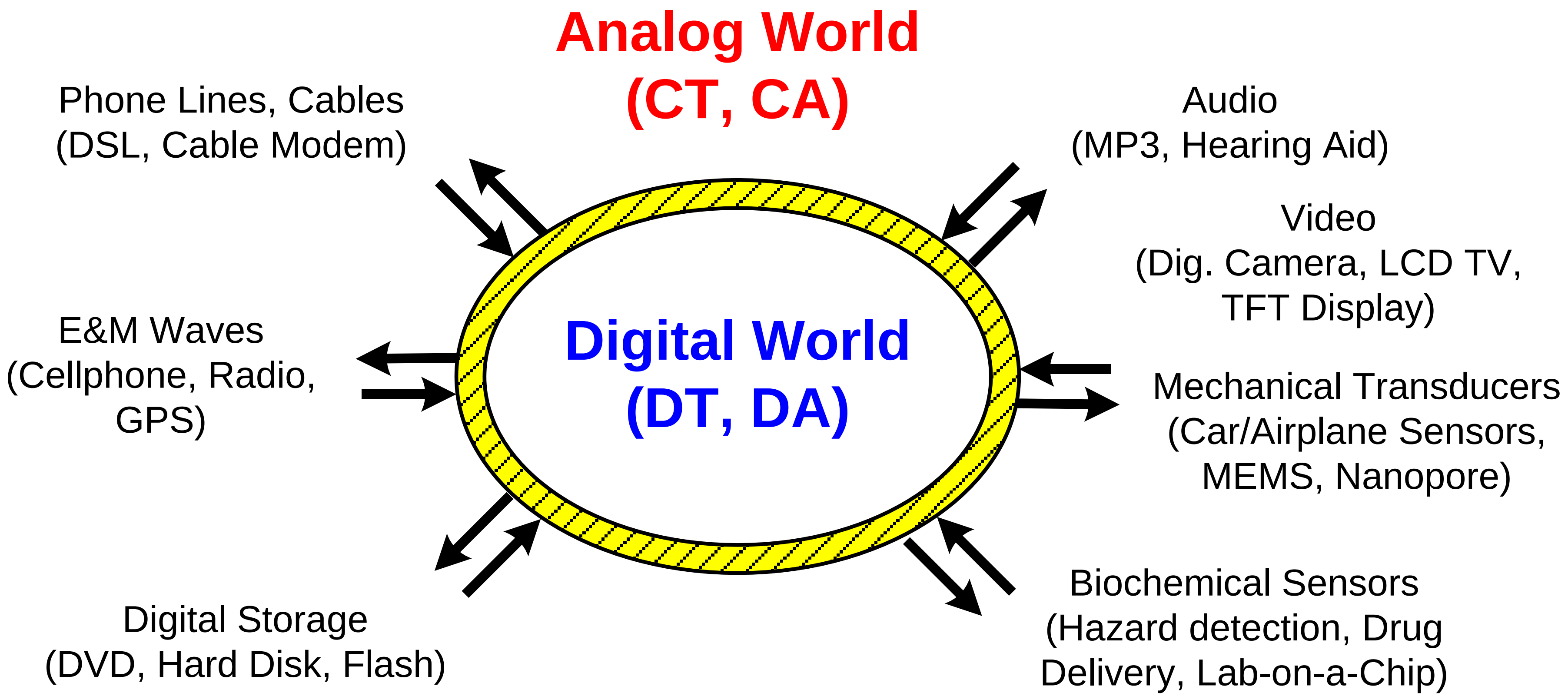
- Digital circuits are
  - Less sensitive to noise (robust)
  - Easier to store (digital memories)
  - Easier to process (digital signal processing: DSP)
  - Amenable to automated design
  - Amenable to automated testing
  - Direct beneficiary of Moore's law (down-scaling)

Why Analog?

- All the physical signals in the world around us are analog
  - Voice, light, temperature, pressure, etc.
- We (will) always need an "analog" interface circuit to connect between our physical world and our digital electronics



Why Analog?


Analog World
(CT, CA)
Digital World
(DT, DA)
Phone Lines, Cables
(DSL, Cable Modem)
E&M Waves
(Cellphone, Radio,
GPS)
Digital Storage
(DVD, Hard Disk, Flash)
Audio
(MP3, Hearing Aid)
Video
(Dig. Camera, LCD TV,
TFT Display)
Mechanical Transducers
(Car/Airplane Sensors,
MEMS, Nanopore)
Biochemical Sensors
(Hazard detection, Drug
Delivery, Lab-on-a-Chip)

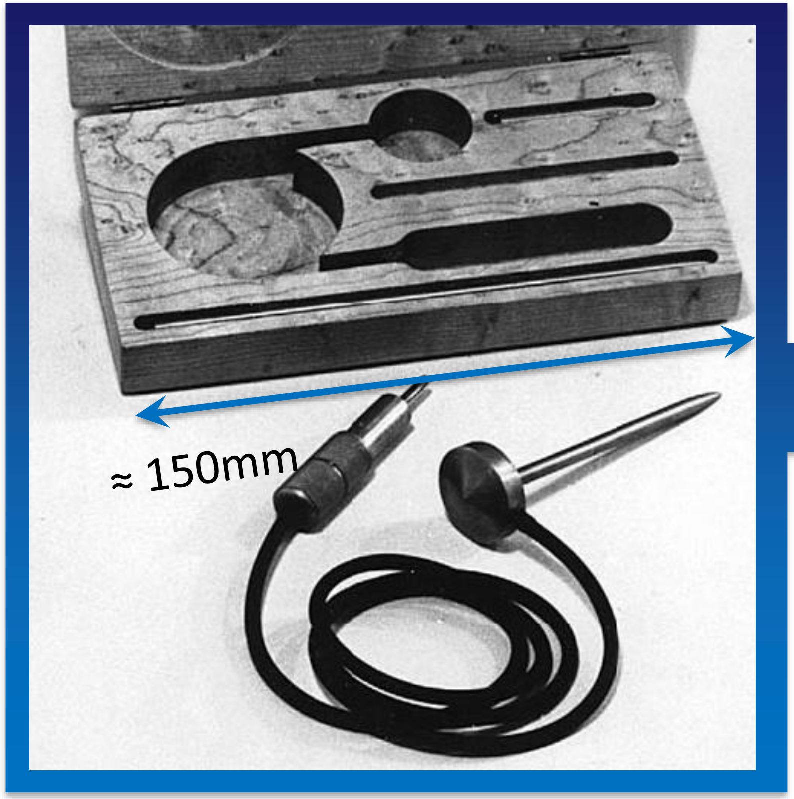
Sensors Proliferation

Sensors Proliferation

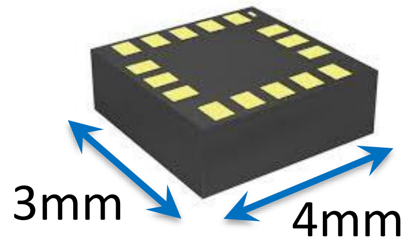
➢ **Smart sensors market will grow from $18 billon in 2015 to $58 billion by 2022**

[www.researchandmarkets.com, www.marketsandmarkets.com]

Sensing Microsystems



First accelerometer
B&K, 1940s
Simple bulky transducer
Acceleration → Voltage

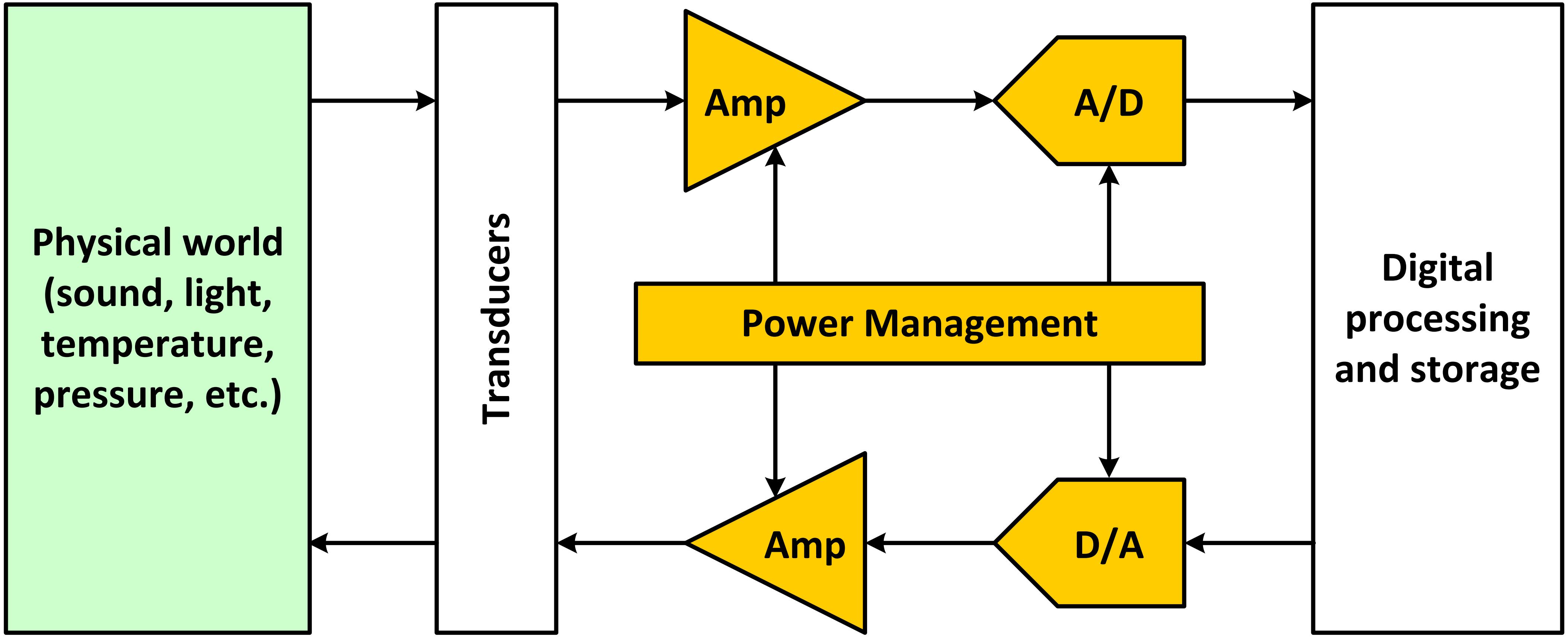


ADXL350
Analog Devices, 2012
Complete system on a tiny chip

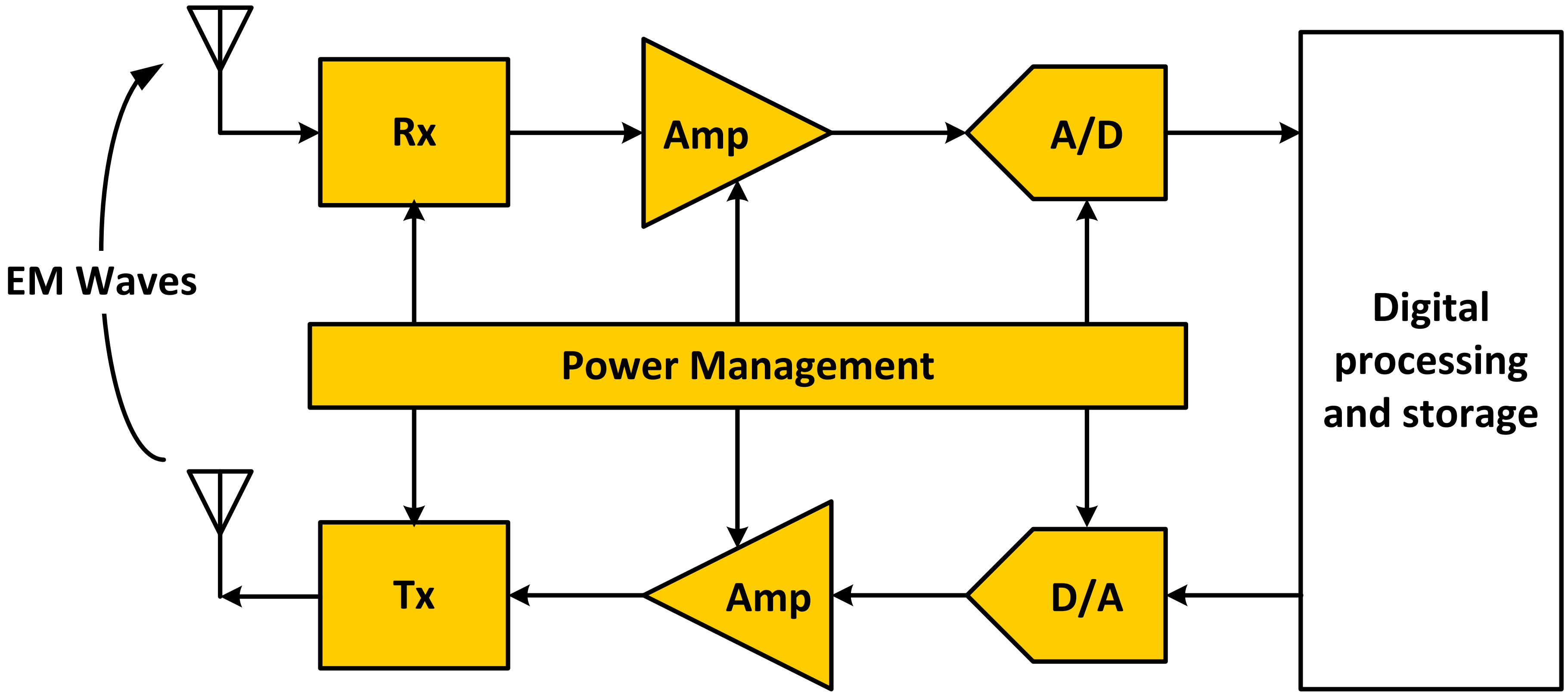
- 3-axis MEMS* accelerometer
- Interface electronics
- Analog-to-digital conversion
- Memory
- Control logic
- Power management
- Digital interface

*MEMS = Micro-Electro-Mechanical Systems

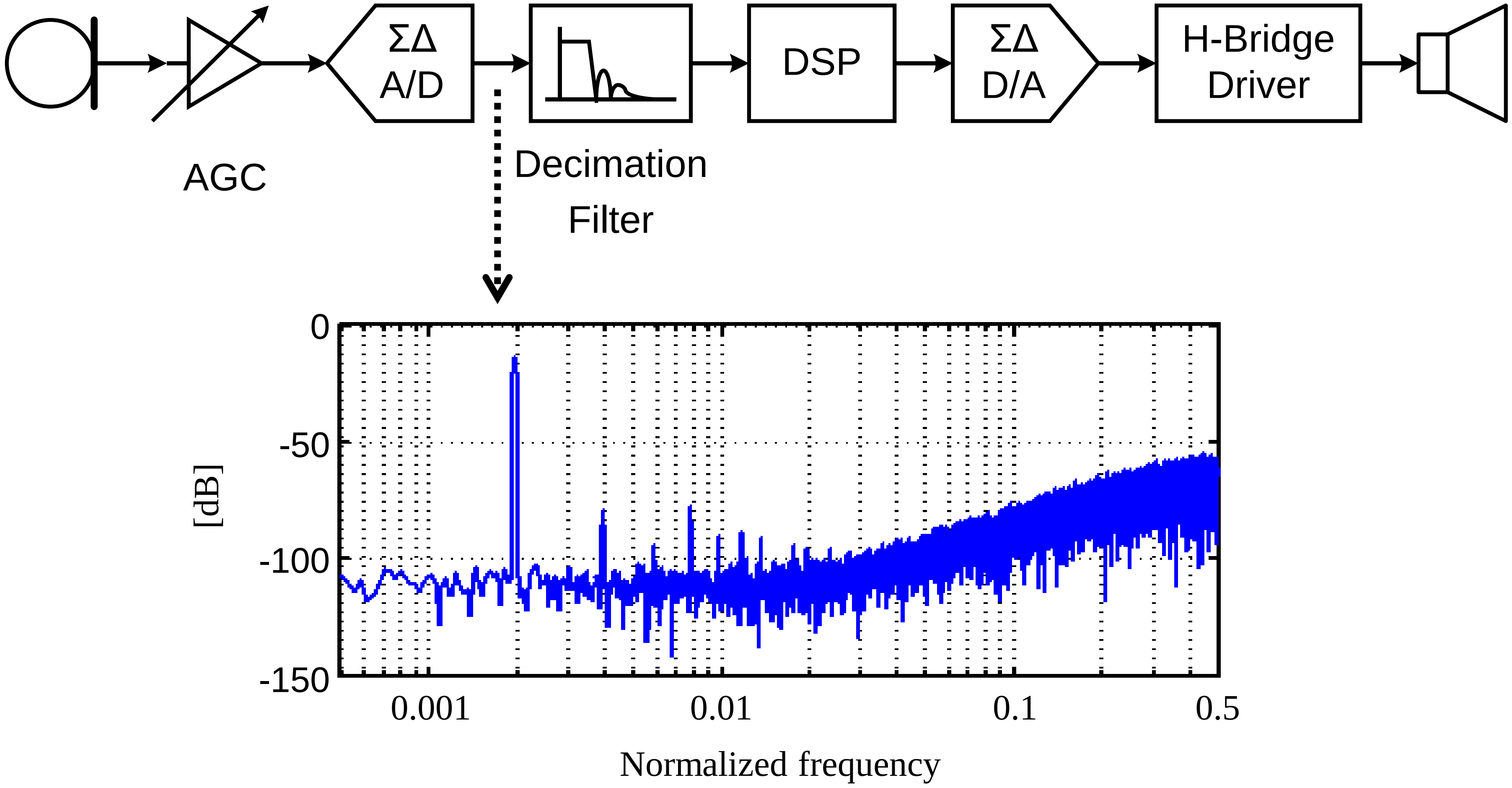
Signal Processing Chain



Electronic System Example: Wireless Transceiver

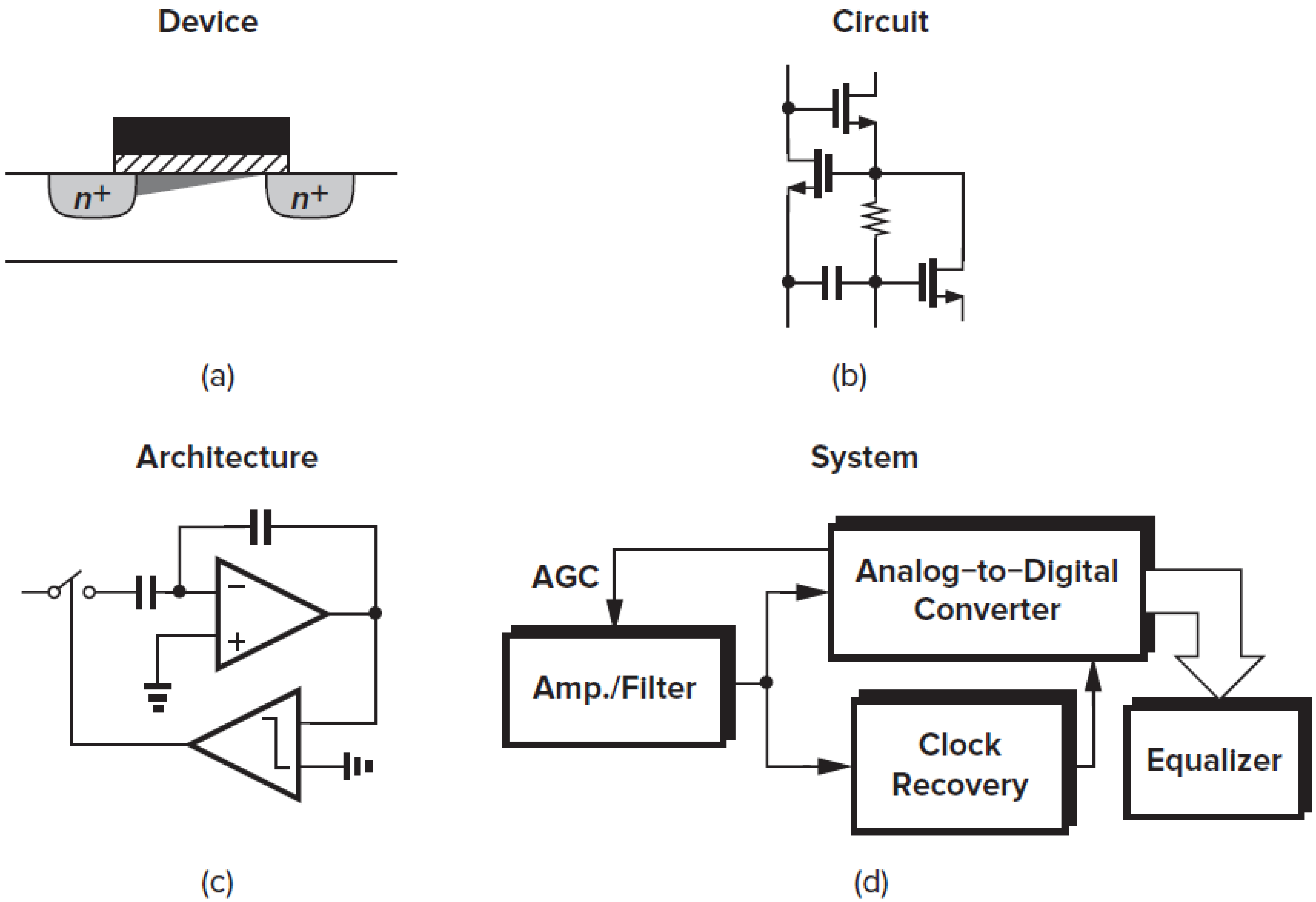


Electronic System Example: Mixed-Signal Hearing Aid



[Y. Chiu, EECT 7327, UTD]

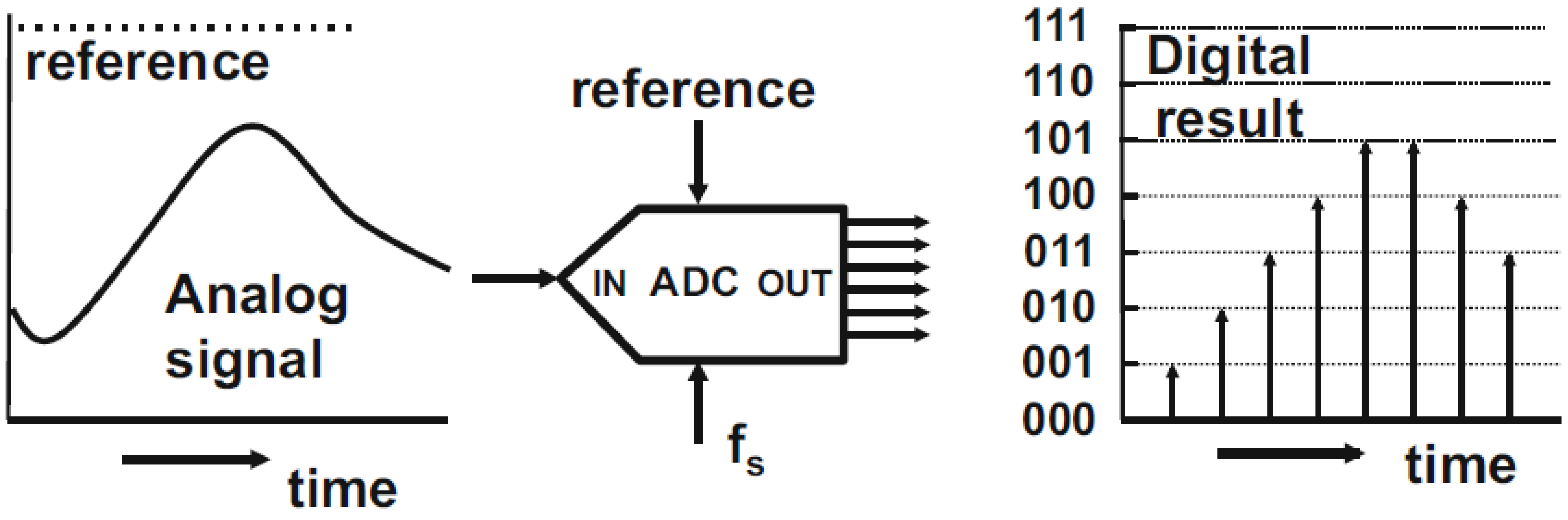
Levels of Abstraction



[Razavi, 2017]

ADC Functions

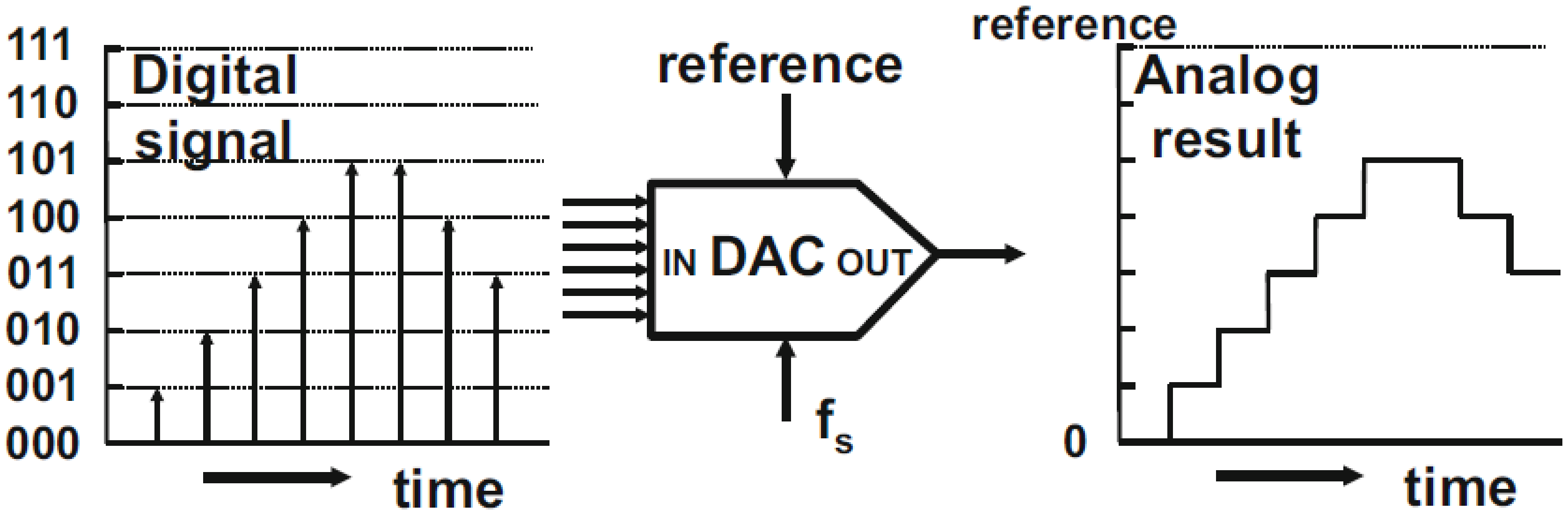
1. Sampling
2. Amplitude quantization
3. Linking to a reference



[M. Pelgrom, 2017]

DAC Functions

1. Amplitude restoration
2. Holding
3. Linking to a reference



[M. Pelgrom, 2017]

Course Topics

1. Sampling and quantization
2. Data converters specifications and testing
3. Switched capacitor circuits
4. Digital to analog converters (DACs)
5. Comparators
6. Nyquist analog to digital converters (ADCs)
7. Oversampling (sigma-delta) ADCs
8. Analog filters

- **Strong hands-on component in the labs**
  - Real design problems and real simulations
  - The best way to learn IC design is by doing it

Course Prerequisites

- It is supposed that you covered fundamental courses on:
  - Signals and systems (DSP is a plus)
  - Analog IC design
  - Digital IC design

References

- Textbook
  - M. Pelgrom, Analog-to-Digital Conversion, Springer, 3rd ed, 2017.
- References
  - W. Kester, The Data Conversion Handbook, ADI, Newnes, 2005.
  - B. Boser and H. Khorramabadi, EECS 247 (previously EECS 240), Berkeley.
  - B. Murmann, EE 315, Stanford.
  - Y. Chiu, EECT 7327, UTD.
  - F. Maloberti, Data Converters, Springer, 2007.
  - J. de la Rosa, R. del Ria, CMOS Sigma-Delta Converters, Wiley-IEEE Press, 2013.

Feedback

- Don't hesitate to send me feedback to improve the course quality.
- Avoid two common misconceptions
  1. Feedback should NOT wait to the end of the course!
     - It will be too late to improve anything!
     - But still you may help next generations ☺
  2. Feedback should NOT be always negative!
     - Too much negative feedback suppresses the output
     - Too much positive feedback causes oscillation
     - Give balanced feedback!

What Students Say About This Course

"This is definitely the best organized course I have ever taken, the progression in the content of the course is almost perfect. Starting from basic theory and then builds upon it from simple implementations to the more complex ones."

"I cannot overstate how extremely useful the Labs were. The fact that it went through the exact steps of setting up the testbench taught us how to professionally and efficiently parameterize everything. The blocks we got to work on were really interesting and widened our perspective. The Labs also explored different parts in Cadence, I am way more confident and efficient now in my use of Cadence thanks to these Labs."

What Students Say About This Course

“This course is by far the best course I've ever taken. The content is really helpful, and I can imagine in the near future how it might affect my career and design skills. I cannot be more thankful.”

“The topic is so interesting and awesome. The lectures are simple and wonderful, and the slides are very good.”

“The labs perfectly demonstrated the different design trade-offs and challenges that we discussed in each lecture, helping us to understand the concepts even more.”

Thank you!