## EECS240 – Spring 2010

Advanced Analog Integrated Circuits
Lecture 1: Introduction

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## Course Focus

- Focus is on analog design
  - Typically: Specs → circuit topology → layout
- Will learn spec-driven approach
  - But will also look at where specs come from
- Key point:
  - Especially in analog, some things are much "easier" to do than others
  - Sometimes (often) the right thing to do is change the specs



## Course Goal

- Learn how to create systematic approaches to analog design
  - Based on fundamental principles
  - For a wide variety of applications
- Will show specific design methodology example
  - OTA designs embedded in ADCs
- And then move on to a more complex system



## Administrative

- Course web page:
  http://bwrc.eecs.berkeley.edu/classes/icdesign/ee240_sp10
- Webcast link:
  http://webcast.berkeley.edu
- Office hours
  - 519 Cory Hall
  - Tues. and Thurs. 11am-12pm (right after class)
- All announcements made through web page
  - Check back often



## Lecture Notes

- Based on material from me, Prof. Bernhard Boser, and Prof. Ali Niknejad
- Primary source of material for the class
  - No required text – reference texts on next slide
- Notes posted on the web at least 1 hour before lecture
  - Will hand out limited # of hard copies in class



## Reference Texts

- **Analysis and Design of Integrated Circuits,**
  Paul R. Gray, Paul J. Hurst, Stephen H. Lewis, Robert G. Meyer, 4th Ed., Wiley, 2001.
- **Design of Analog CMOS Integrated Circuits,**
  Behzad Razavi, McGraw-Hill, 2000.
- **The Design of CMOS Radio-Frequency Integrated Circuits,**
  Thomas H. Lee, 2nd Ed., Cambridge University Press, 2003.
- **Analog Integrated Circuit Design,**
  D. Johns and K.Martin, Wiley, 1997.
- **The Designers Guide to SPICE & SPECTRE,**
  K. S. Kundert, Kluwer Academic Press, 1995.
- **Operation and Modeling of the MOS Transistor,**
  Y. Tsividis, McGraw-Hill, 2nd Edition, 1999.

## Grading

- Grading:
  - HW: 20%
    - One HW roughly every two weeks
    - Essential for learning the class material
    - Need to setup HSPICE or equivalent simulator (SpectreRF, Eldo, or other favorite tool)
  - Project: 25%
    - Groups of 2 – find a partner ahead of time
  - Midterm: 20%
  - Final Exam: 35%



## Homework

- Homework:
  - Can discuss/work together
  - But write-up must be individual
  - Drop in box outside Elad's office (519 Cory)
  - Generally due 5pm on Thursdays

- <u>No</u> late submissions
  - Start early!



## Schedule Notes

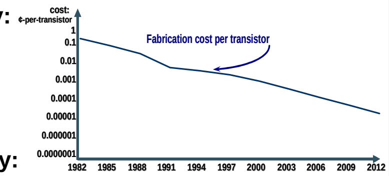
- ISSCC Week: 2/8 - 2/12 (no lectures)
- Midterm: March 11 (tentative)
- Spring break: 3/22 – 3/26
- Project:
  - Part 1 due Apr. 15
  - Part 2 due Apr. 27
  - Part 3 due May 6 (tentative)
- Final: Wed., May 12, 11:30am-2:30pm



## "Analog ICs in a Digital World?"

### Digital circuitry:

- Cost/function decreases by 29% each year
- 30X in 10 years




### Analog circuitry:

- Cost/function may not scale very well
- Common complaints about scaling analog:
  - Supply voltage is too low, device gain is low, horrible matching…

### "Analog will die – everything will be digital!"

- Who agrees?



## (Good) Digital Design Needs Analog Insights

- Can synthesize large blocks at "medium" frequencies in ASIC flow, but
  - Need to know transistors to design the cells
  - Really need to know transistors to design memories

- Lots of analog issues to deal with when push digital performance, power, etc.
  - Charge sharing, interconnect parasitics, etc.

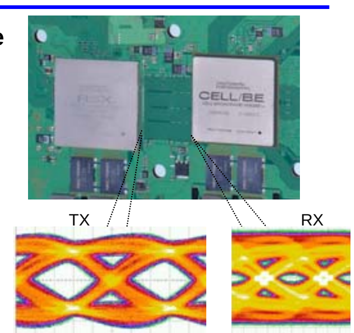
- Matching growing concern in advanced CMOS technologies
  - Especially in memories



## Another Example

- Look at interface between two digital chips
  - Is received bit a "1" or a "0"?

- Analog circuits critical for receiving bits correctly



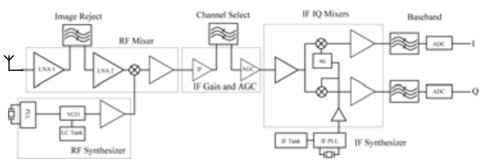
## The More Fundamental Reason

- The "real" or "physical" world is analog
  - Analog is required to interface to just about anything
    - Digital signals have analog characteristics too…
  - In many applications, analog is in the critical path

- Examples:
  - Wireline, optical communications
  - RF transceivers (receiver + transmitter)
  - Sensors and actuators (e.g., MEMS)



## RF Receiver

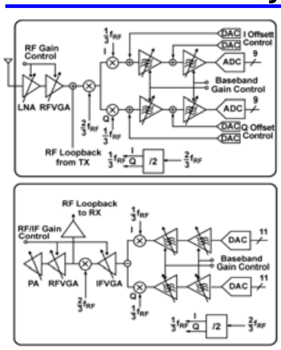


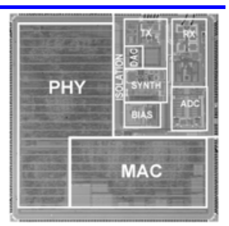

- Why so many RF and analog building blocks?

- Why not just put the ADC right after the antenna?



## RF Transceiver Layout



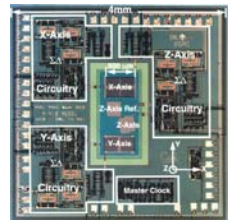




Source: Mehta et al, "An 802.11g WLAN SoC", JSSC Dec. 2005

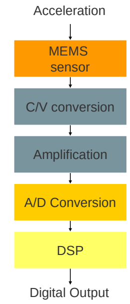
- Analog building blocks take up significant die area
  - Even in 0.18um…



## MEMS Accelerometer




M. Lemkin and B. E. Boser, "A Three-Axis Micromachined Accelerometer with a CMOS Position-Sense Interface and Digital Offset-Trim Electronics," *IEEE J. Solid-State Circuits*, vol. SC-34, pp. 456-468, April 1999






## Digital Versus Analog Design

- Abstraction in digital is Boolean logic (1's, 0's)
  - Works because of noise margins
- At a higher level, it's gates and registers (RTL)
- Digital layout is often automated

- Abstraction in analog is the device model
  - (BSIM is a few thousand lines long)
- At a higher level, it's the (opamps) (filters) (comparators)
  - Abstraction depends on the problem you're solving
- Analog layout is usually hand crafted

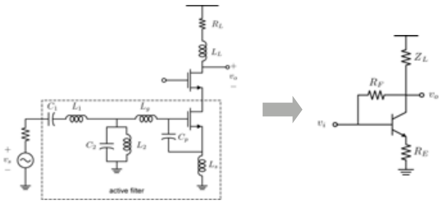


## "Analog" versus "RF"

- RF = "Analog with inductors"
- RF signal is usually narrowband (i.e., sinusoidal)
  - Tuned circuit techniques used for signal processing.
- RF impedance levels are relatively low
  - Can't make antenna impedance too high

- Analog impedances are high (low) for voltage (current) gain.
  - Voltage/current gain versus power gain.
- "Mixed-signal" analog is often discrete time (sampled).

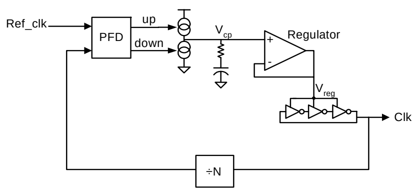
## RF Shifting Toward Analog




- Classic RF uses inductors to tune the circuits
  - Inductors are big – would be nice to get rid of them
- With increasing $f_T$, moving towards wideband analog & feedback
  - What's the penalty?



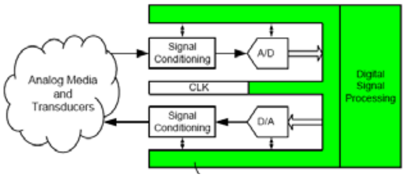
## Mixed-Signal Design




- Many building blocks involve analog and digital circuit co-design
  - PLLs, ADCs, etc.
- Sometimes hard to even distinguish between analog and digital
  - Is VCO analog, or digital?



## Digitally-Assisted Analog




Source: B. Murmann, "Digitally-Assisted Analog Circuits – A Motivational Overview," ISSCC 2007.

- In 90nm, one RF inductor (200μ× 200μ) takes same area as a microprocessor!
  - Leverage digital processing to improve analog circuits
- Good analog design doesn't go away though
  - Need to find right partitioning to maximize the benefit



## Syllabus

- Devices (both passive and active):
  - Models, simulation, layout, and matching
- Electronic noise
- Basic support functions:
  - Current sources, references, biasing
- Basic analog "gate": amplifier
  - Opamps, OTAs, feedback, settling time, common-mode feedback
- Application driver: high-speed links
  - Motivates additional building blocks
    - As well as why you care about certain specs
  - Data converters, comparators, offset cancellation, filters, sample & hold, oscillators, PLLs



## EECS 240 versus 247

- EECS 240
  - Transistor level building blocks
  - Device and circuit fundamentals
  - A lot of the class at a low level of abstraction
    - SPICE
- EECS 247
  - Macro-models, behavioral simulation, large systems
  - Signal processing fundamentals
  - High level of abstraction
  - Matlab



## 240 versus 242/142

- 142/242 mostly concerned with narrowband circuits operating at a "high" carrier frequency
  - Signals mostly look like sinusoids
  - Inductors ubiquitous
  - Use of feedback is rare
- 240 focuses on more "wideband", general-purpose analog and mixed-signal
  - Signals are "arbitrary"
  - Spend a lot of time worrying about capacitance
  - Feedback common

## 240 versus 231

- **231 concentrates on device physics**

- **240: device physics abstracted to the extent possible**
  - **Device models from a “circuit designer’s perspective”**
  - **Treat transistor as black box described by complex equations**
  - **Equations relevant for biasing, nonlinear effects (output swing), and some charge storage effects**
  - **Mostly <u>outside design loop</u>**
  - **→ “small signal analysis”**