EECS 240
Analog Integrated Circuits

Lecture 1: Introduction

Ali M. Niknejad and Bernhard E. Boser

Department of Electrical Engineering and Computer Sciences

Administrative

- Course web page:
  - http://www.eecs.berkeley.edu/~niknejad (link to EECS 240)
  - http://rfic.eecs.berkeley.edu/~niknejad/ee240
- Overview
  - Scope of course
  - Reference texts (no textbook)
  - Grading and homework policy
- Office hours (572 Cory Hall)
  - Tuesday, Thursday 1-2pm
  - By appointment

Grading and Schedule

- HW: 20% (5% is from class participation)
  - Essential for learning the class material
  - Need to setup SpectreRF or equivlant simulator (HSPICE, Eldo, or other favorite tool)
- Project 25% (1-2 students work together)
- Midterm 25%: March 14 (tentative)
- Final Exam 30%: May 16 8-11 AM
- ISSCC Week: 2/5-2/8 (no lecture 2/7)
- Spring Break: 3/28, 3/30 (no lecture)

Analog ICs in a "digital" World?

Digital circuitry:

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

Analog circuitry:

- Cost/function is constant
- Dropping supply voltages threaten feasibility
- Transition to DSP is inevitable!

- Ref: International Technology Roadmap for Semiconductors (ITRS), http://public.itrs.net

Why Analog Processing?

- The “real” or “physical” world is analog
  - Analog is an interface technology
  - In many applications, it’s in the critical path

- Examples:
  - MEMS sensors and actuators
  - RF transceiver (receiver + transmitter)
  - Wireline communications

Digital Versus Analog

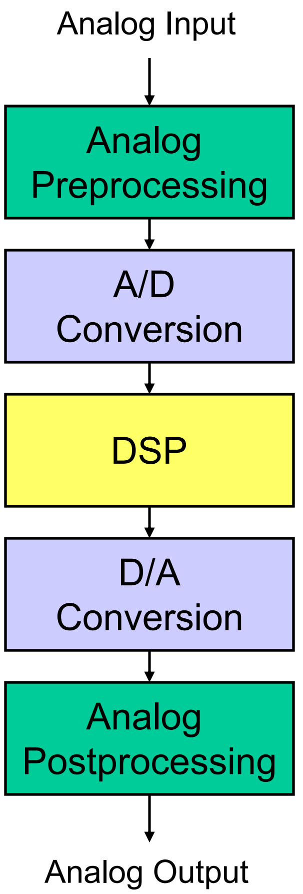
- Abstraction in digital is Boolean logic (1's, 0's)
- At a higher level, it's gates and registers (RTL)
- Abstraction in analog is the device model (BSIM is a few thousand lines long)
- At a higher level, it's the op-amps and OTAs
- Digital layout is often automated
- Analog layout is hand crafted for precision and accuracy

Analog versus RF

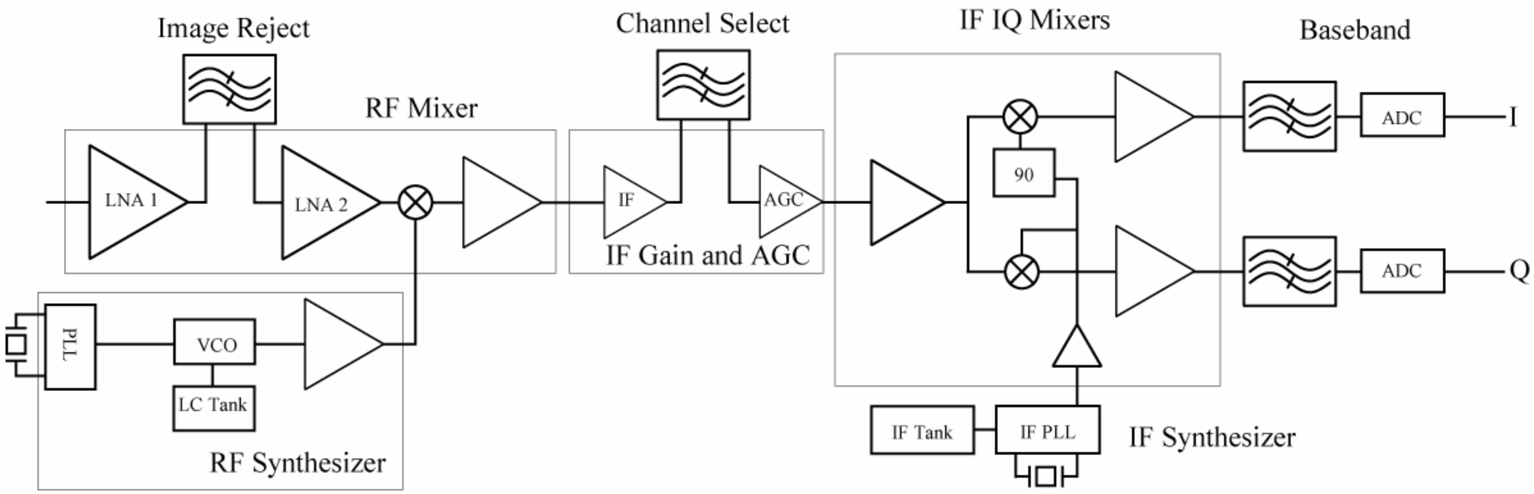
- What is RF? It's analog with inductors!
- Signal is usually narrowband sinusoidal modulation. Tuned circuit techniques are used for signal processing.
- RF impedance levels are relatively low for wideband operation.
- Analog impedances are high (low) for voltage (current) gain.
- Voltage/current gain versus power gain.
- Analog can be discrete time (sampled). RF is usually continuous.

Example: RF Transceiver

- Goals
  - Wireless communication
  - Minimizing use of bandwidth
  - Immunity to interference
- Circuit functions:
  - Preprocessing
    - Filtering
    - Amplification
    - Frequency translation
  - A/D Conversion
  - DSP
    - Demodulation
    - Decoding
  - D/A Conversion

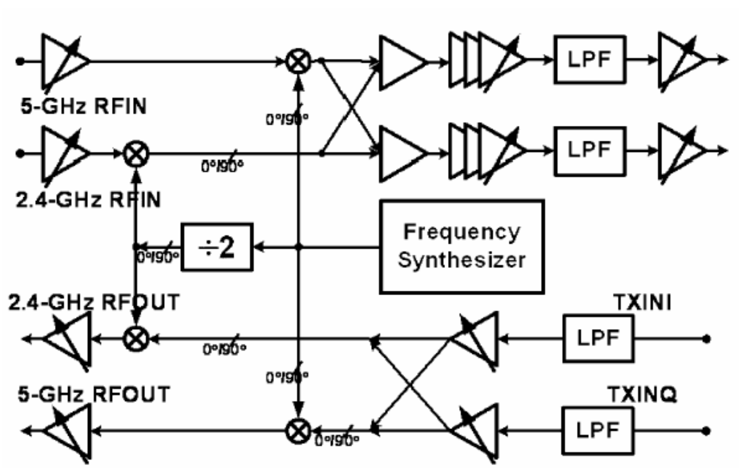


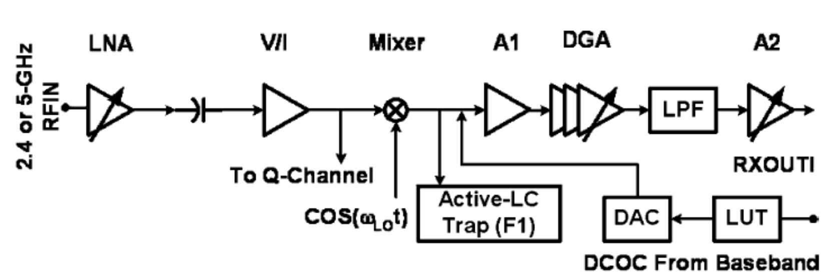
RF Receiver

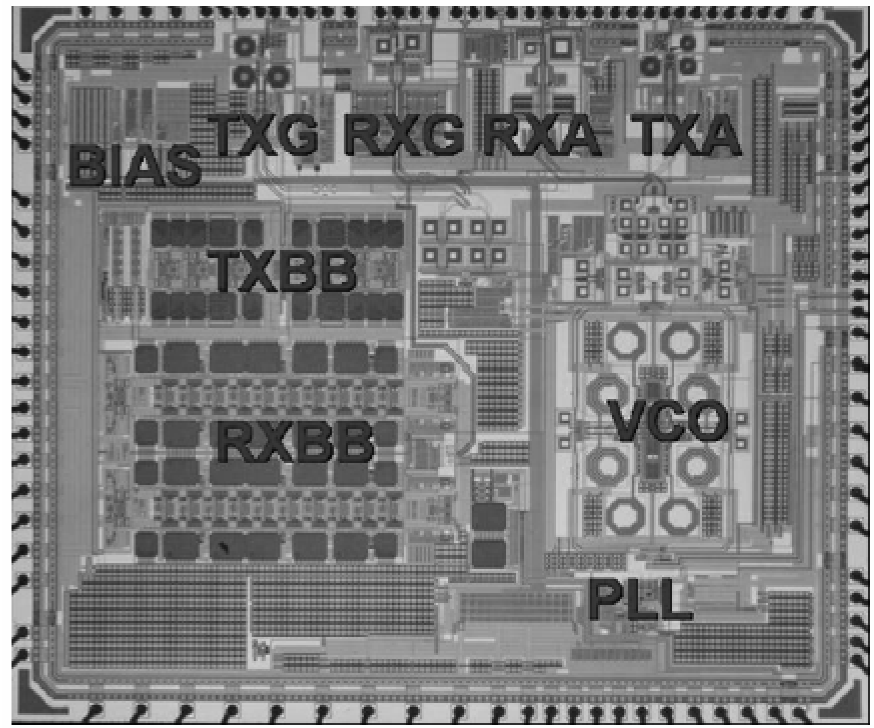


- Many key building blocks are RF and analog.
- RF performs frequency translation. Most channel filtering occurs in the IF stages. In a complex low-IF architecture, even image rejection occurs at baseband.
- Filters are key elements in reducing the required dynamic range of ADC

RF Transceiver Layout



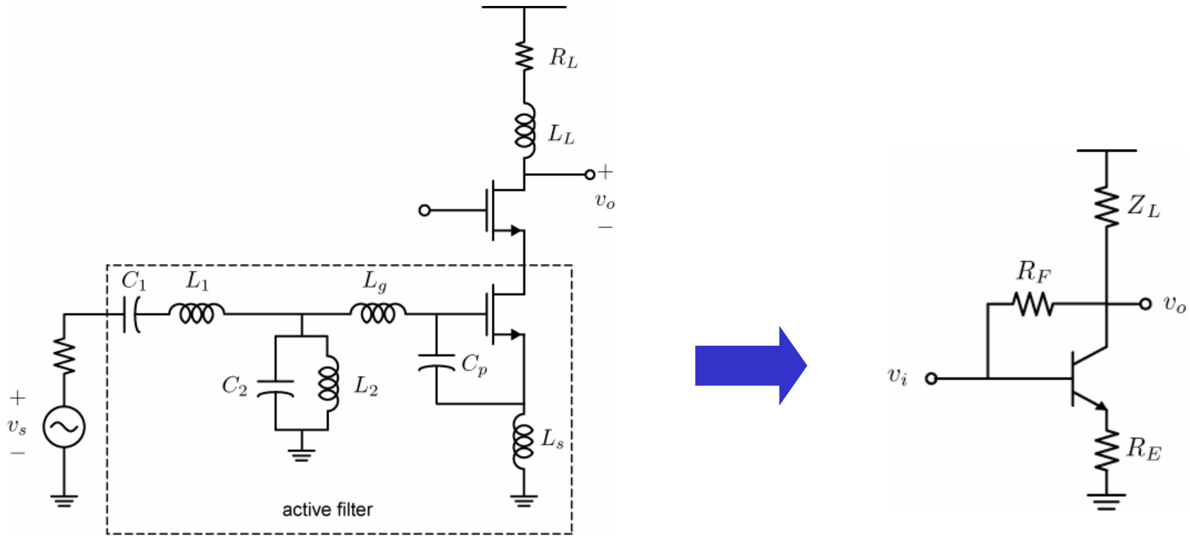




Source: Zhang et al, "A Single-Chip Dual-Band Direct-Conversion IEEE 802.11a/b/g WLAN Transceiver in 0.18-m CMOS", JSSC Sept 2005

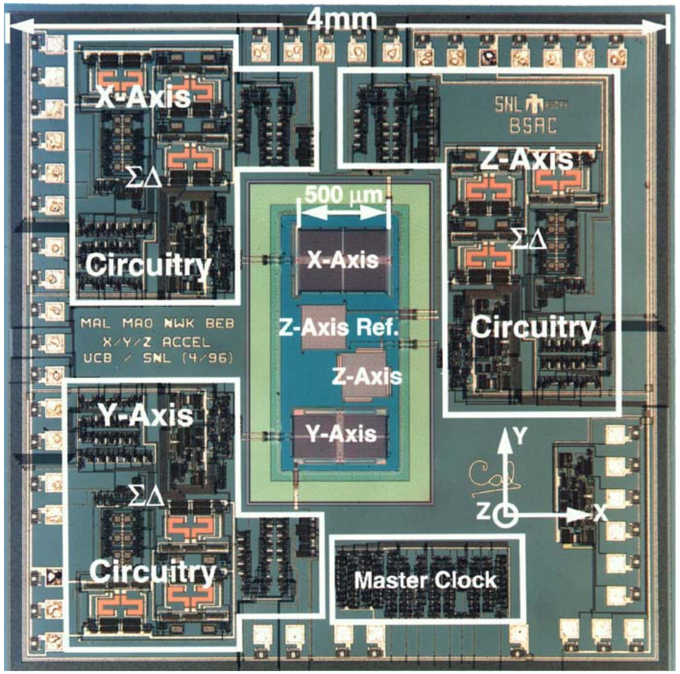
- Analog building blocks take up about ½ of die area

RF Becoming Analog

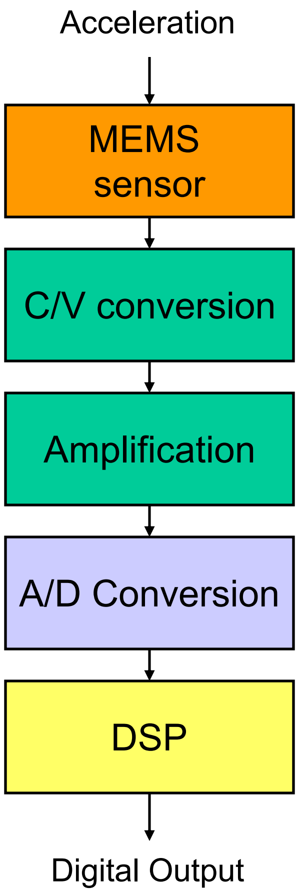


- With rapidly increasing f_T there is great incentive to eliminate inductors and tuned circuits
  - Inductors are physically large (expensive) and couple well to the substrate
  - Narrowband circuits are hard to “tune” (switch capacitors have eliminated this problem)
- Analog circuits use feedback for precision gain and wideband operation. Slightly higher noise is the penalty.

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. pdf



(good) Digital Design Needs Analog

- Modern transistors are leaky. Gate leakage and sub-threshold leakage need careful consideration in design.
- Medium frequency digital is "push button" with modern EDA tools. High frequency digital (cutting edge, critical path) requires intimate knowledge of transistor behavior.
- Long digital lines on-chip/on-board require terminations.
- Matching now a concern in advanced CMOS technologies due to enhanced process variations.

Digital Assisted Analog

- Take advantage of "free" horsepower in a modern CMOS process to perform as much signal processing as possible.
- One RF inductor (200μ× 200μ) can be replaced by a microprocessor in 90nm technology!
- Use digital calibration to tune out offsets, to center the filter cutoff frequencies, to tune the frequency of oscillators, etc.

Mixed Signal Design

- The design of some communication circuit building blocks, such as PLL (phase-locked loops), PLL based frequency synthesizers, analog to digital converters, involves the co-design of several analog/digital building blocks.
- In a PLL, the prescalars and programmable dividers and phase detectors are high speed digital circuits. Increasingly the loop filter and VCO are adopting digital techniques.

Syllabus

- Devices
  - Models
  - Simulation
  - Passive devices
  - Matching
- Support functions
  - Biasing
  - References
  - MOS Sample & Hold
  - Comparators
- Amplifiers
  - "Gate" of analog circuits
  - Critical element in virtually all analog building blocks
  - Illustrates fundamental analog design issues
    - Device characteristics
    - Electronic noise
    - Frequency & step response
    - Feedback & Stability
  - Focus is design: from specifications to topology to layout

EECS 240 versus 247

- EECS 240
  - Transistor level building blocks
  - Device and circuit fundamentals
  - Little abstraction
  - SPICE

- EECS 247
  - Macro-models, behavioral simulation, large systems
  - Signal processing fundamentals
  - High level of abstraction
  - Matlab

240 versus 242/142

- 142/242 are concerned mostly with narrowband amplification (tuned circuits) and sinusoidal response. Circuits are often non-linear (mixers, oscillators, power amplifiers). Feedback is seldom used in classical RF.
- 240 focuses on highly linear precision amplifiers. These amplifiers are usually realized using high gain and feedback.

240 versus 231

- In 240 we review important device physics and CMOS process. But the focus of the course is on circuits and not on devices. For the most part, we treat the transistors as black boxes described by complicated equations. But this is only a concern when determining the DC operating points and the voltage swing of the amplifier.
- Small signal models are very handy for understanding analog circuits. No matter how complicated the transistor (IV, CV), the AC models we use are easy and lend well to hand analysis.

Are you an Analog Designer?

- Curious: You want to know all the details.
- Detail oriented: You constantly think about what can go wrong (process & temp variations, substrate coupling, package coupling, EM coupling, thermal coupling, self heating, leakage, …). You know when to stop worrying !
- You have good insight into process technology and device modeling.