Analysis and Design of Analog Integrated Circuits
Lecture 1

Overview of Course, NGspice Demo, Review of Thevenin/Norton Modeling

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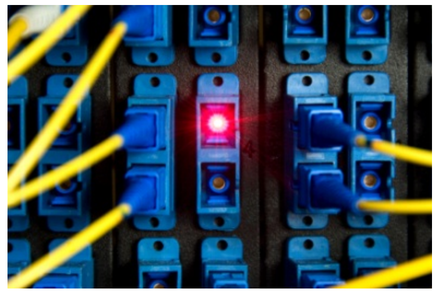
Analog Electronics are Pervasive in our Lives

Smart Phones

Fiber Optic Data Communication



Medical Instruments

Automotive Instruments

Monitoring & Control

But what do analog circuits do?

Analog Circuits Process "Real World" Signals

- **Wireless systems:**
  - **Cell phones, wireless LAN, computer peripherals**

Electrical Circuits ⟷ Electromagnetic Waves

- **Optical networks:**
  - **High speed internet**

Electrical Circuits ⟷ Light

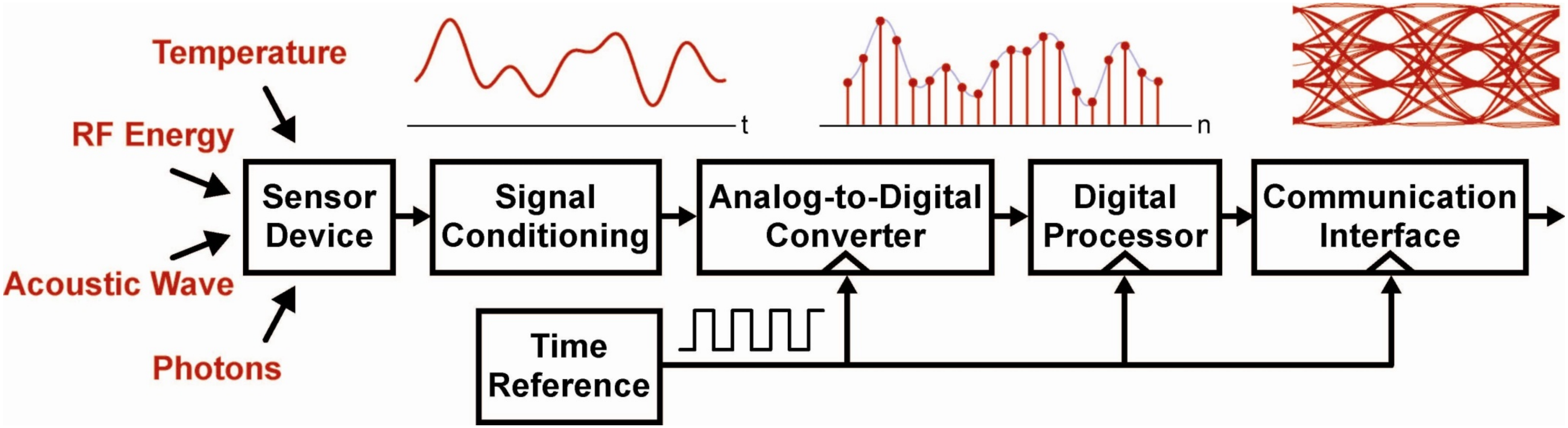
- **Micromechanical devices:**
  - **Resonators, accelerometers, gyroscopes**

Electrical Circuits ⟷ MEMS

- **Bio-electrical applications**
  - **Imaging, patient monitoring, drug delivery, neural stimulation**

Electrical Circuits ⟷ Biological Systems

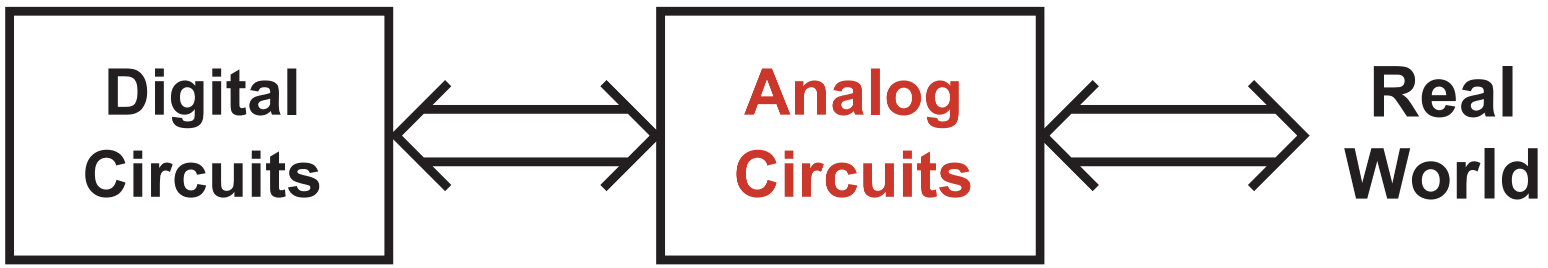
Analog Circuits Allow Interfacing with Digital Processors



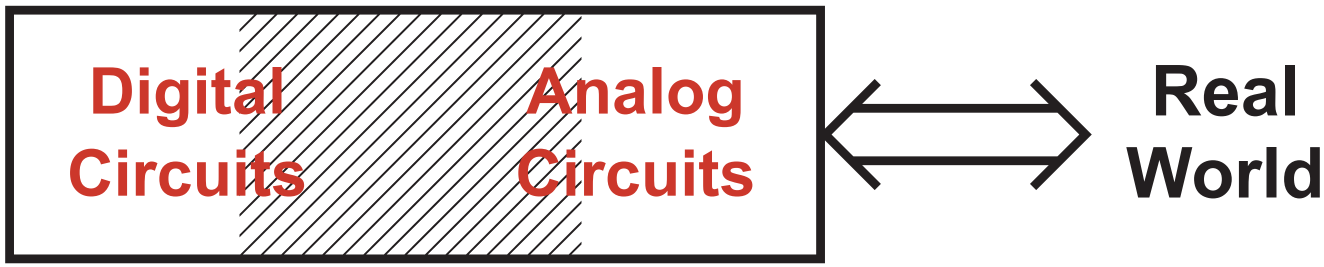
- Sensor devices create analog signals which are responsive to some “real world” signal such as light, temperature, etc.
- Signal conditioning is used to amplify and filter signals so that they may be more easily digitized
- Analog-to-Digital conversion samples the analog signal and then generates its corresponding digital representation
- Digital processors run algorithms on the digital signal
- Communication interface outputs the key signal information

Modern Approach: Mixed-Signal Circuit Design

- Traditional interface



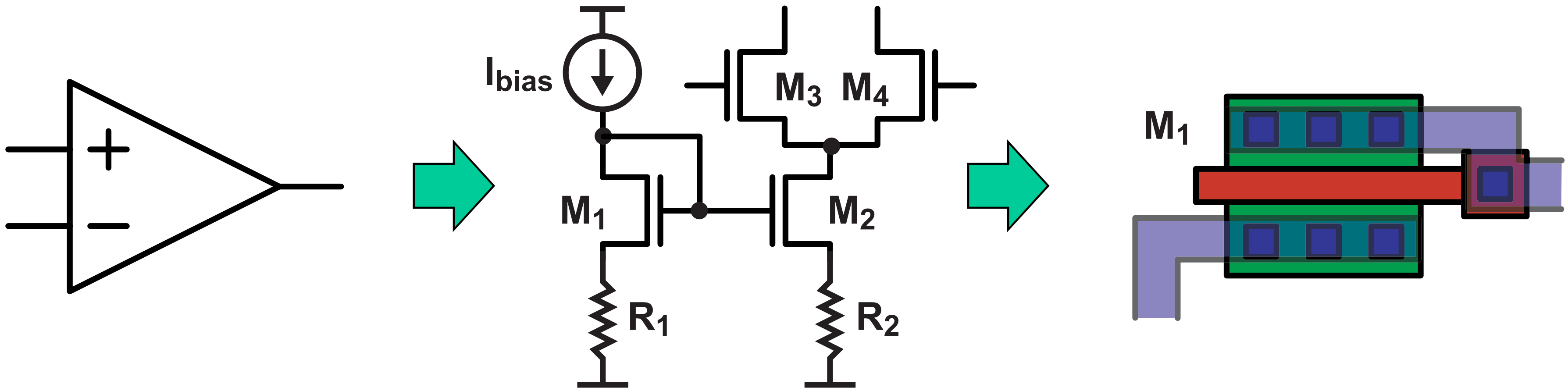
- The mixed signal approach



Lower power, smaller size, better performing interface
… But we need to understand analog design first!

Basics of Analog Design Methodology

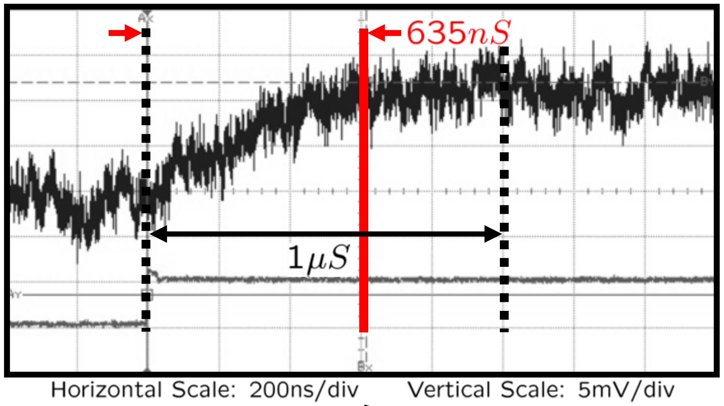
System Architecture | **Schematic Level Circuit Design** | **Layout of Circuits**



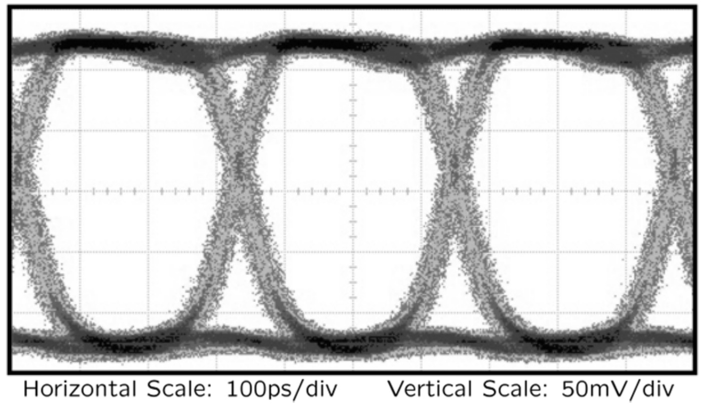
- System level – determine specifications that circuit must achieve
- Schematic level – choose circuit topology and device sizes and simulate with SPICE
- Layout – draw circuit topology which matches schematic (this is sent to a fabrication plant to be made)

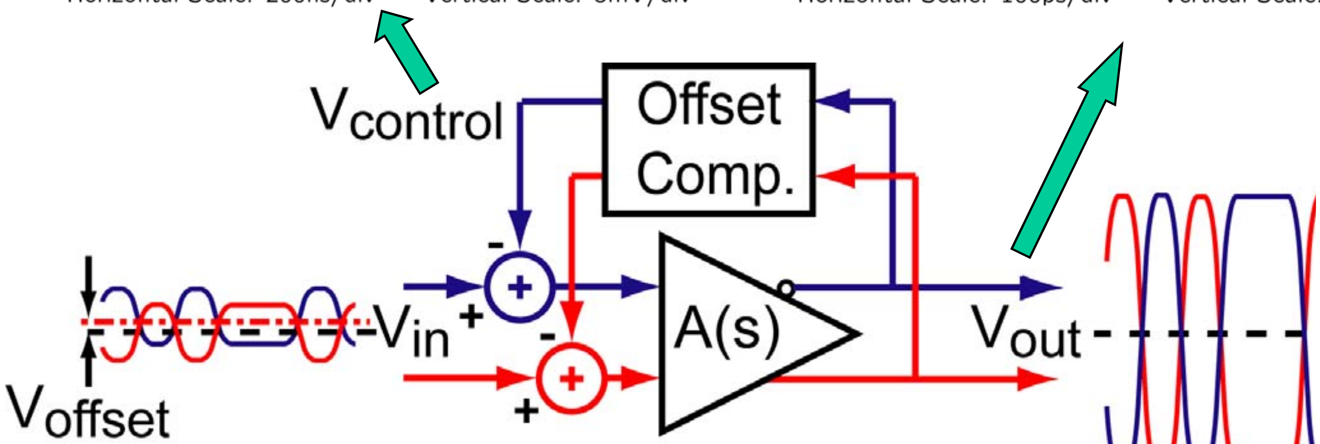
Example 1: A 3 Gb/s Limit Amplifier for PON Networks

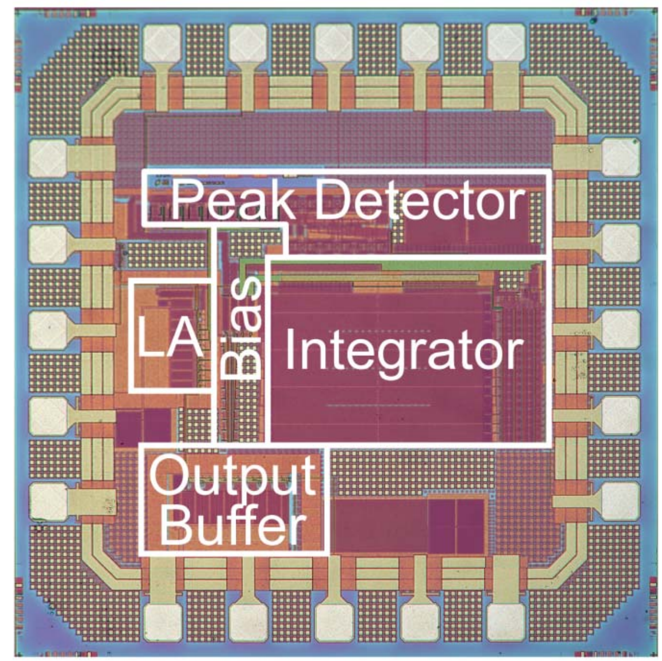
Settling time (< 1 microsecond)



Eye Diagram



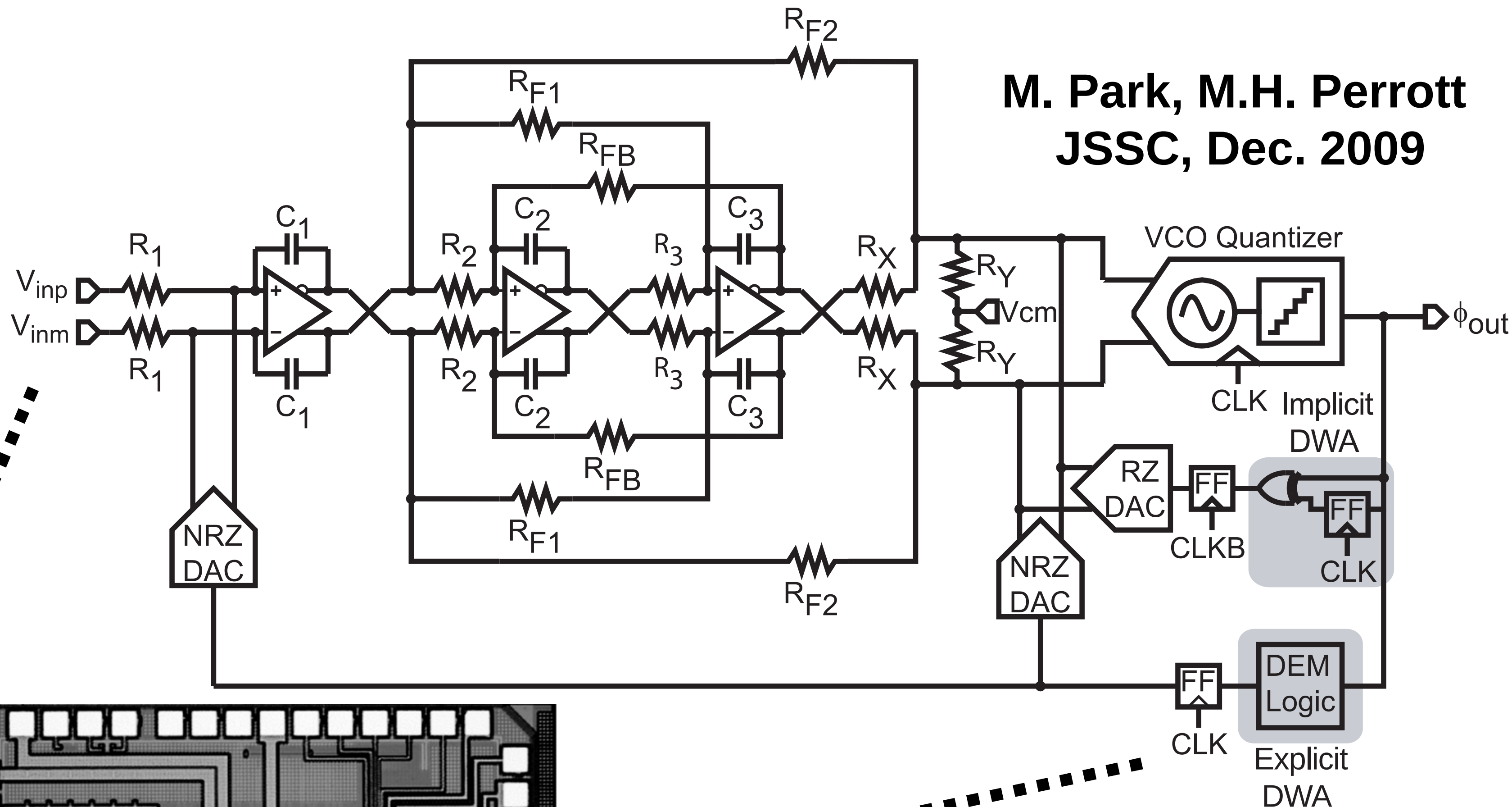


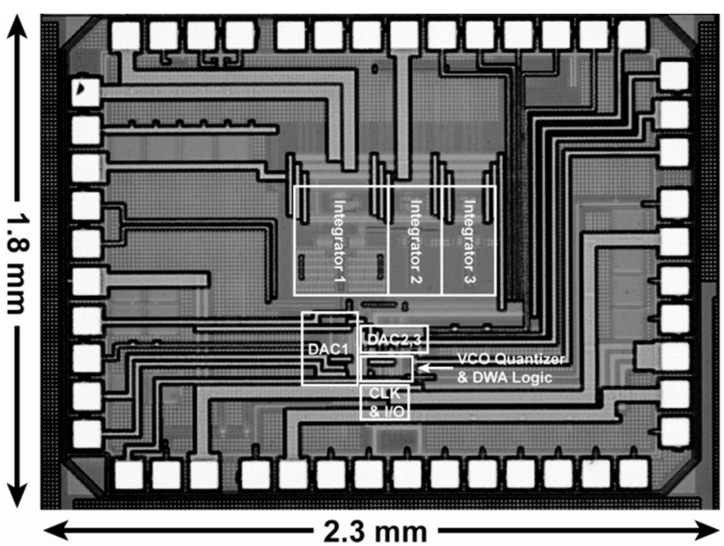


E.A. Crain, M.H. Perrott, JSSC, Feb 2006

Example 2: A VCO-Based Analog-to-Digital Converter

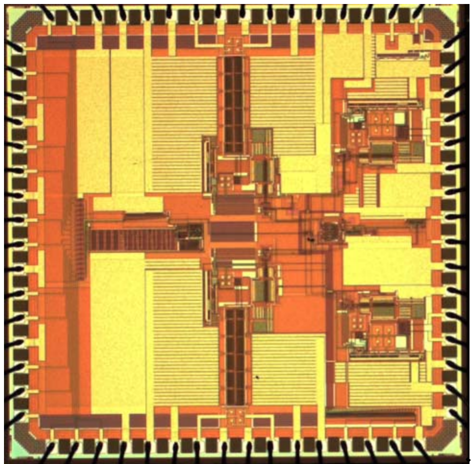
M. Park, M.H. Perrott
JSSC, Dec. 2009





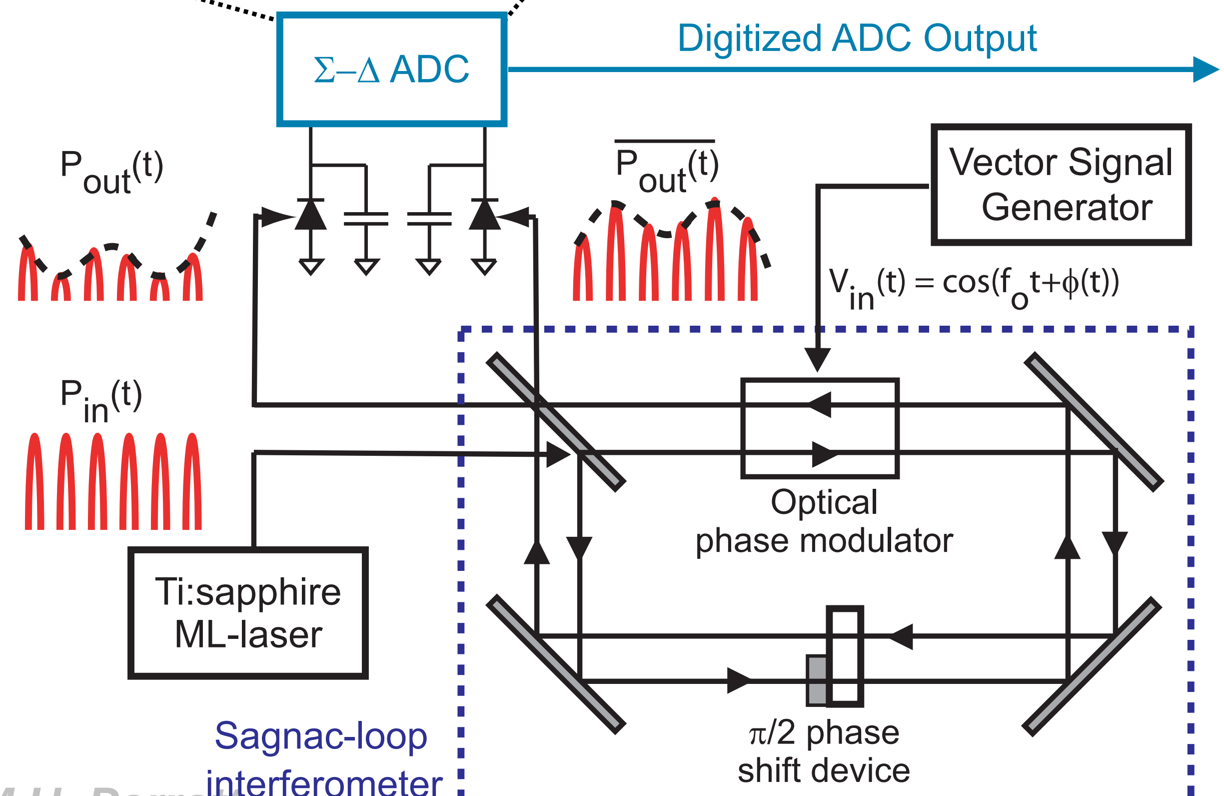
- Peak SNDR of 78 dB with 20 MHz bandwidth
- Figure of merit: 330 fJ/step

Example 3: An Optical/Electrical Demodulator and ADC

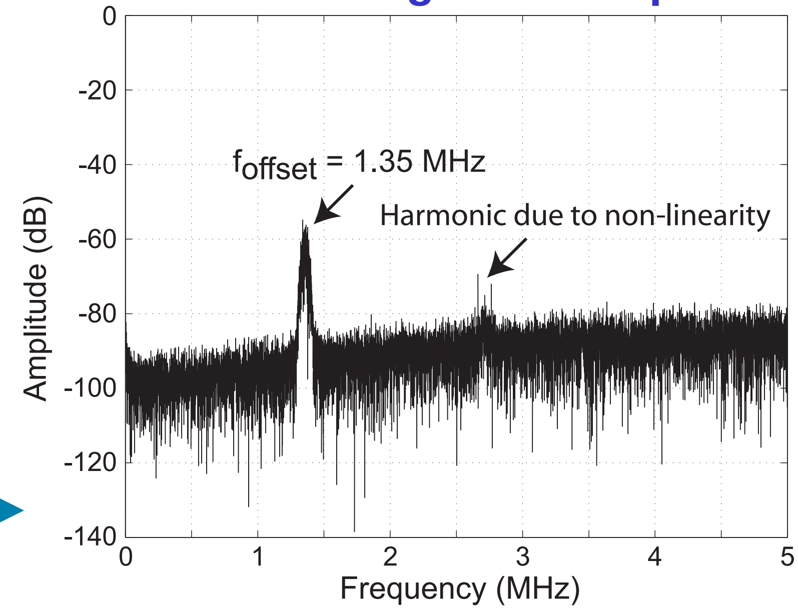


Custom Σ–Δ ADC Integrated Circuit

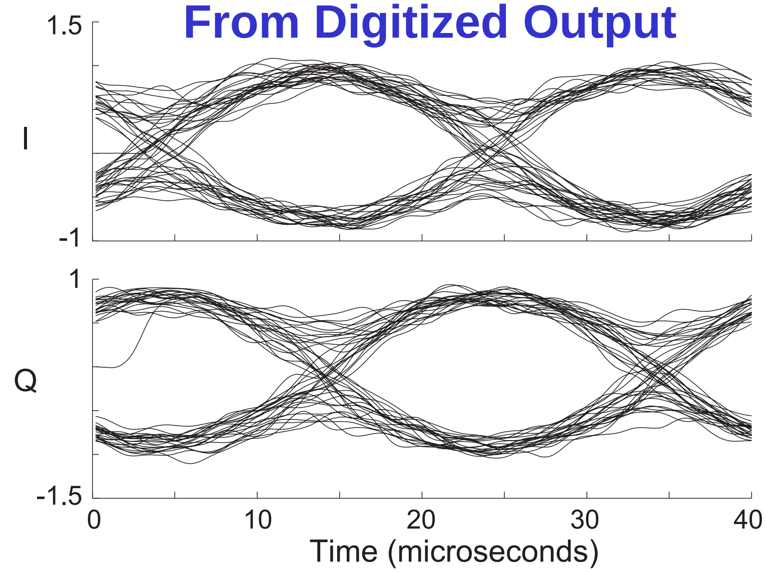
Laser rep. rate:
969.75 Mhz
RF input:
1.938 GHz
Data rate (GMSK):
100 kb/s



FFT of Digitized Output

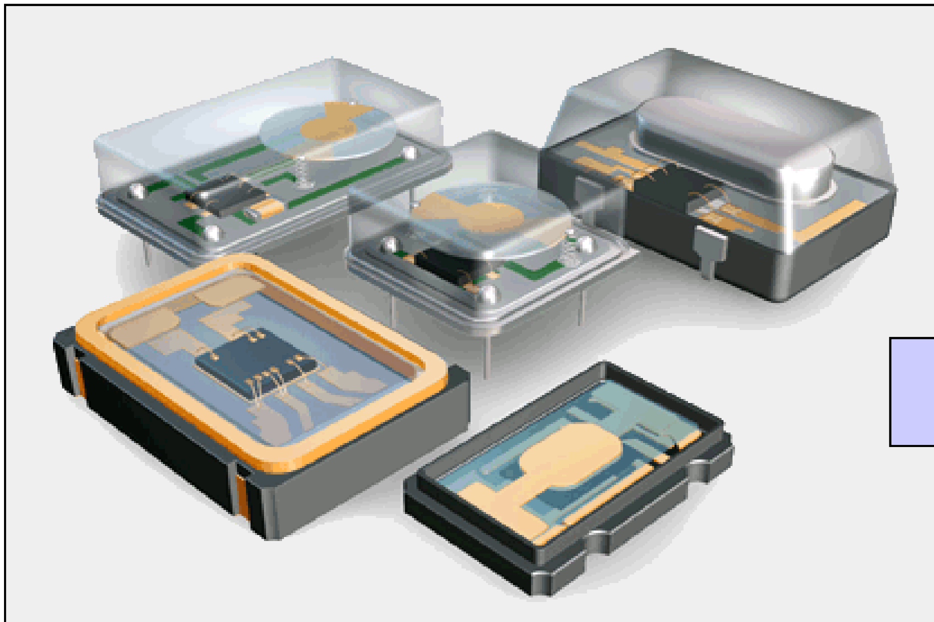


Recovered Eye Diagram From Digitized Output



Example 4: Using Analog Circuits to Change Paradigms

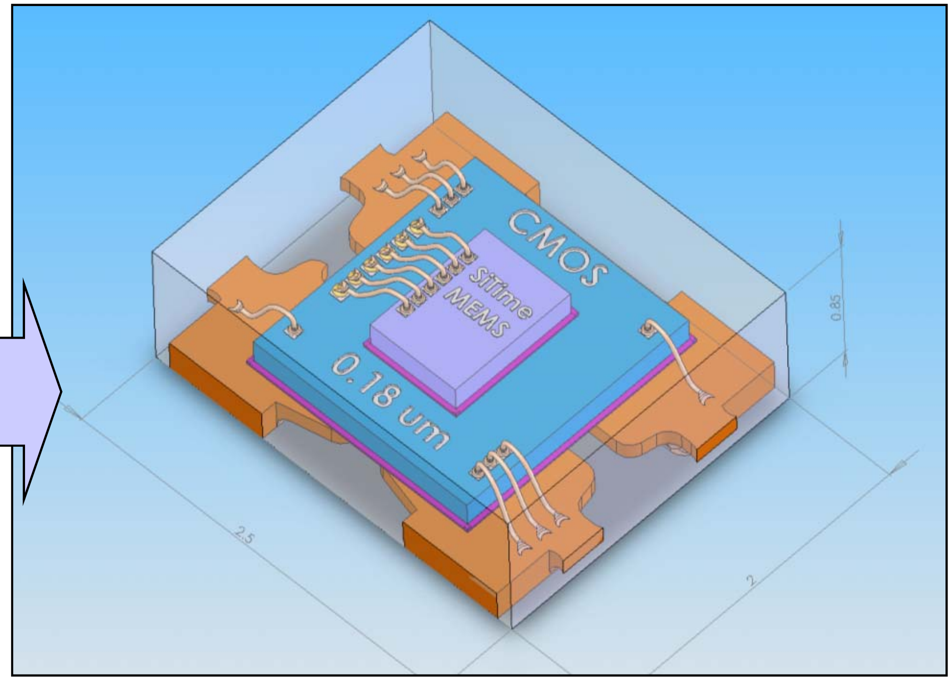
Quartz Oscillators



source: www.ecliptek.com

- A part for each frequency and non-plastic packaging
  - Non-typical frequencies require long lead times

MEMS-based Oscillator



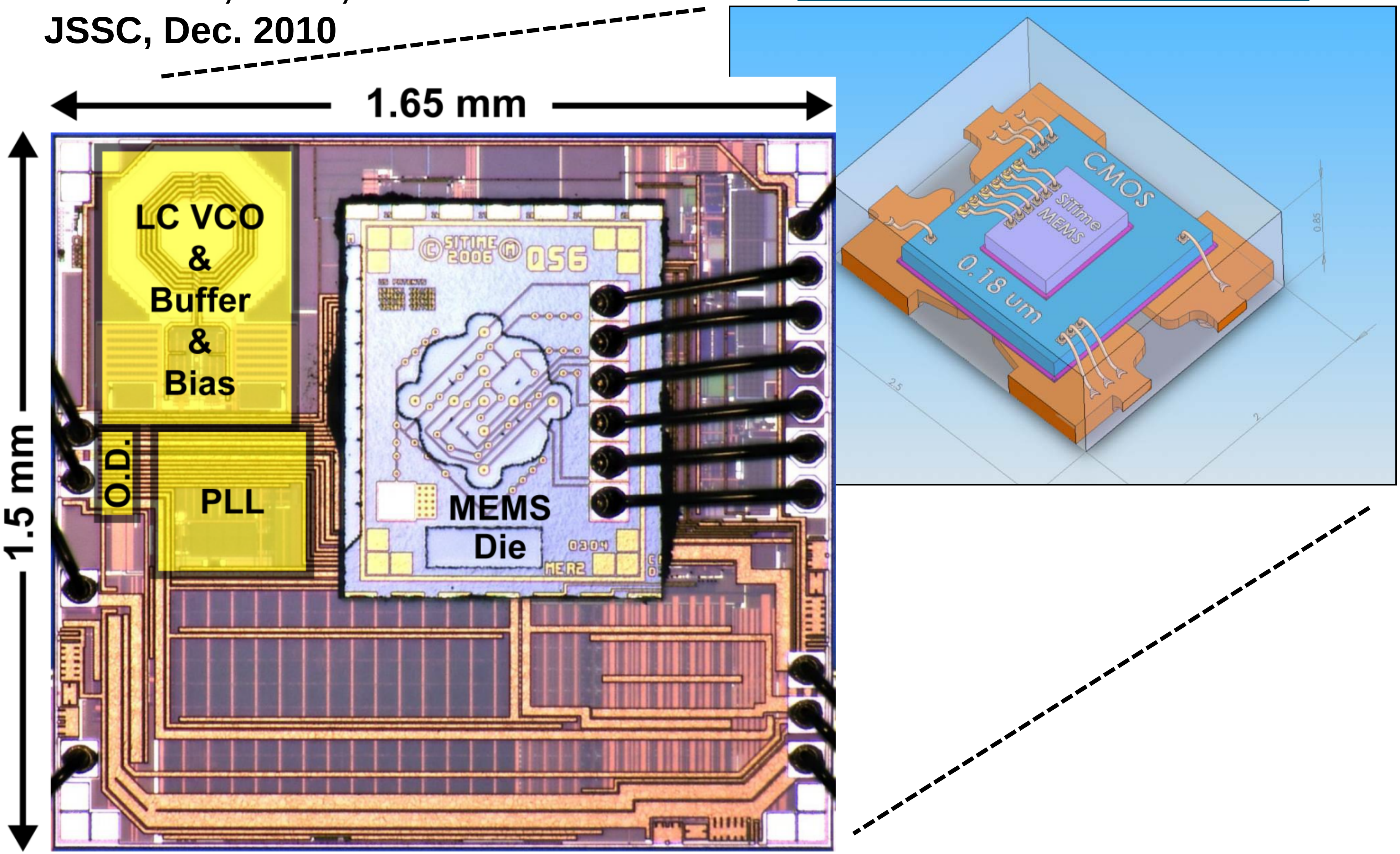
- Same part for all frequencies and plastic packaging
  - Pick any frequency you want without extra lead time

We can achieve high volumes at low cost using IC fabrication

Die Photo for Example 4

M.H. Perrott, et. al.,
JSSC, Dec. 2010

MEMS-based Oscillator



Key Skills To Be Learned In This Class

- **Analyzing transistor level circuits**
  - **Biasing, small signal, frequency response, noise analysis**
- **Simulating analog circuits**
  - **SPICE simulation and analysis with Matlab**
- **Understanding basic building blocks**
  - **Amplifiers, current mirrors, samplers**
- **Understanding analog circuit techniques**
  - **Cascoding, gain boosting, filtering**
- **Familiarity with analog circuit non-idealities**
  - **Mismatch, offset, noise, nonlinearity**
- **Putting together larger circuits**
  - **Multi-stage amplifiers, Opamps**
- **General principles of modeling and synthesis**

Prerequisite Skills

- **Familiarity with basic circuit elements**
  - **Resistors, capacitors, transistors, diodes**
- **Circuit network analysis**
  - **KVL, KCL, Superposition, Thevenin and Norton models**
- **Frequency domain analysis**
  - **Bode plot analysis, Laplace and Fourier transform, basic understanding of filters (lowpass, highpass, bandpass)**
- **Classical feedback design**
  - **Black's formula, stability analysis using phase margin**
- **Basics of nonlinear circuit analysis**
  - **Biasing, small signal analysis**
- **Device physics (MIC503)**

Class Flow

- **Lectures:**
  - **Sundays, Wednesdays from 10:00-11:15 am**
- **Office hours: Sun 11:30-12:30, Wed 11:30-12:30, By Appt.**
- **Homework:**
  - **One problem set per week**
- **Short quizzes (15 minutes at end of lecture):**
  - **Once per week covering homework material**
  - **You are granted one "ignore" credit for these short quizzes**
- **Full quiz: Wednesday, March 7**
- **Project: Passed out on April 11, Due May 2**
- **Final exam: During finals week**

Lecture Style and Recommendations

- Lecture notes will have gaps in them that need to be filled in while you are in class
  - Goal is to facilitate learning
  - Consider using blank back-side of slides for notes and then show results in given slide
- If you miss a class, you will need to ask others in class for their notes
  - You can ask me follow up questions once you have gone through those notes
- As you do each homework, try to fill in to a one page sheet with the *key* information that you need to know to solve the problems
  - You will be able to bring this sheet (front and back side) to the quizzes

Class Policies

- **Homework and projects are to be completed individually, though you are allowed to work with others**
  - **You must specify the names of anyone you work with on each assignment/project**
  - **You must not show identical work to others for any assignment/project (i.e., no copying)**
- **Homework and projects must be turned in at the *beginning of class (i.e., 10:15 am)* on their due date**
  - **Reduction of grade by 10% for every day late**
    - Anything after *beginning of class* counts as at *least one day*
  - **You will have 7 days *total* of "late" day credits for homeworks and projects (*not* 7 days for homeworks, 7 days for projects)**
    - No reduction of grade when applying this credit – use it wisely
- **Absolutely no copying or collaborating during a quiz/final**
  - **One summary sheet allowed during quizzes, two during final**

Homework and Project Clarity

- You must present your work clearly
  - Box answers
  - Show supporting work before the boxed answer with clearly shown steps of how you arrived at the answer
  - Grade reduction will occur for sloppy work
- Example of correct presentation

Problem 1:

Drawing

Equation(s)

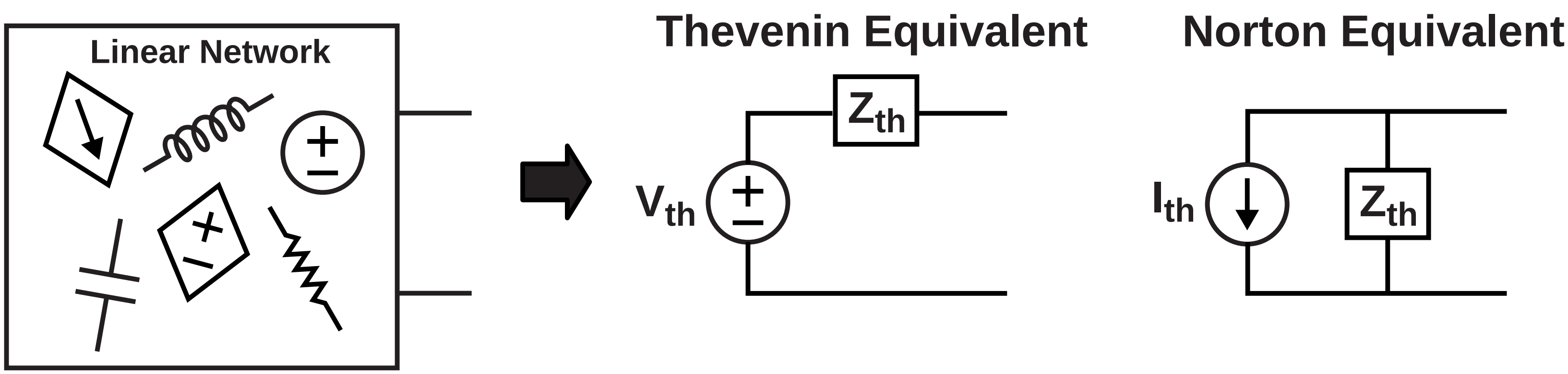
Answer = ……….

Simulation Tools Will Be Run On Your Laptop

- **NGspice will be the main simulation tool**
  - **Windows only, download CppSim onto your laptop from http://www.cppsim.com/download**
  - **Go through the Ngspice Primer Within CppSim manual at http://www.cppsim.com/manuals**
- **Octave will be used to run postprocessing on Ngspice results**
  - **Download from http://octave.sourceforge.net/**
  - **Be sure to add most toolboxes except for oct2map**
    - Causes an error that can fixed by running:
      - pkg rebuild -noauto oct2mat

Short, in-class demo now…

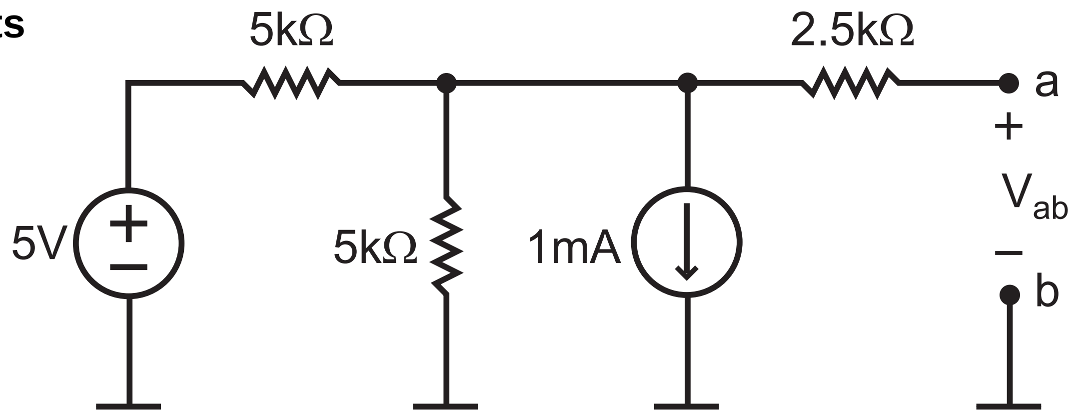
Basics of One-Port Modeling



- V_{th} computed as open circuit voltage at port nodes
- I_{th} computed as short circuit current across port nodes
- Z_{th} computed as V_{th}/I_{th}
  - All independent voltage and current sources are set to zero value

Thevenin/Norton Modeling: Example 1

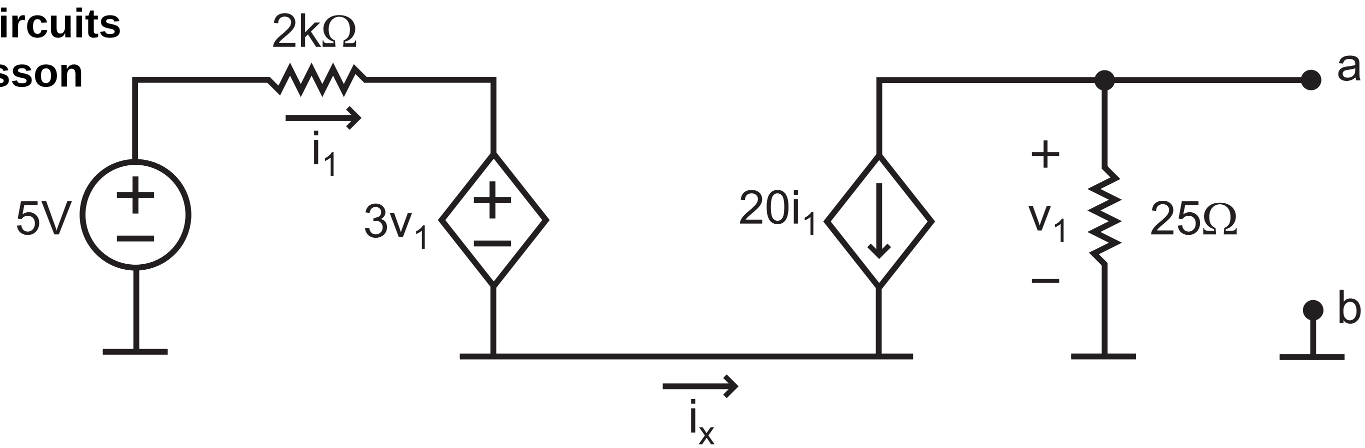
From Electric Circuits
By James Nilsson



- **Compute Thevenin and Norton models…**

Thevenin/Norton Modeling: Example 2

From Electric Circuits
By James Nilsson



- **Compute i_x and Thevenin and Norton models…**