All-Analog Digital Multimeter (DMM)
6.101 Final Project

Sam Chinnery

1Department of Electrical Engineering and Computer Science
Massachusetts Institute of Technology

April 19, 2018
What is an all-analog DMM?

Goal: Create an all-analog digital multimeter

- All-analog: no digital circuits/logic (except where necessary)
- Digital: no “needle-style” readouts (seven-segment displays)

Figure 1: Traditional DMM
Why is this difficult?

- Accurary: harder because everything is analog
- Digitization: A/D conversion is inherently digital
- Flow control: Multiple ranges, functions means lots of analog multiplexing
- Serialization: Need to use same circuit multiple times to save space
System overview

- **Frontend:** Circuits to convert measured parameter to voltage (all-analog)
- **Backend:** Discrete ADC, displays measured signals on seven-segment displays (hybrid A/D)
Why is this cool?

- It’s a really unusual thing to do
- I develop a new ADC topology and implement it
- The end result is functional
- Complexity (it ends up being an analog computer)
Data acquisition modules

Series of selectable circuits that convert device parameters to voltage

- Voltage: Calibrated attenuator
- Current: Calibrated shunt resistor
- Resistance: Precision current source
- Capacitance: Pulsed current source (integrator)
Voltage measurement

Figure 2: Voltage block
Current measurement

Input +

Input -

High-current shunt

Output (to voltage block)

Figure 3: Current block
Resistance measurement

![Resistance Measurement Diagram](image)

Figure 4: Resistance block
Capacitance measurement

Ideas:

- Constant-current pulse generator with discharge resistor (use DUT as integrator), measure peaks:

  \[ I_C = C \frac{dV_C(t)}{dt} \quad \Rightarrow \quad V_C(t) = \frac{1}{C} \int I_C \, dt \quad \Rightarrow \quad C = \frac{t_{on} I_C}{V_C} \]

- LM555 variable-width pulse generator (duty cycle varies with capacitance, average the output)

- Use the DUT as a LPF and measure the reactance:

  \[ X_C = \frac{1}{2\pi fC} \]
Designing a discrete ADC

Goals:
- Output as base-10 (not binary) for digital display
- High (≥ 3 digit) accuracy
- Minimal cost: use as few components as possible

(a) Flash ADC

(b) Folding ADC
My solution

- Combine flash ADC (easy to implement) with folding ADC (modulus operator)
- Serialize the process to minimize the component count
  - Implement a three-state analog “state machine” that computes one digit at a time
  - Use sample-and-hold amplifiers as “analog registers” to hold data in between states
- Design it so it’s easy to drive seven-segment controllers (CD4511)
Analog modulus comparator unit (ACU)

Figure 6: ACU block
Projected key dates

Timeline

- Week of April 9: Seven-segment controllers finished, magnitude comparator and voltage reference completed
- Week of April 16: Voltage reference multiplexer completed, finish ACU (tentative)
- Week of April 23: Frontend modules completed (voltage, current, resistance)
- Week of April 30: Complete capacitance module, integrate frontend and debug