EE 435

Lecture 41

DAC Design
  Current Steering DACs
  Dynamic Element Matching
  Charge Redistribution DACs

ADC Design
Another R-2R DAC

Node voltages change with input code

Review from Last Lecture
Another R-2R DAC

Requires matching both current sources and resistors

But switch impedance does not affect performance
Another R-2R DAC

Clocks must be nonoverlapping

Does this offer any benefits over previous approach?
Current Steering DAC

$$I_{OUT} = kl$$

Switch impedance of little concern
Current Steering DAC

\[ I_{OUT} = kI \]
Current Steering DAC

- **Current Steering DAC**

  - **Binary to Thermometer**
  - **Thermometer Coded Array**
  - **Binary Coded Array**

  - $X_{MSB}$
  - $n_1$
  - $V_{XX}$
  - $X_{LSB}$
  - $n_2$
  - $V_{OUT}$
  - $I_{OUT}$
  - $R_F$
Current Steering DAC

![Diagram of Current Steering DAC](image)
Current Steering DAC

\[ I \]

\[ V_{DD} \]

\[ V_{XX} \]

\[ I \]

\[ d_k \]

\[ V_{DD} \]

\[ V_{XX} \]

\[ C_P \]

\[ I \]

\[ d_k \]

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Current Steering DAC

\[ I_{\text{OUT}} = kI \]

\[ V_{\text{OUT}} = V_{\text{DD}} \]

Cascode Current Source (Mirror)

Differential Amplifier (Analog)
Current Steering DAC
Current Steering DAC

Binary to Thermometer Decoder (all ON)

\[ I_{\text{OUT}} = kI \]

\[ I_{D1} \]

\[ I_{D2} \]

\[ V_1 \]

\[ V_2 \]

\[ V_{\text{DD}} \]

\[ V_{\text{XX}} \]

\[ V_{\text{YY}} \]
Current Steering DAC with Supply Independent Biasing

If transistors on top row are all matched, $I_X = V_{REF}/R$

Thermometer coded structure (requires binary to thermometer decoder)

$$I_A = \left( \frac{V_{REF}}{R} \right)^{N-1} \sum_{i=0}^{N-1} d_i$$

Provides Differential Output Currents
Current Steering DAC with Supply Independent Biasing

If transistors on top row are all matched, $I_X = V_{REF}/R$

$$V_A = \left( -V_{REF} \frac{R_A}{R} \right)^{N-1} \sum_{i=0}^{N-1} d_i$$

Provides Differential Output Voltages
Current Current Steering DAC with Supply Independent Biasing

If transistors on top row are binary weighted

\[ I_A = \left( \frac{V_{\text{REF}}}{R} \right)^{n-1} \sum_{i=0}^{n-1} \frac{d_i}{2^{n-i}} \]

Provides Differential Output Currents
Matching is Critical in all DAC Considered

Obtaining adequate matching remains one of the major challenges facing the designer!
Dynamic Current Source Matching

- Correct charge is stored on C to make all currents equal to $I_{REF}$
- Does not require matching of transistors or capacitors
- Requires refreshing to keep charge on C
- Form of self-calibration
- Calibrates current sources one at a time
- Current source unavailable for use while calibrating
- Can be directly used in DACs (thermometer of binary coded)

Often termed “Current Copier” or “Current Replication” circuit
Dynamic Current Source Matching

Extra current source can be added to facilitate background calibration
End of Lecture 41