EE 435

Lecture 38

DAC Design
  Current Steering DACs
  Charge Redistribution DACs
ADC Design
Inherently Insensitive to Nonlinearities in Switches and Resistors Smaller ON resistance and less phase-shift from clock edges

- Termed “bottom plate switching”
- Thermometer coded
Review from last lecture

Current Steering DACs

Transistor Implementation of Switches

$$\beta = \frac{\frac{R_{\text{CELL}}}{k}}{\frac{R_{\text{CELL}} + R_F}{k}} = \frac{R_{\text{CELL}}}{R_{\text{CELL}} + kR_F}$$

If $$V_{\text{OUTFS}} = V_{\text{REF}}$$

$$R_{\text{CELL}} = NR_F$$

$$0.5 < \beta \leq 1$$
Current Steering DACs

Binary-Weighted Resistor Arrays

- Need for decoder eliminated!
- DNL may be a major problem
- INL performance about same as thermometer coded if same unit resistors used
- Sizing and layout of switches is critical

Observe thermometer coding and binary weighted both offer some major advantages and some major limitations
Review from last lecture

Current Steering DACs

Binary-Weighted Resistor Arrays

Actual layout of resistors is very important
Another R-2R DAC

Review from last lecture
Another R-2R DAC
Another R-2R DAC
Current Steering DAC

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

Switch impedance of little concern
Current Steering DAC

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

\[\text{Binary to Thermometer} \rightarrow \text{Thermometer Coded Array} \rightarrow \text{Binary Coded Array} \rightarrow \text{Comparator} \rightarrow V_{\text{OUT}}\]
Current Steering DAC

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

Binary to Thermometer Decoder (all ON)

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

\[ V_{DD} \]

\[ d_k \]

\[ R_F \]
Current Steering DAC


d_k
V_{XX}

\[ V_{DD} \]

\[ I \]

\[ d_k \]

\[ V_{DD} \]

\[ V_{XX} \]

\[ I \]

\[ d_k \]

\[ V_{DD} \]

\[ V_{XX} \]

\[ I \]

\[ d_k \]

\[ C_P \]
Current Steering DAC

I

\[ I \]

\[ d_k \]

Binary to Thermometer Decoder (all ON)

\[ v_{xx} \]

\[ I_{OUT} = kI \]

\[ V_{OUT} \]

\[ V_{DD} \]

\[ V_{XX} \]

\[ V_{YY} \]

Cascode Current Source (Mirror)

Differential Amplifier (Analog)
Current Steering DAC

Binary to Thermometer Decoder (all ON)

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

Binary to Thermometer Decoder (all ON)

\[ I_{OUT} = kI \]

\[ I_{D1} \]

\[ V_1 \]

\[ M_1 \]

\[ M_2 \]

\[ V_2 \]

\[ I_T \]

\[ I_{D2} \]

\[ -\sqrt{2}V_{EB} \]

\[ \sqrt{2}V_{EB} \]
Current Steering DAC with Supply Independent Biasing

If transistors on top row are all matched, \( I_X = \frac{V_{REF}}{R} \)

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, \( I_X = V_{\text{REF}}/R \)

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

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

If transistors on top row are binary weighted

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

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 38