EE 435

Lecture 38

DAC Design

Dynamic Current Source Matching
Charge Redistribution DACs

ADC Design

ADC Architectures
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
A charge redistribution circuit

Clocks are complimentary non-overlapping
During phase $\phi_1$

\[
Q_{\phi_1} = CV_{IN} \\
- \frac{CV_{IN}}{C_F} = V_{OUT} \\
\frac{V_{OUT}}{V_{IN}} = - \frac{C}{C_F}
\]

During phase $\phi_2$

\[
Q_{CF} = 0 \\
Q_C = 0
\]

Serves as an inverting amplifier

Gain can be very accurate

Output valid only during $\Phi_1$
Another charge redistribution circuit

$C_X$ does some good things
(mitigates $V_{OS}$, $1/f$ noise and finite gain errors)

Will not consider $C_X$ affects at this time

During phase $\phi_1$

$Q_{C\phi_1} = CV_{IN}$

$Q_{CF\phi_1} \approx 0$

During phase $\phi_2$

$\frac{Q_{C\phi_1}}{C_T} = V_{OUT}$

$\frac{CV_{IN}}{C_T} = V_{OUT}$

$\frac{V_{OUT}}{V_{IN}} = \frac{C}{C_T}$

Serves as a noninverting amplifier
Gain can be very accurate
Output valid only during $\Phi_1$
Another charge redistribution circuit

During phase $\phi_1$

$$Q_{C\phi_1} = CV_{IN}$$

$$Q_{CF\phi_1} = C_F V_{IN}$$

During phase $\phi_2$

$$Q_{C\phi_2} = 0$$

$$Q_{CF\phi_2} = Q_{C\phi_1} + Q_{C\phi_1}$$

$$-\frac{Q_{CF\phi_2}}{C_F} = V_{OUT}$$

$$\frac{CV_{IN} + C_F V_{IN}}{C_F} = V_{OUT}$$

$$\frac{V_{OUT}}{V_{IN}} = 1 + \frac{C}{C_F}$$

Serves as a noninverting amplifier

Gain can be very accurate

Termed a “flip-around” amplifier
Another charge redistribution circuit

![Diagram of a charge redistribution circuit with switches and an operational amplifier]

- $V_{IN}$
- $C$
- $\phi_1$
- $\phi_2$
- $\phi_1$
- $\phi_2$
- $V_{OUT}$
- $C_F$
- $T_{CLK}$

- Waveforms for $\phi_1$ and $\phi_2$ are shown with a period $T_{CLK}$.
Another charge redistribution circuit

During phase $\phi_1$

$$Q_{\phi_1} = CV_{IN}$$
$$Q_{CF} = 0$$

During phase $\phi_2$

$$\frac{Q_{\phi_1}}{C_F} = V_{OUT}$$
$$\frac{CV_{IN}}{C_F} = V_{OUT}$$
$$\frac{V_{OUT}}{V_{IN}} = \frac{C}{C_F}$$

Serves as a noninverting amplifier
Gain can be very accurate
Output valid only during $\Phi_2$
Another charge redistribution circuit

During phase $\phi_1$

\[ Q_{\phi_1} = CV_{IN} \]
\[ Q_{CF} = -CV_{IN} = CFV_{OUT} \]
\[ \frac{V_{OUT}}{V_{IN}} = -\frac{C}{C_F} \]

During phase $\phi_2$

\[ V_{OUT} = 0 \]
\[ Q_C = Q_{CF} = 0 \]

Serves as an inverting amplifier
Gain can be very accurate
Output valid only during $\Phi_1$
A charge redistribution DAC

C_X does some good things
(mitigates V_{os}, 1/f noise and finite gain errors)

Will not consider C_X affects at this time
A charge redistribution DAC

During phase $\phi_1$

$$Q_{\phi_1} = V_{REF} \sum_{i=0}^{n-1} d_i \cdot 2^i C$$

$$Q_{CF} = 0$$

During phase $\phi_2$

$$V_{OUT}(\phi_2) = \frac{1}{C_F} Q_{\phi_1}$$

$$V_{OUT}(\phi_2) = \frac{1}{2^n C} V_{REF} \sum_{i=0}^{n-1} d_i \cdot 2^i C$$

$$V_{OUT}(\phi_2) = V_{REF} \sum_{i=0}^{n-1} \frac{d_i}{2^{n-i}}$$