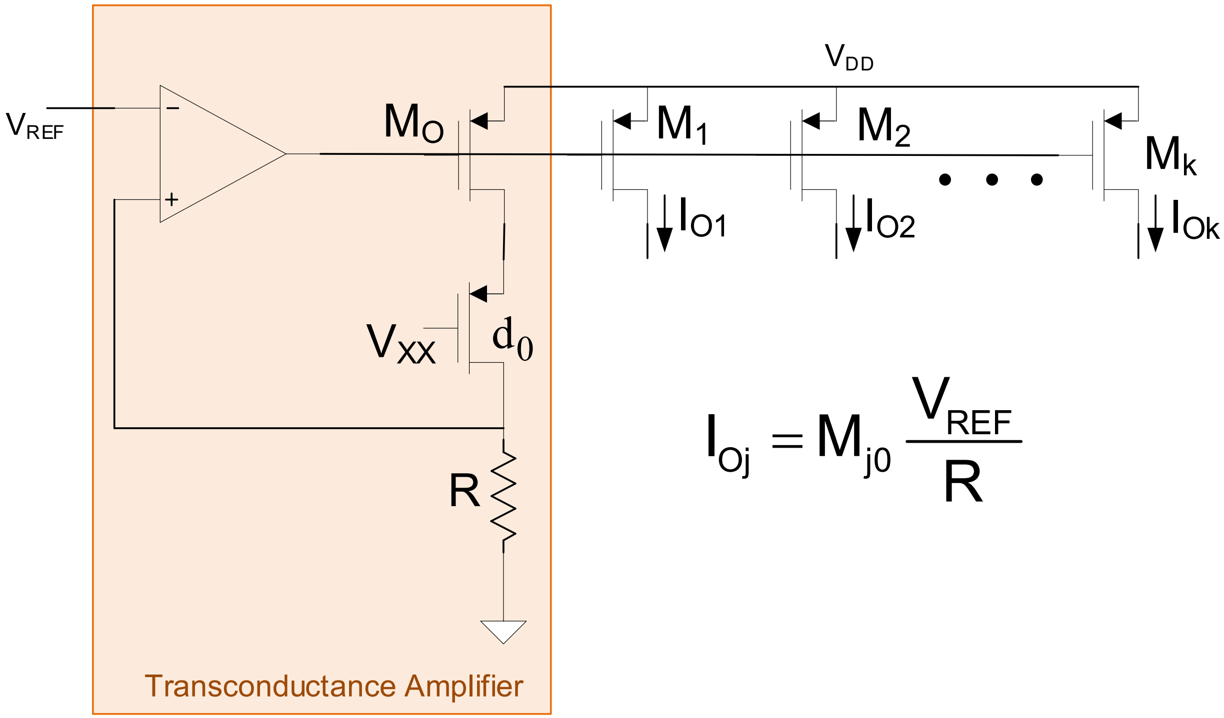
EE 435

Lecture 36

Charge Redistribution DACs
ADC Design

Multiple-output Transconductance Amplifier

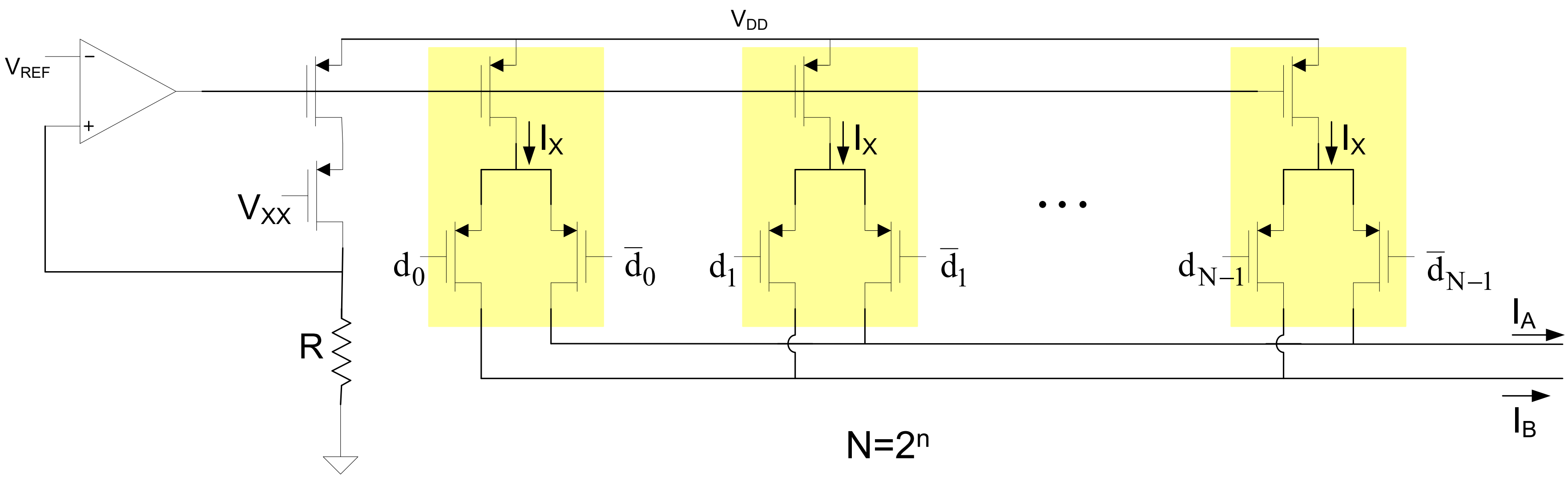


$$I_{Oj} = M_{j0}\frac{V_{REF}}{R}$$

- Good linearity
- Each additional output requires only one additional transistor

Review from Last Lecture

Current Steering DAC with Supply Independent Biasing



N=2^n

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

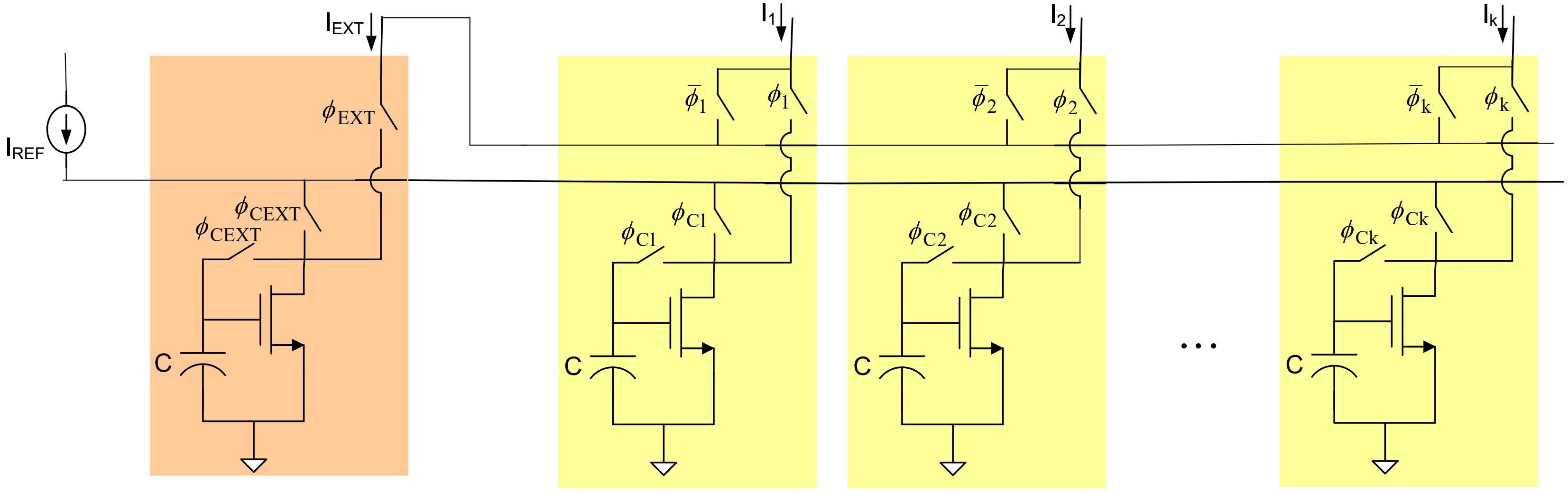
Thermometer coded structure (requires binary to thermometer decoder)

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

Provides Differential Output Currents

Review from Last Lecture

Dynamic Current Source Matching



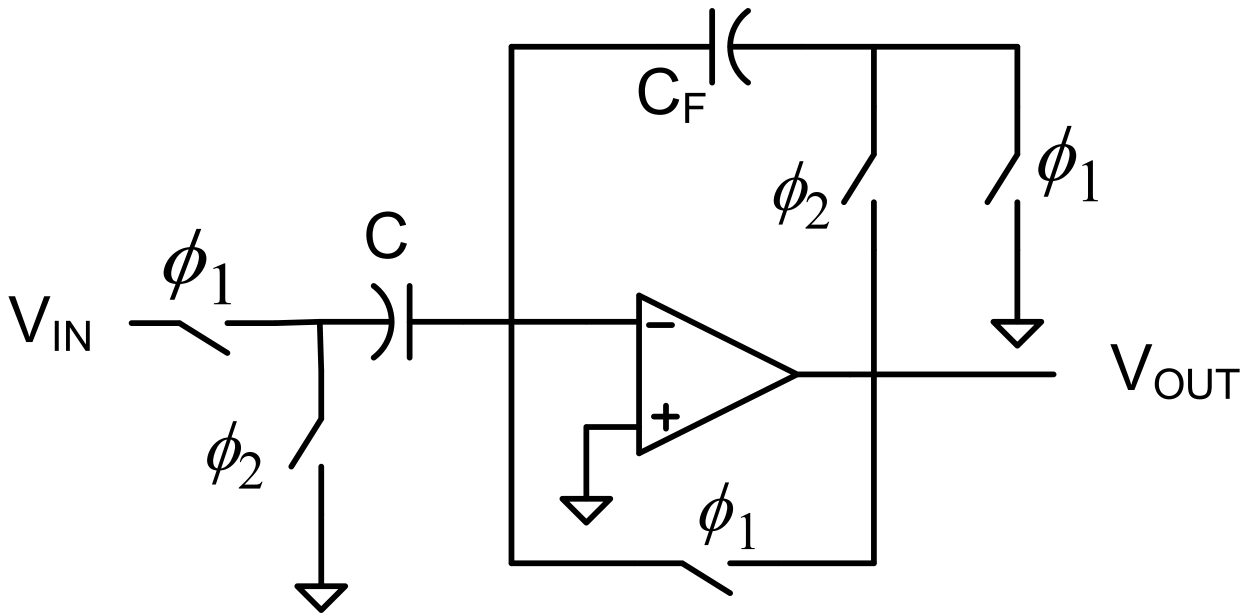
Extra current source can be added to facilitate background calibration

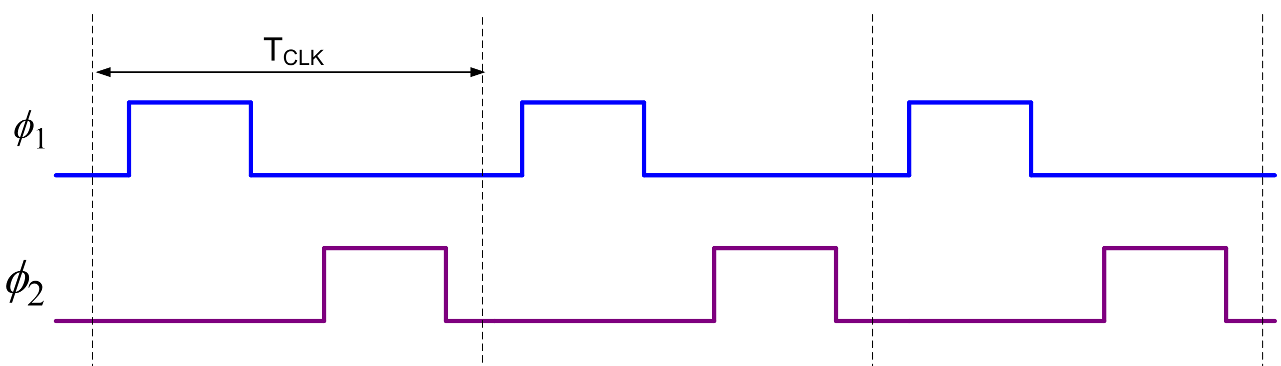
Charge Redistribution DACs

- Previous DACs based upon matching of resistors or transistors
- Switch impedance was of concern in most of the structures
- Capacitor matching can be very good in most processes and area required for a given level of matching may be smaller for capacitors than for resistors or transistors in some processes
- Capacitor linearity is often excellent

Will now focus on building DACs that take advantage of good capacitor matching and linearity

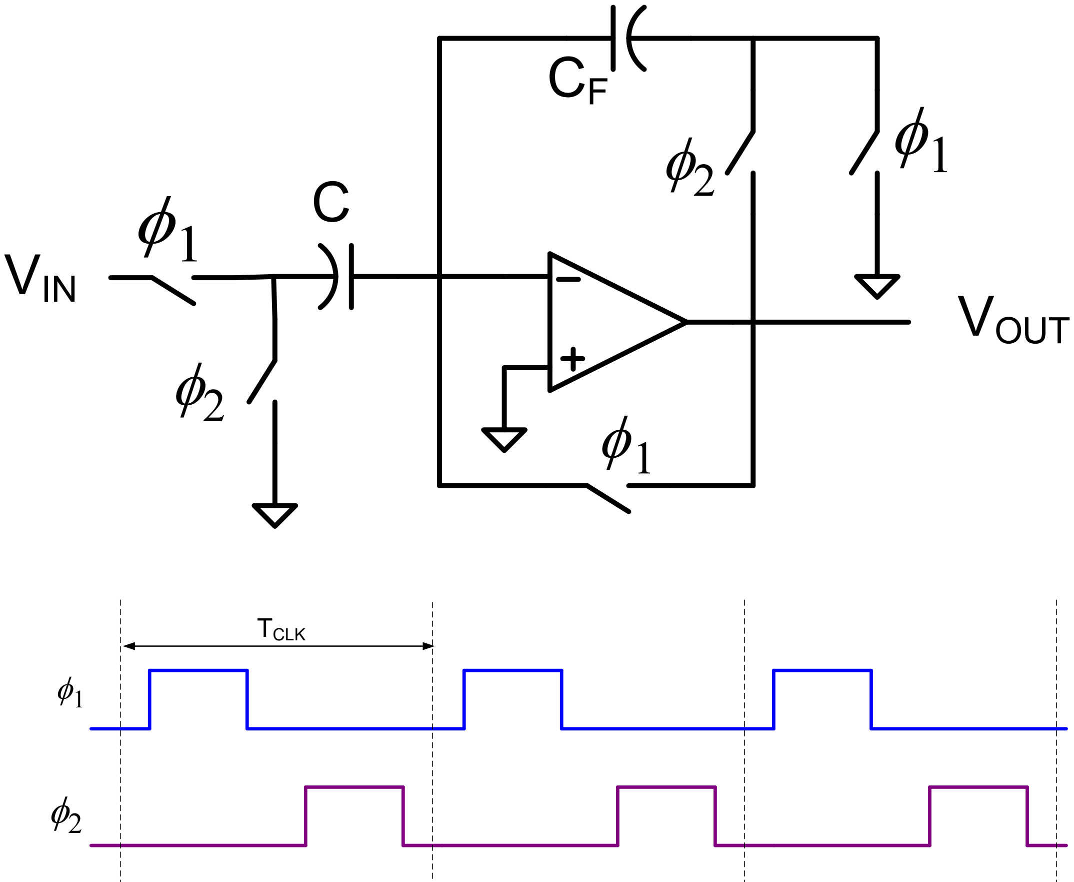
A charge redistribution circuit





Clocks are complimentary non-overlapping

A charge redistribution circuit



During phase φ_1

$$Q_{\phi 1} = CV_{IN}$$

$$Q_{CF} = 0$$

During phase φ_2

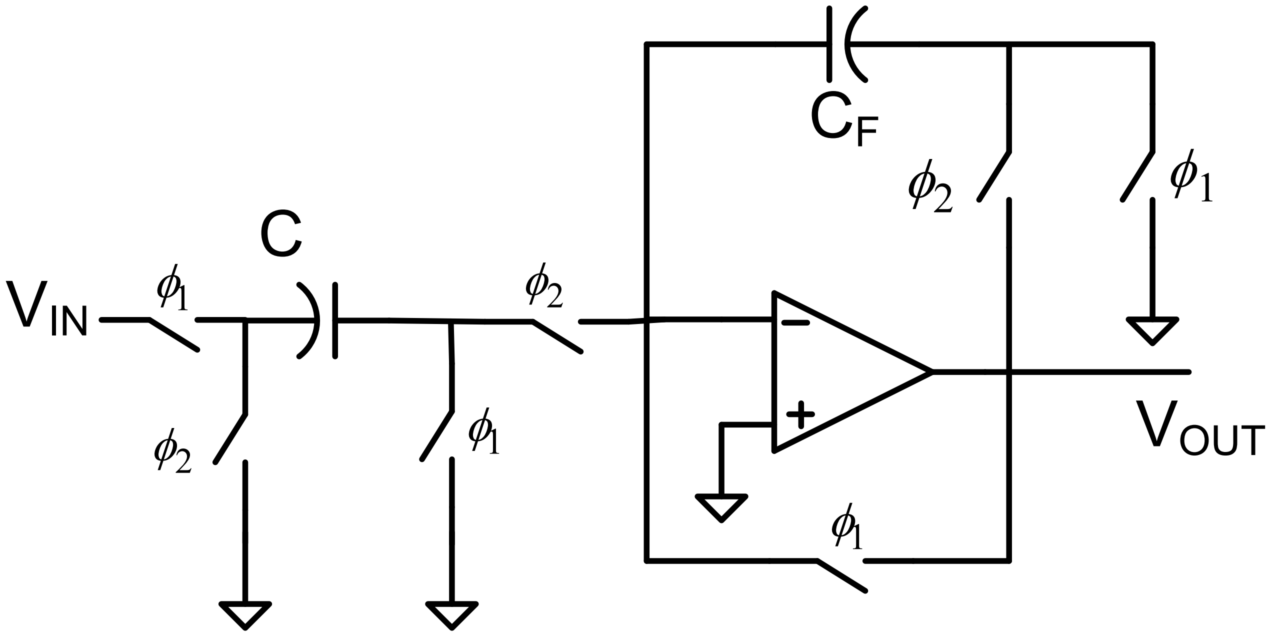
$$\frac{Q_{\phi 1}}{C_F} = V_{OUT}$$

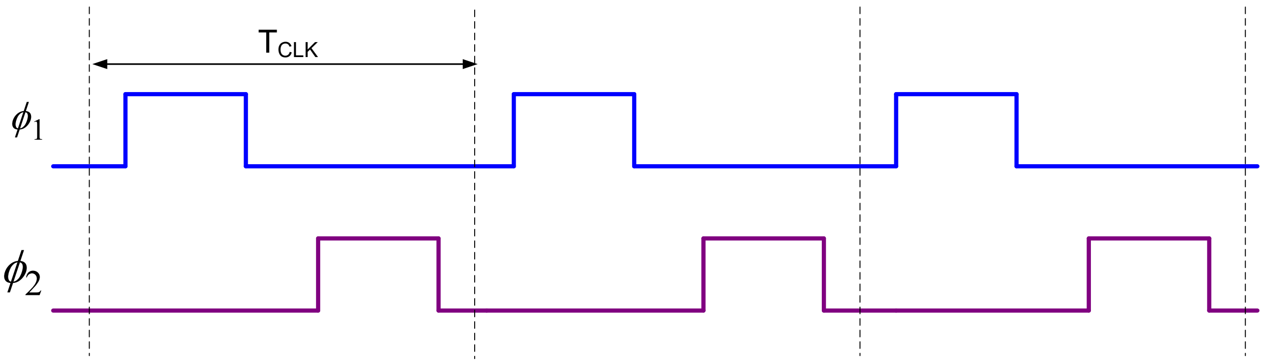
$$\frac{CV_{IN}}{C_F} = V_{OUT}$$

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

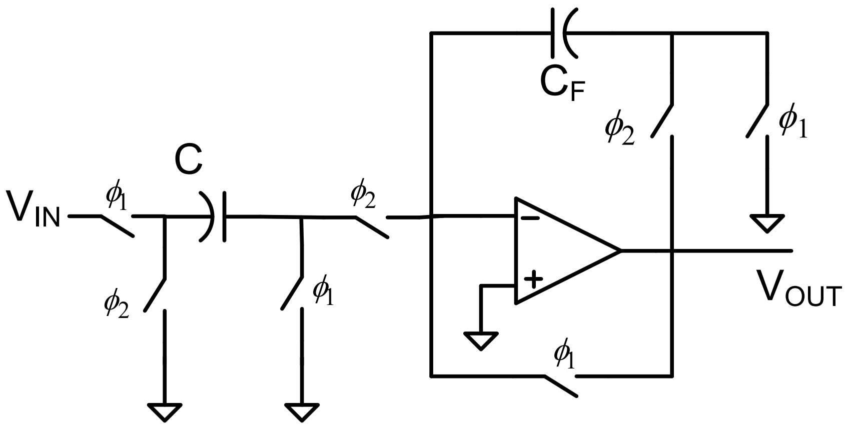
Serves as a noninverting amplifier
Gain can be very accurate
Output valid only during Φ_2

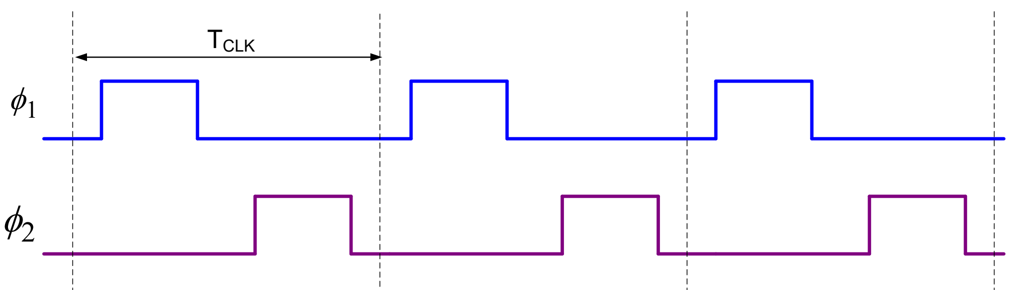
Another charge redistribution circuit





A charge redistribution circuit





During phase φ_1

$$Q_{\phi 1} = CV_{IN}$$

$$Q_{CF} = 0$$

During phase φ_2

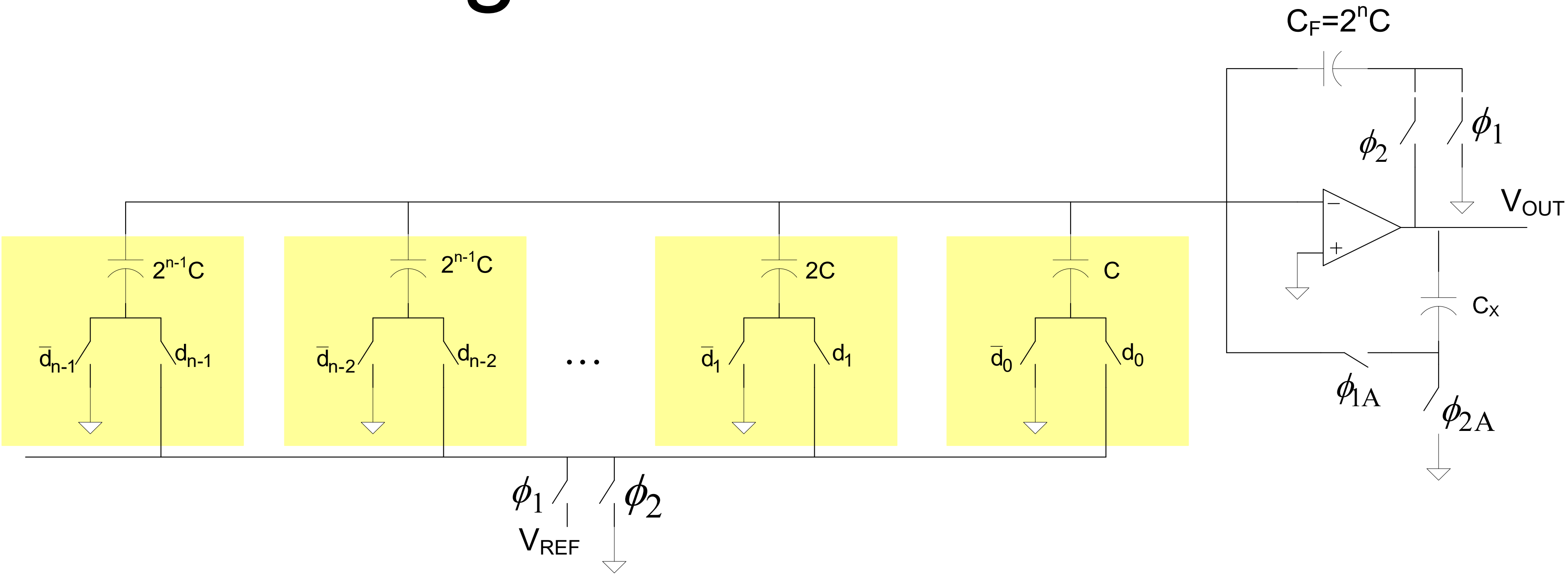
$$\frac{-Q_{\phi 1}}{C_F} = V_{OUT}$$

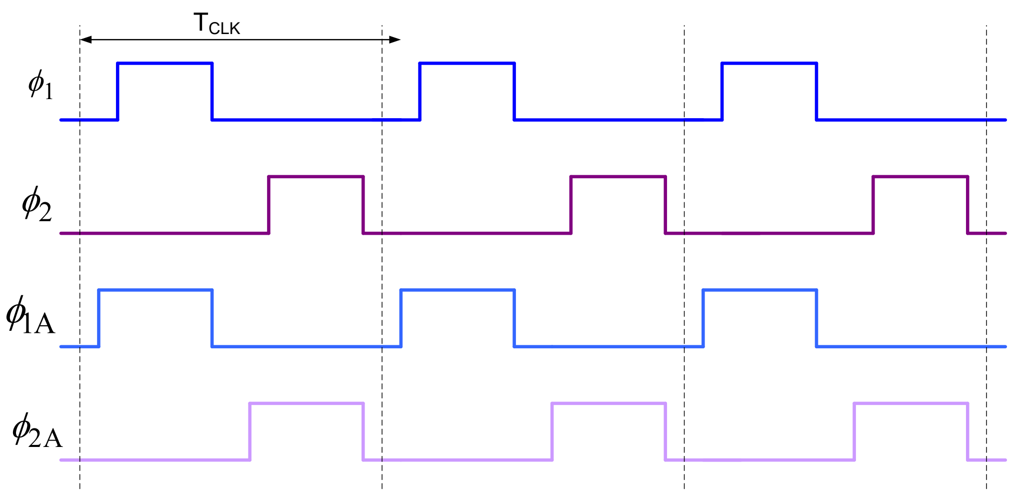
$$\frac{-CV_{IN}}{C_F} = V_{OUT}$$

$$\frac{V_{OUT}}{V_{IN}} = -\frac{C}{C_F}$$

Serves as a inverting amplifier
Gain can be very accurate
Output valid only during Φ_2

A charge redistribution DAC

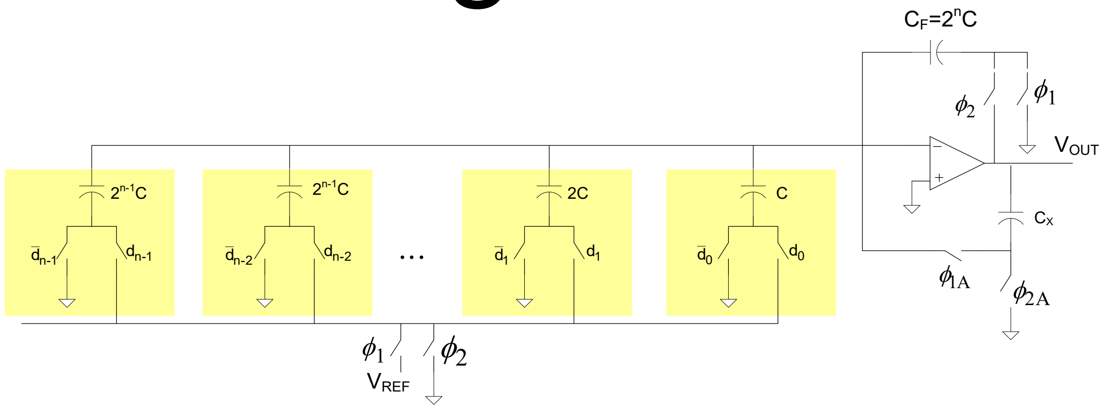


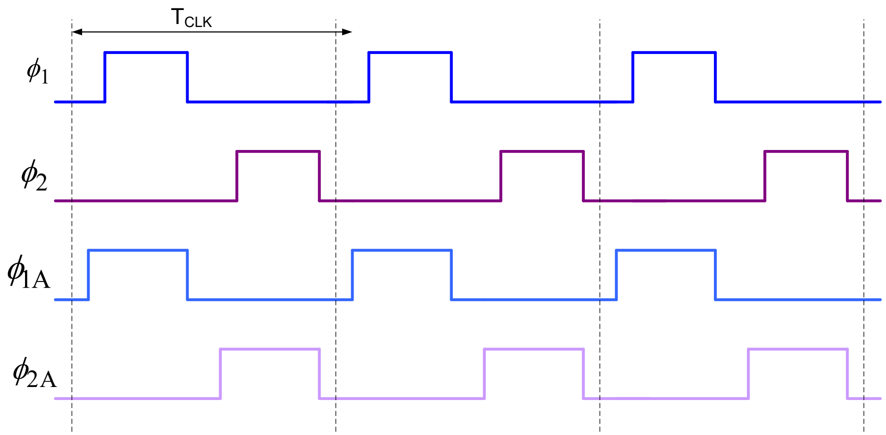


C_X does some good things
(mitigates V_{OS}, 1/f noise and finite gain errors)

Will not consider C_X affects at this time

A charge redistribution DAC





During phase φ_1

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

$$Q_{CF} = 0$$

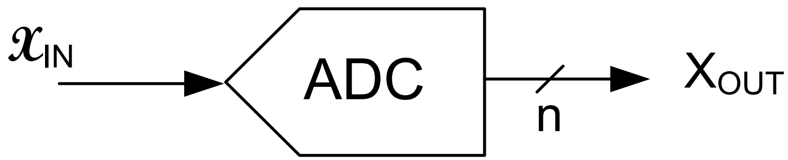
During phase φ_2

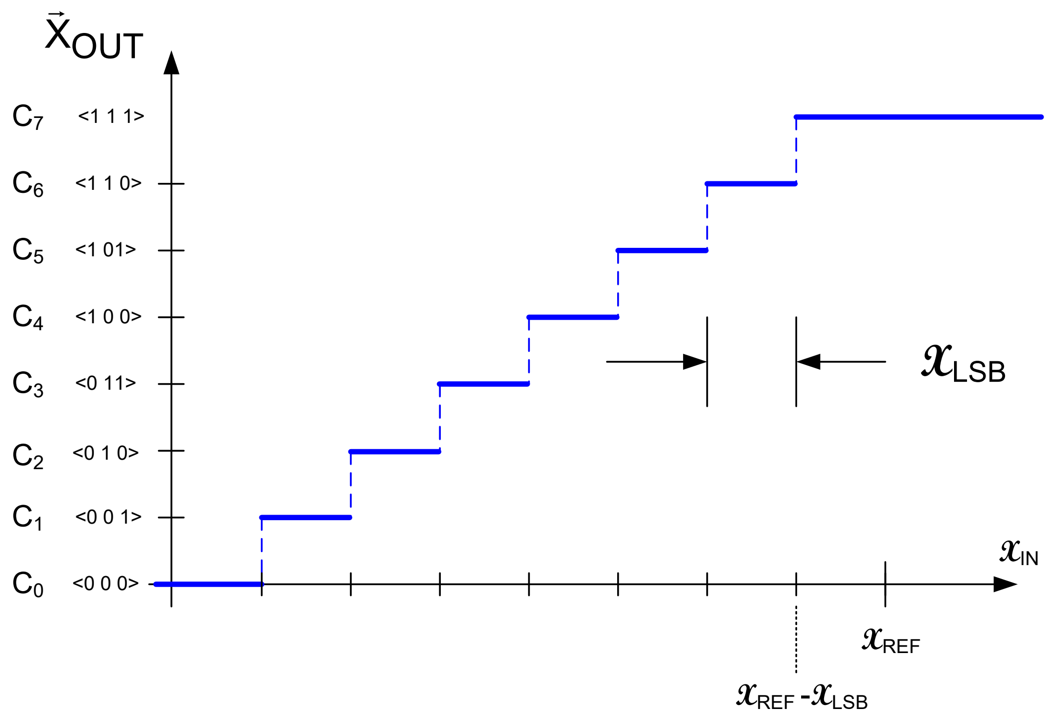
$$V_{OUT}(\phi_2) = \frac{1}{C_F} Q_{\phi 1}$$

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

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

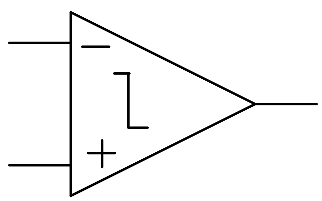
Analog to Digital Converters

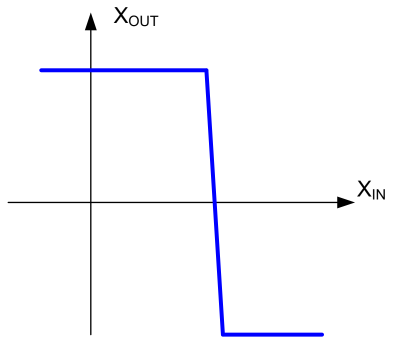




Analog to Digital Converters

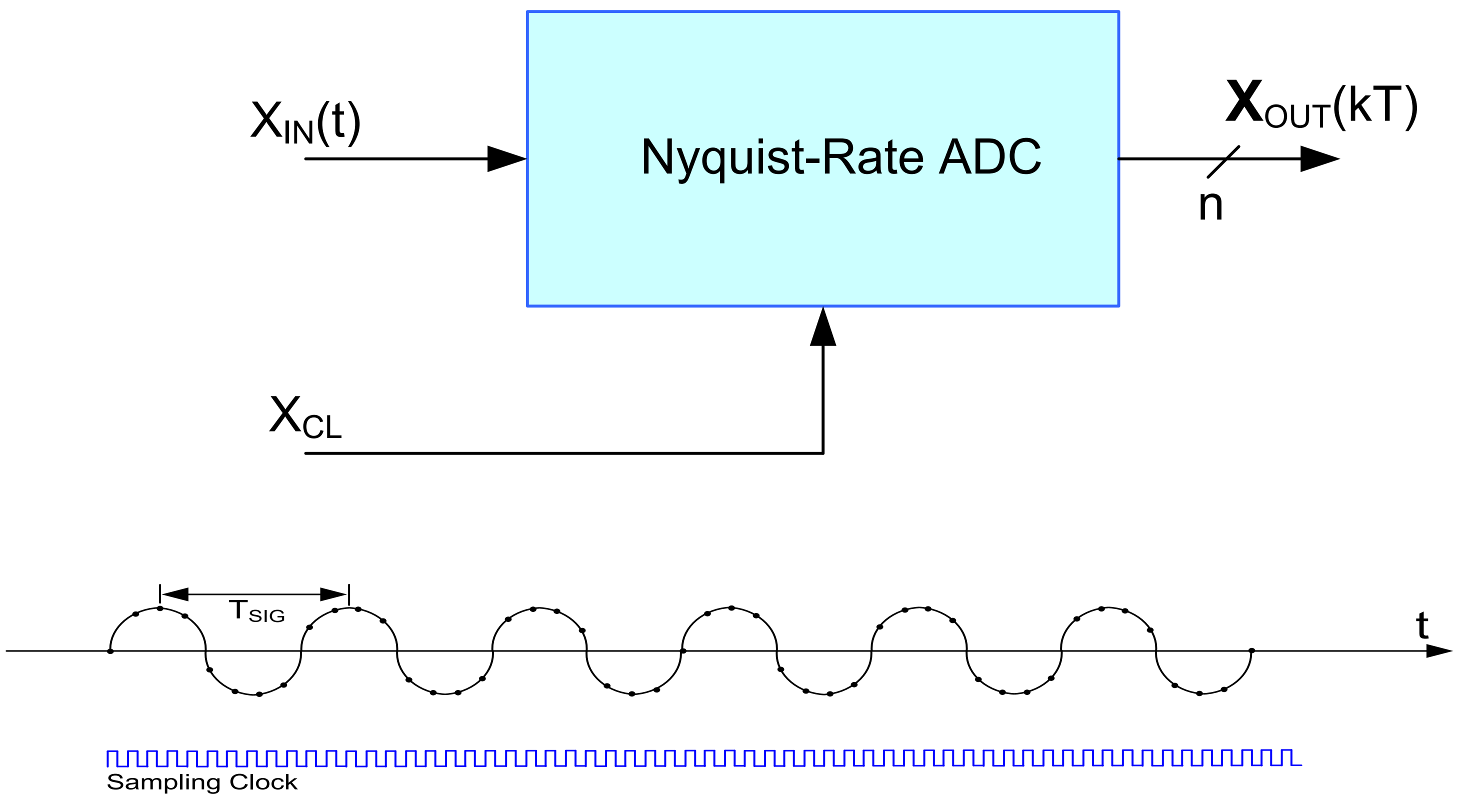
The conversion from analog to digital in most ADCs is done with comparators



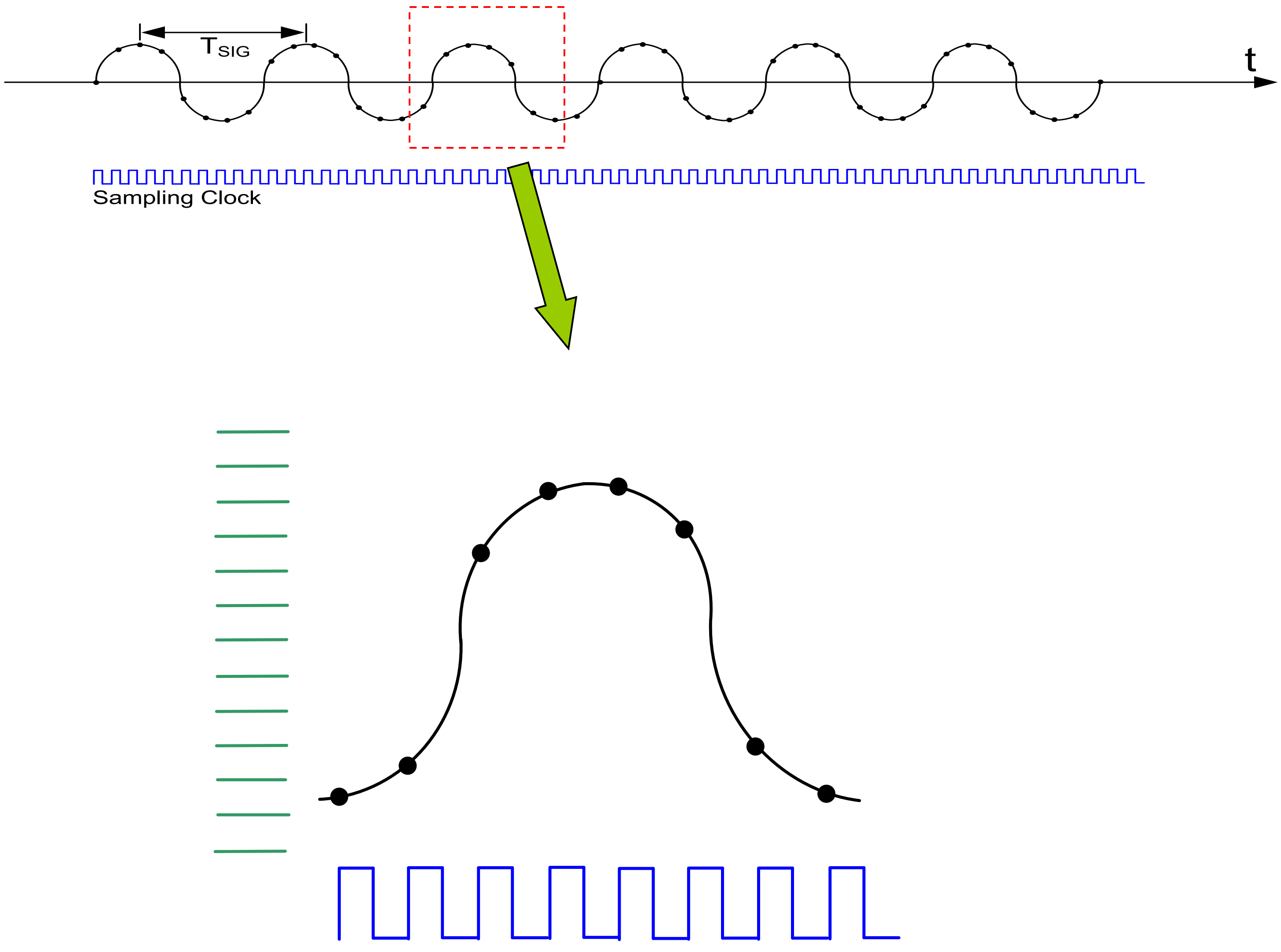


Most ADC design is primarily involved with designing comparators and embedding these into circuits that are robust to nonideal effects

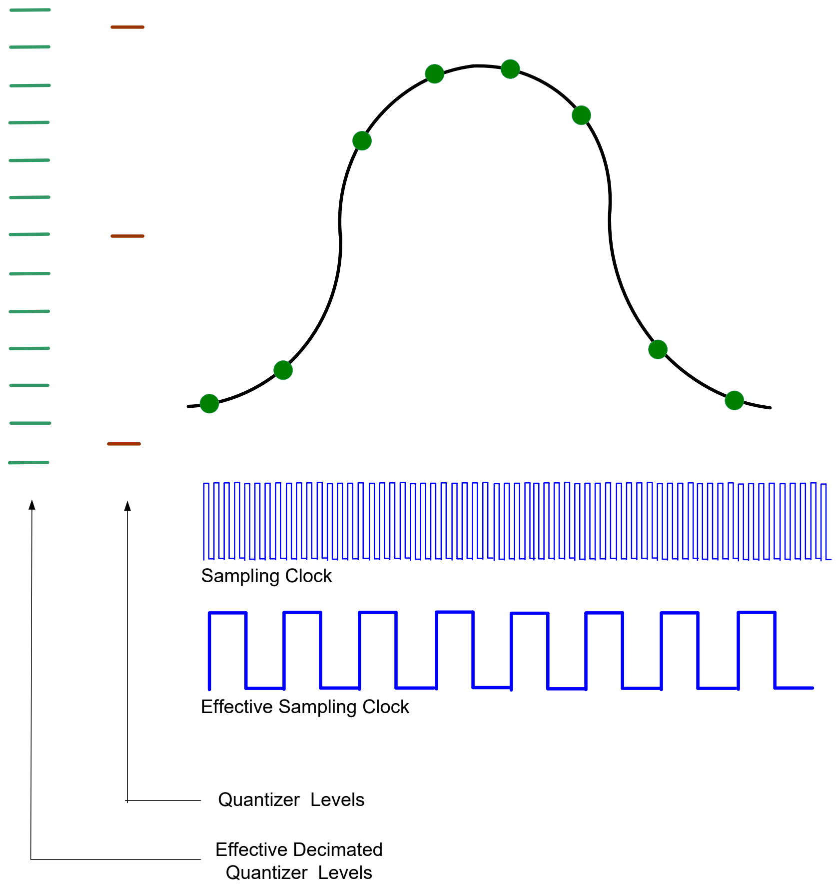
Nyquist Rate



Nyquist Rate

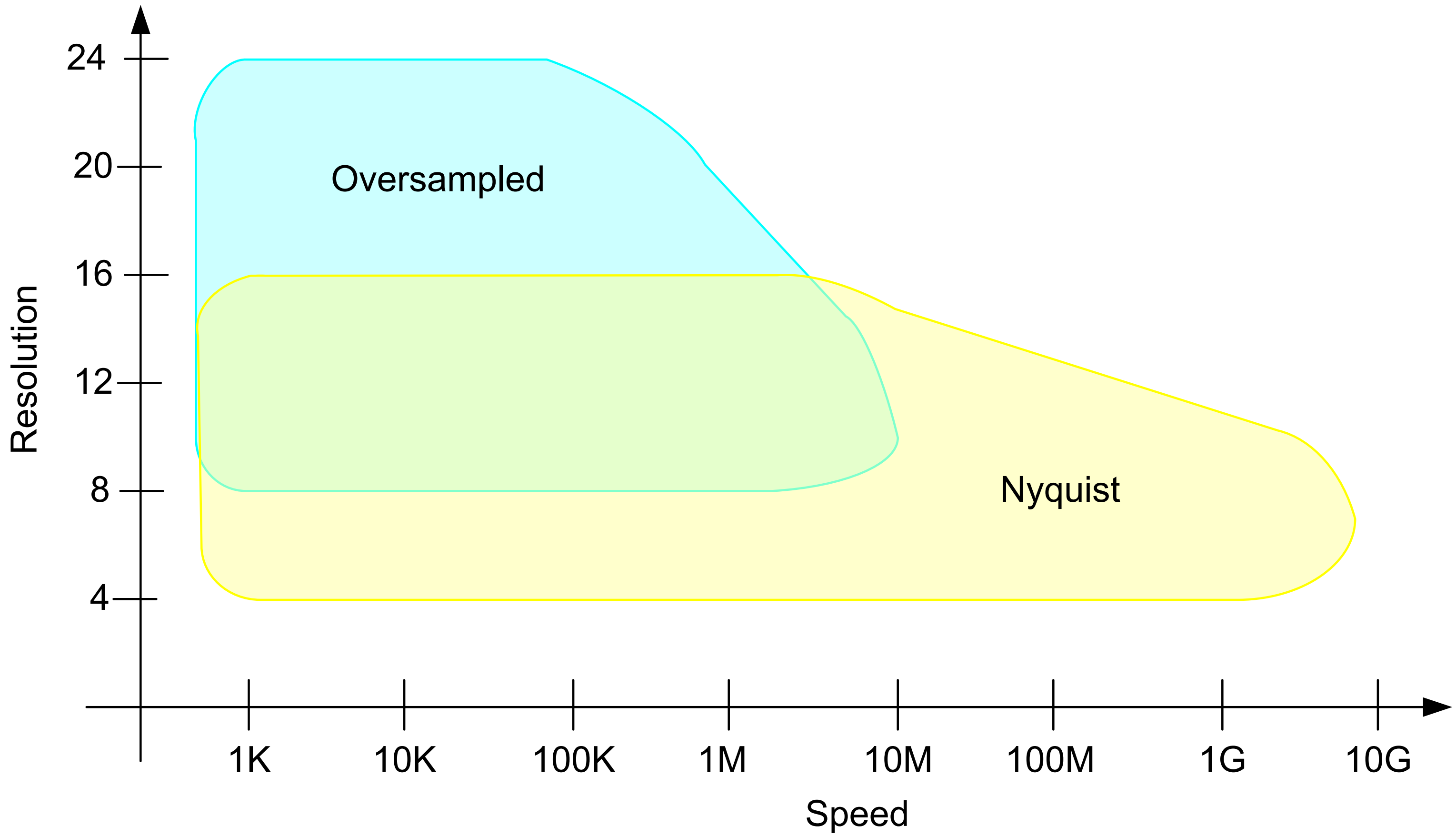


Over-Sampled



Over-sampling ratios of 128:1 or 64:1 are common
Dramatic reduction in quantization noise effects
Limited to relatively low frequencies

Data Converter Type Chart



ADC Types

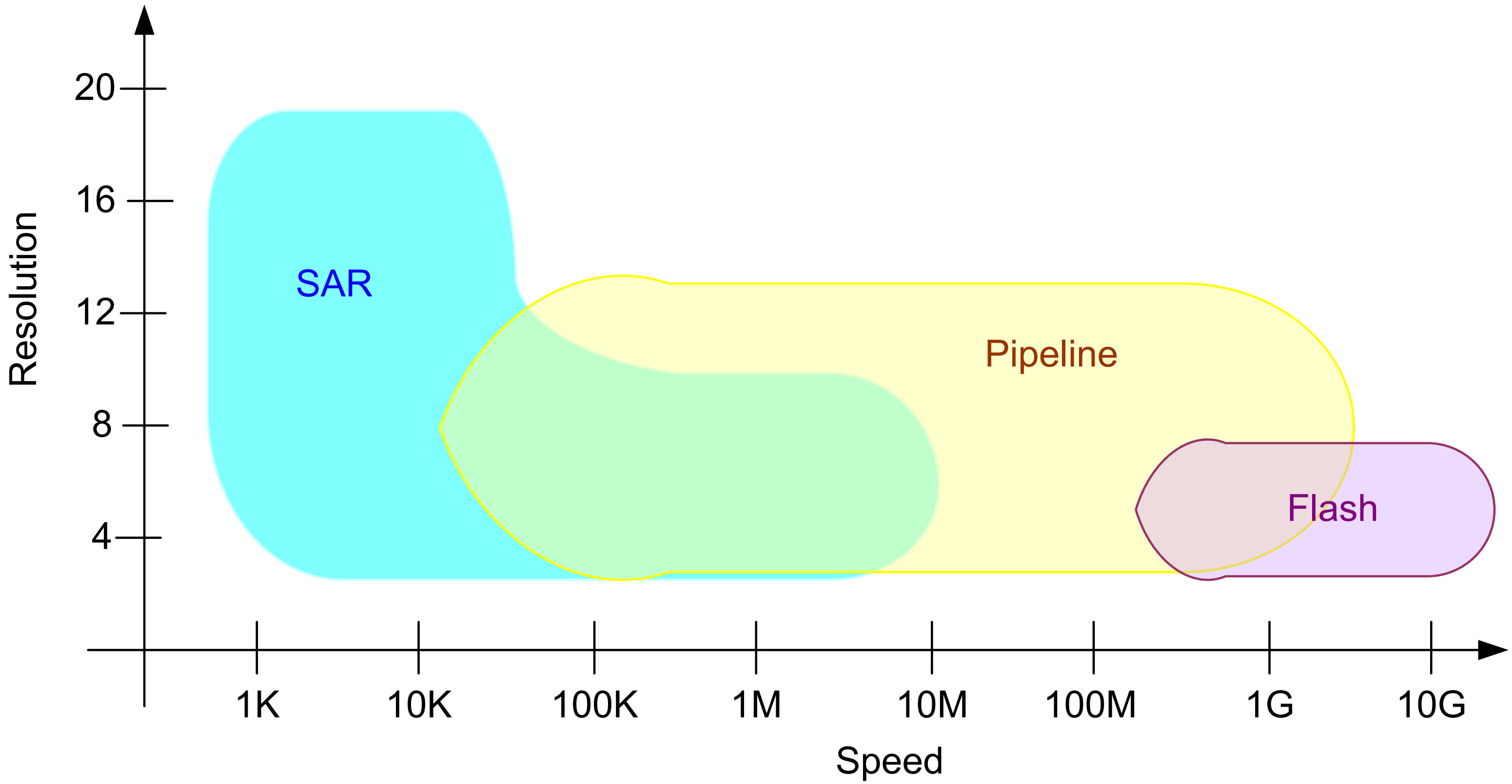
Nyquist Rate

- Flash
- Pipeline
- Two-Step Flash
- Multi-Step Flash
- Cyclic (algorithmic)
- Interpolating
- Successive Approximation
- Folded
- Dual Slope

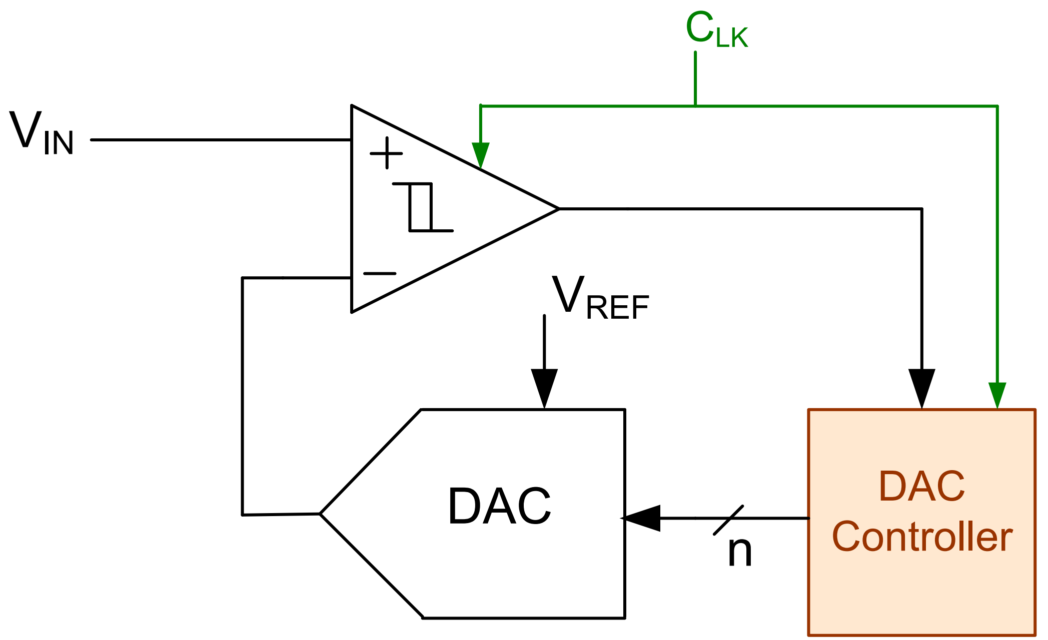
Over-Sampled

- Single-bit
- Multi-bit
- First-order
- Higher-order
- Continuous-time

Nyqyist Rate Usage Structures



SAR ADC



- DAC Controller may be simply U/D counter
- Binary search controlled by Finite State Machine is faster
- SAR ADC will have no missing codes if DAC is monotone
- Not very fast but can be small

ADC Types

Nyquist Rate

- Flash
- Pipeline
- Two-Step Flash
- Multi-Step Flash
- Cyclic (algorithmic)
- Interpolating
- Successive Approximation
- Folded
- Dual Slope

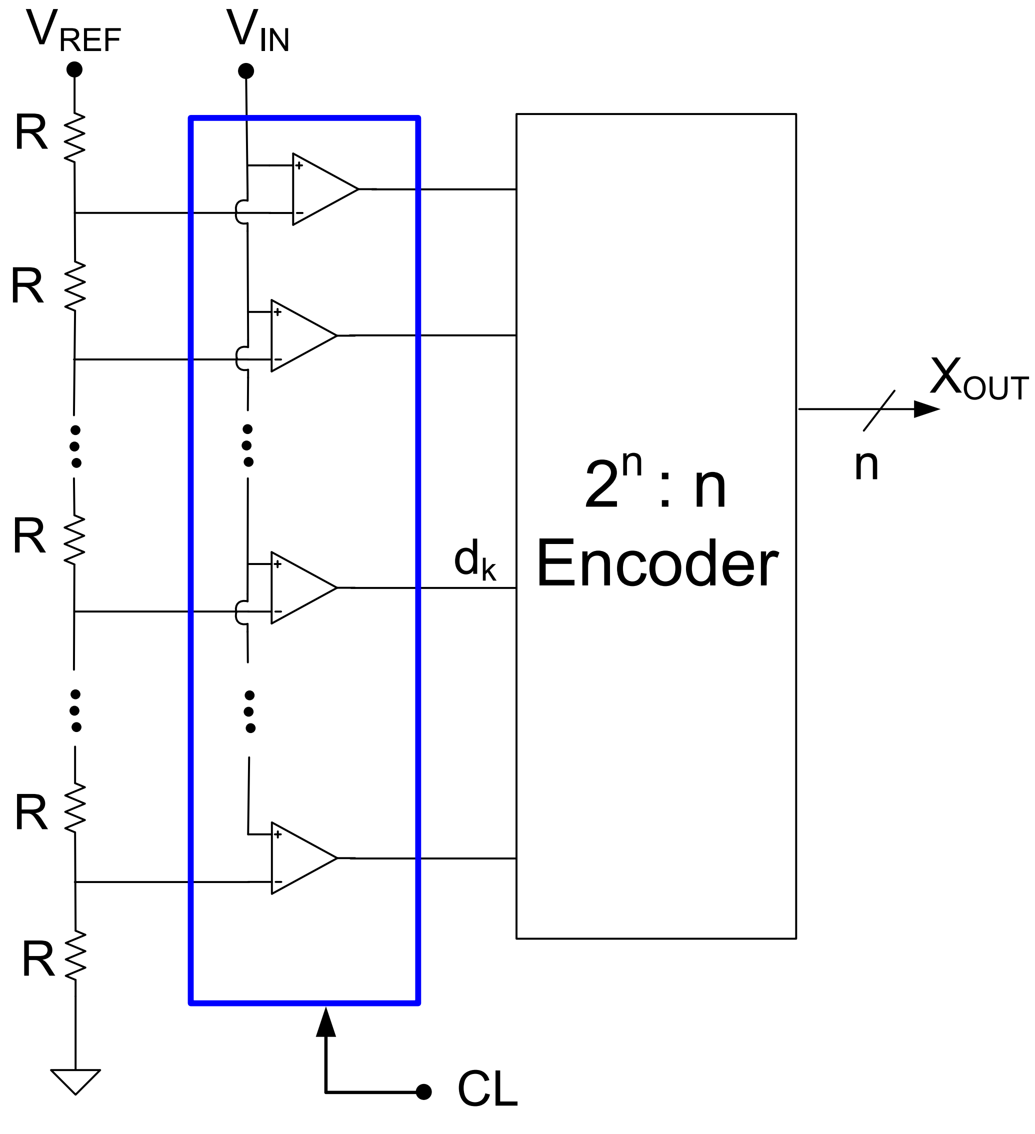
Over-Sampled

- Single-bit
- Multi-bit
- First-order
- Higher-order
- Continuous-time

All have comparable conversion rates

Basic approach in all is very similar

Flash ADC



Stay Safe and Stay Healthy !

End of Lecture 36