EE 505

Lecture 21

ADC Design
Input change during conversion

Review from last lecture

Front-End S/H and Clock of Comparators in Flash ADC

- Speed of sample/hold of concern
- Noise of S/H
- Nonlinearity of S/H
- Input range of S/H
- Loose asynchronous operation of ADC
Review from last lecture

Input change during conversion

Flash ADC with Front-End S/H

Input S/H with Clk

Input S/H with Clk and clocked comparators
Input change during conversion

Clocking of Comparators only in Flash ADC

- Eliminates need for S/H
- Extremely tight requirements on CLK generator and Input propagation
- Clocking of pre-amps may not be easy to do
Input change during conversion

Clock of Comparators only in Flash ADC
Input change during conversion

Routing of Clock and Input is Critical

Symmetric Equal Path Length Layout

Path length of $V_{IN}$ and $C_{LK}$ need not be identical but convenient if they are

Have maintained minimal overlap of $V_{IN}$ and $C_{LK}$
Routing of Clock and Input is Critical

Symmetric Paths for $V_{IN}$ and $C_{LK}$
Flash ADC

Basic structure has thermometer code at output

Performance Issues:

+ Very fast
+ Simple architecture
+ Instantaneous output

- Bubble vulnerability
- Input change during conversion
- Number of components and area (for large n)

- Speed of comparators
  - Loading of $V_{\text{REF}}$ and $V_{\text{IN}}$
  - Propagation of $V_{\text{IN}}$ and Kickback
  - Power dissipation (for large n)
  - Offset of comparators
  - Layout of resistors
  - Voltage and temperature dependence of R’s
  - Matching of R’s
Speed of Comparators

Linear Amplifier as Comparator
- Gain may be inadequate to generate Boolean output for some inputs (metastability)
- Common-mode input varies significantly with $V_{REF_k}$

Regenerative Feedback Comparators
- Reduces metastability concerns
- Common-mode input still varies with $V_{REF_k}$
- Offset Voltage High
- CLK can significantly improve speed
- Kickback to Input of concern
Speed of Comparators

- Preamp often precedes regenerative stage
- Regenerative stage can be single-ended or differential
- Common-mode input to preamp still of concern
- Common-mode inputs of all regenerative stages can be the same
- Significant reduction in offset voltage possible
- Kickback to $V_{IN}$ and $V_{REFk}$ can be reduced
Speed of Comparators

- Two or more stages of preamp gain often used
- Further reduces offset voltage and metastability concerns
- Number of stages can be selected to optimize speed and power
- Common-mode input in all stages after first can be the same
Flash ADC

Basic structure has thermometer code at output

Performance Issues:

+ Very fast
+ Simple architecture
+ Instantaneous output

- Bubble vulnerability
- Input change during conversion
- Number of components and area (for large n)
- Speed of comparators
- Loading of $V_{REF}$ and $V_{IN}$
- Propagation of $V_{IN}$ and Kickback
- Power dissipation (for large n)
- Offset of comparators
- Layout of resistors
- Voltage and temperature dependence of R’s
- Matching of R’s
Loading of \( V_{\text{REF}} \) and \( V_{\text{IN}} \)

- Capacitive load on \( V_{\text{IN}} \) is large for large \( n \)
- Resistors in R-string small for fast recovery when \( V_{\text{IN}} \) changes
- Inductance on bonding leads for \( V_{\text{REF}} \) of concern if \( V_{\text{REF}} \) externally generated
- Output impedance must remain low at high frequencies if \( V_{\text{REF}} \) internally generated
Flash ADC

Basic structure has thermometer code at output

Performance Issues:

+ Very fast
+ Simple architecture
+ Instantaneous output

- Bubble vulnerability
- Input change during conversion
- Number of components and area (for large n)
- Speed of comparators
- Loading of $V_{REF}$ and $V_{IN}$
- Propagation of $V_{IN}$ and Kickback
- Power dissipation (for large n)
- Offset of comparators
- Layout of resistors
- Voltage and temperature dependence of R’s
- Matching of R’s
Propagation of $V_{IN}$ and Kickback

- Key decisions being made by comparators near 0-1 thermometer code transition
- Several comparators often changing states during each conversion introducing lots of kickback
- Kickback can be reduced by introducing preamp
- Input-output coupling on each comparator introduces large transients in R-string for large input changes
- Delay in $V_{IN}$ propagating down string but introducing delay in clock can mitigate concern
Flash ADC

Basic structure has thermometer code at output

**Performance Issues:**

+ Very fast
+ Simple architecture
+ Instantaneous output

- Bubble vulnerability
- Input change during conversion
- Number of components and area (for large n)
- Speed of comparators
- Loading of $V_{REF}$ and $V_{IN}$
- Propagation of $V_{IN}$ and Kickback
- Power dissipation (for large n)
- Offset of comparators
  - Layout of resistors
  - Voltage and temperature dependence of R’s
  - Matching of R’s
Clocked Linear Comparator with Offset Compensation

Preamplifier or Linear Comparator with offset compensation

- Ideally removes all offset effects
- May not have a large enough gain
- Offset Compensation can be added to regenerative latch
- Several variants of offset compensation circuits are available
Some Variants of Clocked Offset Compensation
Flash ADC

Basic structure has thermometer code at output

**Performance Issues:**

- Very fast
- Simple architecture
- Instantaneous output
- Bubble vulnerability
- Input change during conversion
- Number of components and area (for large n)
- Speed of comparators
- Loading of $V_{REF}$ and $V_{IN}$
- Propagation of $V_{IN}$ and Kickback
- Power dissipation (for large n)
- Offset of comparators
- Layout of resistors
- Voltage and temperature dependence of R’s
  - Matching of R’s
Voltage and temperature dependence of R’s

From lecture notes of Phil Allen

**Polysilicon Resistor**

- Metal
- Polysilicon resistor
- FOX
- p-substrate
- Older LOCOS Technology

- 30-100 ohms/square (unshielded)
- 100-500 ohms/square (shielded)
- Absolute accuracy = ±3 0%
- Relative accuracy = 2% (5 μm)
- Temperature coefficient = 500-1000 ppm/°C
- Voltage coefficient = 100 ppm/V
Voltage and temperature dependence of R’s

From lecture notes of Phil Allen

**MOS Resistors - Source/Drain Resistor**

**Diffusion:**
- 10-100 ohms/square
- Absolute accuracy = ±35%
- Relative accuracy = 2% (5μm), 0.2% (50μm)
- Temperature coefficient = 1500 ppm/°C
- Voltage coefficient = 200 ppm/V

**Ion Implanted:**
- 500-2000 ohms/square
- Absolute accuracy = ±15%
- Relative accuracy = 2% (5μm), 0.15% (50μm)
- Temperature coefficient = 400 ppm/°C
- Voltage coefficient = 800 ppm/V

**Comments:**
- Parasitic capacitance to substrate is voltage dependent.
- Piezoresistance effects occur due to chip strain from mounting.
Voltage and temperature dependence of R’s

From lecture notes of Phil Allen

Resistance from A to B = Resistance of segments $L_1, L_2, L_3, L_4, \text{ and } L_5$ with some correction subtracted because of corners.

Sheet resistance:

- 50-70 m$\Omega$/square $\pm$ 30% for lower or middle levels of metal
- 30-40 m$\Omega$/square $\pm$ 15% for top level metal

Watch out for the current limit for metal resistors.

Contact resistance varies from 5$\Omega$ to 10$\Omega$.

Tempco $\approx +4000$ ppm/$^\circ$C

Need to derate the current at higher temperatures:

$$I_{DC}(T_j) = D_I I_{DC}(T_R)$$

<table>
<thead>
<tr>
<th>$T_A$($^\circ$C)</th>
<th>$T_F$($^\circ$C)</th>
<th>$D_I$</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;85</td>
<td>85</td>
<td>1</td>
</tr>
<tr>
<td>100</td>
<td>85</td>
<td>0.63</td>
</tr>
<tr>
<td>110</td>
<td>85</td>
<td>0.48</td>
</tr>
<tr>
<td>125</td>
<td>85</td>
<td>0.32</td>
</tr>
<tr>
<td>150</td>
<td>85</td>
<td>0.18</td>
</tr>
</tbody>
</table>
Voltage and temperature dependence of R’s

From lecture notes of Phil Allen

N-well Resistor

1000-5000 ohms/square
Absolute accuracy = ±40%
Relative accuracy = 5%
Temperature coefficient = 4000 ppm/°C
Voltage coefficient is large = 8000 ppm/V
Comments:
• Good when large values of resistance are needed.
• Parasitics are large and resistance is voltage dependent
• Could put a p+ diffusion into the well to form a pinched resistor
Voltage and temperature dependence of R’s

From lecture notes of Phil Allen

**Thin Film Resistors**
A high-quality resistor fabricated from a thin nickel-chromium alloy or a silicon-chromium mixture.

Uppermost metal layer:

Performance:
Sheet resistivity is approximately 5-10 ohms/square
Temperature coefficients of less than 100 ppm/°C
Absolute tolerance of better than ±0.1% using laser trimming
Selectivity of the metal etch must be sufficient to ensure the integrity of the thin-film resistor beneath the areas where metal is etched away.
Interpolating ADC

- Key decisions being made by comparators near 0-1 thermometer code transition in Flash ADCs
- Other comparators consume power and area
- Each regenerative comparator typically requires a preamp stage in full flash ADC
Interpolating Flash ADC

It may appear that the number of comparators and resistors have been increased but …

First stage comparators can be a pre-amp
Second stage comparators can be a latch
Number of critical resistors in first stage has been decreased
Interpolating Flash ADC

- Reduction in pre-amp area and power
- Latches all referenced to ground
- Loading on $V_{IN}$ reduced
- Kickback to $V_{REF}$ reduced
- $V_{IN}$ coupling to $V_{REF}$ reduced
- Multiple levels can be included in interpolator array
Interpolating Flash ADC

4 levels of interpolation
Preamp gain not critical
Common mode set at $V_{REF/2}$

Comparator Outputs:

$V_k$ 0
$V_{k1}$ 0
$V_{k2}$ 1
$V_{k3}$ 1
$V_{k+1}$ 1

4 levels of interpolation
Preamp gain not critical
Common mode set at $V_{REF/2}$
End of Lecture 21