\[ \beta = \frac{1}{V_{DD}} \]

\[ V_{IN} \rightarrow V_{OUT} \]

\[ V_{GS} = V_{DD} - V_{OUT} \]
\[ = V_{DD} - V_{IN} \]

\[ R_{ON,n} = \frac{1}{\beta_n (V_{DD} - V_{IN} - V_{THn})} \]

\[ \beta = 0 \]

\[ V_{SG} \rightarrow V_{IN} \rightarrow V_{OUT} \]

\[ V_{SA} = V_{IN} \]

\[ R_{ON,p} = \frac{1}{\beta_p (V_{IN} - V_{THp})} \]
\[ R_{on, eq} = R_{on,n} \parallel R_{on,p} \]

\[ = \frac{1}{\frac{1}{\beta_n (V_{DD} - V_{in} - V_{THP})} \parallel \frac{1}{\beta_p (V_{in} - V_{THN})}} \]

\[ = \frac{1}{\frac{\beta_n (V_{DD} - V_{THN}) - [\beta_n - \beta_p] V_{in} - \beta_p (V_{THN})}{\beta_n (V_{DD} - V_{THN})}} \]
\[ \phi \xrightarrow{\Delta t} \bar{\phi} \] 

\[ \bar{\phi} \xrightarrow{\Delta V} \text{Ideal Value} \]

\[ \text{Identifying jersake in the Sampled Value} \]

\[ \phi \xrightarrow{\text{Click}} \bar{\phi} \]

\[ \Rightarrow \text{Ambiguity in the Sampled Instance} \]
Time-constant $T = R_{on} \cdot C_{th}$

$V_{out} = \left( 1 - e^{-\frac{t_s}{2R_{on}C_{th}}} \right)$

$V_{out} = \left( 1 - e^{-\frac{t_s}{2}} \right) V_{in0}$

$t_s = 2 \ln \left( \frac{1}{\varepsilon} \right)$

<table>
<thead>
<tr>
<th>% error</th>
<th>$\varepsilon$</th>
<th>$\frac{t_s}{2}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>10%</td>
<td>0.1</td>
<td>2.2</td>
</tr>
<tr>
<td>1%</td>
<td>0.01</td>
<td>4.6</td>
</tr>
<tr>
<td>0.1%</td>
<td>0.001</td>
<td>6.9</td>
</tr>
<tr>
<td>0.01%</td>
<td>0.0001</td>
<td>9.21</td>
</tr>
</tbody>
</table>
Precise Considerations:

1. Channel "charge injection"
2. Clock feedthrough
3. \( KTC \) Noise

\[
\text{Assuming } V_{\text{out}} = V_{\text{in}} \\
Q_{\text{ch}} = W L C_0 \chi (V_{\text{gs}} - V_{\text{thn}}) \\
= W L C_0 \chi (V_{\text{dd}} - V_{\text{ih}} - V_{\text{thn}})
\]

\[
\Delta V = \frac{-Q_{\text{ch}}}{C_H} \\
\Delta V = -\frac{W L C_0 (V_{\text{dd}} - V_{\text{in}} - V_{\text{thn}})}{2 C_H}
\]

\( V_{\text{thn}} + 8 \left( \sqrt{2} F + V_{\text{in}} - \sqrt{2} F \right) \) (leakage error)
\[ \Delta v = -\frac{WL C_{ox}(V_{DD} - V_{ih} - V_{THH})}{2C_H} \]

\[ \Delta v \propto \frac{WL}{C_H} \]

\[ \propto \frac{1}{C_H} \]
Assumption of \(-Q_{eq}\) being injected into \(C_t\)

\(L\), in reality, depends upon the \(L_d + L_s\) at the time of clock transition.

\(L\), no exact expression

\(L\) as a worst estimate, assume all of

- \(Q_{eq}\) is injected into \(C_t\).
Impact of C.I. on precision

\[ V_{\text{out}} = V_{\text{in}} - \Delta V \]

\[ = V_{\text{in}} - \frac{W L C_{\text{ox}} (V_{\text{DD}} - V_{\text{in}} - V_{\text{THw}})}{C_{\text{H}}} \]

Neglecting the phase shift b/c \( V_{\text{in}} \approx V_{\text{out}} \)

\[ \Rightarrow V_{\text{out}} = V_{\text{in}} \left(1 + \frac{W L C_{\text{ox}}}{C_{\text{H}}} \right) - \frac{W L C_{\text{ox}} (V_{\text{DD}} - V_{\text{THw}})}{C_{\text{H}}} \]

\[ \text{gain} \]

\[ \text{offset} \]

\[ V_{\text{THw}} = f(V_{\text{in}}) \]
\[ V_{ocx} = V_{in} \left(1 + \frac{WLC_{ox}}{C_{ih}}\right) + \frac{2 WLC_{ox}}{C_{ih}} \sqrt{2 \phi_{B} + V_{in}} \]

\[ - \frac{WLC_{ox}}{C_{ih}} \left( V_{dd} - V_{th0} + 2 \sqrt{2 \phi_{B}} \right) \]

* Nonlinearity in the input-output characteristics

* Charge-injection contributes errors in S/I circuits

* Gain error can tolerate using circuit techniques

* DC offset cannot be tolerated
2) Clock feedthrough:

\[ \Delta V = V_{CC} \cdot \frac{W_{Cov}}{W_{Cov} + C_t} \]

\[ C_{ov} \approx \text{overlap cap per unit width} \]

\[ \Delta V \leq \text{indep. of } V_{in} \]

\[ \implies \text{introduces a constant offset in the sampled output} \]

\[ W_{Cov} \Rightarrow \Delta V \]

Could use \( C_t \Rightarrow W_{Cov} \)
Charge injection cancellation

When $M_1$ turns off & $M_2$ turns on, the channel charge $\Delta q_1$ deposited on $C_H$ is absorbed by $M_2$ to create its channel ($\Delta q_2$)

For perfect cancellation

$\Delta q_1 = \Delta q_2$

$\frac{W_1 L_1 C_{ox}}{2} (V_{clk} - V_{in} - V_{th\text{in}}) = W_2 L_2 C_{ox} (V_{cm} - V_{in} - V_{th\text{in}})$

For $W_2 = \frac{W_1}{2}$ and $L_2 = L_1$, it could work!
the assumption of 1/2 way splitting makes it less robust.

However,

\[
\text{Clock feedthrough is cancelled using this scheme.}
\]

\[
\Rightarrow \text{ Solution: use } \frac{1}{2} \text{-size dummy to absorb injected charge.}
\]
Complementary Switches

\[ \Delta q_1 = \Delta q_2 \]

\[ \text{We must have} \quad W_{1L} \cdot C_{ox} \left( V_{cc} - V_{in} - V_{th} \right) = W_{2L} \cdot C_{ox} \left( V_{in} - (V_{th} + V \delta) \right) \]

Cancellation only works for one input value \( V \delta \).

* Doesn't provide clock feedthrough cancellation as \( C_{own} \neq C_{ooy} \)
Differential Circuit

\[ \Delta q_1 - \Delta q_2 = WLC_{ox} \left[ -(V_{ip} - V_{im}) + (V_{T+V_N2} - V_{T+V_N1}) \right] \]

\[ = WLC_{ox} \left[ -(V_{ip} - V_{im}) + 8 \left( \sqrt{2\Phi_3 + V_{im}} - \sqrt{2\Phi_3 + V_{ip}} \right) \right] \]

2nd order
Odd function.
No DC offset due to CI.

* non-linear terms \(\Rightarrow\) odd-order distortion remains

All even-order distortion is cancelled