EE 505

Lecture 18

String DACs
Recall:

\[ V_0 \]

Switch impedance signal-level dependent.

\[ \Rightarrow \text{settling time code dependent} \]
Transmission Gate Switch

\[ R_{sw} = \frac{L}{\mu_C \omega |V_{EB}|} \]

\[ W_P = \frac{\mu_n W_n}{W_P} \]

Example:

\[ V_{DD} = 5 \text{ V} \]
\[ V_{REF} = 2 \text{ V} \]
\[ \text{AMT 0.5um Proc.} \]

\[ R_{sp} = \begin{cases} \infty & \text{OT} \\ 3.8k & \text{IT} \end{cases} \]

\[ R_{sn} = \begin{cases} 6 & \text{OT} \\ 1.5k & \text{IT} \end{cases} \]
with this transmission gate switch

1) Some improvement in reducing the signal dependence of $R_{SW}$ (minimal improvement)

2) Factor of 4 increase in $C_L$

---

Why did the "on" impedance improve so little?

- Because inadequate excess bias when operating with inputs near ground!
\[ V_{REF} = 2V \]
\[ V_{DD} - V_{SS} = 5V \]
\[ |V_{TP}| = V_{TH} \]
\[ \omega_p = \frac{\mu_n \omega_n}{\mu_p} \]

\[ R_{OT} = \frac{1}{2} \left( \frac{L_0}{\mu_n C_{OX} \omega_n (2.5 - 1 - V_T)} \right) \]
\[ R_{OT} = 260 \Omega \]
\[ R_{IT} = 260 \Omega \]
\[ R_{I_z} = 260 \Omega \]

- at least at the 3 pts considered, the on-impedance is constant
Analysis of TG Switch.

\[ g_{\text{TOT}} = \begin{cases} 
\frac{M_{\text{cox}} w_n}{L_n} (V_{\phi} - V_i - V_{\text{Tn}}) & V_{\phi} - V_{\text{Tp}} > V_i \\
\frac{M_n c_{\text{ox}} w_n}{L_p} (V_{\phi} - V_i - V_{\text{Tn}}) - \frac{-M_{\alpha} c_{\text{ox}} w_{\alpha}}{L_p} (V_{\phi} - V_i - V_{\text{Tn}}) & V_{\phi} - V_{\text{Tp}} < V_i < V_{\phi} - V_{\text{Tn}} \\
\frac{-M_{\alpha} c_{\text{ox}} w_{\alpha}}{L_p} (V_{\phi} - V_i - V_{\text{Tn}}) & \text{otherwise}
\end{cases} \]
To make $g_{tot}$ independent of $V_i$:

\[
\frac{U_n \cos \theta_n}{X_n} = \frac{U_p \cos \theta_p}{X_p}
\]

\[
W_p = \frac{U_n}{U_p} \cdot W_n
\]

- We can make $g_{tot}$ independent of $V_i$ over a limited operating range.
- If that range is exceeded:
  a) Full benefit of compensation will not be realized
  b) residual signal dependence on $g_{tot}$
  c) minimal benefit if not close to symmetric condition on $V_i$
Constant Excess Bias

\[ R_{on} = \frac{1}{\mu C_{ox} \omega V_{EB}} \]

For standard Boolean voltages \( V_{\Phi_1} \) and \( V_{\Phi_2} \), the excess biases will be different.

a) Change \( \frac{1}{\omega} \) with position

b) Could change \( V_{DD_{eq}} \) for each switch
Issues: Complexity, Area, Power.

But -
Bootstrapped Switches

Basic Principle

\[ V_x = V_{DD} - V_{SS} \]

\[ R_{sw} = \frac{L}{\mu C_{ox}(V_x - V_T)} \]

Note: This is \( \frac{1}{2} \) of \( V_1 \)

- Switch can operate
  \[ V_{SS} \leq V_1 \leq V_{DD} \]
- \( R_{sw} \) is small 😊

? Unacceptable Process Stress?
Conceptual Implementation

![Diagram]

Steensgaard  ISCAS'99  P29
Abo4 Gray  IEEE JSC  5/99  P599

Issues: If n-channel switches are used, difficult to pull up to VDD. If p-channel devices are used, easy to turn on but:

1) may need to contend with forward bias or diffusion-well junction

2) may have a problem turning p-channel devices off:
   a) don't connect well to VDD
   b) Bootstrap the clock for p-channel device
Considerable overhead but performance degradation is so serious that these problems are worth solving.

In some applications on key S/H enables entire product so considerable effort is justified on this S/H.
Switch Turn-On time

\[ V_i \]

\[ V_i \]

\[ \Phi \]

\[ C \]

\[ V_i(t) \]

If samples are not taken at the "right" time, serious performancy degradation can result.
want sample at \( t = T_1 \)

obtain sample near \( t = T_2 \)

- as switch starts to open, R.C. time constant increases thus changing \( \tilde{V}_i \)

- latency is input dependent

and has serious detrimental impact on spectral performance (for high-speed inputs)
Make all clocks fast to circumvent the delay problem.

If \( V_i = V_m \sin \omega t \)

\[
\frac{dV_i}{dt} = \omega V_m \cos \omega t
\]

maximum \( |\frac{dV_i}{dt}| = \omega V_m \)

If \( V_m = \frac{V_{DD}}{2} \)

If \( n = 14 \)

\[
V_{LSB} = \frac{V_{DD}}{2^{15}} = \frac{V_{DD}}{32,000}
\]

If \( V_{DD} = 3.5 \mu V \)

\[
V_{LSB} \approx 10 \mu V
\]

If \( \omega = (2\pi n) \times 10^8 \)

\[
\Delta T = \frac{\Delta V}{2\pi \times 10^8 \frac{V_{DD}}{2}} = \frac{\Delta V}{(\gamma)(10^8)(3.5 \mu V)} = 10^{-14} \text{ sec}
\]