High-speed Serial Interface

Lect. 7 – TX Driver

(Ref.: Razavi, Prof. Palermo's Lecture Notes for "High-Speed Links Circuits and Systems", Texas A&M)
How to send digital data from Tx to Rx?
- Modulation Format? NRZ (Non-Return-to-Zero)
- More advanced formats are being considered for more demanding applications

PAM4 (Pulse Amplitude Modulation 4)
- NRZ Tx driver structure:
  Single or differential signaling, current or voltage mode, termination
Simplest Tx Driver

- CMOS inverter
- Voltage mode
- No static power consumption
- Operation speed is limited by full-swing (rail-to-rail)
- Impedance matching is difficult
Open-Drain Tx Driver

- Current mode
- Output voltage swing: $I_{ss}R_L$
- Can be fast but static power consumption
- $R_L = Z_0$ for Rx impedance matching
- Noise immunity?
Differential Open-Drain

- Current mode
- Differential signaling
- Output voltage swing: $2 I_{ss} R_L$
- Much better noise immunity
- Impedance matching on Tx side?
Single-ended vs Differential Signaling

- Larger output voltage swing for differential signaling
- Common-mode noise rejection with differential signaling
- Self-referencing for receiver threshold for differential signaling
  - Supply and ground levels can be different for TX and RX

⇒ Differential signaling much preferred for high-speed serial interface
⇒ High-speed circuits often use differential signaling for their logic circuits
Current-Mode Logic (CML) Driver

- Current mode
- Differential signaling
- Termination: $R_1 = R_2 = R_L = Z_0$
- Output voltage swing
  
  \[
  V_{d1} = \left(\frac{I_S}{2}\right) R_L \quad V_{dp} = I_S R_L \\
  V_{d0} = -\left(\frac{I_S}{2}\right) R_L
  \]

- Most popular for high-speed serial interface applications
50-Ω termination

• Why 50Ω for transmission lines?
  – Historical reason

  • For coax cables for early microwave systems (1930s),
    – 33Ω gave best performance in max power handling capacity
    – 75Ω gave the minimum loss
    – 50 Ω, a value close to the medium (54 Ω) was selected as a compromise

  • Nowadays, almost all high-speed instruments, interconnects, circuits are 50Ω-based
    – Some CATV systems still use 75-Ω coax cables
CML with Differential Rx Termination

- Output voltage swing:

\[
V_{d,1} = \left(\frac{I_{SS}}{2}\right) R_L
\]
\[
V_{d,0} = -\left(\frac{I_{SS}}{2}\right) R_L
\]
\[
V_{d,pp} = I_{SS} R_L
\]

- Output voltage swing:

\[
V_{d,1} = \left(\frac{I_{SS}}{4}\right) 2R_L
\]
\[
V_{d,0} = -\left(\frac{I_{SS}}{4}\right) 2R_L
\]
\[
V_{d,pp} = I_{SS} R_L
\]
CML with Differential Rx Termination
DC/AC Coupling

- Rx common-mode voltage? IR/2
  ➔ Cannot be independently controlled

- Rx common-mode? \( V_{CM} \)

- Low frequency cut-off

- Data must be coded

- 8B/10B: Map 8-bit symbol into 10-bit symbol
  so that counts for 1's and 0's are balanced
  (not more than five 1's or 0's)

  ➔ Several standards use 8B/10B coding but there is overhead for data rate
Voltage-mode Tx Driver

Current source + **Parallel** Tx termination

Voltage source + **Serial** Tx termination

Factor of 2 Tx power reduction

\[
V_{d,1} = (I/2)R \\
V_{d,0} = -(I/2)R \\
V_{d,pp} = IR \\
I = \frac{V_{d,pp}}{R}
\]

\[
V_{d,1} = \frac{V_s}{2} \\
V_{d,0} = -\frac{V_s}{2} \\
V_{d,pp} = V_s \\
I = \frac{V_s}{2R} \\
I = \frac{V_{d,pp}}{2R}
\]

→ Voltage mode driver
Differential Rx Termination

Single-ended Rx termination

Differential Rx termination

Further power reduction of factor 2
Voltage Mode Driver Implementation

\[ D_P = 1, \quad D_N = 0 \]

\[ D_P = 0, \quad D_N = 1 \]
Tx Termination

Replica circuits fix the voltages so that the desired Tx output impedance is achieved.