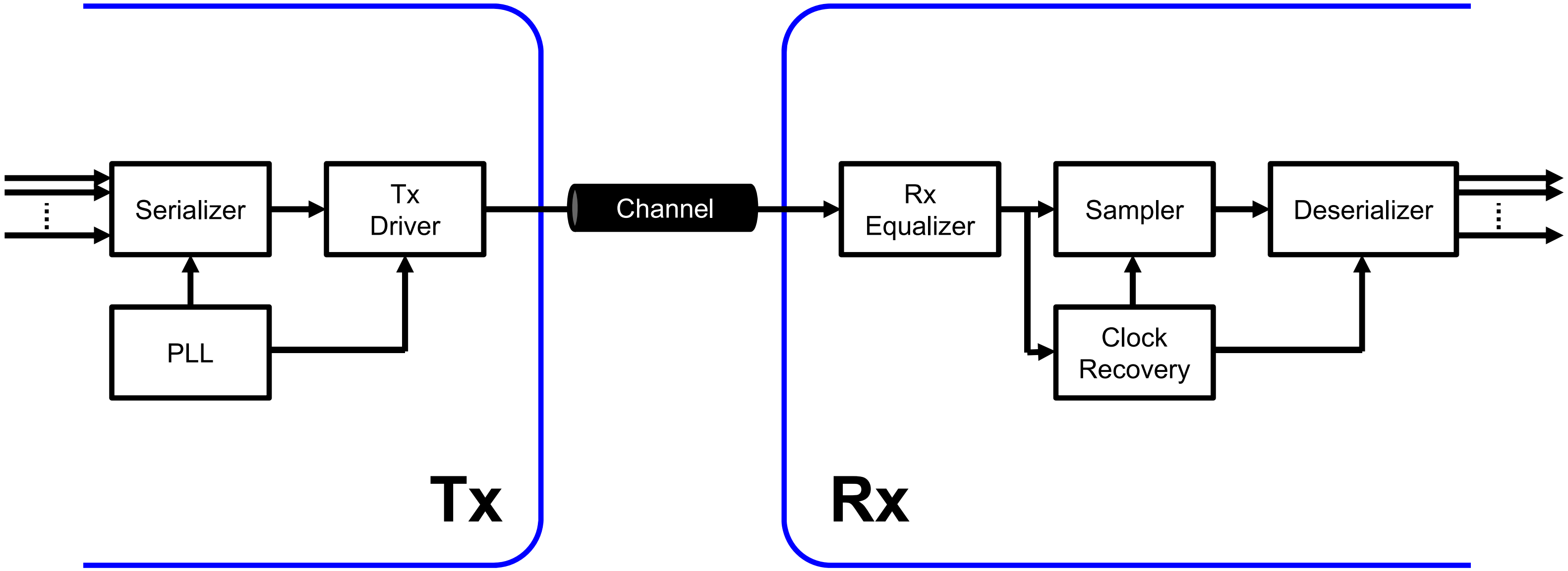
High-speed Serial Interface

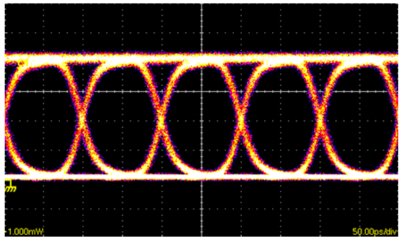
Lect. 7 – TX Driver

(Ref.: Razavi, Prof. Palermo's Lecture Notes for "High-Speed Links Circuits and Systems", Texas A&M)

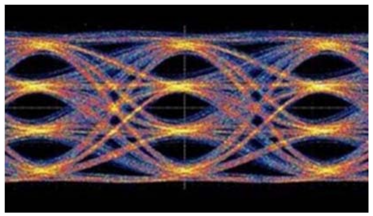


How to send digital data from Tx to Rx?

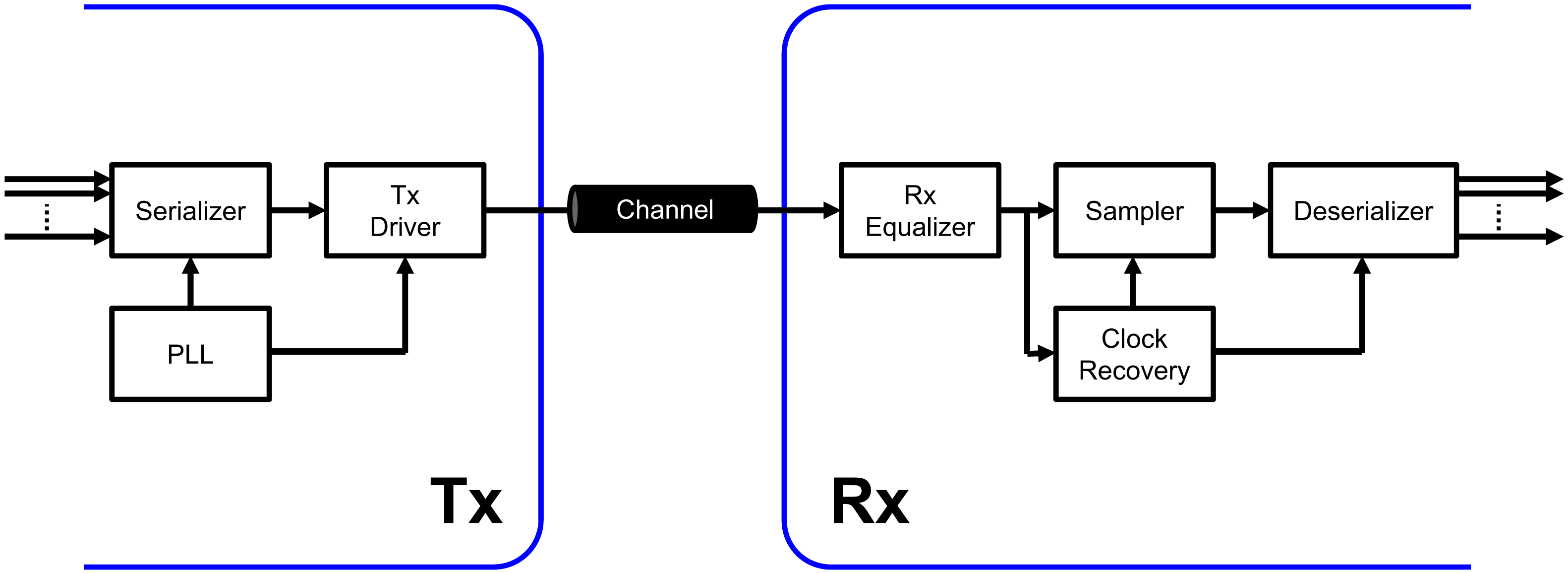
- Modulation Format? NRZ (Non-Return-to-Zero)



- More advanced formats are being considered for more demanding applications



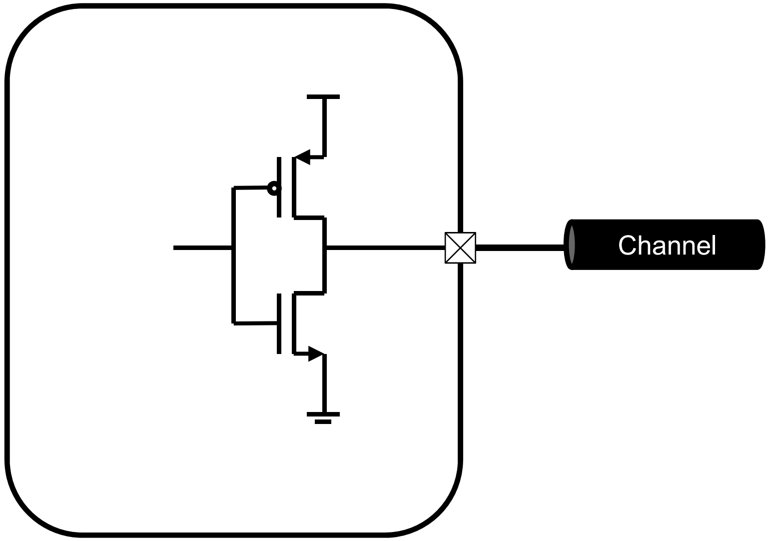
PAM4 (Pulse Amplitude Modulation 4)



- NRZ Tx driver structure:

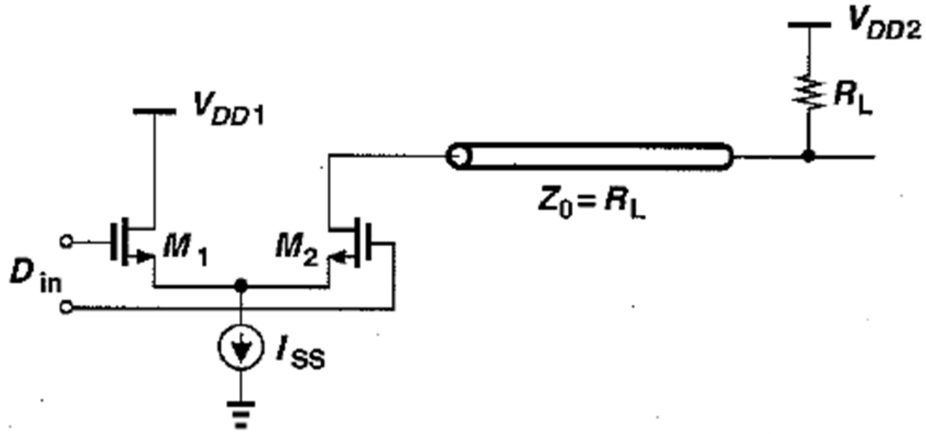
  Single or differential signaling, current or voltage mode, termination

Simplest Tx Driver



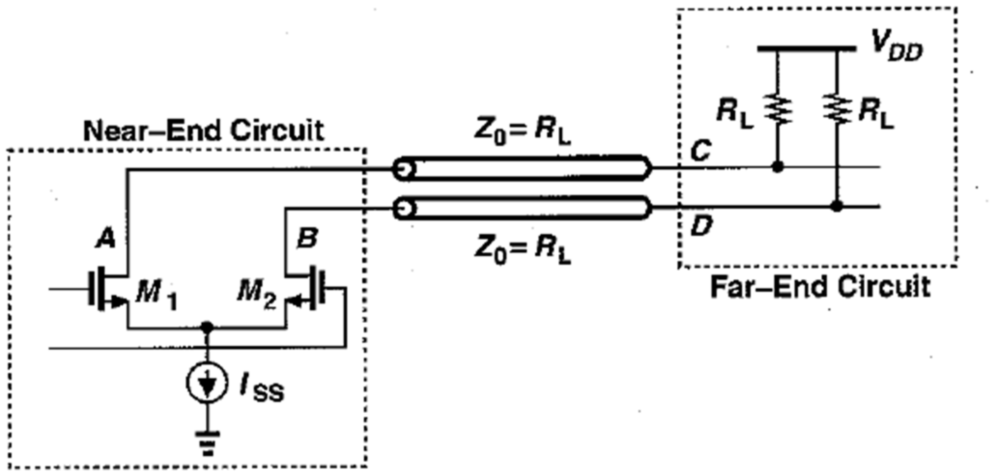
- CMOS inverter
- Voltage mode
- No static power consumption
- Operation speed is limited by full-swing (rail-to-rail)
- Impedance matching is difficult

Open-Drain Tx Driver



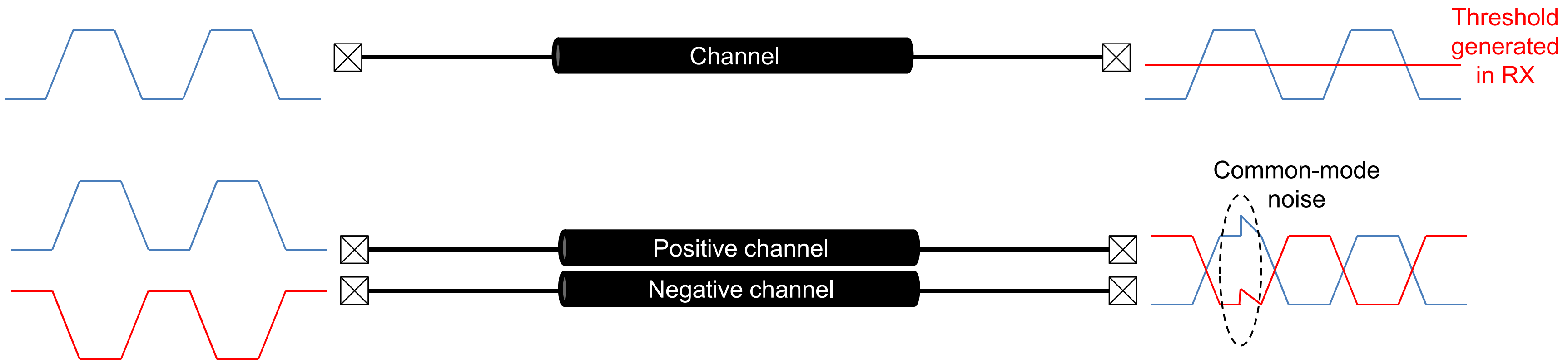
- Current mode
- Output voltage swing: $I_{ss}R_L$
- Can be fast but static power consumption
- $R_L = Z_o$ for Rx impedance matching
- Noise immunity?

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

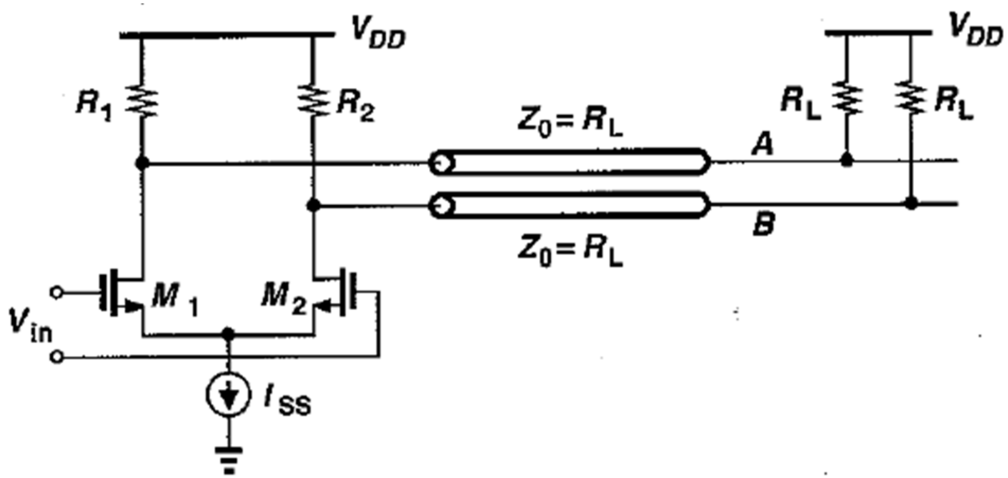


- Larger output voltage swing for differential signaling
- Common-mode noise rejection with differential signaling
- Self-referencing for receiver threshold for differential signaling
    - Supply and ground levels can be different for TX and RX

➔ 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

$V_{d,1} = (I_{SS}/2)\ R_L$

$V_{d,0} = -\ (I_{SS}/2)\ R_L$

$V_{d,pp} = I_{SS}\ R_L$

➔ Most popular for high-speed serial interface applications

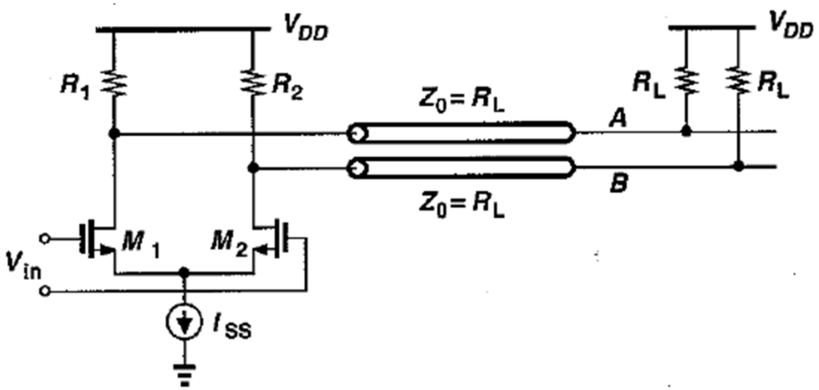
50-Ω termination

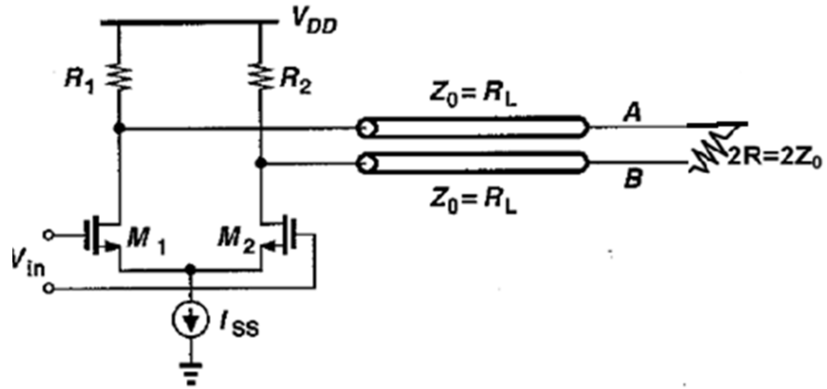
- Why 50Ω for transmission lines?
  – Historical reason

    - 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:

$$V_{d,1} = (I_{SS}/2)\, R_L$$

$$V_{d,0} = -\,(I_{SS}/2)\, R_L$$

$$V_{d,pp} = I_{SS}\, R_L$$

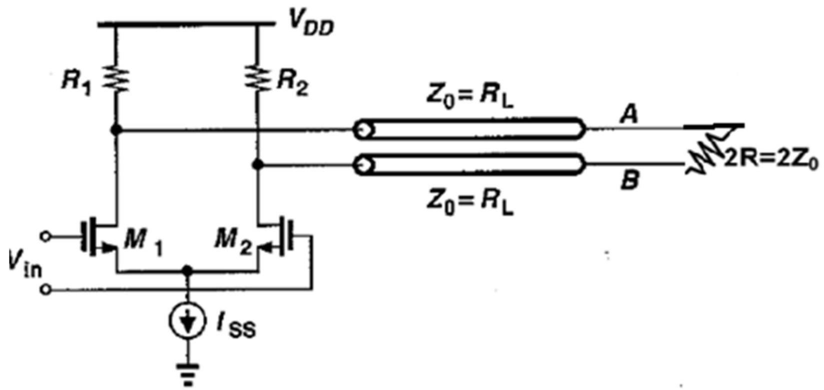
- Output voltage swing:

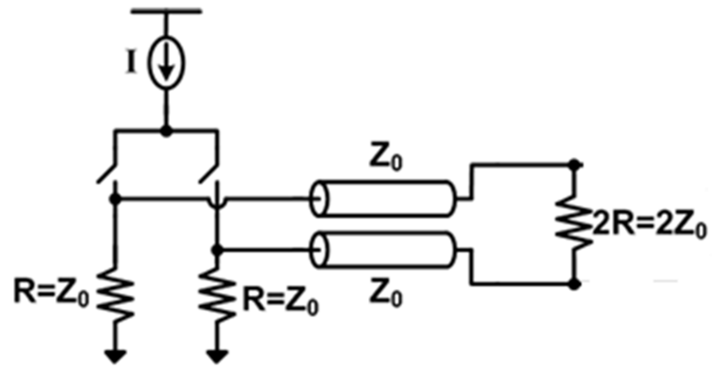
$$V_{d,1} = (I_{SS}/4)\, 2R_L$$

$$V_{d,0} = -\,(I_{SS}/4)\, 2R_L$$

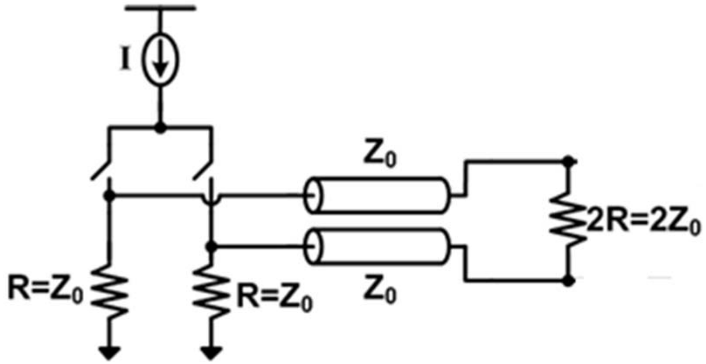
$$V_{d,pp} = I_{SS}\, R_L$$

CML with Differential Rx Termination



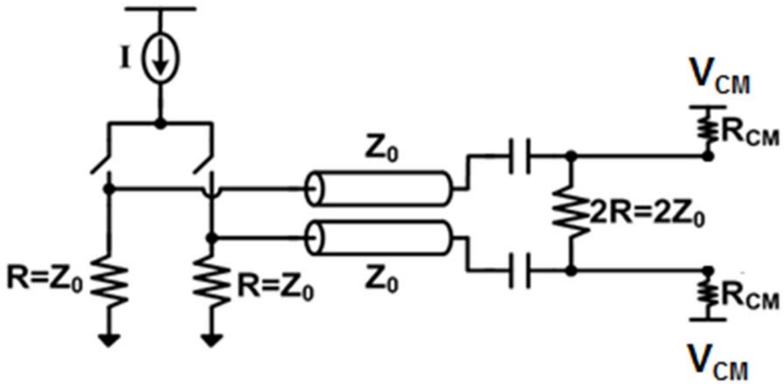


DC/AC Coupling



- Rx common-mode voltage? IR/2

➔ Cannot be independently controlled

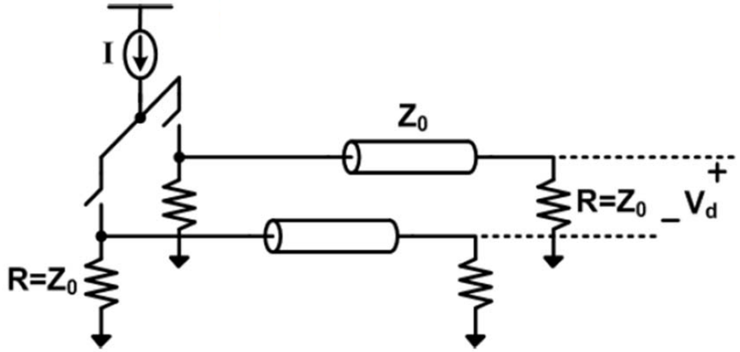


- Rx common-mode? V_{CM}
- Low frequency cut-off
- Data must be coded

- 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)

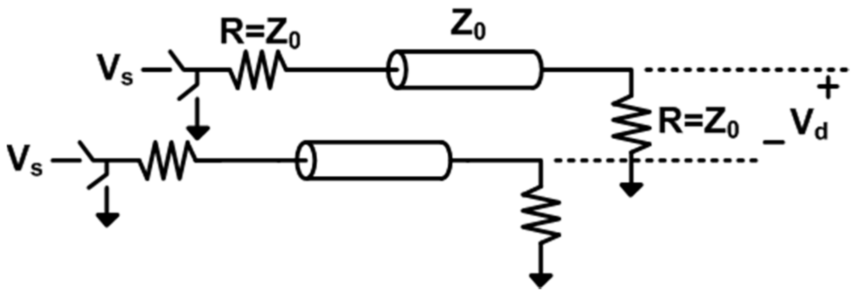
➔ Several standards use 8B/10B coding but there is overhead for data rate

Voltage-mode Tx Driver



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

Current source + **Parallel** Tx termination

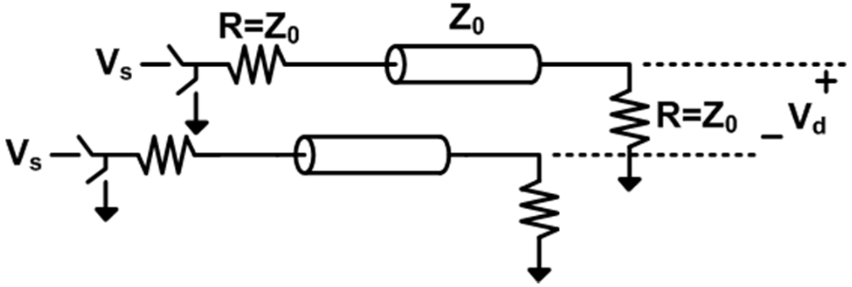


$$V_{d,1} = (V_s/2)$$
$$V_{d,0} = -(V_s/2)$$
$$V_{d,pp} = V_s$$
$$I = (V_s/2R)$$
$$\boldsymbol{I = \frac{V_{d,pp}}{2R}}$$

Voltage source + **Serial** Tx termination ➔ Voltage mode driver

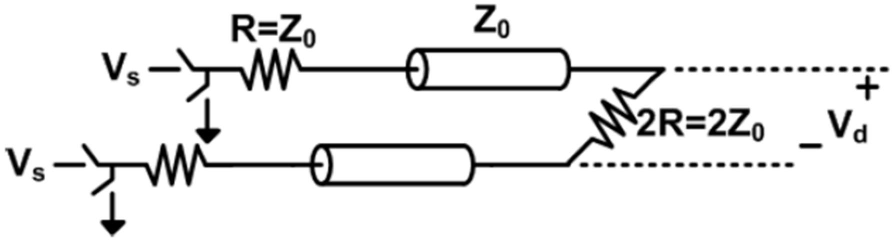
Factor of 2 Tx power reduction

Differential Rx Termination



$$V_{d,1} = (V_s/2)$$
$$V_{d,0} = -(V_s/2)$$
$$V_{d,pp} = V_s$$
$$I = (V_s/2R)$$
$$\boldsymbol{I = \frac{V_{d,pp}}{2R}}$$

Single-ended Rx termination

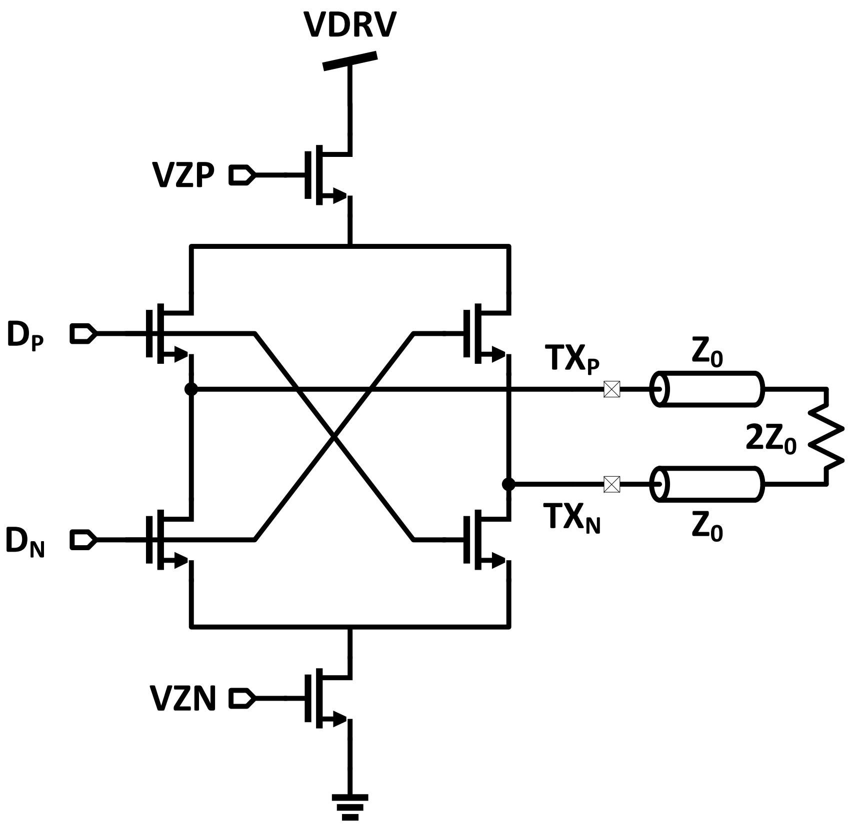


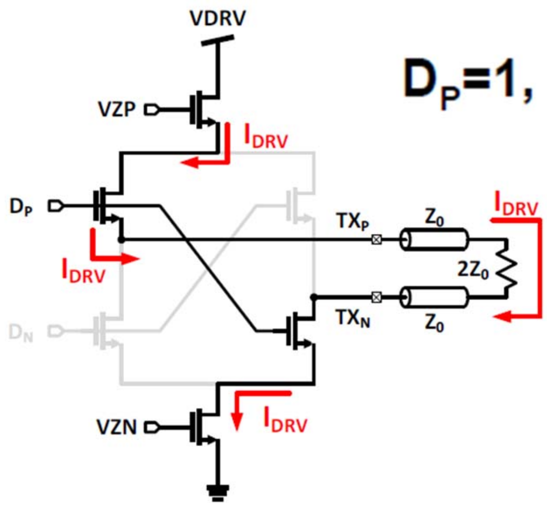
$$V_{d,1} = (V_s/2)$$
$$V_{d,0} = -(V_s/2)$$
$$V_{d,pp} = V_s$$
$$I = (V_s/4R)$$
$$\boldsymbol{I = \frac{V_{d,pp}}{4R}}$$

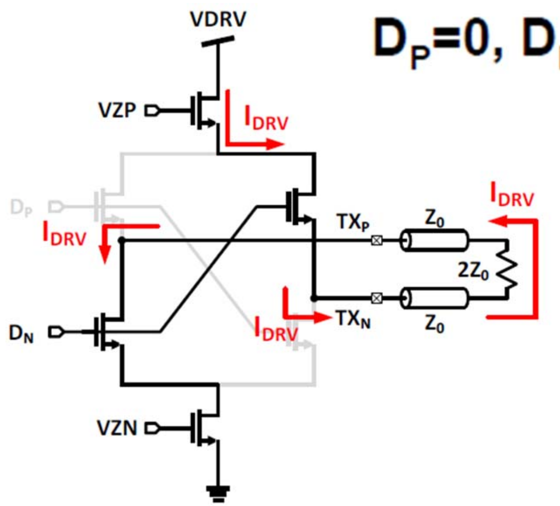
Differential Rx termination

Further power reduction of factor 2

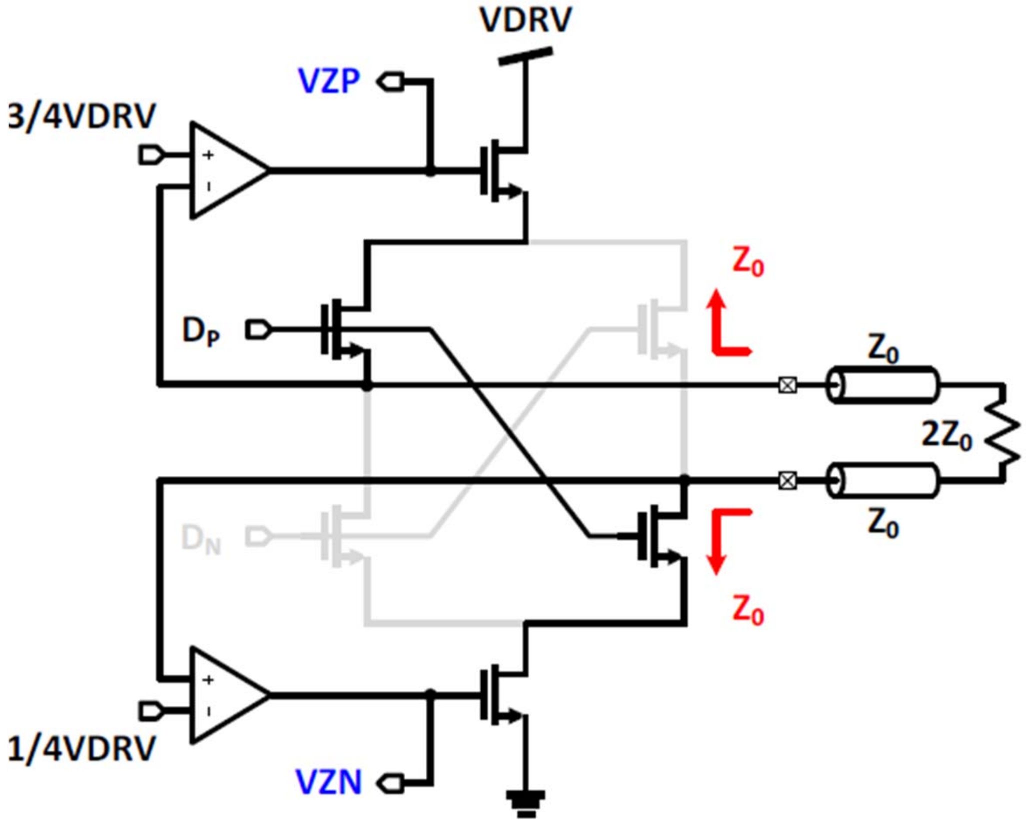
Voltage Mode Driver Implementation







Tx Termination



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