ECEN689: Special Topics in High-Speed Links Circuits and Systems
Spring 2010

Lecture 11: Transmitter Circuits

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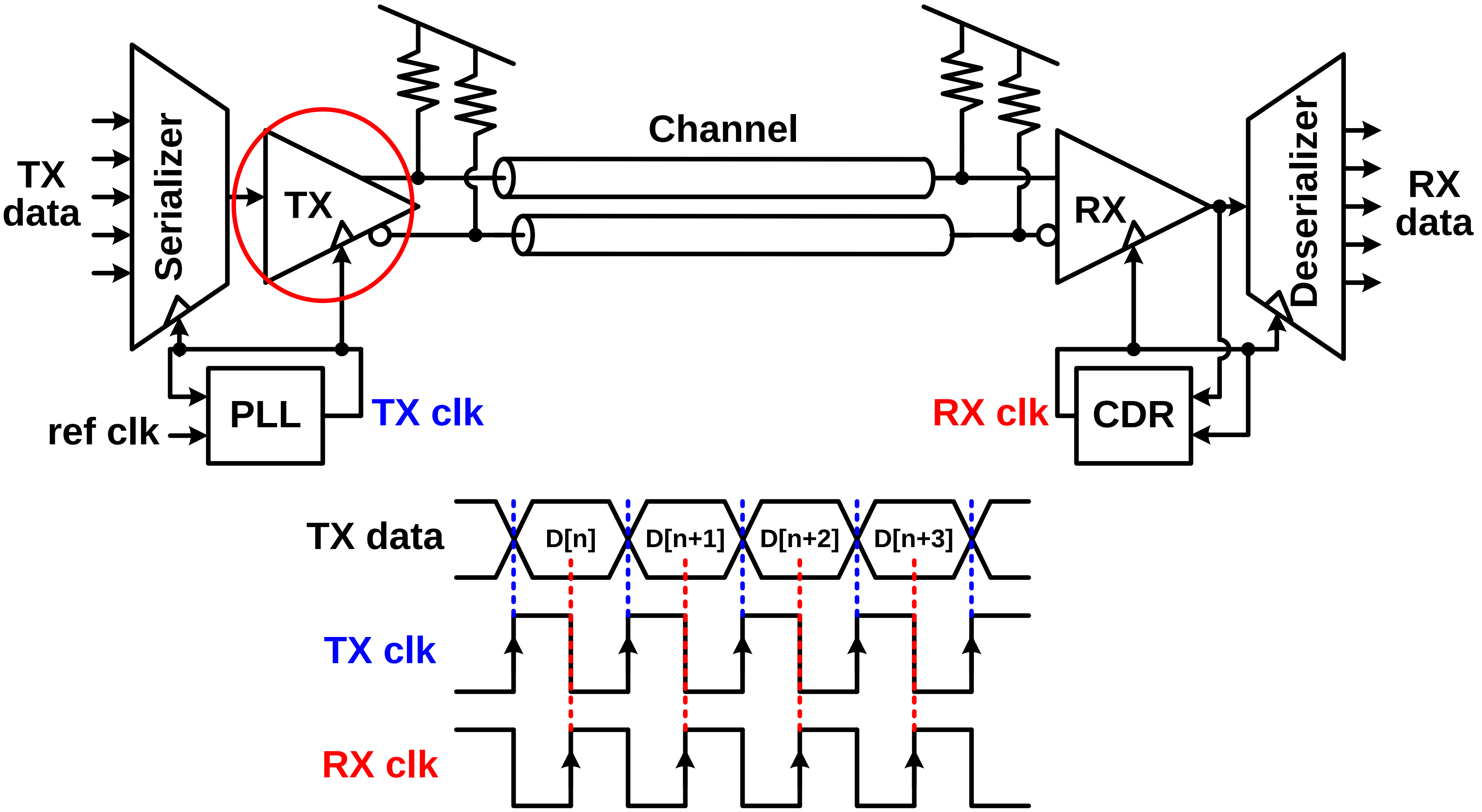
Announcements

- Exam 1 is tentatively scheduled for March 12
- Homework 3 will be posted tomorrow
- Reading
  - Dally 11.1-11.3

Agenda

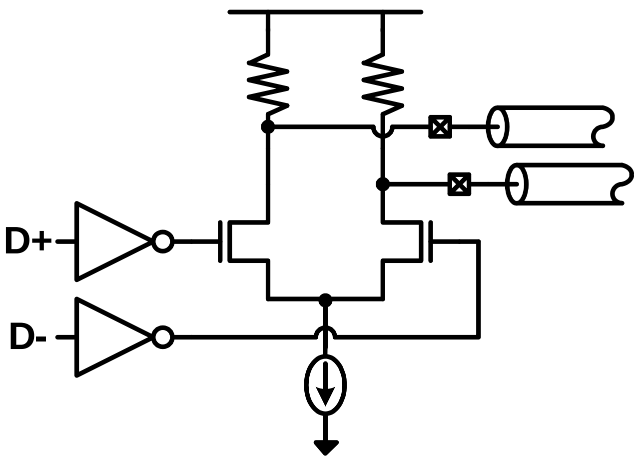
- Transmitter circuits
  - Current-mode drivers
  - Voltage-mode drivers
  - Slew rate control

High-Speed Electrical Link System

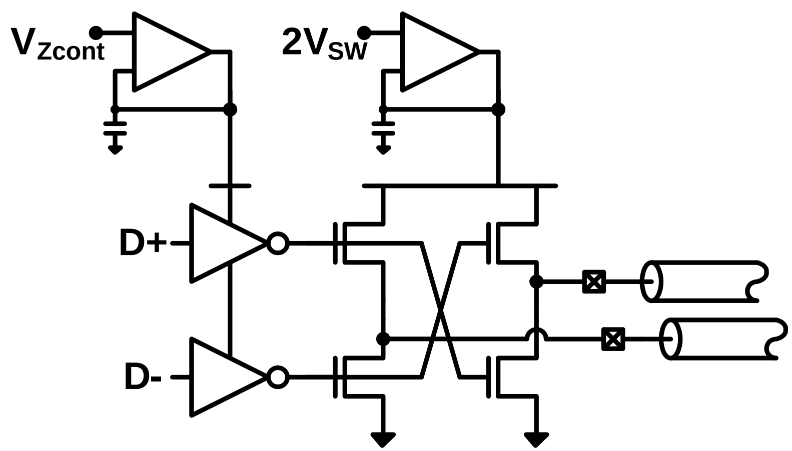


Current vs Voltage-Mode Driver

- Signal integrity considerations (min. reflections) requires 50Ω driver output impedance
- To produce an output drive voltage
  - Current-mode drivers use Norton-equivalent parallel termination
    - Easier to control output impedance
  - Voltage-mode drivers use Thevenin-equivalent series termination
    - Potentially ½ to ¼ the current for a given output swing

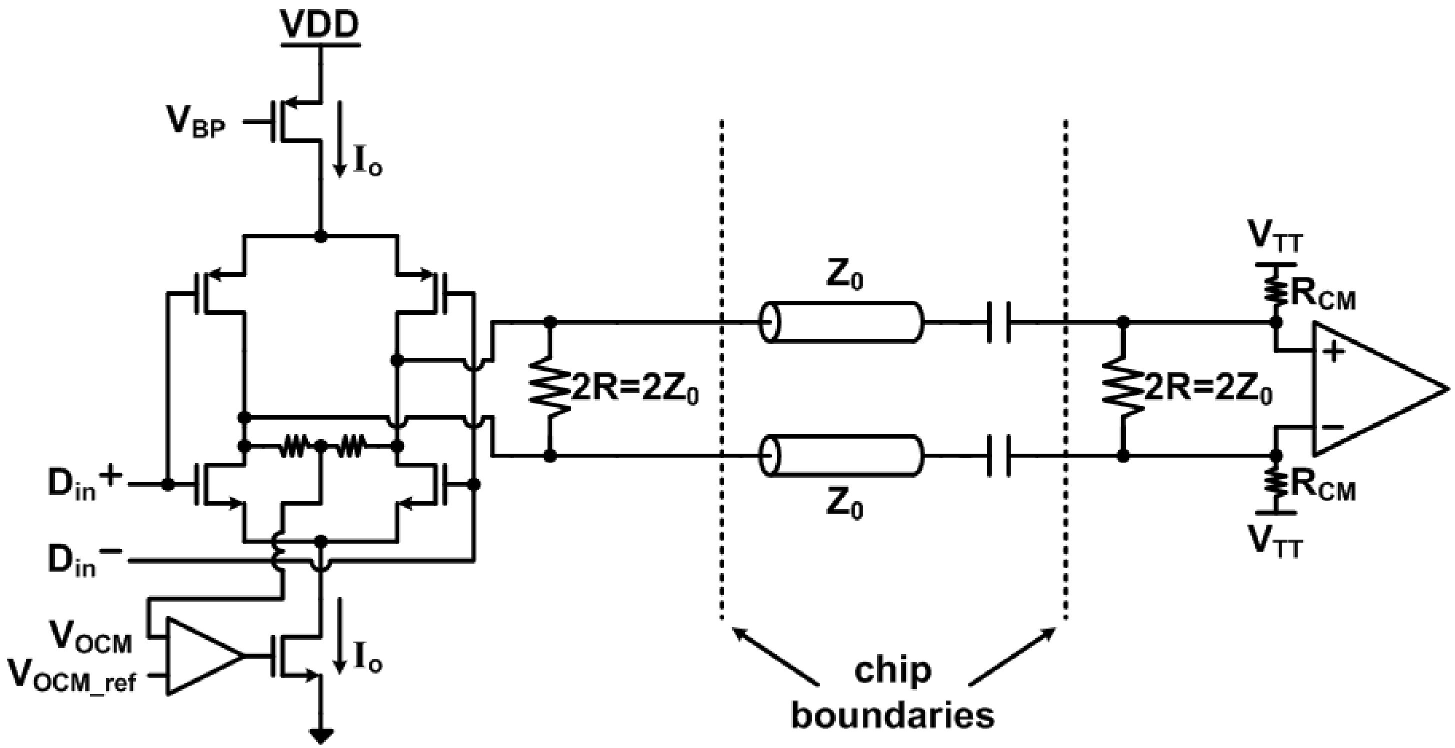


Current-Mode



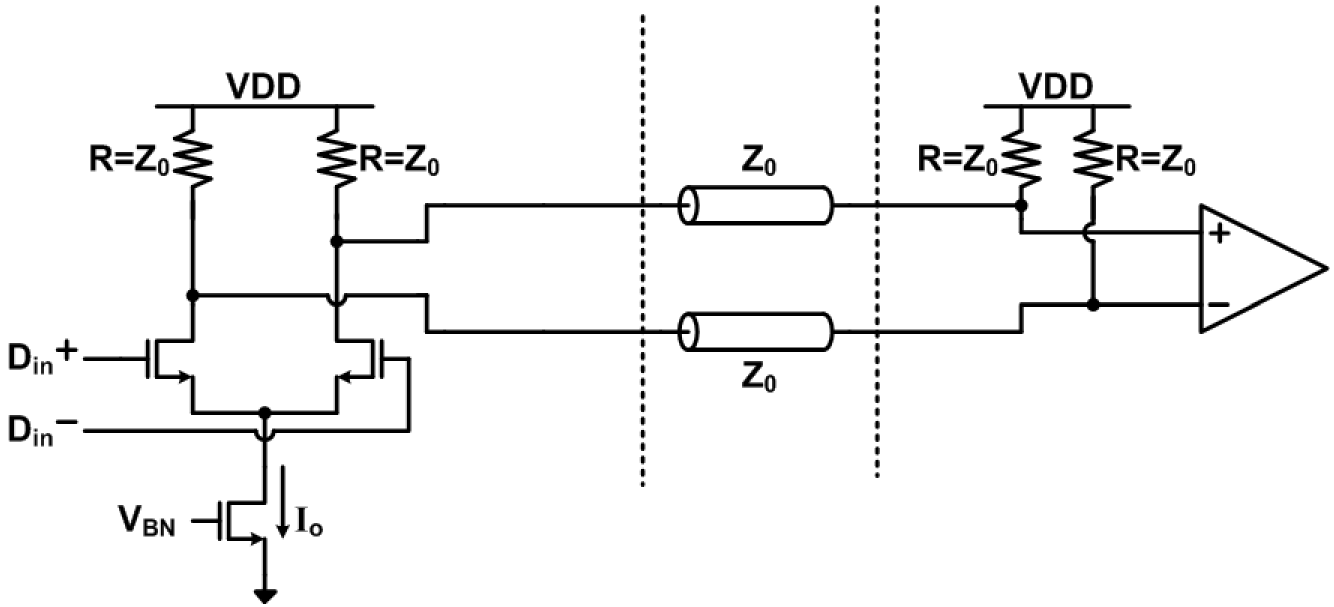
Voltage-Mode

Push-Pull Current-Mode Driver



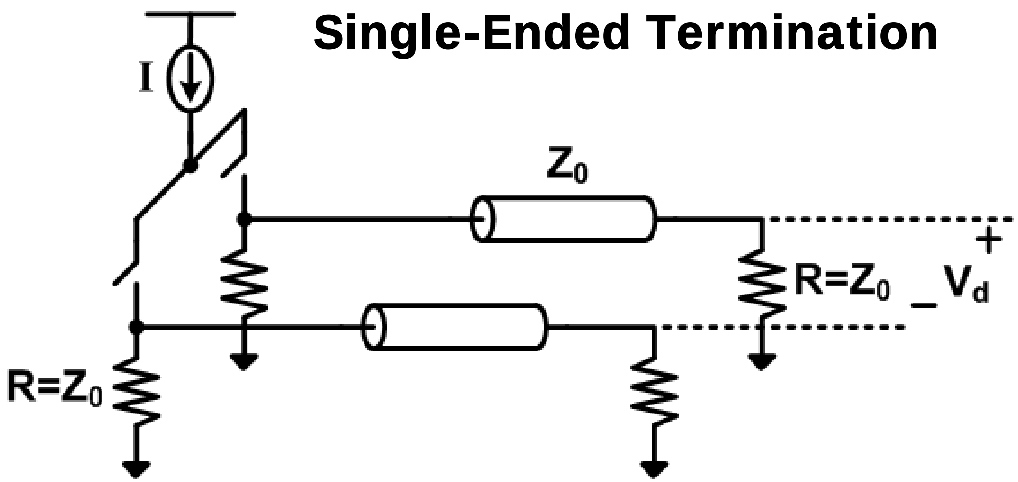
- Used in Low-Voltage Differential Signals (LVDS) standard
- Driver current is ideally constant, resulting in low dI/dt noise
- Dual current sources allow for good PSRR, but headroom can be a problem in low-voltage technologies
- Differential RX swing is $\pm I_o R$ with double termination

Current-Mode Logic (CML) Driver

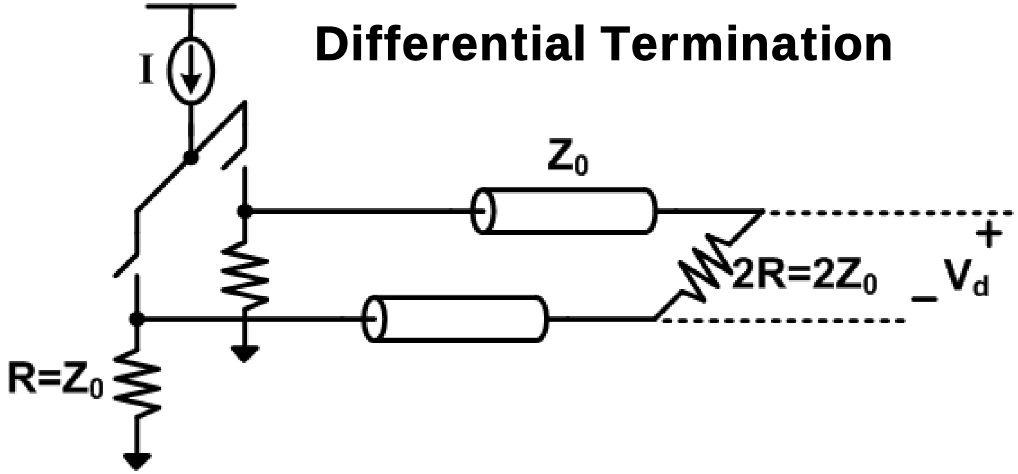


- Used in most high performance serial links
- Low voltage operation relative to push-pull driver
  - High output common-mode keeps current source saturated
- Can use DC or AC coupling
  - AC coupling requires data coding
- Differential RX swing is $\pm I_o R/2$ with double termination

Current-Mode Current Levels



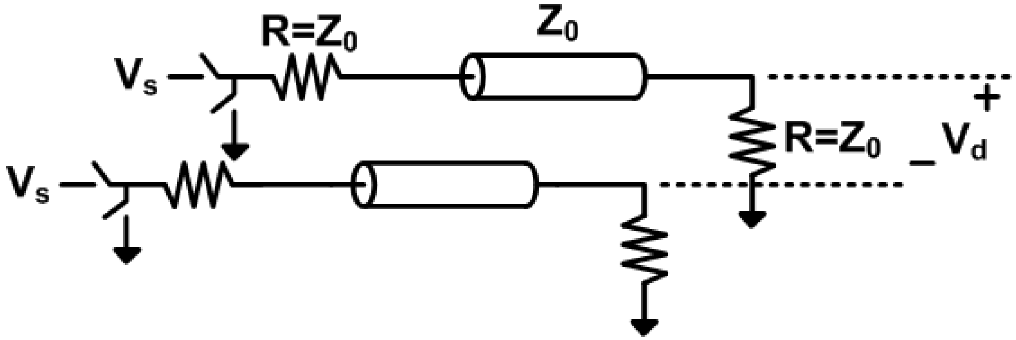
$$V_{d,1} = (I/2)R$$
$$V_{d,0} = -(I/2)R$$
$$V_{d,pp} = IR$$
$$\boldsymbol{I = \frac{V_{d,pp}}{R}}$$



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

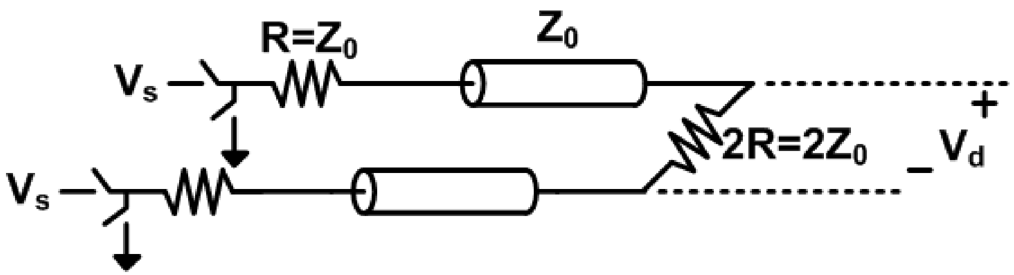
Voltage-Mode Current Levels

Single-Ended Termination



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

Differential Termination



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

Current-Mode vs Voltage-Mode Summary

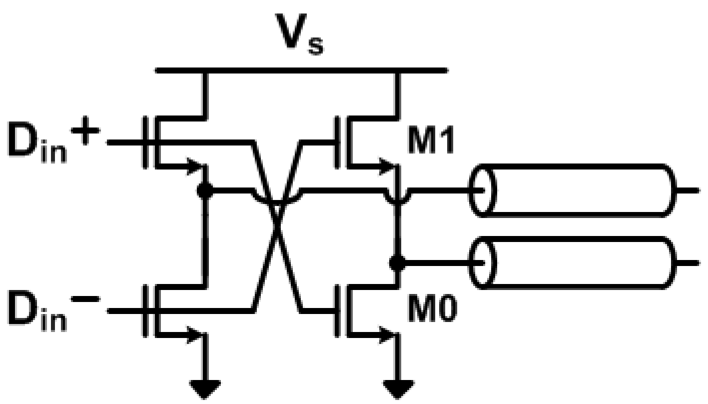
Driver/Termination	Current Level	Normalized Current Level
Current-Mode/SE	$V_{d,pp}/Z_0$	1x
Current-Mode/Diff	$V_{d,pp}/Z_0$	1x
Voltage-Mode/SE	$V_{d,pp}/2Z_0$	0.5x
Voltage-Mode/Diff	$V_{d,pp}/4Z_0$	0.25x

- An ideal voltage-mode driver with differential RX termination enables a *potential* 4x reduction in driver power
- *Actual* driver power levels also depend on
  - Output impedance control
  - Pre-driver power
  - Equalization implementation

Voltage-Mode Drivers

- Voltage-mode driver implementation depends on output swing requirements
- For low-swing (<400-500mVpp), an all NMOS driver is suitable
- For high-swing, CMOS driver is used

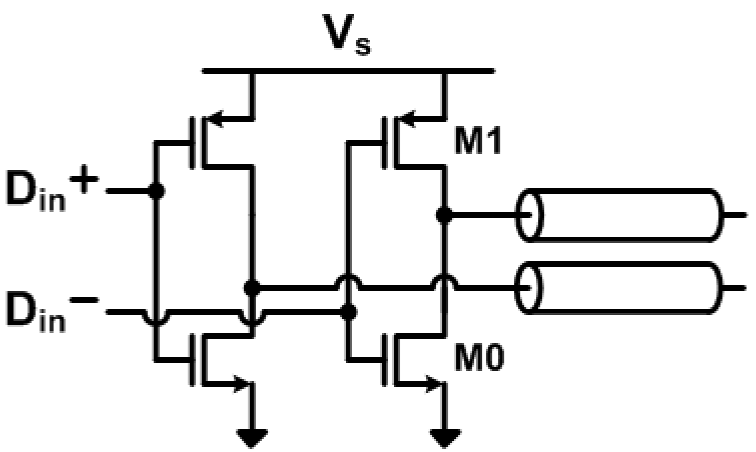
Low-Swing Voltage-Mode Driver



$$V_s < \frac{4}{3}\left(VDD - V_{t1} - V_{OD1}\right) \text{ (Diff. Term)}$$

$$V_s < 2\left(VDD - V_{t1} - V_{OD1}\right) \text{ (SE Term)}$$

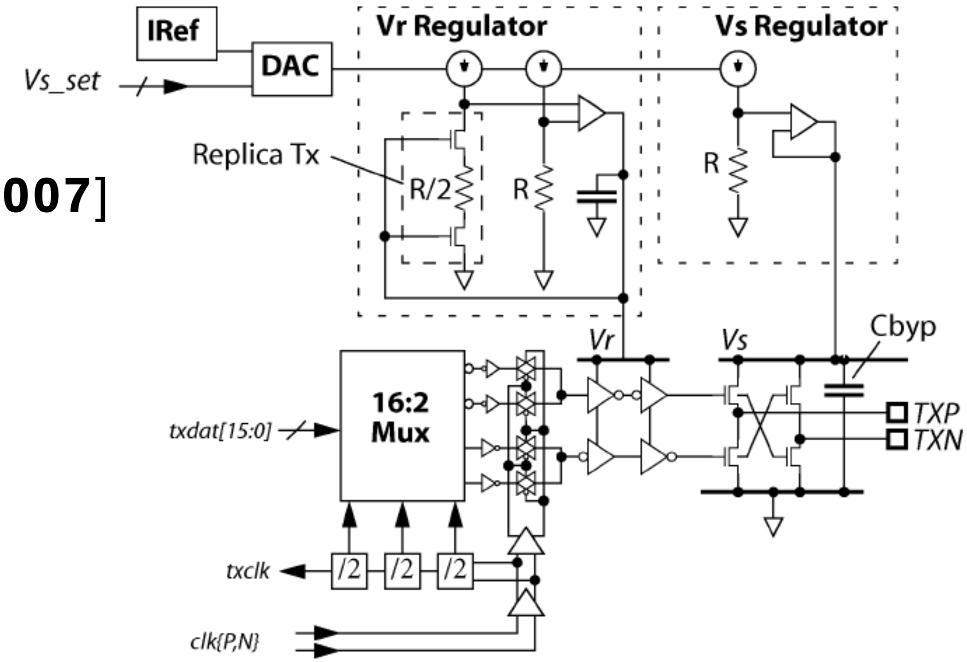
High-Swing Voltage-Mode Driver



$$V_s > \left|V_{t1}\right| + V_{OD1}$$

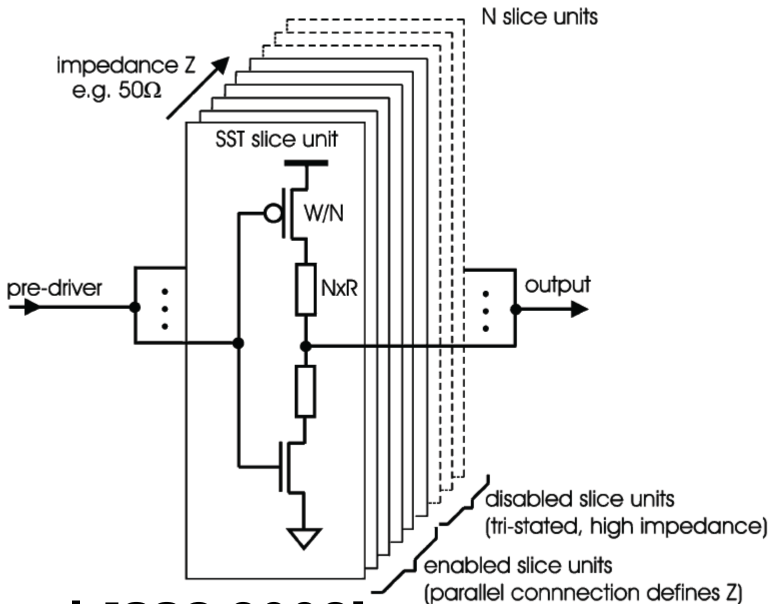
Low-Swing VM Driver Impedance Control

[**Poulton JSSC 2007**]



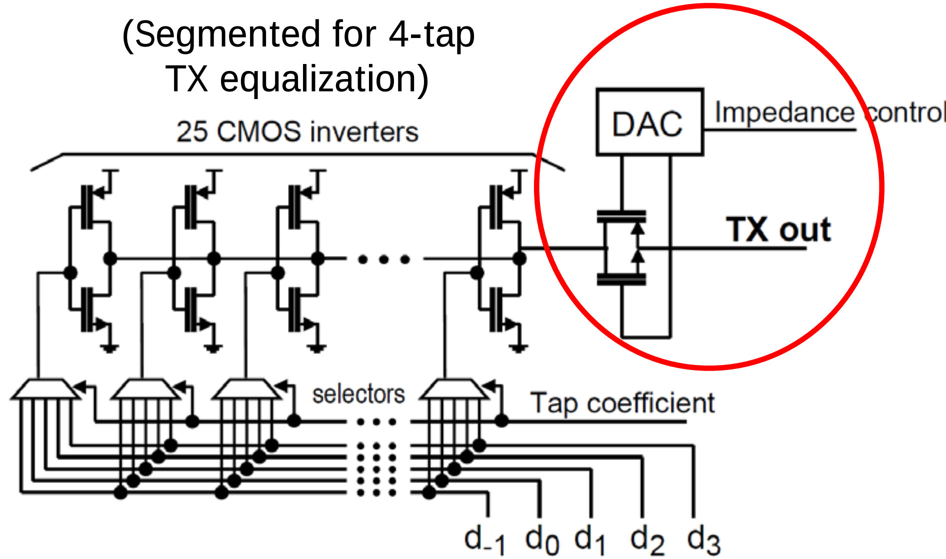
- A linear regulator sets the output stage supply, V_s
- Termination is implemented by output NMOS transistors
- To compensate for PVT and varying output swing levels, the pre-drive supply is adjusted with a feedback loop
- The top and bottom output stage transistors need to be sized differently, as they see a different V_{OD}

High-Swing VM Driver Impedance Control



[**Kossel JSSC 2008**]

(Segmented for 4-tap TX equalization)



[**Fukada ISSCC 2008**]

- High-swing voltage-mode driver termination is implemented with a combination of output driver transistors and series resistors
- To meet termination resistance levels (50Ω), large output transistors are required
  - Degrades potential power savings vs current-mode driver

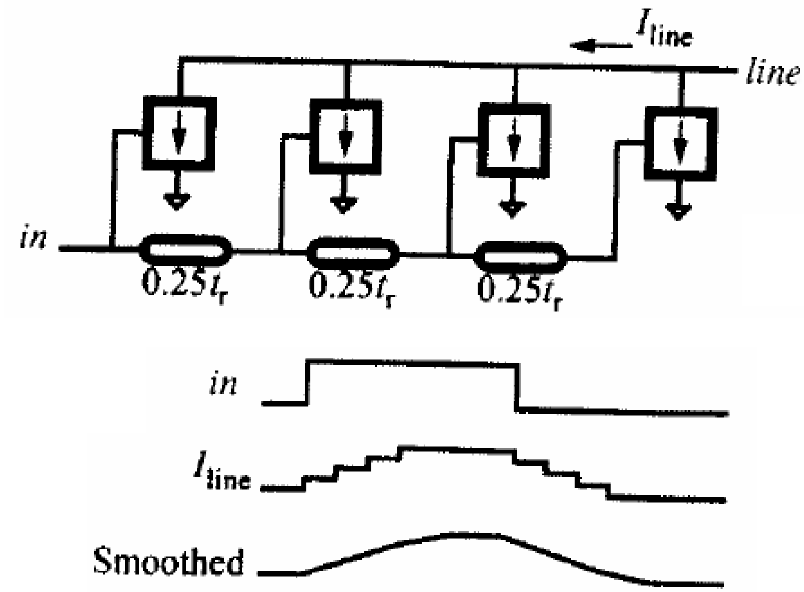
TX Driver Slew Rate Control

- Output transition times should be controlled
  - Too slow
    - Limits max data rate
  - Too fast
    - Can excite resonant circuits, resulting in ISI due to ringing
    - Cause excessive crosstalk

- Slew rate control reduces reflections and crosstalk

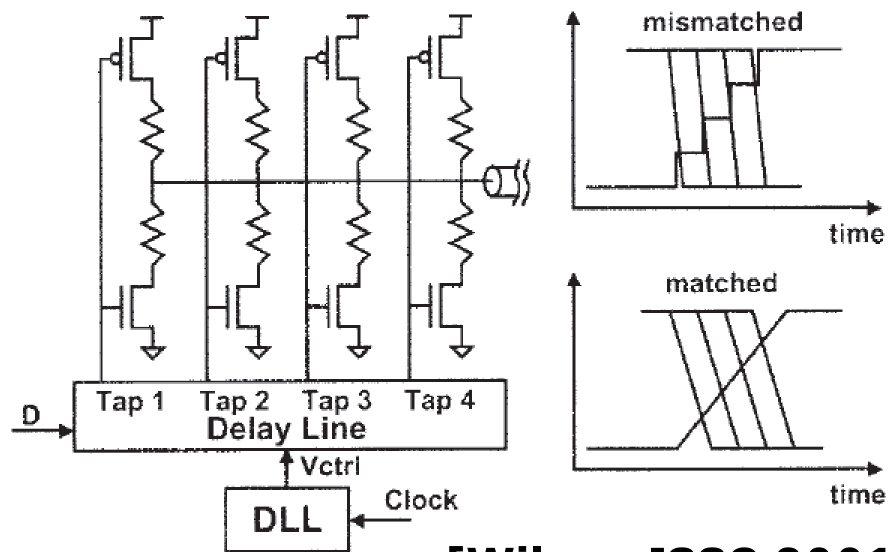
Slew Rate Control w/ Segmented Driver

Current-Mode Driver



[Dally]

Voltage-Mode Driver



[Wilson JSSC 2001]

- Slew rate control can be implemented with a segmented output driver
- Segments turn-on time are spaced by 1/n of desired transition time
- Predriver transition time should also be controlled

Next Time

- TX circuit speed limitations
  - Clock distribution
  - Multiplexing circuits
- Receiver Circuits