

Outline

Circuits

- Goals
- Drivers
- Receivers
- On-chip parallel termination
- ESD protection
- On-chip interconnect circuits

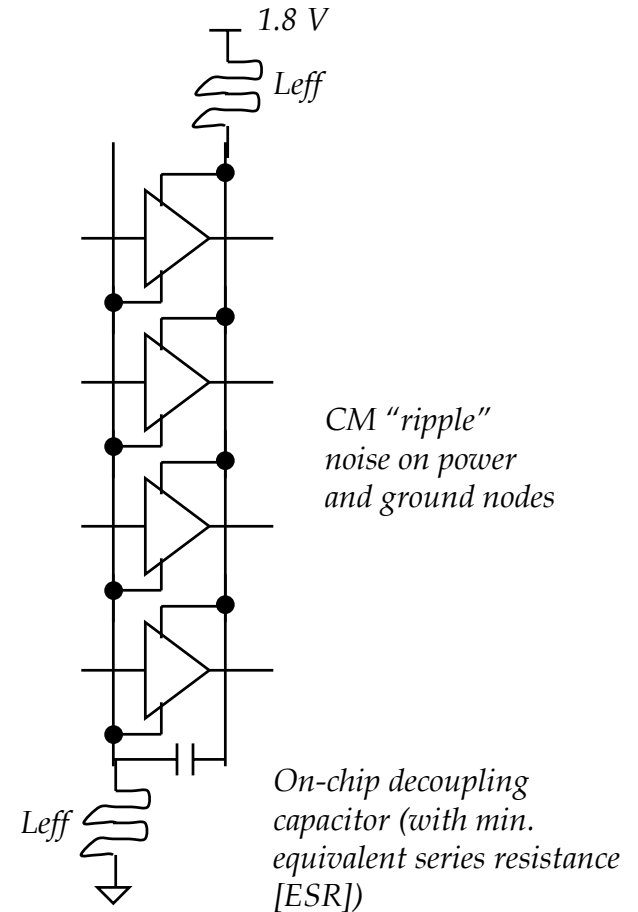
References

- D& P, Ch. 11, 7, 8

Goals of Interconnect Circuits

- Achieve good BER under realistic noise conditions, with realistic clocks
- Low power consumption
- Control common mode noise
 - Especially di/dt noise (simultaneous switching noise [SSN])
 - ◆ Impacts bit errors in other circuits, as well as this circuit
- Protect chip against electrostatic discharge through pin

E.g. 4-pin TX circuit:



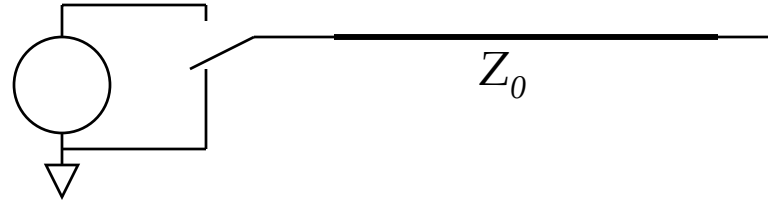
Drivers

Outline:

- Voltage mode drivers
 - ◆ Drive and pre-drive
 - ◆ Tri-state
 - ◆ Rise time control
 - ◆ Self-termination
 - ◆ Differential
- Current mode drivers
- Transmitter pre-emphasis

Voltage Mode Drivers

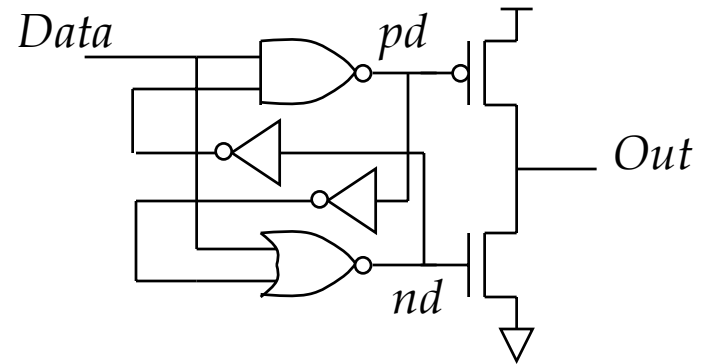
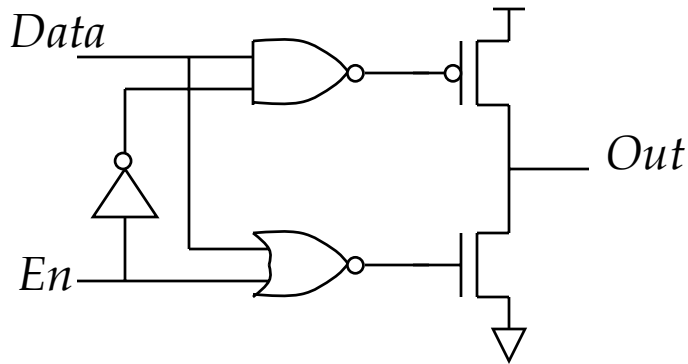
Basic Objectives:



- For $V_{\text{swing}} > 0.9 V_{\text{dd}}$, $R_{\text{out}} < 0.1 Z_0$
 - ◆ → Large drive transistors
 - ◆ → Pre-drive circuit needed
 - Remember ratio'd driver (see CMOS notes)
- Must avoid nFET and pFET being on at same time
 - ◆ Otherwise large short circuit current during transition
 - Break before Make circuit
- Reasonable area
- Small di/dt
 - ◆ Rise time control

Basic Voltage Drivers

Techniques to prevent short-circuit current:

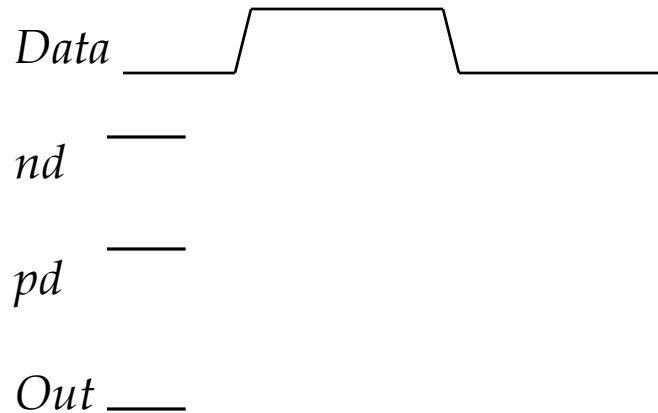


NAND : $t_r > t_f$

NOR : $t_f > t_r$

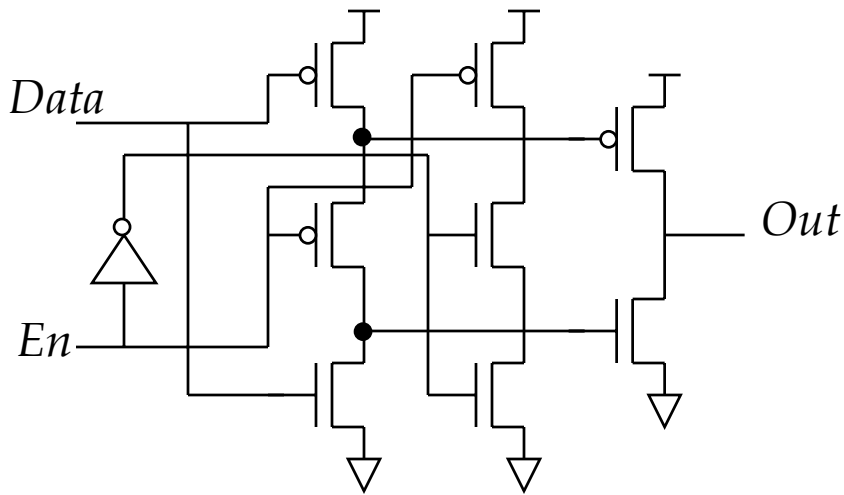
Use rise, fall times to prevent I_{sc}
(beware of process spread)

En	Data	Out
0	0	:
0	1	:
1	0	:
1	1	:



... Voltage Drivers

Reduce tri-state driver:

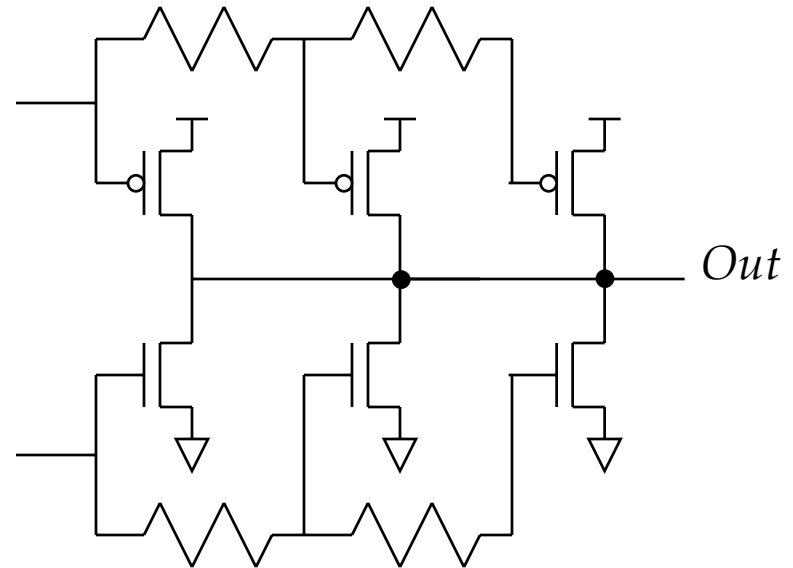


Same functionality as previous page, with fewer transistors and break-before-make

Rise Time Control

Goal : Reduce di/dt without significant reduction in delay

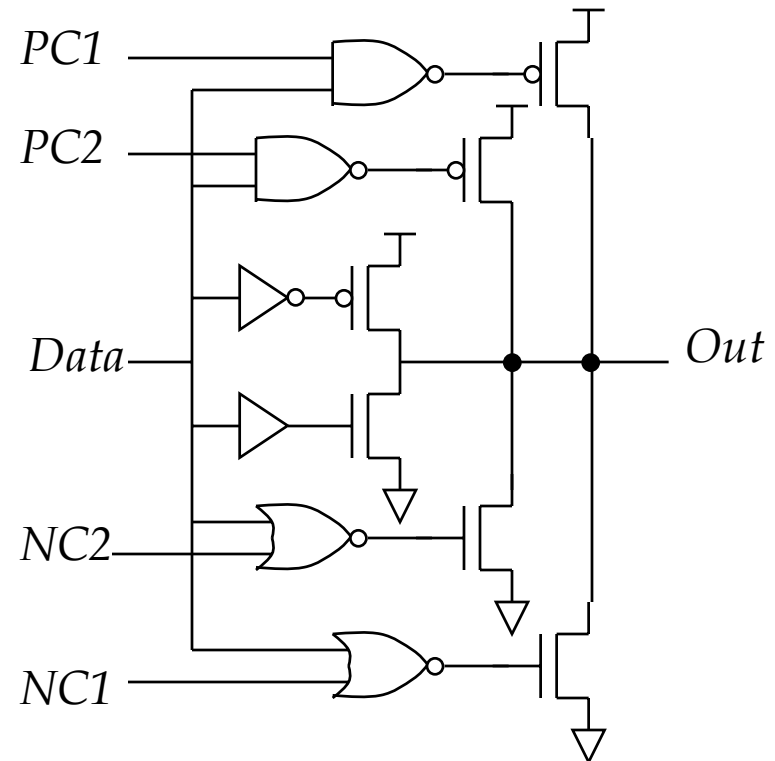
- Typically $t_r < 0.3 - 0.5 t_{bit}$
- Process, temperature variations → Active control might be desirable (e.g. Use nMOS as pFET and control “resistance”)
- First stage to switch usually the largest



Output Impedance Control

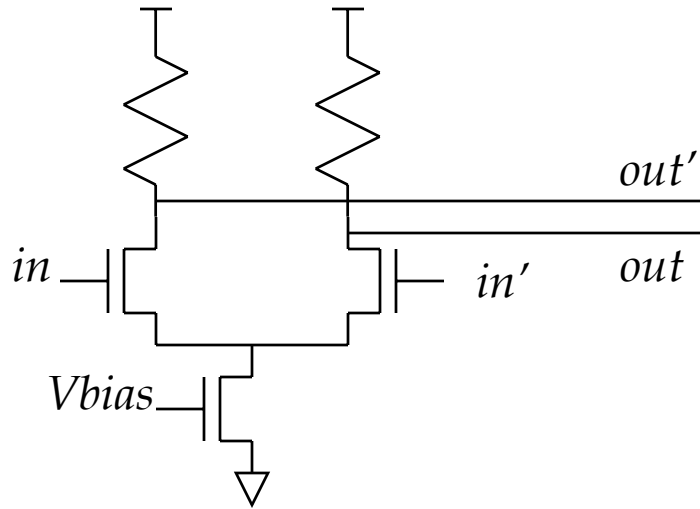
e.g. To precisely match line in series termination

- Digitally trimmed circuit
- NC1, NC2, PC1, PC2 produced by comparing copies of the drive FETs with an off-chip resistor (e.g. voltage division or a bridge)



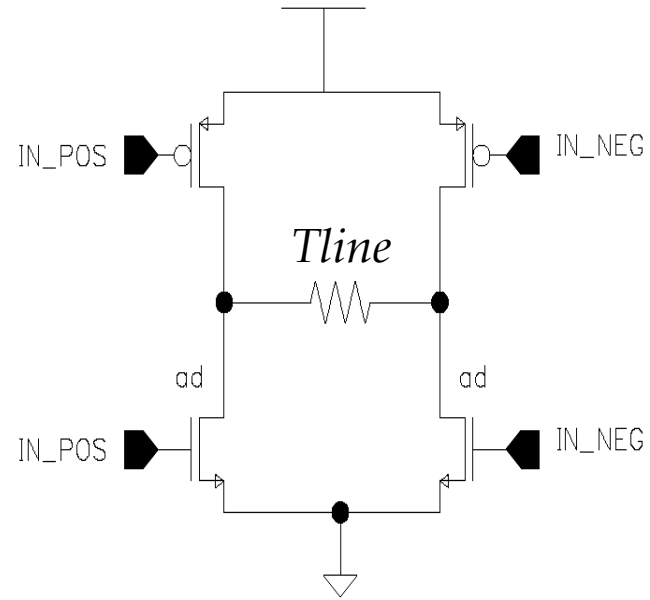
Differential

Small Swing:



(Size for a small but finite R_{out})

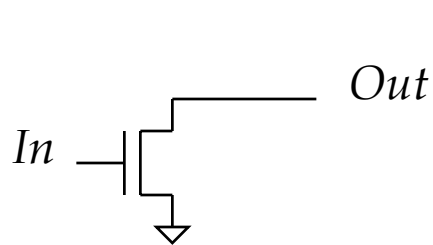
Large Swing:



Current Mode Drivers

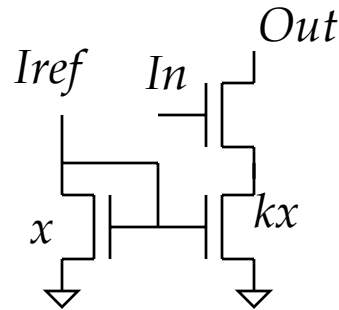
Single sided:

- Relies on saturated FET



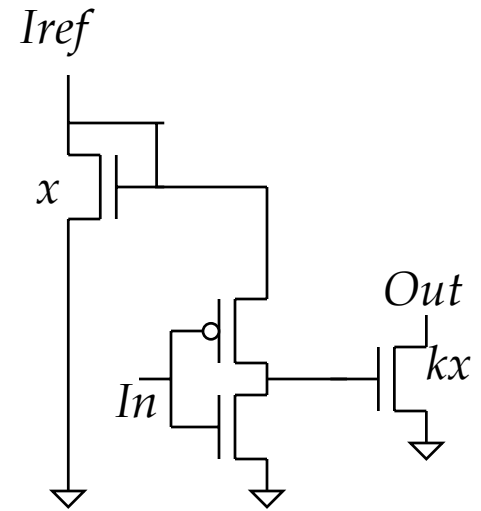
Requires:

- $V_{out} > V_{DD} - V_t$
- Digital trimming to provide I_{out} across process and temp spreads



Switched Current Mirror

- series devices must be large
- Small V_G on mirror to max V_{sw}



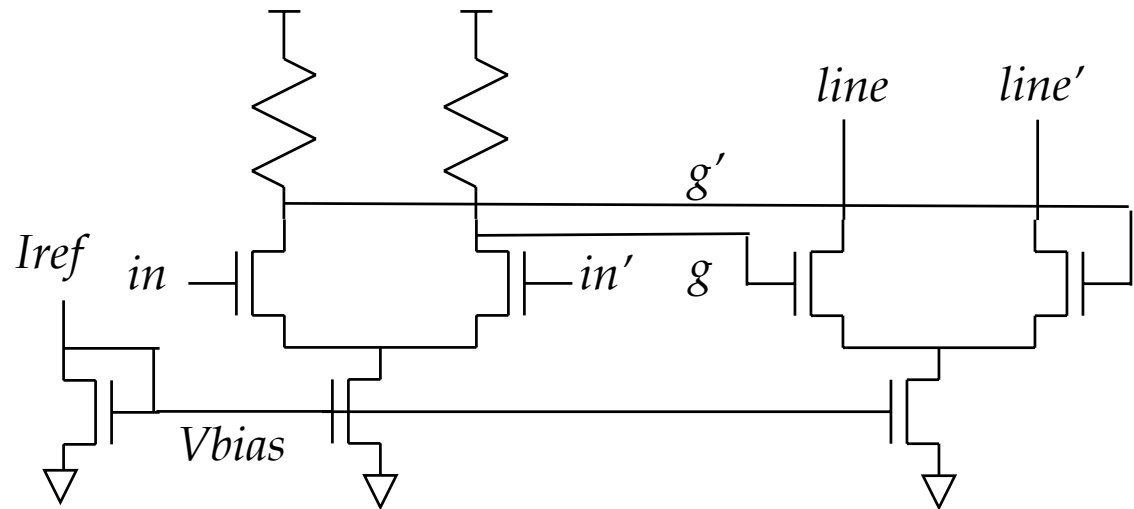
Gated Current Mirror

- Smaller devices
- Slower transient response

Differential Current Mode TX

Current Steering Circuits:

- Stage 1 : Converts large swing to small swing
 - ◆ Eliminates dead band at ends of swing in stage 2



Bipolar Current Mode TX

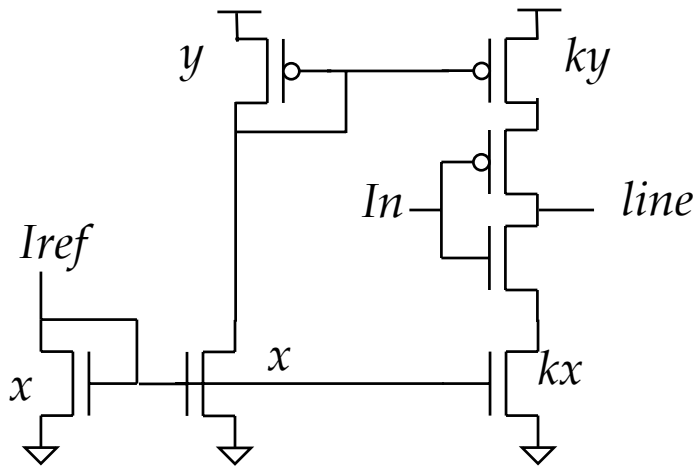
Above Unipolar

- Levels : 0 and x mA

Create bipolar with complementary pull-up of above

- Logic levels = $\pm x$ mA

Example:



Rise Time Control

Can be achieved as per Voltage Mode TX

- Segment drive transistors connected to In (or g) and stagger their turn-on as before

Pre-Emphasis

Simple digital z-domain high pass filter

- Must ensure proper voltage swing

E.g. 2-tap FIR

$$H(z) = a_0 + a_1 z^{-1}$$

$$r = -a_1 / a_0$$

$$H(z) = a_0(1 - rz^{-1})$$

$$H(\omega) = a_0(1 - re^{j\omega T})$$

$$|H(\omega)| = a_0(1 + r^2 - 2r\cos(\omega T))^{0.5}$$

$$|H(\omega=0)| = a_0(1 - r) = a_0 + a_1$$

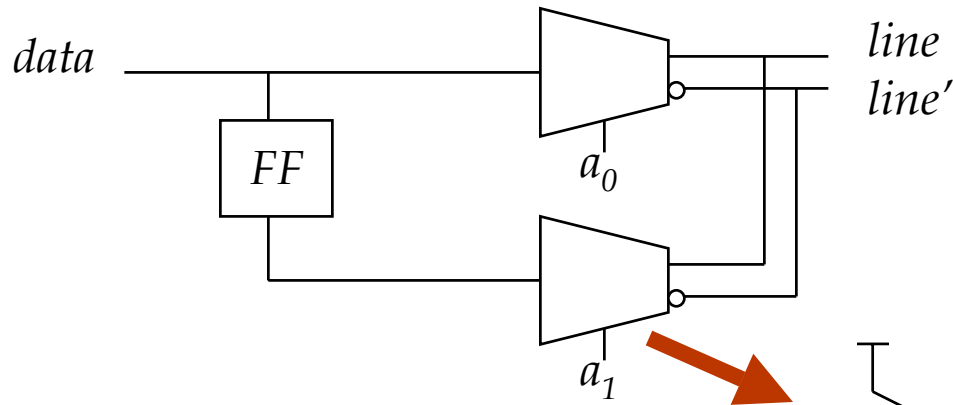
$$|H(\omega T = n\pi)| = a_0(1 + r) = a_0 - a_1$$

$$\text{Boost} = (a_0 - a_1) / (a_0 + a_1) = (1 + r) / (1 - r)$$

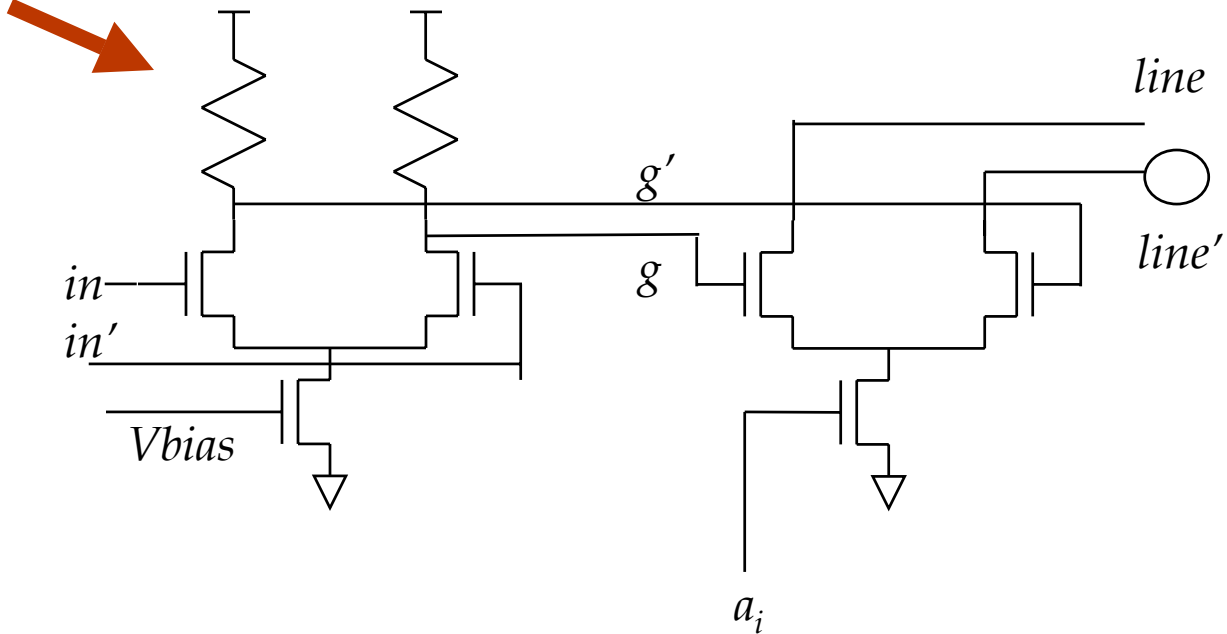
HPF if $a_0 > 0$, and $a_1 < 0$

Current-Mode Pre-Emphasis Circuit

2-tap filter



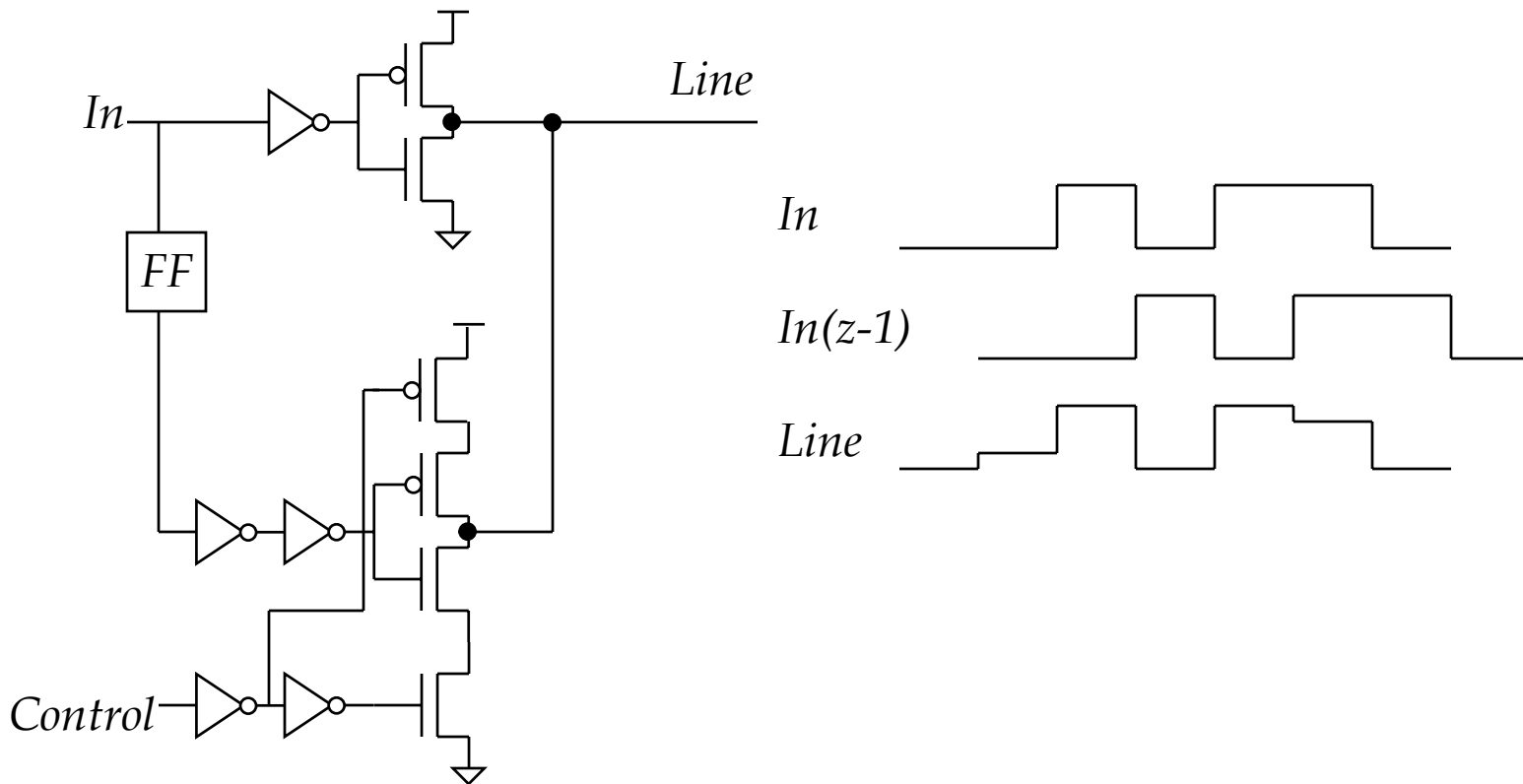
Requirement
 $|a_0| + |a_1| \rightarrow I_{sw_max}$



Voltage Mode Pre-emphasis

Tap weights effectively set by transistor sizes:

- a1 tap smaller transistors than a0 tap



Receivers

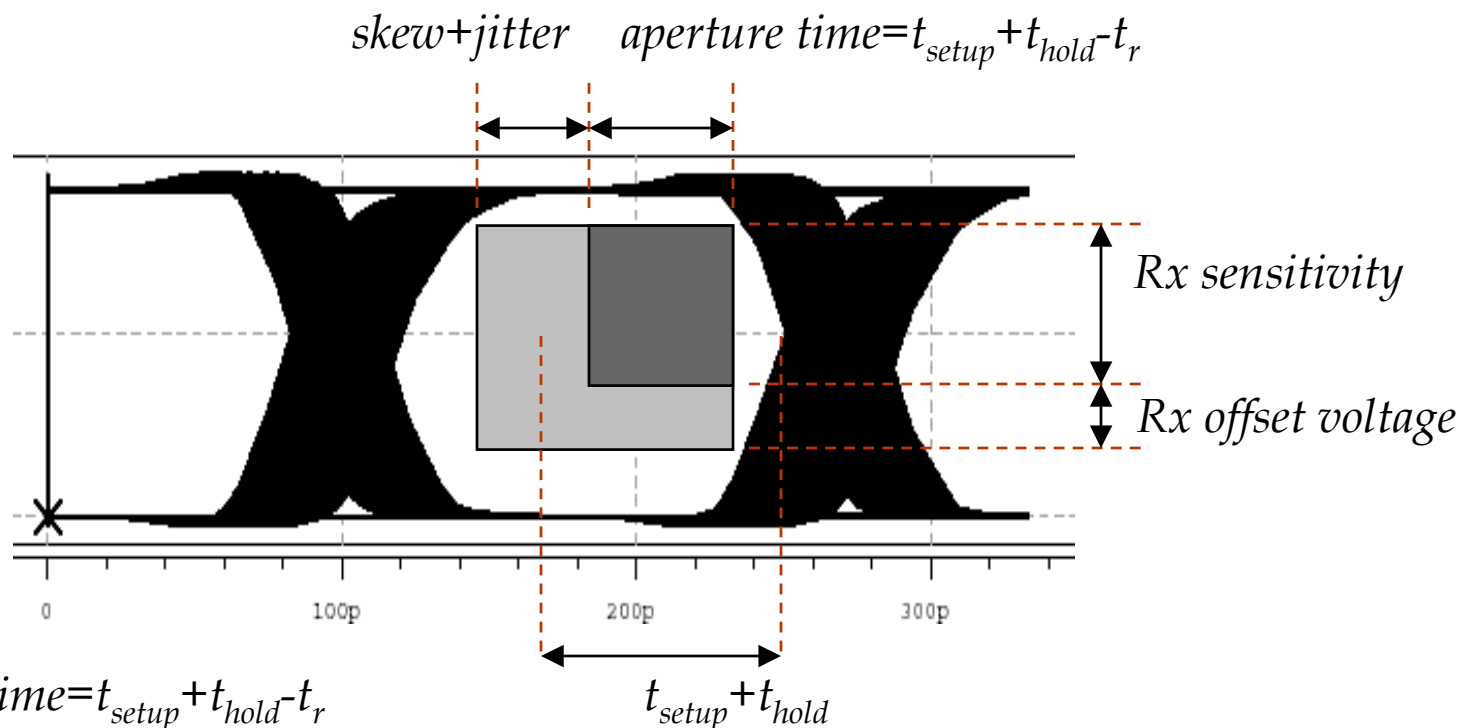
Receivers:

- Basics on detection and sampling
- Inverters
- Differential
- Clocked differential receivers
 - ◆ Integrating
 - ◆ Matched filter

Detection & Sampling

Eye requirements at input to RX:

- To meet requirements to sample and amplify signal in presence of noise, timing skew and jitter



Why? $aperture\ time = t_{setup} + t_{hold} - t_r$

As t_{setup} , t_{hold} measured to 50% points, aperture at top & bottom of eye (at 10%, 90% points)

Detection & Sampling

Alternatives

- Separate amplifier + sampler (I.e. Flip-flop)
- Clocked amplifier (integrated)

- **Advantages of clocked amplifier**
 - Lower power
 - Jitter contribution of amplifier “portion” reduced
 - More sensitivity
 - Sampling rate not constrained by gain-bandwidth product

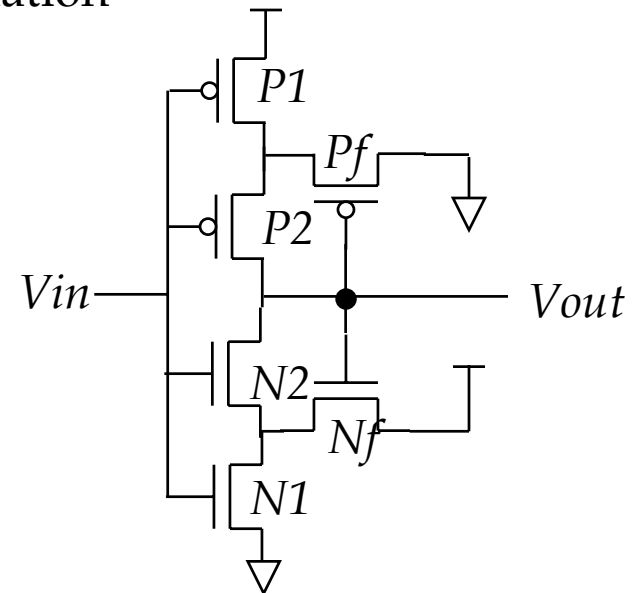
Static (separate) Amplifiers

Inverters

- Gain around $V_{inv} \approx 4 / ((V_{GS} - V_t)(\lambda_p + \lambda_n))$
- Gain ≈ 20 for “book” 0.35 μm process
- \rightarrow Sensitivity $\approx (V_{IH} - V_{IL}) / \text{Gain} = 2.5 / 20 = 125 \text{ mV}$
- Offset determined variation in V_{inv} with process, temp and V_{dd} variations
 - ◆ About 300 mV for process variation
 - ◆ About 500 mV including temp & V_{dd} variation
- Not best used for initial gain stage in RX
- Useful for final gain stage, however

Inverter Variation

- Schmidt Trigger
 - ◆ Hysterisis \rightarrow very wide NM

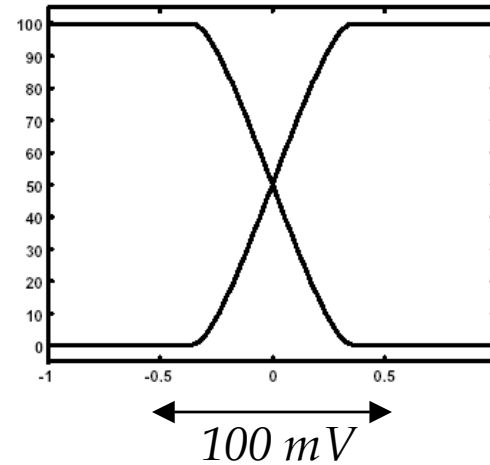


Static Differential Receivers

Advantages:

- More sensitive
 - ◆ Determined by g_m of source coupled pair and $R\Delta$ of load
 - ◆ 20 - 100 mV
- Less offset voltage
 - ◆ Determined by nFET, pFET mismatch
 - ◆ 10 mV

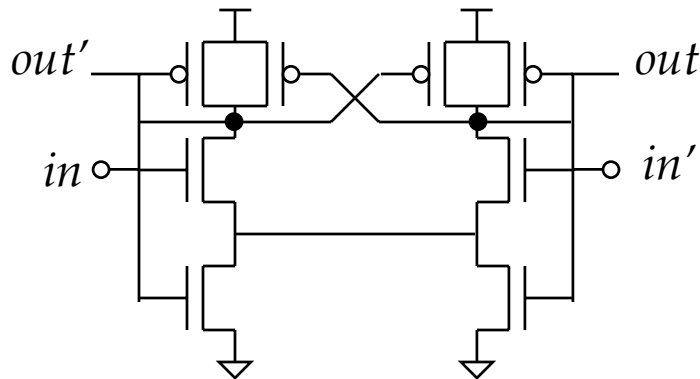
FIGURE 4-59. DC Transfer Characteristics of a Source-Coupled Pair



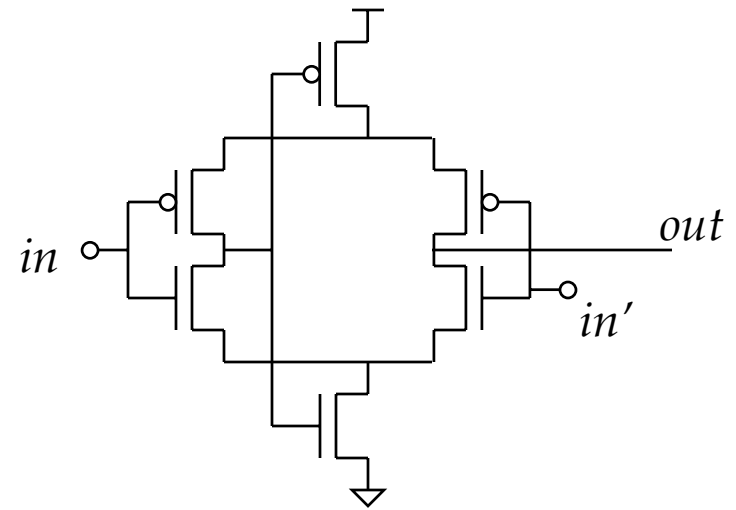
Self-Biased Differential RX

Self-biased (Chappell) Receiver

- Current source bias
 - ◆ Too high → pull input devices out of saturation
 - ◆ Too low → limits output swing
 - ◆ → Self-bias against temp, process variation



Symmetric Chappell Amplifier



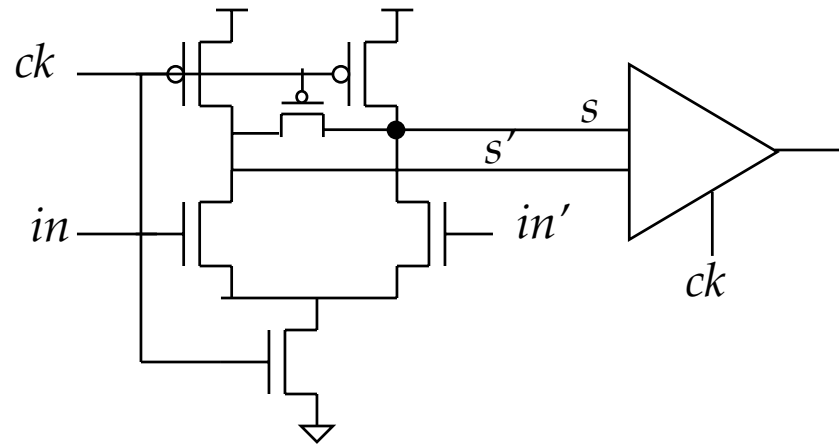
High input range amp

Clocked Differential Amplifiers

See earlier section on differential flip-flops

Integrating Amplifier

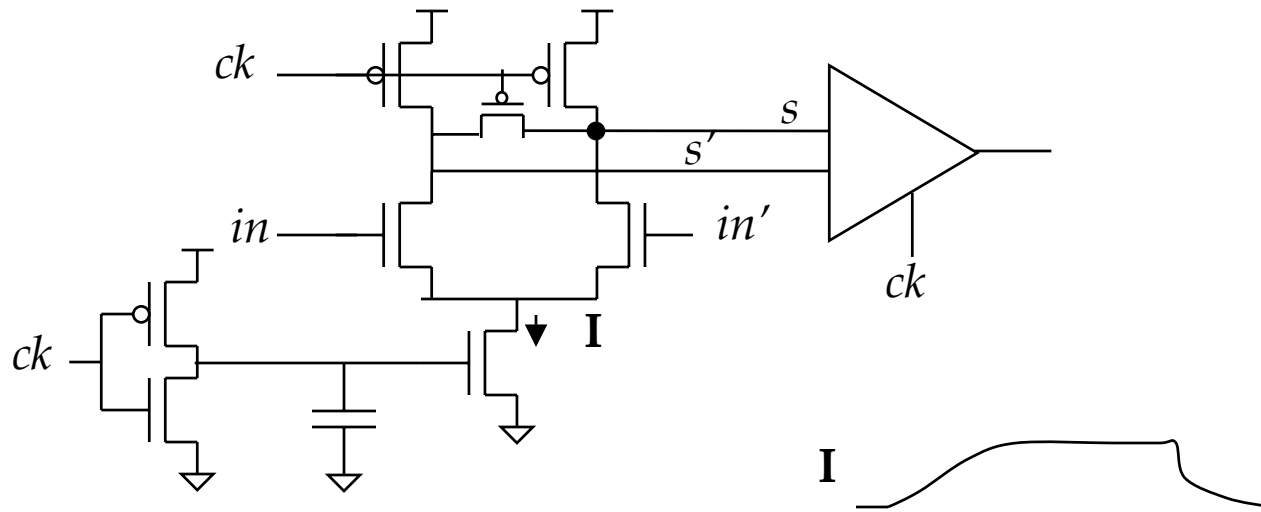
- Integrator acts like a low-pass filter rejecting high frequency noise



Matched Filter Amplifier

Match bias current with shape of V_{in}

- Matched Filter



On-chip Termination

Binary-weighted trim resistors

- Set trim bits through comparison of a reference circuit with an off-chip resistor

