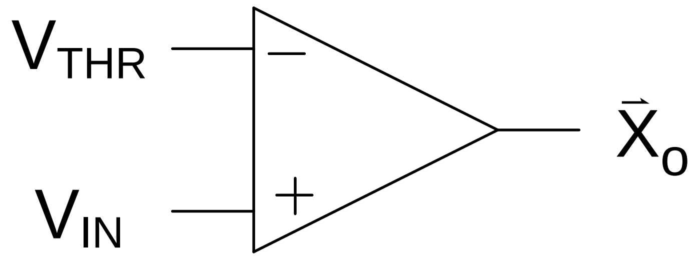
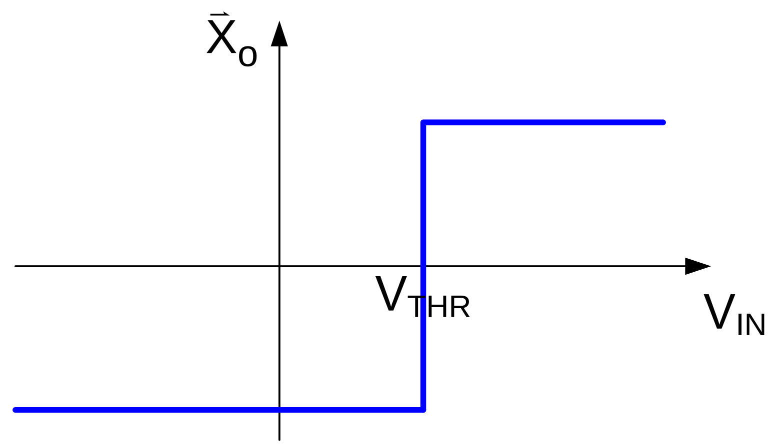
Dynamic Comparators

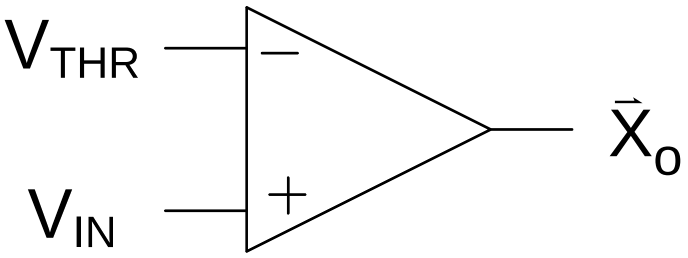
Comparator

A comparator is a circuit that provides a high Boolean output if the differential input is positive and a low Boolean output if the differential input is negative





Comparator



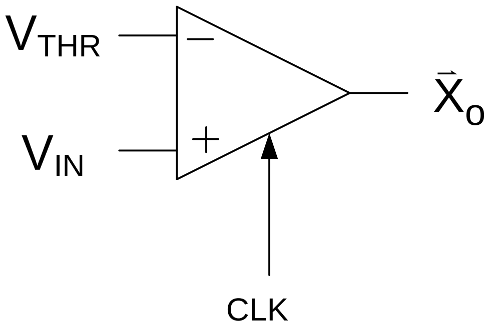
High gain amplifiers are often used as comparators since the outputs of most amplifiers naturally clip at high and low levels when overdriven

Since comparators are usually not used with feedback, there is not a need for compensation so neither the area reduction or speed reduction penalty is incurred

Since feedback is not used, higher-order amplifiers such as cascades can be used to increase the gain of a comparator to arbitrarily high levels

If over-driven amplifiers are used for comparators, the power dissipation of these types of comparators is often high

Comparator



Some comparators are clocked and only provide an output after the transition of the clock

The value of the input to a clocked comparator is only of concern in a short time interval around the clock transition

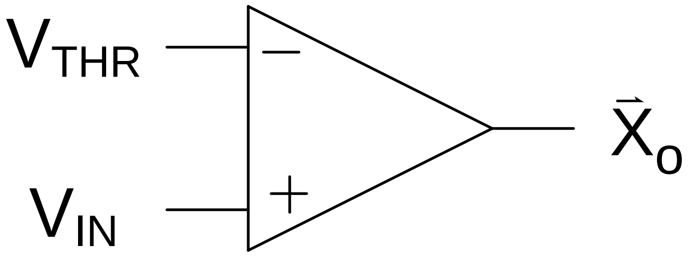
The speed of clocked comparators can be very high and the power dissipation of clocked comparators can be very low

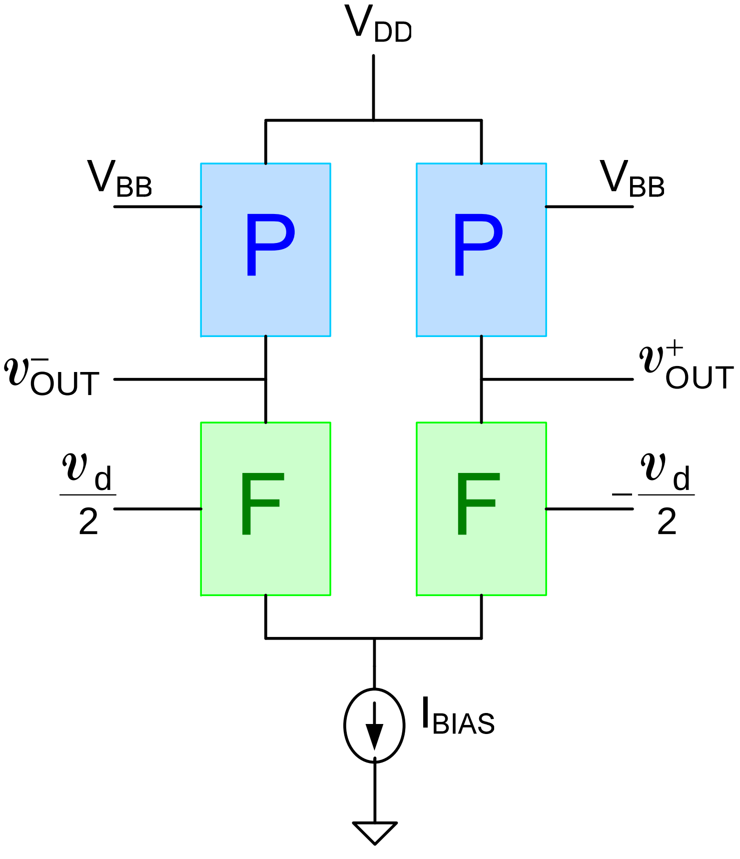
Clocked comparators are often called Dynamic Comparators

Regenerative feedback is often used in dynamic comparators and occasionally in non-clocked comparators

Dynamic comparators are widely used in the design of high-speed ADCs

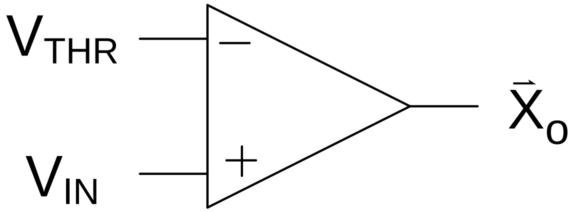
Comparator

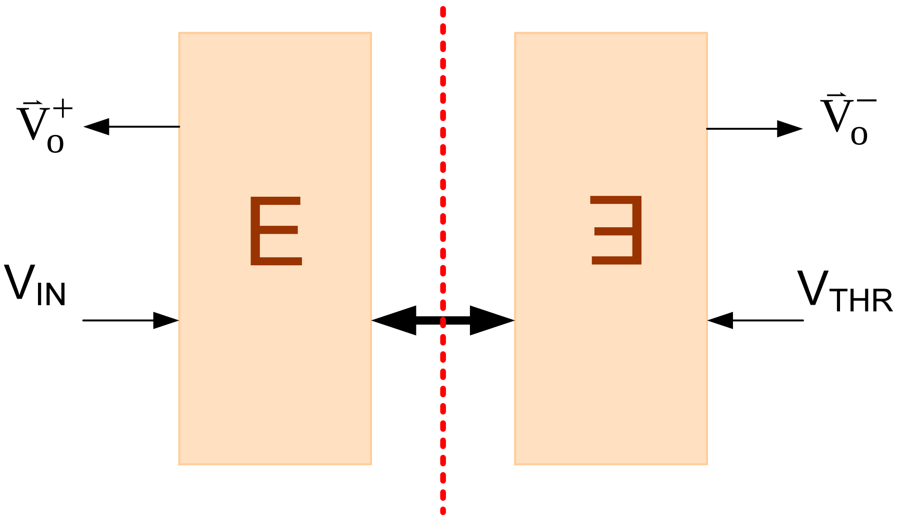




Amplifier-Based Comparator

Comparator

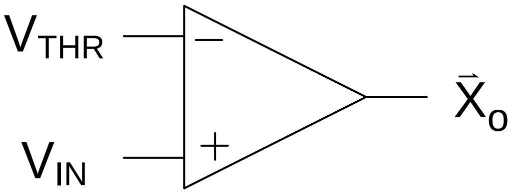


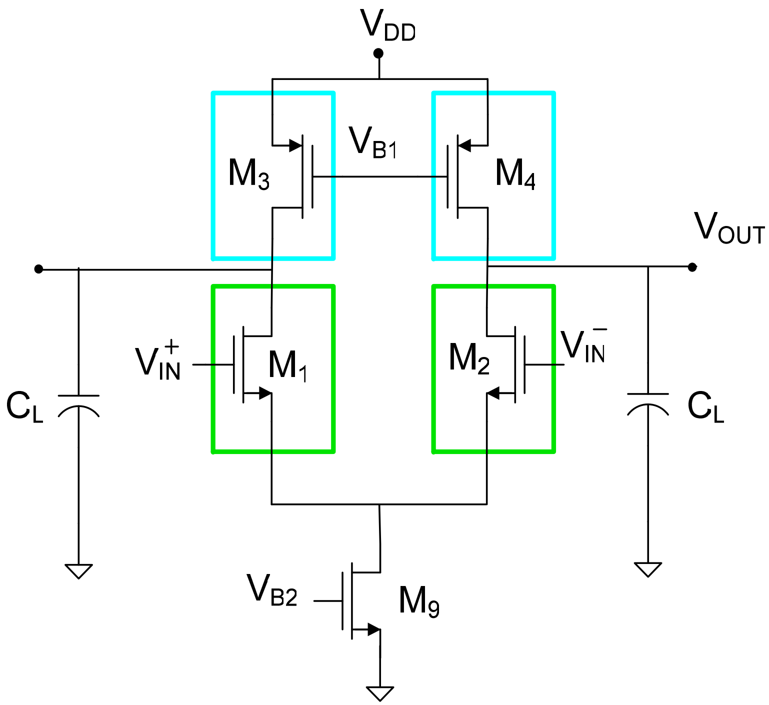


Amplifier-Based Comparator

Note symmetry in the comparator

Comparator





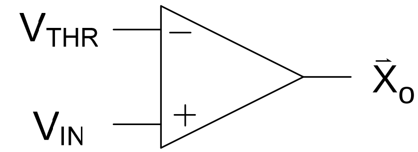
$$v_d = v_{in}^{+} - v_{in}^{-}$$

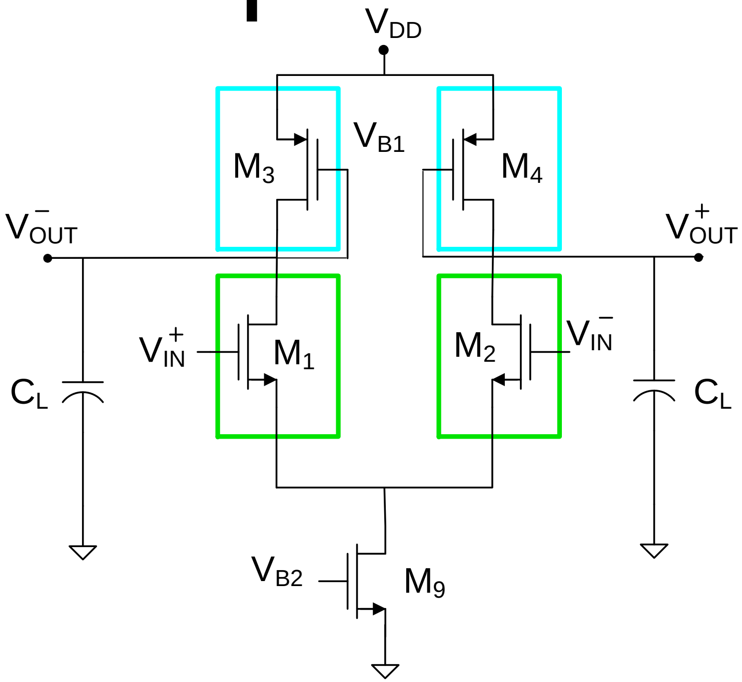
Amplifier-Based Comparator

At the start of the comparison process, an amplifier-based comparator behaves as a linear amplifier

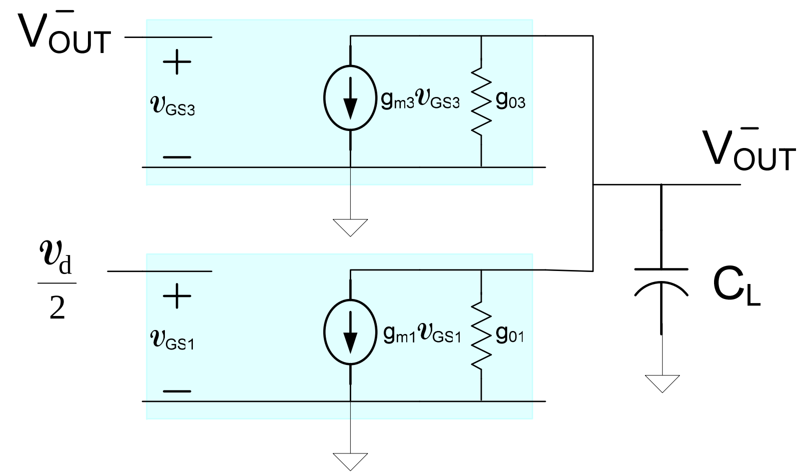
$$A(s) = \frac{v_{out}}{v_d} = \frac{1}{2}\frac{g_{m1}}{sC_L + g_{o1} + g_{o2}}$$

Comparator





$$v_d = v_{in}^+ - v_{in}^-$$



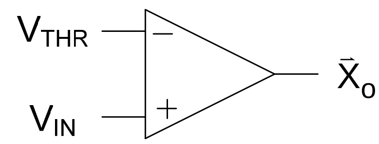
$$v_{OUT}^-\left(sC_L + g_{o3} + g_{o1}\right) + g_{m1}\frac{v_d}{2} + g_{m3}\left(v_{OUT}^-\right) = 0$$

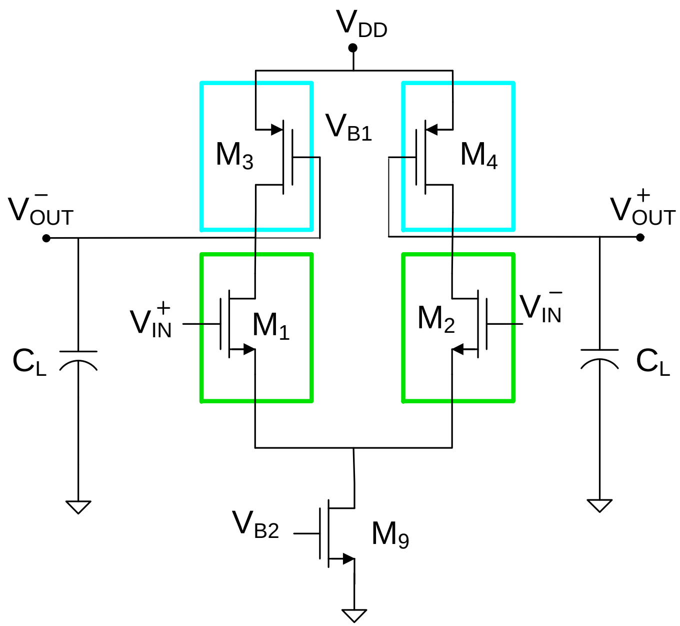
Lower-gain Amplifier-Based Comparator

$$A(s) = \frac{v_{out}}{v_d} = -\frac{1}{2}\frac{g_{m1}}{sC_L + g_{o1} + g_{o2} + g_{m3}}$$

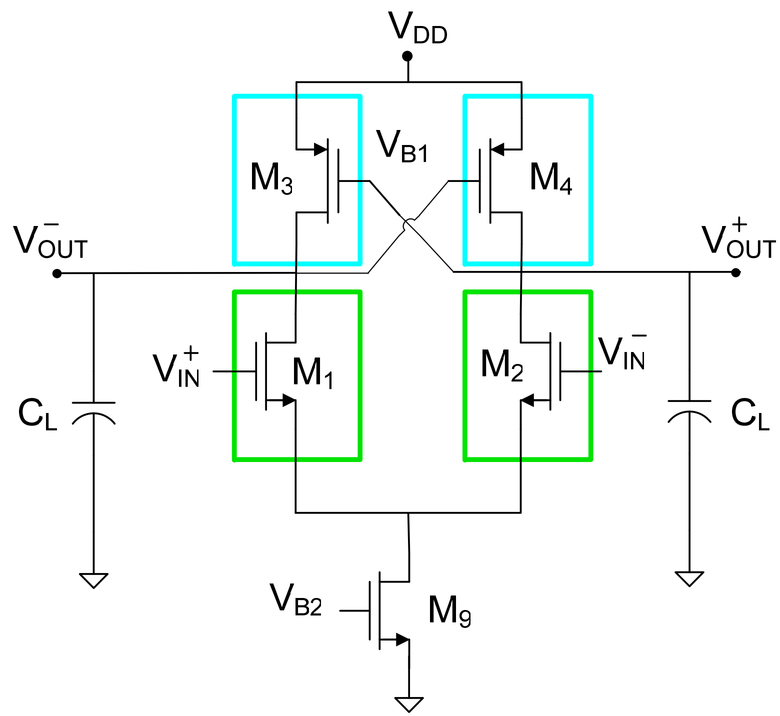
At the start of the comparison process, an amplifier-based comparator behaves as a linear amplifier

Comparator



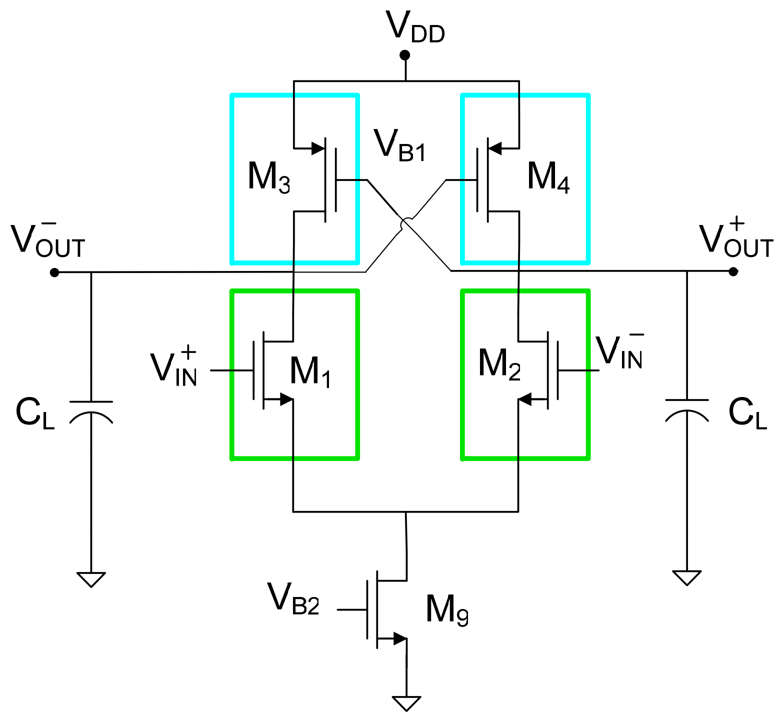


Lower-gain Amplifier-Based Comparator



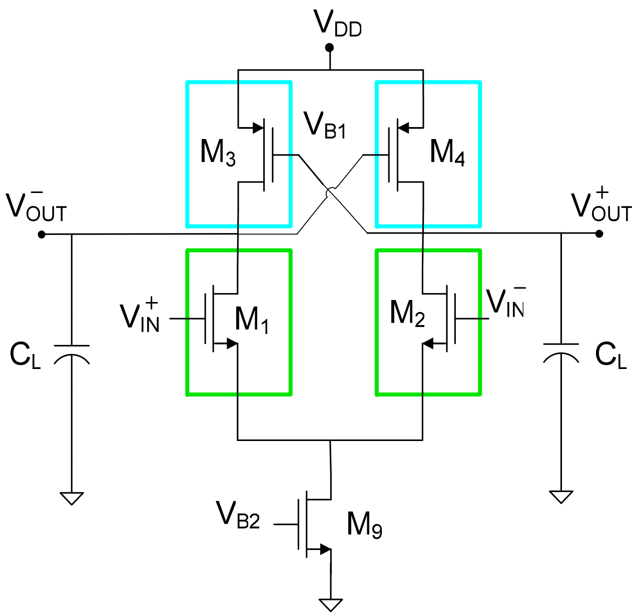
Amplifier-Based Comparator with Regenerative Feedback

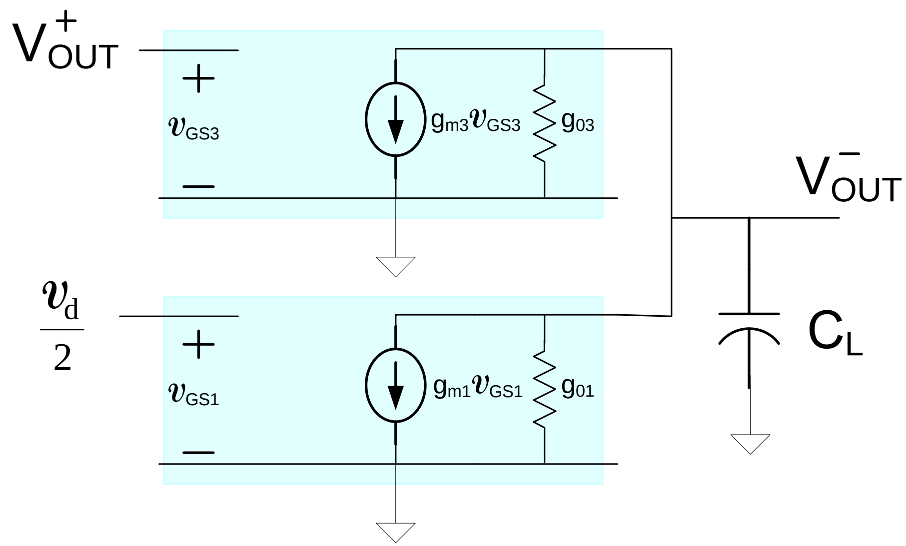
Amplifier-Based Comparator with Regenerative Feedback



At the start of the comparison process, an amplifier-based comparator behaves as a linear amplifier

Amplifier-Based Comparator with Regenerative Feedback





At the start of the comparison process, an amplifier-based comparator behaves as a linear amplifier

$$v_{OUT}^{-}\left(sC_L + g_{o3} + g_{o1}\right) + g_{m1}\frac{v_d}{2} + g_{m3}\left(-v_{OUT}^{-}\right) = 0$$

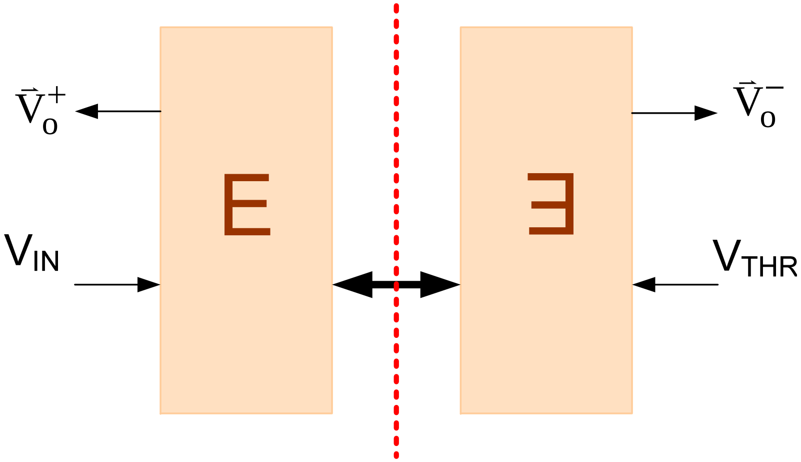
$$\frac{v_{OUT}^{-}}{v_d} = \frac{-\frac{g_{m1}}{2}}{sC_L + g_{o3} + g_{o1} - g_{m3}}$$

Since $g_m >> g_o$, this comparator has a pole on positive real axis in the RHP

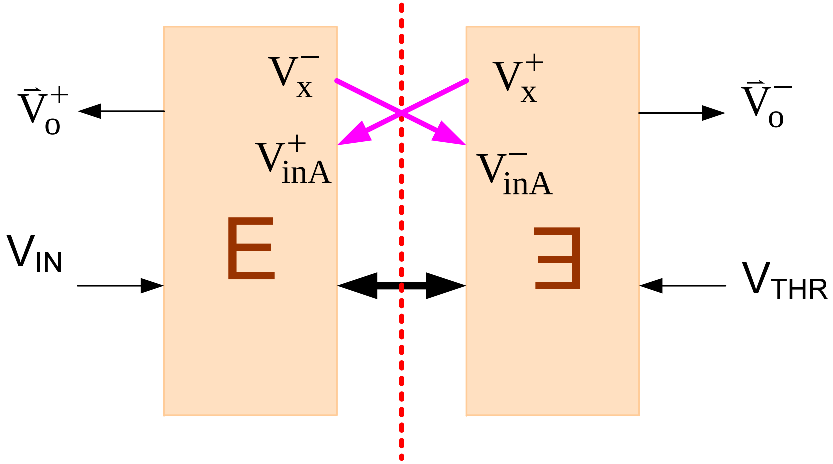
Regenerative feedback will cause the output to latch at one of two levels

But will not recover if small changes in input dictate a change in the output

Comparator Structures



Amplifier-Based Comparator



Comparator with Regenerative Feedback

Almost all comparators based upon two symmetric sub-circuits

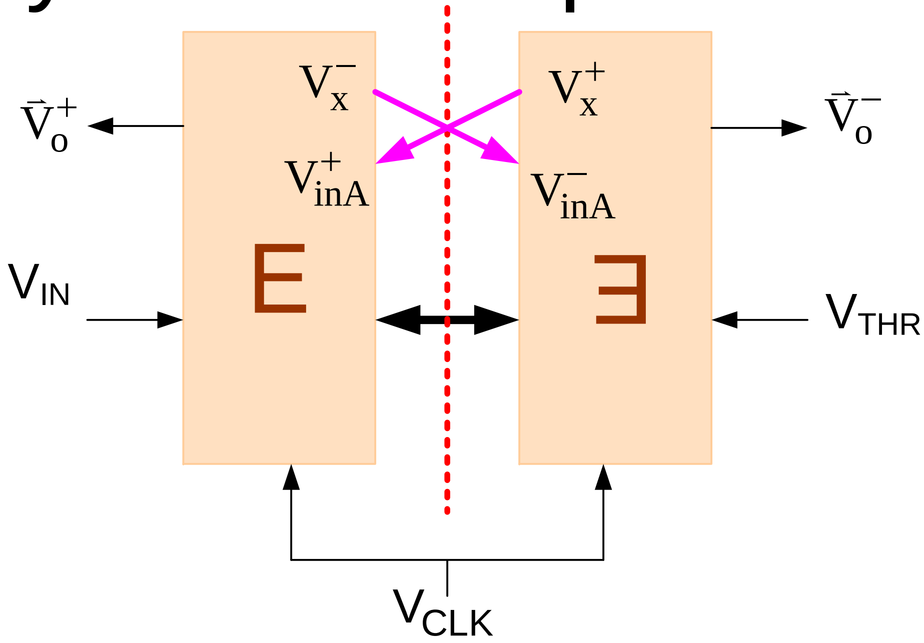
Regeneration obtained by symmetrically cross-coupling across axis of symmetry from an output to an input

Any symmetric structure with this cross-coupling will create regenerative feedback but whether the poles move into the RHP depends upon the architecture

Clocks are often added to remove the restriction of regenerative-type structures not recovering when inputs change a little

Structure in upper right will be called a "Cross-Symmetric" structure

Generic Dynamic Comparator Structure

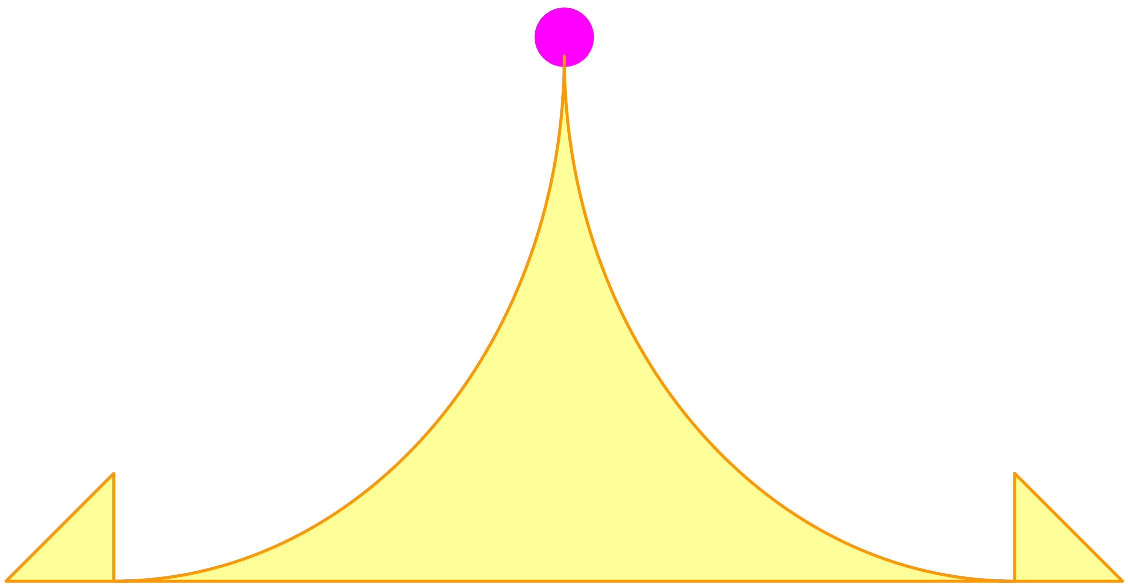


Most circuits with this architecture that have a modest regenerative feedback gain will have a RHP positive real axis pole

All circuits with the cross-symmetric structure and a positive real axis pole can serve as dynamic comparators!

The clock is used to reset the circuit and thus to put it in a balanced state prior to regeneration

Mechanical Analogy of Dynamic Comparator

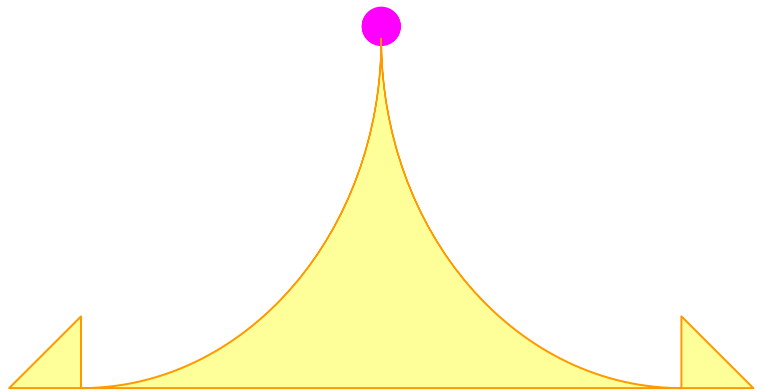


Ball in position shown is said to be in a metastable state

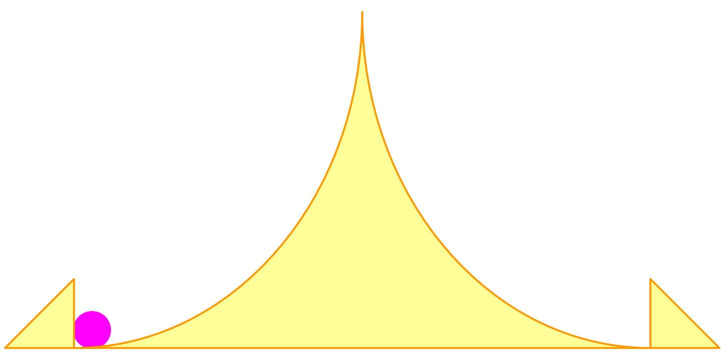
This system can not stay in this state indefinitely

A “reset” must be applied to put the system in the metastable state

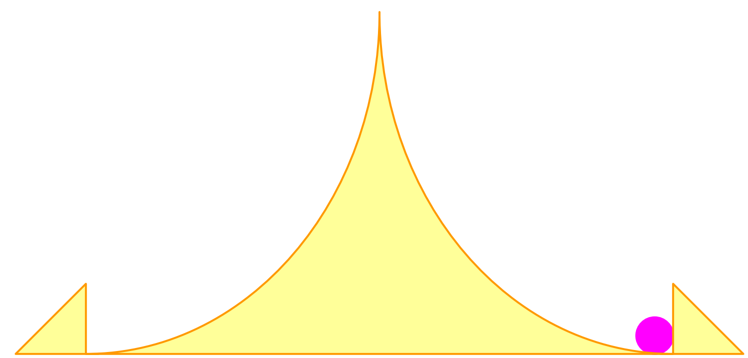
Mechanical Analogy of Dynamic Comparator



Metastable State



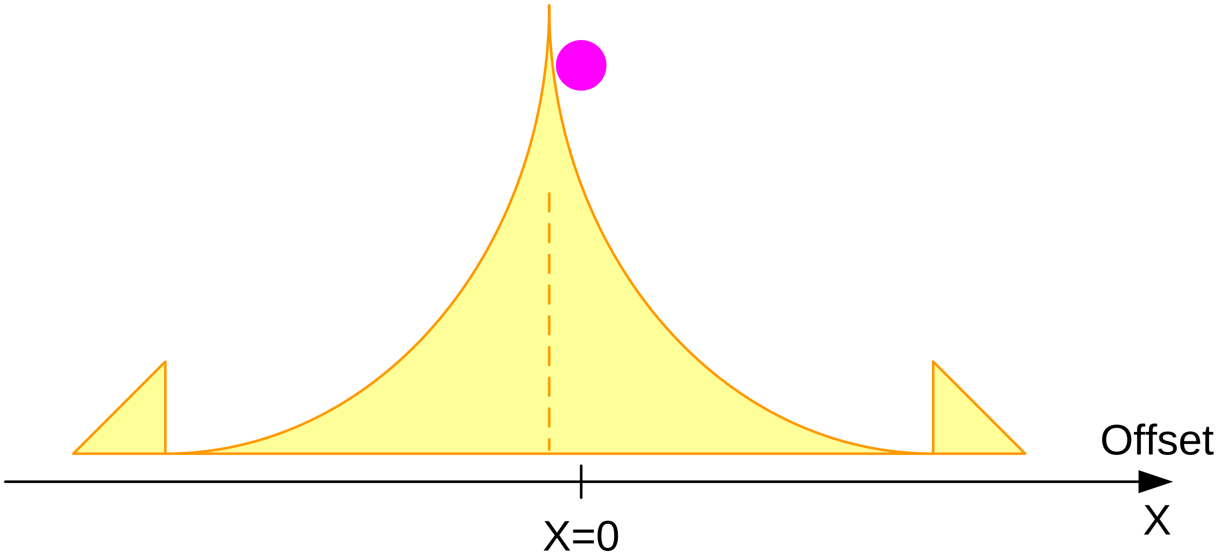
Left Stable State



Right Stable State

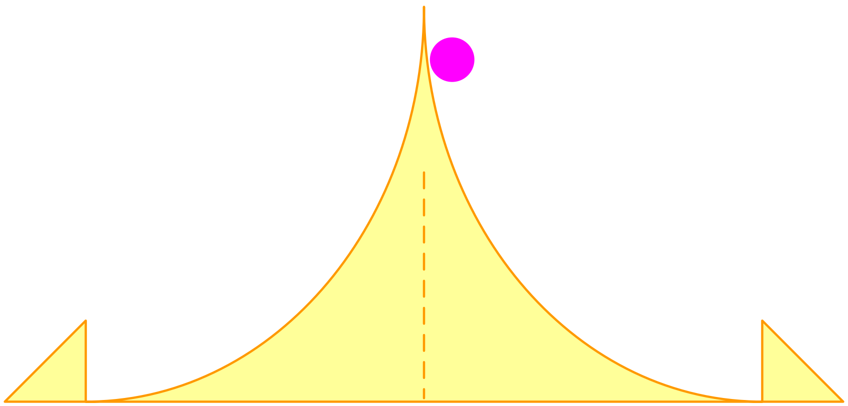
- Given enough time, system will always enter one of the two stable states
- Time required to enter one of the two stable states is usually very small

Mechanical Analogy of Dynamic Comparator



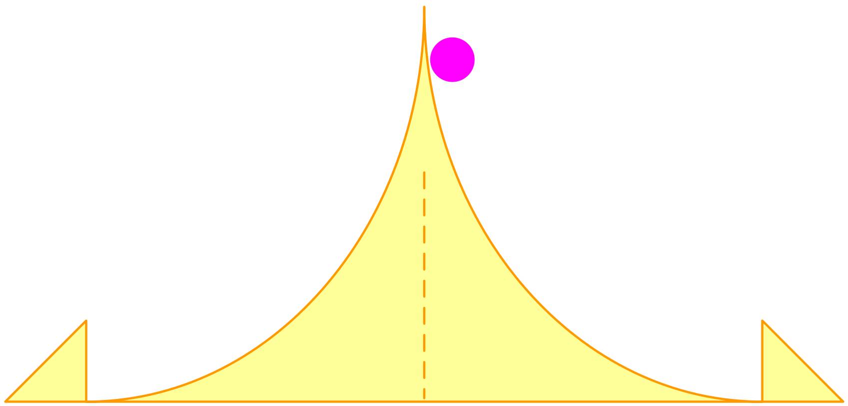
- If at reset (ball at position x=0) the system is offset a small amount, a stable state will be reached very quickly
- Time required to enter one of the two stable states is usually very small
- The state it reaches tells whether the system offset is positive or negative
- The position of the ball after a small period of time provides a “boolean” output that gives the result of the comparison between the position of the ball and the position of the system
- This thus serves as a mechanical dynamic comparator

Mechanical Analogy of Dynamic Comparator



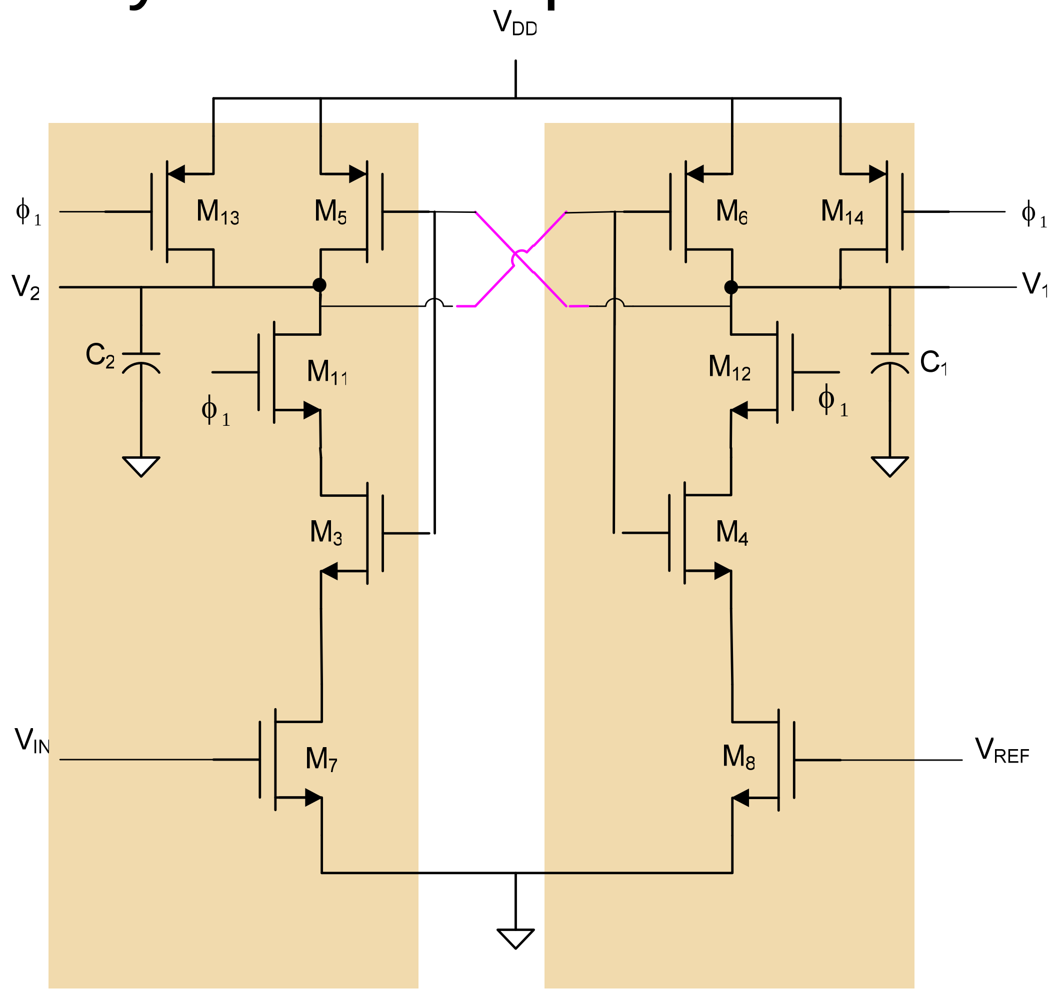
- Probability is 0 of having the initial offset be exactly 0
- Dynamic comparator will always make a decision
- But, if the offset is sufficiently close to 0, it may take a long time to make a decision
- In this mechanical system, the time it takes to make a decision is dependent upon the geometry of the system, the mass of the ball, and the coefficient of friction

Mechanical Analogy of Dynamic Comparator



- If the initial offset is uniformly distributed around x=0, for any time t, there is a small probability that the decision will not have been made at time t
- This probability is large if t is very small and is very small if t is large
- Some authors refer to the system being in a “metastable” state when a decision has not been reached but this term is misleading.
- If at any time t, the comparator has not made a decision, the system is in a transition state
- Most useful circuits that serve as dynamic comparators are very fast – that is, they have a very high probability of making a decision in a very short time

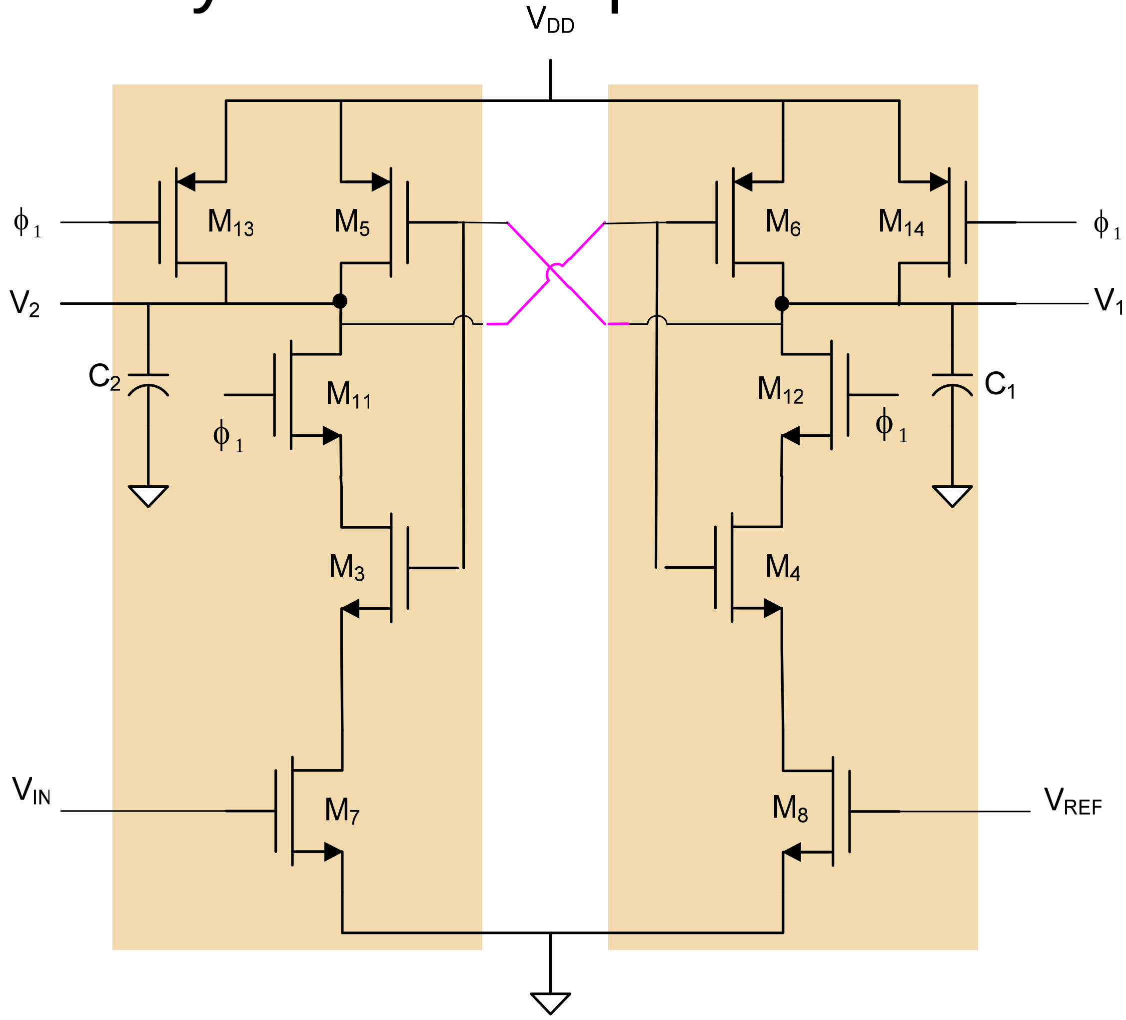
Popular Dynamic Comparator Structure



Brief discussion of operation:

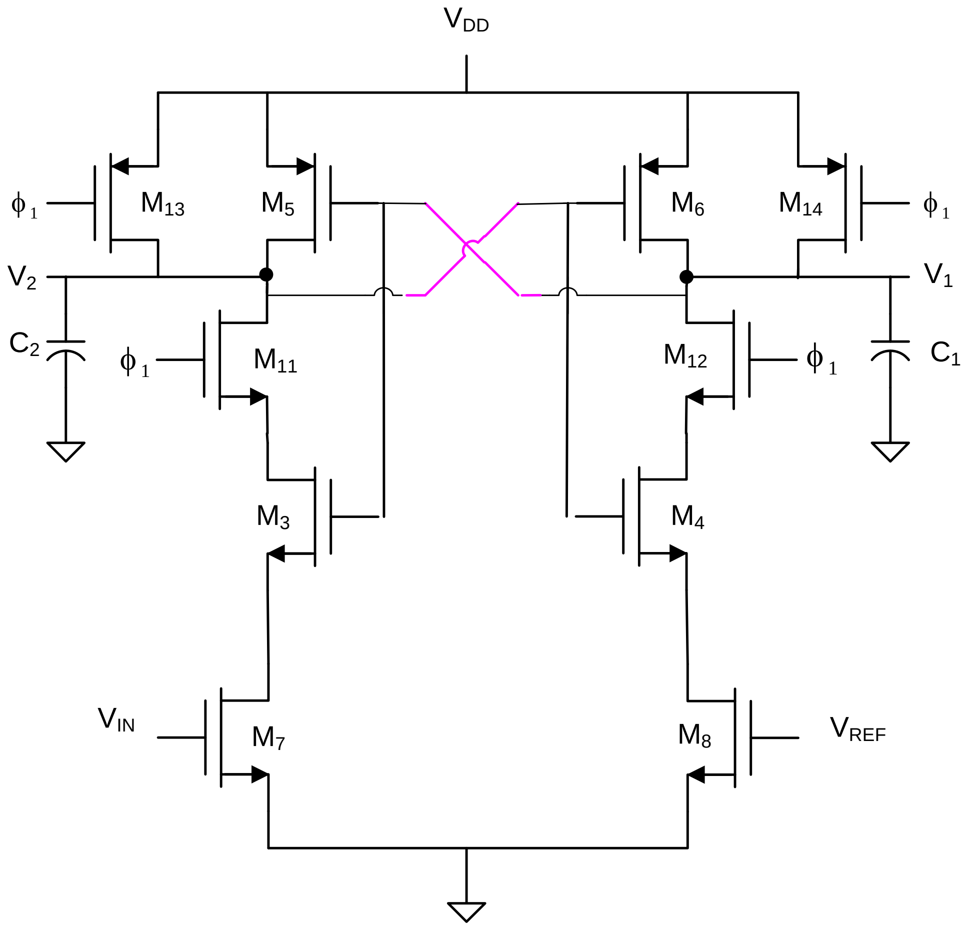
If $V_{IN}>V_{REF}$ at the start of the evaluate state, the current in M_7 will increase more rapidly than the current in M_8. Hence the current in M_5 will cause the magnitude of V_{GS} on M_5 to increase. This drives V_1 down and ultimately V_2 up

Popular Dynamic Comparator Structure



Load can be viewed as two cross-coupled Boolean inverters
Note zero static power dissipation

Popular Dynamic Comparator Structure



- Load can be viewed as two cross-coupled Boolean inverters
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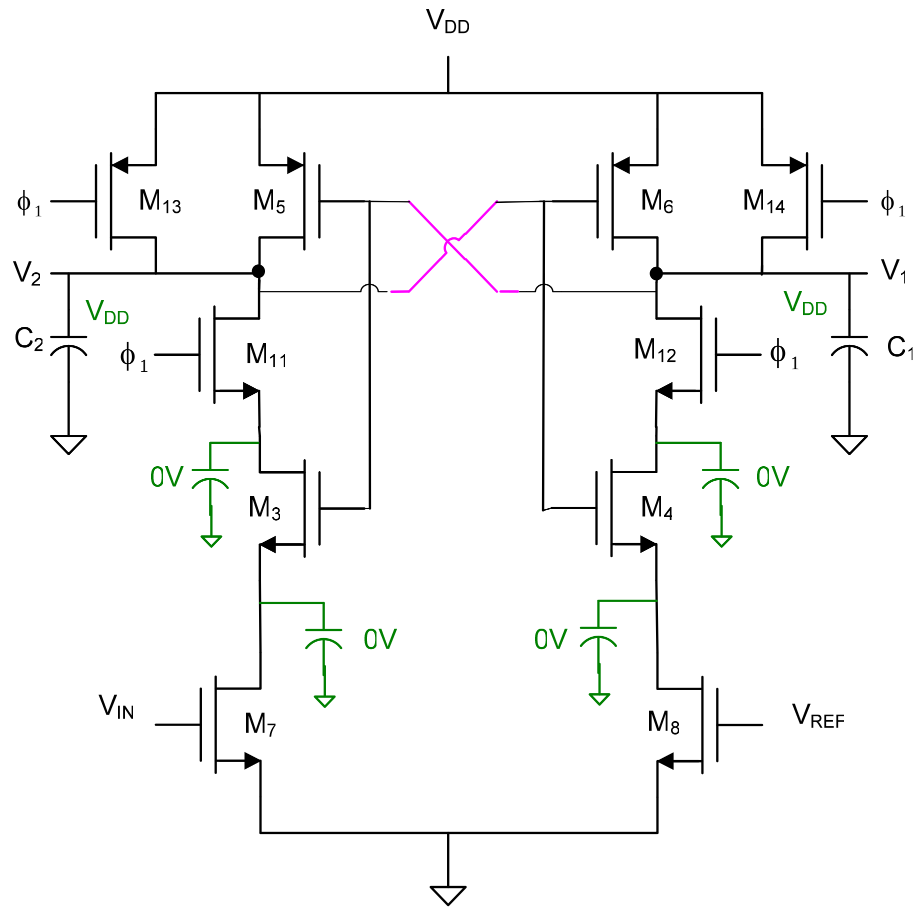
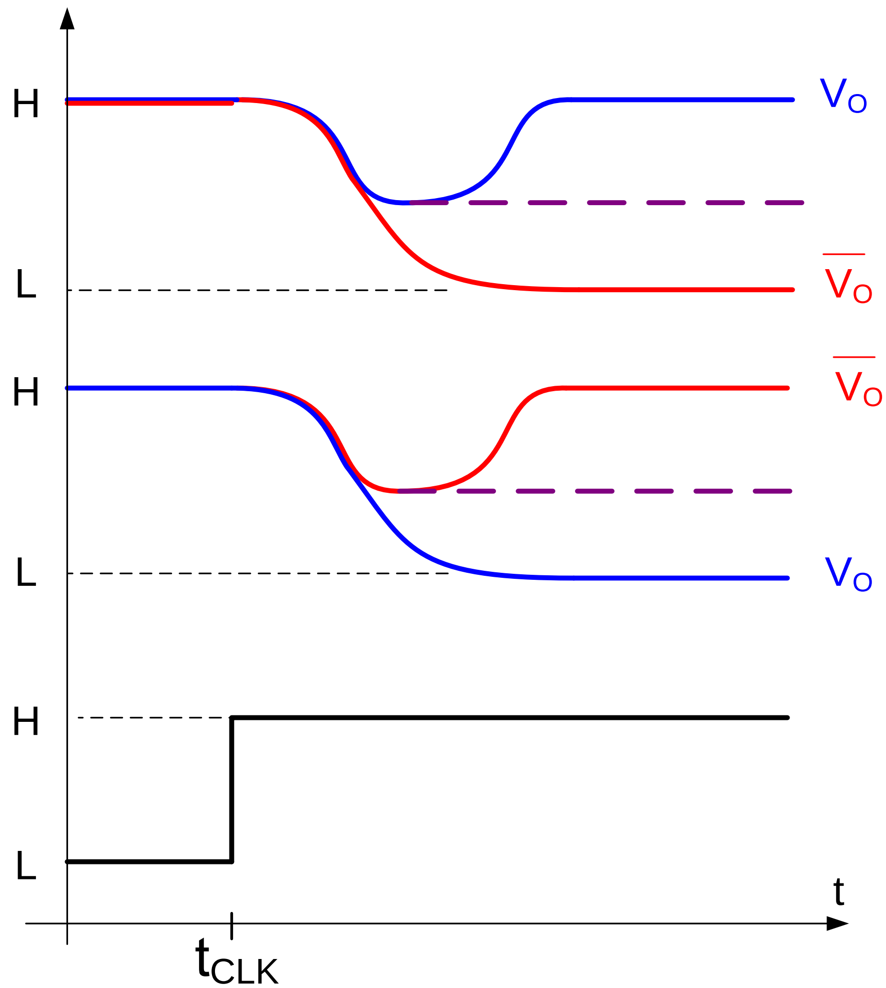
Popular Dynamic Comparator Structure

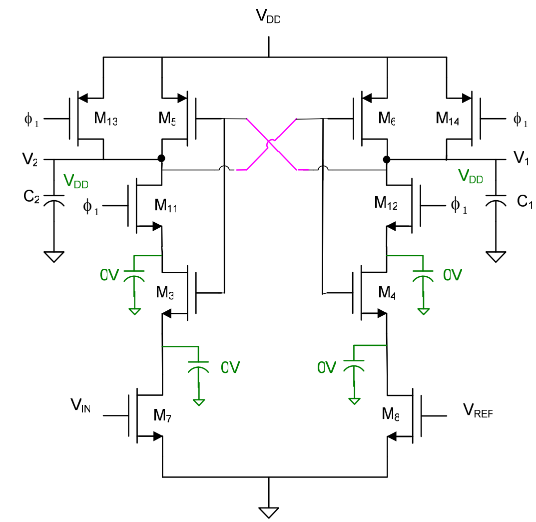


- Reset precharges
  - V_1 and V_2 to V_{DD}
  - the voltage on the source node of M_1 to 0V
  - The volgate on the source node of M_3 to 0V
- Note zero static power dissipation !

Popular Dynamic Comparator Structure

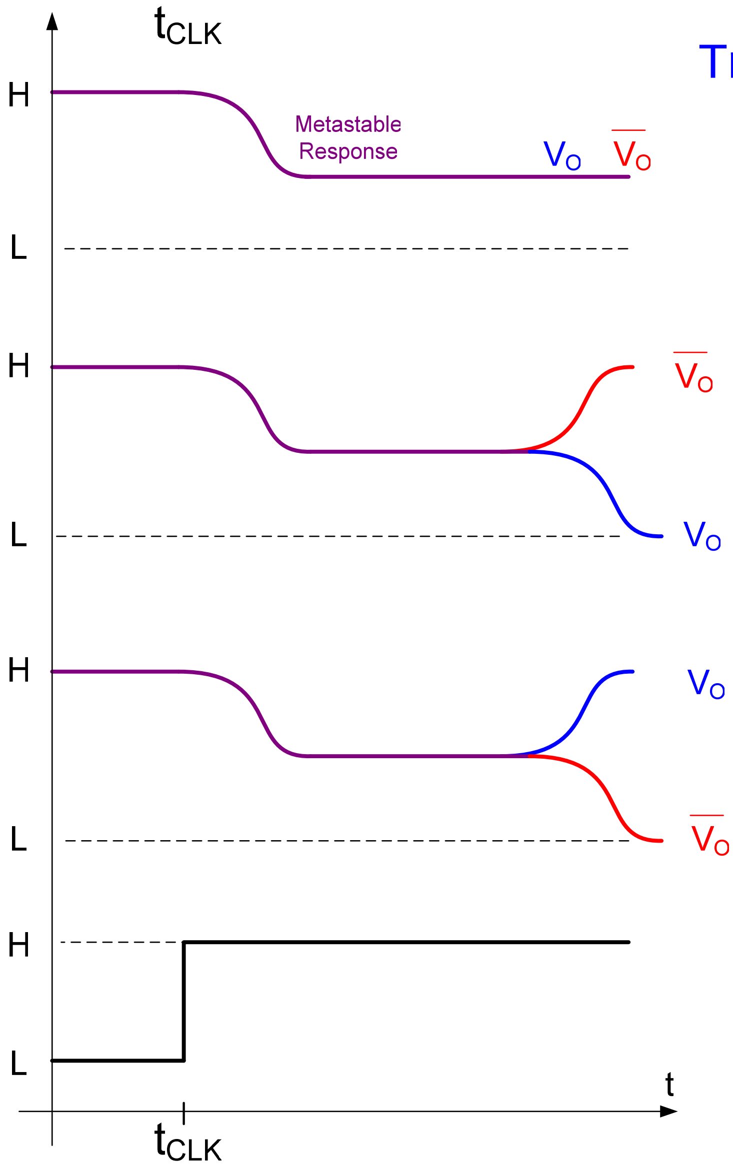


Transient Response

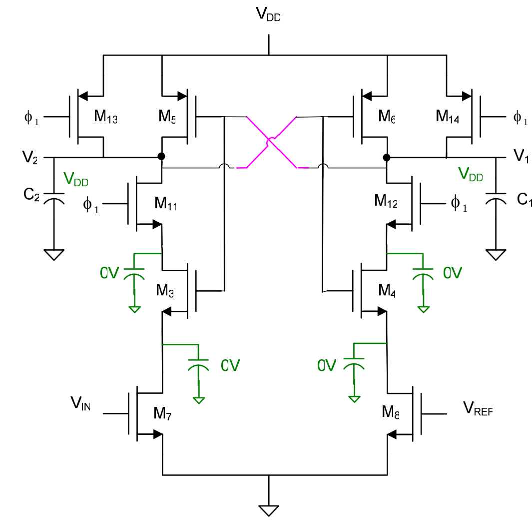


Note: Both outputs always start high and then transition

Popular Dynamic Comparator Structure



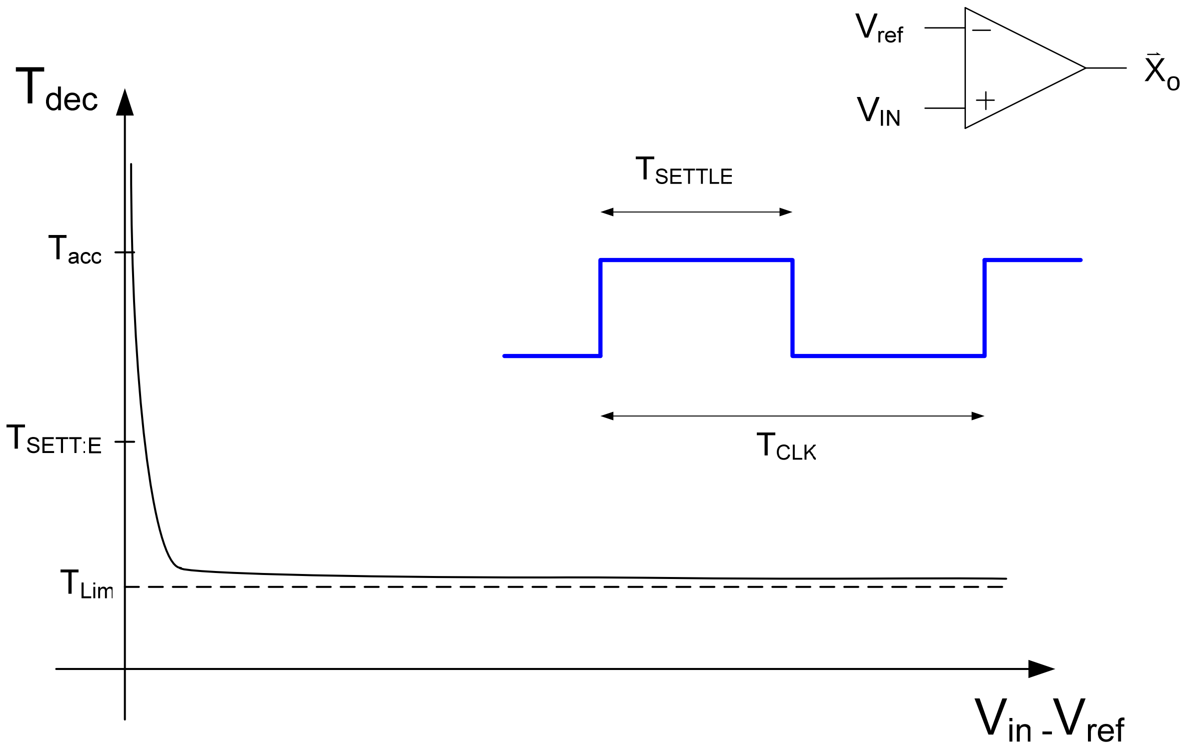
Transient Response

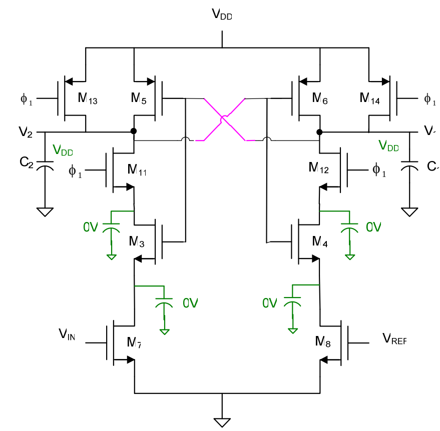


Note: Will always leave metastable region but will occasionally not leave region soon enough

Popular Dynamic Comparator Structure

Time for Decision

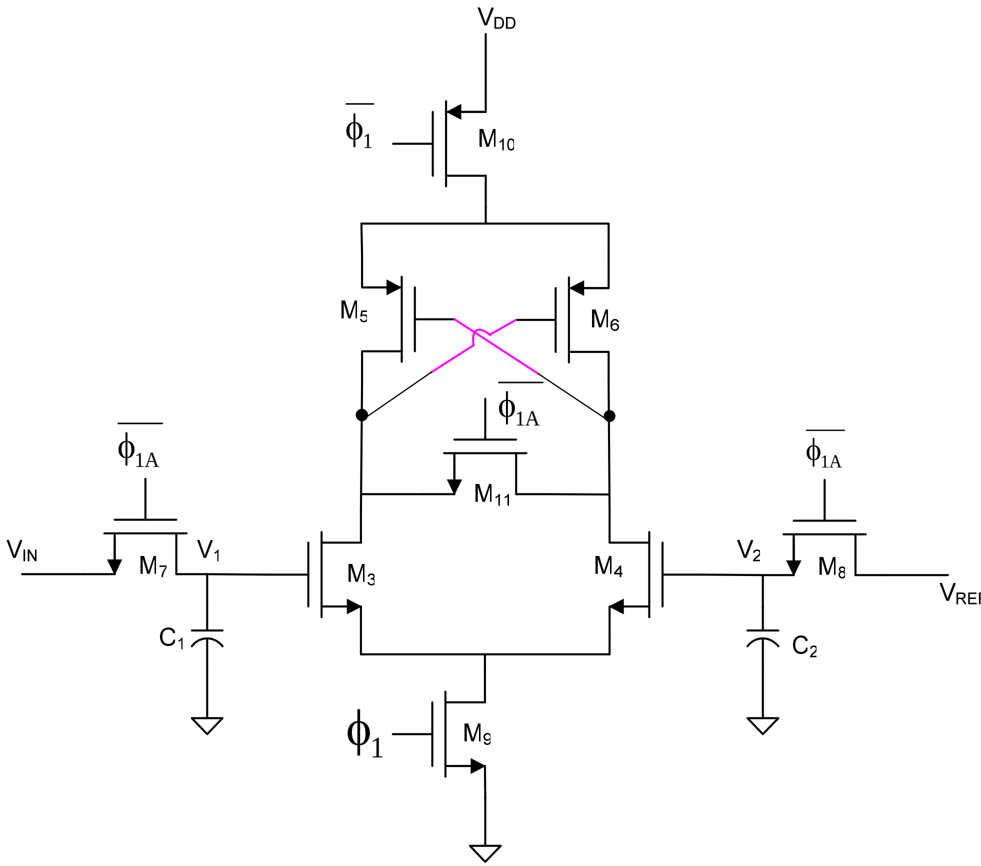




T_{acc} is the maximum clock settling period that will give an acceptable probability of error in a comparator

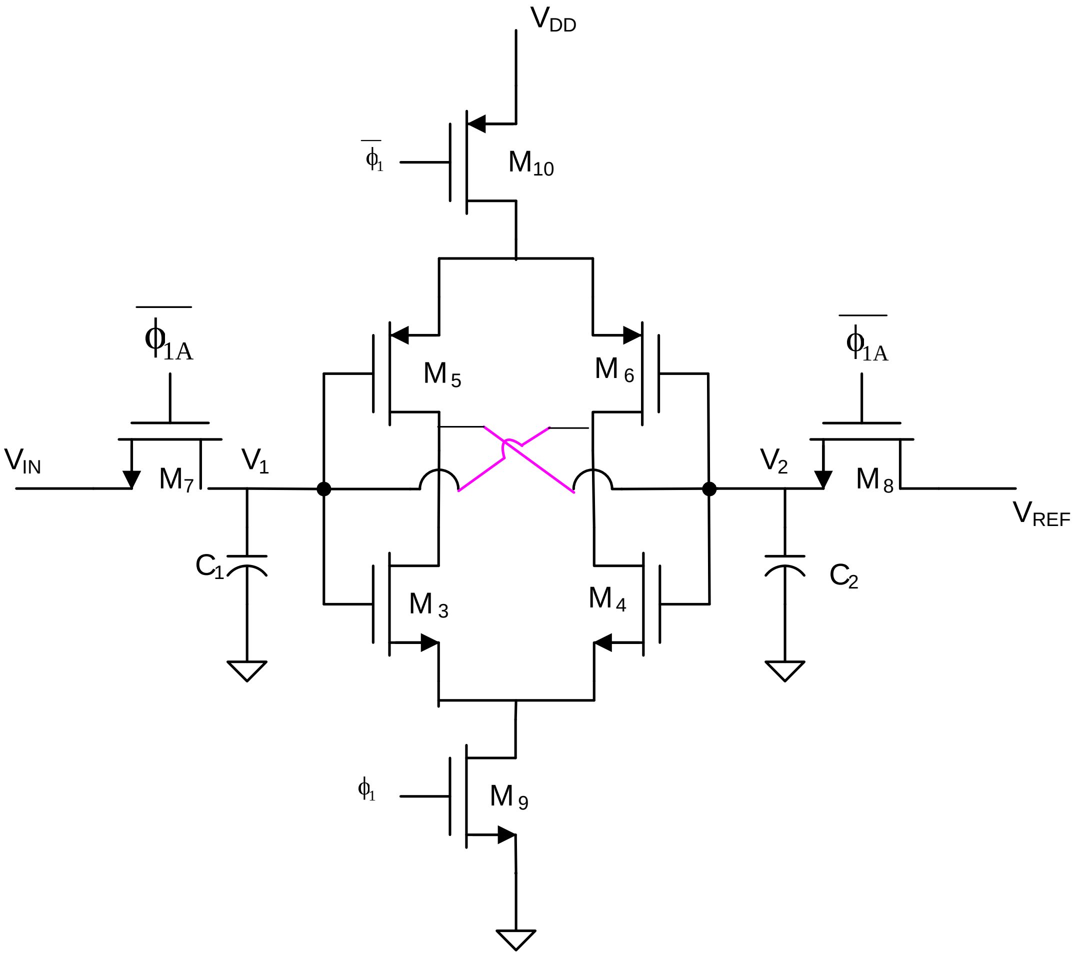
T_{Lim} is the limit of the settling time at the overdrive becomes large

Popular Dynamic Comparator Structure



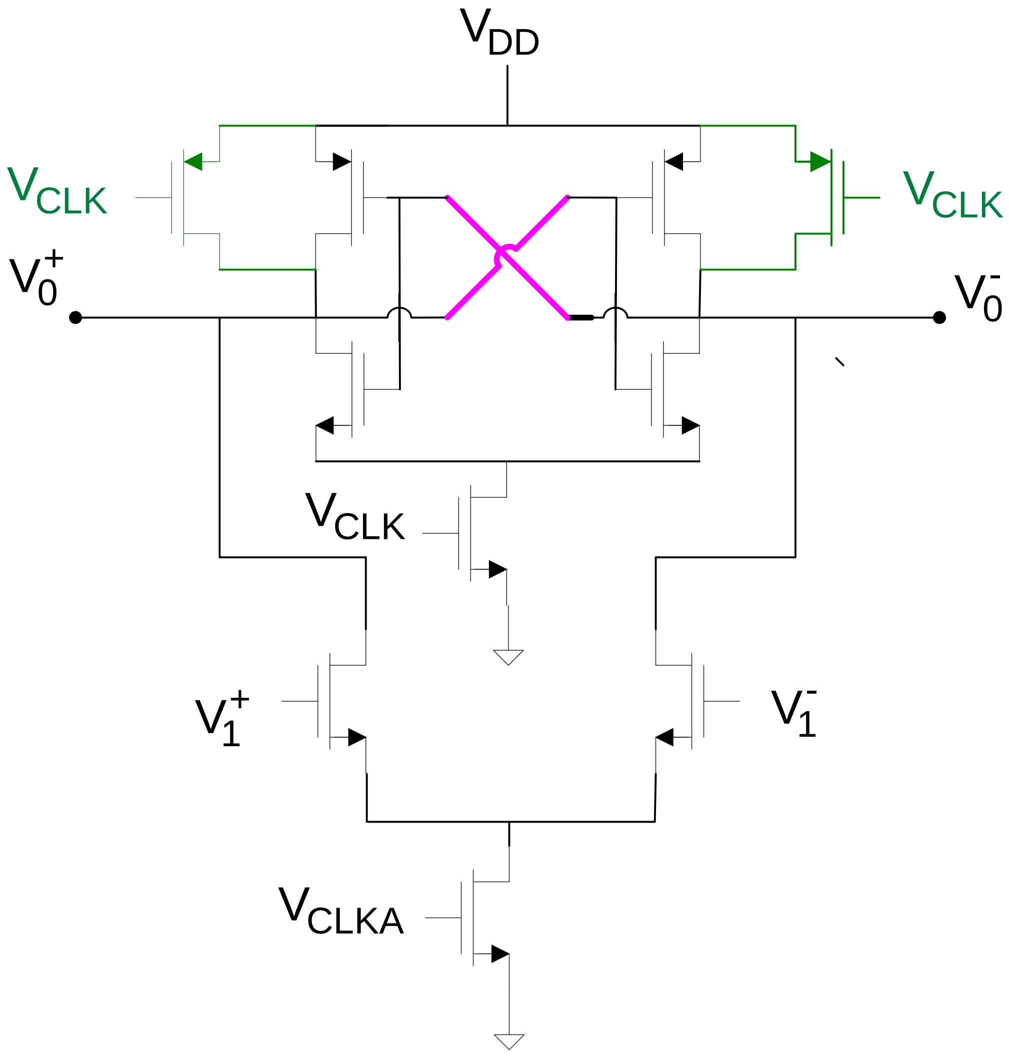
- Note zero static power dissipation in the “arm” state !

Popular Dynamic Comparator Structure



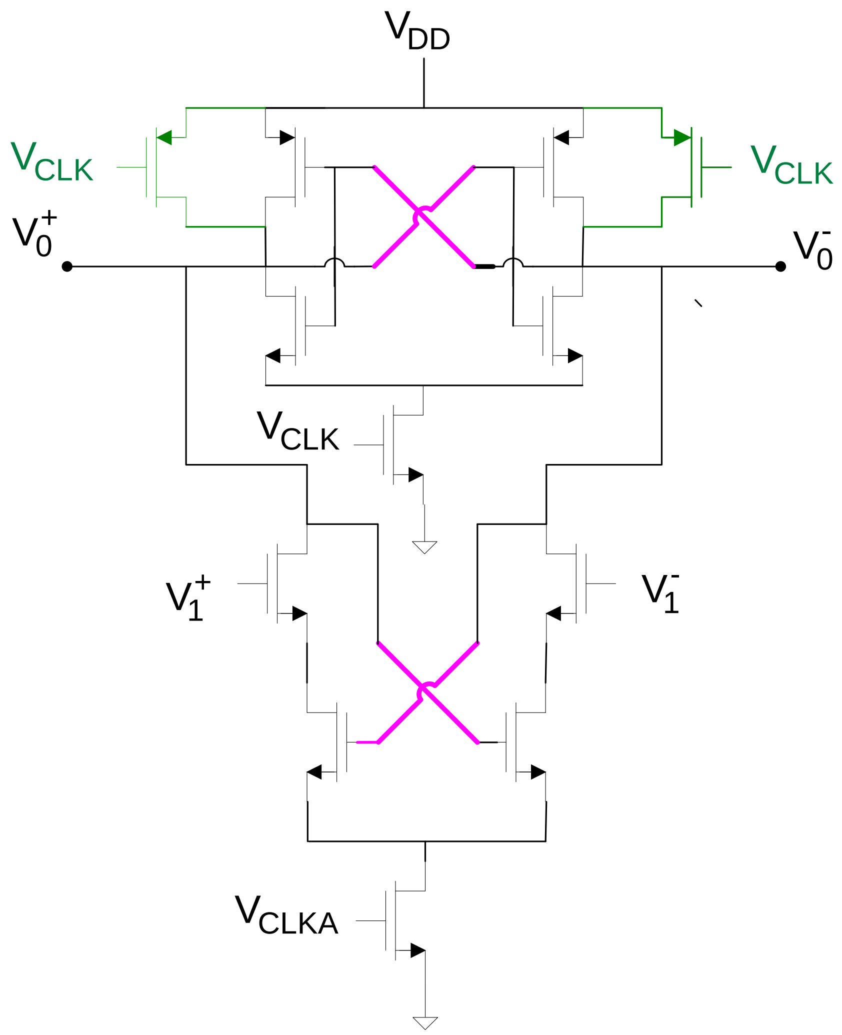
- Reset sets inverter pair at trip point
- Note zero static power dissipation !

Popular Dynamic Comparator Structure



- Note zero static power dissipation !

Popular Dynamic Comparator Structure



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New Dynamic Comparator Structure

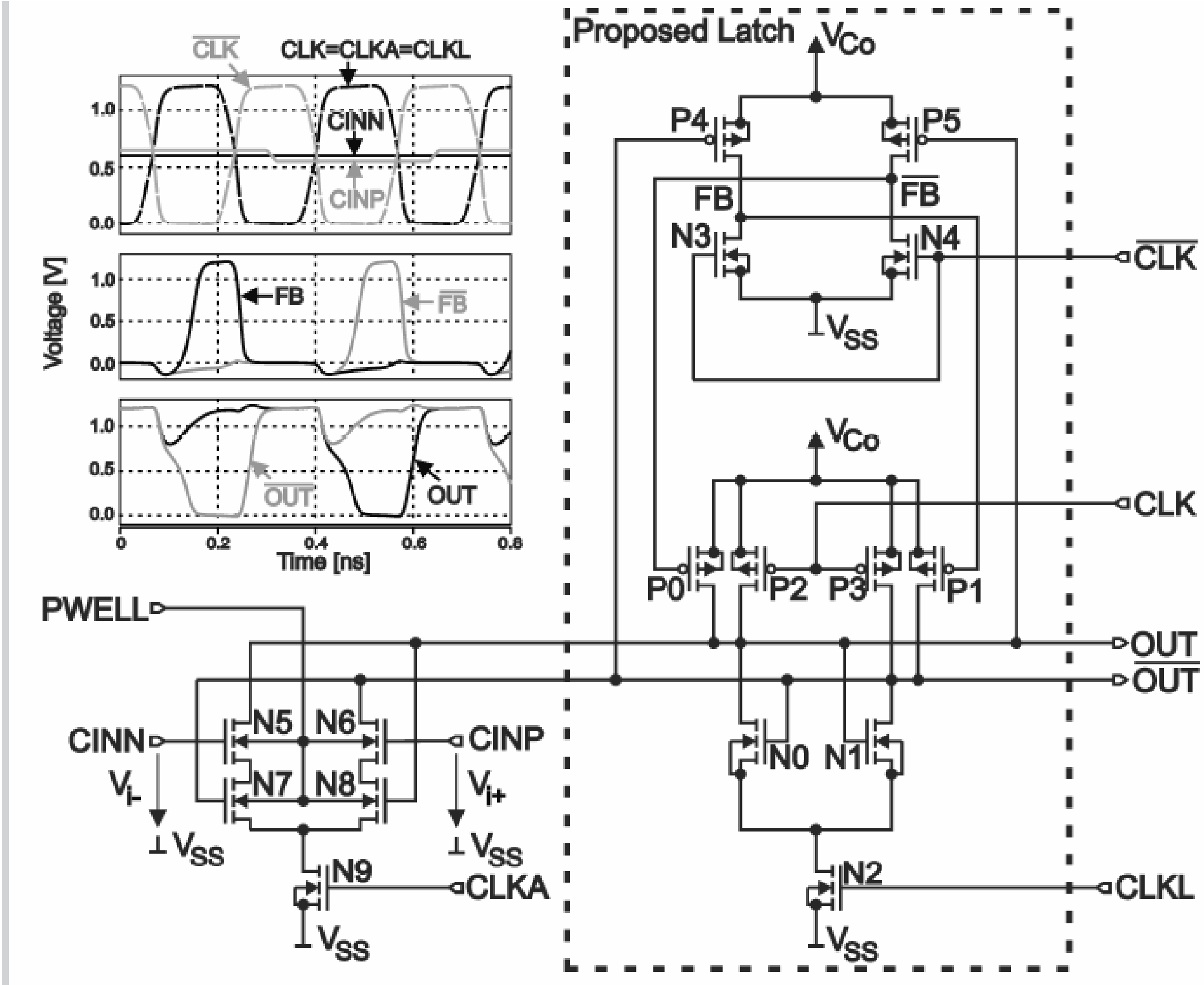

Figure 19.4.1: Schematic of the comparator.

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New Dynamic Comparator Structure

How does this compare with previous structure?

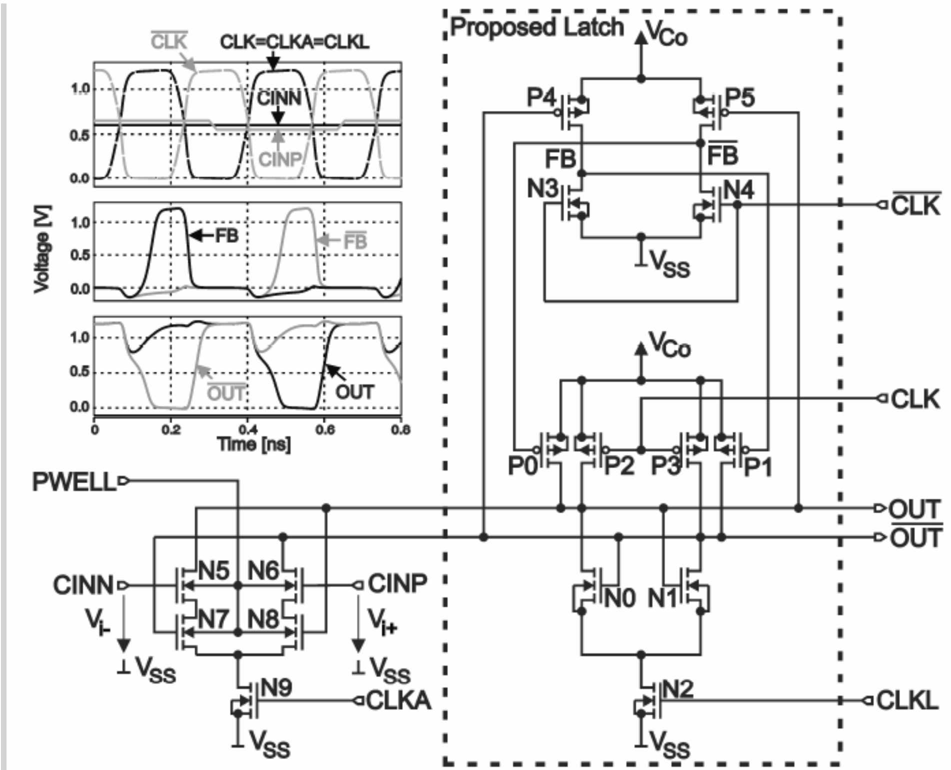
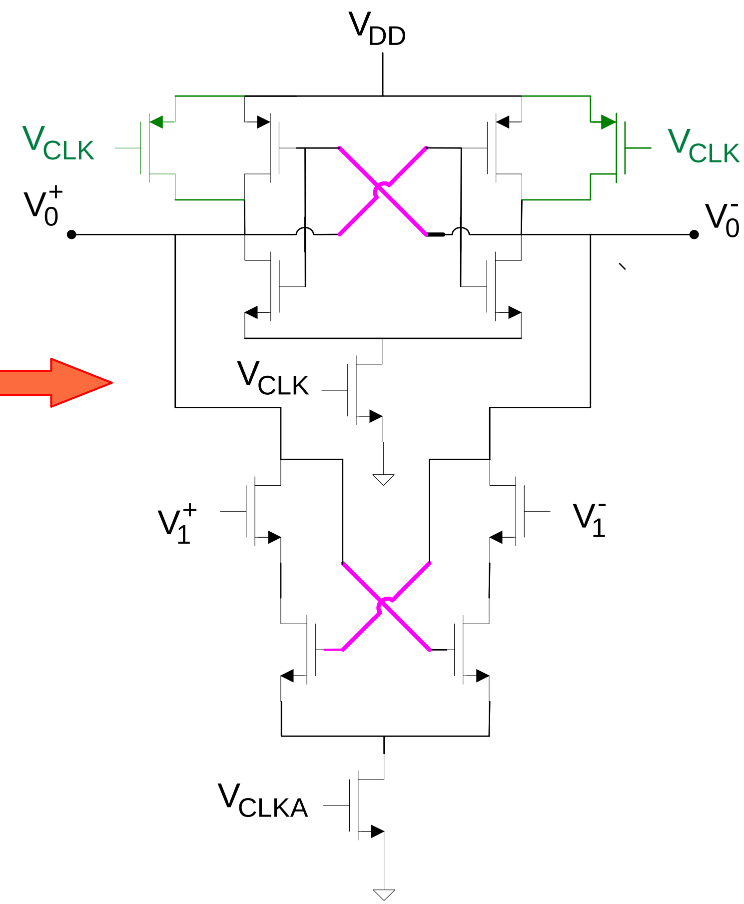


Figure 19.4.1: Schematic of the comparator.



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New Dynamic Comparator Structure

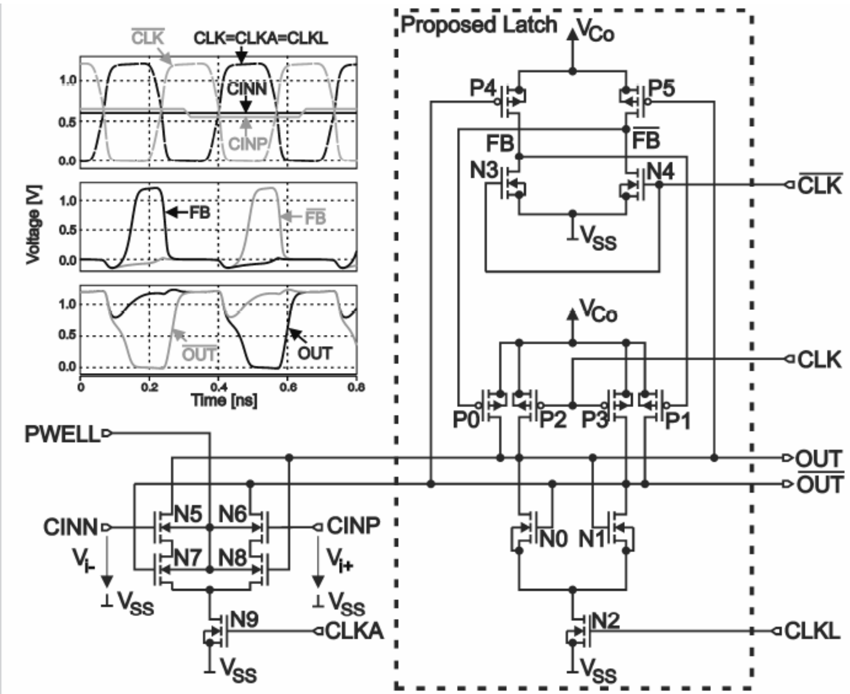
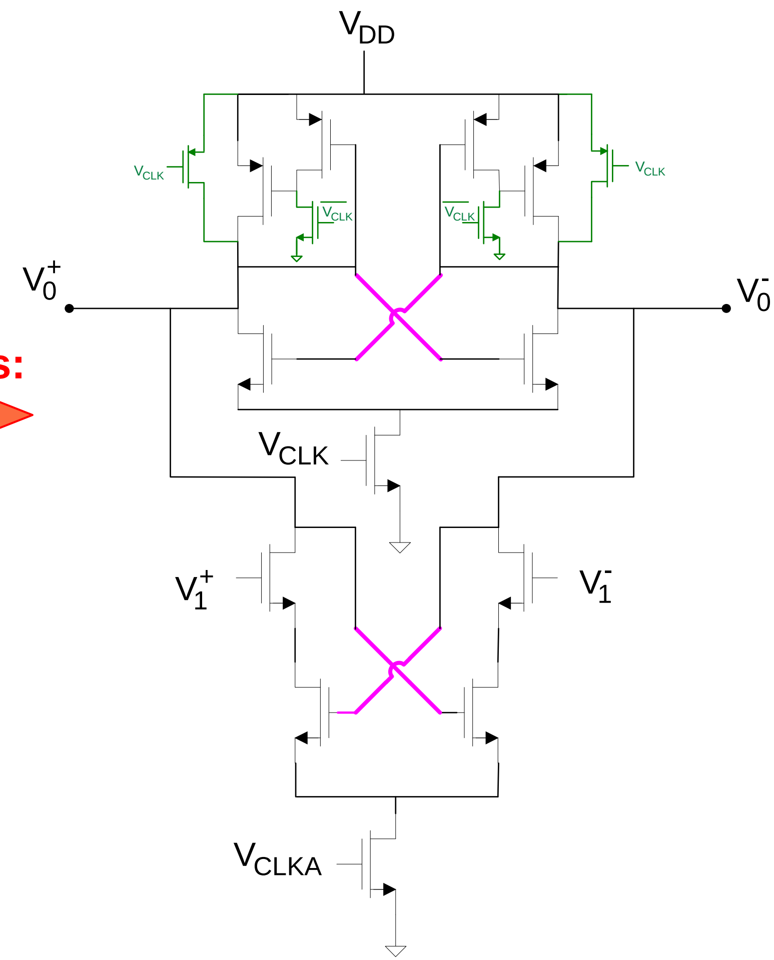


Figure 19.4.1: Schematic of the comparator.

redraw as:



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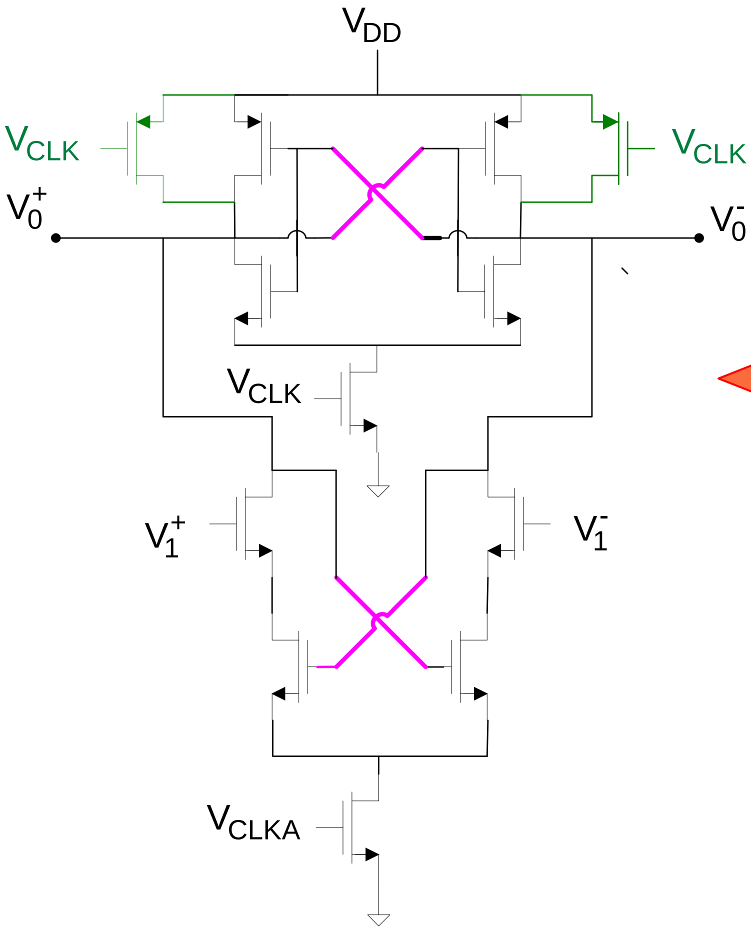
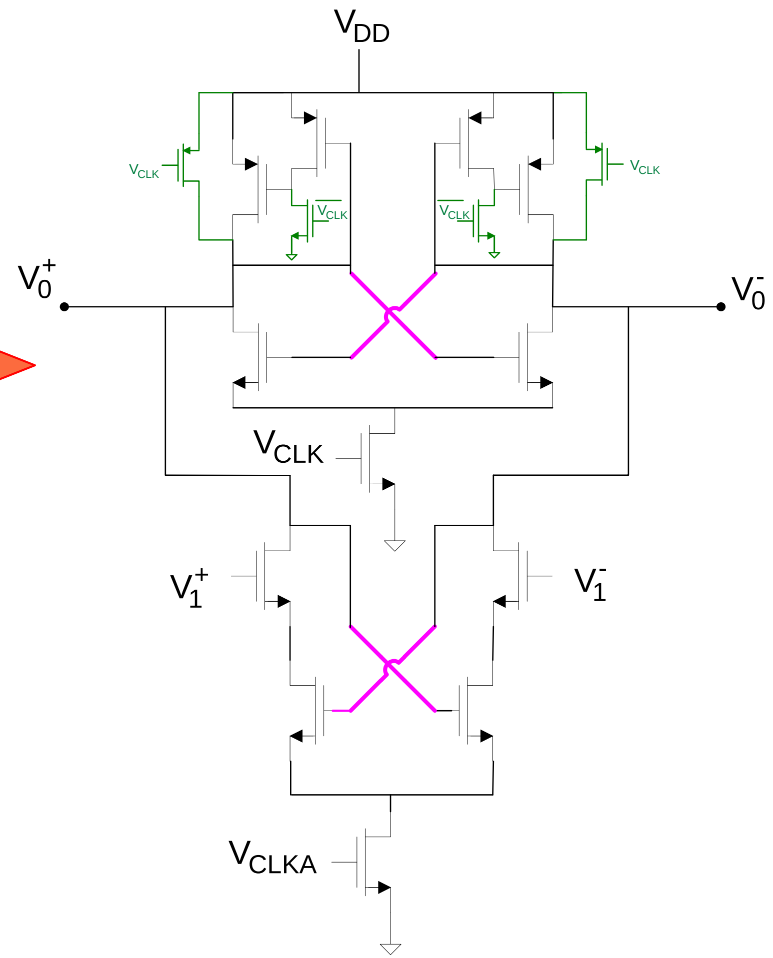
New Dynamic Comparator Structure

How does this compare with the previous structure?



Goff ISSCC 2009 (maybe not original source)



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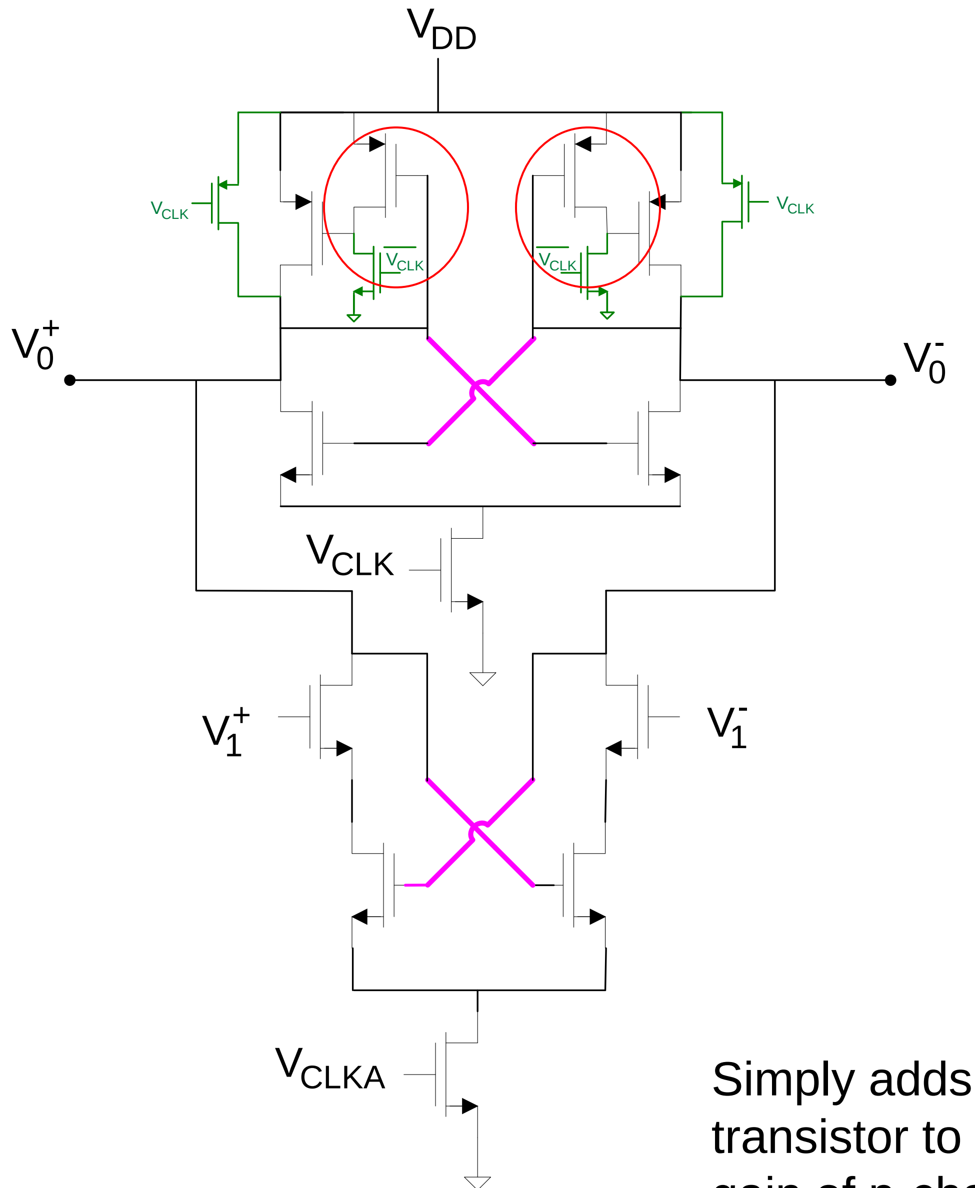
New Dynamic Comparator Structure



Simply adds one more PMOS transistor to basic circuit to increase gain of p-channel load

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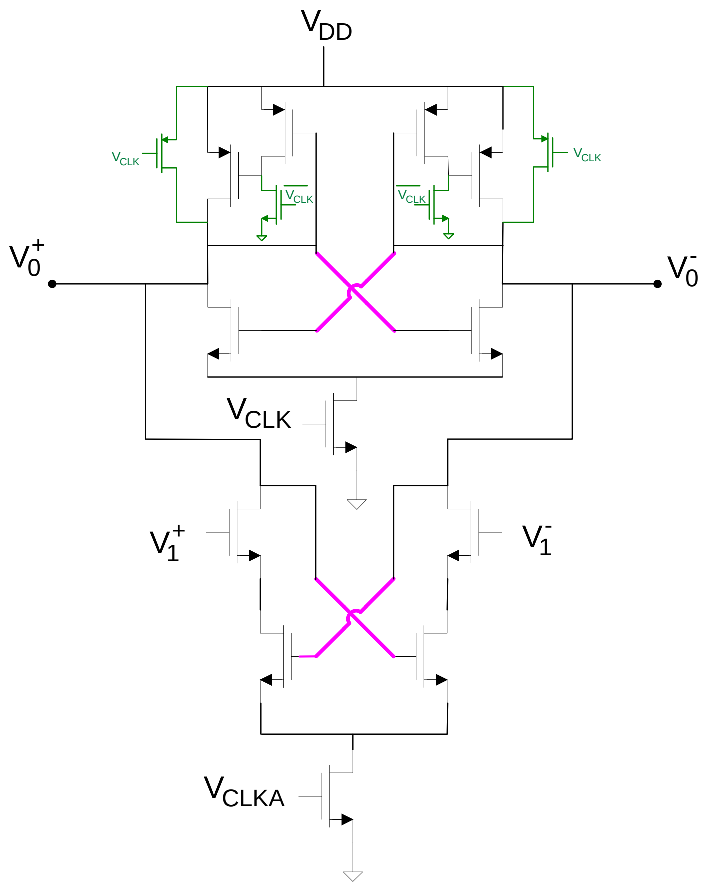
New Dynamic Comparator Structure



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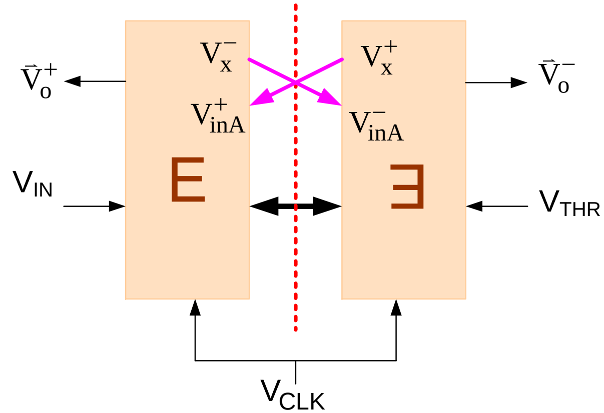
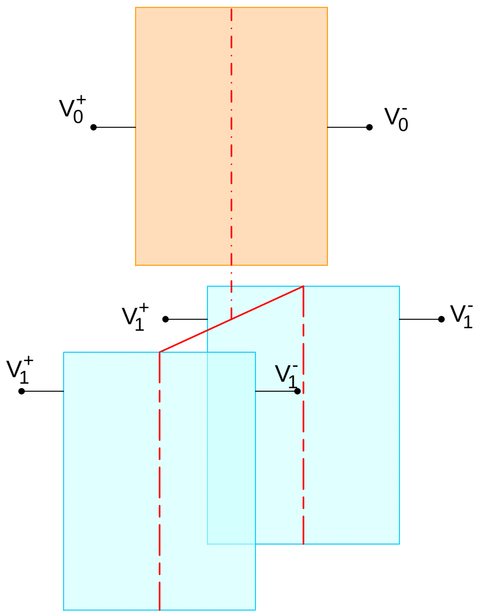
Natural questions arise -

If benefit was obtained from cascading p-channel devices in latch, how about cascading n-channel devices?

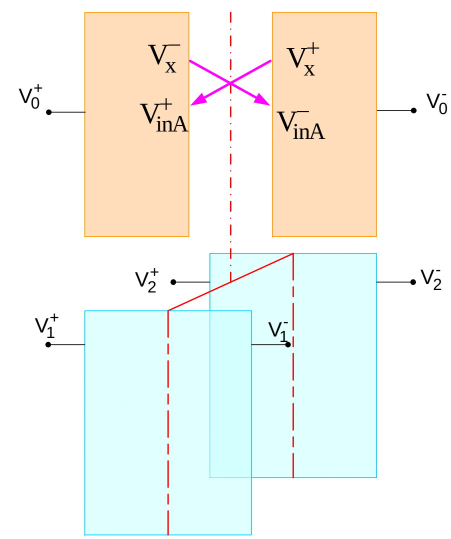
What about a fully-differential version of this concept?

Dynamic Comparator Structures





Symmetric Circuit
(V_{CLK} not shown)

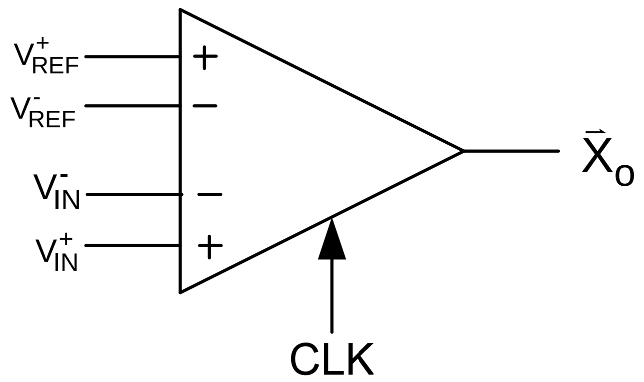


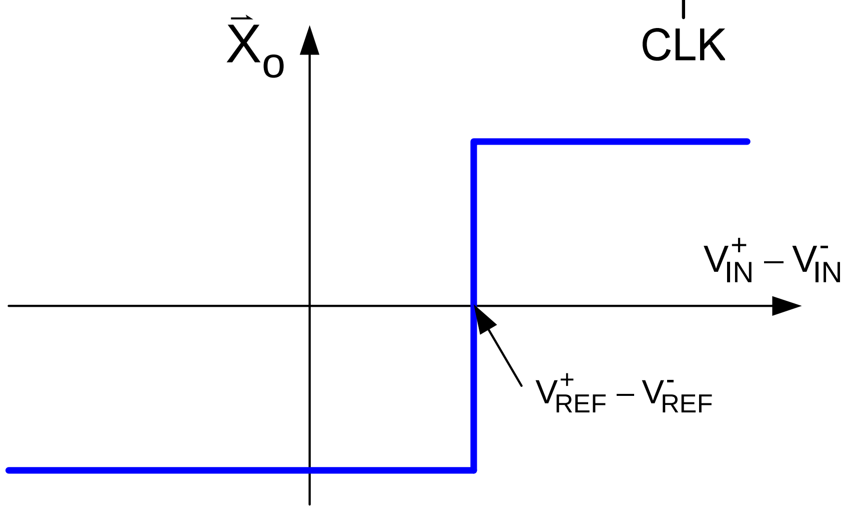
Symmetric Circuit with Regenerative Feedback (V_{CLK} not shown)

- Symmetric Circuit need not be planar
- Differential comparators often not planar

Differential Comparator

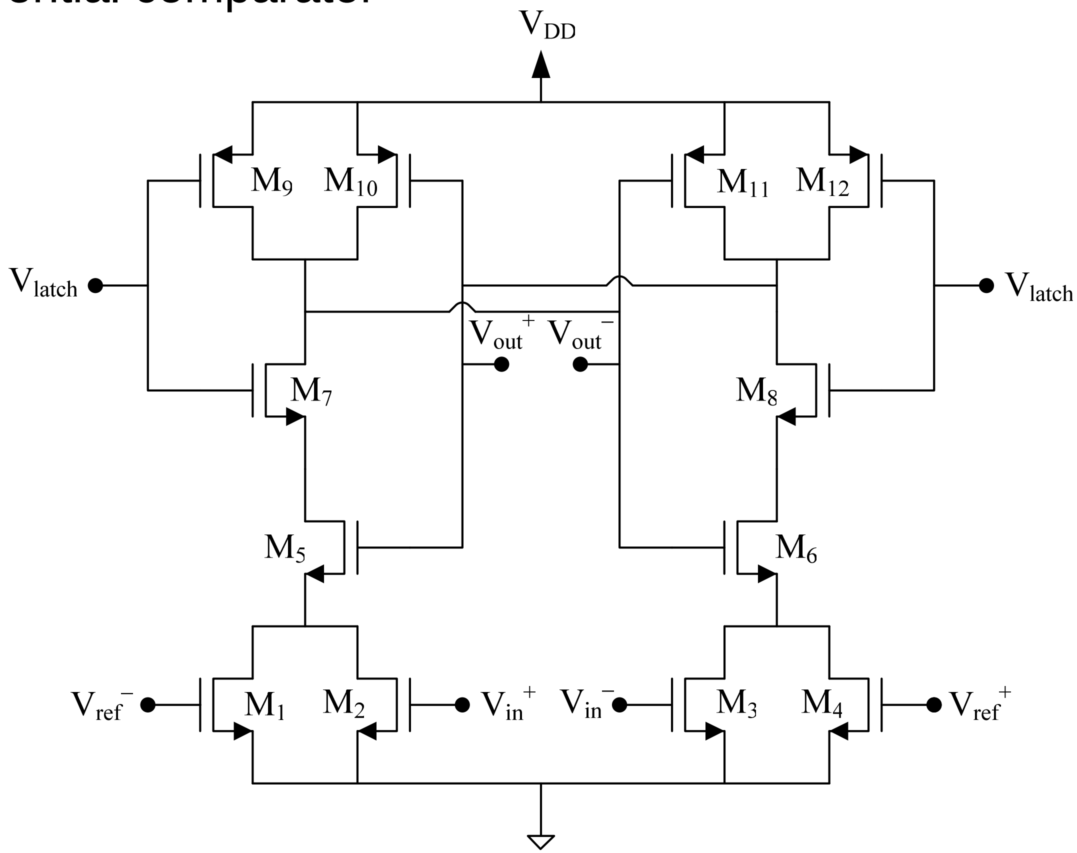
A differential comparator is a circuit that provides a high Boolean output if the differential input is positive and a low Boolean output if the differential input is negative





Differential Comparator

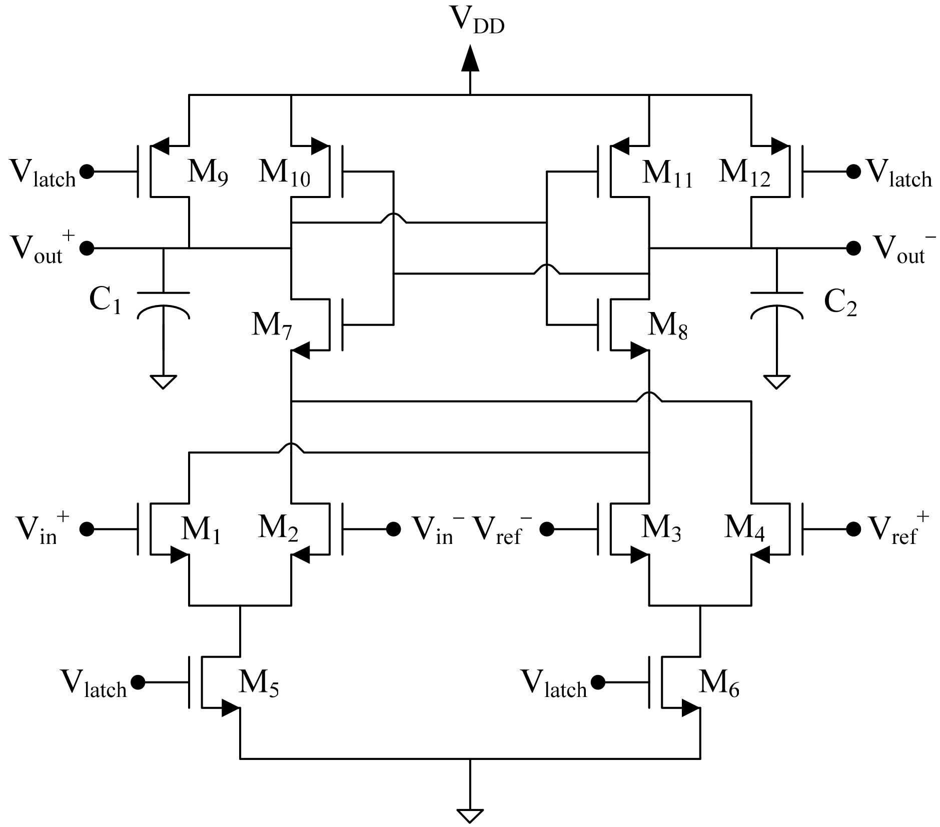
Popular differential comparator



Lewis – Gray Comparator

Differential Comparator

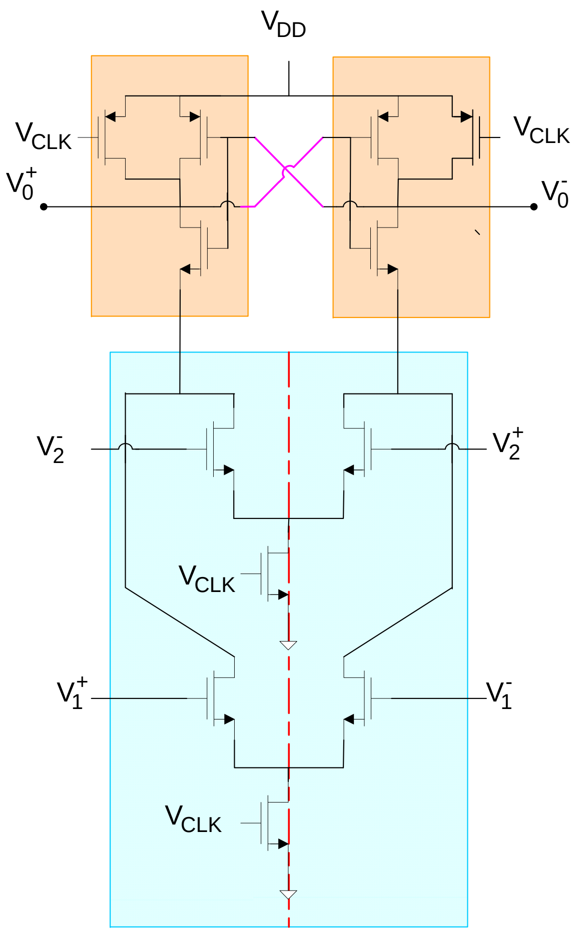
Popular differential comparator



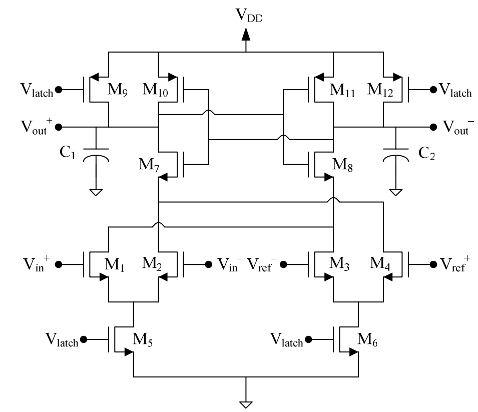
Halonen Comparator

Differential Comparator

Popular differential comparator

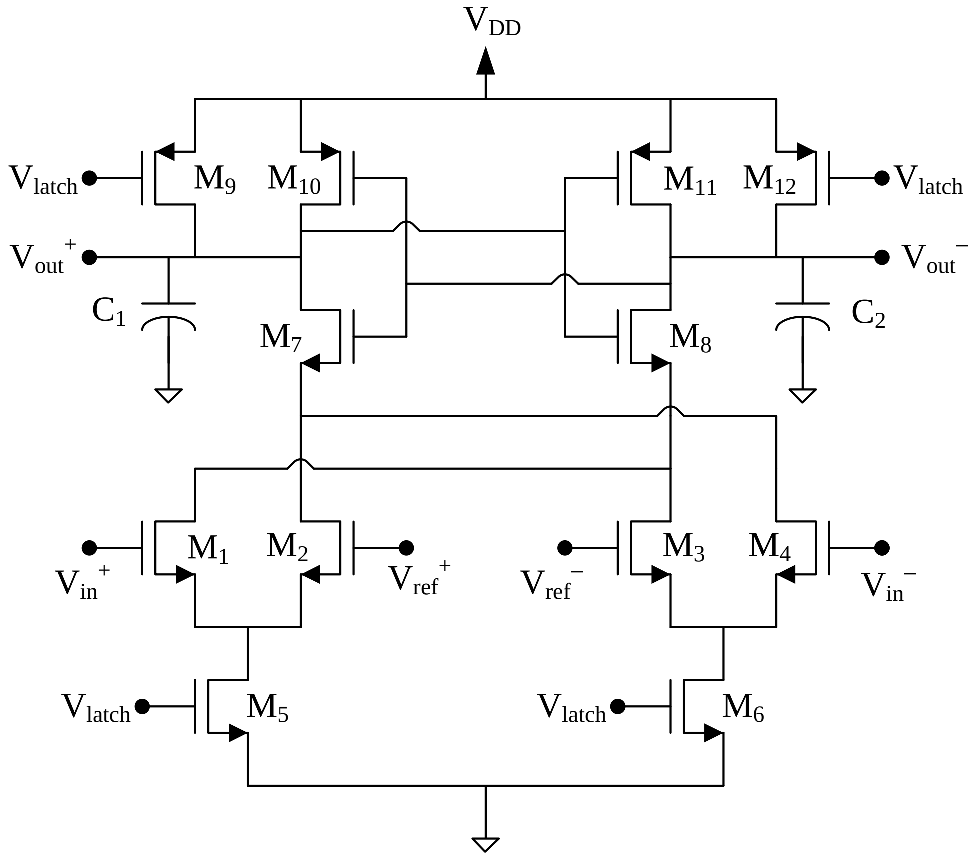


Halonen Comparator



Differential Comparator

Popular differential comparator

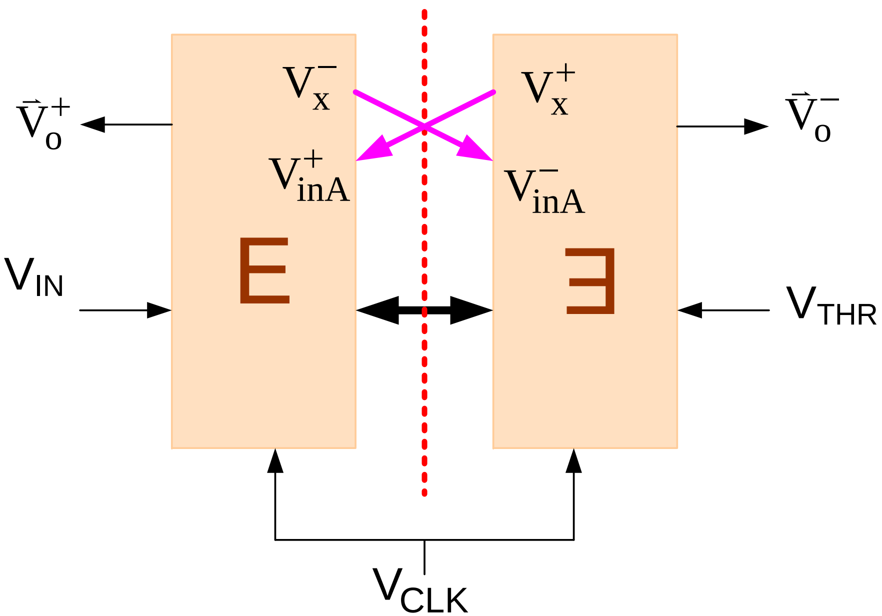


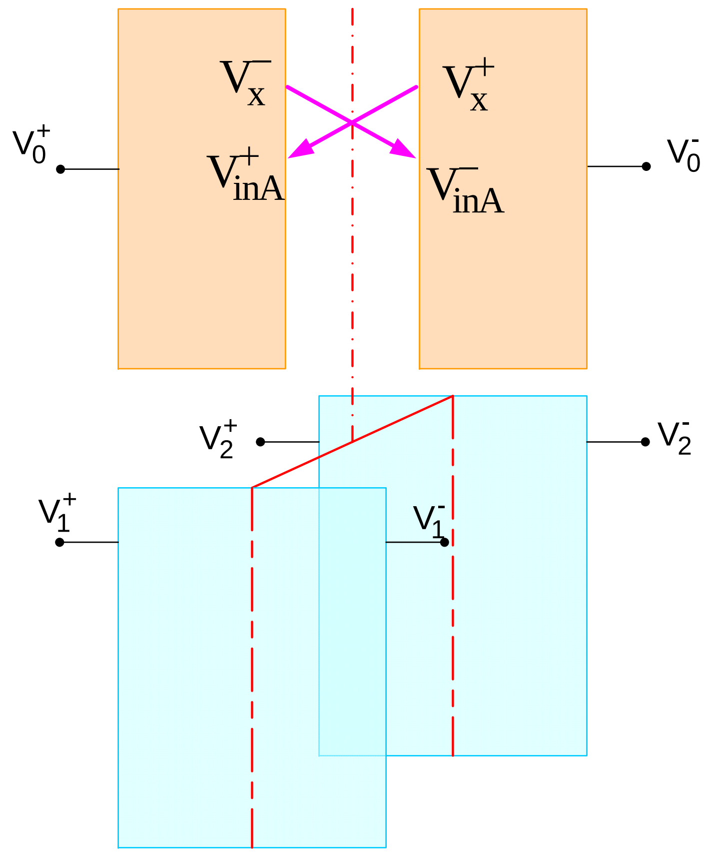
Katyal Comparator

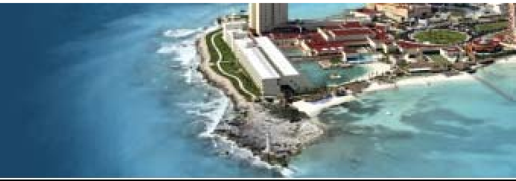
Dynamic Comparator Opportunities

- Dynamic Comparators can easily be designed
- Likely some of best structures have not evolved
- Symmetric circuit with regenerative feedback gives opportunity to identify new structures that may be particularly useful

Dynamic Comparator Opportunities







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The Midwest Symposium on Circuits and Systems (MWSCAS) is the oldest Circuits and Systems symposia sponsored by the IEEE. The 52nd symposium will be held in Cancun, Mexico. Topics include, but are not limited to:

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- CS4: Data Converters
- CS5: RF, Microwave Circuits
- CS6: Digital Circuits
- CS7: SoC and VLSI
- CS8: CAD and layout
- CS9: Verification
- CS10: Embedded Systems and Electronics
- CS11: Reconfigurable Computing
- CS12: Neural Networks and Fuzzy Systems
- CS13: Power Electronics
- CS14: Optics and Photonics
- CS15: Bioengineering Circuits and Systems
- CS16: MEMS/NEMS
- CS17: Digital Signal Processing
- CS18: Communications and Wireless Systems
- CS 19: Control Systems, Mechatronics and Robotics
- CS 20: Image Processing and Multimedia Systems
- CS21: Special Sessions

Prospective authors of papers describing original work are invited to submit full papers up to four pages long, with title, abstract, and topic category from the list above in standard IEEE two-column format for consideration as lecture or poster.Both formats have the same value, and presentation method will be chosen for suitability. All submissions should be made electronically through the conference web site at http://www-elec.inaoep.mx/mwscas2009. Students are encouraged to participate in the best student paper award contest. Accepted papers will be published in the conference proceedings subject to advance registration of at least one of the authors.

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Proposals for Special Sessions and Tutorials	February 20, 2009
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Special Session (invited) Papers submission	April 18, 2009
Notification of Acceptance	May 9, 2009

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