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Comparator Theory

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Contents

Comparator is a component that is used to indicate whether a signal V1 is higher than signal V2 or not. If V1 is connected to positive terminal of the comparator, high voltage shall be produced at the output. If not, low voltage is produced at the output. Thus, the output has one of two possible values; High or low.

Ideal comparator shall detect any small difference between two signals V1 and V2. However practical comparator can't detect difference lower than its resolution.

Resolution of the comparator is varying according to time available to comparison. If the time is long, comparator can be built with high resolution (can detect small differences, so high accuracy). If the time is short, resolution is going to be bigger (can't detect small differences). So design of the comparator is forced to trade off between resolution and speed. Also as well as any RF block, it is subjected to trade off between power consumption and area.

Comparators can be designed for Voltage comparison or Current comparison.

1 Transfer Characteristics of Comparators

Figure 1 shows static transfer characteristic of an ideal comparator where E_{OH} and E_{OL} are levels that correspond to the logic one and zero, respectively.

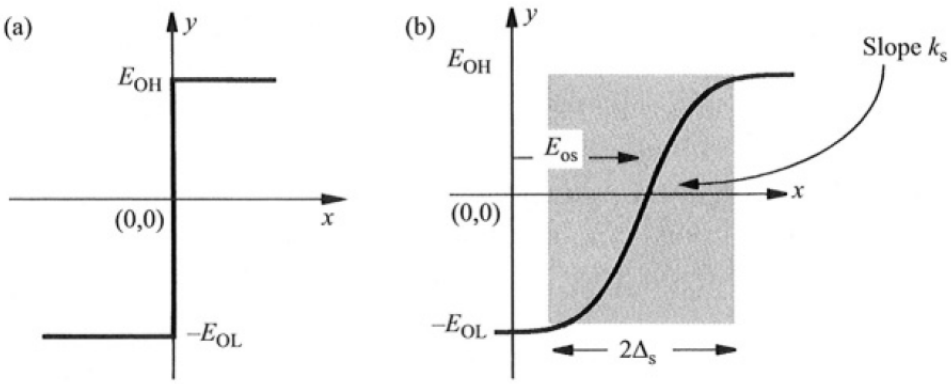


Figure 1: Comparator Transfer Characteristics (a) Ideal (b) Non-Ideal [1]

From Figure 1(a) it is seen that an ideal voltage comparator must exhibit infinite voltage gain around the zero value of the differential input x. Obviously, this cannot be achieved by any real device. Figure 14(b) shows a better approximation of the static transfer characteristics exhibited by actual comparators.

Therefore, the transfer characteristic is assumed to have a finite static gain k_s around an input offset voltage E_{OS}. On the basis of this nonlinear characteristic, the minimum value of the resolution, called herein static resolution, is $\xi \backsimeq \mid E_{OS} \mid + \frac{E_{OH}+E_{OL}}{2k_s}$

ξ is resolution of the comparator and it represents the shaded area. The random nature of the offset has been accounted for by including its modulus, and it has been assumed that the shaded transition interval is symmetrical around the input offset. For any input level inside the resolution area (shaded area), the comparator digital output state is uncertain.[1]

2 Comparators Architectures

If we looked at transfer characteristics of the comparator, you can find it is matching transfer characteristics of well known circuits like Inverters or Differential Amplifiers. This means that we can use Inverters or Differential Amplifiers to make a comparator.

2.1 Inverter Based Comparator

Inverter Transfer function can be read as if we have low voltage, we should get high voltage at the output. If we have high voltage we should get low voltage at the output. This is as shown in figure 2.

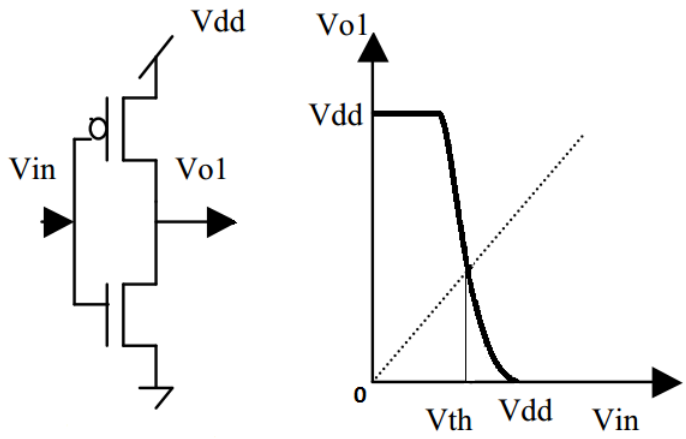


Figure 2: Transfer Characteristics of Inverter [2].

This is actually based on comparison with internal voltage Vth. i.e. if input voltage is higher than Vth, we will get 0 volts at the output. If we have lower voltage than Vth, high voltage will present at the output. Comparison here is between input voltage Vin and internal voltage Vth. In practice there is a comparator which is built using this idea. It is called TIQ comparator. Its simple structure is as shown in figure 3.

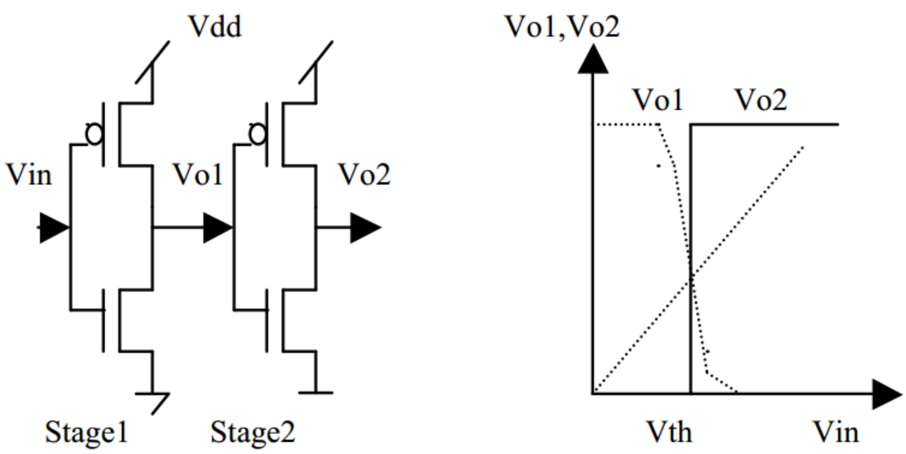


Figure 3: TIQ Comparator [2].

The second inverter stage is used for increased gain and logic level inversion so that the circuit behaves as an internally set comparator circuit The main idea of the TIQ comparator is that the reference voltage is internally fixed by the transistor size of the inverter.

2.2 Differential Pair Based Comparator

Another circuit that has transfer function as comparator function is the differential pair. In figure 4 you can notice that differential pair circuit is performing subtraction between V_{in1} and V_{in2}. So if difference is positive (that means V_{in1} is higher than V_{in2}), the output should be V_{DD}. If the difference is negative (that means V_{in2} is higher than V_{in1}), the output should be $V_{DD} - R_D I_{SS}$. Where R_D is active load DC resistance.

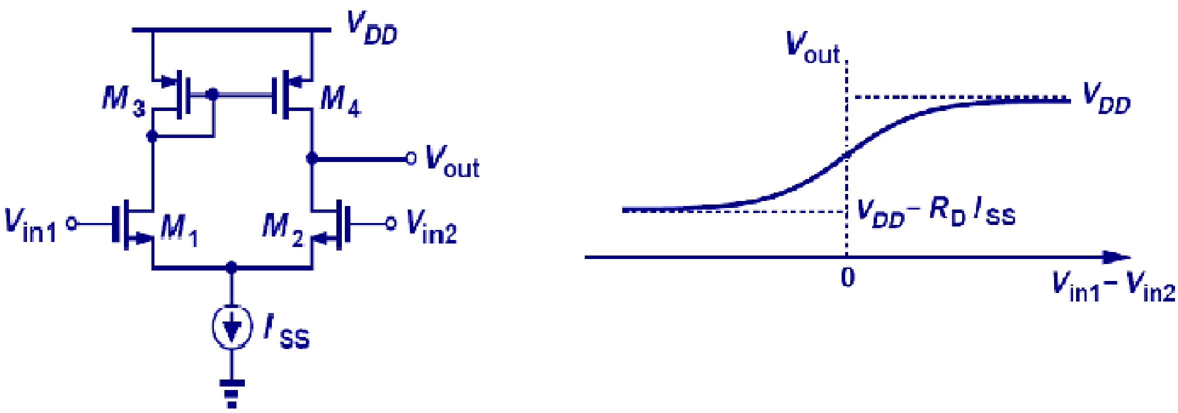
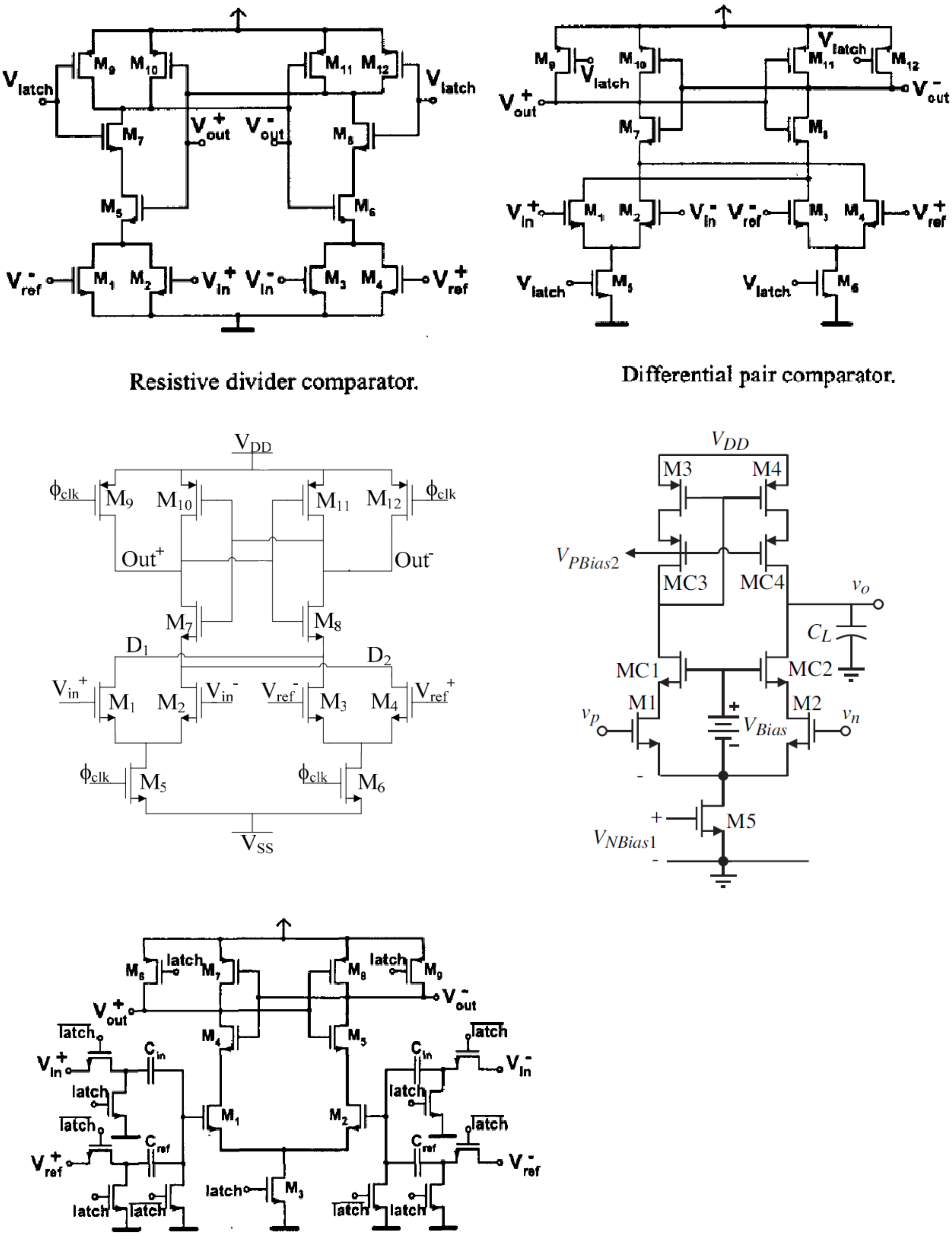


Figure 4: Transfer Characteristics of Differential Pair.

Practically Differential Pair is modified more to meet needs of the application. Too many architectures of the differential based comparators are now presented. Figure 5 shows examples of some architectures that were presented in many research papers



Resistive divider comparator.

Differential pair comparator.

Capacitive differential pair comparator.

Figure 5: Various Comparator Architectures [3].

Each of comparator architectures displayed in figure 5 is set to meet specific requirement. Generally comparator architectures can be classified as shown in figure 6.

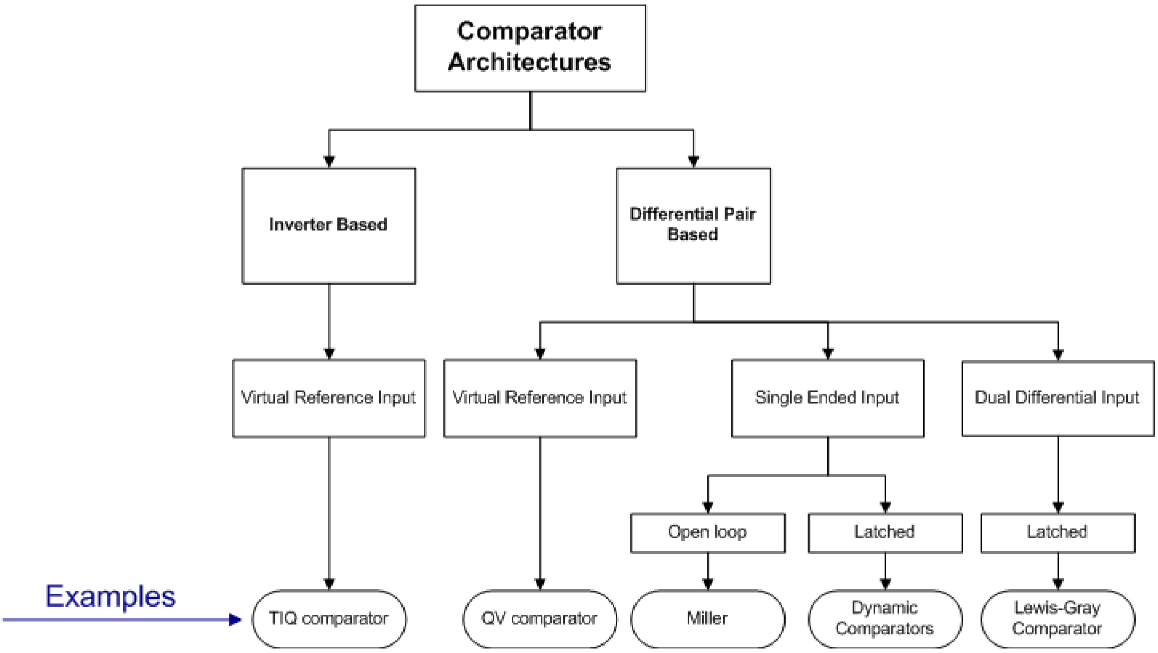


Figure 6: Classification of Comparator Architectures.

This figure is a trial to categorize all existing comparators architectures. ”Inverter Based” and ”Differential Based” terms were introduced before. Virtual Reference is the internal reference voltage that can be fixed by controlling MOSFET size (revise Inverter Based section). Single Ended input are comparators that accept input voltage and reference voltage as single ended. Dual differential Input are comparators that accept both input voltage and reference voltage but both are in differential form. Single Ended or Dual Differential Input can be latched or clocked. 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. Open loop comparators are simple differential pair but with 2 or more stages.

Bibliography

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[2] “The CMOS Inverter” as a comparator in ADC designs, Ali TANGEL, Kyusun CHOI.

[3] CMOS DYNAMIC COMPARATORS FOR PIPELINE A/D CONVERTERS, Lauri Sumanen, Mikko Waltari, Vaino Hakkarainen, Kari Halonen.