D/A AND A/D CONVERTERS

- All the real world quantities are analog in nature. We can represent these quantities electrically as analog signals.

- An **analog signal** is a time varying signal that has any number of values (variations) for a given time slot.

- A **digital signal** varies suddenly from one level to another level and will have only finite number of values (variations) for a given time slot.

- The electronic circuits, which can be operated with analog signals are called as analog circuits. Similarly, the electronic circuits, which can be operated with digital signals are called as digital circuits.

- A data converter is an electronic circuit that converts data of one form to another.

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There are two **types of data converters** −

- Analog to Digital Converter
- Digital to Analog Converter

If we want to connect the output of an analog circuit as an input of a digital circuit, then we have to place an interfacing circuit between them. This interfacing circuit that converts the analog signal into digital signal is called as **Analog to Digital Converter**.

Similarly, if we want to connect the output of a digital circuit as an input of an analog circuit, then we have to place an interfacing circuit between them. This interfacing circuit that converts the digital signal into an analog signal is called as **Digital to Analog Converter**.

The **specifications** that are related to data conversions are −

- Resolution
- Conversion Time

Resolution

Resolution of DAC is the minimum possible change at the output of the DAC for any change in digital input.

$$\text{Resolution} = \frac{V_R}{2^N - 1} \quad (\text{For N bit})$$

Resolution of ADC is the **minimum amount of change** needed in an analog input voltage for it to be represented in binary (digital) output. It depends on the number of bits that are used in the digital output.

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Mathematically, resolution can be represented as

$$\text{Resolution} = \frac{VFS}{2^N - 1}$$

where,
VFS is the full scale input voltage or maximum analog input voltage,
'N' is the number of bits that are present in the digital output.

Conversion Time

The amount of time required for a data converter in order to convert the data (information) of one form into its equivalent data in other form is called as **conversion time**. Since we have two types of data converters, there are two types of conversion times as follows:

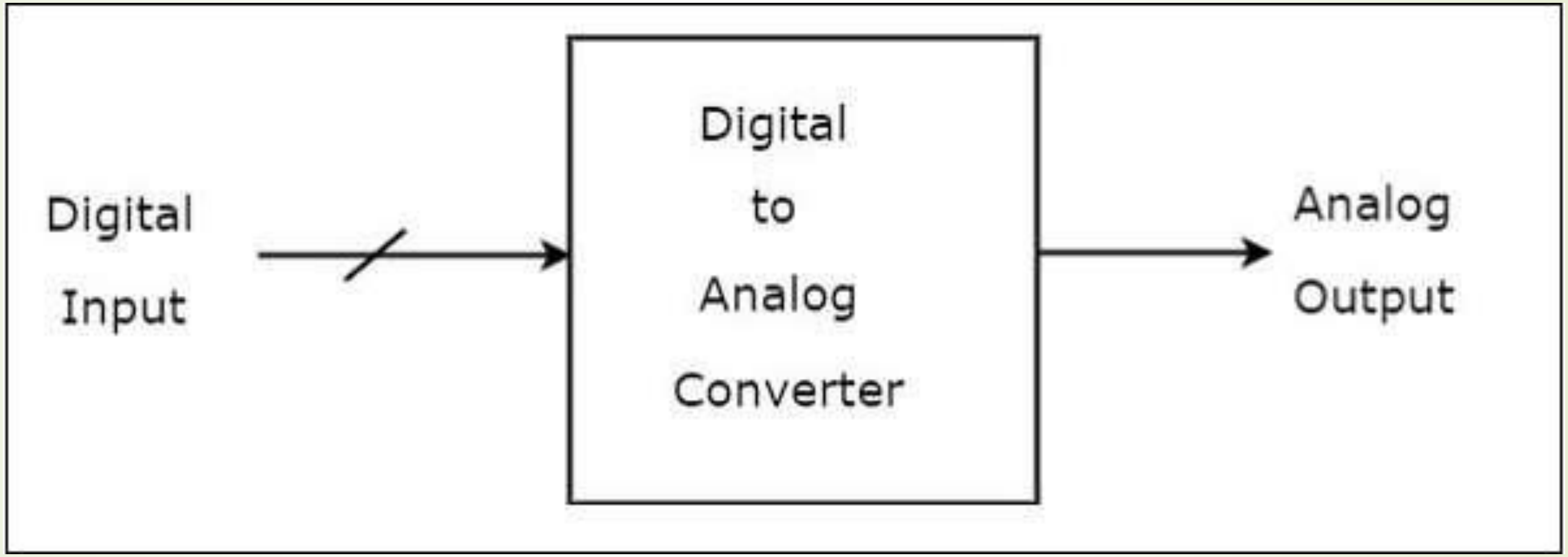
•Analog to Digital Conversion time
•Digital to Analog Conversion time

The amount of time required for an Analog to Digital Converter (ADC) to convert the analog input voltage into its equivalent binary (digital) output is called as **Analog to Digital conversion time**. It depends on the number of bits that are used in the digital output.

The amount of time required for a Digital to Analog Converter (DAC) to convert the binary (digital) input into its equivalent analog output voltage is called as **Digital to Analog conversion time**. It depends on the number of bits that are present in the binary (digital) input.

D/A Converter

A **Digital to Analog Converter (DAC)** converts a digital input signal into an analog output signal. The digital signal is represented with a binary code, which is a combination of bits 0 and 1.



A Digital to Analog Converter (DAC) consists of a number of binary inputs and a single output.

Types of DACs

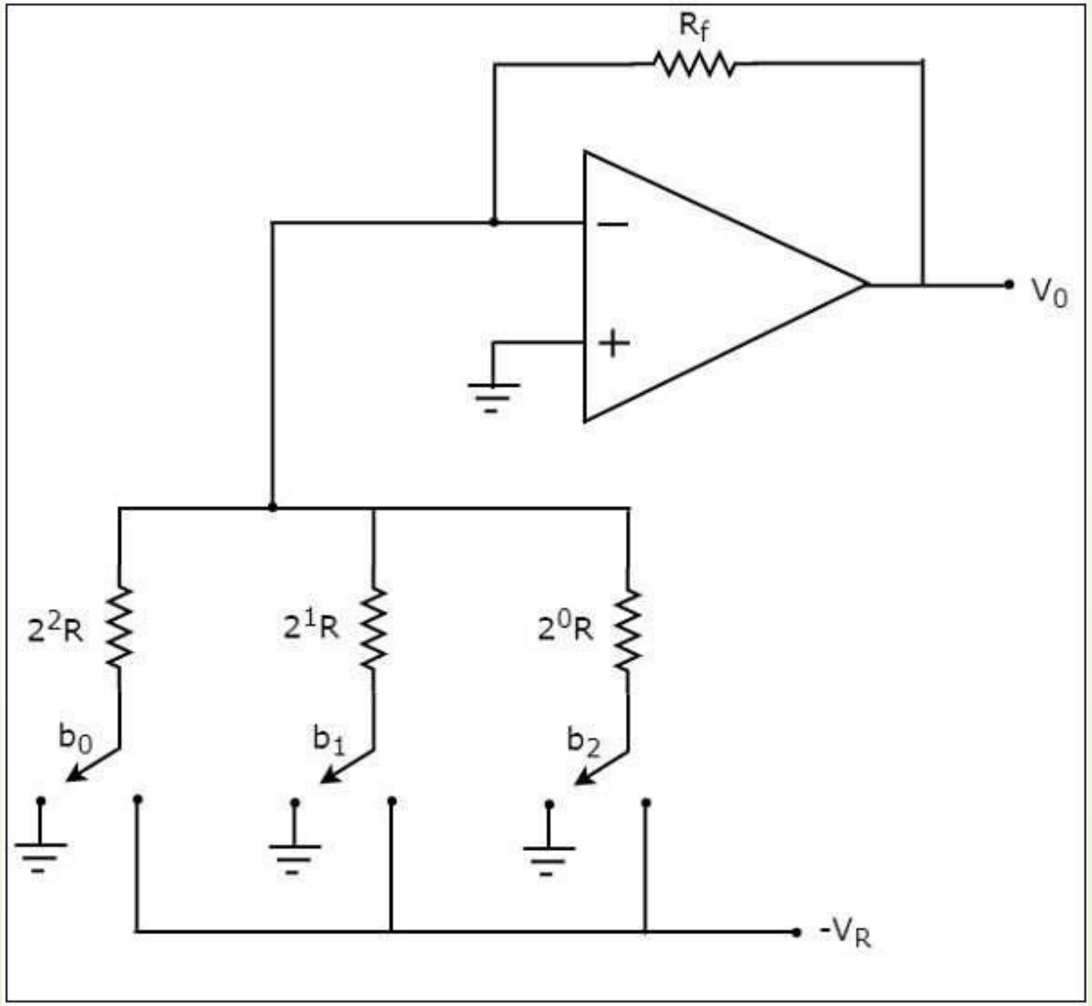
There are **two types** of DACs:

•Weighted Resistor DAC

•R-2R Ladder DAC

Weighted Resistor DAC

A weighted resistor DAC produces an analog output, which is almost equal to the digital (binary) input by using **binary weighted resistors** in the inverting adder circuit. In short, a binary weighted resistor DAC is called as weighted resistor DAC.



The bits of a binary number can have only one of the two values. i.e., either 0 or 1.

- Let the **3-bit binary input** is $b_2 b_1 b_0$. Here, the bits b_2 and b_0 denote the **Most Significant Bit (MSB) and Least Significant Bit (LSB)** respectively.

- The **digital switches** shown in the above figure will be connected to ground, when the corresponding input bits are equal to ‘0’. Similarly, the digital switches shown in the above figure will be connected to the negative reference voltage, $-$VR when the corresponding input bits are equal to ‘1’.

- In the above circuit, the non-inverting input terminal of an op-amp is connected to ground. That means zero volts is applied at the non-inverting input terminal of op-amp.

- According to the **virtual short concept**, the voltage at the inverting input terminal of opamp is same as that of the voltage present at its non-inverting input terminal. So, the voltage at the inverting input terminal’s node will be zero volts.

The **nodal equation** at the inverting input terminal's node is:

$$\frac{0+V_R b_2}{2^0 R}+\frac{0+V_R b_1}{2^1 R}+\frac{0+V_R b_0}{2^2 R}+\frac{0-V_0}{R_f}=0$$

$$=> \frac{V_0}{R_f}=\frac{V_R b_2}{2^0 R}+\frac{V_R b_1}{2^1 R}+\frac{V_R b_0}{2^2 R}$$

$$=> V_0=\frac{V_R R_f}{R}\left\{\frac{b_2}{2^0}+\frac{b_1}{2^1}+\frac{b_0}{2^2}\right\}$$

Substituting, $R=2R_f$ f in above equation.

$$=> V_0=\frac{V_R R_f}{2R_f}\left\{\frac{b_2}{2^0}+\frac{b_1}{2^1}+\frac{b_0}{2^2}\right\}$$

$$=> V_0=\frac{V_R}{2}\left\{\frac{b_2}{2^0}+\frac{b_1}{2^1}+\frac{b_0}{2^2}\right\}$$

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The above equation represents the **output voltage equation** of a 3-bit binary weighted resistor DAC. Since the number of bits are three in the binary (digital) input, we will get seven possible values of output voltage by varying the binary input from 000 to 111 for a fixed reference voltage, V_R.

We can write the **generalized output voltage equation** of an N-bit binary weighted resistor DAC as shown below based on the output voltage equation of a 3-bit binary weighted resistor DAC.

$$=> V_0 = \frac{V_R}{2}\left\{\frac{b_{N-1}}{2^0} + \frac{b_{N-2}}{2^1} + \ldots + \frac{b_0}{2^{N-1}}\right\}$$

The **disadvantages** of a binary weighted resistor DAC are as follows −

•The difference between the resistance values corresponding to LSB & MSB will increase as the number of bits present in the digital input increases.

•It is difficult to design more accurate resistors as the number of bits present in the digital input increases.

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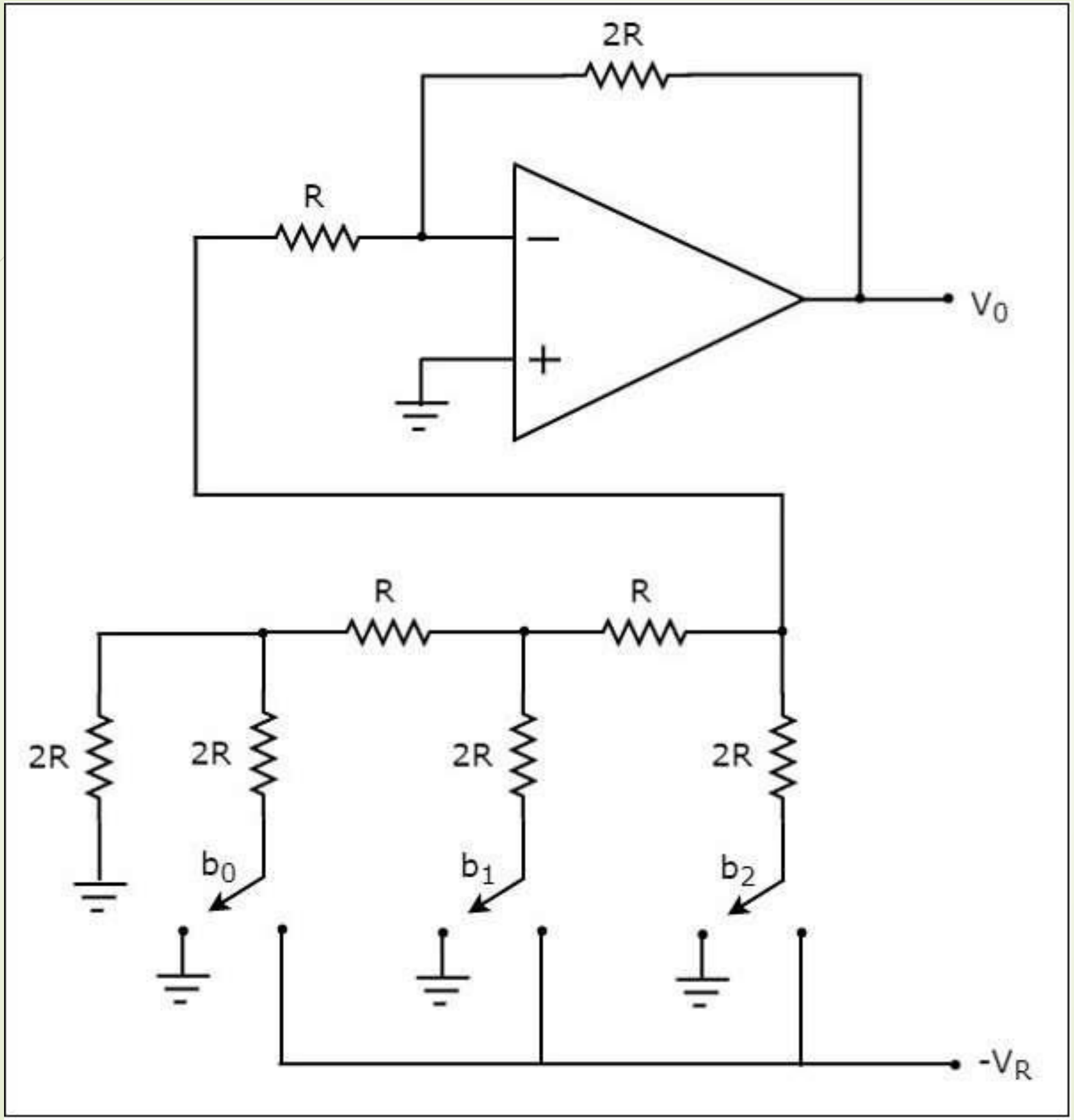
R-2R Ladder DAC

The R-2R Ladder DAC overcomes the disadvantages of a binary weighted resistor DAC. As the name suggests, R-2R Ladder DAC produces an analog output, which is almost equal to the digital (binary) input by using a **R-2R ladder network** in the inverting adder circuit.



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Recall that the bits of a binary number can have only one of the two values. i.e., either 0 or 1.

Let the **3-bit binary input** is $b_2 b_1 b_0$. Here, the bits b_2 and b_0 denote the Most Significant Bit (MSB) and Least Significant Bit (LSB) respectively.

The digital switches shown in the above figure will be connected to ground, when the corresponding input bits are equal to ‘0’. Similarly, the digital switches shown in above figure will be connected to the negative reference voltage, −VR when the corresponding input bits are equal to ‘1’.

It is difficult to get the generalized output voltage equation of a R-2R Ladder DAC. But, we can find the analog output voltage values of R-2R Ladder DAC for individual binary input combinations easily.

The **advantages** of a R-2R Ladder DAC are as follows −

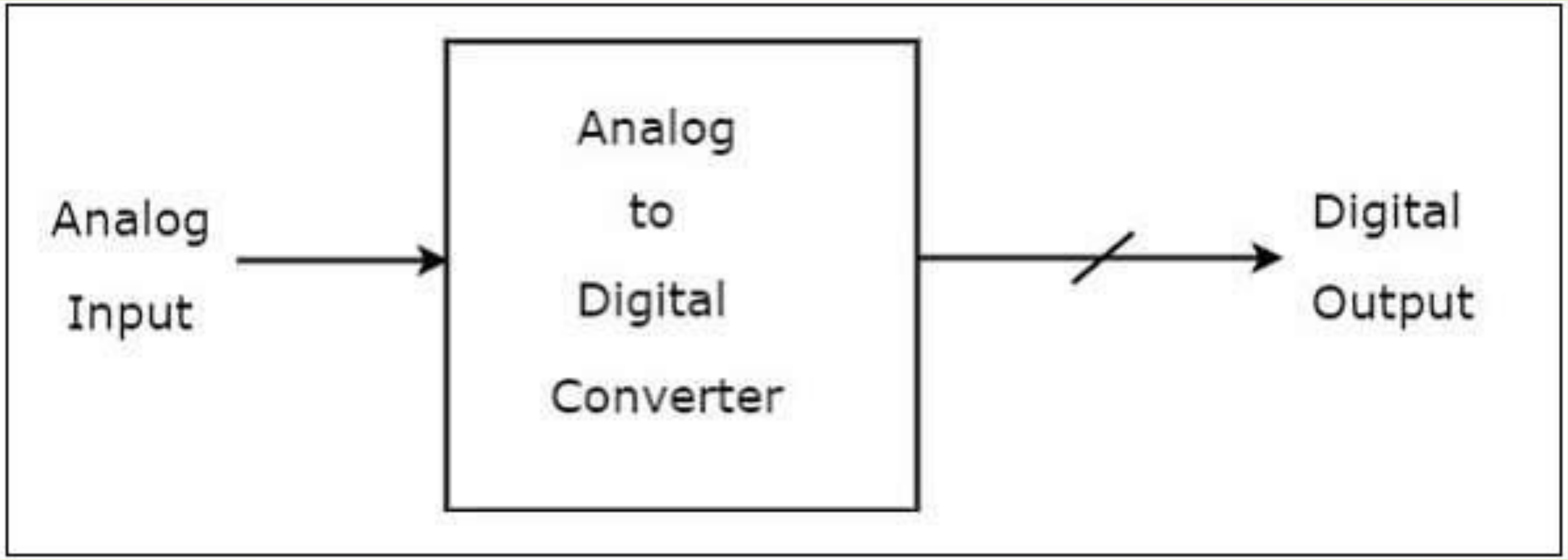
•R-2R Ladder DAC contains only two values of resistor: R and 2R. So, it is easy to select and design more accurate resistors.

•If more number of bits are present in the digital input, then we have to include required number of R-2R sections additionally.

Due to the above advantages, R-2R Ladder DAC is preferable over binary weighted resistor DAC.

Analog to Digital Converter

An Analog to Digital Converter **(ADC)** converts an analog signal into a digital signal. The digital signal is represented with a binary code, which is a combination of bits 0 and 1.



Observe that in the figure shown above, an Analog to Digital Converter **(ADC)** consists of a single analog input and many binary outputs. In general, the number of binary outputs of ADC will be a power of two.

There are **two types** of ADCs: Direct type ADC
Indirect type ADC

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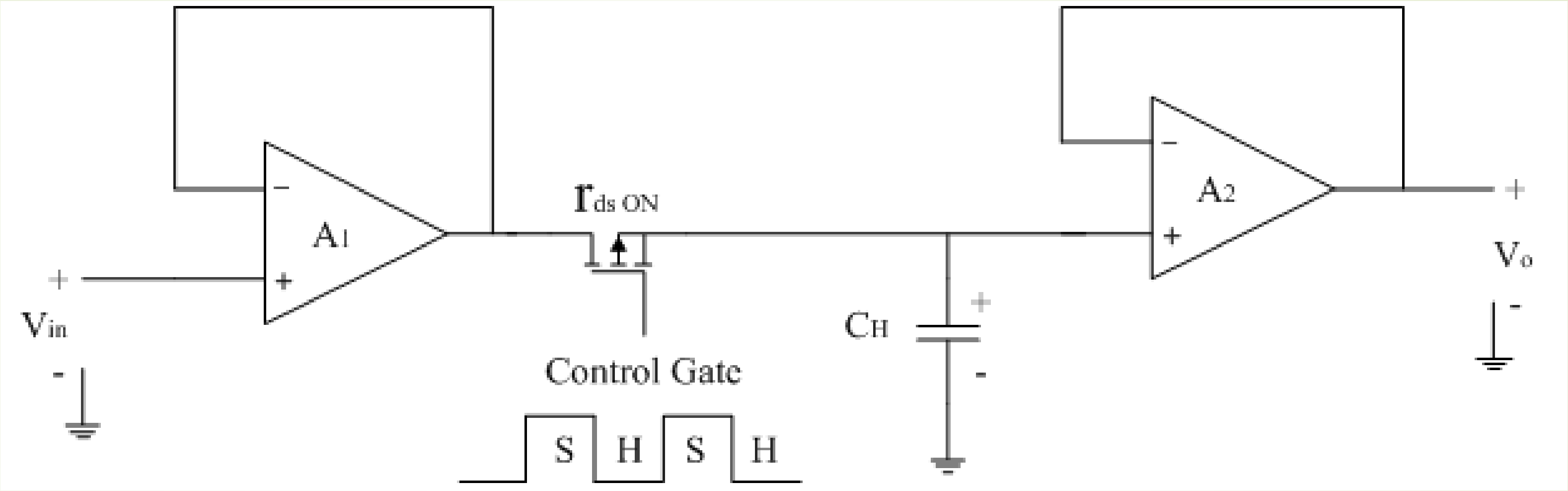
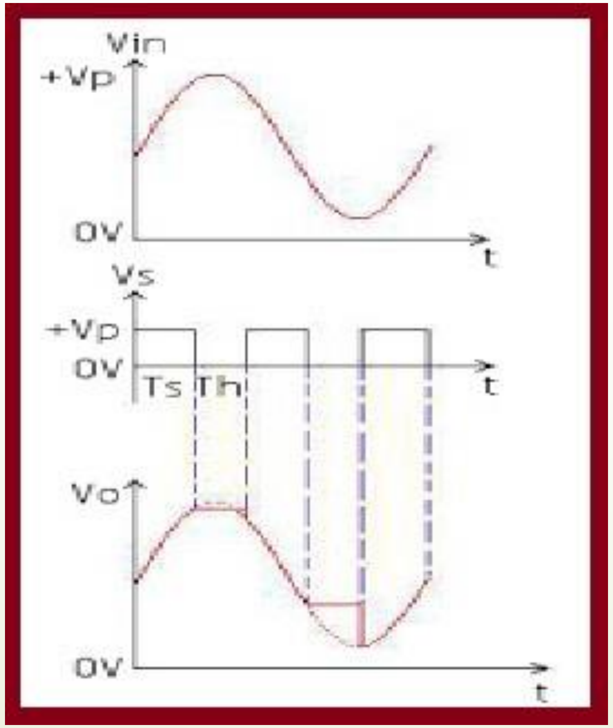
Sample and Hold Circuit





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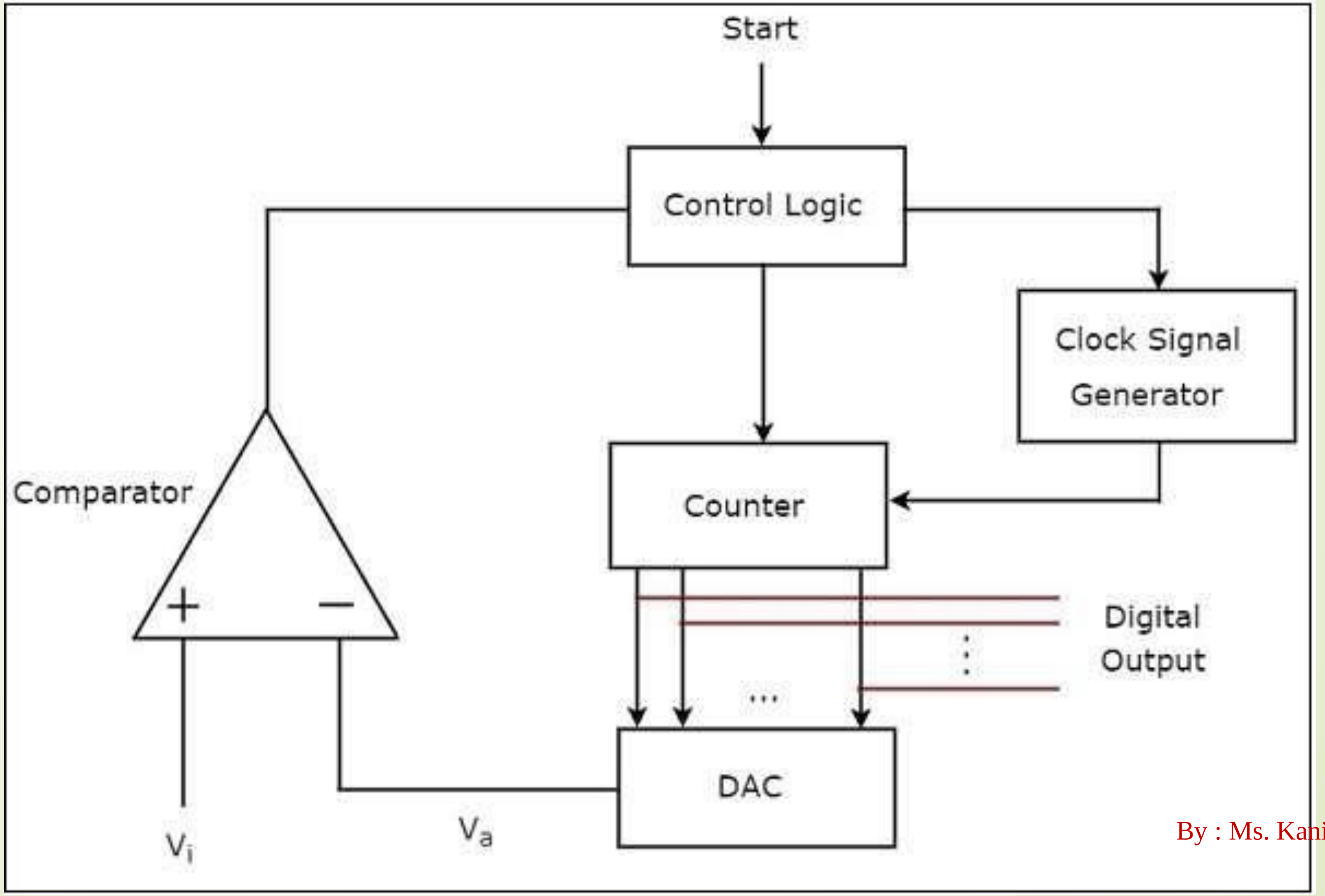
Counter type ADC

A **counter type ADC** produces a digital output, which is approximately equal to the analog input by using counter operation internally.



The counter type ADC mainly consists of 5 blocks: Clock signal generator, Counter, DAC, Comparator and Control logic.

The **working** of a counter type ADC is as follows −

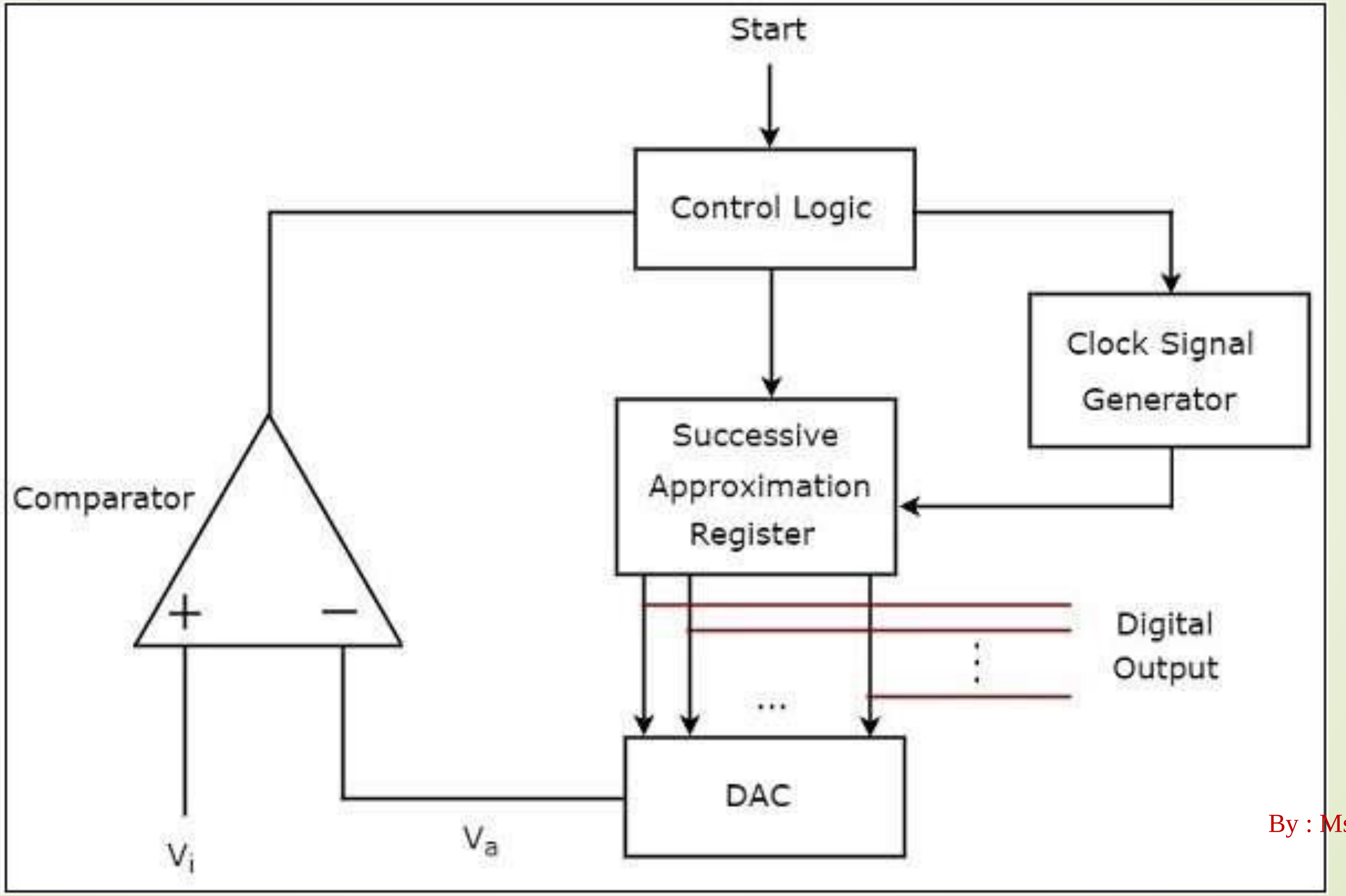
•The **control logic** resets the counter and enables the clock signal generator in order to send the clock pulses to the counter, when it received the start commanding signal.

•The **counter** gets incremented by one for every clock pulse and its value will be in binary (digital) format. This output of the counter is applied as an input of DAC.

•**DAC** converts the received binary (digital) input, which is the output of counter, into an analog output. Comparator compares this analog value,V_a with the external analog input value V_i.
•The **output of comparator** will be **'1'** as long as V_i is greater than. The operations mentioned in above two steps will be continued as long as the control logic receives '1' from the output of comparator.
•The **output of comparator** will be **'0'** when V_i is less than or equal to V_a. So, the control logic receives '0' from the output of comparator. Then, the control logic disables the clock signal generator so that it doesn't send any clock pulse to the counter.
•At this instant, the output of the counter will be displayed as the **digital output**. It is almost equivalent to the corresponding external analog input value V_i.

Successive approximation ADC

A **successive approximation type ADC** produces a digital output, which is approximately equal to the analog input by using successive approximation technique internally.



The successive approximation ADC mainly consists of 5 blocks− Clock signal generator, Successive Approximation Register (SAR), DAC, comparator and Control logic.

The **working** of a successive approximation ADC is as follows −

•The **control logic** resets all the bits of SAR and enables the clock signal generator in order to send the clock pulses to SAR, when it received the start commanding signal.

•The binary (digital) data present in **SAR** will be updated for every clock pulse based on the output of comparator. The output of SAR is applied as an input of DAC.

•**DAC** converts the received digital input, which is the output of SAR, into an analog output. The comparator compares this analog value V_a with the external analog input value V_i.

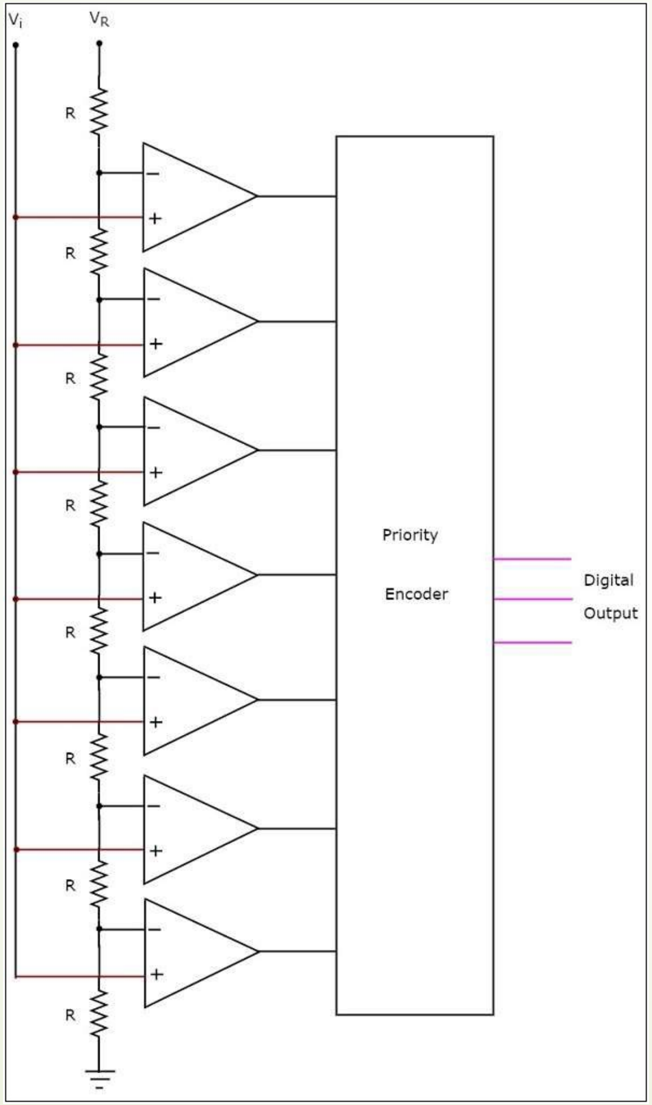
•The **output of a comparator** will be '1' as long as V_i is greater than V_a. Similarly, the output of comparator will be '0', when V_i is less than or equal to V_a.

•The operations mentioned in above steps will be continued until the digital output is a valid one.
The digital output will be a valid one, when it is almost equivalent to the corresponding external analog input value V_i.

Flash type ADC

A **flash type ADC** produces an equivalent digital output for a corresponding analog input in no time. Hence, flash type ADC is the fastest ADC.

The **circuit diagram** of a 3-bit flash type ADC is shown in the following figure −



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The 3-bit flash type ADC consists of a voltage divider network, 7 comparators and a priority encoder. The **working** of a 3-bit flash type ADC is as follows.

•The **voltage divider network**contains 8 equal resistors. A reference voltage VRVR is applied across that entire network with respect to the ground. The voltage drop across each resistor from bottom to top with respect to ground will be the integer multiples (from 1 to 8) of VR8VR8.

•The external **input voltage** ViVi is applied to the non-inverting terminal of all comparators. The voltage drop across each resistor from bottom to top with respect to ground is applied to the inverting terminal of comparators from bottom to top.

•At a time, all the comparators compare the external input voltage with the voltage drops present at the respective other input terminal. That means, the comparison operations take place by each comparator **parallelly**.

•The **output of the comparator** will be ‘1’ as long as ViVi is greater than the voltage drop present at the respective other input terminal. Similarly, the output of comparator will be ‘0’, when, ViVi is less than or equal to the voltage drop present at the respective other input terminal.

•All the outputs of comparators are connected as the inputs of **priority encoder**.This priority encoder produces a binary code (digital output), which is corresponding to the high priority input that has ‘1’.

•Therefore, the output of priority encoder is nothing but the binary equivalent **(digital output)** of external analog input voltage, ViVi.

The flash type ADC is used in the applications where the conversion speed of analog input into digital data should be very high.

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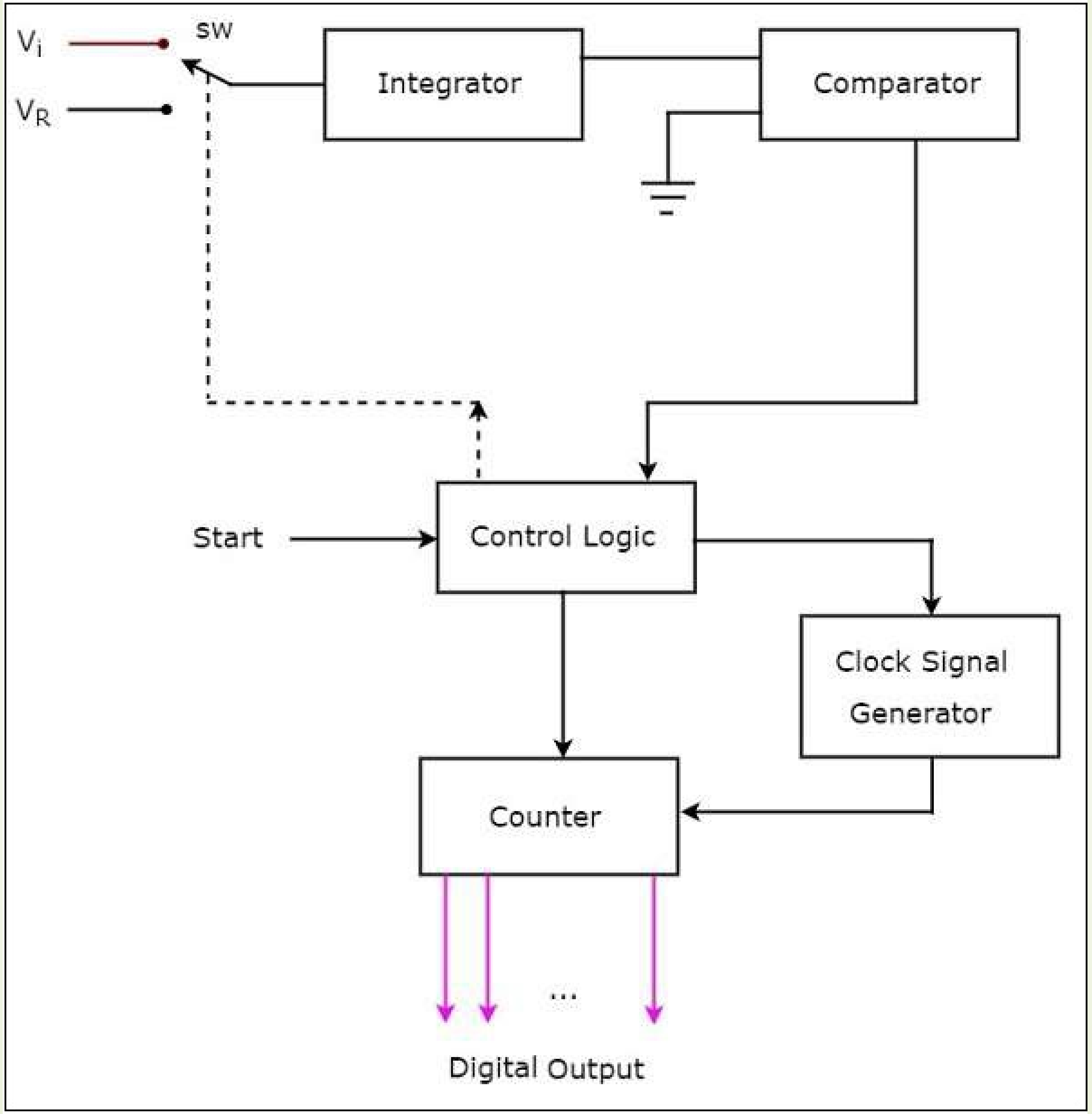
Dual Slope ADC

If an ADC performs the analog to digital conversion by an indirect method, then it is called an **Indirect type ADC**. In general, first it converts the analog input into a linear function of time (or frequency) and then it will produce the digital (binary) output.
Dual slope ADC is the best **example** of an Indirect type ADC.

As the name suggests, a dual slope ADC produces an equivalent digital output for a corresponding analog input by using two (dual) slope technique.
The block diagram of a dual slope ADC is shown in the following figure −



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The dual slope ADC mainly consists of 5 blocks: Integrator, Comparator, Clock signal generator, Control logic and Counter.

The **working** of a dual slope ADC is as follows −

- The **control logic** resets the counter and enables the clock signal generator in order to send the clock pulses to the counter, when it is received the start commanding signal.
- Control logic pushes the switch **sw** to connect to the **external analog input voltage** ViVi, when it is received the start commanding signal. This input voltage is applied to an integrator.
- The output of the **integrator** is connected to one of the two inputs of the comparator and the other input of comparator is connected to ground.
- **Comparator** compares the output of the integrator with zero volts (ground) and produces an output, which is applied to the control logic.
- The **counter** gets incremented by one for every clock pulse and its value will be in binary (digital) format. It produces an overflow signal to the control logic, when it is incremented after reaching the maximum count value. At this instant, all the bits of counter will be having zeros only.
- Now, the control logic pushes the switch **sw** to connect to the **negative reference** voltage −Vref−Vref. This negative reference voltage is applied to an integrator. It removes the charge stored in the capacitor until it becomes zero.
- At this instant, both the inputs of a comparator are having zero volts. So, comparator sends a signal to the control logic. Now, the control logic disables the clock signal generator and retains (holds) the counter value. The **counter value** is proportional to the external analog input voltage.
- At this instant, the output of the counter will be displayed as the **digital output**. It is almost equivalent to the corresponding external analog input value ViVi.

The dual slope ADC is used in the applications, where **accuracy** is more important while converting analog input into its equivalent digital (binary) data.

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