Introduction of Sequential Circuits

Sequential circuits are digital circuits that store and use the previous state information to determine their next state. Unlike combinational circuits, which only depend on the current input values to produce outputs, sequential circuits depend on both the current inputs and the previous state stored in memory elements.

Sequential Circuit

Sequential circuits are digital circuits that store and use previous state information to determine their next state. They are commonly used in digital systems to implement state machines, timers, counters, and memory elements and are essential components in digital systems design. Sequential circuits are commonly used in digital systems to implement state machines, timers, counters, and memory elements. The memory elements in sequential circuits can be implemented using flip-flops, which are circuits that store binary values and maintain their state even when the inputs change.

Sequential circuit is a combinational logic circuit that consists of inputs variable (X), logic gates (Computational circuit), and output variables (Z).

Figure: Combinational Circuits

A combinational circuit produces an output based on input variables only, but a sequential circuit produces an output based on current input and previous output variables. That means sequential circuits include memory elements that are capable of storing binary information.

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That binary information defines the state of the sequential circuit at that time. A latch capable of storing one bit of information.

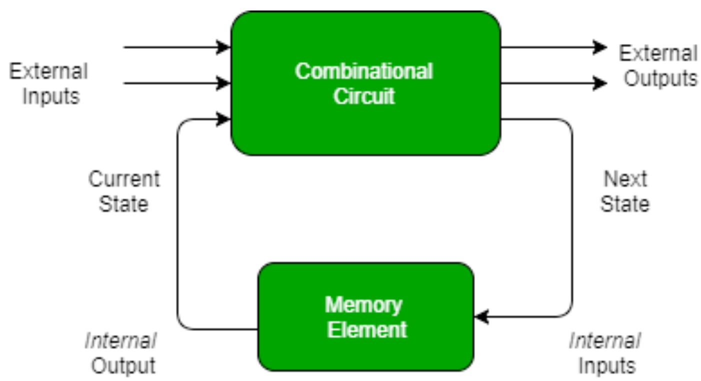

Figure: Sequential Circuit

As shown in the figure, there are two types of input to the combinational logic :

1. External inputs which are not controlled by the circuit.
2. Internal inputs, which are a function of a previous output state.

Secondary inputs are state variables produced by the storage elements, whereas secondary outputs are excitations for the storage elements.

Types of Sequential Circuits

There are two types of sequential circuits

1) Asynchronous Sequential Circuit

These circuits do not use a clock signal but uses the pulses of the inputs. These circuits are faster than synchronous sequential circuits because there is clock pulse and change their state immediately when there is a change in the input signal. We use asynchronous sequential circuits when speed of operation is important and independent of internal clock pulse.

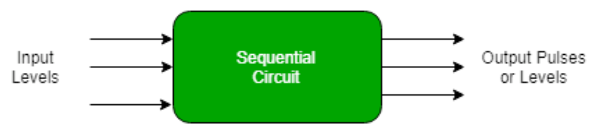

Figure: Asynchronous Sequential Circuit

But these circuits are more difficult to design and their output is uncertain.

2) Synchronous Sequential Circuit

These circuits uses clock signal and level inputs (or pulsed) (with restrictions on pulse width and circuit propagation). The output pulse is the same duration as the clock pulse for the clocked sequential circuits. Since they wait for the next clock pulse to arrive to perform the next operation, so these circuits are bit slower compared to asynchronous. Level output changes state at the start of an input pulse and remains in that until the next input or clock pulse.

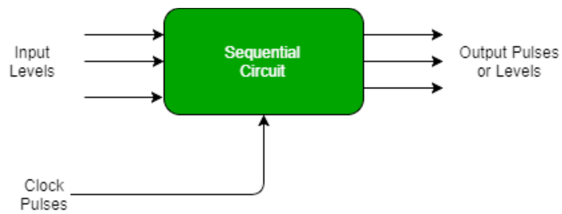

Figure: Synchronous Sequential Circuit

We use synchronous sequential circuits in synchronous counters, flip flops, and in the design of MOORE-MEALY state management machines. We use sequential circuits to design Counters, Registers, RAM, MOORE/MEALY Machine and other state retaining machines.

Clock Signal and Triggering

Clock signal is a kind of control signal that allows the elements of synchronous circuits to be in phase or phenomena that occur in circuits. It is derived from the square wave that has a high and a low level, it helps in measuring the sequential changes in the circuit states. The clock signal also makes a pulse simultaneously on all the circuit parts that are needed for the proper work of synchronous sequential circuits.

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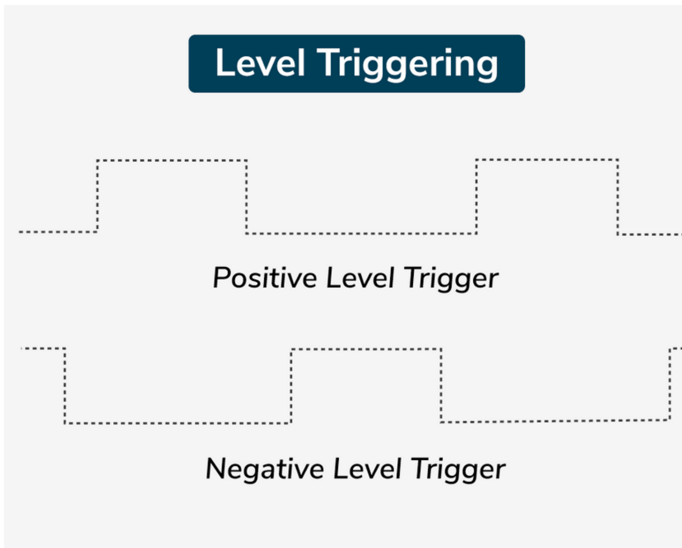
Types of Triggering

In Sequential circuits, triggering denotes the way, in terms of which the state changes take place. There are two main types of triggering



Level Triggering

Level triggering happens when the change of state is from the level of the clock signal is high or low. The circuit depends on the level of the clock signal rather than the rising or the falling edge of it. There are two types of level triggering:

1. **Positive Level Triggering: The circuit changes state when it is high time in the clock cycle i.e. when the clock signal is high.**
2. **Negative Level Triggering: The circuit changes state when the clock signal is in the low state.**

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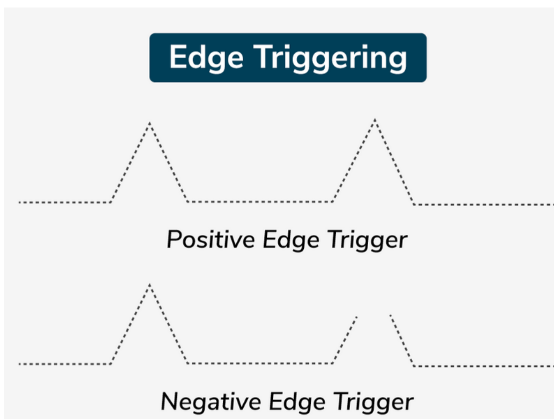
Edge Triggering

Edge triggering occurs when the state change is initiated by the transition (rising or falling edge) of the clock signal. The circuit responds to the clock signal's edges rather than its levels. There are two types of edge triggering:

1. **Positive Edge Triggering: The circuit changes state on the rising edge (transition from low to high) of the clock signal.**
2. **Negative Edge Triggering: The circuit changes state on the falling edge (transition from high to low) of the clock signal.**



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Advantages of Sequential Circuits

1. **Memory: Sequential circuits have the ability to store binary values, which makes them ideal for applications that require memory elements, such as timers and counters.**
2. **Timing: Sequential circuits are commonly used to implement timing and synchronization in digital systems , making them essential for real-time control applications.**
3. **State machine implementation: Sequential circuits can be used to implement state machines, which are useful for controlling complex digital systems and ensuring that they operate as intended.**
4. **Error detection: Sequential circuits can be designed to detect errors in digital systems and respond accordingly, improving the reliability of digital systems.**

Disadvantages of Sequential Circuits

1. **Complexity: Sequential circuits are typically more complex than combinational circuits and require more components to implement.**
2. **Timing constraints: The design of sequential circuits can be challenging due to the need to ensure that the timing of the inputs and outputs is correct.**
3. **Testing and debugging: Testing and debugging sequential circuits can be more difficult compared to combinational circuits due to their complex structure and state-dependent outputs.**

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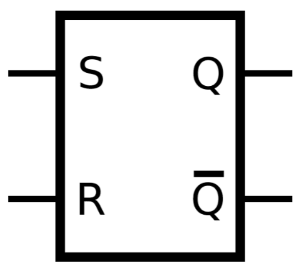
Applications

Sequential circuits find application in virtually almost every digital system today because of their capacity to handle state information. Some common applications include:

- Counters: Appearing in commonly in digital clocks, frequency counters, and event counters.
- Registers: Found in microprocessors and digital systems as a storage medium, a transfer medium and a medium for manipulating data.
- Memory Elements: Used in RAM and other storage devices to keep data in a temporary hold.
- State Machines: Made use in control systems, communication processes, and different digital devices for state control.
- Timers: It is applied in time measurement, delay production, and scheduling functions in digital circuits.

The SR Latch

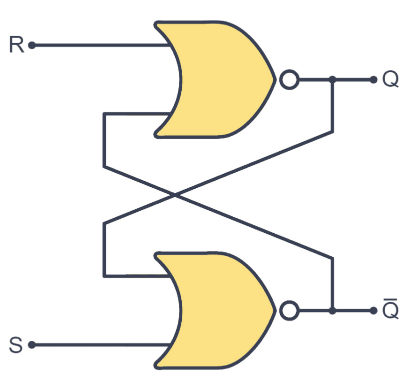
The **SR Latch**, also known as the **Set-Reset Latch**, is a fundamental digital memory circuit that stores one bit of binary data using two inputs, namely Set (S) and Reset (R). When Set is activated, the latch outputs '1' (HIGH), and when Reset is activated, it outputs '0' (LOW). The stored value remains stable even after inputs are removed, making it a **basic memory element**. This latch can be built using either NOR or NAND gates, with the key difference being that NAND implementation uses inverted (active LOW) inputs compared to NOR gates.



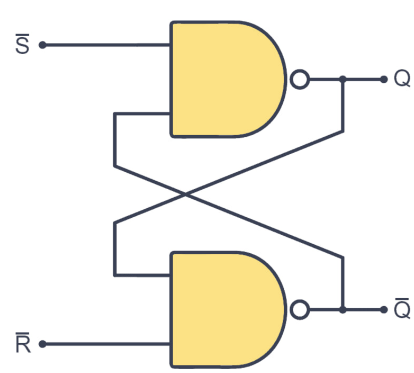
S-R Latch Symbol

Key Elements of SR Latches

- **Set (S) Input:** Forces Q output to the HIGH state (logic 1)
- **Reset (R) Input:** Forces Q output to the LOW state (logic 0)
- **Q Output:** Primary output (representing stored bit)



SR Latch NOR Gate



SR Latch NAND Gat

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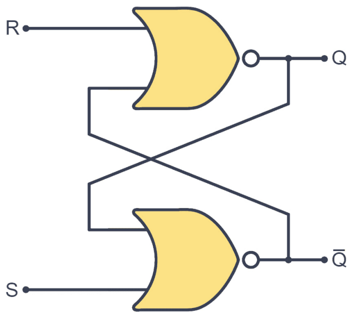
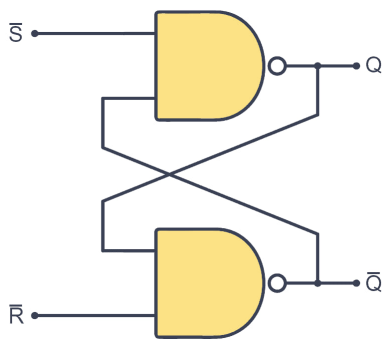
NOR-Based SR Latch Truth Table



S	R	Q	Q'	State
0	0	Q	Q'	Hold (No Change)
0	1	0	1	Reset
1	0	1	0	Set
1	1	0	0	Invalid (Avoided)

NAND-Based SR Latch Truth Table



S'	R'	Q	Q'	State
1	1	Q	Q'	Hold (No Change)
1	0	0	1	Reset
0	1	1	0	Set
0	0	1	1	Invalid (Avoided)

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Homework:

Upload the answer to Google Classroom

Q1: Draw a digital circuit diagram that uses XOR gates connected to an SR Latch

Q2: Define a Combinational Circuit and list its main characteristics?

Q3: What is the difference between Combinational and Sequential Circuits?

Q4: Explain the role of memory in Sequential Circuits?

Q5: Explain what a Clock Signal is and its function in sequential circuits?

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