江西理工大学
Jiangxi University of Science and Technology
信息工程学院
School of information engineering

Dr Ata Jahangir Moshayedi

Digital System Design

Clip Lecture series

Spring_2020

Prof Associate , School of information engineering Jiangxi university of science and technology, China
EMAIL: ajm@jxust.edu.cn

Jiangxi University of Science and Technology

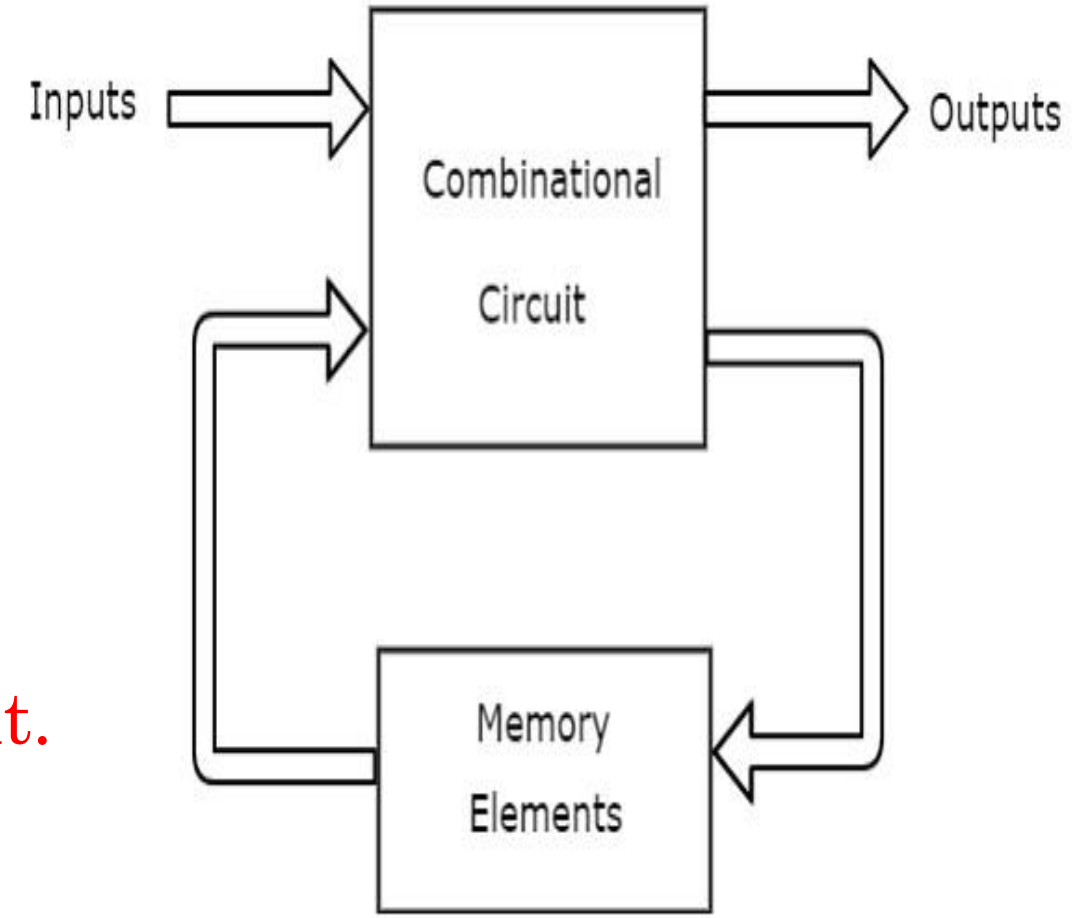
Sequential Circuits

Introduction_01

Introduction

- We discussed various combinational circuits in earlier.
- All these circuits have a set of output(s), which depends only on the combination of present inputs.

The following figure shows
the **block diagram** of sequential circuit.



Logic devices

- **Combinational Logic**
  - Current output depends on current input only
  - Gates, decoders, multiplexers, ALUs

- **Sequential Logic**
  - Current output depends on past inputs as well as current input
  - Thus has a memory (usually called the state)
  - Latches, flip-flops, state machines, counters, shift registers

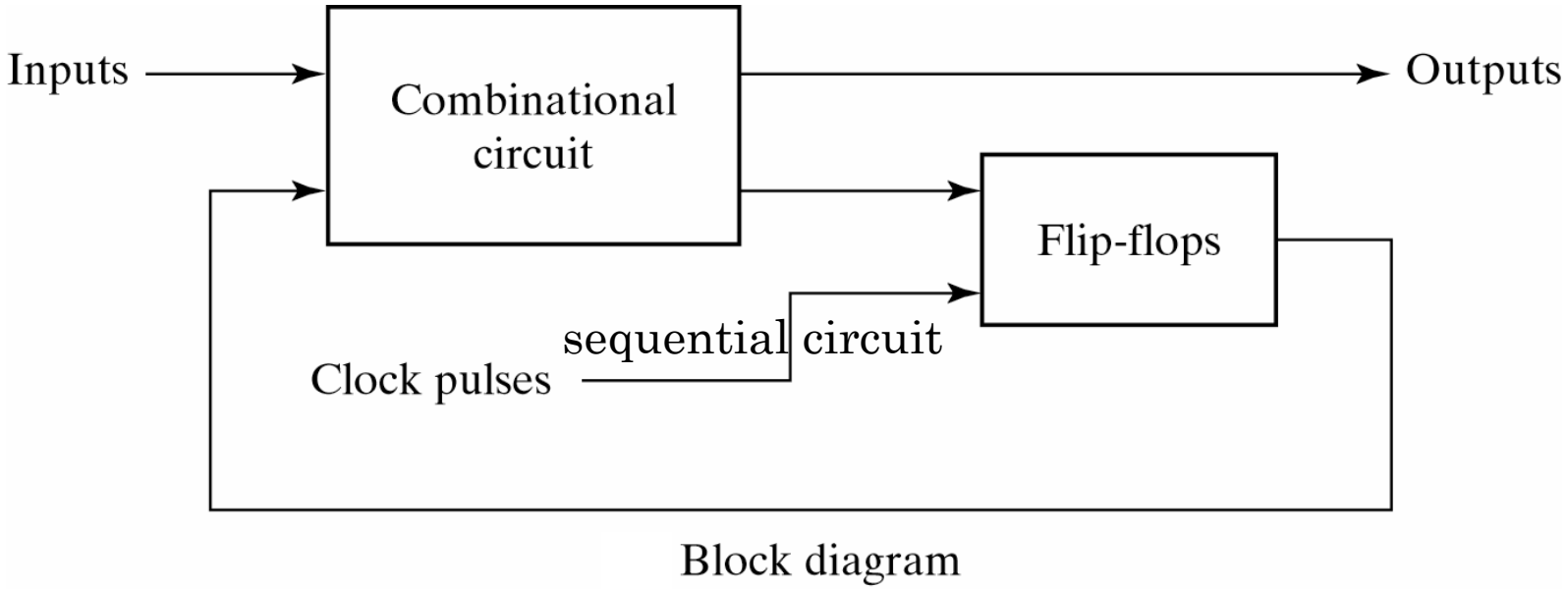
SEQUENTIAL CIRCUIT

- This sequential circuit contains a set of inputs and output(s).

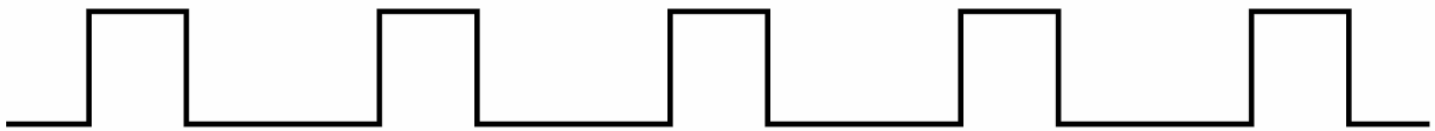
The output(s) of sequential circuit depends not only on the combination of present inputs but also on the previous output(s). Previous output is nothing but the **present state**.

- Therefore, sequential circuits contain combinational circuits along with memory (storage) elements. Some sequential circuits may not contain combinational circuits, but only memory elements.

Sequential circuits



Block diagram



Timing diagram of clock pulses

Combinational Circuits VS Sequential Circuits

- Following table shows the **differences** between combinational circuits and sequential circuits.

Combinational Circuits	Sequential Circuits
Outputs depend only on present inputs.	Outputs depend on both present inputs and present state.
Feedback path is not present.	Feedback path is present.
Memory elements are not required.	Memory elements are required.
Clock signal is not required.	Clock signal is required.
Easy to design.	Difficult to design.

Types of Sequential Circuits

1. the two types of sequential circuits –
   - Asynchronous sequential circuits
   - Synchronous sequential circuits

Asynchronous sequential circuits

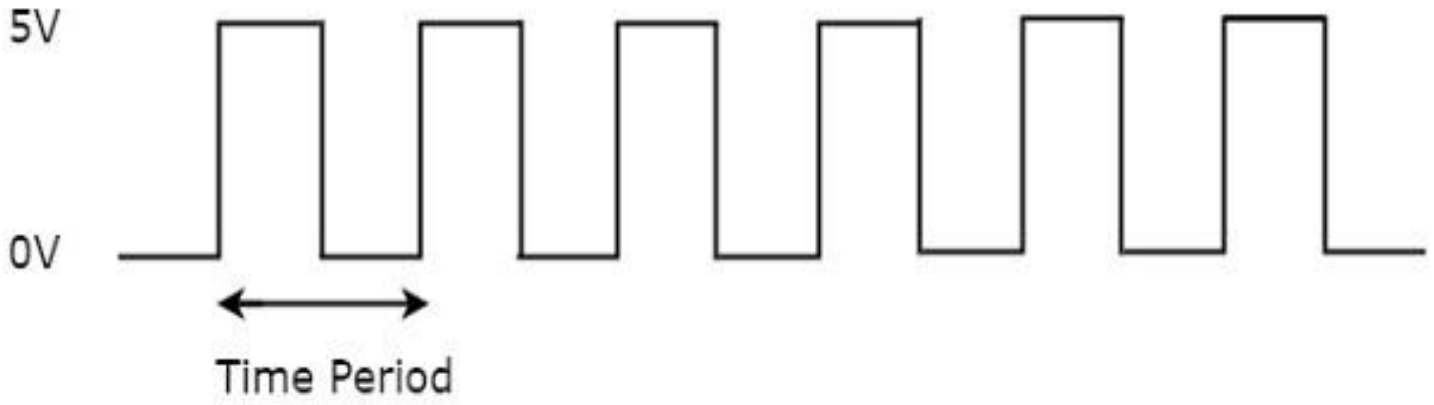
- If some or all the outputs of a sequential circuit do not change (affect) with respect to active transition of clock signal, then that sequential circuit is called as **Asynchronous sequential circuit**.
- That means, all the outputs of asynchronous sequential circuits do not change (affect) at the same time.
- Therefore, most of the outputs of asynchronous sequential circuits are **not in synchronous** with either only positive edges or only negative edges of clock signal.

Synchronous sequential circuits

- If all the outputs of a sequential circuit change (affect) with respect to active transition of clock signal, then that sequential circuit is called as **Synchronous sequential circuit**.
- That means, all the outputs of synchronous sequential circuits change (affect) at the same time.
- Therefore, the outputs of synchronous sequential circuits are in synchronous with either only positive edges or only negative edges of clock signal.

Clock Signal and Triggering

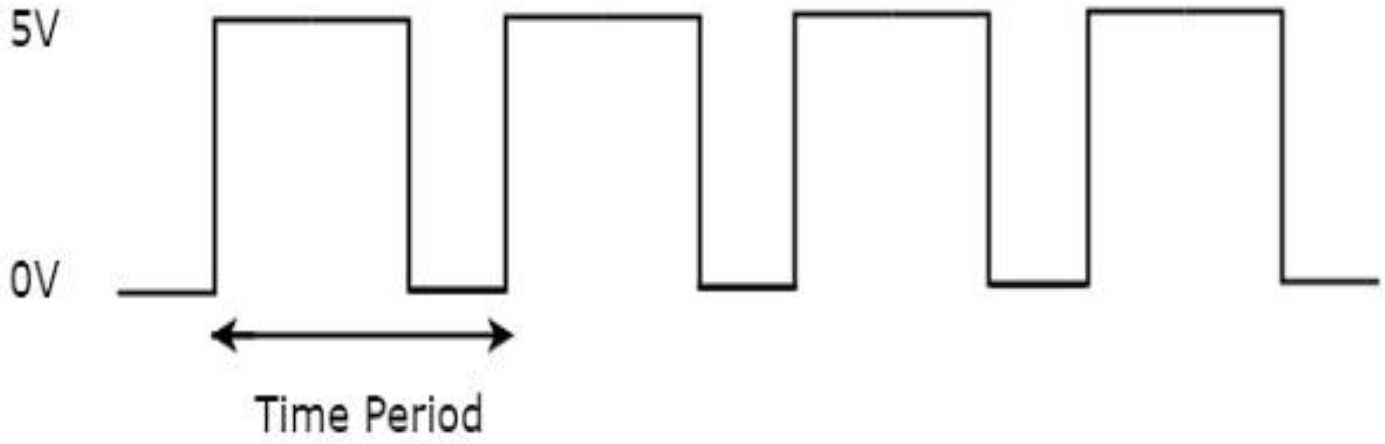
- **Clock signal**
- Clock signal is a periodic signal and its ON time and OFF time need not be the same. We can represent the clock signal as a **square wave**, when both its ON time and OFF time are same. This clock signal is shown in the following figure.



in this figure, square wave is considered as clock signal. This signal stays at logic High (5V) for some time and stays at logic Low (0V) for equal amount of time.

Time Period

- This pattern repeats with some time period. In this case, the **time period** will be equal to either twice of ON time or twice of OFF time.
- We can represent the clock signal as **train of pulses**, when ON time and OFF time are not same. This clock signal is shown in the following figure.



In the figure, train of pulses is considered as clock signal. This signal stays at logic High (5V) for some time and stays at logic Low (0V) for some other time. This pattern repeats with some time period. In this case, the **time period** will be equal to sum of ON time and OFF time.

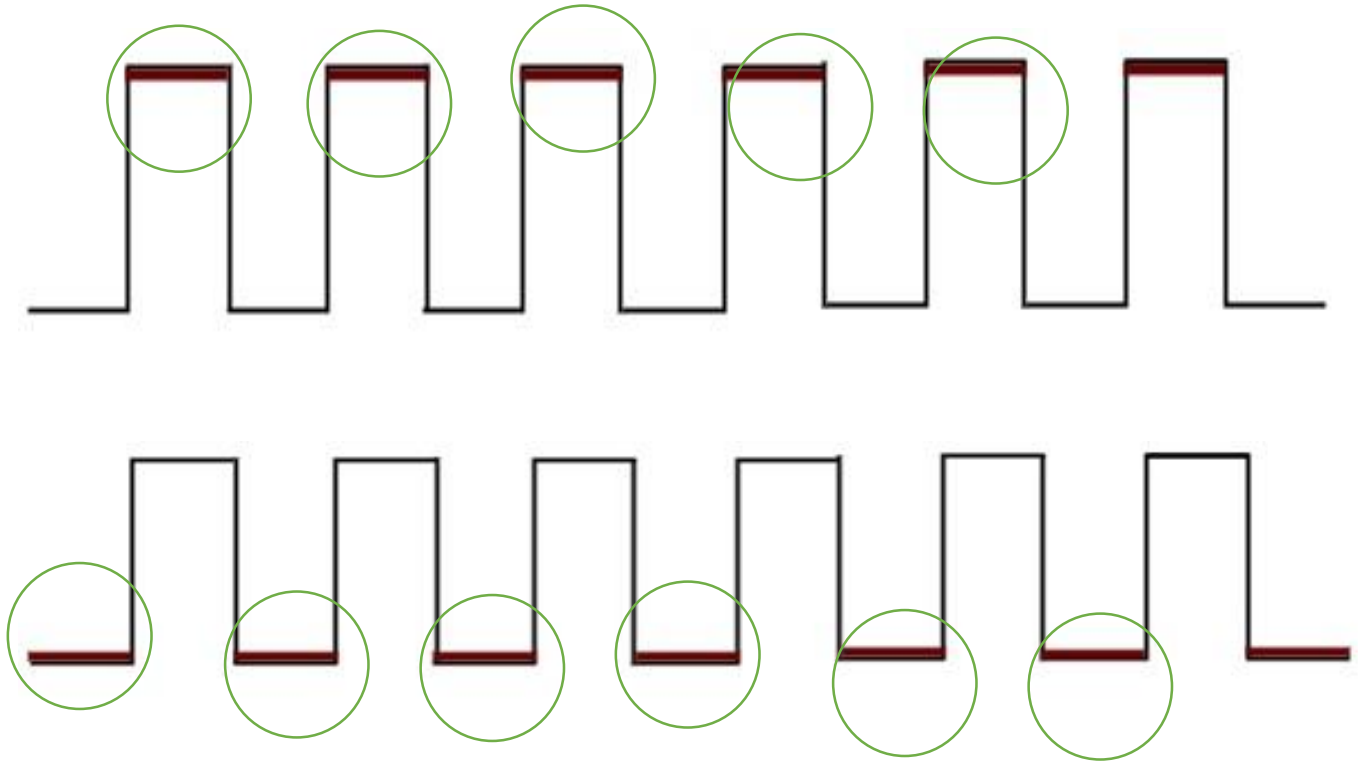
Time and Frequency

- The reciprocal of the time period of clock signal is known as the **frequency** of the clock signal. All sequential circuits are operated with clock signal. So, the frequency at which the sequential circuits can be operated accordingly the clock signal frequency has to be chosen.

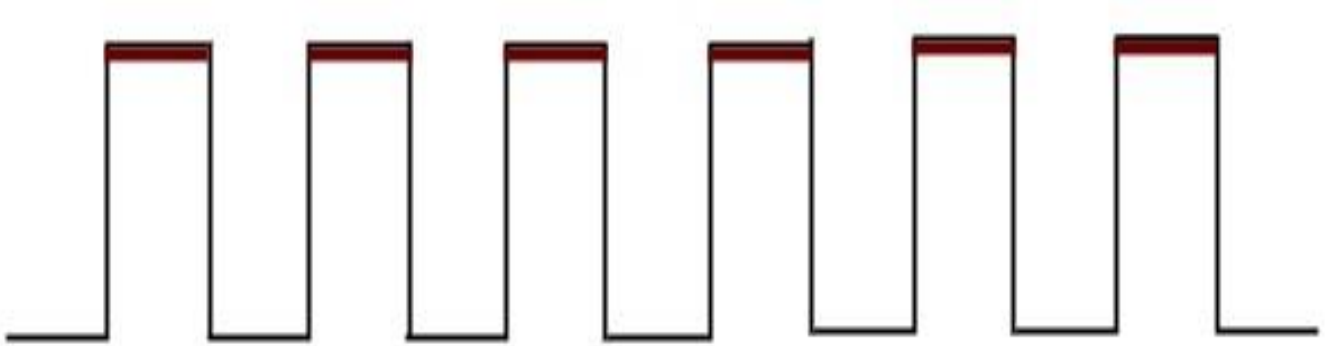
Types of Triggering

The two possible types of triggering that are used in sequential circuits.

- Level triggering
- Edge triggering



Positive level triggering.



If the sequential circuit is operated with the clock signal when it is in **Logic High**, then that type of triggering is known as **Positive level triggering**.

It is highlighted in figure.

Negative level triggering

- If the sequential circuit is operated with the clock signal when it is in **Logic Low**, then that type of triggering is known as **Negative level triggering**.

It is highlighted in figure.

Edge triggering

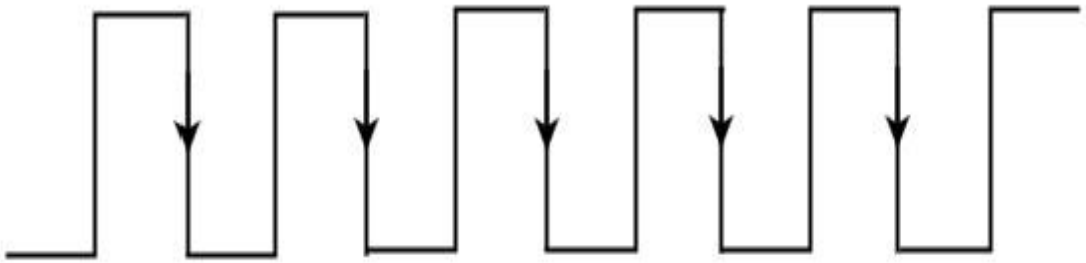
- There are two types of transitions that occur in clock signal. That means, the clock signal transitions either from Logic Low to Logic High or Logic High to Logic Low.

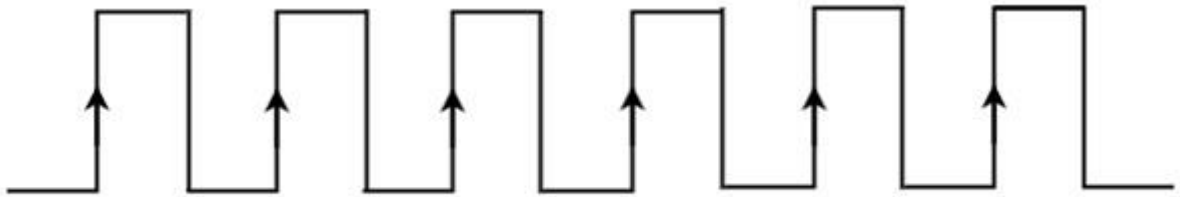
- Following are the two types of edge triggering based on the transitions of clock signal.
  - Positive edge triggering
  - Negative edge triggering

- If the sequential circuit is operated with the clock signal that is transitioning from Logic Low to Logic High, then that type of triggering is known as Positive edge triggering. It is also called as rising edge triggering. It is shown in the following figure.

Positive/ Negative edge triggering

If the sequential circuit is operated with the clock signal that is transitioning from Logic Low to Logic High, then that type of triggering is known as **Positive edge triggering**. It is also called as rising edge triggering. It is shown in the following figure.





If the sequential circuit is operated with the clock signal that is transitioning from Logic High to Logic Low, then that type of triggering is known as **Negative edge triggering**. It is also called as falling edge triggering. It is shown in the following figure.

Classification of Sequential Logic

- As standard logic gates are the building blocks of combinational circuits, bistable latches and flip-flops are the basic building blocks of sequential logic circuits.
- Sequential logic circuits can be constructed to produce either simple edge-triggered flip-flops or more complex sequential circuits such as storage registers, shift registers, memory devices or counters.

Classification of Sequential Logic

Either way sequential logic circuits can be divided into the following three main categories:

1. Event Driven

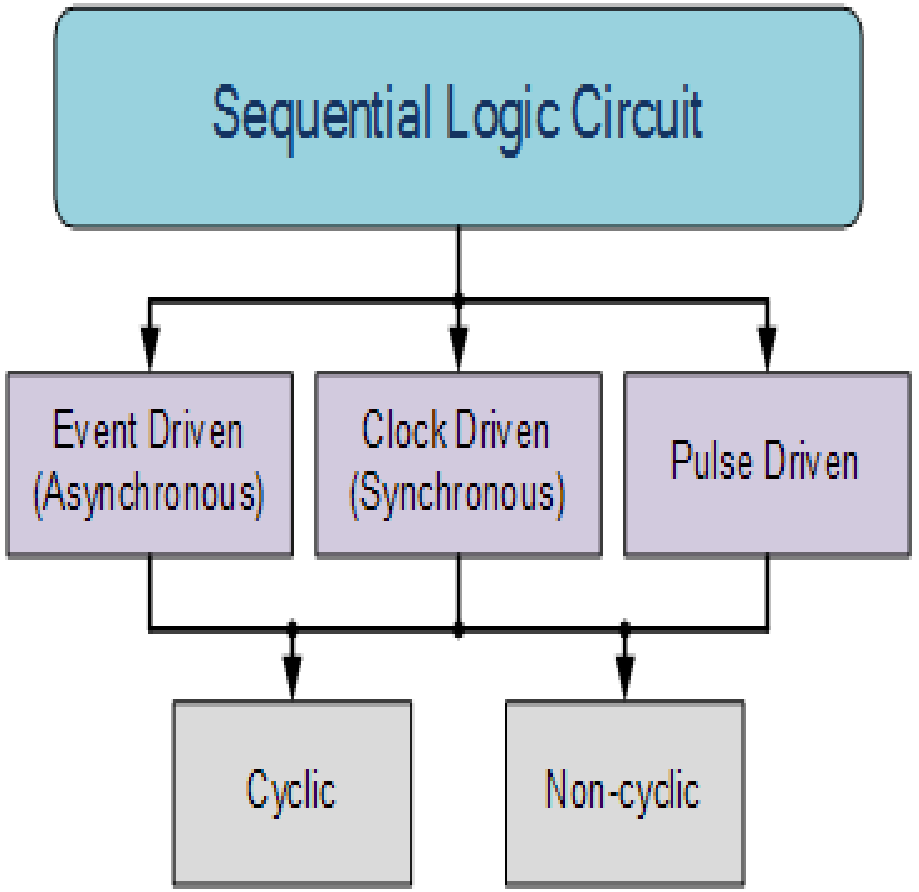
– asynchronous circuits that change state immediately when enabled.

2. Clock Driven

– synchronous circuits that are synchronised to a specific clock signal.

3. Pulse Driven

– which is a combination of the two that responds to triggering pulses.



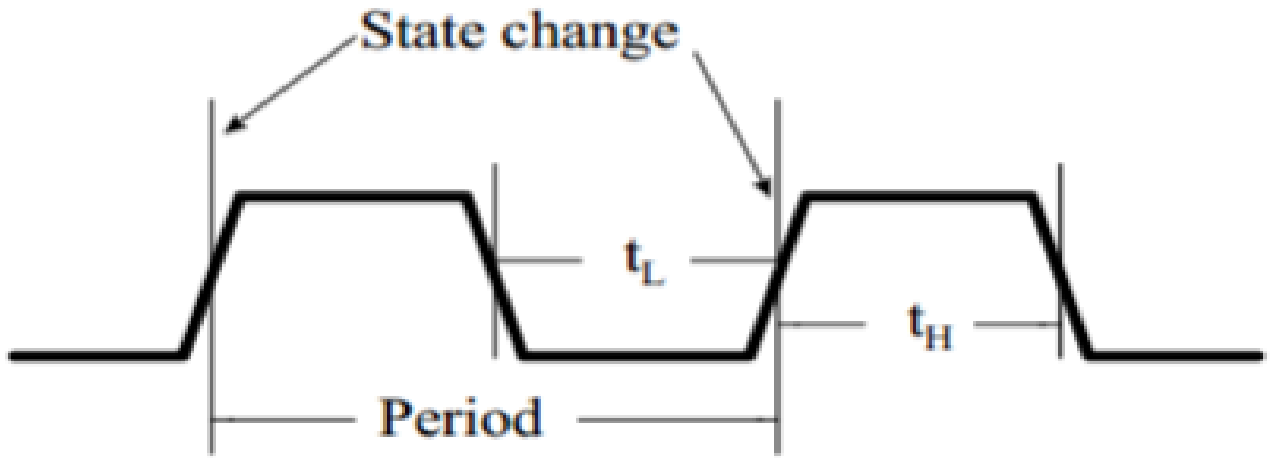
Sequential Logic

- **Clock** - the master timing element behind the state changes of most sequential circuits.
  - a clock signal is active high if the state changes occur at the rising edge
  - and active low if state changes occur at the falling edge.

- **Clock Period** - time between successive transitions in the same direction.
- **Clock Frequency** - reciprocal of the clock period.

- **Duty Cycle** - the percentage of time that a clock is at its assertion level.

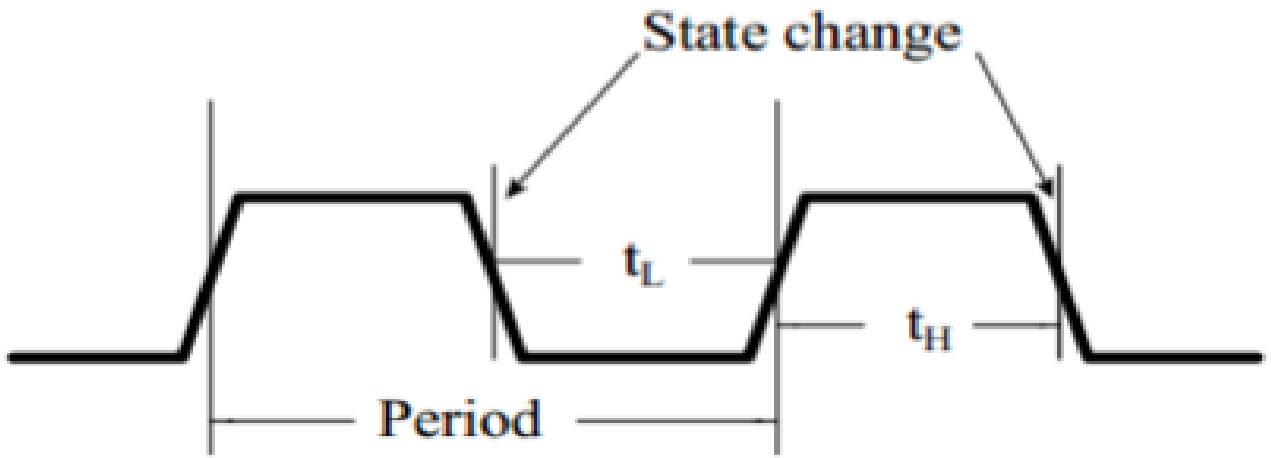
Clock Characteristics



Active High

Frequency = 1/Period

Duty Cycle = t_H/Period



Active Low

Duty Cycle = t_L/Period

- In sequential circuits changes occur only on the application of a clock signal making it synchronous, otherwise the circuit is asynchronous and depends upon an external input.

Reference

1. Mano book
2. ee.hawaii.edu/~sasaki/EE361/Fall06/Lab/7disp.html
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4. https://www.electronics-tutorials.ws/sequential/seq_1.html