KHON KAEN UNIVERSITY
DEPARTMENT OF ELECTRICAL ENGINEERING

EXPERIMENT EE2-10: T FLIP-FLOP AND A COUNTER CIRCUIT

OBJECTIVES:

1. To see the operation of T flip-flop.
2. To build a binary counter using T flip-flop.
3. To be able to use a 7 segments LED to display the counter output.

INTRODUCTION

Flip-flops are logic devices that their output(s) are depended on their input(s) and their state. They are basic element of the sequential circuit (so called the finite state machine). There are 4 basic types of flip-flops namely, RS flip-flop, JK flip-flop, T flip-flop, and D flip-flop. Ones can build a counter from any type of flip-flops. However, for the sake of simplicity, in this experiment students shall build a decade counter using several T flip-flops made from JK flip-flops.

The outputs of the counter are binary signals. It is not convenient for human to make use of such information. A 7-segments LED is applied to display the counter outputs. Students shall make a circuit using a 7-segments LED to display the counter output.

THEORY

Flip-Flop

In the entry level of digital circuit design, students should have learned the logic combination circuits design and how to optimize then. Those circuits' outputs are depended only on their input. They are considered as stateless circuits, which means circuits do not recognize states, in another word, the circuits do not have memory.

Later in the course, student should have learned the sequential circuits, or the finite state machines. The sequential circuits are circuits that their outputs depend not only on its inputs, but also its state. An example of an application of such a circuit is a multi-functions photocopy machine where the start button can perform different operations such as copy, scan, or print, depend on the machine mode (state) when the button is pressed. The sequential circuits are very useful and can be found in many digital devices, e.g. memory chip, CPU, MCU, clock, etc.

Flip-flops are the basic elements of the sequential circuits. Even though ones can build a flip-flop from logic gates, it is preferable to use prepackaged devices in a standard integrated circuit (IC). To use a flip-flop, ones must be able to read the IC datasheet to study at least its pins out, and its truth table or its timing diagram. This experiment focusses only on using T flip-flop created from JK flip-flop to make a counter.

JK Flip-Flop

J means jump, and K means kill. If nothing active, then there is nothing change in the output. If J is active, the output will jump to the active state (it could be either "0" or "1"). If K is active, the output will be killed in to the inactive state. If both J and K are active, the output is then toggled, i.e. the output is the inversed of the previous state. A kind of JK flip-flop (CD4027) functional diagram and it truth table are shown in Figure 1 and in Table 1, respectively.

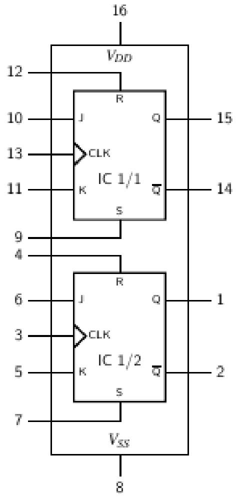


Figure 1 Functional diagram and pinouts of a CD4027, a dual JK flip-flop.

Table 1 Truth table of CD4027, a dual JK flip-flop.

Present State						**Next State**
Inputs					**Output**	**Output**
S	**R**	**J**	**K**	**CLK**	**Q**	**Q**
0	0	0	0	Rising	X	No Change
0	0	0	1	Rising	X	0
0	0	1	0	Rising	X	1
0	0	1	1	Rising	X	Toggle
0	1	X	X	X	X	0
1	0	X	X	X	X	1
1	1	X	X	X	X	1*

Note : * Both Q and $\overline{Q}$ are 1 simultaneously.

From Table 1, if both J and K are active then the flip-flop will toggle, i.e. the JK flip-flop becomes a T flip-flop. It is straightforward to build a decade counter from T flip-flops.

Decade Counter

A decade counter gives output 0 – 9. It is also known as the mod-10 counter. Its output will change at every clock trigger. Once the outputs become 10 (1010_B), they form a signal that reset all flip-flops to become 0 (0000_B). In this experiment, we will implement a design approach that the output of the lower significant bit flip-flop will be the trigger signal of the higher next significant bit flip-flop. It can be seen as if the trigger propagates through the flip-flops, hence its name the ripple counter. The official name of this kind of counter is the asynchronous counter. Figure 2 shows a conceptual schematic of a mod-10 synchronous up counter. It does not designate the IC part numbers nor the power supply pins for the sake of simplicity.

Seven Segments LED

The output of the counter comes in a binary form, i.e. either logic “0” or “1”. These are translated in to the electric circuit domain as a low voltage state, and a high voltage state. This kind of information is hard to use directly by human. Thus, we need a display that shows the information that is meaningful to human, i.e. digits.

There was a type of display that was very popular in 1980s – 1990s called 7-segments LED. It is included in this experiment because its simple mechanism. Its simplicity allows students to build something interesting in no time. Its appearance and simplify drawing are shown in Figure 3. Its pin 1 is at the lower left of the module. And the rest pins are ordered counter-clockwise. The pin 10 is at the upper left of the module.

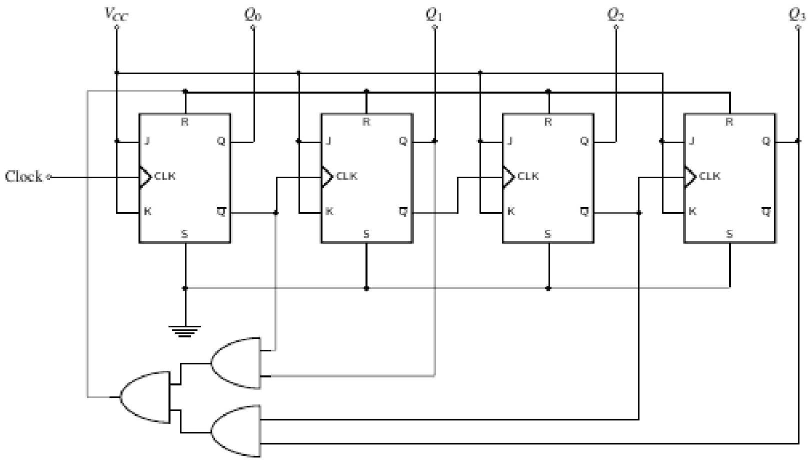
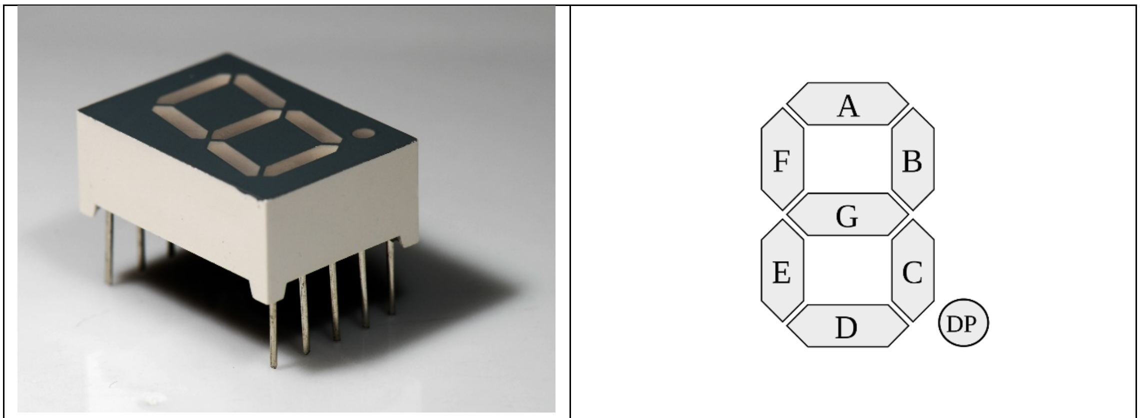


Figure 2 A Mod-10 Asynchronous Up Counter. The power supply (Vcc and Gnd) are omitted in the schematic for the sake of simplicity.



a) b)

Figure 3 (a) A 7 segments LED[1] (b) Segment designations[2].

The module is called a 7 segments LED because it uses 7 LEDs, at most, to form a number. Each LED is called a segment and has its own designation. To display a number, a set of LEDs shall be lighted. For example, if we want to display number four, LED segment B, C, F, and G shall be lighted. The 7 segments LED in the market nowadays has the 8th LED called DP which is the dot shown in the above figure.

Even though there are 8 LEDs in the 7 segments LED, the module does not need to have 16 pins. Instead, they share a common pin, either the anode or the cathode of each LED segment. Hence the name, the common cathode LED, and the common anode LED. Schematics of both types are shown in Figure 4.

To use the common anode LED, the Com pin shall be connected to the positive node of the circuit. The segment pins (A-DP) are normally either “High” or “Float” state. At this state, all LEDs are off. If any segment pin is pulled down to “Low” state, that LED segment will be turned on.

On the other hand, the Com pin of the common anode LED shall be connected to the negative node of the circuit. The segment pins are normally either “Low” or “Float” state and all LEDs are currently off. If any segment pin is pulled up to “High” state, that segment will be turned on. In both case, engineers shall employ current limit resistors to the segment pins as shown later in the experiment.

[1] This file is licensed under the Creative Commons Attribution-Share Alike 3.0 Unported license by Peter Halasz. The original work can be found at https://en.wikipedia.org/wiki/File:Seven_segment_02_Pengo.jpg.

[2] This file is licensed under the Creative Commons Attribution-Share Alike 3.0 Unported license by David Batley. The original work can be found at https://en.wikipedia.org/wiki/File:7_segment_display_labeled.svg.

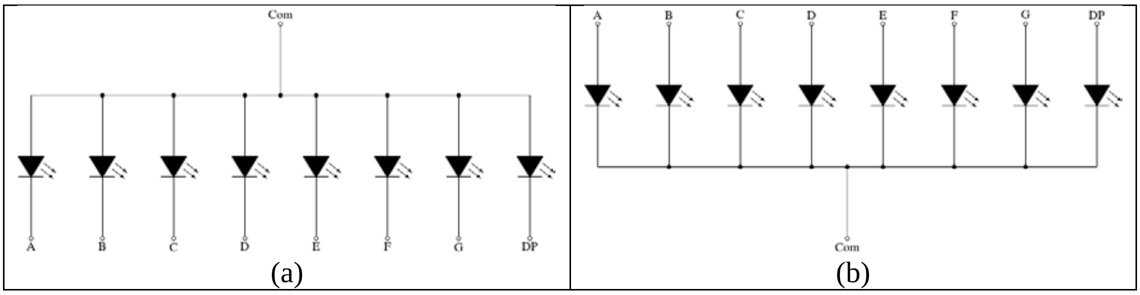


Figure 4 (a) Common anode 7 segments LED, (b) Common cathod 7 segments LED.

BCD to 7 Segment Decoder

The output of the 4 bits counter is called binary code decimal (BCD). This is not useable by the 7 segment LED. The circuit that transform the BCD signal to the 7 segments signal is call the BCD to 7 segments decoder. An IC that does this job is CD4511. Its pinout and truth table are shown in Figure 5 and Table 2, respectively. From the truth table, we can see that this decoder is designed for common cathode 7 segments LED. Notice that the “DP” LED is not included in the decoding system.

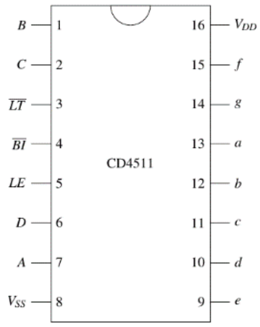


Figure 5 Pinout of CD4511, a BCD to 7 Segments Decoder.

Table 2 Truth table of the CD4511.

$\overline{LT}$	$\overline{BI}$	LE	D	C	B	A	a	b	c	D	e	f	g	LED
X	X	0	X	X	X	X	1	1	1	1	1	1	1	8
X	0	1	X	X	X	X	0	0	0	0	0	0	0	Blank
0	1	1	0	0	0	0	1	1	1	1	1	1	0	0
0	1	1	0	0	0	1	0	1	1	0	0	0	0	1
0	1	1	0	0	1	0	1	1	0	1	1	0	1	2
0	1	1	0	0	1	1	1	1	1	1	0	0	1	3
0	1	1	0	1	0	0	0	1	1	0	0	1	1	4
0	1	1	0	1	0	1	1	0	1	1	0	1	1	5
0	1	1	0	1	1	0	0	0	1	1	1	1	1	6
0	1	1	0	1	1	1	1	1	1	0	0	0	0	7
0	1	1	1	0	0	0	1	1	1	1	1	1	1	8
0	1	1	1	0	0	1	1	1	1	0	0	1	1	9
0	1	1	1	0	1	0	0	0	0	0	0	0	0	Blank
0	1	1	1	0	1	1	0	0	0	0	0	0	0	Blank
0	1	1	1	1	0	0	0	0	0	0	0	0	0	Blank
0	1	1	1	1	0	1	0	0	0	0	0	0	0	Blank
0	1	1	1	1	1	0	0	0	0	0	0	0	0	Blank
0	1	1	1	1	1	1	0	0	0	0	0	0	0	Blank
1	1	1	X	X	X	X	Depends on previous displayed digit when LE=0							

In this experiment, students shall construct a mod-10 counter circuit, and display its output through a 7 segment LED using a BCD to 7 segments decoder.

PRELIMINARY REPORT

Draw the timing diagram of an asynchronous decade counter on an A4 paper. Let the frequency of the clock signal to 1 Hertz. This will be very useful when students are diagnosing their own circuits in the laboratory.

Prepare an empty plot for recording the actual timing diagram in the experiment. The plot shall consist of 5 axes, i.e. clock, Q_0, Q_1, Q_2, and Q_3.

APPARATUS

1. A variable DC power supplies
2. A function generator
3. An oscilloscope
4. Two protoboards

MATERIAL

R	330 Ω 5% ¼ W	x	7
IC	CD4027	x	2
	CD4081	x	1
	CD4511	x	1
D	LED (Any color)	x	4
	Common cathode 7 Segments LED	x	1

PROCEDURE (P1 – P4 and R1 – R4; 40 points)

PART A: Mod-10 asynchronous counter

P1 Set the function generator to generate a clock signal with these parameters:

- Minimum voltage : 0 V
- Maximum voltage : 5 V
- Signal type : Square wave
- Frequency : 1 Hertz

This can be done by setting amplitude to 2.5 V and then adjust the offset to 2.5 V.

R1 (5 points) Sketch the clock signal onto the timing diagram.

P2 Build a binary asynchronous counter circuit as shown in Figure 6. Students can try to construct the counter one flip-flop at a time. R1 to R4 are 330 ohms resistors. D1 to D4 are LEDs. V_{DD} is 5 volts. IC1 and IC2 are CD4027s.

R2 (10 points) Supply clock signal from P1 to the circuit through the Clock port. Observe the LEDs sequence pattern. Sketch the timing diagram of the circuit. The diagram shall include Clock, Q_0, Q_1, Q_2, and Q_3. How many output states are there?

P3 Modify the circuit shown in the Figure 6 to be a mod-10 counter as shown in Figure 7. Beware that the reset signal of every flip-flop shall be removed from the ground node. The IC3 is a CD4081. Noted that the designation pins of IC3 in the schematic is not strict. And gates and their pins in the schematic are interchangeable as long as they give the same logical function.

R3 (15 points) Supply clock signal from P1 to the circuit through the Clock port. Observe the LEDs sequence pattern. Sketch the timing diagram of the circuit. The diagram shall include Clock, Q_0, Q_1, Q_2, and Q_3. How many output states are there?

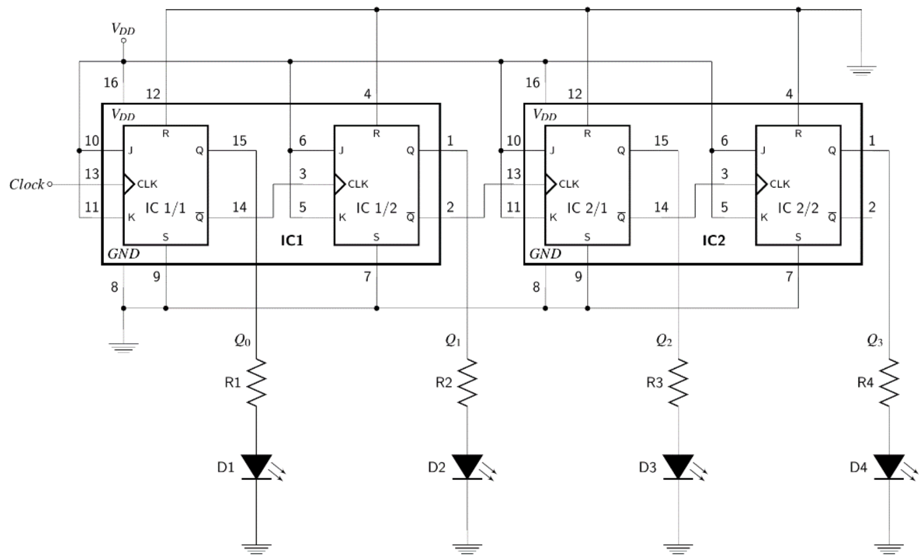


Figure 6 A 4 bits asynchronous binary counter.

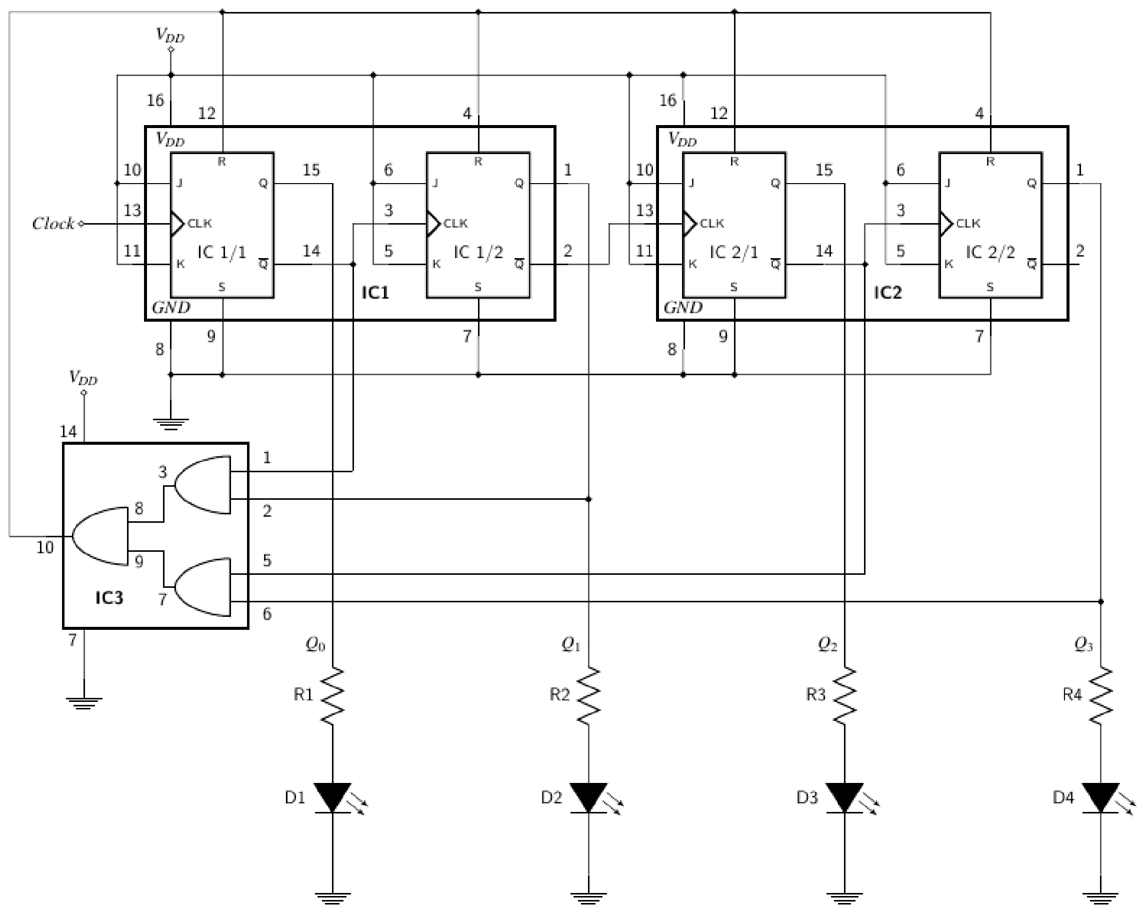


Figure 7 A complete schematic of a mod-10 asynchronous counter.

P4 Add the display module to the circuit as shown in Figure 8. IC4 is a CD4511 and D1 is the 7 segments LED. R1 – R7 are 330 ohms resistors.

R4 (10 points) Let the counter counts from 0 to 9 using the clock signal from the function generator.

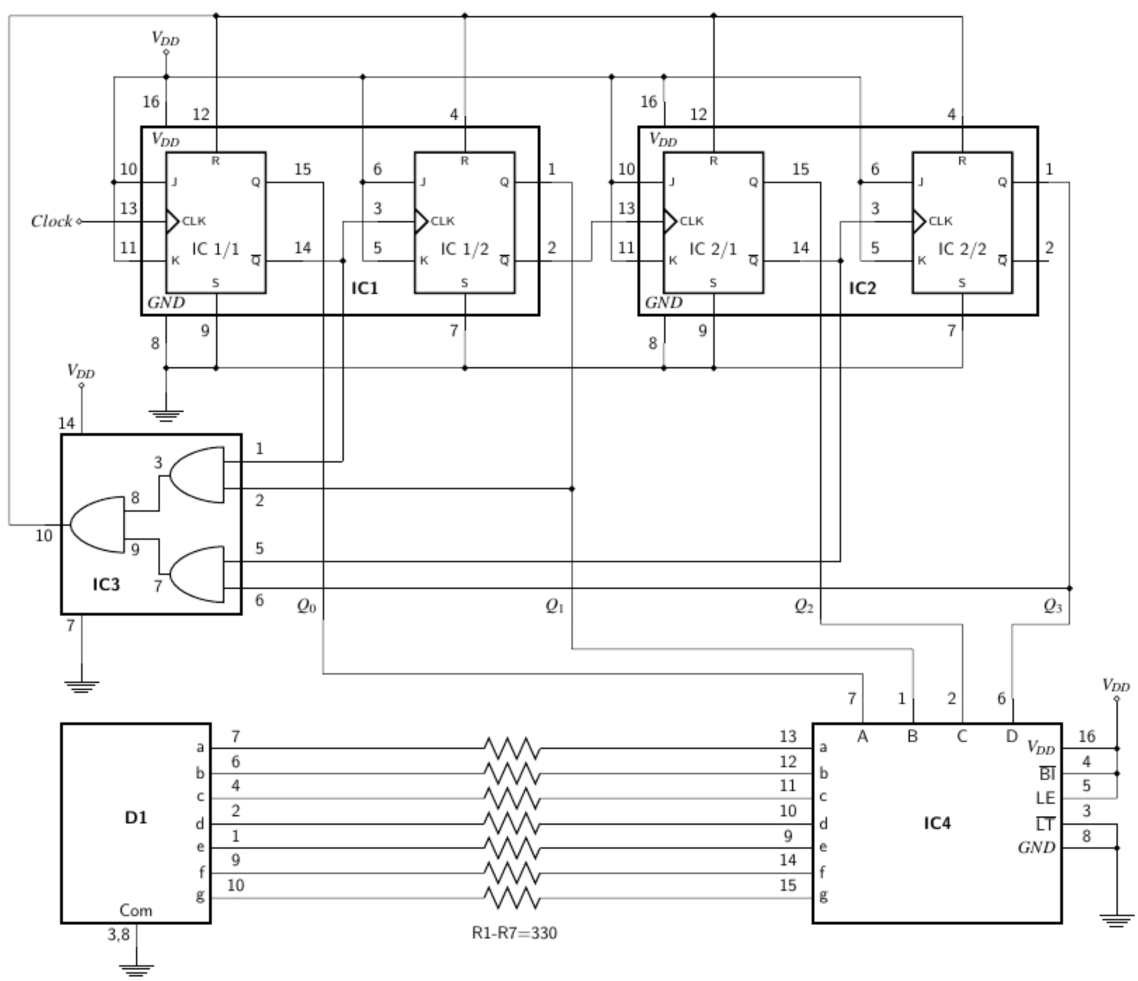


Figure 8 The counter circuit in Figure 7 with a 7 segments LED display

QUESTIONS *(Q1 – Q3; 20 points)*

Q1 (7 points) How do we change this circuit to be a mod-6 counter?

Q2 (7 points) What will happen of $\overline{\text{BI}}$ is “0”.

Q3 (6 points) What shall we do if we want to see the counter counts faster?

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