Chapter 14 Instructor Notes

Chapter 14 logically follows the material on combinational digital logic circuits introduced in Chapter 13. Section 14.1 contains a discussion of sequential logic modules; the box *Focus on Measurements: Digital Measurement of Angular Position and Velocity* (pp. 679-681) illustrates the use of a counter to measure the speed of rotation of a slotted wheel; this is a very common measurement in mechanical systems; the box *Focus on Measurements: Seven-Segment Display* (pp. 682-683) draws attention to a very common logic module. Section 14.2 provides an elementary introduction to sequential logic design, and Section 14.3 introduces microcomputers. This, and the two following sections on microcomputer architecture and microcontrollers, have been extensively revised, and are designed to provide an introduction to the concept of mechatronic design (see box on p. 688), recognizing that it is impossible to include a serious coverage of microcontrollers in a single chapter. Thus, the treatment is focused on an overview of the organization of microcontrollers, including a brief, qualitative illustration of computer interface issues presented in *Focus on Measurements: Reading Sensor Data By Using Interrupts* (pp. 697-698). The last section, 14.6, is dedicated to an example (courtesy of Delphi – Delco Electronic Systems) that describes a current automotive engine microcontroller. The example is a qualitative description, but will permit the instructor who desires to do so to motivate further study of this topic. The Find-It-On-The-Web references will provide students and instructor with additional reference material on the subject of automotive engine control.

In recent years mechanical and industrial engineering programs have seen a significant growth in courses related to mechatronics, or more specifically to microcontroller applications in industrial and mechanical systems. The objective of Chapter 14 is to serve as an introduction to such courses.

The homework problems are mostly devoted to sequential logic circuits; the last 6 problems review simple concepts related to the architecture and functions of microcomputers.

Learning Objectives

1. Analyze the operation of sequential logic circuits. Section 1.
2. Understand the operation of digital counters. Section 1.
3. Design simple sequential circuits using state transition diagrams. Section 2.
4. Study the basic architecture of microprocessors and microcomputers. Sections 3,4, 5.

Section 14.1: Sequential Logic Modules

Section 14.2: Sequential Logic Design

Problem 14.1

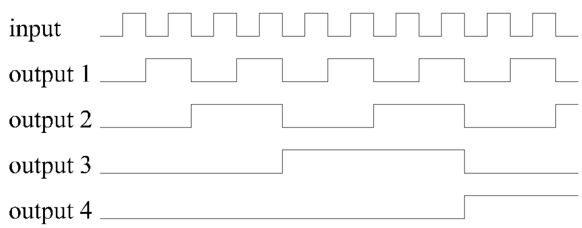
Solution:

Known quantities:
For the circuit shown in Figure P14.1, the input is a square wave having a period of 2 s, maximum value of 5 V, and minimum value of 0 V. Assume all flip-flops are initially in the RESET state.

Find:
a) Explain what the circuit does.
b) Sketch the timing diagram, including the input and all four outputs.

Analysis:
a) The device is called a MOD-16 ripple counter. It can count clock pulses from 0 to (2^4-1). The outputs divide the frequency by 2^1, 2^2, 2^3, and 2^4 respectively. Therefore, you can use this circuit as a divide by N counter, where N is 2, 4, 8 and 16.

b)



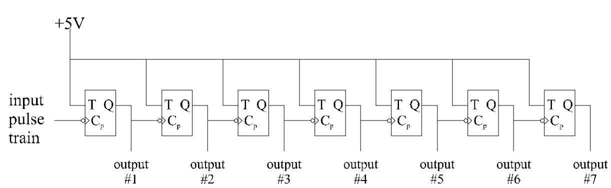
Problem 14.2

Solution:

Find:
a) How many flip-flops would be required to construct a binary pulse counter, which can count up to 100_{10}, by interconnecting *T-type* flip-flops in an appropriate manner.
b) Sketch the circuit needed to implement this counter.

Analysis:
a) $100_{10} = 1100100_2 \quad \Rightarrow$ 7 flip flops required.

b)



This circuit could be modified with combinational logic if it is desired to have it reset at 100_{10} and start counting again from 0000000_2.

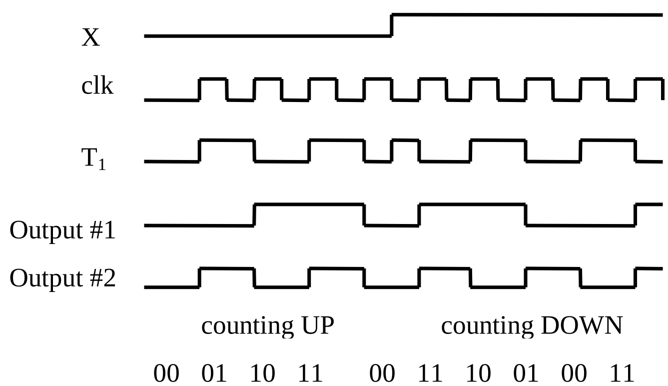
Problem 14.3

Solution:

Known quantities:
The circuit shown in Figure P14.3.

Find:
Explain what the circuit does and how it works.

Analysis:
The basic operation of the circuit is to count up when X = 0, and to count down when X = 1.



Clock	X	Output #2	T_1	Output #1
↑	0	0	0	No change
↑	1	1	0	No change
↑	0	1	1	toggle
↑	1	0	1	toggle

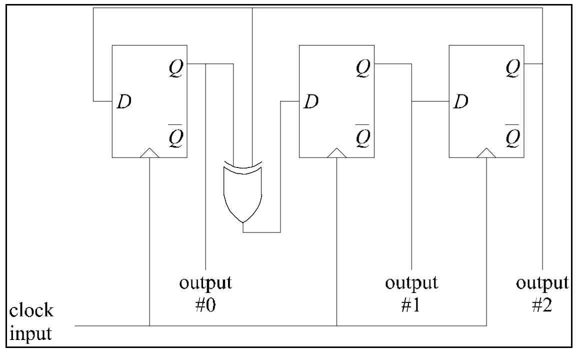
Problem 14.4

Solution:

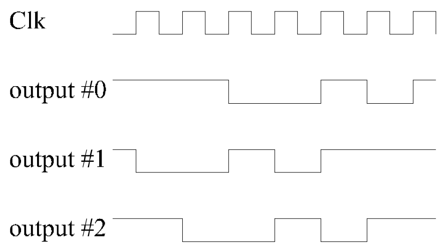
Known quantities:
If a circuit is constructed from 3 *D-type* flip-flops,
with: $D_0 = Q_2$ $D_1 = Q_2 \oplus Q_0$ $D_2 = Q_1$.

Find:
a) Draw the circuit diagram.
b) Assuming the circuit starts with all flip-flops SET, sketch a timing diagram which shows the outputs of all three flip-flops.

Analysis:
a)



b)

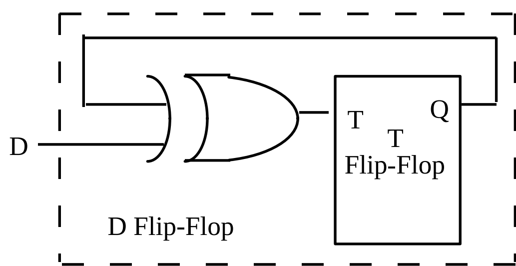


Problem 14.5

Solution:

Find:
Assuming you have all the logic gates available, make a *D* flip-flop using a *T* flip-flop and some logic gate(s).

Analysis:



Assume that Q is logic 0 initially. If the input D is logic 0, the output of the gate is logic 0 which means that the output of the *T* flip-flop will not be toggled (i.e., will remain logic 0). When the input D is logic 1, the output of the gate will be logic 1. Therefore, the output of the flip-flop will be 1. Thus, the circuit will operate as a *D* flip-flop.

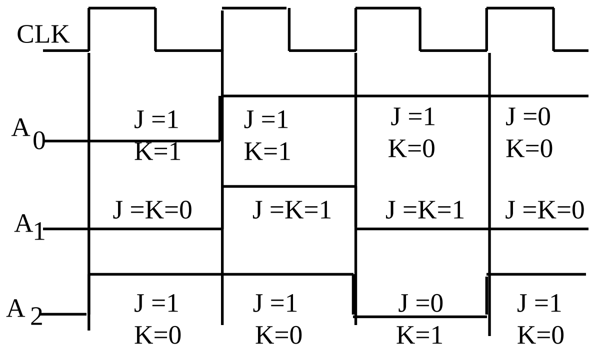
Problem 14.6

Solution:

Known quantities:
For the circuit shown in Figure P14.6, assume that all the initial values are 0. Note that all the flip-flops are negative edge-triggered.

Find:
Draw a timing diagram (four complete clock cycles) for A_0, A_1, and A_2.

Analysis:



Problem 14.7

Solution:

Known quantities:

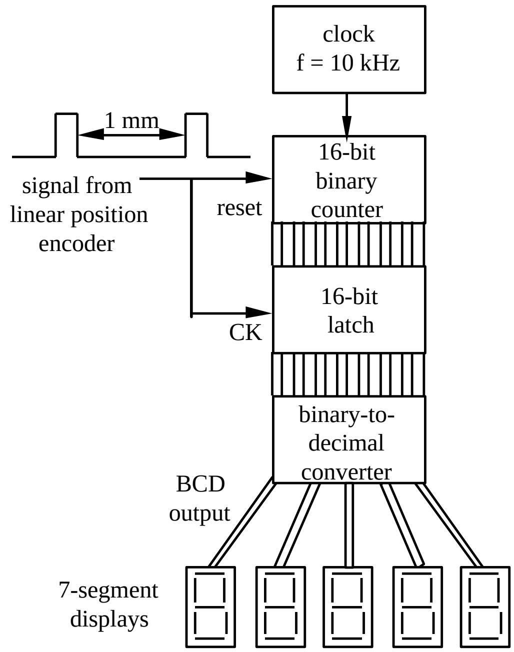
Assume that the slotted encoder shown in Figure P14.7 has a length of 1 meter and a total of 1,000 slots (i.e., there is one slot per millimeter.

Find:

If a counter is incremented by 1 each time a slot goes past a sensor, design a digital counting system that determines the speed of the moving encoder (in meters per second).

Analysis:

Assuming a maximum speed of 10 m/s and a minimum speed of 1 mm/s, we can calculate the instantaneous speed of the slotted encoder by counting the number of clock pulses between slots using a fixed frequency clock. This resolution should be sufficient to measure the speed of the encoder over the range of interest. The figure depicts the arrangement: A 10 kHz clock increments a 16-bit binary counter. The choice for a 16-bit counter is due to the maximum speed requirement: $2^{16} = 65{,}536$, will be the maximum count between slots. At a speed of 10 m/s, the time for one slot to go by is 10^{-4} s, thus the number of counts would be 1 count; at the minimum speed of 1 mm/s the number of counts would be 10^{4}. A 14-bit counter would be sufficient, but in practice it is easier to cascade two 8-bit counters; thus the choice of a 16-bit counter. The count is held by a latch, and then converted to BCD for use with seven-segment displays. The details of the seven-segment display encoders are not shown (see Focus on Measurements: Seven-Segment Display). If a decimal point is placed to the right of the second seven-segment display (starting from the left in the figure), the display will read the speed in m/s, up to a maximum of 10 m/s, with a resolution of 1 mm/s.



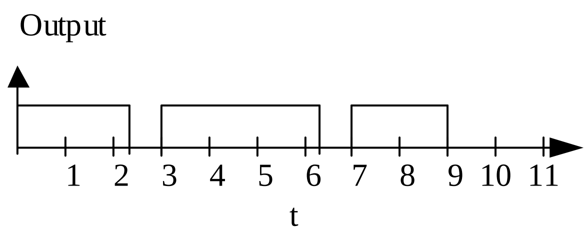
Problem 14.8

Solution:

Known quantities:
The circuit shown in Figure P14.8.

Find:
The output Q for the given circuit.

Analysis:



Problem 14.9

Solution:

Find:
Describe how the ripple counter works. Why is it so named? What disadvantages can you think of for this counter?

Analysis:
This is briefly discussed in the digital counters section (see Figure 14.12).

Problem 14.10

Solution:

Find:
Write the truth table for an *RS* flip-flop with enable (E), preset (P), and clear (C) lines.

Analysis:
Knowing that an input to the R or S line will be effective only when the enable input is 1, and the outputs are initially 0, the truth table for an *RS* flip-flop with set and preset is as follows:

S	*R*	*P*	*C*	*Q*
0	0	0	0	0
0	0	0	1	0
0	0	1	0	1
0	1	0	0	0
0	1	0	1	0
1	0	0	0	1
1	0	1	0	1

Problem 14.11

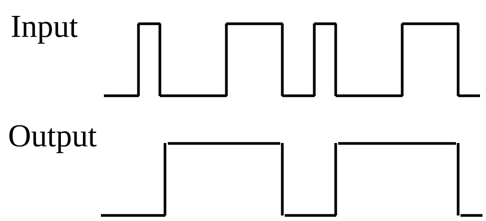
Solution:

Known quantities:
The *JK* flip-flop shown in Figure P14.11, with a given input signal.

Find:
Assuming that Q is at logic 0 initially and the trailing edge triggering is effective, sketch the output Q.

Analysis:

J_n	K_n	Q_{n+1}
1	1	$\overline{Q_n}$ (toggle)



Problem 14.12

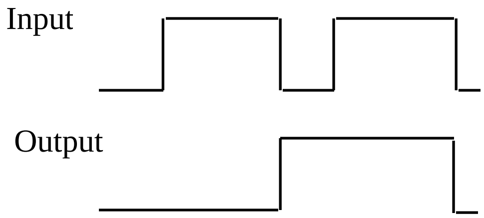
Solution:

Known quantities:
With reference to the *JK* flip-flop shown in figure P14.11, assume that the output at the Q terminal is made to serve as the input to a second *JK* flip-flop wired exactly as the first.

Find:
Sketch the output Q of the second flip-flop.

Analysis:

J_n	K_n	Q_{n+1}
1	1	$\overline{Q_n}$ (toggle)



Problem 14.13

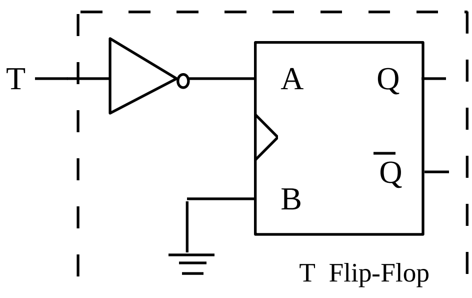
Solution:

Known quantities:
The flip-flop with the characteristic given in Figure P 14.13, where A and B are the inputs to the flip-flop and Q is the next state output.

Find:
Using necessary logic gates, make a *T* flip-flop from the given flip-flop.

Analysis:

T	A	B	Q
0	1	0	q
1	0	0	$\overline{q}$



Section 14.3: Microprocessors

Section 14.4: Computer System Architecture

Section 14.5: Microcontrollers

Problem 14.14

Solution:

Find:
If a typical PC has 32 Mbytes of standard memory:
a) How many words is this?

b) How many nibbles is this?
c) How many bits is this?

Analysis:

$$32\,\text{Mbytes} = 32 \times 2^{20}\ \text{bytes} = 33554432\,\text{bytes}$$

a) $33554432\,\text{bytes} \times \dfrac{1\,\text{word}}{2\,\text{bytes}} = 16777216\,\text{words}$

b) $33554432\,\text{bytes} \times \dfrac{2\,\text{nibbles}}{1\,\text{byte}} = 67108864\,\text{nibbles}$

c) $33554432\,\text{bytes} \times \dfrac{8\,\text{bits}}{1\,\text{byte}} = 268435456\,\text{bits}$

Problem 14.15

Solution:

Find:
Suppose a microprocessor has n registers.
a) How many control lines do you need to connect each register to all other registers?
b) How many control lines do you need if a bus is used?

Analysis:
a) $n \cdot (n-1)$.
b) $2n$.

Problem 14.16

Solution:

Find:
Suppose it is desired to implement a 4K 16-bit memory.
a) How many bits are required for the memory address register?
b) How many bits are required for the memory data register?

Analysis:
a) We need $2^N = 4\text{Kbytes} = 4096\,\text{bits} \Rightarrow N = 12$
Therefore, we need 12 bits for the memory address register.
b) The data register must be at least as large as each word in memory. Therefore, the data register must be 16 bits in length.

Problem 14.17

Solution:

Find:
What is the distinction between volatile and nonvolatile memory.

Analysis:
“Volatile” memory is memory whose contents are lost when the power is turned off. This is the RAM in a computer. "Nonvolatile" means that the information in the memory is not lost when the power is off. This is a magnetic disk, magnetic tape or ROM in a computer.

Problem 14.18

Solution:

Known quantities:
Suppose that a particular magnetic tape can be formatted with 8 tracks per centimeter of tape width. The recording density is 200 bits/cm, and the transport mechanism moves the tape past the read heads at a velocity of 25 cm/s.

Find:
How many bytes/s can be read from a 2-cm-wide tape.

Analysis:

$$\frac{8\text{tracks}}{\text{cm}} \times 2\text{cm} = 16\text{tracks}$$

$$16\text{tracks} \times 200\frac{\text{bits}}{\text{cm}} = 3200\frac{\text{bits}}{\text{cm}}$$

$$3200\frac{\text{bits}}{\text{cm}} \times \frac{1\text{byte}}{8\text{bits}} = 400\frac{\text{bytes}}{\text{cm}}$$

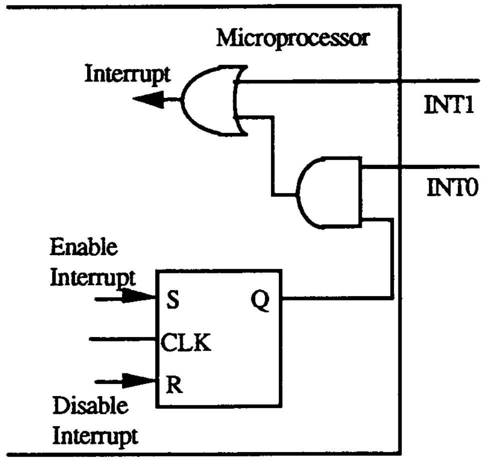
$$400\frac{\text{bytes}}{\text{cm}} \times 25\frac{\text{cm}}{\text{s}} = 10000\frac{\text{bytes}}{\text{s}}$$

Problem 14.19

Solution:

Find:
Draw a block diagram of a circuit that will interface two interrupts, INT0 and INT1, to the INT input of a CPU so that INT1 has the higher priority and INT0 has the lower. In other words, a signal on INT1 is to be able to interrupt the CPU even when the CPU is currently handling an interrupt generated by INT0, but not vice versa.

Analysis:
There are two types of interrupts: non-maskable, and maskable. When a logic signal is applied to a maskable interrupt input (INT1 in this case), the microprocessor is immediately interrupted. When a logic signal is applied to a maskable input (INT0 in this case), the microprocessor is interrupted only if that particular input is enabled. Maskable interrupts are disabled or enabled under program control.



Microprocessor
Interrupt
INT1
INT0
Enable
Interrupt
S
Q
CLK
R
Disable
Interrupt
