

Digital Circuits, Binary Numbering, and Logic Gates Cornerstone Electronics Technology and Robotics II

- **Administration:**
 - Prayer
- **Electricity and Electronics, Section 20.1, Digital Fundamentals:**
 - **Fundamentals:**
 - Two major fields of electronics:
 - Analog:
 - A system of continuous change without interruption.
 - Example: Potentiometer to control an LED
 - Digital:
 - A system that has discrete values.
 - Example: Digital thermometer or DMM
 - Advantages of digital over analog systems:
 - Less expensive compared to analog systems
 - Information easier to store
 - Digital data can be processed and transmitted more efficiently and reliably
 - Compatible to computer systems
 - Less temperature effect resulting in more stable operation
 - Less sensitive to noise sources.
 - In digital systems, the voltages are limited to the “logic HIGH voltage” ($V_{dd} = +5V$ for our discussion) and “logic LOW voltage” ($GND = 0V$). Remember that GND (ground) is the universal reference voltage that all other voltages are measured or compared.
 - In digital systems, the “logic HIGH voltages” (V_{dd}) and the “logic LOW voltages” (GND) are just for supplying power to the circuit, they also represent information.
 - Digital signals that are used to move data are a collection of these two voltage states (V_{dd} and GND).
 - Systems that use two state data to move information are commonly known as binary systems.
 - Analog-to-digital converters (ADC)
 - Microphone to ADC to CD (many other steps involved)
 - Digital-to-analog converters (DAC)
 - CD to DAC to speakers

- **Decimal Number System:**
 - Based upon us having ten fingers
 - Decimal has 10 numerals (0, 1, 2,3,4,5,6,7,8, and 9).
 - Example: 306
 - Complete LAB 1 – Counting in Decimal

When the symbols for the first digit are exhausted, the next-higher digit (to the left) is incremented, and counting starts over at 0. In decimal, counting proceeds like so:

000,
 001,
 002, ...,007
 008,
 009,
 010, (rightmost digit starts over, and the next digit to the left (in bold) is incremented)
 011,
 012, ...
 ...
 098,
 099, (rightmost two digits start over, and next digit to the left (in bold) is incremented)
 100,
 101,
 102, ...

- After a digit reaches 9, an increment resets it to 0 but also causes an increment of the next digit to the left.
- Decimal numbering system is a weighted system.
- That is, the position of each digit in a decimal number is assigned a weight.
- Weight here refers to the relative importance granted to something
- The leftmost digit is the **Most Significant Digit (MSD)** and the rightmost digit is the **Least Significant Digit (LSD)**.
- The MSD in a number is the digit that has the greatest effect on that number. The LSD in a number is the digit that has the least effect on that number.
- The rightmost bit (LSB) in a decimal number has a weight of $10^0 = 1$. Each bit to the left increases the weight by a power of ten.

Positive Powers of Ten (Whole Numbers)									
Position of Digit Left to Right	8	7	6	5	4	3	2	1	0
Decimal Weight	10^8	10^7	10^6	10^5	10^4	10^3	10^2	10^1	10^0
Decimal Equivalent	100,000,000	10,000,000	1,000,000	100,000	10,000	1,000	100	10	1

- Recall that:
 - For any integer a, $a^0 = 1$.
 - For any integer a, $a^1 = a$.
 - $10^4 = 10 \times 10 \times 10 \times 10 = 10,000$.
- For whole numbers, each position is given a positive power of ten, e.g., 10^3
- A decimal number is the sum of the weights of each digit.
- Example:

$$\begin{aligned}
 \text{The number } 306 &= (3 \times 10^2) + (0 \times 10^1) + (6 \times 10^0) \\
 &= (3 \times 100) + (0 \times 10) + (6 \times 1) \\
 &= 300 + 0 + 6 \\
 &= 306
 \end{aligned}$$

○ **Binary Numbering System:**

- Introduction: Digital electronic circuits can be in only two states, on or off. This two state system is called binary and is suited for computers. 2-Way switches are simpler than 10-way switches.
- The binary numbering system has only 2 different numerals (0 and 1).
- To distinguish a binary number from a decimal number, the prefix % will be added to a binary number, e.g., %1100111. So 1,100,111 is a decimal number and %1100111 is a binary number (1,100,111 does not equal %1100111).
- Counting in Binary:
 - Binary has only 2 different numerals (0 and 1), unlike decimal which has 10 numerals (0,1,2,3,4,5,6,7,8, and 9).

Counting in binary is similar to counting in any other number system. Beginning with a single digit, counting proceeds through each symbol, in increasing order. Decimal counting uses the symbols **0** through **9**, while binary only uses the symbols **0** and **1**. Each 0 or 1 is a binary digit, or bit.

In binary, counting is the same except that only the two symbols 0 and 1 are used. Thus after a digit reaches 1 in binary, an increment resets it to 0 but also causes an increment of the next digit to the left:

%000,
 %001,
 %0**1**0, (rightmost digit starts over, and next digit to the left (in bold) is incremented)
 %011,
 %**1**00, (rightmost two digits start over, and next digit to the left (in bold) is incremented)
 %101, ...

From http://en.wikipedia.org/wiki/Binary_numeral_system#Counting_in_binary

- Complete LAB 2 – Counting in Binary
- Complete LAB 3 – LED Display of Binary Numbers
- Binary numbering system is a weighted system,
 - Like a decimal number, the position of each digit in a binary number is assigned a weight.
 - For whole numbers, the leftmost bit is the **Most Significant Bit (MSB)** and the rightmost digit is the **Least Significant Digit (LSB)**.
 - For whole numbers, each position is given a positive power of two, e.g., 2^3
 - The rightmost bit (LSB) in a binary number has a weight of $2^0 = 1$. Each bit to the left increases the weight by a power of two.

Positive Powers of Two (Whole Numbers)								
Position of Bit Left to Right	7	6	5	4	3	2	1	0
Binary Weight	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
Decimal Equivalent	128	64	32	16	8	4	2	1

This table only shows eight bit positions. Many more bits may be added to the left if needed.

- Not all binary codes are weighed. Two codes that will be covered in later lessons are unweighed, the ASCII and 7-segment codes.

- Converting Binary to Decimal:

- Like a decimal number, a binary number is the sum of the weights of each digit.
- Example:

$$\begin{aligned}
 \text{The binary number \%101} &= (1 \times 2^2) + (0 \times 2^1) + (1 \times 2^0) \\
 &= (1 \times 4) + (0 \times 2) + (1 \times 1) \\
 &= 4 + 0 + 1 \\
 &= 5
 \end{aligned}$$

- See: <http://elm.eeng.dcu.ie/~digital1/afdez/Java++/Decimal/decimal.html>
- Convert the number %101 to a decimal using a Binary Weight Table:

Binary Weight	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
Decimal Equivalent	128	64	32	16	8	4	2	1
Binary Number						1	0	1
Decimal Value						4	0	1

Summing the decimal values, $4+0+1=5$
 Therefore, %101 = 5

- Convert the number %10110111 to a decimal using a Binary Weight Table:

Binary Weight	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
Decimal Equivalent	128	64	32	16	8	4	2	1
Binary Number	1	0	1	1	0	1	1	1
Decimal Value	128	0	32	16	0	4	2	1

Summing the decimal values, $128+0+32+16+0+4+2+1=183$
 Therefore, %10110111 = 183

- Complete LAB 4 – Converting Binary to Decimal
- An easy way to convert back and forth from binary to decimal is to use Microsoft Windows Calculator. You can find this program in the Accessories menu of your Programs. To perform the conversion, you must first place the calculator in scientific mode by clicking on the View menu and selecting Scientific mode. Then click on the "Bin" check box and enter the binary number. Now click on the Dec check box and the calculator will convert the binary number to the equivalent decimal number. Decimal to binary conversions may be performed using the reverse process.

- Summary of Binary Conditions:

On

1

True

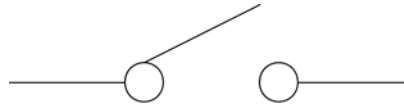


Condition 1

Off

0

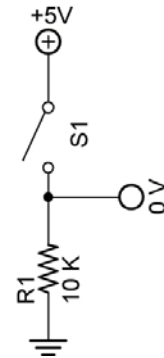
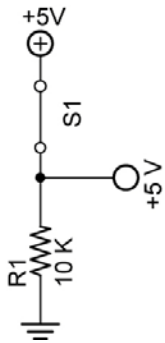
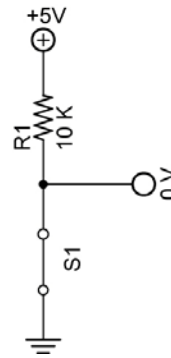
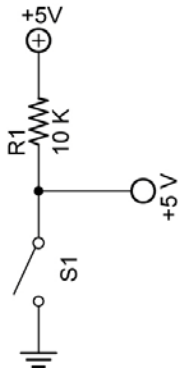
False



Condition 0

Vdd = +5 Volts (may be less)

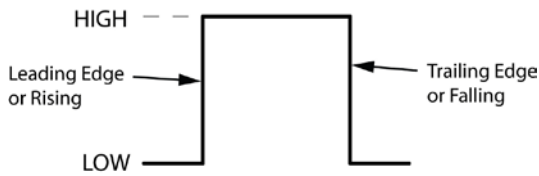
GND = 0 Volts



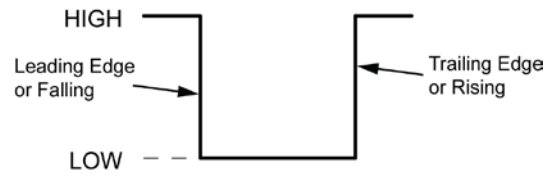
- **Logic Gates:**

- **Digital Waveforms:**

- Pulses illustrate the voltage levels (HIGH and LOW) with respect to time.

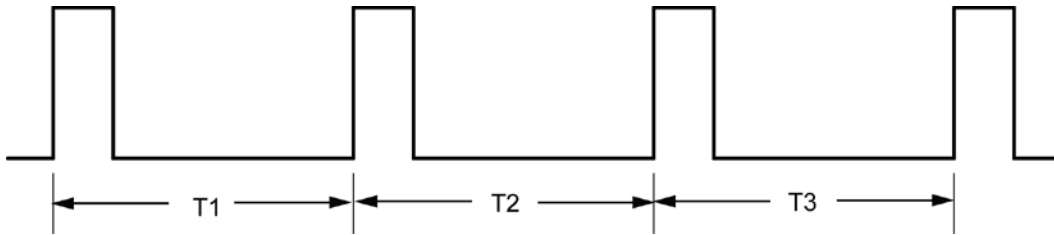


Positive Going Pulse (Rising)

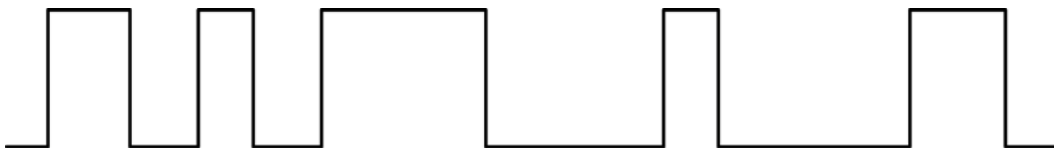


Negative Going Pulse (Falling)

- **Periodic and Non-periodic Pulses:**



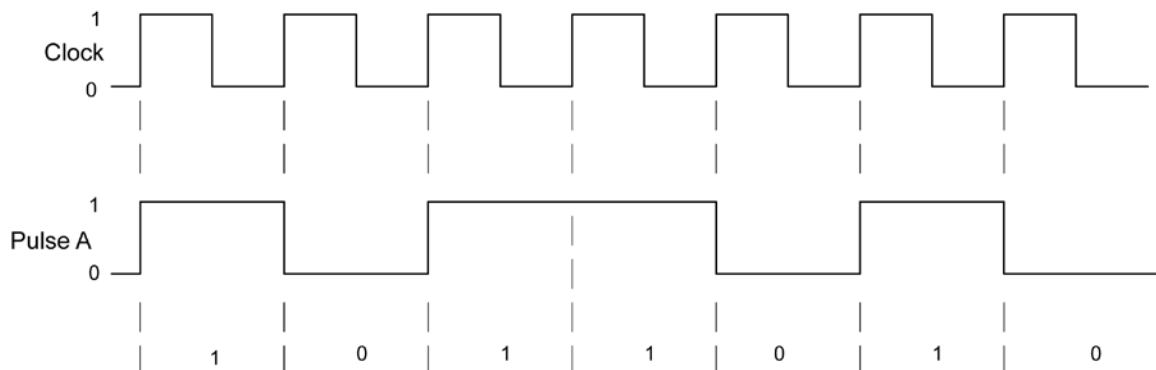
Periodic Pulse, Period T1 = Period T2 = Period T3



Non-Periodic Pulse, Periods Are Not Equal

- **Clock Waveforms:**

- In digital systems, all waveforms are synchronized by a timing waveform called a clock.
 - A clock waveform is periodic
 - Example:



Clock Waveform with Associated Waveform A

- The clock waveform is a basic timing waveform that synchronizes all waveforms in digital circuits.

Electronics Technology and Robotics II Digital Fundamentals LAB 2 – Counting in Binary

- **Purpose:** The purpose of this lab is to develop the student's skill in counting in binary.
- **Materials:**
 - 1 - Pencil
- **Procedure:**
 - In Table 1, fill in the binary equivalent for the decimal given:
 - In Table 2, fill in the next binary number if you are counting:
- **Results:**

Decimal Number	Binary Number
0	
1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	
13	
14	
15	
16	
17	
18	
19	
20	

Table 1

Binary Number	%1001
Next Binary Number	
Binary Number	%0001101
Next Binary Number	
Binary Number	%100100111
Next Binary Number	
Binary Number	%00001111
Next Binary Number	
Binary Number	%10001001010
Next Binary Number	
Binary Number	%11111111111
Next Binary Number	

Table 2

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Digital Fundamentals LAB 3 – LED Display of Binary Numbers

- **Purpose:** The purpose of this lab is to let the student see a visual representation of binary numbers and to show the student several ways of demonstrating a binary state.
- **Materials:**
 - 1 – Analog/Digital Trainer
- **Procedure:**
 - Connect four consecutive HI/LOW toggle switches to four consecutive LEDs on the analog/digital trainer.
 - Remember that 0 is represented by an off or LOW state (0V) and a 1 is represented by an on or HIGH state (+5V).
 - Give an LED display for each of the following binary numbers:
 - %0000
 - %0001
 - %0101
 - %1111
 - %1000

Electronics Technology and Robotics II

Digital Fundamentals LAB 4 – Converting Binary to Decimal

- **Purpose:** The purpose of this lab is to develop the student’s skill in converting binary numbers to decimal numbers.
- **Materials:**
 - 1 – Pencil
- **Procedure:**
 - Convert each binary number to a decimal number. Show results below:
 - %111
 - %1001
 - %001001
 - %101010
 - %010111
 - %11100011
 - %11111111
 - Use the Binary Weight Tables as guides:

Binary Weight	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
Decimal Equivalent	128	64	32	16	8	4	2	1
Binary Number								
Decimal Value								

Binary Weight	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
Decimal Equivalent	128	64	32	16	8	4	2	1
Binary Number								
Decimal Value								

Binary Weight	2^7	2^6	2^5	2^4	2^3	2^2	2^1	2^0
Decimal Equivalent	128	64	32	16	8	4	2	1
Binary Number								
Decimal Value								

- **Results:**
 - %111 = _____
 - %1001 = _____
 - %001001 = _____
 - %101010 = _____
 - %010111 = _____
 - %11100011 = _____
 - %11111111 = _____