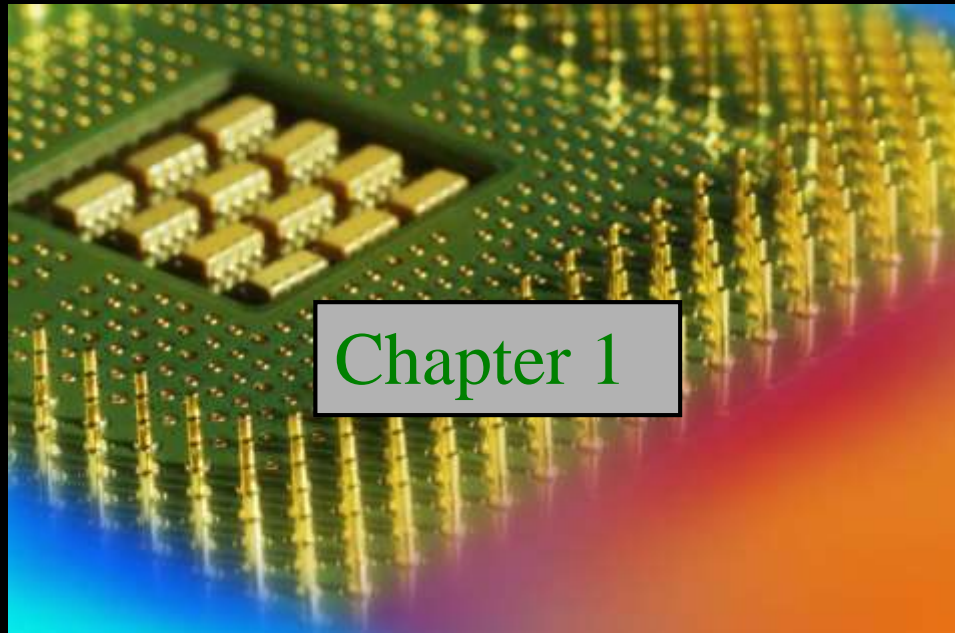


# Digital Fundamentals

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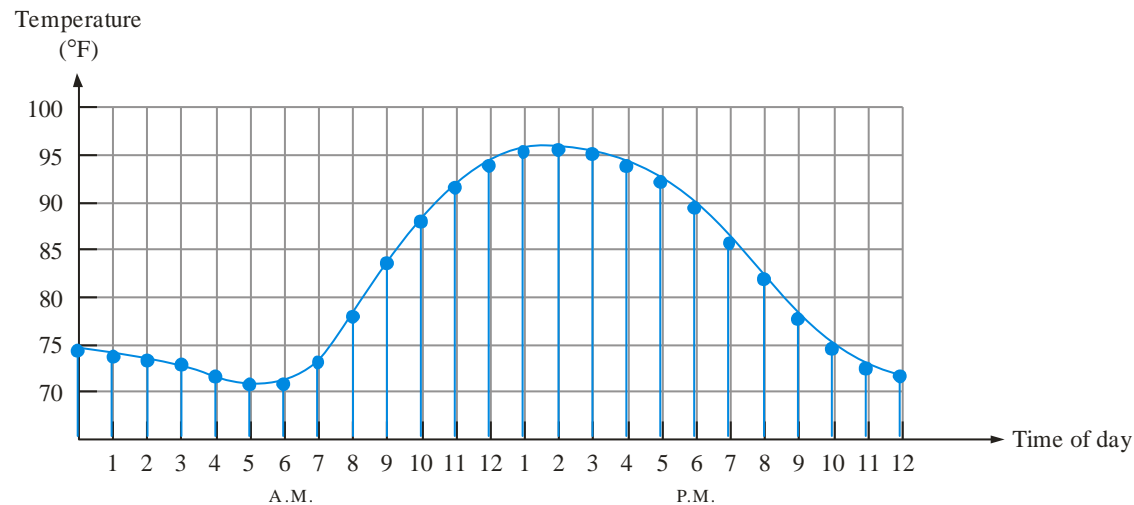


## Chapter 1

# Summary

## Analog Quantities

Most natural quantities that we see are **analog** and vary continuously.

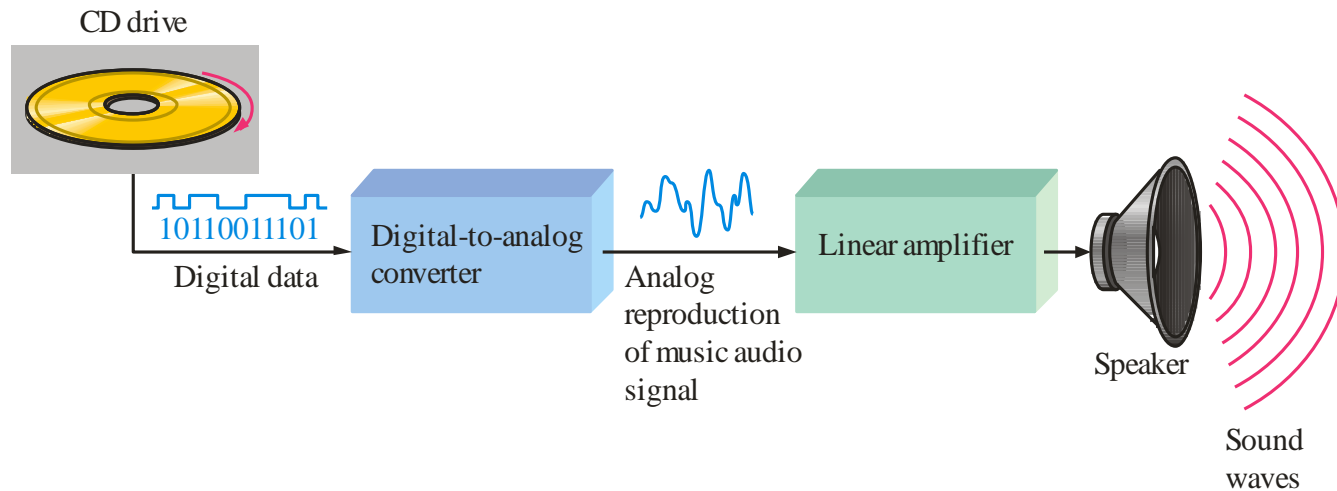


Digital systems can process, store, and transmit data more efficiently but can only assign discrete values to each point.

# Summary

## Analog and Digital Systems

Many systems use a mix of analog and digital electronics to take advantage of each technology. A typical CD player accepts digital data from the CD drive and converts it to an analog signal for amplification.

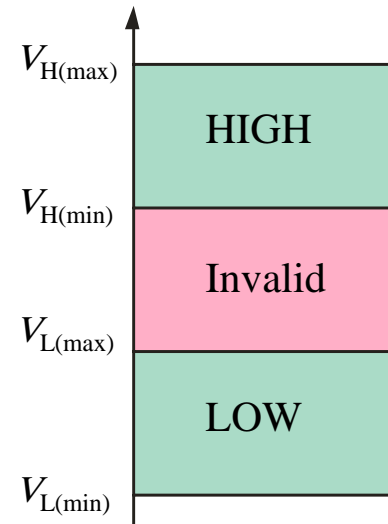


# Summary

## Binary Digits and Logic Levels

Digital electronics uses circuits that have two states, which are represented by two different voltage levels called HIGH and LOW. The voltages represent numbers in the binary system.

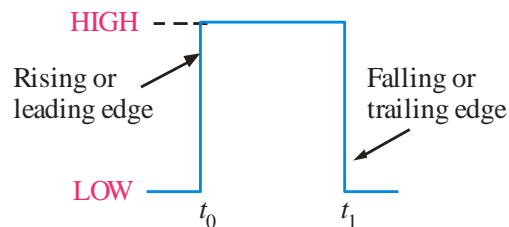
In binary, a single number is called a *bit* (for *binary digit*). A bit can have the value of either a 0 or a 1, depending on if the voltage is HIGH or LOW.



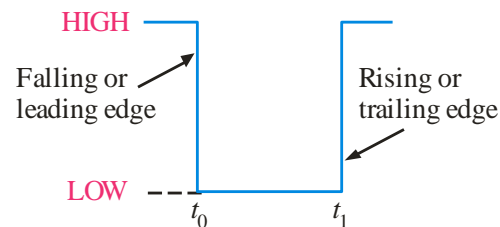
# Summary

## Digital Waveforms

Digital waveforms change between the LOW and HIGH levels. A positive going pulse is one that goes from a normally LOW logic level to a HIGH level and then back again. Digital waveforms are made up of a series of pulses.



(a) Positive-going pulse

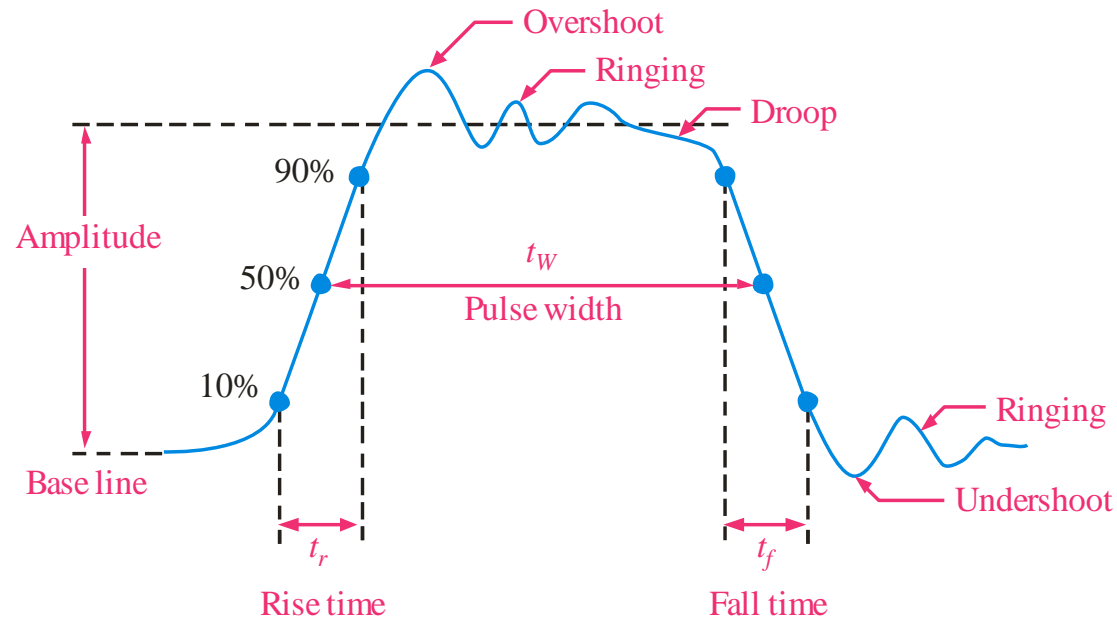


(b) Negative-going pulse

# Summary

## Pulse Definitions

Actual pulses are not ideal but are described by the rise time, fall time, amplitude, and other characteristics.



# Summary

## Periodic Pulse Waveforms

Periodic pulse waveforms are composed of pulses that repeats in a fixed interval called the **period**. The **frequency** is the rate it repeats and is measured in hertz.

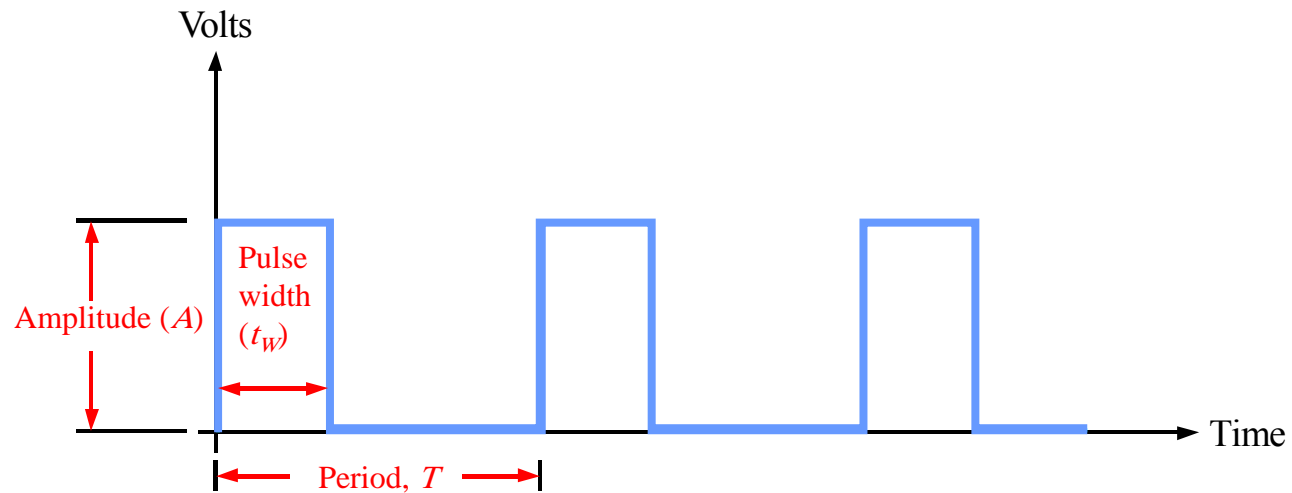
$$f = \frac{1}{T} \qquad T = \frac{1}{f}$$

The **clock** is a basic timing signal that is an example of a periodic wave.

# Summary

## Pulse Definitions

In addition to frequency and period, repetitive pulse waveforms are described by the amplitude ( $A$ ), pulse width ( $t_w$ ) and duty cycle. Duty cycle is the ratio of  $t_w$  to  $T$ .

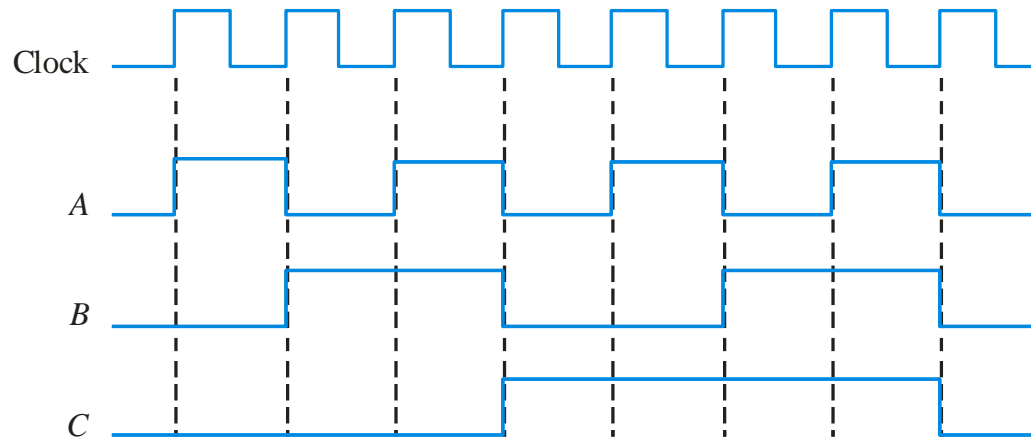




# Summary

## Timing Diagrams

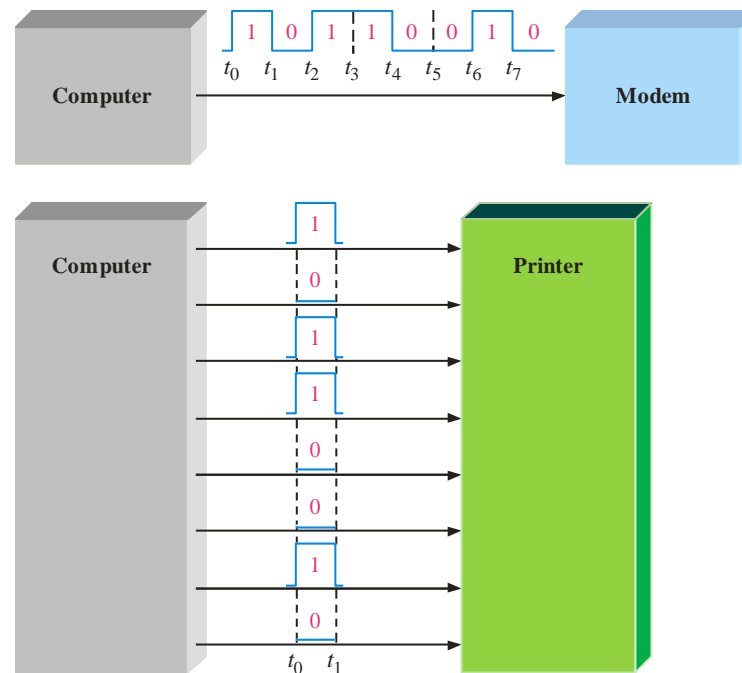
A timing diagram is used to show the relationship between two or more digital waveforms,



# Summary

## Serial and Parallel Data

Data can be transmitted by either serial transfer or parallel transfer.

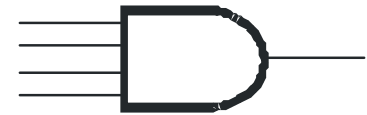


# Summary

## Basic Logic Functions

**AND**

True only if *all* input conditions are true.



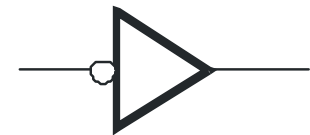
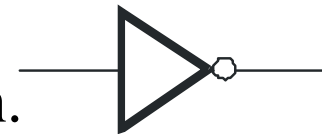
**OR**

True only if *one or more* input conditions are true.



**NOT**

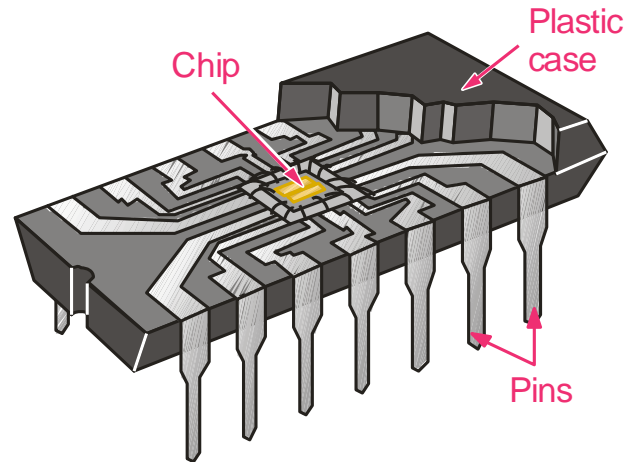
Indicates the *opposite* condition.



# Summary

## Integrated Circuits

Cutaway view of DIP (Dual-In-line Pins) chip:



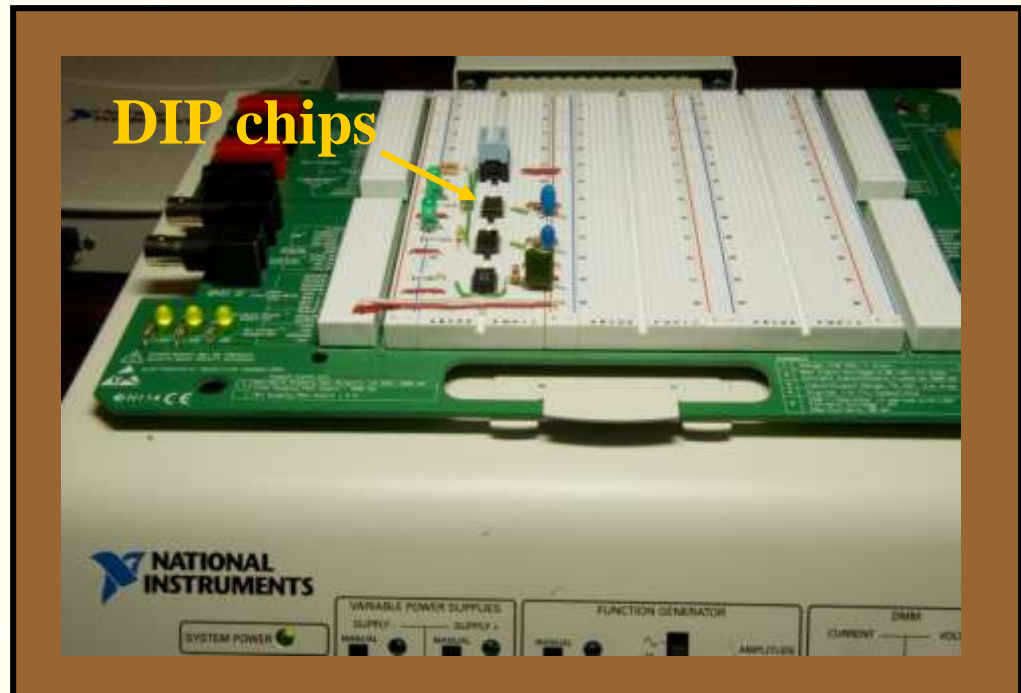
The TTL series, available as DIPs are popular for laboratory experiments with logic.

# Summary

## Integrated Circuits

An example of laboratory prototyping is shown. The circuit is wired using DIP chips and tested.

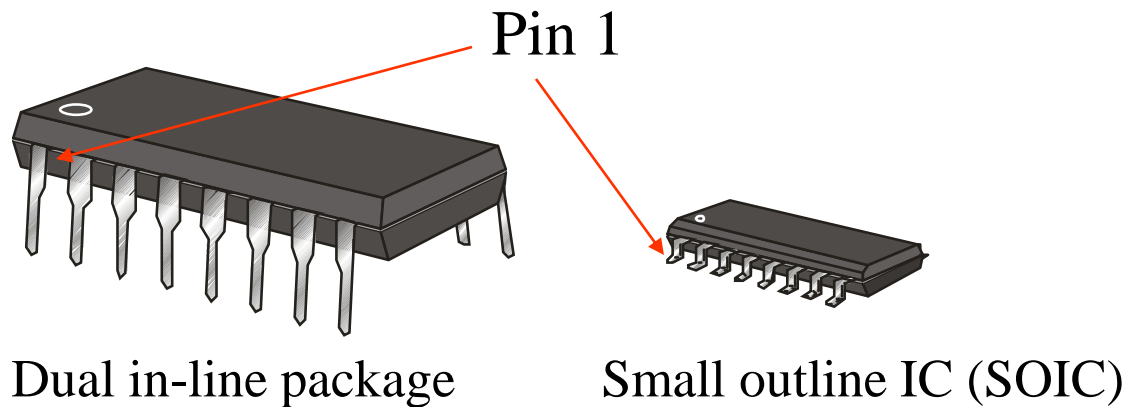
In this case, testing can be done by a computer connected to the system.



# Summary

## Integrated Circuits

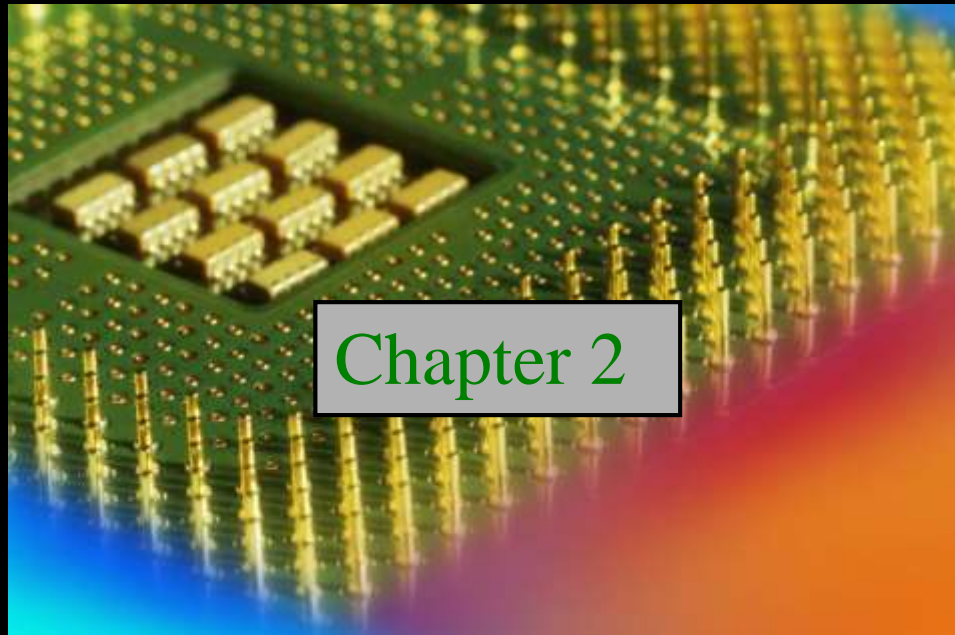
DIP chips and surface mount chips



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## Chapter 2

# Summary

## Decimal Numbers

The radix of decimal numbers is ten, because only ten symbols (0 through 9) are used to represent any number.

The column weights of decimal numbers are powers of ten that increase from right to left beginning with  $10^0 = 1$ :

$$\dots 10^5 \ 10^4 \ 10^3 \ 10^2 \ 10^1 \ 10^0.$$

For fractional decimal numbers, the column weights are negative powers of ten that decrease from left to right:

$$10^2 \ 10^1 \ 10^0. \ 10^{-1} \ 10^{-2} \ 10^{-3} \ 10^{-4} \ \dots$$



# Summary

## Decimal Numbers

Decimal numbers can be expressed as the sum of the products of each digit times the column value for that digit. Thus, the number 9240 can be expressed as

$$(9 \times 10^3) + (2 \times 10^2) + (4 \times 10^1) + (0 \times 10^0)$$

or

$$9 \times 1,000 + 2 \times 100 + 4 \times 10 + 0 \times 1$$

### Example

Express the number 480.52 as the sum of values of each digit.

### Solution

$$480.52 = (4 \times 10^2) + (8 \times 10^1) + (0 \times 10^0) + (5 \times 10^{-1}) + (2 \times 10^{-2})$$

# Summary

## Binary Numbers

For digital systems, the binary number system is used. Binary has a radix of two and uses the digits 0 and 1 to represent quantities.

The column weights of binary numbers are powers of two that increase from right to left beginning with  $2^0 = 1$ :

$$\dots 2^5 \ 2^4 \ 2^3 \ 2^2 \ 2^1 \ 2^0.$$

For fractional binary numbers, the column weights are negative powers of two that decrease from left to right:

$$2^2 \ 2^1 \ 2^0. \ 2^{-1} \ 2^{-2} \ 2^{-3} \ 2^{-4} \ \dots$$

# Summary

## Binary Numbers

A binary counting sequence for numbers from zero to fifteen is shown.

Notice the pattern of zeros and ones in each column.

Decimal Number	Binary Number
0	0 0 0 0
1	0 0 0 1
2	0 0 1 0
3	0 0 1 1
4	0 1 0 0
5	0 1 0 1
6	0 1 1 0
7	0 1 1 1
8	1 0 0 0
9	1 0 0 1
10	1 0 1 0
11	1 0 1 1
12	1 1 0 0
13	1 1 0 1
14	1 1 1 0
15	1 1 1 1

# Summary

## Binary Addition

The rules for binary addition are

$$0 + 0 = 0 \quad \text{Sum} = 0, \text{ carry} = 0$$

$$0 + 1 = 1 \quad \text{Sum} = 1, \text{ carry} = 0$$

$$1 + 0 = 1 \quad \text{Sum} = 1, \text{ carry} = 0$$

$$1 + 1 = 10 \quad \text{Sum} = 0, \text{ carry} = 1$$

When an input carry = 1 due to a previous result, the rules are

$$1 + 0 + 0 = 01 \quad \text{Sum} = 1, \text{ carry} = 0$$

$$1 + 0 + 1 = 10 \quad \text{Sum} = 0, \text{ carry} = 1$$

$$1 + 1 + 0 = 10 \quad \text{Sum} = 0, \text{ carry} = 1$$

$$1 + 1 + 1 = 11 \quad \text{Sum} = 1, \text{ carry} = 1$$

# Summary

## Binary Addition

**Example** Add the binary numbers 00111 and 10101 and show the equivalent decimal addition.

**Solution**

$$\begin{array}{r} 0111 \\ 00111 \quad 7 \\ 10101 \quad 21 \\ \hline 11100 = 28 \end{array}$$

# Summary

## Binary Subtraction

The rules for binary subtraction are

$$0 - 0 = 0$$

$$1 - 1 = 0$$

$$1 - 0 = 1$$

$$10 - 1 = 1, 0-1 \text{ with a borrow of } 1$$

**Example** Subtract the binary number 00111 from 10101 and show the equivalent decimal subtraction.

**Solution**

$$\begin{array}{r} \phantom{1} \phantom{1} \phantom{1} \\ 10101 \phantom{00} \\ \underline{00111} \\ 01110 \end{array} \quad \begin{array}{r} 21 \\ \phantom{0} \underline{7} \\ = 14 \end{array}$$

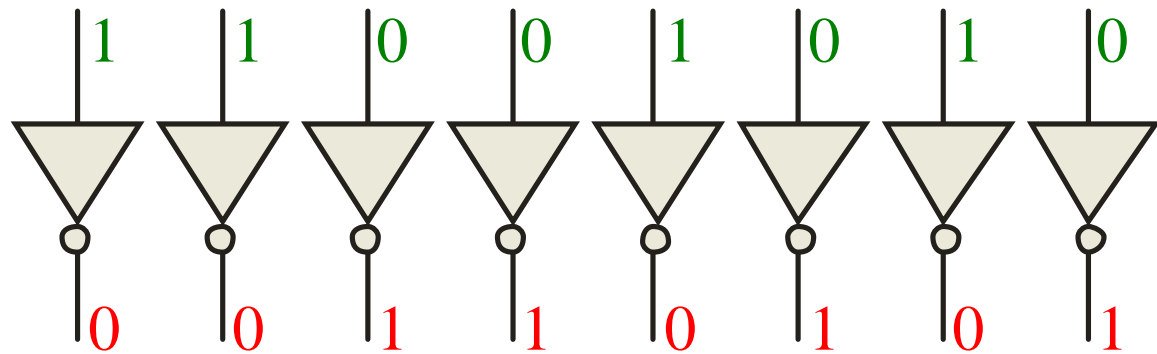
# Summary

## 1's Complement

The 1's complement of a binary number is just the inverse of the digits. To form the 1's complement, change all 0's to 1's and all 1's to 0's.

For example, the 1's complement of **11001010** is  
**00110101**

In digital circuits, the 1's complement is formed by using inverters:



# Summary

## 2's Complement

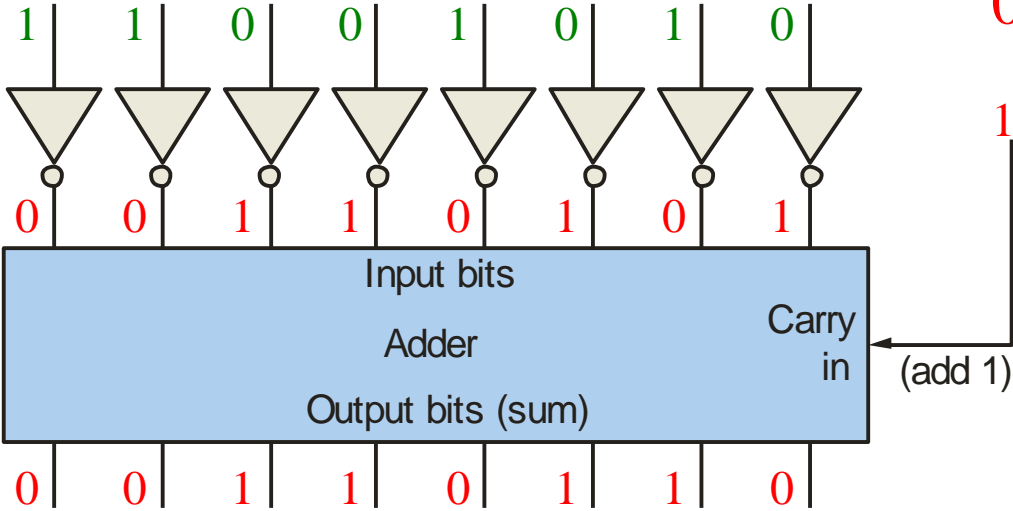
The 2's complement of a binary number is found by adding 1 to the LSB of the 1's complement.

Recall that the 1's complement of **11001010** is

**00110101** (1's complement)

To form the 2's complement, add 1:

$$\begin{array}{r} 00110101 \\ + 1 \\ \hline 00110110 \end{array}$$
  
(2's complement)





# Summary

## Signed Binary Numbers

There are several ways to represent signed binary numbers. In all cases, **the MSB in a signed number is the sign bit**, that tells you if the number is positive or negative.

Computers use a modified 2's complement for signed numbers. **Positive numbers** are stored in *true* form (with **a 0 for the sign bit**) and negative numbers are stored in *complement* form (with a 1 for the sign bit).

For example, the positive number 58 is written using 8-bits as

**00111010** (true form).

**Sign bit** → **Magnitude bits**

# Summary

## Signed Binary Numbers

- **Negative** numbers are written as the **2's complement** of the corresponding positive number.

The negative number  $-58$  is written as:

$$-58 = 11000110 \text{ (complement form)}$$

Sign bit  $\rightarrow$   $\leftarrow$  Magnitude bits

- An easy way to read a signed number that uses this notation is to assign the sign bit a column weight of  $-128$  (for an 8-bit number).
- Then add the column weights for the 1's.

**Example**

Assuming that the sign bit =  $-128$ , show that  $11000110 = -58$  as a 2's complement signed number:

**Solution**

Column weights:  $-128$  64 32 16 8 4 2 1.

$$\begin{array}{cccccccc} & 1 & 1 & 0 & 0 & 0 & 1 & 1 & 0 \\ & -128 & +64 & & & & +4 & +2 & \\ & & & & & & & & = -58 \end{array}$$

## Hexadecimal Numbers

- Hexadecimal uses sixteen characters to represent numbers: the numbers 0 through 9 and the alphabetic characters A through F.
- Large **binary number** can easily be converted to hexadecimal by grouping bits **4 at a time** and writing the equivalent hexadecimal character.

**Example** Express 1001 0110 0000 1110<sub>2</sub> in hexadecimal:

**Solution** Group the binary number by 4-bits starting from the right. Thus, **960E**

Decimal	Hexadecimal	Binary
0	0	0000
1	1	0001
2	2	0010
3	3	0011
4	4	0100
5	5	0101
6	6	0110
7	7	0111
8	8	1000
9	9	1001
10	A	1010
11	B	1011
12	C	1100
13	D	1101
14	E	1110
15	F	1111

## Hexadecimal Numbers

- Hexadecimal is a weighted number system.
- The column weights are powers of 16, which increase from right to left.

$$\text{Column weights } \begin{cases} 16^3 & 16^2 & 16^1 & 16^0 \\ 4096 & 256 & 16 & 1 \end{cases}$$

**Example** Express  $1A2F_{16}$  in decimal.

**Solution** Start by writing the column weights:

$$\begin{array}{cccc} 4096 & 256 & 16 & 1 \\ 1 & A & 2 & F_{16} \end{array}$$

$$1(4096) + 10(256) + 2(16) + 15(1) = 6703_{10}$$

## Octal Numbers

- Octal uses eight characters the numbers 0 through 7 to represent numbers.
- There is no 8 or 9 character in octal.
- Binary number can easily be converted to octal by grouping bits **3 at a time** and writing the equivalent octal character for each group.

Decimal	Octal	Binary
0	0	0000
1	1	0001
2	2	0010
3	3	0011
4	4	0100
5	5	0101
6	6	0110
7	7	0111
8	10	1000
9	11	1001
10	12	1010
11	13	1011
12	14	1100
13	15	1101
14	16	1110
15	17	1111

**Example** Express 1 001 011 000 001 110<sub>2</sub> in octal:

**Solution** Group the binary number by 3-bits starting from the right. Thus, **113016<sub>8</sub>**

## Octal Numbers

- Octal is also a weighted number system.
- The column weights are powers of 8, which increase from right to left.

$$\text{Column weights } \begin{cases} 8^3 & 8^2 & 8^1 & 8^0 \\ 512 & 64 & 8 & 1 \end{cases}$$

**Example** Express  $3702_8$  in decimal.

**Solution** Start by writing the column weights:

$$\begin{array}{cccc} 512 & 64 & 8 & 1 \\ 3 & 7 & 0 & 2_8 \end{array}$$

$$3(512) + 7(64) + 0(8) + 2(1) = 1986_{10}$$

## BCD

- Binary coded decimal (BCD) is a weighted code that is commonly used in digital systems when it is necessary to show decimal numbers such as in clock displays.
- The table illustrates the difference between straight binary and BCD. BCD represents each decimal digit with a 4-bit code.
- Notice that the codes 1010 through 1111 are not used in BCD.

Decimal	Binary	BCD
0	0000	0000
1	0001	0001
2	0010	0010
3	0011	0011
4	0100	0100
5	0101	0101
6	0110	0110
7	0111	0111
8	1000	1000
9	1001	1001
10	1010	00010000
11	1011	00010001
12	1100	00010010
13	1101	00010011
14	1110	00010100
15	1111	00010101

## BCD

- You can think of BCD in terms of column weights in groups of four bits.
- For an 8-bit BCD number, the column weights are:

80 40 20 10 8 4 2 1.

**Question:** What are the column weights for the BCD number 1000 0011 0101 1001?

**Answer:**

8000 4000 2000 1000 800 400 200 100 80 40 20 10 8 4 2 1

Note that you could add the column weights where there is a 1 to obtain the decimal number. For this case:

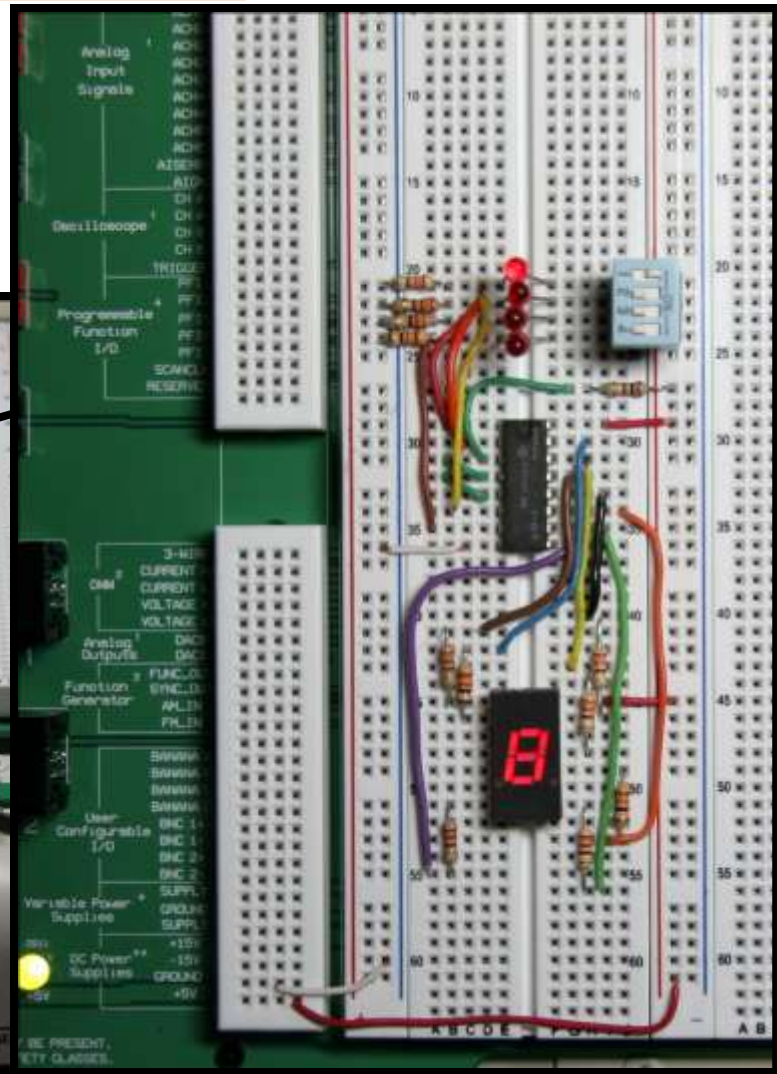
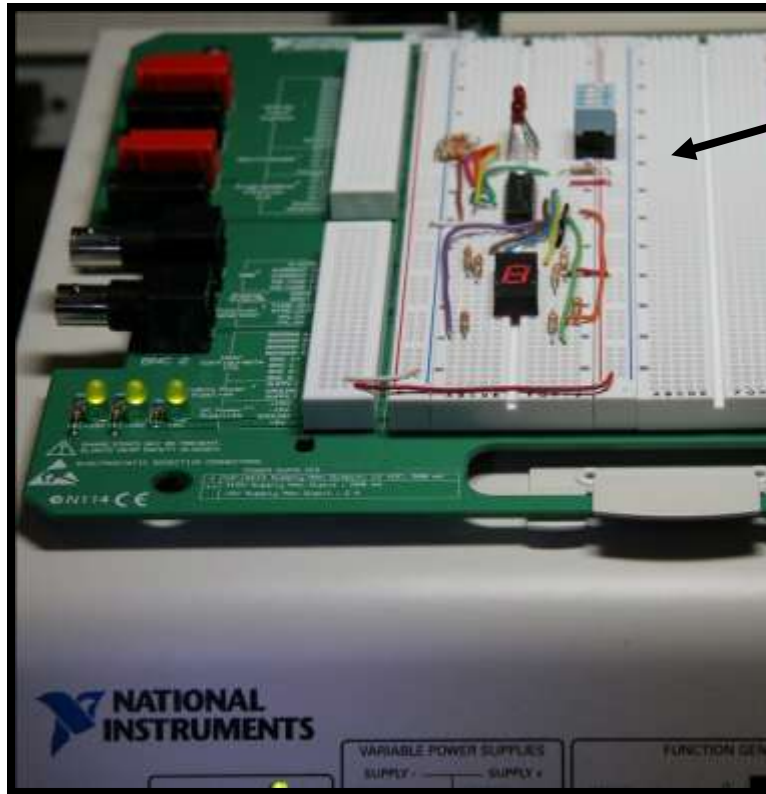
$$8000 + 200 + 100 + 40 + 10 + 8 + 1 = 8359_{10}$$



# Summary

## BCD

A lab experiment in which BCD is converted to decimal is shown.



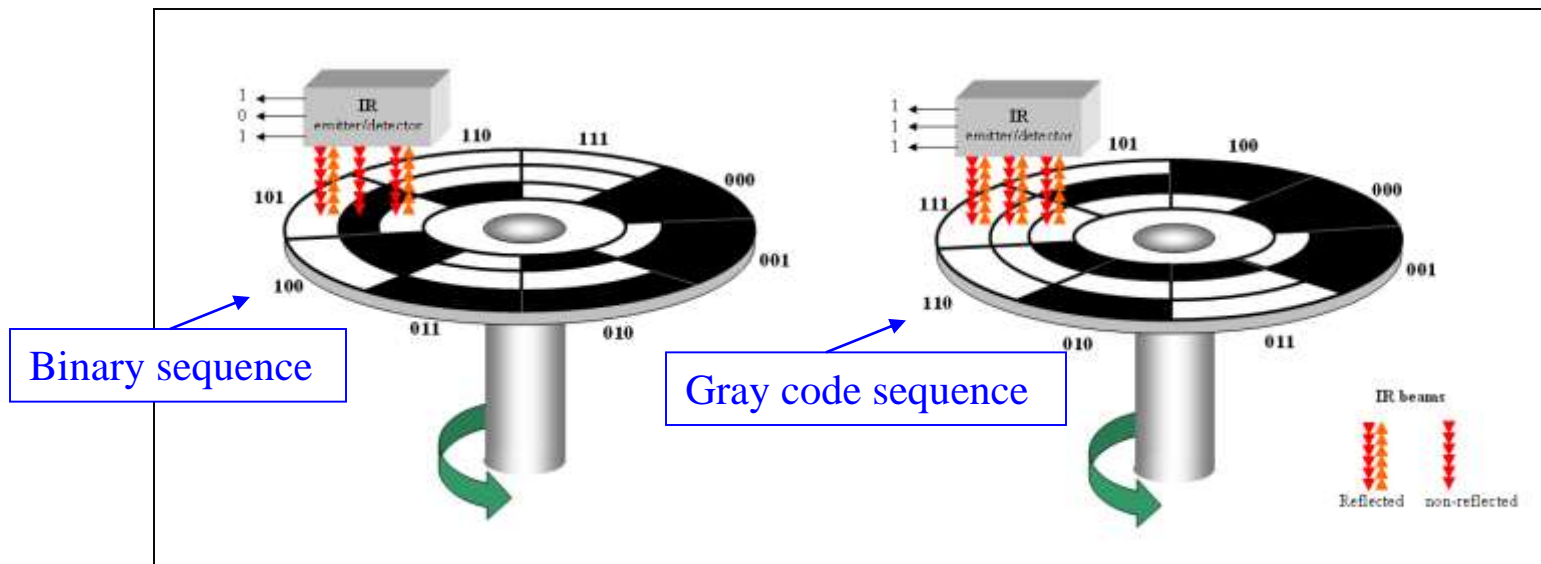
## Gray code

- Gray code is an **unweighted** code that has a single bit change between one code word and the next in a sequence.
- Gray code is used to avoid problems in systems where an error can occur if more than one bit changes at a time.

Decimal	Binary	Gray code
0	0000	0000
1	0001	0001
2	0010	0011
3	0011	0010
4	0100	0110
5	0101	0111
6	0110	0101
7	0111	0100
8	1000	1100
9	1001	1101
10	1010	1111
11	1011	1110
12	1100	1010
13	1101	1011
14	1110	1001
15	1111	1000

## Gray code

- A shaft encoder is a typical application.
- Three IR emitter/detectors are used to encode the position of the shaft.
- The encoder on the left uses binary and can have three bits change together, creating a potential error.
- The encoder on the right uses gray code and only 1-bit changes, eliminating potential errors.



## ASCII

- ASCII is a code for alphanumeric characters and control characters.
- In its **original form**, ASCII encoded 128 characters and symbols using 7-bits. The first 32 characters are control characters, that are based on obsolete teletype requirements, so these characters are generally assigned to other functions in modern usage.
- In 1981, IBM introduced **extended ASCII**, which is an 8-bit code and increased the character set to 256. Other extended sets (such as Unicode) have been introduced to handle characters in languages other than English.