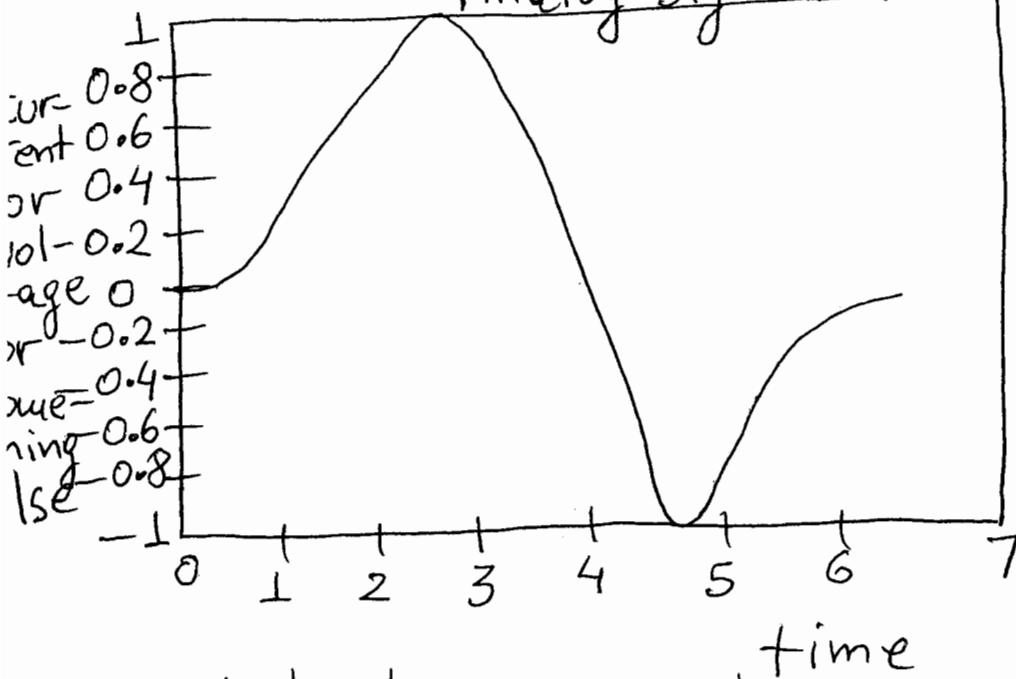


EE 2720

Handout # 0

IntroductionAnalog versus digital

- Analog devices and systems process time-varying signals that can take on any value across a continuous range of voltage, current or other metric. Analog signal (takes continuous values of voltage, current or another metric)



- Digital devices and systems process signals that can take only one of two discrete values which we call 0 and 1 (or LOW and HIGH, FALSE and TRUE, negated and asserted, Alex and George etc).

Usually logic 0 signal represents a <sup>②</sup> signal of 0 Volts (V) and logic 1 signal represents a signal of 5 Volts (V).

- For digital systems all inputs and outputs are zeroes and ones.
- 

Why is digital chosen over analog..

- Reproducibility of results:

Given the same set of inputs a digital circuit always produces exactly the same results. The outputs of an analog circuit vary with temperature, power-supply voltage and aging (see page 5 of text).

- Ease of design.

- Programmability: For example, you can write a program for a digital computer to perform a specific task (see pg. 5 of text)

- Speed: Today's digital devices are very fast. For example, a complex digital device can accept inputs and produce outputs

in less than 2 nanoseconds;  $< 1$  nanosecond =  $10^{-9}$  second; (see pages 5, 6 of textbook). (3)

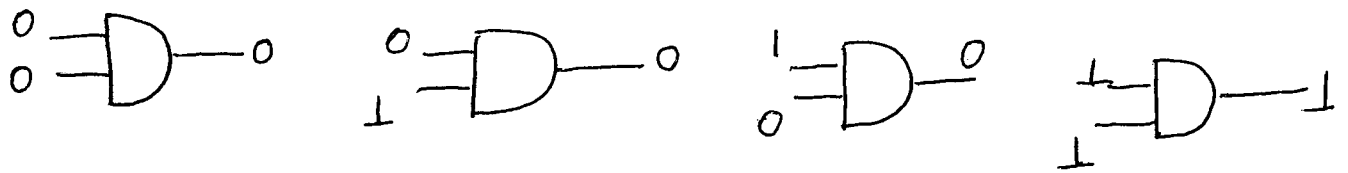
- Economy: Digital circuits can provide a lot of functionality in a small space. ~~area~~ Circuits can be "integrated" into a single "chip" and mass-produced at very low cost. (see page 6 of text).

### Digital devices

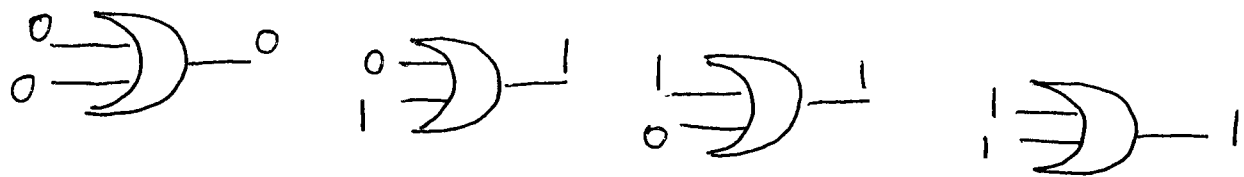
- The most basic components of a digital system are called gates.
- The gates have one or more inputs and produce an output that is a function of the current input values.
- Any digital function can be realized with just three (3) types of gates, the AND, OR and NOT (Inverter) gates.

• AND gate :

(4)



• OR Gate :



• NOT Gate or Inverter :



• Other gates used in digital systems are: NAND gate, NOR gate, EXCLUSIVE-OR gate, EXCLUSIVE-NOR gate. These gates can be implemented using AND, OR, NOT gates.

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Classification of Digital ~~Circuits~~

Circuits

⑤

Digital circuits are classified into two types, "combinational" and "sequential".

- A combinational circuit is one whose outputs depend only on its current inputs.
- A sequential circuit is one whose outputs depend not only on the current inputs but also on the past sequence of inputs, possibly arbitrarily far back in time. (In other words, a sequential circuit has memory of past events)
- A combinational circuit does not have feedback loops.
- (A feedback loop generally creates a sequential circuit).
- The basic element of sequential circuits are the flip-flops.
- A flip-flop is a device that stores either a 0 or 1.

- In EE 2720 we will study combinational <sup>(6)</sup> circuits.
- In EE 2730 you will study sequential circuits.

### Integrated Circuits.

- A collection of one or more gates fabricated on a single (silicon) "chip" is called an integrated circuit (IC).
- Large ICs with millions of gates may be half an inch or more on each side, while small ICs may be less than one-tenth of an inch on each side.

## Size Classification of Integrated Circuits (8)

- SSI or small-scale integration<sup>on</sup> circuits.  
— They contain 1 to 20 gates.
- MSI or medium-scale integration<sup>on</sup> circuits.  
— They contain 20 to 200 gates.
- LSI or large-scale integration circuits.  
— They contain 200 to 200,000 gates.
- VLSI or very large-scale integration circuits.  
— They contain over 1,000,000 transistors.  
May be tens of millions of transistors.
- A transistor is an electronic device which is the basic building element of logic gates. It acts like a switch ✓  
which can be open or closed.



Transistors are beyond the scope of ⑨ this course.

## Number Systems and Computer Arithmetic

- Fixed Point (FXP) Systems.

### Positional Number Systems.

- Here a number is represented by a string of digits where each digit has an associated weight or weight-factor.

The left-most digit has the largest weight and is called the "most significant digit" (MSD); the right-most digit has the smallest weight and is called the "least significant digit" (LSD).

The value of the number is a weighted sum of the digits.

- The base in which we perform arithmetic is also called radix ( $r$ )

- If  $r=10$  we have a decimal system
- If  $r=2$  " " " binary "
- If  $r=8$  " " " an octal "
- If  $r=16$  " " " a hexadecimal "

(10)

Example: Find the value of the decimal number  $1734_{10}$

Answer:  $1734_{10} = 1 \times 10^3 + 7 \times 10^2 + 3 \times 10^1 + 4 \times 10^0 = 1 \times 1000 + 7 \times 100 + 3 \times 10 + 4 \times 1.$

Example: Find the value of the decimal number  $5185.68_{10}$ .

Answer:  $5185.68_{10} = 5 \times 10^3 + 1 \times 10^2 + 8 \times 10^1 + 5 \times 10^0 + 6 \times 10^{-1} + 8 \times 10^{-2}.$

In general consider the following decimal number:

$$X = (\underbrace{x_{n-1} x_{n-2} \dots x_1 x_0}_{\text{integer part}} \cdot \underbrace{x_{-1} x_{-2} \dots x_{-k}}_{\text{fractional part}})_{10}$$

↑  
decimal point

Here the digits  $x_i$  belong to the set (11)  
 $\{0, 1, 2, 3, \dots, 9\}$ .

The value of the above number  $X$  is :

$$X_{\text{value}} = \sum_{i=-k}^{n-1} x_i \times 10^i$$

Generalization for any radix  $r$ .

Consider the following radix- $r$  number:

$$X = (\underbrace{x_{n-1} x_{n-2} \dots x_1 x_0}_{\text{integer part.}} \underbrace{\cdot}_{\text{radix point.}} \underbrace{x_{-1} x_{-2} \dots x_{-k}}_{\text{fractional part.}})_r$$

~~The value is~~ Here the digits  $x_i$  belong to the set  $\{0, 1, 2, \dots, r-1\}$ .

The value of the above number  $X$  is :

$$X_{\text{value}} = \sum_{i=-k}^{n-1} x_i \times r^i$$

we'll use this formula to find the value of a number in any radix  $r$ .

If  $r=10 \Rightarrow$  decimal system; if  $r=8 \Rightarrow$  octal system;  
 If  $r=16 \Rightarrow$  hexadecimal " ; if  $r=2 \Rightarrow$  binary "

• The systems we study so far are (12) called fixed point (FXP) because the radix point (•) assumes a fixed location. The radix point can be located someplace in the middle of the number, in which case the number will consist of an integer as well as fractional part, it can be located after the right-most digit (like  $X = x_{n-1}x_{n-2} \dots x_1x_0. = x_{n-1}x_{n-2} \dots x_1x_0$ ) in which case the number is 100% integer or it can be located before the left-most digit (like  $.x_{-1}x_{-2} \dots x_{-n}$ ) in which case the number is 100% fractional.

• The two extremes for radix  $r$  fixed point systems and how they relate:

Notation:  $[a \ b]$  means all the numbers between  $a$  and  $b$  including  $a$  and including  $b$ . Here  $a < b$ .

$$A = x_{n-1}x_{n-2} \dots x_1x_0r$$

$$B = \cdot x_{n-1}x_{n-2} \dots x_1x_0r$$

$$A \in [0 \quad r^n - 1] ; \in \text{ means } \underline{\text{belongs to}}$$

$$B = [0 \quad 1 - r^{-n}]$$

$$\cancel{A} \times r^{-n} = B$$

$$B \times r^n = A$$

I am not proving these. They can easily be proven

### Binary numbers.

If the radix is  $r=2$ , the system is called binary.

Definition: A binary digit is called bit.

Bits can have two (2) values: 0 or 1.

Consider the following binary (radix  $r=2$ ) number.

$$X = (\underbrace{x_{n-1}x_{n-2} \dots x_1x_0}_{\text{integer part}} \cdot \underbrace{x_{-1}x_{-2} \dots x_{-k}}_{\text{fractional part}})_2$$

↑  
binary point

Here the bits  $x_i$  belong to the set  $\{0, 1\}$ . The value of  $X$  is: (14)

$$X_{\text{value}} = \sum_{i=-k}^{n-1} x_i \times 2^i.$$

The left-most bit is called the most significant bit (MSB); the right-most bit is called the least significant bit (LSB).

Example: Find the value of  $10011_2$ .

Answer:  $10011_2 = 1 \times 2^4 + 0 \times 2^3 + 0 \times 2^2 + 1 \times 2^1 + 1 \times 2^0$

$$= 1 \times 16 + 2 + 1 = 19_{10}$$

Example: Find the value of  $100010_2$ .

Answer:  $100010_2 = 1 \times 2^5 + 0 \times 2^4 + 0 \times 2^3 + 0 \times 2^2 + 1 \times 2^1 + 0 \times 2^0 = 32 + 2 = 34_{10}$ .

Example: Find the value of  $101.001_2$

Answer:  $101.001_2 = 1 \times 2^2 + 0 \times 2^1 + 1 \times 2^0 + 0 \times 2^{-1} + 0 \times 2^{-2} + 1 \times 2^{-3} = 4 + 1 + 0.125 = 5.125_{10}$

## Octal and Hexadecimal Numbers.

(15)

- If  $r=8$ , the system is called octal. The digits used are  $0, 1, 2, \dots, 7$ .
- If  $r=16$ , the system is called hexadecimal. Here we need 16 digits:  $0, 1, 2, \dots, 15$ . For the digits  $10, 11, 12, 13, 14, 15$  we use the letters  $A, B, C, D, E, F$  respectively.

Example: Find the value of

$61.4_8$  ← this 8 means radix 8 or octal #.

Answer:  $61.4_8 = 6 \times 8^1 + 1 \times 8^0 + 4 \times 8^{-1} =$   
 $= 48 + 1 + 4 \times 0.125 = 49 + 0.5 = 49.5_{10}.$

Example: Find the value of  $3C.8_{16}$

this 16 means radix 16 ↑  
or hexadecimal number

Answer:  $3C.8_{16} = 3 \times 16^1 + 12 \times 16^0 + 8 \times 16^{-1}$   
 $= 48 + 12 + 8 \times 0.0625 = 60 + 0.5 = 60.5_{10}$

# Conversion Table

Decimal	Binary	Octal	Hexadecimal
0	0	0	0
1	1	1	1
2	10	2	2
3	11	3	3
4	100	4	4
5	101	5	5
6	110	6	6
7	111	7	7
8	1000	10	8
9	1001	11	9
10	1010	12	A
11	1011	13	B
12	1100	14	C
13	1101	15	D
14	1110	16	E
15	1111	17	F