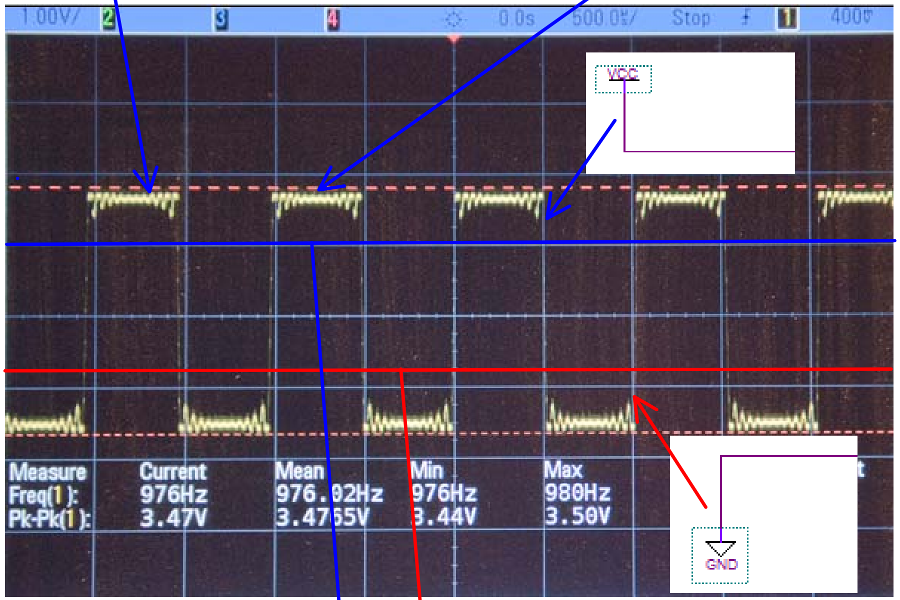
Lecture 2 Page_1

Mixed Signal Oscilloscope (MOS)

Analog (voltage) Signal

Actual Voltages

Analog

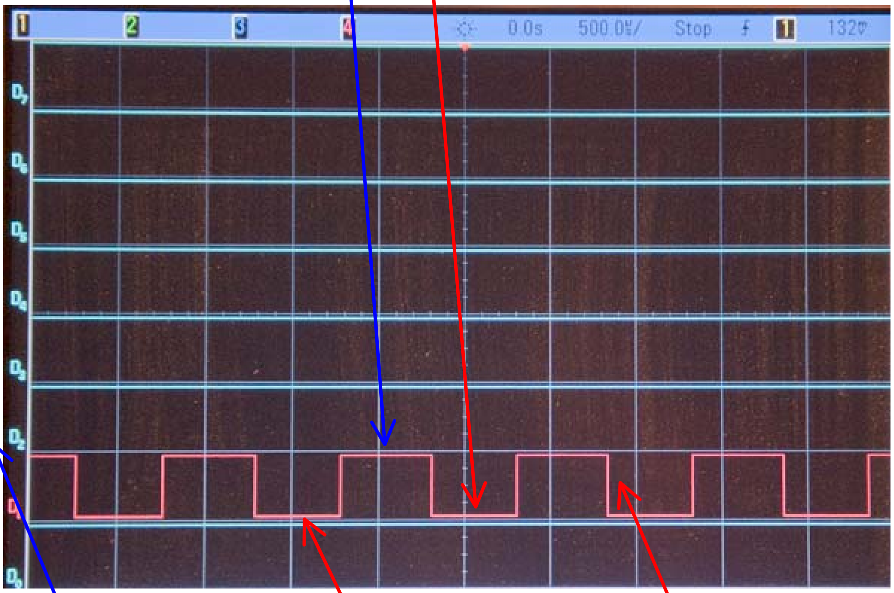


Measure	Current	Mean	Min	Max
Freq(1):	976Hz	976.02Hz	976Hz	980Hz
Pk-Pk(1):	3.47V	3.4765V	3.44V	3.50V

Interpretation

Digital signal is Hi or 1 if analog signal voltage > blue voltage

Digital signal is Lo or 0 if analog signal voltage < red voltage



Logical Values
not actual Voltages

1 Bit (Binary Digit)

Digital Signal

Digital

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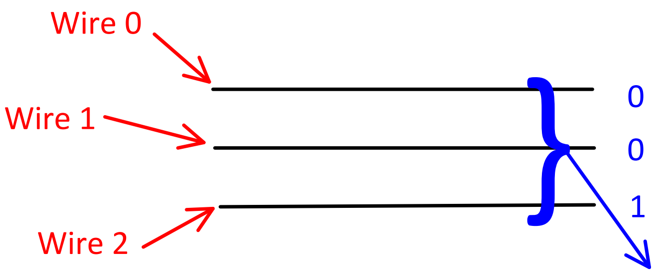
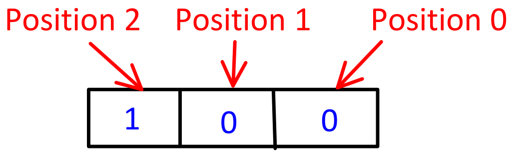


Wires carrying digital signals
Each wire carrying one bit

Collection of related wires is
known as a bus



Cow or number 4?

Register (memory) storing
digital signals. Each position
carrying one bit

A Computer Code

0 0 0 -> Pig
0 0 1 -> Dog
0 1 0 -> Cat
0 1 1 -> Mouse
1 0 0 -> Cow
1 0 1 -> Sheep
1 1 0 -> Skunk
1 1 1 -> Horse

Binary Numbers

$1x2^2 + 0 x 2^1 + 0x2^0$ = decimal number 4

Number Systems

decimal number system

↑ every day arithmetic

$$\underset{2}{\overset{\uparrow}{7}}\,\underset{1}{\overset{\uparrow}{2}}\,\underset{0}{\overset{\uparrow}{4}}.\underset{-1}{\overset{\uparrow}{5}} = 7\times\underbrace{10}^{2} + 2\times\underbrace{10}^{1} + 4\times\underbrace{10}^{0} + 5\times\underbrace{10}^{-1}$$

Base 10

Radix 10

decimal point

$$A_{n-1}\, A_{n-2} \cdots A_2 A_1 A_0 \overset{\downarrow}{.}\, A_{-1}\, A_{-2} \cdots A_{-m+1}\, A_{-m}$$

$$A_i \in \{\underbrace{0, 1, 2, \cdots 9}_{10 \text{ digits}}\}$$

$$A_{n-1}\times 10^{n-1} + A_{n-2}\times 10^{n-2} + \cdots + A_1\times 10^{1} + A_0\times 10^{0} + A_{-1}\times 10^{-1} + \cdots + A_{-m}\times 10^{-m}$$

In general base (radix r) number

r digits 0, 1, 2, ⋯ r−1

radix point

$$A_{n-1} \cdots A_1 A_0 \overset{\swarrow}{.}\, A_{-1}\, A_{-2} \cdots A_{-m}$$

$$A_{n-1}\times r^{n-1} + \cdots + A_1\times r^{1} + A_0\times r^{0} + A_{-1}\times r^{-1} + \cdots + A_{-m}\, r^{-m}$$

$$(A_{n-1} A_{n-2} \cdots A_1 A_0 . A_{-1} A_{-2} \cdots A_{-m})_r \leftarrow \text{optional}$$

decimal $32.65 = (32.65)_{10}$

radix 8 (octal) $32.65 = (32.65)_8$

not the same number

$$(312.4)_5 = 3\times5^2 + 1\times5^1 + 2\times5^0 + 4\times5^{-1}$$

$$= (75)_{10} + (5)_{10} + (2)_{10} + (0.8)_{10} = (82.8)_{10}$$

Binary numbers

base, radix $= 2$

$$A_{n-1}\cdots A_1 A_0 . A_{-1} A_{-2} \cdots A_{-m}$$

$A_i \in \{0, 1\}$ $A_i \to$ binary digit (bit)

Binary number

↳ $\underset{\uparrow\ \text{bit}}{1}011\underset{\uparrow\ \text{bit}}{0}1\underset{\uparrow\ \text{binary point}}{.}1101 = (101101.1101)_2$

Converting from binary to decimal

$$(\underset{5}{1}\underset{4}{1}\underset{3}{0}\underset{2}{1}\underset{1}{0}\underset{0}{1}.\underset{-1}{1}\underset{-2}{1})_2 = 1\times2^5 + 1\times2^4 + 0\times2^3 + 1\times2^2 + 0\times2^1 + 1\times2^0$$

$$+ 1\times2^{-1} + 1\times2^{-2} = (53.75)_{10}$$

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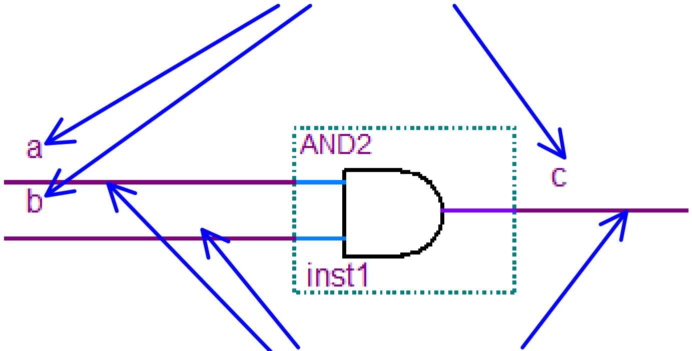
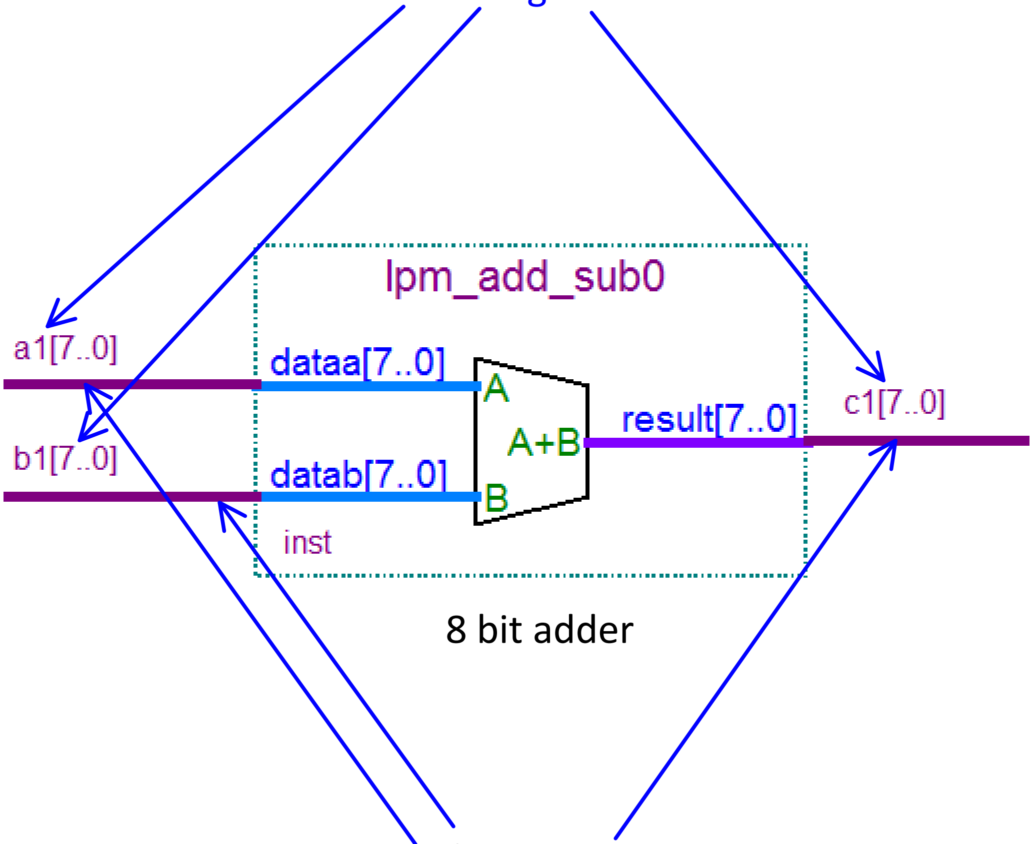
1 bit signals



One bit wires

could for example represent an 8 bit unsigned integer

8 bit signals



8 bit adder

8 bit Busses
(eight 1-bit wires)

Octal & Hexadecimal numbers

Octal radix = 8 $8 = 2^3$ → radix is a power of 2

Hexadecimal radix = 16 $16 = 2^4$

useful to represent binary numbers easily in compact form (easier on human beings than binary representation)

Octal numbers:

$$\overbrace{0, 1, 2, 3, 4, 5, 6, 7}^{\text{8 octal digits}}$$

$$(127.4)_8 = 1\times 8^2 + 2\times 8^1 + 7\times 8^0 + 4\times 8^{-1}$$
$$= (87.5)_{10}$$

Hexadecimal numbers

$$\underbrace{0, 1, 2, 3, 4, 5, 6, 7, 8, 9, \overset{10}{A}, \overset{11}{B}, \overset{12}{C}, \overset{13}{D}, \overset{14}{E}, \overset{15}{F}}_{\text{16 hexadecimal digits}}$$

$$(B65F)_{16} = 11\times 16^3 + 6\times 16^2 + 5\times 16^0 + 15\times 16^0$$
$$= (46687)_{10}$$

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Important table for converting bases among binary, octal and hexadecimal number representation

Decimal	**Binary**	**Octal**	**Hex**
00	0000	00	0
01	0001	01	1
02	0010	02	2
03	011	03	3
04	0100	04	4
05	0101	05	5
06	0110	06	6
07	0111	07	7
08	1000	10	8
09	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

Converting from binary to octal
(use table)

groups of three

pad zeros if required

010 110 001 101 011 . 111 100 000 110

2 6 1 5 3 . 7 4 0 6

add zeros here if needed to complete group of 3

start from here

= $(26153.7406)_8$

Converting from binary to hexadecimal

pad zeros if required

0010 1100 0110 1011 . 1111 0000 0110

2 C 6 B . F 0 6

pad zeros if required

start from here

= $(2C6B.F06)_{16}$

Converting from octal to binary

this zero is not needed

$(673.12)_8$ = 110 111 011 . 001 010

Converting from hexadecimal to binary

discard

(use Table)

$(3A6.C)_{16}$ = 0011 1010 0110 . 110

= $(1110100110.11)_2$