Lesson 9: Digital Input-Output Signal Interfacing

ET 438b Sequential Control and Data Acquisition

Department of Technology

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Learning Objectives

After this presentation you will be able to:

- Identify the electrical characteristics of a TTL interface
- Explain the difference between sourcing and sinking digital inputs
- Select and design appropriate digital I/O interface circuits
- Use software to control digital I/O lines and ports.

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DIGITAL INPUT & OUTPUT SIGNALS

Digital input and output control and monitor external devices that have only on/off levels

Boolean Logic form basis of numbering system and computer structure.

Boolean Logic	
Boolean Logic Symbol	**State**
1	logic high
0	logic low

Logical Groupings

Individual bits: 1 and 0's
Groups of bits: 8-bits = byte
16-bits = 2 bytes = 1 word

All collections of bits are powers of 2

DIGITAL INPUT & OUTPUT SIGNALS

Addressing bits in a byte

7	6	5	4	3	2	1	0	Address location
1	1	0	0	0	1	1	0	Bit

Bit 7 = 1 Bit 5 = 0 Bit 3 = 0 Bit 1 = 1
Bit 6 = 1 Bit 4 = 0 Bit 2 = 1 Bit 0 = 0

Weighted number system - conversion from binary to decimal

$n = 1 \cdot 2^7 + 1 \cdot 2^6 + 0 \cdot 2^5 + 0 \cdot 2^4 + 0 \cdot 2^3 + 1 \cdot 2^2 + 1 \cdot 2^1 + 0 \cdot 2^0$

$n = 1 \cdot 128 + 1 \cdot 64 + 1 \cdot 4 + 1 \cdot 2 = 198$

198 decimal equivalent of binary number

Digital Hardware Standards

Digital standards specify voltage levels of logic highs and logic lows, current output and input levels. Makes chips from same family compatible with each other

Logic Standards

Transistor-Transistor Logic (TTL) 7400 74LS00 series devices

Nominal 5 V dc logic high and 0 V dc logic low

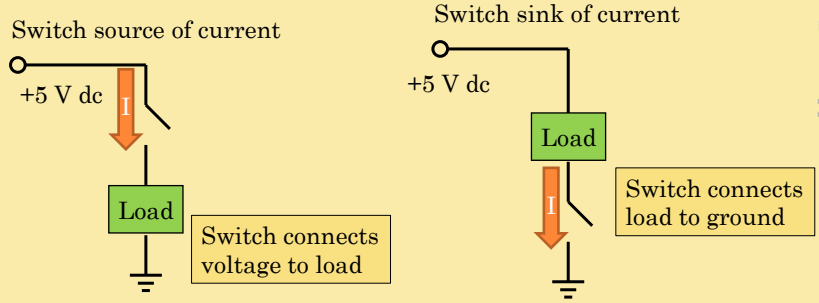
TTL chip I/O pin electrical characteristics

Source current: 400 μA
Sink current: 1.6 mA (1 unit load)
Logic 1 threshold voltage : V≥2.4 V dc
Logic 0 threshold voltage V≤0.8 V dc

Digital Hardware Standards- Source and Sink Currents

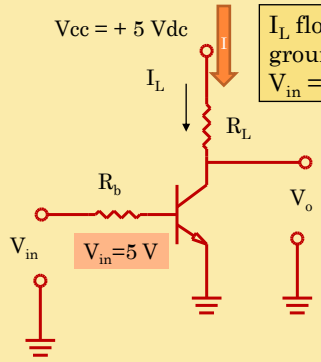
What is sourcing and sinking of device currents?

Determined by position of voltage source, the switching device, and the load.



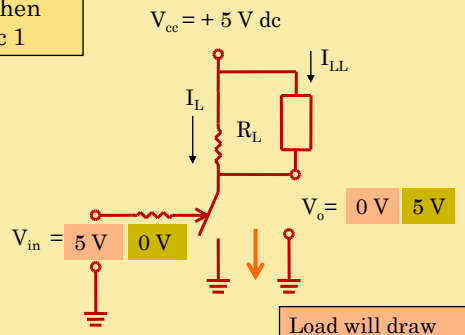
Digital Hardware Standards- Source and Sink Currents

Simple transistor sink and source representations



I_L flows to ground when V_{in} = logic 1

Switch model of gate



Load will draw current when V_{in} = 5 V dc. Switch (Transistor) must sink load current

V_{in} = 5 V for logic high and 0 V for logic low

When V_{in} = 5 Vdc V_o = 0 V
When V_{in} = 0 Vdc V_o = 5 V

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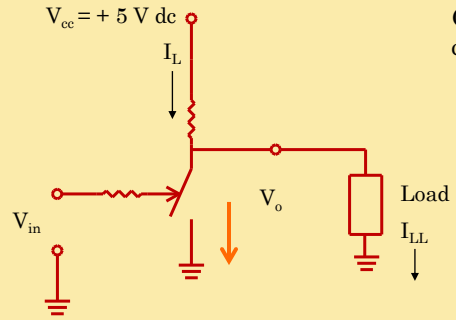
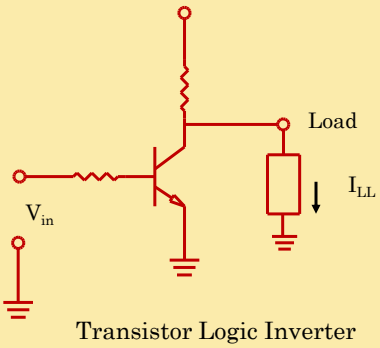
Source and Sink Currents

Switch model of gate - current sourcing



Circuit with transistor showing current sourcing



Transistor Logic Inverter

When V_{in} is 5 V load is de-activated (switch closed)
When V_{in} is 0 V load draws current from source

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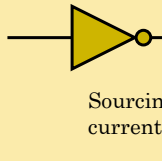
Source and Sink Currents

TTL Inverter symbol



TTL Inverters Sinking Current

Resistors used to limit current through gate.
TTL buffer limit:16 mA (10 unit loads)

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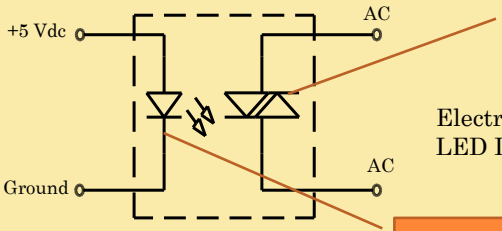
Digital Interfaces

For high current output use discrete transistor or relay (electromechanical or solid state)

Solid State Relay



Electrical Isolation : 7500 V
LED Input: 3-30 Vdc

Devices integrated on the same chip. LED light output triggers TRIAC that passes ac current.

Does not electrically disconnect load from source – beware of leakage currents

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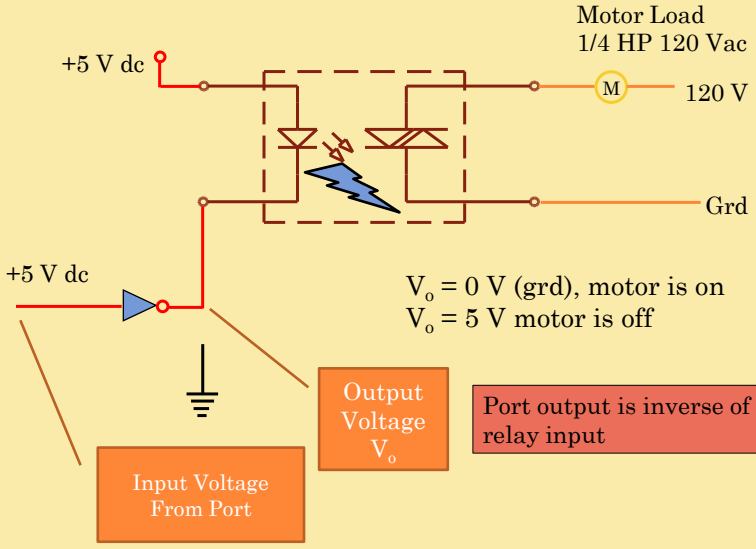
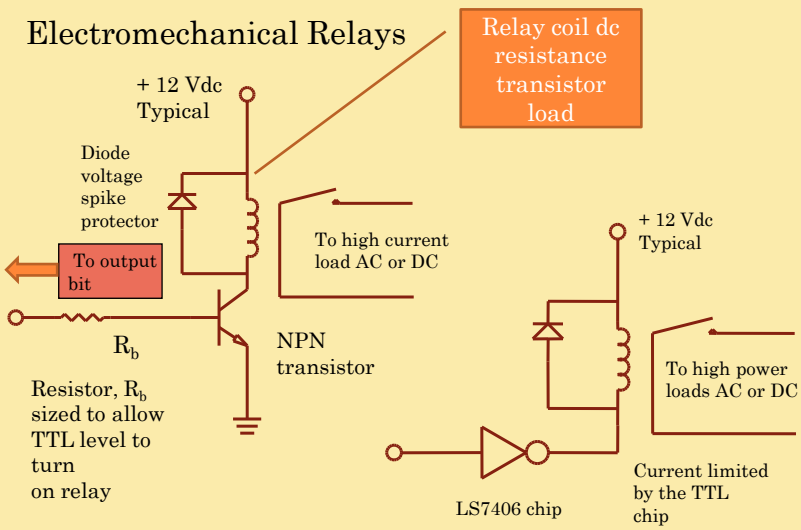
DIGITAL INTERFACES

Typical Application – Ac Motor starting



DIGITAL INTERFACES

Electromechanical Relays

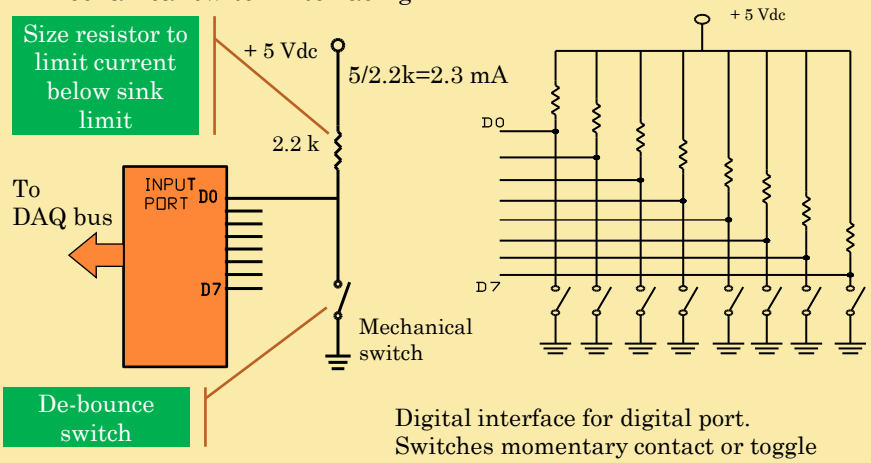


Relay interface using open collector TTL inverter

Digital Input Interfaces

Interface should limit currents and voltage levels to TTL limits

Mechanical switch interfacing



Digital interface for digital port.
Switches momentary contact or toggle

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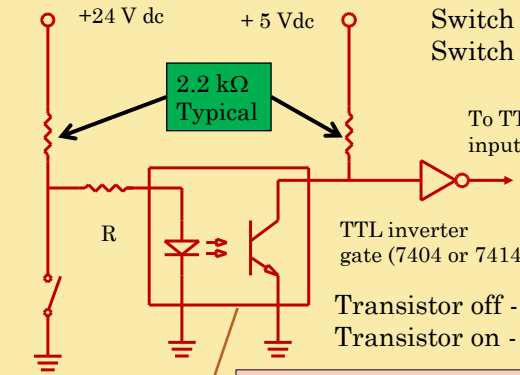
Digital Interface: Non-TTL Levels

Use Optocoupler to isolate high voltages from TTL levels



Switch closed - LED de-energized
Switch open - LED energized

Transistor off - inverter input +5 Vdc output 0 V
Transistor on - inverter input 0 Vdc output 5 V

Optocoupler – Integrated LED and optical transistor
Energizing LED causes optical transistor to conduct

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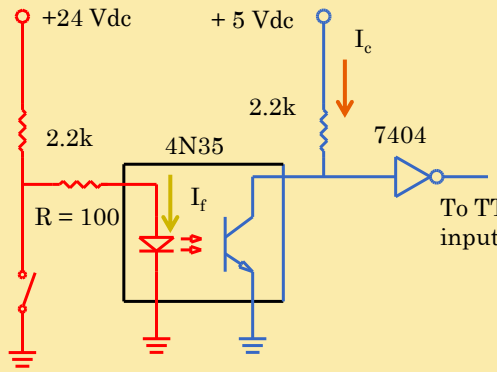
INTERFACE EXAMPLE

Determine the logic levels and currents in the digital interface circuit shown below. Assume that the optocoupler diode has an on-state voltage drop of 1.4 V and the optical transistor has an on-state collector-to-emitter drop of 0.4 V.



Logic
open switch = 0 = 0 V
close switch = 1 = 5 V

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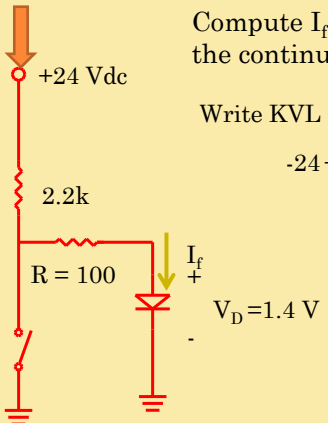
INTERFACE EXAMPLE SOLUTION

Device Specification 4N35

I_f = continuous forward current: 60 mA
I_c = continuous collector current: 150 mA
Source voltage isolation: 7500 V peak



Compute I_f with switch open to see if it exceeds the continuous rating

Write KVL around loop

$$-24+(2.2k)(I_f)+100(I_f)+1.4=0$$

$$2300 \cdot I_f = 24-1.4$$

$$I_f = \frac{24-1.4}{2300} = 0.00983\,A = 9.83\,mA$$

Current is within specifications

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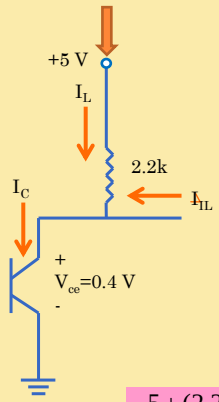
Interface Example Solution (Continued)

With switch closed, LED is shorted out so I_f=0. Switch must be open for optical transistor to conduct



7404 Specifications

I_{OH} = maximum source current from output: 400 μA
I_{OL} = maximum sink current into output: 16 mA
I_{IL} = current flowing out of input when logic low V level (0.4 V) is applied: 1.6 mA (1 unit load)

Assume optical transistor is in saturation

Find I_c and determine if it is below 150 mA

$$I_C = I_L + I_{IL}$$

Find I_L from KVL around collector-emitter loop

$$-5 + (2.2k)(I_L) + 0.4 = 0$$

$$I_L = \frac{5 - 0.4}{2.2k} = 2.1\,mA$$

$$I_C = 2.1\,mA + 1.6\,mA = 3.7\,mA$$

Below maximum

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Interface Example Solution (Continued)

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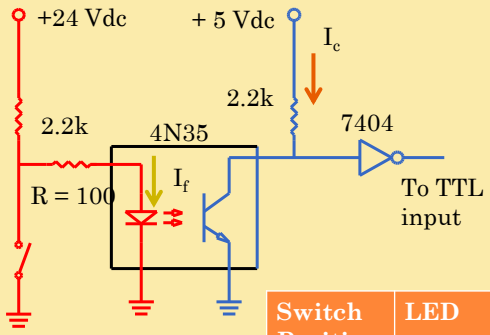
Determine the interface logic.

When optocoupler transistor conducts, the 7404 input is logic low, therefore the inverter output is high. See table below



Switch Position	LED	Transistor	7404 Input	7404 Output
open	on	on	Low (0.4 V)	High (4.6)
closed	off	off	High (5 V)	Low (0.4 V)

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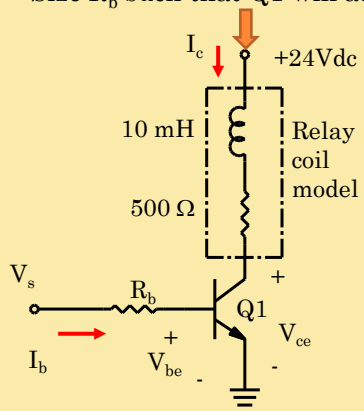
Electromechanical Relay Example

Size R_b such that Q1 will activate with a TTL input



Transistor Parameters, Q1 (2N3904)

h_{FE} = 200 (nominal)
$V_{ce(sat)}$ = 0.2 V
$V_{be(sat)}$ = 0.8 V

Assume transistor is in saturation and compute the value of I_c

Write a KVL equation around the collector-emitter circuit

$$-24 + 500(I_c) + V_{CE(sat)} = 0$$

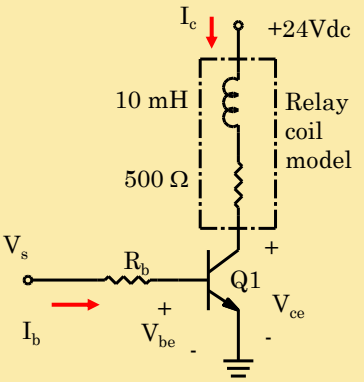
$$-24 + 500(I_c) + 0.2 = 0$$

$$500 I_c = 24 - 0.2$$

$$I_c = \frac{24 - 0.2}{500} = 47.6\ \text{mA}$$

Electromechanical Relay Example (Continued)

Relate the collector current, I_c, to the base current I_b using the dc gain, h_{FE}.



The parameter, h_{FE} also known as β is:

$$h_{FE} = \frac{I_c}{I_b} = 200$$

Dc gain drops in saturation. Use $h_{FE}/10$ to account for this phenomena

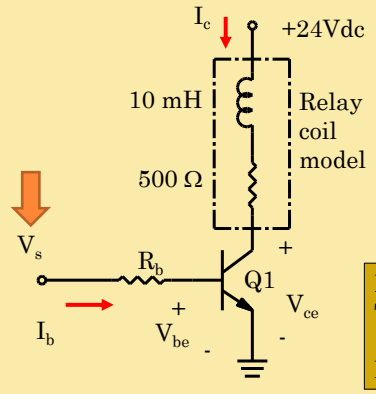
$$\frac{h_{FE}}{10} = \frac{200}{10} = \frac{I_c}{I_b}$$

$$20 = \frac{I_c}{I_b} \Rightarrow I_b = \frac{I_c}{20} = \frac{47.6\ \text{mA}}{20} = 2.38\ \text{mA}$$

$$I_b = 2.38\ \text{mA}$$

Electromechanical Relay Example (Continued)

Find value of R_b from a KVL equation around the base-emitter circuit



Assume a TTL high level of 4.8 V
Remember $V_{be(sat)}$=0.8 V

$$-V_s + I_b(R_b) + V_{be(sat)} = 0$$

$$R_b = \frac{4.8\,V - 0.8\,V}{2.38\,mA} = 1.68\,k\Omega$$ **Ans**

Note: this value is above the maximum TTL source current of 400 μA.

Drive Q1 from open-collector invertor

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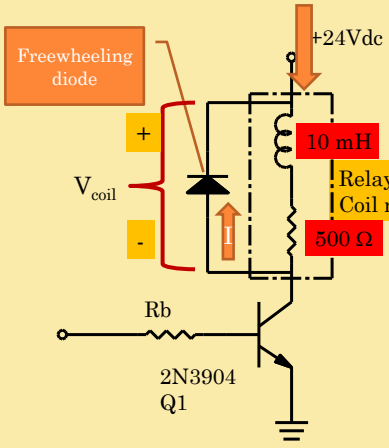
Electromechanical Relay Example (Continued)

Inductive voltage protection using freewheeling diodes



Cuting-off Q1 reduces I_c to zero

Coil voltage changes polarity due to induction

Collapsing magnetic field produces I

Diode D1 provides a path for the current induced when the transistor is switched off. It also clamps the induced voltage to the forward drop of the diode. (0.7 V)

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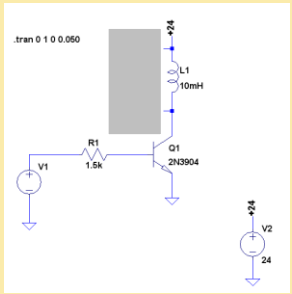
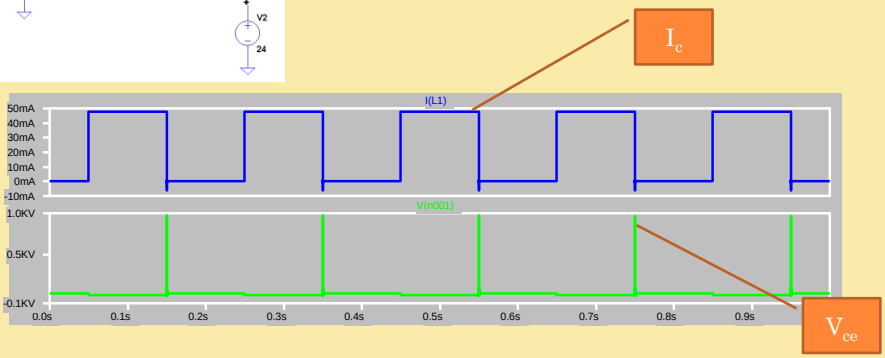
SIMULATION RESULTS-LTSPICE

Simulation without diode



Circuit simulated



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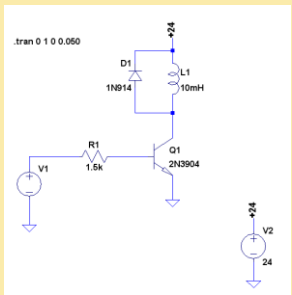
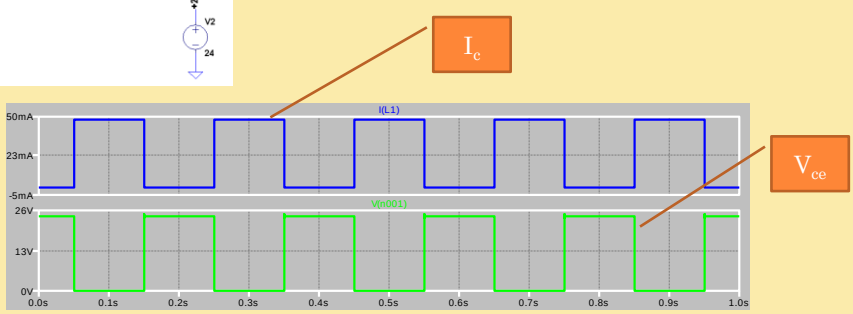
SIMULATION RESULTS-LTSPICE

Simulation with diode





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Software Control of Digital I/O

Individual bit of an output byte can be toggled by the application of a binary mask number and the appropriate bit-wise logic function.

These functions include: OR, AND, XOR

Procedure:

1.) Identify present port binary pattern
2.) Determine desired port binary pattern
3.) Select appropriate bitwise operator
4.) Determine correct mask value
5.) Apply bitwise operator to present pattern and mask to create desired pattern.

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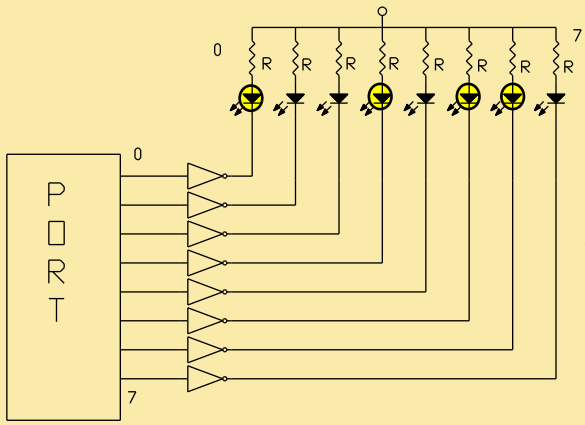
Software Control Example

Example: An 8 bit digital output port drives a group of 8 LEDs through TTL inverters.



Determine the binary byte value that will cause LEDs 0, 3, 5, 6 to light. Convert this byte to a decimal value.

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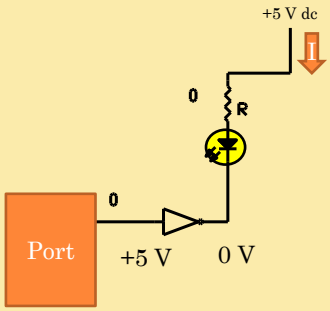
Software Control Example Solution



Answer

To light the LEDs, port outputs must be Logic 1 (5 Vdc) input to the inverting buffer. This causes the inverter output to go to a logic 0 (0 V dc) sinking current through the inverter.

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Bit	7							0
	0	1	1	0	1	0	0	1

Convert to decimal

$1 \cdot 2^6 + 1 \cdot 2^5 + 1 \cdot 2^3 + 1 \cdot 2^0 = 64 + 32 + 8 + 1 = 105$

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Software Control Example Solution

Determine the binary mask value and logic function that will toggle off LED 5 yet leave the other LEDs in their original state.

New byte value

			5				
0	1	0	0	1	0	0	1

Answer

Use AND function and a mask value that has a logic low bit in bit location 5.

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				5				
	0	1	1	0	1	0	0	1
AND	0	1	0	0	1	0	0	1
	0	1	0	0	1	0	0	1

original
mask
desired

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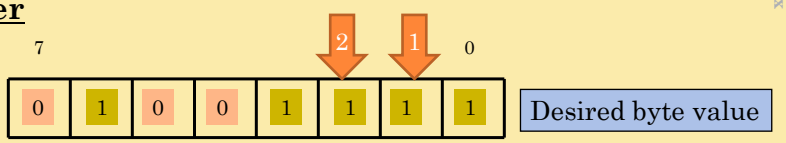
Software Control Example Solution

Determine the decimal value of the mask value from above.

Mask 01001001 = $1 \cdot 2^6 + 1 \cdot 2^3 + 1 = 73$

Now use a mask value and a logic function to turn on LEDs 1 and 2 while leaving the others unchanged.

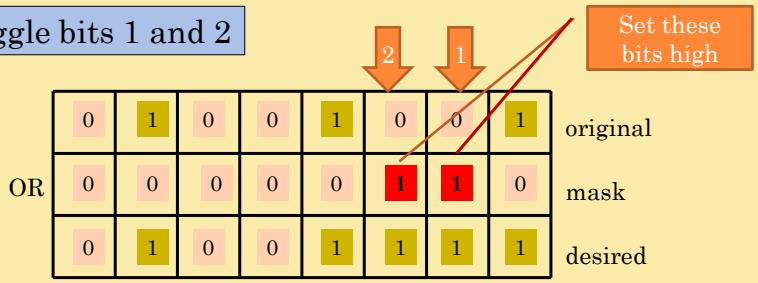
Answer



Use the OR function and set the bits in positions 1 and 2 in the mask to the high position. Make all the other bit values 0 to complete the mask.

Software Control Example Solution

Toggle bits 1 and 2



XOR function could also be used to toggle bits if a different mask value is used. Use the XOR function to turn all LEDs off.

Software Control Example Solution

Review of XOR logic $Y = A \oplus B$

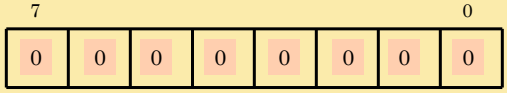
A	B	Y
0	0	0
0	1	1
1	0	1
1	1	0

Like bits produce logic 0
Unlike bits produce logic 1

Answer

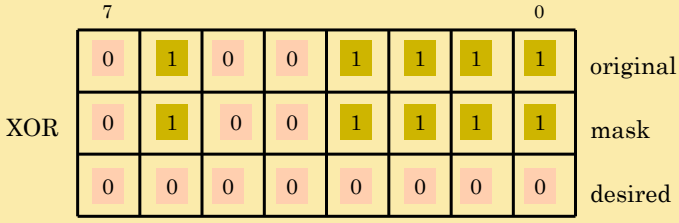
Copy the original byte value and use it as the mask value.
Using the XOR bit-wise logic function will set all bits low.

Desired byte value



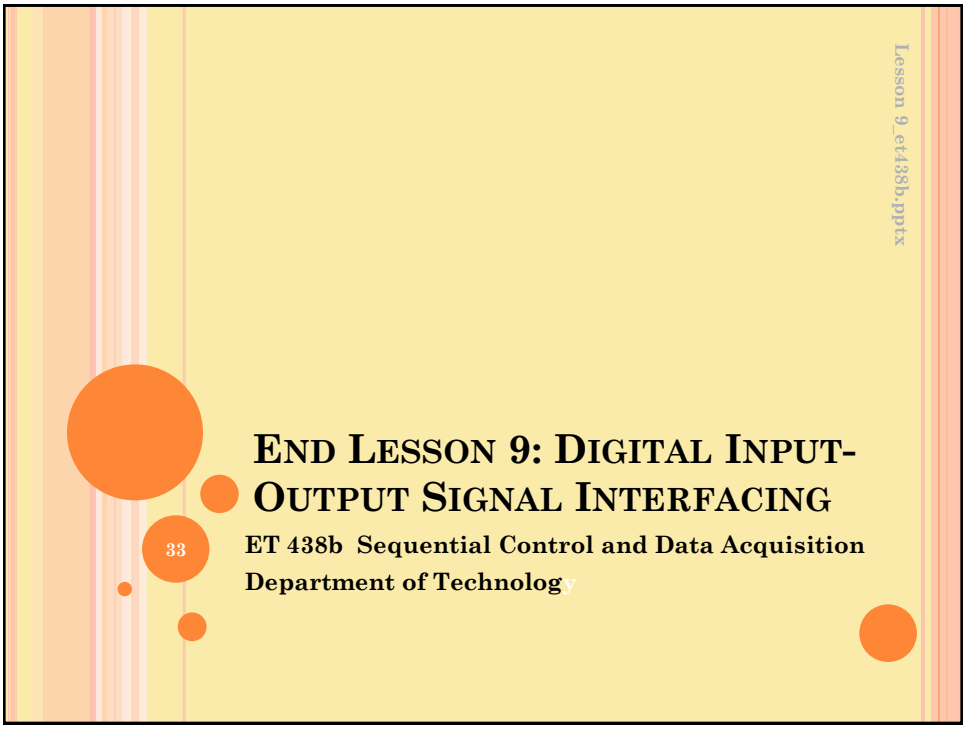
Software Control Example Solution

XOR Mask Result



Example Summary

1.) AND Function with 0 bit in mask resets output bit
2.) OR Function with 1 bit in mask sets output bit
3.) XOR Function with opposite bit value from original set output bit
XOR with same value as original value resets output bit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