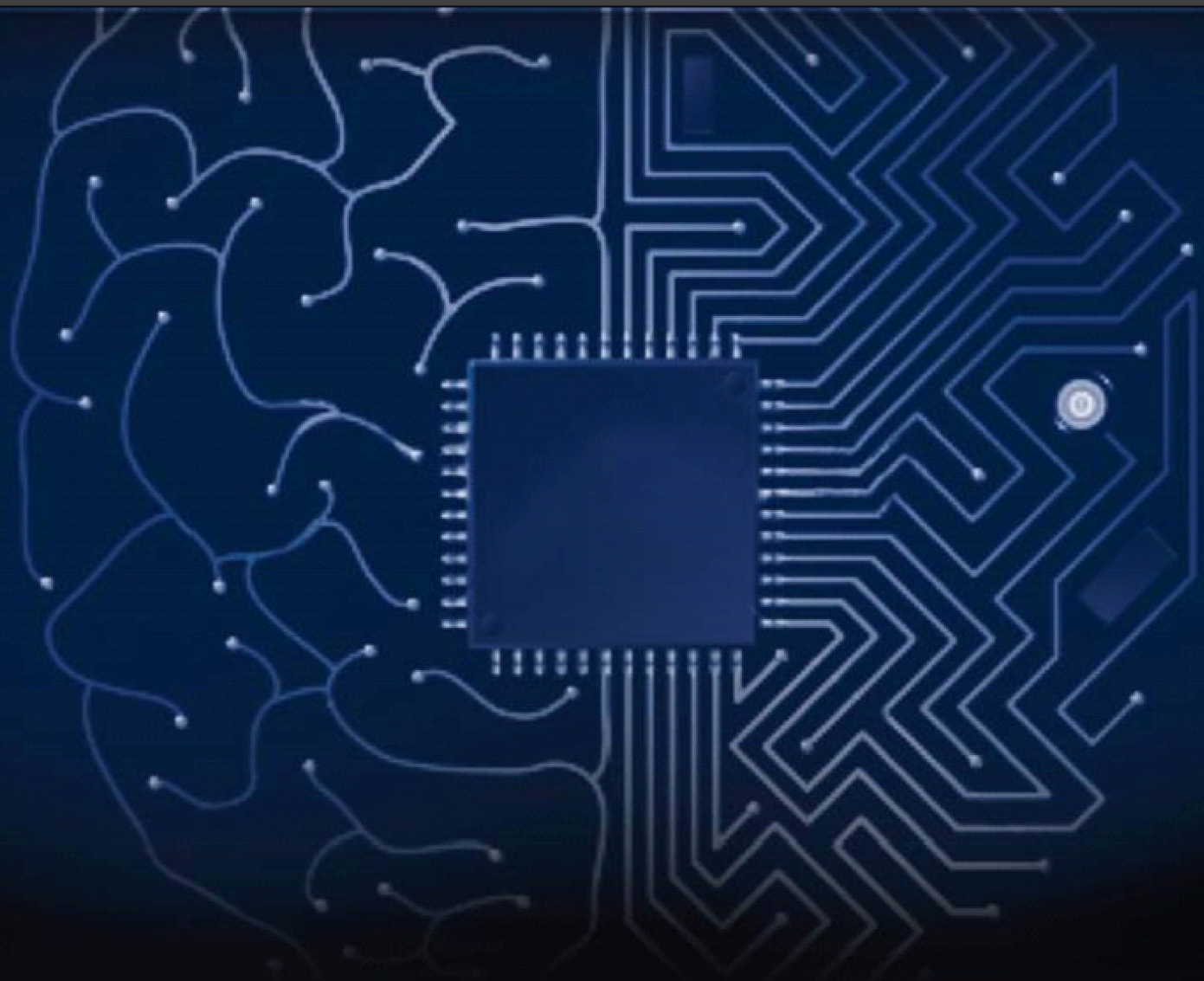


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An introduction to digital electronics



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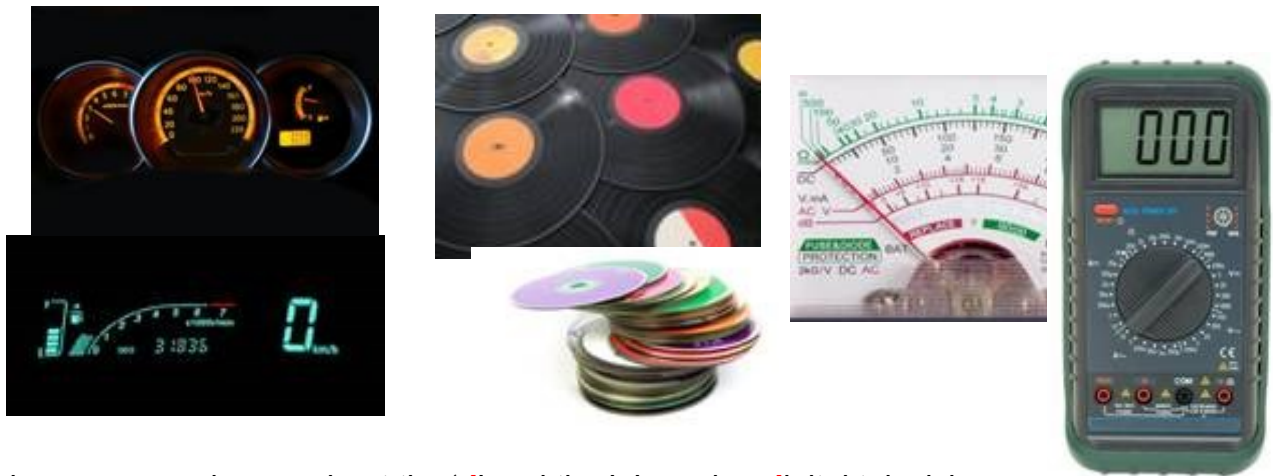
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Worksheet 1

Analogue vs digital



We hear more and more about the 'd' and the 'e' words - digital television, dab, dvd, digital cameras ... e-cards, e-commerce, e-books, e-skills, e-learning ...

Why is that? Whatever happened to the 'a' word - analogue?

This first worksheet looks at the differences between analogue and digital, and suggests why the electronic world seems to have gone digital.

Over to you:

The first circuit uses an analogue sensing device, a phototransistor connected in series with a 50k Ω resistor, to make a light-sensing unit. The output voltage is measured using a DMM (digital multimeter.) Set up this circuit as shown opposite.

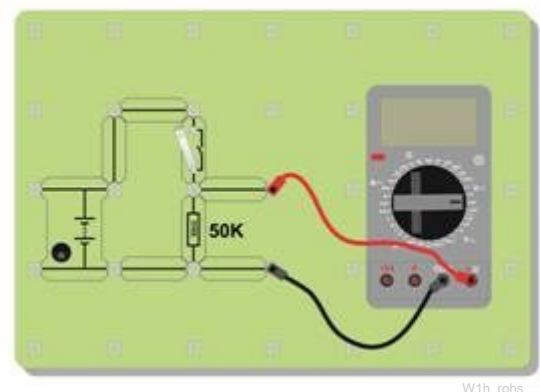
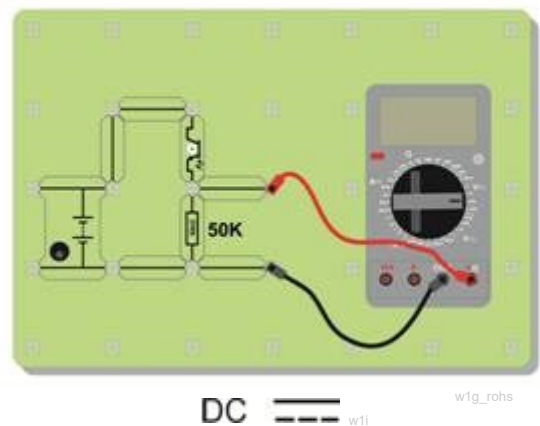
Set the DC power supply to 6V, and switch it on. Set the DMM to read voltages up to 20V DC. The symbol for DC is shown underneath the picture. Switch it on.

Vary the amount of light reaching the sensor by slowly lowering your hand over it. What do you notice about the output voltage?

Now set up the second circuit, a digital sensing unit, using a switch unit. All you need to do is replace the phototransistor with a switch. Measure the output voltage when the switch is open (off) and again when it is closed (on.)

Invert the switch unit. All this means is swap over the switch and the resistor. Measure the output voltages again, when the switch is closed and open.

Compare the behaviour of the analogue and digital circuits.



Worksheet 1

Analogue vs digital

So what?

An analogue sensor gives an analogy - a copy of the behaviour it is sensing. In the case of the light-sensing unit, as the light level goes down, the output voltage goes down. The voltage mimics the light level. As we can change the light level by very small amounts, so we can change the output voltage by very small amounts. A digital sensor, on the other hand, is a two-state affair. A switch is either on or off - just two possible states. The output voltage, as a result, has one of only two possible values.

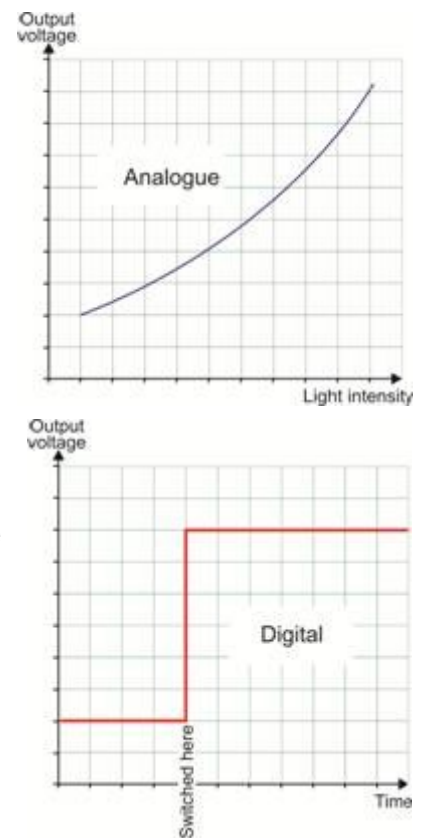
These ideas are shown in the graphs opposite. The top one shows an analogue signal, which changes continuously as the light intensity changes. The lower graph must be plotted in a different way. The state of the switch does not change smoothly from off to on. It can't be slightly on, and then a bit more on, and so on. It is **on** or **off**. The horizontal axis shows the time at which the change from on to off occurs. The output voltage always has one of two possible values.

The vocabulary of digital electronics talks about these two voltages as 'logic 0' and 'logic 1'. Somewhere in a particular design, these will be defined, usually as a range of possible voltages. For example, logic 0 may be defined as any value between 0V and 1.0V, while logic 1 is any value between 10.0V and 12.0V. Giving a range of values recognises that signals can change a little as they move through an electronic system.

A major advantage of digital signals is that we, and electronic systems themselves, can make a pretty good guess at what the signal should be if, for some reason, it arrives with a voltage of say 8.7V. We'd guess that it was really logic 1. This ability to recreate the original signal is called **regeneration**, and is one of the major benefits of digital signals. Analogue signals do not allow us to do this.

For your records:

- An analogue quantity is one that copies the behaviour of another.
- An analogue signal can have any voltage value, usually between the voltages of the power supply rails.
- A digital quantity has only two possible states. A switch, for example can be off or on.
- A digital signal has only two possible voltage values, usually known as logic 0 and logic 1.
- This allows a digital signal which has been affected by noise or distortion to be regenerated - returned to its original value.
- Analogue signals cannot be regenerated in this way.



Worksheet 2

The NOT function



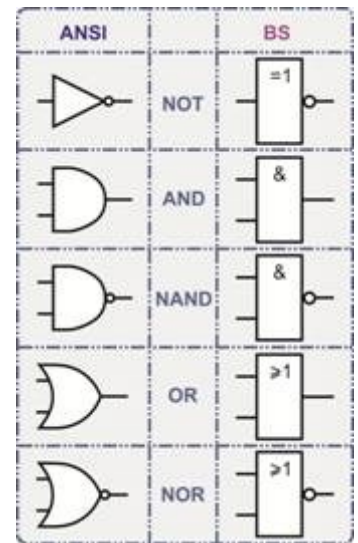
A *logic function* is one way of manipulating digital signals.
 A *logic gate* is a device that will carry out a particular logic function.
 A *programmable logic system* is one which can carry out a range of logic functions, depending on how it is programmed.

There are not many logic functions. This worksheet looks at the simplest of these, the NOT function. This could trigger a warning when a vehicle door is NOT closed.



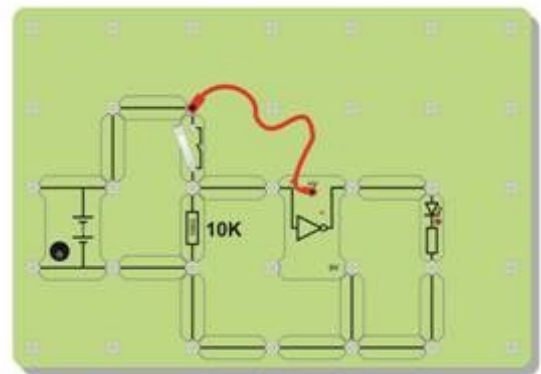
Logic gates can be built in a number of ways, which has led to a number of logic 'families' each with its own set of capabilities and limitations. One of these is called **CMOS**. The photograph shows a CMOS NOT gate, identified by '4049'. It is known as a 'hex inverting buffer,' meaning that there are six NOT gates on the chip,

(hex = 6, inverting = NOT) which buffer the signal (deliver a few milliamps of current .) Like all electronic devices, logic gates are represented by circuit symbols. However, there are several versions of these symbols. The common ones are 'ANSI' (American National Standards Institute) and 'BS' (British Standard) sometimes called 'SB' (System Block) symbols. Both are given in the diagram opposite.



Over to you:

Set up the circuit shown, with the DC power supply set to 6V. Notice the LED connected between the output of the NOT gate and 0V. This is in addition to the LED built into the NOT gate carrier itself.



With the multimeter on the 20V DC range, measure the voltage at the input of the NOT gate when the switch is turned off (open.) Then measure the output voltage of the NOT gate. Make a copy of the two tables. Record both readings in the first table. Note whether the LED attached to the output is on or off. Now close the switch, and repeat the measurements. Record them in the first table.

Invert the switch unit, by swapping over the switch and 10kΩ resistor, as you did in the investigation in worksheet 1. Repeat the measurements and record them in the second table.

Switch unit	Input voltage	Output voltage	State of LED
Open (off)			
Closed (on)			

Switch unit - inverted	Input voltage	Output voltage	State of LED
Open (off)			
Closed (on)			

Worksheet 2

The NOT gate

So what?

First, a word about logic levels. The voltages you measured are either pretty close to +6V or 0V. For CMOS logic gates, logic 1 is any voltage greater than 70% of the supply voltage, and logic 0 anything less than 30% of supply voltage. In this case, with a 6V power supply, logic 1 is bigger than 4.2V and logic 0 is less than 1.8V. Use this information to convert your input and output voltage readings into logic levels. Then use the results to complete the table, known as the **truth-table** for the NOT gate, which describes the behaviour of the gate.

The NOT gate produced the same effect, whether the switch unit was inverted or not. It turned a logic 0 input into a logic 1 output, and vice-versa.

NOT gate	
Input	Output
(Logic) 0	
(Logic) 1	

The behaviour of the switch unit changed. To begin with, it produced a logic 0 signal when the switch was open, and a logic 1 signal when closed. When inverted, the behaviour inverted so that with the switch open, it generated a logic 1 signal and, with it closed logic 0.

A challenge - Why do we need a resistor in the switch unit? Why not just have the switch?

- See what happens when you remove the resistor from the switch unit.

With the switch between the +6V supply and the input, things seem to behave as before, when the resistor was in place. However, with the switch connected between the input and the 0V connection, nothing happens. The output of the NOT gate always sits at logic 1, regardless of the state of the switch.

CMOS circuitry is wonderful, but it has a weakness - the inputs must not 'float' (be left unconnected.) If they are, the outcome is unpredictable. The output can even oscillate so rapidly between logic 0 and logic 1, that the circuit can overheat and be destroyed.

Always use a resistor either to 'pull' the input up to logic 1, by connecting it between the positive supply and the input, or 'pull' it down to logic 0, by connecting it between the input and 0V. The 'Locktronics' NOT gate carrier is wired up so that the input sits at logic 0, when nothing is connected to it.

For your records:

Copy the table with the circuit symbols for the five logic gates, and the NOT gate truth table.

- For CMOS logic gates, logic 1 is any voltage greater than 70% of the supply voltage, and logic 0 anything less than 30% of supply voltage.
- CMOS inputs must not be allowed to 'float'. Always use either a 'pull-up' or a 'pull-down' resistor. The resistance is unimportant. Anything from 1k Ω to 1M Ω will work.
- Complete the sentence:

When the NOT gate input is at logic 0, the output is at logic ..., and vice-versa.

Worksheet 3

The AND function



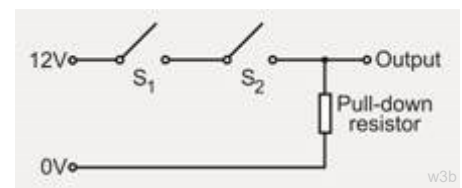
Often, electrical devices in a car, like the indicators, will operate only if the ignition switch **AND** the switch for that device are **both** turned on.

In one make of car, the headlight washers activate only when the windscreen washers are operated **AND** the headlights are switched on.

This brings into play another logic function, the AND function.

It can be implemented using just switches, as shown in the diagram, but that can make the wiring very complicated.

This worksheet investigates the AND function implemented using an AND logic gate.

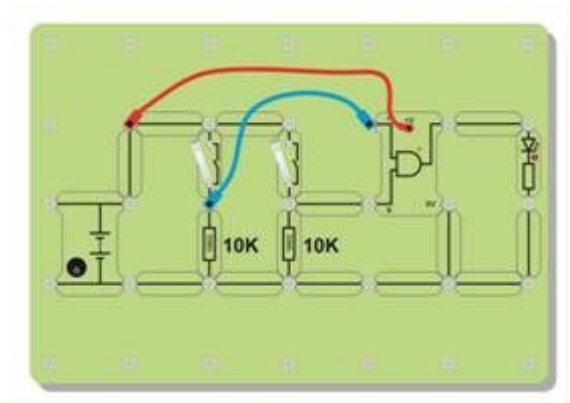


Over to you:

Set up the circuit shown, with the DC power supply set to 6V. Connect a LED from the output of the gate to 0V.

This time, there are four sets of measurements to make.

For the first set, leave both switches open (off.)
With the multimeter on the 20V DC range, measure the voltage at input A, and then at input B.
Next, measure the voltage at the output of the AND gate.



Copy the table .

Switch 1	Switch 2	Input A voltage	Input B voltage	Output voltage	State of LED
Open (off)	Open (off)				
Open (off)	Closed (on)				
Closed (on)	Open (off)				
Closed (on)	Closed (on)				

Record your measurements in the first row.

As before, note down whether the LED attached to the output is on or off.
Now close the left-hand switch (switch 1 in the table,) leaving switch 2 open.
Repeat the measurements, and record them in the second line of the table.

Continue in this way to complete the table for the other combinations of switch positions.

Worksheet 3

The AND function

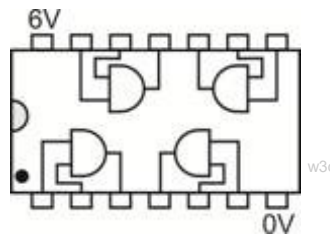
So what?

As before, you used a 6V power supply, meaning that logic 1 is bigger than 4.2V and logic 0 is less than 1.8V. Use this and your measurements to complete the truth-table for the AND gate.

Input A	Input B	Output
0	0	
0	1	
1	0	
1	1	

The logic AND function is a straightforward one to understand. The output of the system will be logic 1 **only** when input A **AND** input B (**AND** input C etc. if there are more inputs,) are all logic 1. Your results should confirm this behaviour.

One way to implement the AND function is to use an AND gate. A CMOS 2-input AND gate chip is numbered 4081. The pinout for this chip is shown below.



Notice that there are four AND gates on the chip.

On page 5, it was pointed out that CMOS logic gate inputs should not be left unconnected - should not be allowed to 'float'.

When you are using a chip like the 4081, you may not want to use all four gates. In that case, connect any unused inputs to the nearest power rail - it does not matter which one. The unused outputs can, in fact must, be left alone. They will sit at the appropriate logic level depending on what signals are applied to the inputs.

For your records:

- Copy the diagram showing how the AND function can be accomplished using switches.
- Explain why the diagram can be called an AND gate.
- Copy and label the symbol for an AND gate.
- Copy the truth table for the AND gate, given opposite.
- Copy and complete the sentence:

AND gate		
Input A	Input B	Output
0	0	0
0	1	0
1	0	0
1	1	1

The output of an AND gate is at logic 1 only when

Worksheet 4

The OR function



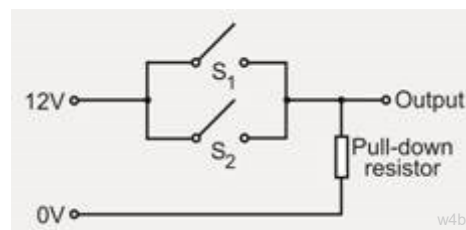
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A simple car theft-alarm system may incorporate a number of sensors:

- door sensors, to detect when one of the doors is opened,
- a pressure sensor, to detect changes in air pressure caused by someone breaking a window,
- a tilt sensor, to warn when the car is being towed away.

The electronic control system will switch on the alarm if the door sensor **OR** the pressure sensor **OR** the tilt sensor is triggered. This is an application of the OR logic function.

The OR function can be visualised using switches, as shown opposite. This worksheet investigates the OR function implemented using an OR logic gate.



Over to you:

Set up the circuit shown, with the DC power supply set to 6V. Connect a LED from the output of the gate to 0V.

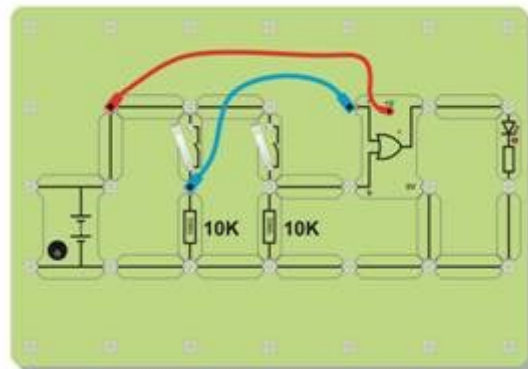
As before, there are four sets of measurements to make.

The first set has both switches open (off.)

With the multimeter on the 20V DC range, measure the

voltages at input A, at input B and at the output of the OR gate.

Copy the table shown below.



w4c

Switch 1	Switch 2	Input A voltage	Input B voltage	Output voltage	State of LED
Open (off)	Open (off)				
Open (off)	Closed (on)				
Closed (on)	Open (off)				
Closed (on)	Closed (on)				

Record the measurements you have just taken, in the first row, including the state (on / off) of the LED.

The procedure is the same as in the last worksheet. For all four combinations of switch positions, measure the voltages at inputs A and B of the OR gate, and then at the output of the gate.

Record all measurements in the table, and, as usual, note whether the LED attached to the output is on or off.

Worksheet 4

The OR function

So what?

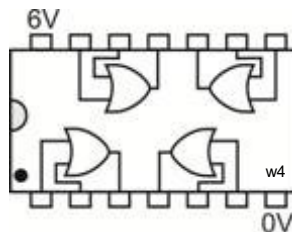
Once again, logic 1 is a voltage bigger than 4.2V and logic 0 is less than 1.8V. Use this and your measurements to complete the truth-table for the OR gate.

Input A	Input B	Output
0	0	
0	1	
1	0	
1	1	

The logic OR function is another straightforward one.

The output of the system will be logic 1 when either input A **OR** input B (**OR** input C etc. if there are more inputs,) is logic 1 (or all of them are logic 1.) Your results should confirm this behaviour.

One way to implement the OR function is to use an OR gate. A CMOS 2-input OR gate chip is numbered 4071. The pinout for this chip is shown below.



Once again, there are four gates on the chip.

On page 5, it was pointed out that CMOS logic gate inputs should not be left unconnected - should not be allowed to 'float'.

As explained on the last worksheet, connect any unused *inputs* to the nearest power rail, but leave alone any unused *outputs*. They will sit at the appropriate logic level depending on the signals that are applied to the inputs.

For your records:

- Copy the diagram showing how the OR function can be accomplished using switches.
- Explain why the diagram can be called an OR gate.
- Copy and label the symbol for an OR gate.
- Copy the truth table for the OR gate, given opposite.
- Copy and complete the sentence:

The output of an OR gate is at logic 1 when

OR gate		
Input A	Input B	Output
0	0	0
0	1	1
1	0	1
1	1	1

Worksheet 5

The NAND function

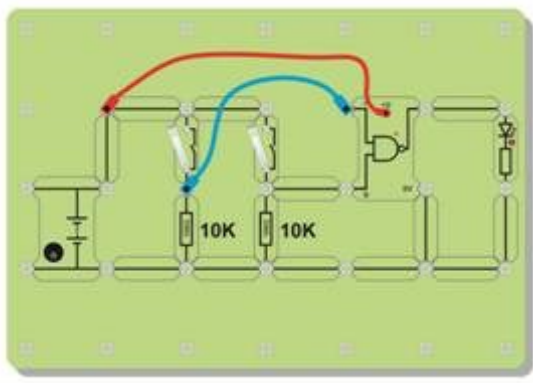


The picture shows the circuit board under the NOT gate carrier, which you used earlier. The chip serial number is 4011, which is the number for a different kind of logic gate, called a NAND gate. This worksheet examines the behaviour of this kind of gate, and shows how it can be used to provide the NOT logic function used in worksheet 2. We'll also see that the NAND logic function lends itself to applications like controlling the seat belt alarm system in an automobile.

Over to you:

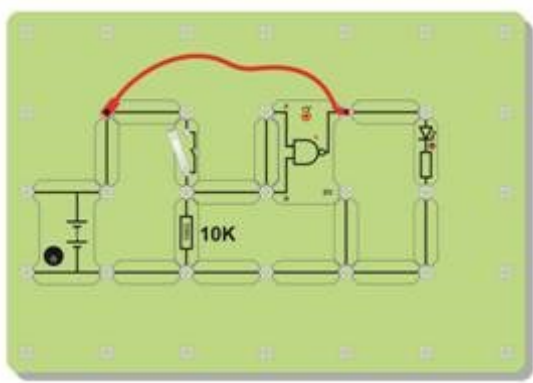
Set up the circuit shown, with the DC power supply set to 6V. Once again, connect a LED from the output of the gate to 0V. Copy the table, given below.

Use the same procedure as before to complete the table with your voltage measurements, and with the state of the LED, for each of the four combinations of switch positions.



Switch 1	Switch 2	Input A voltage	Input B voltage	Output voltage	State of LED
Open (off)	Open (off)				
Open (off)	Closed (on)				
Closed (on)	Open (off)				
Closed (on)	Closed (on)				

Re-arrange the circuit, as shown in the second picture, by removing one switch unit and joining the NAND gate inputs together with a connecting link. Copy the second table, given below. Turn off the switch. Measure the voltage at the inputs of the gate and then at the output. Record both in the second table, together with the state of the LED. Then close the switch. Repeat the measurements and record them in the table too.



Switch unit	Input voltage	Output voltage	State of LED
Open (off)			
Closed (on)			

Worksheet 5

The NAND function

So what?

As before, logic 1 is a voltage greater than 70% of the supply voltage, (4.2V in this case,) and logic 0 less than 30% (here 1.8V.) Use this information, and the measurements in your first results table to complete the NAND gate truth-table.

NAND gate		
Input A	Input B	Output
0	0	
0	1	
1	0	
1	1	

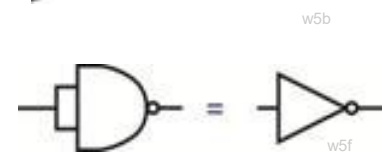
A possible automotive application for the NAND logic function is the seat belt warning alarm. Let's suppose:

- the seat belt sensor outputs a logic 1 signal when the seat belt is fastened, and a logic 0 signal when it is not;
- the alarm is triggered when it receives a logic 1 signal.

The NAND function triggers the alarm when any seat belt is unfastened.

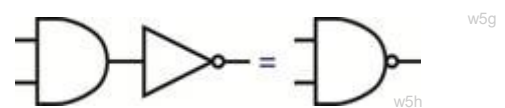
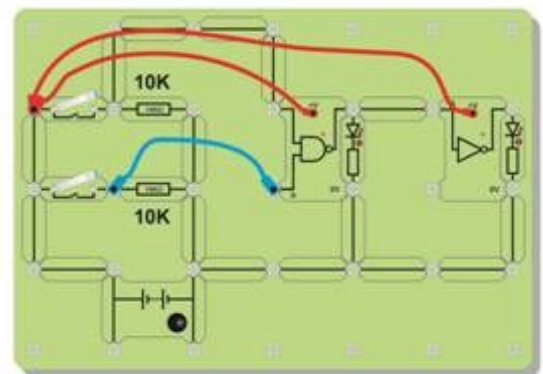


The second part of the investigation re-arranged the circuit so that the two inputs of the NAND gate were joined together. One switch unit fed signals into the gate. Compare your results with those you obtained in the first part of worksheet 2. You should find that the NAND gate now behaves like a NOT gate.



Compare the truth-tables for the AND and NAND functions. Notice that they are opposites. When one outputs logic 1, the other outputs logic 0, and so on.

The NAND function can be generated by an AND gate followed by a NOT gate. Verify this by building and testing the circuit shown.



For your records:

- Copy and label the symbol for a NAND gate.
- Copy the truth table for the NAND gate given opposite.
- Copy and complete the sentence:

The output of a NAND gate is at logic 1 when any of the inputs are at logic

- Copy the diagram showing how a NOT function can be made from a NAND gate.
- Copy the diagram showing how the AND / NOT combination generates a NAND function.

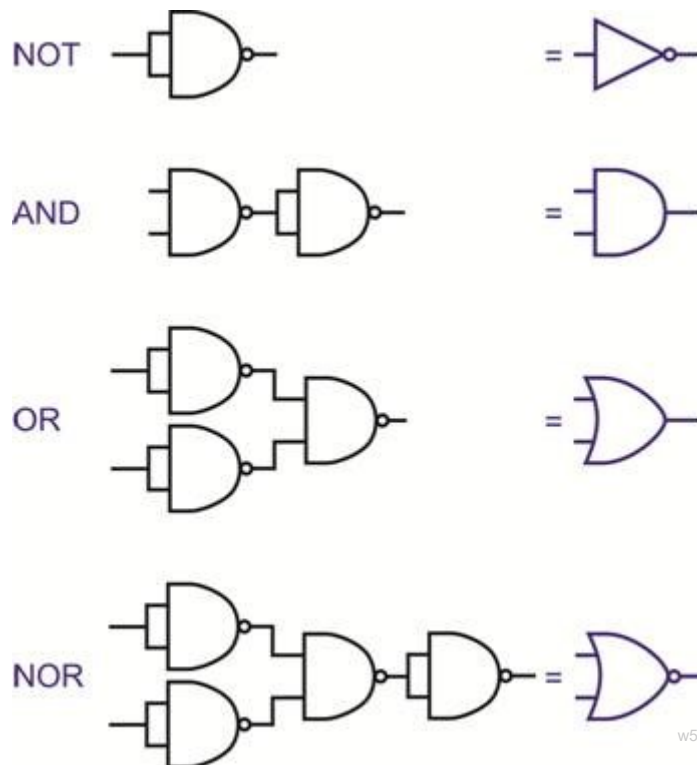
NAND gate		
Input A	Input B	Output
0	0	1
0	1	1
1	0	1
1	1	0

Worksheet 5

The NAND function

Using NAND gates to generate other logic functions

The diagram shows how NAND gates can be used to generate the other logic function:



The question arises -

Why use several NAND logic gates to do the job that one discrete logic gate would do?

The answer -

Common 2-input logic gates are arranged four to a chip. If you want only one, you still use one chip. Using NAND gates is still a one chip solution, even to generate the NOR function. It might even work out cheaper if it means that you can bulk-buy just the one type of chip.

(In cases where several logic functions are combined together, it may be possible to cancel out adjacent NOT functions, resulting in even greater savings. This is known as gate minimisation, but this is beyond the scope of the present course.)

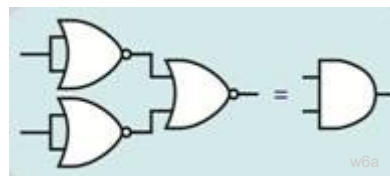
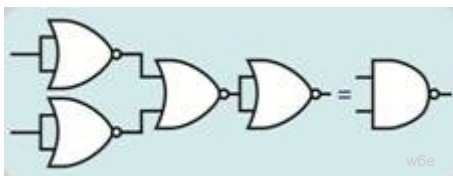
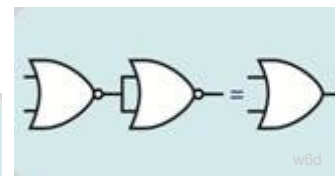
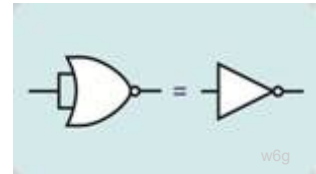
Worksheet 6

The NOR function



The NOR function may be the last one we study, but it is by no means the least important. Perhaps this is why the CMOS logic gate series starts with the serial number 4000, a 3-input NOR gate chip, and then the 4001, a 2-input NOR gate.

As with the NAND function, NOR gates can be combined together to generate any other logic function. The diagrams show how this is done. Doing so can result in cost savings, because of gate minimisation techniques, which are beyond the scope of this course, or through the economy of scale of bulk-buying.



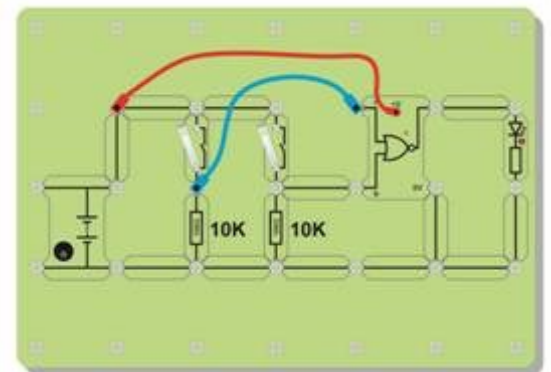
Over to you:

Set up the circuit shown, with the DC power supply set to 6V. Connect a LED from the output of the gate to 0V.

As before, there are four sets of measurements to make.

The first set has both switches open (off.)

With the multimeter on the 20V DC range, measure the voltages at input A, at input B and at the output of the NOR gate.



Copy the table shown below.

Switch 1	Switch 2	Input A voltage	Input B voltage	Output voltage	State of LED
Open (off)	Open (off)				
Open (off)	Closed (on)				
Closed (on)	Open (off)				
Closed (on)	Closed (on)				

Record the measurements you have just taken, in the first row, including the state (on / off) of the LED.

Worksheet 6

The NOR function

So what?

Copy the truth-table given here:

As before, logic 1 is a voltage greater than 4.2V and logic 0 is less than 1.8V.

Use this information, and your measurements to complete the truth-table for the NOR gate.

NOR gate		
Input A	Input B	Output
0	0	
0	1	
1	0	
1	1	



A possible automotive application for the NOR logic function is the air-conditioning system.

There is no point in trying to cool down the cabin of the vehicle when one of the doors is open.

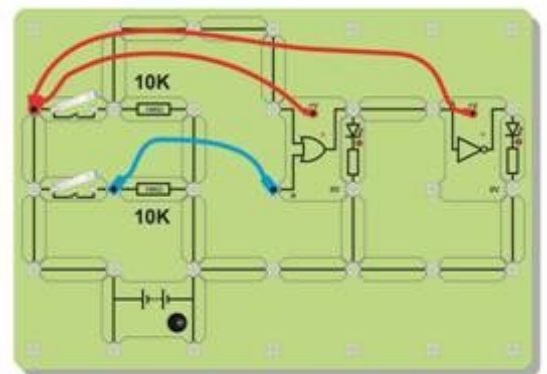
Let's suppose that:

- there are two doors;
- the door sensors output a logic 1 when the door is open, and a logic 0 when it is closed;
- the air-conditioning turns off when it receives a logic 0 signal from the door logic system.

The NOR function allows the air-conditioning to run only when both doors are closed.

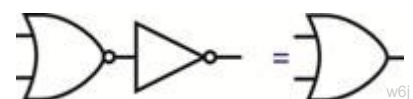
Compare the truth-tables for the OR and NOR functions. Notice that they are opposites. When one outputs logic 1, the other outputs logic 0, and so on. This means that the NOR function can be generated by an OR gate followed by a NOT gate.

Verify this by building and testing the circuit shown in the photograph.



w6h

This relationship is shown in the diagram opposite:



w6j

For your records:

- Copy and label the symbol for an NOR gate.
- Copy the truth table for the NOR gate, given opposite.
- Copy and complete the sentence:
The output of a NOR gate is at logic 0 only when
- Copy the diagram showing how the OR / NOT combination generates a NOR function.

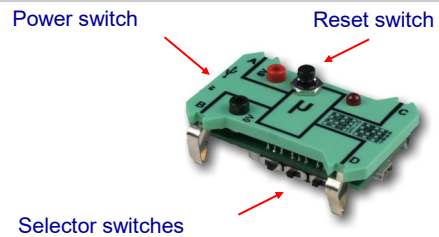
NOR gate		
Input A	Input B	Output
0	0	1
0	1	0
1	0	0
1	1	0

Worksheet 7

Programmable logic

The modern approach to logic functions is to use a programmable system to generate them.

The Locktronics kit includes a PIC microcontroller carrier, which can house up to eight programs. For this module, it has been programmed to deliver a variety of logic functions, depending on the program selected with the Selector switches.



w7a

PIC checklist

When using the PIC make sure that:

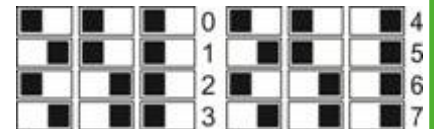
- The power switch is in the '6V' position
- The selector switches are as shown in each exercise
- The LED on the PIC flashes three times on pressing the reset switch and stays lit
- Your power supply is set to 6V
- You have connected PIC +6V and 0V wires to each side of the battery terminals

Programs 0 to 3:

- Program 0 - 2-input AND function
- Program 1 - 2-input OR function
- Program 2 - 2-input NAND function
- Program 3 - 2-input NOR function

The Selector switches:

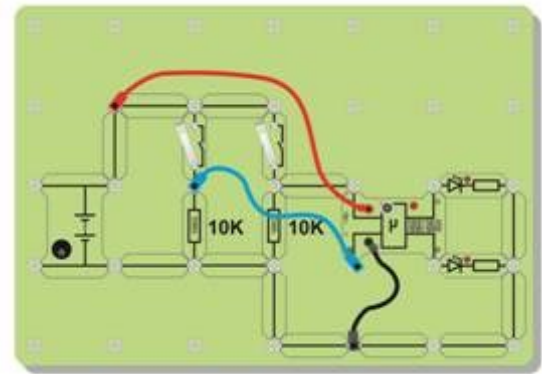
Programs are selected by moving the Selector switches to the appropriate positions. These are shown on top of the PIC carrier. The same diagram is shown opposite.



w7c

Over to you:

All programs have two inputs and two outputs, though for programs 0 to 3, the outputs duplicate each other. The circuit shown opposite allows you to investigate all eight programs stored on the PIC carrier. Select program 0 on the Locktronics microcontroller, by sliding all the selector switches to the left, as shown. Set up the circuit, with the DC power supply set to 6V. Notice that two flying leads, the red one and the black one, are needed to power up the PIC carrier.



w7b

Press the reset button. The microcontroller now behaves as a 2-input AND gate. Test it by working through all input switch positions, and watching the state of the output LED. Next, detach the power leads and remove the PIC carrier. Select program 1. Replace it and reconnect the power leads.

Press the reset button. The microcontroller now behaves as a 2-input OR gate. Test this in the same way as before.

Do the same thing for programs 2 and 3.



w7d

Switch settings for program 0



w7e

Switch settings for program 1

Worksheet 7

Programmable logic

Programs 4 to 7:	Program 4	-	Headlamp controller
	Program 5	-	Hazard warning controller
	Program 6	-	Seat-belt alarm
	Program 7	-	ABS controller

So what?

All programs have two inputs and two outputs. The input switches and output LEDs simulate the behaviour of different circuits in a modern vehicle. The purpose of the switches and LEDs changes from program to program. The circuit is exactly the same as the one you used to test programs 0 to 3. Test each program, using the information given below.

Program 4:

Switch A	Headlamp on / off switch
Switch B	Main beam / dipped beam selector
LED C	Main beam lamps
LED D	Dipped beam lamps

- With the headlamps switched off, closing switch B causes both main beam and dipped beam lamps to come on (as when the driver 'flashes' the headlights during day time.)
- With the headlamps switched on, switch B selects either main beam or dipped lamps.

Program 5:

Switch A	Indicator switch
Switch B	Hazard warning switch
LED C	Left indicator lamp
LED D	Right indicator lamp

- Normally, closing switch A causes the left indicator to flash.
- When the hazard warning switch is on, both indicators flash, regardless of the state of the indicator switch. (A different frequency is used to enhance the effect.)

Program 6:

Switch A	Ignition switch
Switch B	Seat-belt sensor
LED C	Seat-belt alarm
LED D	Seat-belt alarm

- When the ignition switch is on, the seat belt alarm flashes on one LED and then the other until the seat-belt is fastened, (switch B closed.)

Program 7:

Switch A	Brake pedal switch
Switch B	Wheel sensor
LED C	Brake lamp
LED D	Brake pressure actuator

- When the brakes are applied, the brake lamp turns on.
- If a wheel 'locks' (stops turning, simulated by the closing the wheel sensor switch,) the brake lamp stays lit, but the pressure actuator pulses the brake fluid pressure to that wheel.

Introduction

The course is essentially a practical one. Locktronics equipment makes it simple and quick to construct and investigate electrical circuits. The end result can look exactly like the circuit diagram, thanks to the symbols printed on each component carrier.

Aim

The course introduces students to digital electronics in an automotive context. It does so through a series of practical experiments which allow students to unify theoretical work with practical skills. Whilst the context is automotive applications the course can be used by a wide range of students.

Prior Knowledge

It is recommended that students have followed the 'Electricity Matters 1' and 'Electricity Matters 2' courses, or have equivalent knowledge and experience of building simple circuits, and using multimeters.

Learning Objectives

On successful completion of this course the student will:

- recall that an analogue quantity is one that copies the behaviour of another;
- recall that an analogue signal can have any voltage value, usually between the voltages of the power supply rails;
- recall that a digital quantity has only two possible states, known as 'off' and 'on' or 'logic 0' and 'logic 1';
- recall that digital signals can be regenerated, to remove the effects of noise and distortion, whereas analogue signals cannot;
- use a LED and series resistor to test the output state of a logic system;
- set up a switch unit to output a logic 1 signal when the switch is pressed, and logic 0 when not pressed;
- set up a switch unit to output the inverse behaviour;
- test and hence identify a logic function using two switch units and a LED unit;
- know that, for CMOS logic gates, logic 1 is any voltage greater than 70% of the supply voltage, and logic 0 is anything less than 30% of supply voltage;
- explain why CMOS inputs must not be allowed to 'float';
- identify a logic gate from its symbol, using either ANSI or BS symbols;
- complete the truth tables that describe NOT, AND, NAND, OR and NOR logic functions;
- recognise, and write a description of, the behaviour of NOT, AND, NAND, OR and NOR logic gates;
- know how to connect NAND gates to perform the following logic functions: NOT, AND, OR and NOR;
- give an advantage for replacing logic gates with their NAND gate equivalent;
- know that logic functions can be produced by programmable logic systems;
- understand the advantages of using programmable logic systems to generate logic functions.

Progression

The content of this module prepares auto electricians for work on vehicle sensors and actuators, and from there, on the CAN bus protocol.

Matrix Multimedia provides appropriate modules to cover these areas of study.

See the website www.matrixmultimedia.com for further information.

What the student will need:

To complete the Introduction to digital electronics course, the student will need the Equipment shown in the table. In addition the student will need:

- 1 multimeter

Power source:

The investigations in this module require a DC power source such as the HP2666 which is an adjustable DC power supply offering output voltages of 3V, 4.5V, 6V, 7.5V, 9V or 12V, with currents typically up to 1A.

The voltage is changed by turning the selector dial just above the earth pin until the arrow points to the required voltage.

(The instructor may decide to make any adjustment necessary to the power supply voltage, or may allow students to make those changes.)

Locktronics PIC program

The Locktronics PIC in this solution needs to have the appropriate program downloaded onto it. The program has the part number LK7603.

This program is contained on the LK6492 CD ROM that is supplied with this equipment. The program can be downloaded using Flowcode or the PPP download utility which is available from the Matrix web site. This program is loaded into the Locktronics PIC when shipped as part of the Introduction to digital electronics solution.

Further information on downloading the program to the Locktronics PIC using the Locktronicsprog software can be found on the Matrix web site: www.matrixmultimedia.com

Qty	Code	Description
1	LK8275	Power supply carrier with battery symbol
16	LK5250	Connecting Link
2	LK5203	Resistor - 10K, 1/4W, 5% (DIN)
2	LK6209	Switch on/off (stay put, sideways swivel strip)
2	LK6635	LED, red, 5V (DIN)
1	LK6864	NOR - +5V lead spade connector - ANSI
1	LK6860	AND - +5V lead spade connector - ANSI
1	LK6861	OR - +5V lead spade connector - ANSI
1	LK6863	NAND - +5V lead spade connector - ANSI
1	LK6860	NOT - +5V lead spade connector - ANSI
1	LK8900	7 x 5 baseboard with 4mm pillars
1	HP2666	International power supply with adaptors
1	LK4221-56	An Introduction to Digital Electronics Inlay (DIN)
1	HP5540	Deep tray
1	HP4039	Lid for plastic trays
1	HP9564	62mm daughter tray
1	HP7750	Locktronics daughter tray foam insert
1	LK5609	Lead - blue - 500mm, 4mm to 4mm stackable
1	LK5607	Lead - yellow - 500mm, 4mm to 4mm stackable
1	LK5555	Red 2mm to 4mm Logic Gate lead
1	LK5556	Black 2mm to 4mm Logic Gate lead
1	LK6231	Resistor - 50K, 1/4W, 5% (DIN)
1	LK6492	Curriculum pack CD ROM
1	LK7290	Phototransistor
1	LK4000	Locktronics User Guide
1	LK4690	USB reprogrammable PIC carrier



Locktronics HP2666 power supply showing voltage selector

Using this course:

It is expected that the series of experiments given in this course is integrated with teaching or small group tutorials which introduce the theory behind the practical work, and reinforce it with written examples, assignments and calculations.

The worksheets should be printed / photocopied / laminated, preferably in colour, for the students' use. Students should be encouraged to make their own notes, and copy the results tables and sections marked 'For your records' for themselves. They are unlikely to need their own permanent copy of each worksheet.

Each worksheet has:

- an introduction to the topic under investigation;
- step-by-step instructions for the investigation that follows;
- a section headed 'So What', which aims to collate and summarise the results, and offer some extension work. It aims to encourage development of ideas, through collaboration with partners and with the instructor.
- a section headed 'For your records', which can be copied and completed in students' exercise books.

This format encourages self-study, with students working at a rate that suits their ability. It is for the instructor to monitor that students' understanding is keeping pace with their progress through the worksheets. One way to do this is to 'sign off' each worksheet, as a student completes it, and in the process have a brief chat with the student to assess grasp of the ideas involved in the exercises it contains.

Time:

It will take students between four to six hours to complete the worksheets.

It is expected that a similar length of time will be needed to support the learning that takes place as a result.

Instructor's guide

Scheme of work

Work-	Notes for the Instructor	Timing
1	<p>The first aim is to distinguish between analogue and digital signals. This worksheet sets up two sensing sub-systems, one analogue and the other digital.</p> <p>Students are required to take voltage measurements on a digital multimeter (DMM). Some may not have done so for some time, and may need a reminder of how to do so. The first important item is that they use the correct sockets on the meter. The second is that they choose an appropriate scale. As the meter can measure AC quantities as well as DC, the instructor should remind them of the symbols used for AC and for DC ranges. The DC symbol is given on the worksheet.</p> <p>No record of measurements is taken, as it is simply a matter of realising that the analogue signal can take any value (between 0V and 6V - the power supply voltages,) whereas the digital signal has one of two voltage values.</p> <p>The 'So What' section makes the point that, because of the nature of electrical signal transmission, digital signals use bands of voltages to represent digital signals, so that, in a TTL system, (Transistor-Transistor-Logic, one of the logic gate families,) for example, any voltage from 0V to 0.8V is guaranteed to be taken as logic 0, and anything from 3.5V to 5V (the maximum voltage for a TTL system,) as logic 1.</p> <p>Signals may have voltages between these bands (unfortunately.) The outcome is ambiguous. The system will regard these as either logic 0 or logic 1, but exactly which is uncertain and may vary from system to system, and even from day to day.</p> <p>The section also introduces the idea of regeneration, that a digital signal can be returned to its original state, removing the effects of added noise signals, and of distortion, (where the components of the system do not reproduce the signal accurately.) This is not possible with an analogue signal. (The other advantage of digital processing is that it allows error detection, and correction, whereas analogue signals do not.)</p> <p>The logical nature of logic circuits is demonstrated as the last activity of this worksheet. Students find that if you turn the switching unit upside down, you turn the signal 'upside down'. Initially, pressing the switch generated a logic 1 signal, and not pressing it a logic 0. Once inverted, pressing the switch generates a logic 0, and not pressing it a logic 1.</p>	20 - 30 mins
2	<p>This worksheet introduces the first, and simplest, logic gate, the NOT gate.</p> <p>Before that, the introduction makes the necessary distinction between logic gates and logic functions. The more important is the logic function. There are a number of ways to implement a logic function. In digital electronics, you can use a dedicated, discrete logic gate, you could use a series of NAND gates, or NOR gates, or use a programmable system. On a wider front, optical logic gates produce the same logic functions, but using laser light, to speed up the switching process. The technology may differ, but all produce the same outcomes in terms of logic functions.</p> <p>The introduction also contains an important table of logic symbols, both in the ANSI format, and the BS (sometimes called SB) format. The students may encounter further formats, such as the IEC (International Electrotechnical Commission) system.</p> <p>Continued on the next page...</p>	30 - 40 mins

Instructor's guide

Scheme of work

Worksheet	Notes for the Instructor	Timing
2	<p>Continued from the previous page...</p> <p>The investigation involves setting up a switch unit and using it to generate a digital input signal for a NOT gate. The students use this to construct a voltage truth-table for the NOT gate. They then invert the switch unit, but observe that this has no effect on the NOT function itself.</p> <p>The 'So What' section details the voltage bands used by CMOS gates (like that used on the Locktronics NOT gate carrier), and the students use this information to turn their voltage measurements into logic levels, and re-build the truth-table.</p> <p>The students then investigate what happens when the resistor is removed from the switch unit. In general, this is an unwise move for CMOS gates.</p> <p>The inputs operate on minute currents and so can be affected by stray electromagnetic fields, such as radio, television and mobile phone transmissions. As a result, the inputs can switch rapidly between logic 0 and 1. As they do so, they draw enough current to cause local overheating, which can damage the IC. The rule, then, is that CMOS inputs should not be allowed to 'float', but instead must be either 'pulled down' to the 0V rail, or 'pulled-up' to the positive power rail, by a resistor. The Locktronics NOT carrier has unconnected inputs connected internally to 0V by a large value resistor.</p> <p>As a foretaste of what is to come, the students check the serial number of the chip used in the NOT carrier. CMOS NOT gates carry the serial number 4049. However, the one used on the carrier is a 4011 - a NAND gate. This flags up that it is often more appropriate to generate logic functions using other logic gates, especially NAND gates.</p>	
3	<p>This worksheet investigates the behaviour of an AND gate. It introduces two situations where the AND function might be encountered in a car.</p> <p>The introduction points out a simple way to view the AND function as two switches in series. It is worth the instructor spending time to drive home this picture. The diagram on page 7 includes a pull-down resistor, to ensure that output sits at logic 0 when either switch is open. Again, the significance of this needs to be emphasised.</p> <p>The students set up two switch units and use them to input four combinations of logic signals. Measuring input and output voltages, they complete a table of results, which they then turn into logic levels, and generate the AND gate truth-table.</p> <p>They are encouraged to view the AND function as one which generates a logic 1 output only when both inputs are at logic 1.</p> <p>The 'So What' section includes the pinout for a CMOS 4081 IC. Part of the importance is to highlight again the need to avoid floating inputs. Zealous students often take this message too far, and connect unused outputs to the nearest power rail. This is unfortunate, because the nature of the logic function applied by the gate may try to drive the output to logic 1, while the student has connected it to the 0V rail, or vice-versa. The message then is that the outputs take care of themselves. It is only unused inputs that require our attention.</p>	20 - 30 mins

Worksheet	Notes for the Instructor	Timing
4	<p>A similar approach is now used to investigate the OR gate. The introduction points out a way to view the OR function as two switches in parallel. Again, the diagram includes a pull-down resistor, to ensure that output sits at logic 0 when both switches are open. The significance of both points needs to be emphasised by the instructor.</p> <p>It discusses a typical application, the car security system, though the details of the sensors used will decide what logic function is needed.</p> <p>As before, the discussion in the 'So What' section leads to the building of the truth-table for the OR gate.</p>	20 - 30 mins
5	<p>This worksheet investigates the behaviour of a NAND gate. The students set up two switch units and then use them to input the four different combinations of logic signals. Measuring input and output voltages, they complete a table of results, which they then turn into logic levels, and generate the NAND gate truth-table.</p> <p>They are encouraged to view the NAND function as one which generates a logic 1 output when either input is at logic 0. The seat belt warning system in a car is given as a possible application of this function. In reality, it depends on how the seat belt sensor is set up. This application assumes that the sensor outputs a logic 0 when the seat belt is not fastened, and a logic 1 when it is, and assumes that the alarm is triggered when the logic function outputs a logic 0. Other configurations will require a different logic function.</p> <p>Students reproduce the effect of a NOT gate by connecting the inputs of the NAND gate together with a connecting link, and by using only one switch unit to input digital signals. They are able to verify that this arrangement generates the NOT logic function.</p> <p>Next, they build a combination of an AND and a NOT gate and show that together these generate the NAND function. A diagram shows this using circuit symbols.</p> <p>Page 12 is dedicated to the idea that NAND gates can be combined together to produce any other logic functions. Diagrams show how this can be achieved. Students may wish, or might be directed, to set up these systems to confirm what happens. Some justification is given for this substitution in terms of reducing the purchase and storage costs if only one type of IC is used.</p>	30 - 40 mins

Worksheet	Notes for the Instructor	Timin
6	<p>The NOR function is the last of the five to be studied, but not because of low importance. The introduction points out that, like the NAND gate, NOR gates can be combined to generate any logic function. The diagrams in the introduction show how this is done. (The reason why NAND and NOR gates offer this facility, while AND and OR gates do not, stems from the ability of NAND and NOR to generate NOT functions. From there, all other functions are accessible.)</p> <p>The truth-table is investigated in the usual way. It is seen to be the inverse of the OR gate, and so the students are asked to build a system using an OR and a NOT gate to generate the NOR function.</p> <p>Any application which 'turns something off' when anything 'turns on' requires a NOR function. This worksheet discusses the air-conditioning in a vehicle, which turns off when any door is opened. As usual, the exact requirements depend on the way the sensors are oriented.</p>	20 - 30 mins
7	<p>This worksheet introduces students to the powerful and widespread use of programmable systems.</p> <p>In this case, a PIC microcontroller is pre-programmed with eight programs. This microcontroller requires a 6V DC power supply.</p> <p>The programs simulate various logic functions and systems. All have two inputs, provided by two switch units, and two outputs, monitored by LEDs. As a result, the same circuit can be used to test all of them.</p> <p>These are selected from a bank of three switches, by configuring them with the binary equivalent to the decimal number of the program. For example, to select program 5, the switches are set to '101'. (The left-hand selector switch, when viewed from above, provides the least-significant bit of this number - the 'units'.)</p> <p>Students may need some help initially in selecting programs. They should do so with no power connected to the system, and should press the reset button after restoring power to the system.</p> <p>The first four programs, numbered 0 to 3, simulate the behaviour of 2-input logic gates studied in earlier worksheets. Students are directed to work through all four programs. This helps to cement in their minds the behaviour of each logic function, and also demonstrates the power of a programmable system. Changing the settings of the selector switches changes the behaviour of the system.</p> <p>The final four programs are designed to embed the ideas studied so far in an automotive context. A description of each program is given, and the designation of each input and output. Instructors should check that the students understand fully the task that each program is carrying out. If the students work through them too quickly, then the power of the programmable system might be missed.</p>	40 - 60 mins

Instructor's guide

Scheme of work

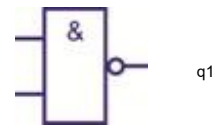
Worksheet	Notes for the Instructor	Timing
Quiz	<p>This is offered as a way to assess a student's grasp of the topics covered in the worksheets.</p> <p>It can be run as a conventional test, answered by each person individually , or can be organised as a 'pub' quiz for the whole group, where the instructor splits students into teams.</p> <p>The questions could be printed out for the teams, or could be projected onto a screen with a data projector.</p> <p>The answers are:</p> <p>Round 1 -</p> <ul style="list-style-type: none">(a) Option C(b) Option D(c) Option B <p>Round 2 -</p> <ul style="list-style-type: none">(a) Option A(b) Option C <p>Round 3 -</p> <ul style="list-style-type: none">(a) AND gate(b) OR function(c) OR gate(d) NAND function(e) AND gate	20 - 30 mins

Round 1

- (a) Which one of the statements is **wrong**?
- A. A digital signal should have a voltage in one of only two voltage bands.
 - B. A digital signal can be regenerated to remove the effects of noise and distortion.
 - C. A digital signal has a voltage which copies the behaviour of a quantity like temperature.
 - D. A digital signal can be checked to detect transmission errors.
- (b) Which one of the following is the symbol for an OR gate?



- (c) What logic function is identified by the following symbol?
- A. AND
 - B. NAND
 - C. NOR
 - D. NOT
 - E. OR



Round 2

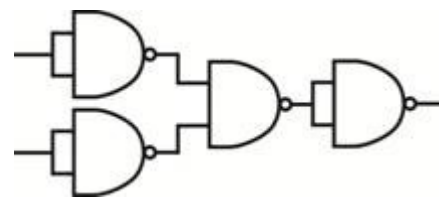
- (a) What logic function is described by the following truth-table?

- A. AND
- B. NAND
- C. NOR
- D. NOT
- E. OR

Input A	Input B	Output
0	0	0
0	1	0
1	0	0
1	1	1

- (b) Which single logic gate could replace the combination shown below?

- A. AND
- B. NAND
- C. NOR
- D. NOT
- E. OR



Round 3

- (a) Which 2-input logic gate outputs a logic 1 only when both inputs are at logic 1?
- (b) Which logic function outputs a logic 1 when any input is at logic 1?
- (c) Which 2-input logic gate outputs a logic 0 only when both inputs are at logic 0?
- (d) Which logic function outputs a logic 1 when any input is at logic 0?
- (e) Which 2-input logic gate has an output which is the inverse of a NAND gate?

Version control



01 04 2010

First version released

06 06 2010

Page 5

formatting changes

Page 7

text changes and reformatting

Page 9, 14, 16, 17, 21, 22, 23, 24, 26 reformatted some tables

15 08 23

Reformatted to new style

About this document:

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Developed for product code LK4221 - Introduction to digital electronics

Date	Release notes	Release version
01 04 2010	First version released	LK7209-80-1 revision 1
06 06 2010	Amendments following external review	LK9392-80-1 revision 2
16 12 2014	RoHS changes	LK9392-80-3