MECHATRONICS CONTEST
GUIDELINES, NOTES, QUESTIONS AND ANSWERS FOR STUDENTS, TEACHERS & PARENTS
Part 2: For Seniors Group (Grade 11 & 12)

THE PROJECT FOR SENIORS
This project introduces you to Logic IC Chips, which would be a good learning exercise to understanding microcontrollers which can be programmed to do various activities by software programming. The scope is to use the supplied IC Chip to light LEDs in various colours & patterns and blinking at predetermined times. The winners will be the ones judged to understand the circuit and designs very well as well as the ones who designed the most ingenious pattern of LED lighting.

Note: *In the notes we have given a lot of materials which you may find interesting reading even later on after the contest. For the purpose of the contest, keep reading, skimming over words and items you do not understand at first. Also try to understand the questions and answers to answer the judges' questions. Understand the working of the circuits given and what you may design (if different to what is given).*

Hint: Lighting pattern could imitate one or more of the following:
1) Turn signals of the car,
2) Hazard lights,
3) Police car lights,
4) Advertising signs,
5) A combination of above or your own design.
Note: *Only the supplied* ***one CD 4011 IC Chip*** *should be used. Other components can be LEDs, diodes, capacitors, resistors and transistors, but* ***no*** *other ICs.*

IC Chips
Early electronic circuits used single (discrete) transistors, diodes, resistors, capacitors and other components. Then they discovered ways of placing many transistors, diodes and resistors inside one monolithic package and called them Integrated Circuits Chips, or IC Chips. Early ICs were examples of Small Scale Integration (SSI), followed by Medium Scale (MSI), LSI, VLSI, ULSI, etc. Rapidly they were able to improve design and fabrication methods and presently the latest computer microprocessors have more than 9 million transistors in a square millimeter. All this is happening in the last few decades!
Please see https://en.wikipedia.org/wiki/Integrated_circuit for more details.
ICs are classified as Analogue/Linear, Digital/Logical, and mixed.

ICs fall into many families such as:

- 7400 series TTL logic building blocks introduced in the 1960's
- 4000 series, the CMOS counterpart to the 7400 series introduced in the 1970's
- 555 Timer series introduced in 1972 and their CMOS counterparts 7555 etc.
- Many new chips, microcontrollers, microprocessors, and other specialised chips. New ones are introduced every few months, or even weeks!

TTL stands for Transistor-Transistor Logic. They use the normal Bi-polar Junction Transistors (BJT). CMOS stands for Complementary Metal Oxide Semiconductor. They use MOSFET (Metal Oxide Semiconductor Field Effect Transistors), both P-type and N-type on the same chip complementing each other– hence the word Complementary. Let these big words not intimidate you. For our actual work on the car you don't need to know such words. I am giving them only for interest and completeness sake.
4011 is a CMOS quad 2-input NAND gate IC. We will know more in a while. First I give some important notes and precautions about CMOS chips and the proper handling of them.

Important Notes and Precautions:
Modern CMOS chips are rugged and highly reliable compared to earlier designs. They contain parts with very high Input Impedance/Resistance in the order of millions of Megohms (10^{12} Ohms). This means any stray static electricity picked up can raise the voltages of these parts to damaging values and destroy them instantaneously. Modern ICs have many protective circuits built-in. Even so these chips are stored with the pins short circuited by special foam. Do not remove the chip from the supplied foam and touch the pins! If you are soldering the pins directly into the Printed Circuit board, the soldering iron has to be properly earthed. We do not recommend you to solder them directly on to the board. Instead we have provided ***IC Sockets*** *which should be soldered on to the PC board. You should design your circuits, study for any possible errors, and then make sure your PC board is properly wired with all components on to the IC holder. Also note that every* ***unused input pin*** *should be either grounded or connected to the supply rail. Once you are satisfied that the circuits are OK, then only you should carefully remove the IC chip from its foam, and assemble it into the socket, the correct way around. How do you know*

which way is correct? We come to that later on. Read on.

NAND logic gates

A logic gate is a device which accepts one or more logical inputs, does a logical operation and outputs the result as a logical output. Here logical means that the output can be high or low, also written as 1 or 0. You have studied Boolean algebra. Well these devices operate using Boolean algebra. There are AND, OR, NOT, NAND, NOR, XOR, XNOR gates.

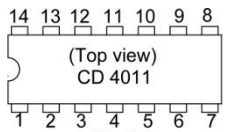


Fig. 3

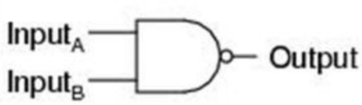
If interested please visit: http://en.wikipedia.org/wiki/Logic_gate.

For our purposes, let us learn only about NAND gates.

NAND is short form for NOT AND, meaning negative of AND gate.

A NAND gate can have many inputs, such as 2-input, 3-input, etc. Our 4011 has 2-input gates. In the IC chip there are 4 separate 2-input gates. Hence it is called Quad 2-input NAND gates. Easy, isn't it? Now let's look at one of these gates. This is made of many p- and n-type MOS Transistors designed to complement each other. Hence the word CMOS is derived. We will draw a simple diagram (symbol) which shows the functions in a block form. See Fig. 1: Below the symbol, we have given what is known as the truth table. The 2-input NAND gate has 2 input pins A and B, and of course 1 output pin. (Every gate has only 1 output).

Fig. 1 *NAND gate*



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

In the truth table, 0 means the pin referred to is at low voltage, and 1 means high voltage.

We see that the output is high (1) for all conditions except for when both inputs are high (1). This table is important; as it is on this you will be basing your designs. You can also see that if both input pins are connected together, then only the 1st and 4th row of the table are valid. It works as a NOT gate, commonly called an **inverter**. That is because the output is always opposite to the input. See Fig. 2

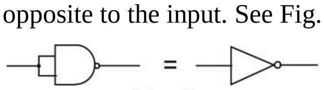


Fig. 2.

Pin Numbering method.

The 4011 IC we supplied has 14 pins with 7 pins on each side of the chip. The pins are spaced at 0.1 inch, in 2 rows 0.3" apart. This arrangement is called DIL (Dual-in-Line) or properly as: PDIL to mean Plastic Dual-in-Line: as the small IC chip inside is covered with plastic. The pin numbering method I am giving here holds true for all ICs of this type. They may have more or less pins than the 14 of 4011.

One side of the chip has a small indent at one end. You number the pins as 1, 2, 3... 14, starting with the pin on the left of indent (when looking from top – with the pins pointing away from you) numbered as 1, and then proceeds anti-clockwise as 2, 3, 4,... 14 for 4011 as it has 14 pins. See Fig. 3. Some DILs have more or less pins (from say 6 to 40 pins): The pin numbering method remains the same.

In a circuit diagram, to keep the diagram easier to follow, the pin numbers may not be shown in sequence. When fabricating the components, make sure you connect to the correct pins. Please see Figure.13. later on.. to see what I mean.

About 4011.

The 4011 IC chip may have some letters in front of the number and behind the number. What we have supplied may have the name CD4011BE. There are meanings to these letters, which are not important for us at this time. It has 4 independent NAND gates. As shown in Fig. 4. The gates are made of Complementary sets of MOSFET transistors. They have very high input impedance and the operating Voltage range (V_{DD}) is 3 to 15 Volts. We shall use the 6-volt supply of the MCC car.

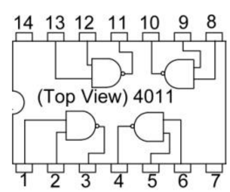


Fig. 4.

Now let us get away from the chip and learn about a Voltage Divider and a RC time delay circuit.

Voltage Divider.

Consider Fig. 5 below: B is a 6 volts battery. Two resistors R_1=100R & R_2=200R are connect-ed in series to the battery through a switch S. When the switch is open there is no voltage applied to the resistors and the voltage across X-Y is 0 and across Y-Z is also 0.

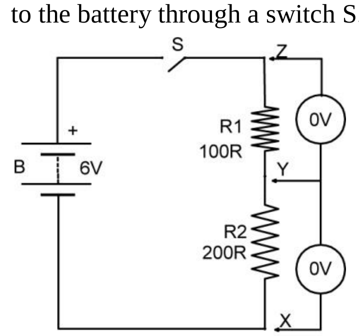


Fig. 5.

When the switch S is closed, (see Fig. 6) immediately the X-Y voltage becomes 4 volts and Y-Z voltage becomes 2 volts. As the same current flows through

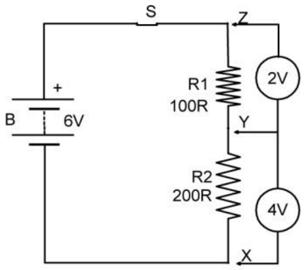


Fig. 6.

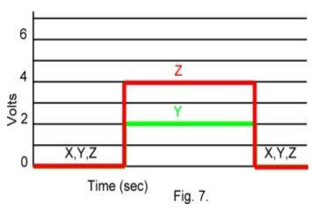


Fig. 7.

both resistors, the voltage drop is proportional to the resistor values: $V_{R1}/V_{R2}=R_1/R_2$. This happens immediately when the switch is closed, and becomes zero as soon as the switch is opened. See Fig. 7, which shows graph of the Voltages vs. Time

RC time delay circuits.
Let us replace the resistor R_2 in Fig. 5 with a Capacitor C, which gives us Fig. 8. Here we have also replaced the

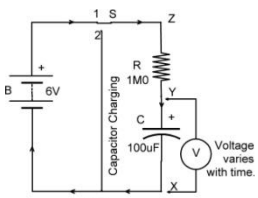


Fig. 8.

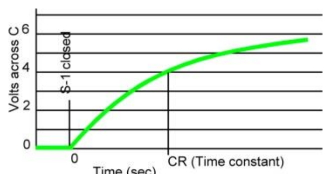


Fig. 9.

switch S with a 2-way switch S, which connects the point Z either with the battery or to earth. (Normally we refer the negative side of the battery as being at voltage 0, and as being at 'earth' or 'ground' voltage.). Let R be 1M0 (1 Megohm), and C be 100µF (100 microFarad). As soon as the switch is moved to position 1, the battery is connected to the resistor. At that moment the resistor carries no current and the voltage across it is 0. Thus the full 6 volts is applied to the Capacitor and it starts charging, and the voltage across it increases from 0 and goes towards the 6 volts. This does not happen immediately. It takes time. The voltage across the capacitor increases exponentially. We can mathematically show that after a time (seconds) equal to R (ohm) x C (Farads), the voltage across the Capacitor is about $^2/_3$ of the voltage applied. RxC (also called simply RC) is known as the Time Constant τ (sec) (***Note:*** *We can use µF for C and MΩ for R in the same equation to get the Time constant in sec)*. So we find that after 100 seconds, the voltage across the Capacitor will be about 4 volts ($^2/_3$ of 6 volts). If we draw a graph of Voltage across the capacitor (V_c) vs. Time, we get an exponential curve as in Fig. 9. Similarly if the switch is now changed to position 2, the resister is shorted to the ground, and the capacitor begins to discharge. See Fig. 10. The discharge curve is another exponential curve as shown in Fig. 11. The time to discharge to about $^1/_3$ of Vc is again RC = time Constant τ. This is useful in designing the circuits required to make the LEDs blink at specific rates of time. For our purposes we can

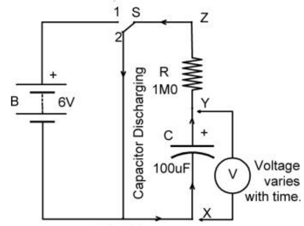


Fig. 10.

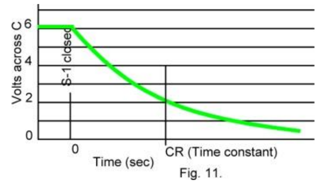


Fig. 11.

assume the LEDs will flash at times dependent on the Time Constant in seconds.
Q: A resistance of 1M0 is connected in series with a capacitor of 0.1µF. What is the Time Constant?
A: Time Constant = RC = 1.0x0.1= 0.1 seconds.
(*Note: if R is in Megohm & C is in microfarads, the time constant is simply RC in seconds).*
Q: I like my car LEDs to flash at 1 second intervals. If I use 1M0 resister, what should be the value of the capacitor?
A: Time Constant should be 1 sec. Hence C=t/R = 1/1 = 1µF.

Rapid charge of Capacitor
If you want the capacitor to charge rapidly, and then discharge slowly through the resistor, the following circuit in Fig. 12 can be used. Here the capacitor charge rapidly through the diode, as it has variable resistance. Once charged, when switch is off the capacitor discharges through R with the time constant of CR.

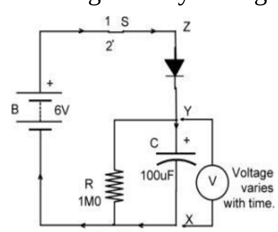


Fig. 12

Oscillating outputs
In order for the voltage at point Y to go up and down we have to move the switch S between position 1 and 2 at proper times. In the circuits that follow, we will be doing these automatically using suitable circuits. Usually the on time and off times are equal. In the circuits that follow I will give the waveform of the inputs and outputs, which can be observed visually if you connect the points to an oscilloscope. You don't need an oscilloscope for our projects. I am giving the waveform for information sake.

You can also have the LEDs to be *on* for a different time to the *off* time. How? We will be giving circuits later on. The ratio of *on* time to *off* time is known as *duty cycle*.

Now I will give some sample circuits. Once you understand the working of the circuits you can design your own circuits to make the LEDs blink together or wink alternately, or any other pattern you design.

SAMPLE CIRCUITS:

Most of the circuits use the gates in the 4011 and are used as linear amplifier, oscillators, monostable, flip-flop or Schmitt trigger. What are these? Let us go through each of the type.

Note: *The voltage applied to pin 14 can be 3 to 15 Volts. However, in our circuits we will be using the 6 Volts supply in the car. Also note that I have given the pin numbers for each of the gates, and unused inputs are connected to low (earth) or high volts. In the actual circuits you should do the same.*

Linear amplifier

If you connect the 2 inputs of a NAND gate together, it forms an Inverter. It means when the input is low, the output is high and vice-versa. If we can maintain an input voltage of ½ the supply voltage, the output also will be ½ the voltage. Any slight changes in the input will be amplified at the output. The easy way of doing this and maintaining a stable condition is to connect a high resistor (say 1M0 to 20M0) across the output and input as a negative feedback. See Fig. 13.

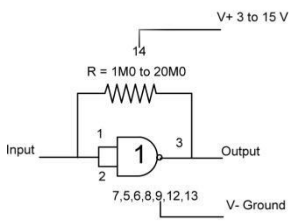


Fig. 13

How does it work? The input and output will stabilise at half the voltage. Any change in input will be amplified as an output in the opposite direction. Lowering of the input will raise the output and vice versa. This circuit will be used in some of the following circuits.

Oscillator

If you connect 2 of the NAND gates in the IC chip as shown in Fig. 14a, you get an RC oscillator.

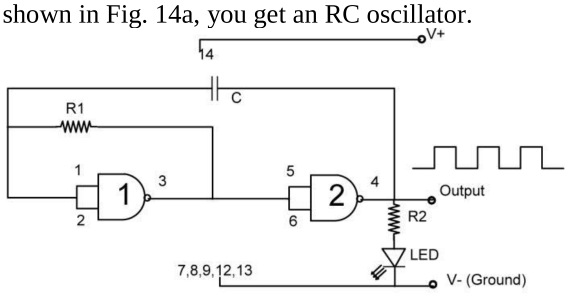


Fig. 14a.

The output of NAND gate 2 will oscillate in a square wave form.

I have shown how an LED can be connected to the output to flash at a frequency determined by R1 & C

If you change the values of R1 or C to get higher frequency (say 50 to 10,000 Hz,) you can connect a headphone or small speaker to hear the sound.

Alternately you can connect the LED to V+ side of the battery as shown in Fig 14b.

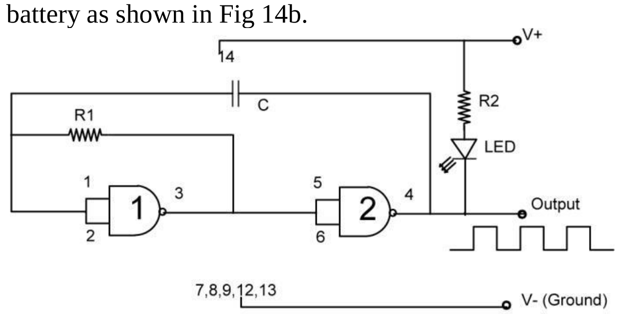


Fig. 14 b.

How does it work? The gates are connected as inverters by joining the 2 inputs together. Gate 1 is connected as a linear amplifier with R (1M0) being the negative feedback resistor. Capacitor C provides positive feedback from output of Gate 2 to input of gate 1. R & C form a RC circuit. The frequency of the oscillations at the output will be 0.5/RC. For the values give the frequency will be 0.5/(1x.01) = 50 cycles/sec(also called Hz.). If you connect an earphone or small speaker to the output you will hear the 50Hz sound.

Q: *If you connect an LED to the output, will you see the LED blinking?*

A: No you may find that the LED will light dim, but the switching on or off will not be seen as the eye cannot see lights flashing faster than about 25 Hz, due to the persistence of vision.

Q: *If you want an LED connected to the output to switch on and off at 1 second intervals, what should be the value of C?*

A: frequency 1=0.5/1xC Hence C=0.5 μF. You will use a standard 0.47μF.

Q: Can you use 2 LEDs in series?

A: Yes. As an LED drops about 1.9Volts to 2.2Volts depending on the colour, and the supply voltage is 6 V, it would be possible to connect 2 LEDs in series. The series resistor value has to be reduced to suit.

PEO Scarborough Chapter, Mechatronics Volunteer team

That's the end of this set (Part 2) of guidelines and Notes.

When you register for the Contest and we supply you the parts, we will be giving you **more guidelines, notes and Questions and Answers.** Also **practical circuits and connections diagrams will be supplied** so that your team can choose the best circuits for your car.

Should the LEDs come on only when the car motor is running? Or should it be switched on before the car starts? These and many other questions will be answered in the guidelines we supply along with the parts.

SO, PLEASE REGISTER EARLY AND DESIGN YOUR OWN LED LIGHTING SETS FOR THE MECHATRONICS CAR CONTEST.