FUN WITH DIGITAL ELECTRONICS

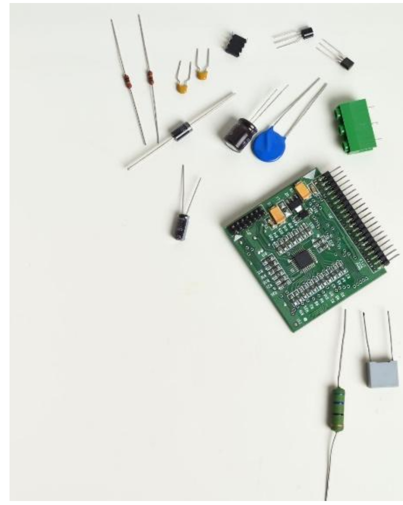
If you have never studied digital electronics before and want to get started broadening your knowledge of all things digital, then you have come to the right place.

Valley Christian
High School
John Crandall

v. 20250303

Contents

Introduction



This camp is designed to give you an introduction into digital circuits. It is not exhaustive, but hopefully covers enough to give a fairly complete overview and have some fun in he process.

Introduction to Digital Electronics:

If you have never studied digital electronics before and want to get started broadening your knowledge of all things digital, then you have come to the right place. This first lesson explains what this course is about, what tools you'll need to follow along with the course and what expectations you should have from taking this course.

Number Systems

The first step in the digital world is getting to know number systems. Specifically, in this lesson we will look more closely at the binary and decimal number systems. Understanding binary and how it works is crucial to understanding digital logic because everything in the digital world is either a 0 or 1, or if you prefer, true or false.

Logic Gates

The fundamental representation of digital hardware comes in a symbol form, called logic gates. These gates perform boolean algebra in a visual way that leads to what are called logic diagrams. In this lesson, we'll learn the basic logic gates of digital electronics and experiment with them to make sure they do what they should.

Lesson 4 Karnaugh Maps

Moving beyond number systems and logic gates, we have boolean equations and karnaugh maps. In this lesson we will learn two methods for simplifying logic circuits using boolean equations and kmaps and then we will implement the circuits to verify our math. This lesson is a tough one, so get your brain ready to be jammed full with information.

Lesson 5 Combinational Logic

The term "combinational"

Lesson 5 The SR Latch

The next step into the digital world is to create stable logic elements. The first such element is called a latch and it can be built using simple logic gates. In this lesson we will explore how to build a latch using NOR logic gates and NAND logic gates. In addition, we will take a look at what timing diagrams are and how to use them.

[Lesson 6] Flip-Flops And Latches

To take another gigantic step into the world of digital electronics, we need to learn about flip-flops. In this lesson we take a look at two types of the flip-flops, the JK and D flip-flops. To learn what they are and how they work, we will put them in some experimental circuits and see how they react. Additionally, we will start to learn about clock signals.

[Lesson 7] The Crystal Oscillator

The heart and soul of any digital system is the main clock signal. It drives every single flip-flop that is inside of the system and therefore it is the most important signal. In this lesson we will learn how to use a 555 timer as a clock signal generator and we will also look at using crystal oscillators to generate clock signals.

[Lesson 8] Designing A 4-Bit Shift Register

With all the basics covered, we can start to combine digital logic elements together and make useful devices. In this lesson we will take some flip-flops and other logic elements to build a 4-bit shift register. Some LEDs will be used to show you exactly how the shift register works.

[Lesson 9] Designing A 4-Bit Counter

A great strength of digital circuitry is that the clock can act as a timer or counter with appropriate flip-flop circuitry in place. In this lesson, using some LEDs, we will learn how to build a 4-bit binary counter that uses the clock input to tell our circuit to increment a counter with every clock period.

[Lesson 10] Designing an LED Chaser

Electronics is not all about theory all the time, some moments do come when you get to have some fun. In this lesson we are going to celebrate our wealth of knowledge and just go design something fun. An LED chaser is loosely defined as a system where LEDs follow one another in a certain pattern, so start go start designing!

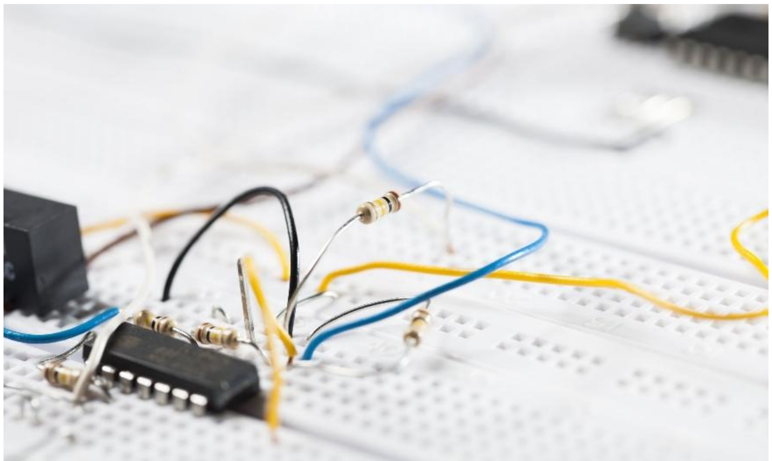
[Lesson 11] 7400 Series Logic Devices

After you have mastered the digital fundamentals, you are ready to grow and move to the more complex areas that exist. This bonus lesson dives into the more advanced 7400 logic IC's available to us as designers and looks specifically at 3 interesting IC's. The experiment for this lesson is to build a knight rider LED circuit.

[Lesson 12] 4000 Series Logic Devices

After you have mastered the digital fundamentals, you are ready to grow and move to the more complex areas that exist. This bonus lesson dives into the more advanced 4000 logic IC's available to us as designers and looks specifically at 3 interesting IC's. The experiment for this lesson is to build a 4-bit single IC counter.

Lesson 1 Introduction to Digital Electronics



Kit Contents

Your kit contains several parts. Below is a list of all the parts provided. You maybe given additional parts to add to your kit.

Quantity	Part Number/Description
10	100Ω resistor
20	10kΩ resistor
2	10uF Capacitors
2	100uF Capacitors
8	Red LEDs (5mm)
1	74HC00 (Quad 2-input NAND gate: An IC with four standard NAND gates)
1	74HC02 (Quad 2-input NOR gate: An IC with four standard NOR gates)
1	74HC04 (Hex inverter/NOT-gate: An IC with six inverters - NOT-gates)
2	74HC08 (Quad 2-input AND gate: An IC with four standard AND gates)
1	74HC32 (Quad 2-input OR gates.: An IC with four basic OR gates)
1	74HC74 (Dual D Flip−Flop with Set and Reset)
1	74HC86 (Quad 2-input XOR gates.: An IC with four basic XOR gates)
1	74HC107 (Dual JK Flip-Flop)
1	74HC138 (3-to-8 Line Decoder/Demultiplexer)
1	74HC193 (4-Bit Binary Up/Down Counter)
1	74HC283 (4-bit binary full adder - has carry in function)
1	74HC595 (8-bit shift registers, serial-in, parallel-out, output latches, output enable)
1	4026 (Decade Counter/Divider with Decoded 7-Segment Display Outputs)
1	4511 (A BCD to 7-Segment Display Driver)
1	555 (Timer)
1	20 MHz Crystal Oscillator
1	7805 +5v Regulator
1	9V Battery Clip

Types of Electronic Components

The Resistor

Electrical resistance is a measure of opposition to current flow. Current decreases as resistance increases. The resistor is a passive electrical component that creates resistance in the flow of electric current. Engineers use resistors to limit the amount of current through sensitive electrical components so as not to overload them. The resistance is measured in ohms (Ω). The symbol representing a resistor in a schematic is to the right.

Reading Resistor Values

Standard resistors have four color bands. Three of the bands tell you the nominal value, which means the value the resistor was designed to have. The fourth band tells you the tolerance of the resistor, which indicates how far off the nominal value the actual resistance could be. (The manufacturing process isn't perfect, so most resistors are a little off.)

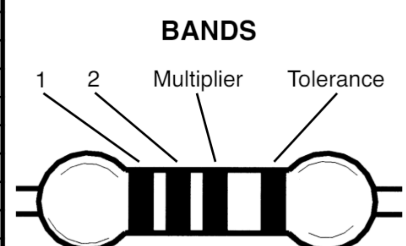
For instance, you may buy what you think is a 100 Omega resistor, but the actual resistance most likely isn't exactly 100 Omega. It may be 97 or 104 Omega, or some other value close to 100 Omega. For most circuits, "close" is good enough. Below is the color code chart for a standard four color resistor.

BAND 1 1st Digit	
Color	**Digit**
Black	0
Brown	1
Red	2
Orange	3
Yellow	4
Green	5
Blue	6
Violet	7
Gray	8
White	9

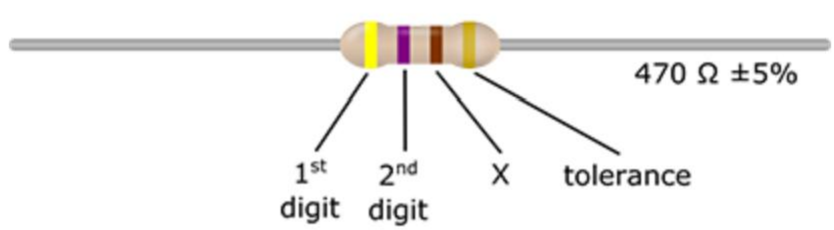
BAND 2 2nd Digit	
Color	**Digit**
Black	0
Brown	1
Red	2
Orange	3
Yellow	4
Green	5
Blue	6
Violet	7
Gray	8
White	9

Multiplier	
Color	**Multiplier**
Black	1
Brown	10
Red	100
Orange	1,000
Yellow	10,000
Green	100,000
Blue	1,000,000
Silver	0.01
Gold	0.1

Resistance Tolerance	
Color	**Tolerance**
Silver	±10%
Gold	±5%
Brown	±1%
Red	±2%
Orange	±3%
Green	±0.5%
Blue	±0.25%
Violet	±0.1%



The basic steps to decoding the value are as follows:

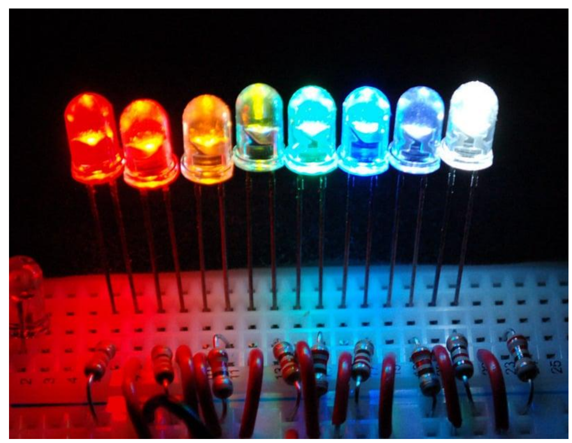


1. Decide which band is the first band. Compare the ends of the resistor. Usually, the colored band at one end is closer to that end than is the colored band at the other end. If that is the case, the band that is closest to one end of the resistor is the first band. If you can't determine which is the first

band, look at the two outer bands. If one of the outer bands is silver or gold, that band is probably the last band, so the first band is at the other end.

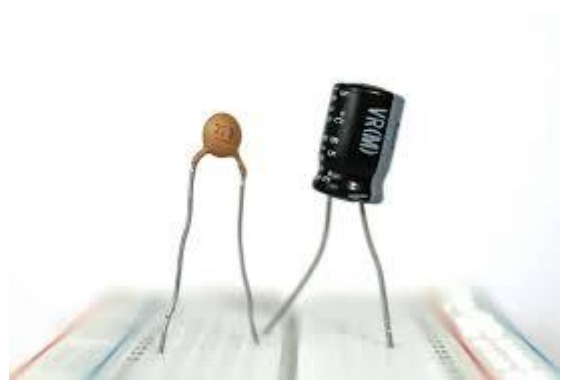
2. Look up the color of the first band in the column labeled "1st digit" and find the number associated with that color. This number is the first digit of the resistance. In the resistor shown above, the first band is yellow, so the first digit is 4.
3. Look up the color of the second band in the column labeled "2nd digit" and find the number associated with that color. This number is the second digit of the resistance. In the resistor shown above, the second band is violet, so the second digit is 7.
4. Look up the color of the third band in the column labeled "X" and find the number associated with that color. This number is the multiplier. In the resistor shown in the above, the third band is brown, so the multiplier is 10^1 (which is 10).
5. Put the first two digits side-by-side to form a two-digit number. For the resistor shown above, the first two digits are 4 and 7, so the two-digit number is 47.
6. Multiply the two-digit number by the multiplier. This gives you the nominal value of the resistor in ohms. In the resistor shown in the preceding figure, the two-digit number is 47 and the multiplier is 10, so the nominal value is 470 Ω (47*10).

LED



A light-emitting diode (LED) is a semiconductor device that emits light when an electric current is passed through it. It is basically a specialized type of diode. This means that an LED will pass current in its forward direction but block the flow of current in the reverse direction. The LED symbol is the standard symbol for a diode with the addition of two small arrows denoting emission (of light). Hence the name, light emitting diode (LED). Below, left , is the LED symbol. To understand the direction of flow (positive to negative), think of the triangle as an arrow where the line at the end of the arrow represents the negative side.

Capacitor

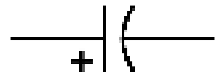


Capacitors are used in several different ways in electronic circuits:

- Sometimes, capacitors are used to store charge for high-speed use. That's what a flash does. Big lasers use this technique as well to get very bright, instantaneous flashes.
- Capacitors can also eliminate electric ripples. If a line carrying DC voltage has ripples or spikes in it, a big capacitor can even out the voltage by absorbing the peaks and filling in the valleys.

- A capacitor can block DC voltage. If you hook a small capacitor to a battery, then no current will flow between the poles of the battery once the capacitor charges.

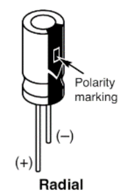
In the schematics, you will see the symbol to the right that represents a capacitor. The unit of electrical capacitance is farad (symbol: F). For most applications, the farad is an impractically large unit of capacitance. Many electrical and electronic applications are mF (millifarad), μF (microfarad), nF (nanofarad), and pF (picofarad).



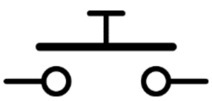
Capacitor polarity markings

One important marking for polarized capacitors is the polarity. Great care must be taken to ensure the polarity markings are observed when inserting these capacitors into circuits otherwise damage to the component, and more importantly to the remainder of the circuit board can result.

Many recent capacitors are marked with the actual + and - signs and this makes it easy to determine the polarity of the capacitor. But the ones we will be working with do not. The capacitors we will use have polarity markings that use a stripe that indicates the negative terminal. They also have the negative end having the shorter terminal. The diagram to the right is an example,



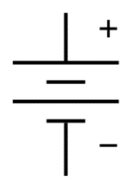
Switch



A switch is an electrical component that can "make" or "break" (On/Off) an electrical circuit. We will be using a push button switch which will "make" the circuit. Shown is a schematic symbol of a Single Pole, Single Throw (SPST) switch which our push button switch is where the two terminals are either connected together (normally closed) or disconnected from each other (normally open).

Voltage Source

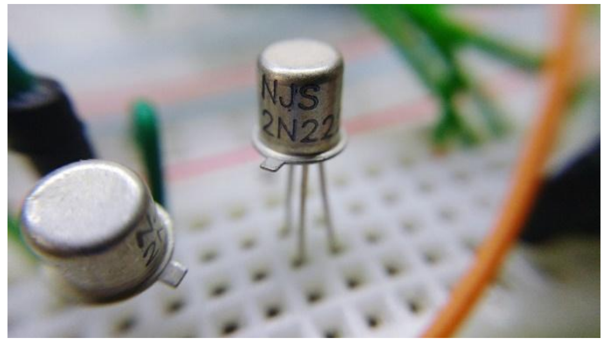
In a schematic diagram, voltage sources are usually shown. Below are two types of symbols used for voltage source. The symbol with the circle represents a direct current (DC) power source. The schematic symbol for a battery is made up of short and long parallel lines. The longer line represents the positive terminal of the battery, while the shorter line represents the negative terminal.



Ground

In electrical engineering, ground, or GND, is a reference point in an electrical circuit that has a voltage of 0V. It can also be a common return path for electric current or a direct physical connection to the Earth. In an electrical schematic, ground connections are indicated by symbols.

Transistor



The design of a transistor allows it to function as an amplifier or a switch.

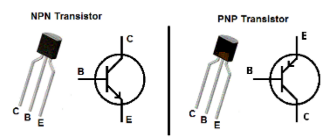
This is accomplished by using a small amount of electricity to control a gate on a much larger supply of electricity, much like turning a valve to control a supply of water.

Transistors are composed of three parts:

1. The base is the gate controller device for the larger electrical supply.
2. The collector is the larger electrical supply.
3. The emitter is the outlet for that supply.

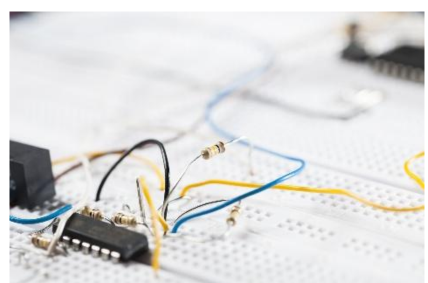
By sending varying levels of current from the base, the amount of current flowing through the gate from the collector may be regulated. In this way, a very small amount of current may be used to control a large amount of current, as in an amplifier.

The same process is used to create the binary code for the digital processors but in this case a voltage threshold of five volts is needed to open the collector gate. In this way, the transistor is being used as a switch with a binary function: five volts ' ON, less than five volts ' OFF.



In this camp we only use a common NPN bipolar junction transistor (2N2222) for the extra assignments. This transistor is used for general purpose low-power amplifying or switching applications.

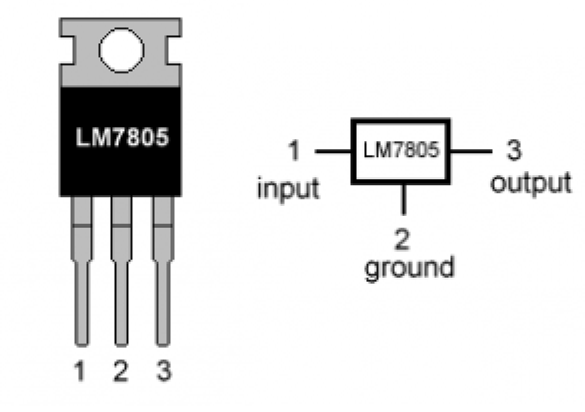
Integrated Circuit (IC)[i]



An integrated circuit (IC) — commonly called a chip — is a small small electronic components made up of transistors and wired together with interconnects.

There are both analog and digital ICs. For the purpose of this material, we will only be discussing digital ICs. A digital IC is an electronic device that collects several digital electronic components on a small semiconductor chip. Usually, each integrated circuit (IC) is designed to perform a particular function. The defined functionality could be to apply the logic AND on three (3) inputs, or to act as a decoder turning one of several outputs “on” based on the logic of the inputs.

Fixed Voltage Regulator

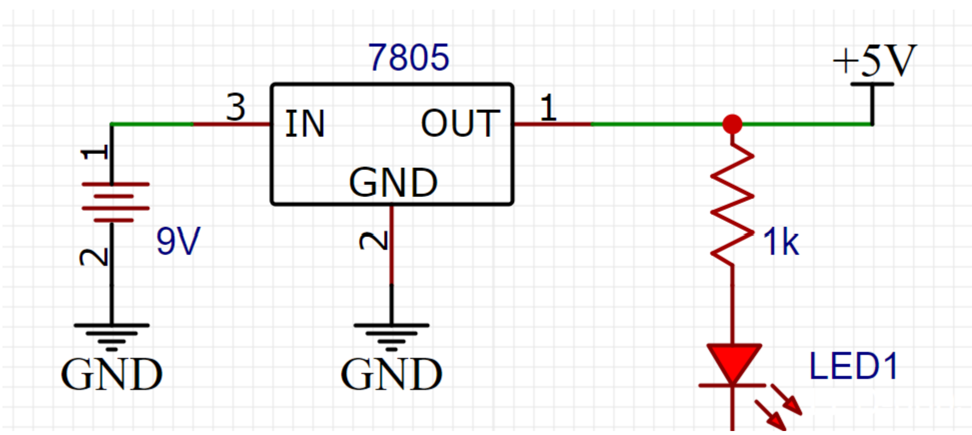


Voltage sources in a circuit may have fluctuations resulting in not providing fixed voltage outputs. A voltage regulator IC maintains the output voltage at a constant value. 7805 Voltage Regulator, which we will be using in class, is a member of the 78xx series of fixed linear voltage regulators used to maintain such fluctuations, is a popular voltage regulator integrated circuit (IC).

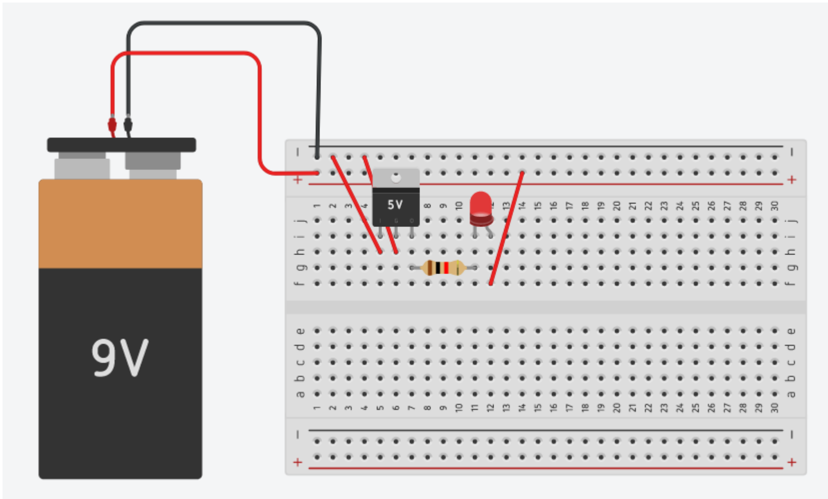
The xx in 78xx indicates the output voltage it provides. 7805 IC provides +5 volts regulated power supply with provisions to add a heat sink.

Schematics

Below is a diagram explaining how to connect 9V to a circuit and light an LED. The diagram is called a schematic diagram which shows the components and interconnections of the circuit using standardized symbolic representations. In the schematic below is a 5V voltage regulator whose output is connected to a 100 ohm resistor which is connected to an LED which is then connected to ground. This will be one of the first circuits you build.



Below is the breadboard for the above schematic.



Tools

Digital Logic Probe

Using A Digital Logic Probe

TESTING YOUR DIGITAL PROBE

Checking out your Logic Probe for proper operation is fairly easy. All that is needed is a 9V battery or other DC power source (5-10V). Connect the red alligator clip to the positive terminal of the battery and the black clip to the negative terminal. Set the PULSE-MEM switch to the PULSE position and the TTL-CMOS switch to the TTL position. Touch the probe tip to the positive side of the battery, the PULSE LED should blink once and the HIGH LED should light up. Place the probe tip to the negative terminal and the LOW LED should light up. To check the operation of the memory switch, set the PULSE-MEM switch to the MEM position and set the TTL-CMOS switch to the TTL position. Now touch the probe tip to the positive side of the battery. The PULSE LED should come on and stay on until the switch is flipped back to the pulse position. No LED's should light up when the tip is not touching anything (open circuit). The logic probe should operate at the following logic levels when the power supply voltage is precisely set to 5VDC.

DTL/TTL Position Logic 0 - under 0.8V + 0.1V

DTL/TTL Position	Logic 0 - under 0.8V + 0.1V
	Logic 1 - above 2.3V + 0.25V
CMOS Position	Logic 0 - under 1.5V + 0.2V
	Logic 1 - above 3.5V + 0.35V

Multi-mode Meter

DC Power Supply

A DC power supply converts AC power from a standard outlet into a stable DC power source. This regulated direct current is then used to power a device, module or component. DC power supplies come in varying levels of input and output voltage, output current and power rating. You can generally choose between a Constant Voltage (CV) model or a Constant Current (CC) model. In CV models, you set the output voltage you need from the power supply, and it remains constant at that level even if changes occur in the load. In CC models, you set them to maintain a constant output current. Some DC power supplies offer both these options as alternative CV or CC modes of operation. The model in class we are using has both.

Electrostatic Mat

When you are assembling or repairing electronic products, an anti-static work mat is an indispensable tool.

Why you need an anti-static mat?

In our daily life, static electricity can be generated everywhere. I think everyone has experience of getting zapped by static electricity. This is called static discharge. The voltage generated during electrostatic discharge can sometimes be as high as hundreds, thousands or tens of thousands of volts. Such a high electrostatic voltage has a high probability of destroying or damaging IC chips and most electronic components.

Using electro-static mat

Electro-static mats needed to be grounded. Typically they have either:

- ESD Wristband: Adjustable and High-quality ESD Wristband.
- Grounding Cord: High quality and durable ground cord plays a good role of grounding connection for anti-static mat.

Put the anti-static mat on the workbench and one end of crocodile clip of grounding cord clamps any part of the anti-static mat. In this way, the mat is connected to the ground.

When you need to repair or assemble an electronic circuit, you should also wear the ESD wristband.

Lesson 2 Number Systems and Boolean Algebra

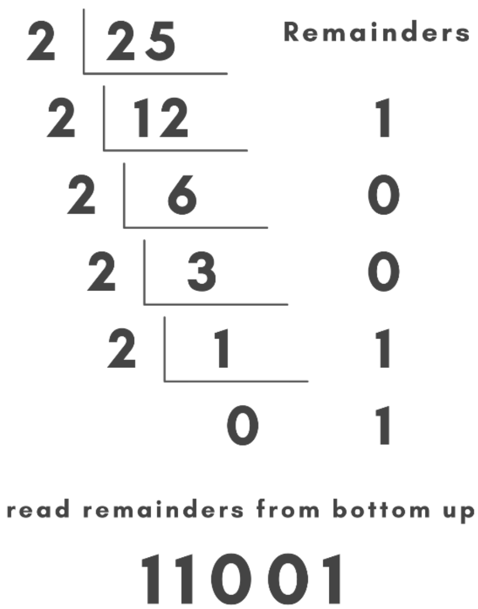
Decimal vs Binary Number System

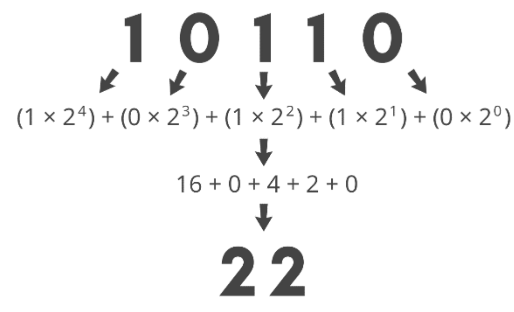
Decimal is base10 (0..9). Binary number system is base 2 (0 or 1).

Converting

To convert decimal to binary we divide by 2.

To convert binary to decimal we multiply each binary position value by two to the power of its place minus 1 (Value*$2^{place-1}$).





Below is a table showing decimal to binary. This is often referred to as Binary Coded Decimal or BCD.

0	0000
1	0001
2	0010
3	0011
4	0100
5	0101
6	0110
7	0111

8	1000
9	1001
10	1010
11	1011
12	1100
13	1110
14	1110
15	1111

Addition and Subtraction

Binary addition is very much like decimal addition except 1+1=0 with a carry of 1. If there is a carry of 1 and you are adding 1+1 then you have 1 with a carry of 1. Below is an example of addition.

```
11111  (Carry)
 11011 (27)
+10101 (21)
 -----
110000 (48)
```

Subtraction follows generally the same rules as decimal also. So if you have 0-1 you need to borrow which brings 2 and changes the 1 you borrowed from 0.

```
  02 02
 1101101 (109)
-0011011 (27)
 -------
 1010010 (82)
```

We will get to try this out with half adders and full adders in a later section.

Multiplication

```
       1011   (11)
     × 1110   (14)
     ======
       0000   (this is 1011 × 0)
      1011    (this is 1011 × 1, shifted one position to the left)
     1011     (this is 1011 × 1, shifted two positions to the left)
  + 1011      (this is 1011 × 1, shifted three positions to the left)
  =========
   10011010   (154)
```

Lesson 3 Logic Gates

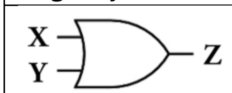
Boolean Operators

AND Gate

Logic Symbol	Boolean Operator
	Z = X * Y or Z = XY

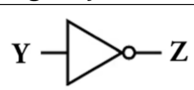
Truth Table	
Inputs	Outputs
X Y	Z
0 0	0
0 1	0
1 0	0
11	1

OR Gate

Logic Symbol	Boolean Operator
	Z = X + Y

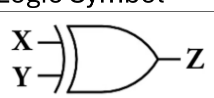
Truth Table	
Inputs	Outputs
X Y	Z
0 0	0
0 1	1
1 0	1
11	1

NOT Gate

Logic Symbol	Boolean Operator
	Z = $\bar{Y}$

Truth Table	
Inputs	Outputs
Y	Z
0	1
1	0

XOR Gate

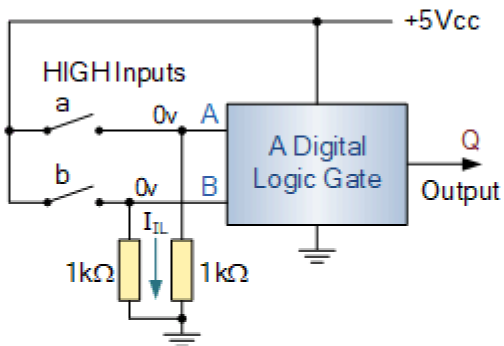
Logic Symbol	Boolean Operator
	Z = $X \oplus Y = (\bar{X} * Y) + (X * \bar{Y})$

Truth Table	
Inputs	Outputs
X Y	Z
0 0	0
0 1	1
1 0	1
1 1	0

Pull-up Resistor and Pull-down Resistor[ii]

What happens when nothing is wired to a pin input. What value would you assume it would read? Most beginners assume it would read as a 0 because there is nothing wired to it, no voltage, so it must be a 0. Well if you read that pin you would find that you would get inconsistent values, sometime 0 sometimes 1. The pin in that state of nothing wired to it is said to be a 'floating' input pin and circuit noise will cause it to give inconsistent readings.

So, one needs to add either an external pull-up resistor or a pull-down resistor. This will ensure that when reading the pin the software will return a consistent value. So an input pin with a pull-up will have a switch wired to the pin and ground, so when you press the switch the chip logic will see a 0 state, and if you are using a pull down resistor then the switch wired to +5vdc and will read as a 1 when pressed.



This pull-down resistor configuration is particularly useful for digital circuits like latches, counters and flip-flops that require a positive one-shot trigger when a switch is momentarily closed to cause a state change.

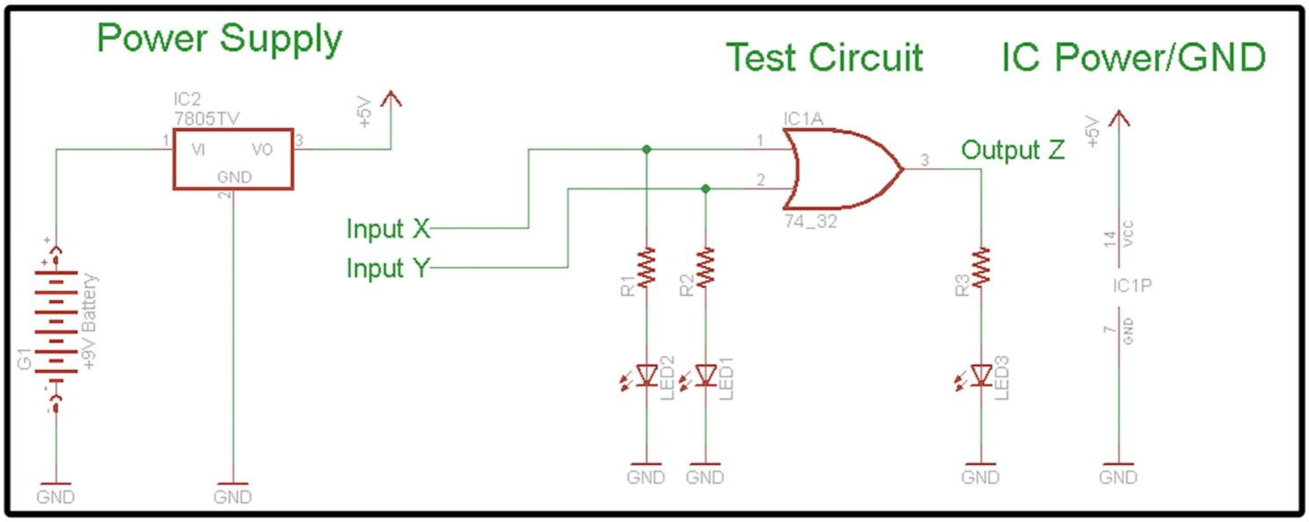
OR Gate Experiment

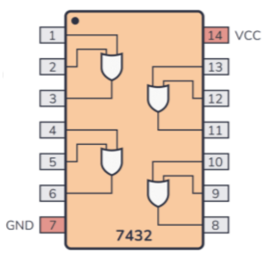
74HC04 NOT Logic IC
A 6 NOT gate logic IC that acts as an inverter.

74HC08 AND Logic IC
A quad dual input AND gate logic IC.

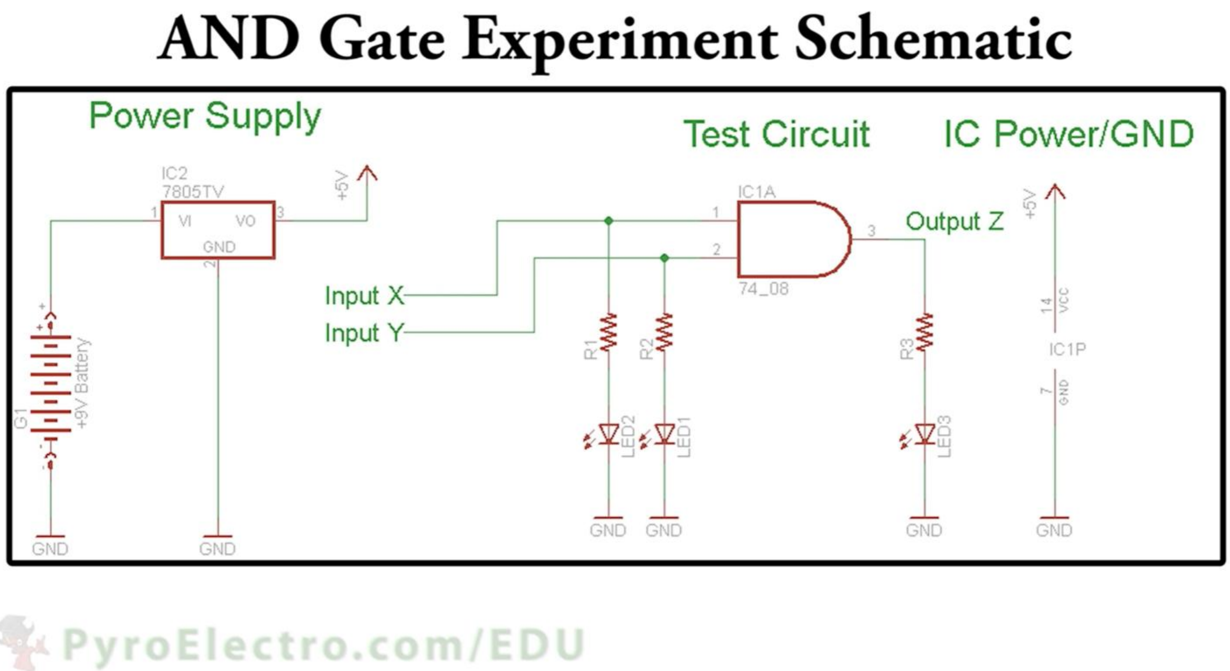
74HC32 NOR Logic IC
A quad dual input OR gate logic IC.

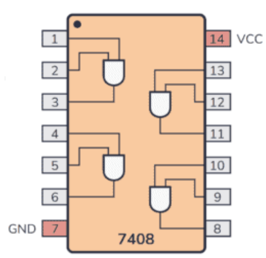
OR Gate Experiment Schematic



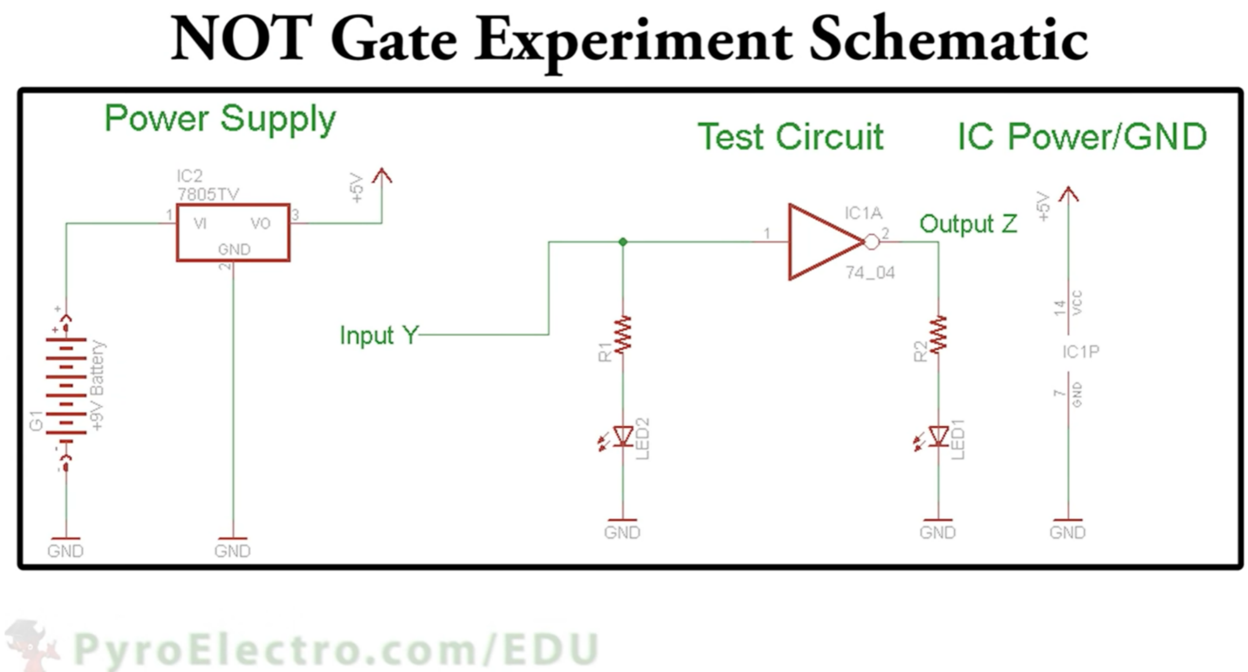


AND Gate Experiment





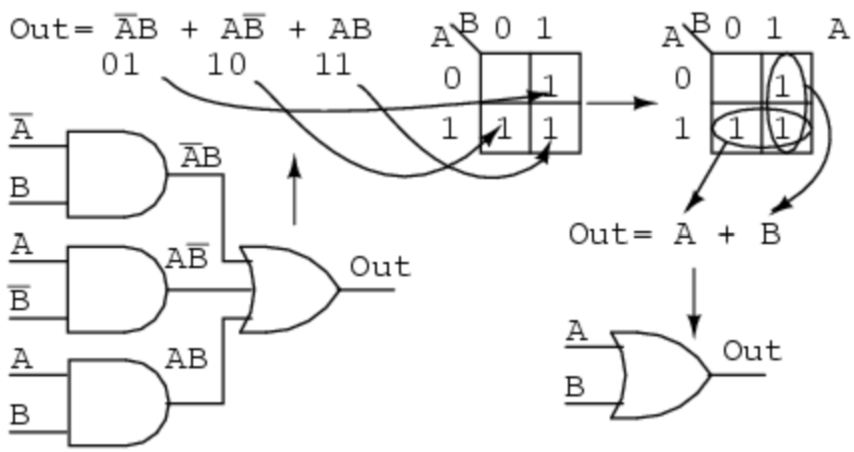
NOT Gate Experiment



Lesson 4 Karnaugh Maps

De Morgan's theorem states that complementing the result of OR'ing variables together is equivalent to AND'ing the complements of the individual variables. Also complementing the result of AND'ing variables together is equivalent to OR'ing the complements of the individual variables.

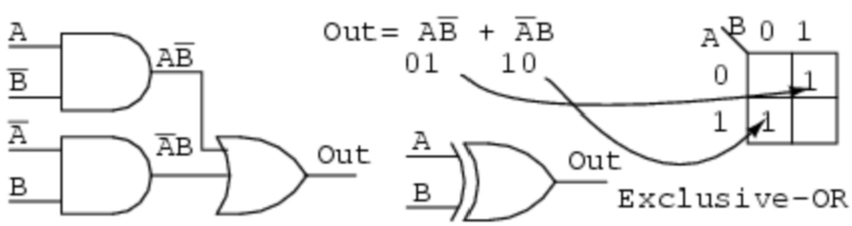
A’B + AB’+ AB



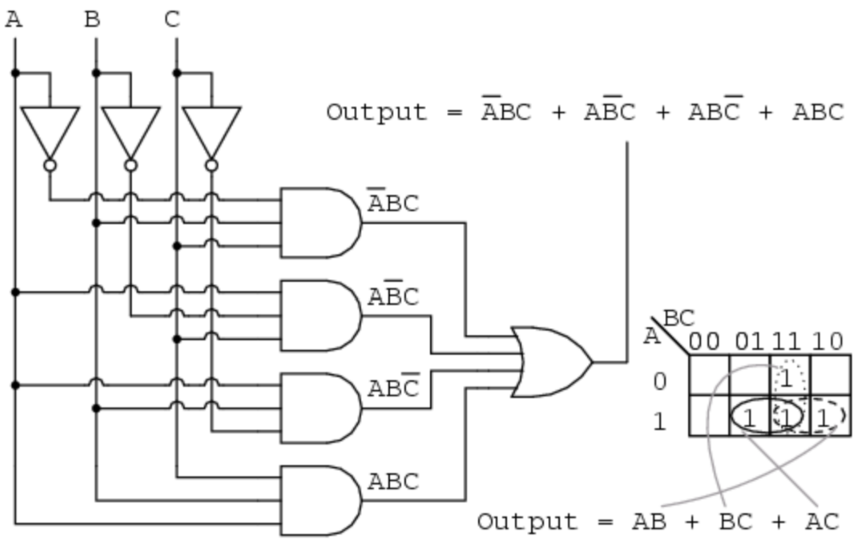
A	B	Out
0	0	0
1	0	1
0	1	1
1	1	1

AB’ + A’B

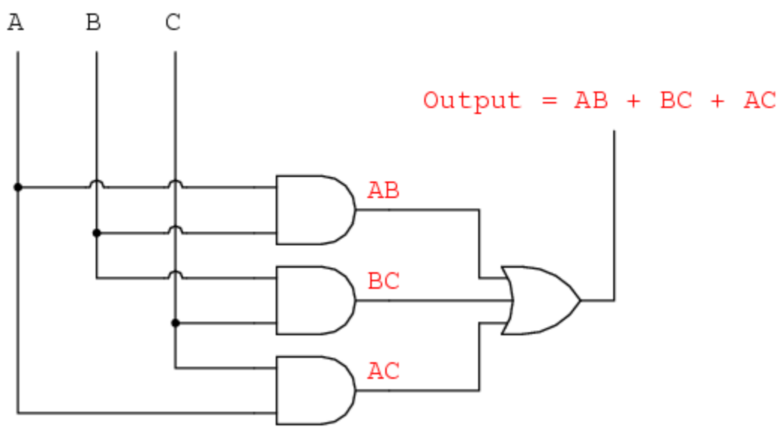
A	B	Out
0	0	0
1	0	1
0	1	1
1	1	0



A’BC + AB’C + ABC’ + ABC



A	B	C	Out
0	0	0	0
0	0	1	0
0	1	0	0
0	1	1	1
1	0	0	0
1	0	1	1
1	1	0	1
1	1	1	1



Lesson 5 Combinational Logic

Combinational Logic Circuits are memoryless digital logic circuits whose output at any instant in time depends only on the combination of its inputs. In other words, the circuit produces the same output regardless of the order of inputs.

Half Adder

A Half Adder adds two 1-bit binary digits and generates a carry and sum of both the inputs. A Half Adder does not add the carry obtained from the previous addition to the next one.

You can design it by connecting one AND gate and one EX-OR gate. A half-adder circuit consists of two input terminals- namely A and B. Both of these add two input digits (one-bit numbers) and generate the output in the form of a carry and a sum. Thus, there are two output terminals.

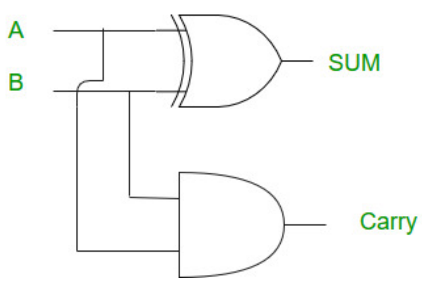
The output that one obtains from the EX-OR gate is the sum of both one-bit numbers. The output obtained from the AND gate is called the carry. But you cannot forward the carry that you obtain in one addition into another addition. It is because of the absence of any logic gate to process it. Thus, it's called the Half Adder circuit.

A	B	Sum (∑)	Carry (C_{out})
0	0	0	0
0	1	1	0
1	0	1	0
1	1	0	1

Sum = A'B +AB' = A XOR B

Carry = AB = A AND B

The the logic diagram for the equation is below.



Full Adder

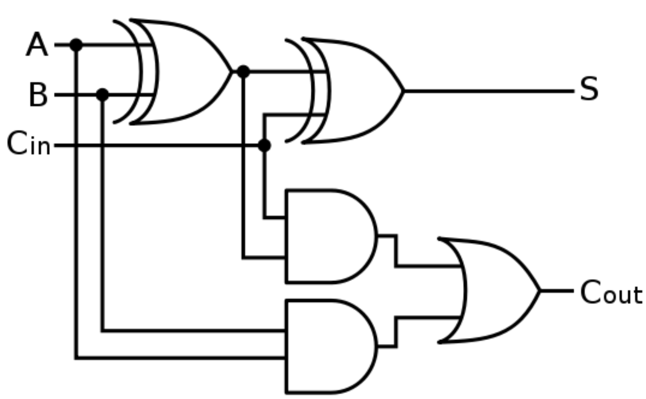
The full adder adds three binary digits. Among the three, one is the carry that we obtain from the previous addition as C_{IN}, and the other two are inputs A and B. It designates the input carry as the C_{OUT} and the normal output as S (or SUM).

A full adder is a circuit that has two AND gates, two EX-OR gates, and one OR gate. Because it adds the previous carry (C_{IN}) to generate the complete output it is called the Full Adder.

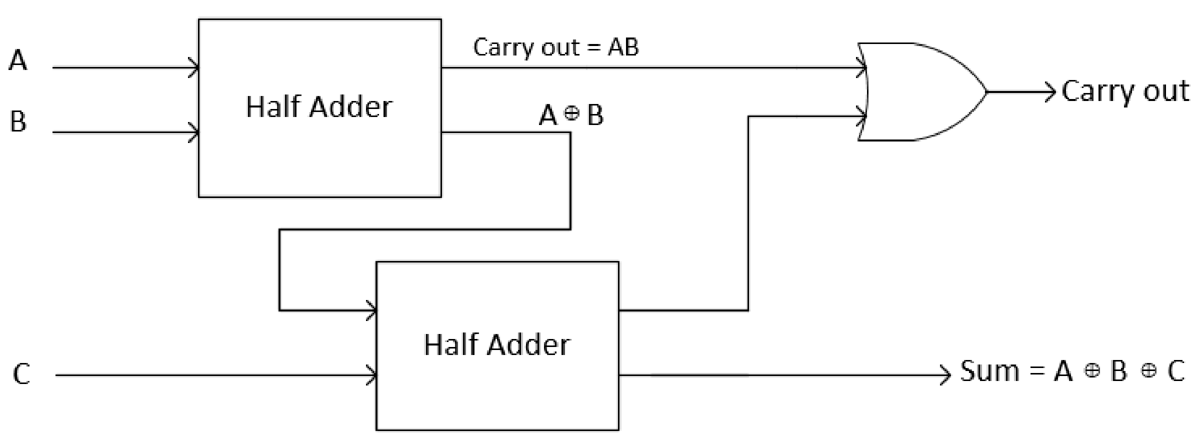
Carry In (C_{in})	A	B	Sum (∑)	Carry Out (C_{out})
0	0	0	0	0
0	0	1	1	0
0	1	0	1	0
0	1	1	0	1
1	0	0	1	0
1	0	1	0	1
1	1	0	0	1
1	1	1	1	1

SUM = (A XOR B) XOR C

C_{out} = ((A XOR B) AND C_{IN}) AND (A AND B)

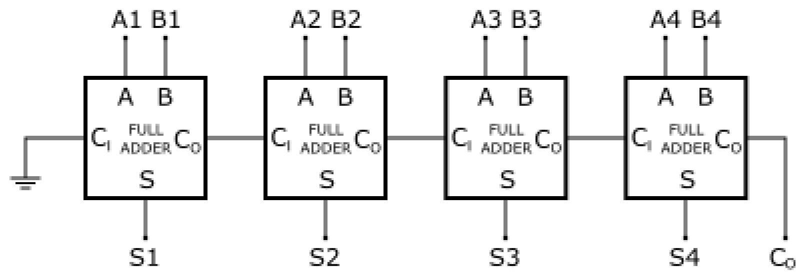


One can also illustrate a Full Adder using one OR gate and two Half Adders. The OR gate here generates a carry that it obtains after the addition. We obtain the sum of these digits in the form of output from the second Half Adder.

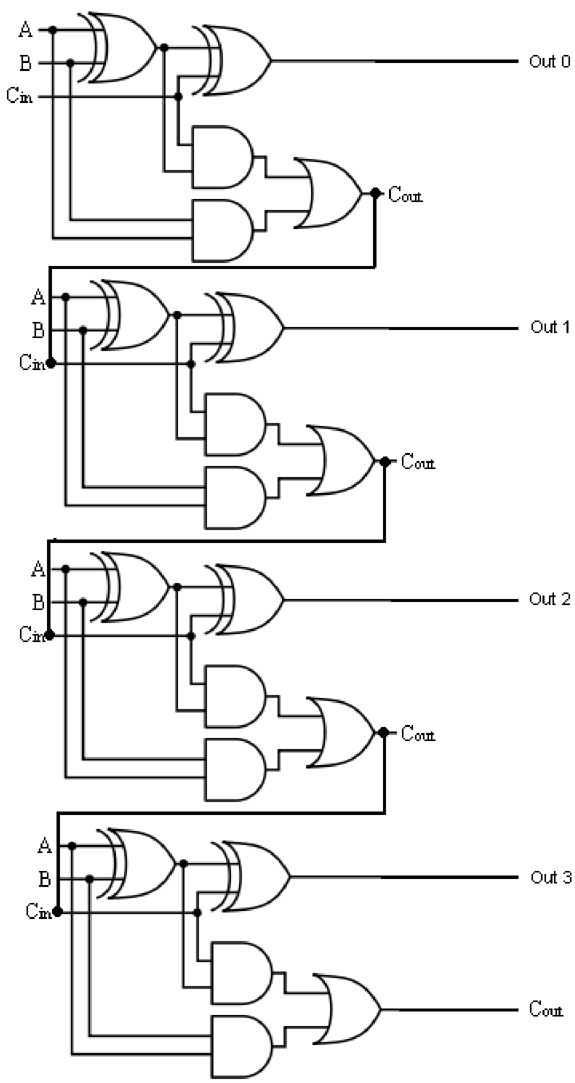


Four Bit Adder

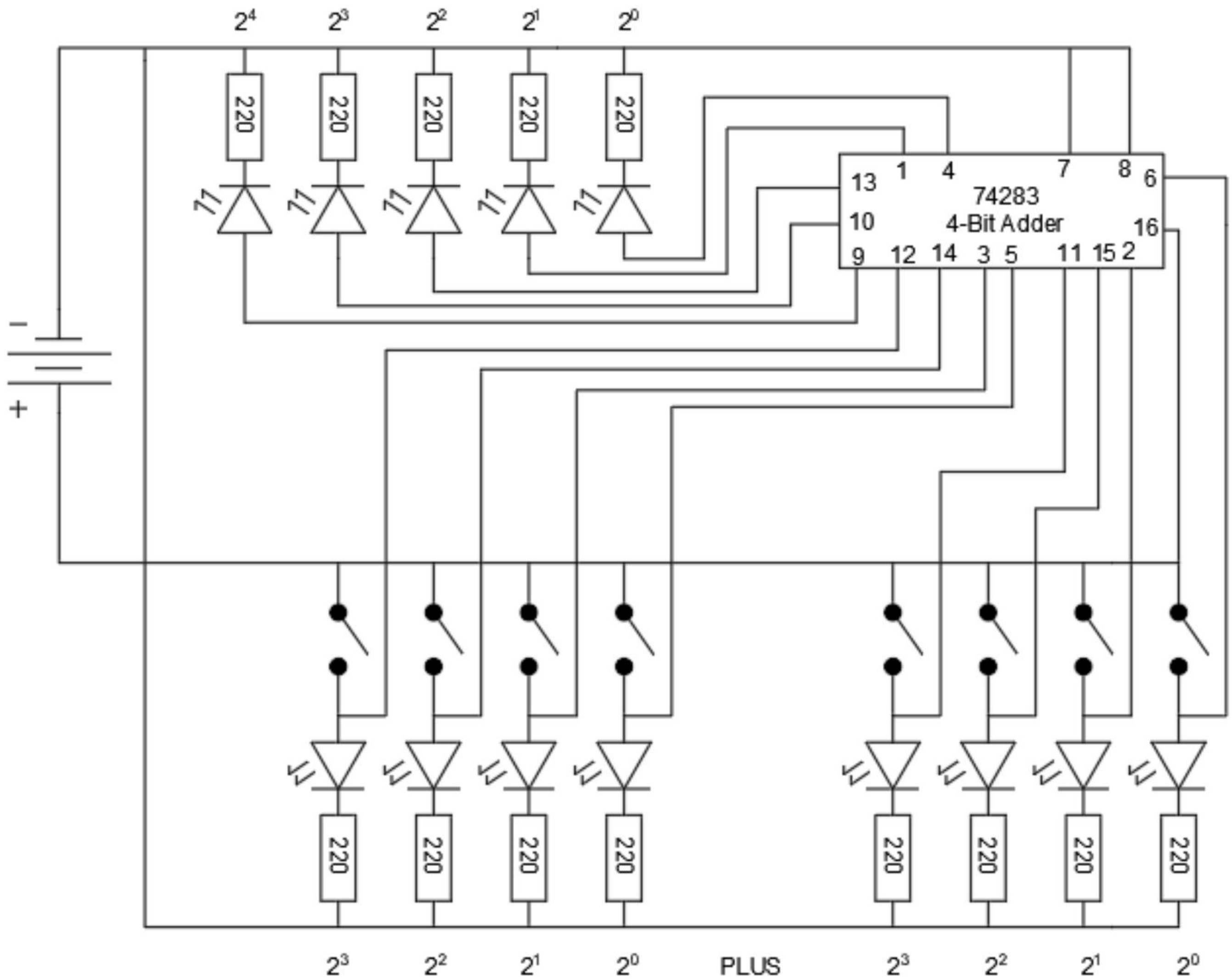
You can diagram a four bit adder using four full adders as show below.



To make it easier to build, below is a four-bit adder with all of the logic gates.

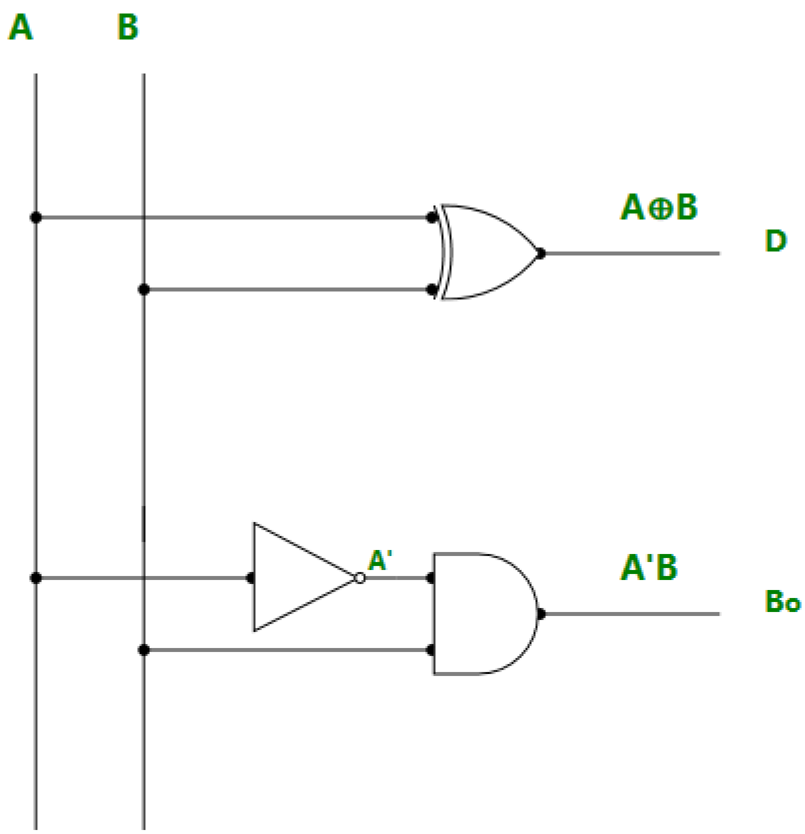


Using a 74283 4-bit Adder



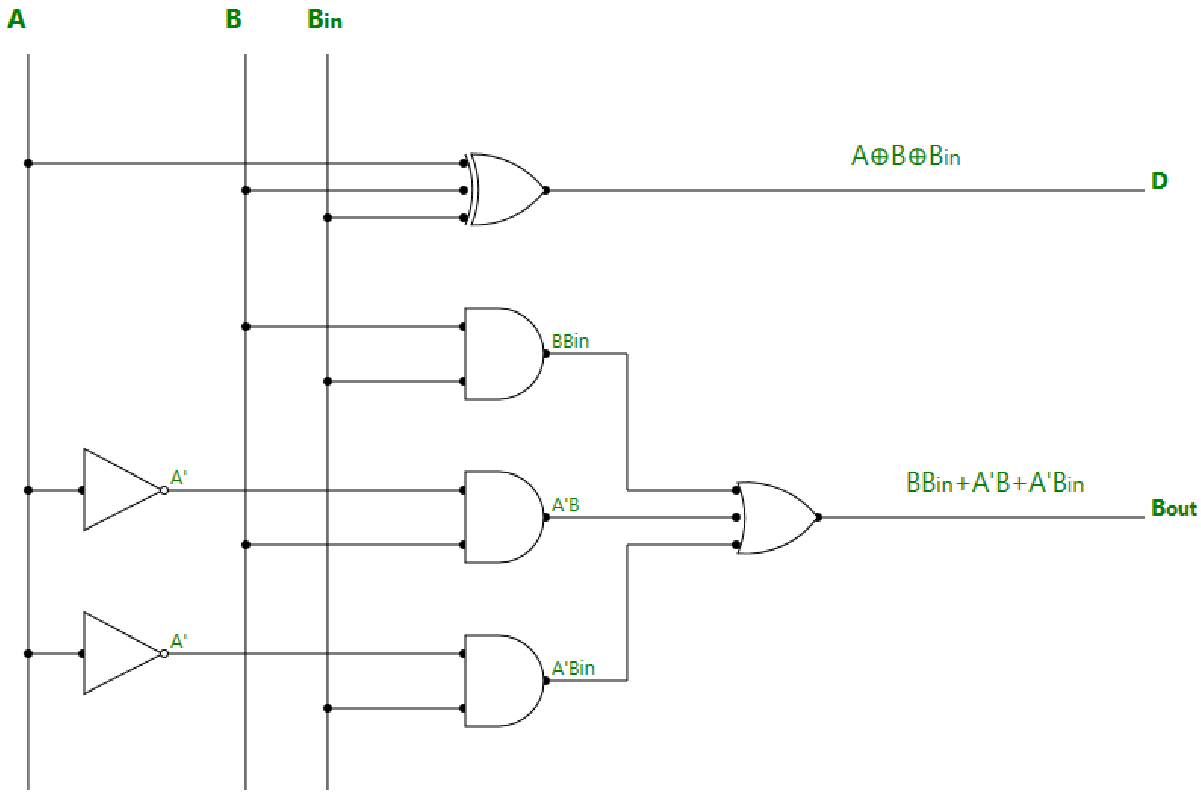
Half Subtractor

A	B	Difference	Borrow Out (B_{out})
0	0	0	0
0	1	1	1
1	0	1	0
1	1	0	0



Full Subtractor

A	B	Borrow In (B_{in})	Difference	Borrow Out (B_{out})
0	0	0	0	0
0	0	1	1	1
0	1	0	1	1
0	1	1	0	1
1	0	0	1	0
1	0	1	0	0
1	1	0	0	0
1	1	1	1	1

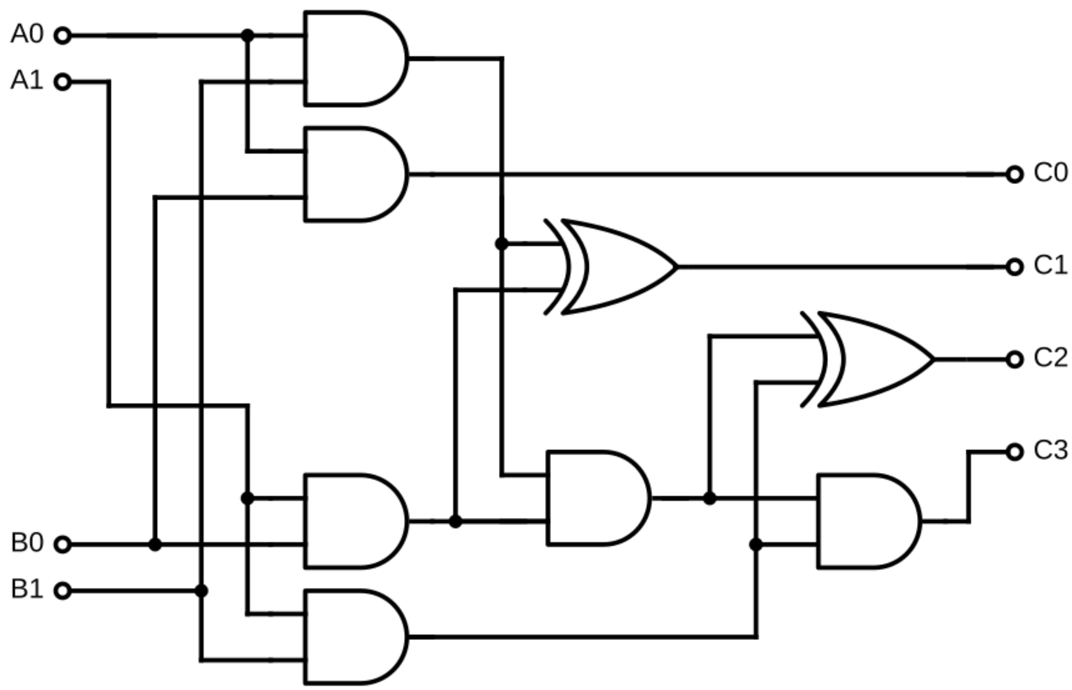


Two Bit Multiplier

Below is the truth table for a two-bit multiplier.

A0	A1	B0	B1	C3	C2	C1	C0
0	0	0	0	0	0	0	0
0	0	0	1	0	0	0	0
0	0	1	0	0	0	0	0
0	0	1	1	0	0	0	0
0	1	0	0	0	0	0	0
0	1	0	1	0	0	0	1
0	1	1	0	0	0	0	0
0	1	1	1	0	0	1	1
1	0	0	0	0	0	0	0
1	0	0	1	0	0	1	0
1	0	1	0	0	1	0	1
1	0	1	1	0	0	1	1
1	1	0	0	0	0	0	0
1	1	0	1	0	0	1	1
1	1	1	0	0	1	1	0
1	1	1	1	1	0	0	1

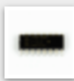
Below is a logic diagram for the a two-bit multiplier.



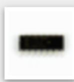
Lesson 5 The SR Latch

The next step into the digital world is to create stable logic elements. The first such element is called a latch and it can be built using simple logic gates. In this lesson we will explore how to build a latch using NOR logic gates and NAND logic gates. In addition, we will take a look at what timing diagrams are and how to use them. S-R (Set-Reset) Latches: S-R latches are the simplest form of latches and are implemented using two inputs: S (Set) and R (Reset). The S input sets the output to 1, while the R input resets the output to 0. When both S and R are at 1, the latch is said to be in an “undefined” state.

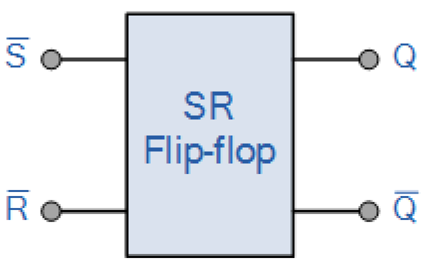
The circuit uses feedback to "remember" and retain its logical state even after the controlling input signals have changed. When the S and R inputs are both high, feedback maintains the Q outputs to the previous state.



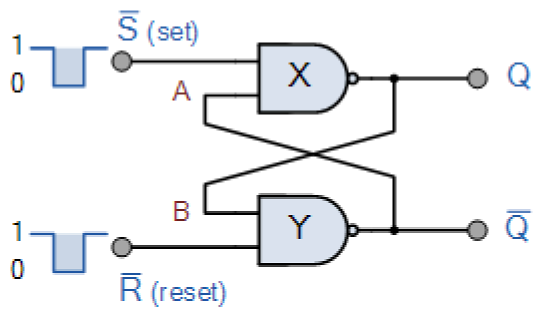
74HC00 NAND Logic IC
A quad dual input NAND logic gate IC.



74HC02 NOR Logic IC
A quad dual input NOR logic gate IC.



Symbol



Circuit

The Set State[iii]

Consider the circuit shown above. If the input R is at logic level “0” (R = 0) and input S is at logic level “1” (S = 1), the NAND gate Y has at least one of its inputs at logic “0” therefore, its output Q must be at a logic level “1” (NAND Gate principles). Output Q is also fed back to input “A” and so both inputs to NAND gate X are at logic level “1”, and therefore its output Q must be at logic level “0”.

Again NAND gate principals. If the reset input R changes state, and goes HIGH to logic “1” with S remaining HIGH also at logic level “1”, NAND gate Y inputs are now R = “1” and B = “0”. Since one of its inputs is still at logic level “0” the output at Q still remains HIGH at logic level “1” and there is no change of state. Therefore, the flip-flop circuit is said to be “Latched” or “Set” with Q = “1” and Q = “0”.

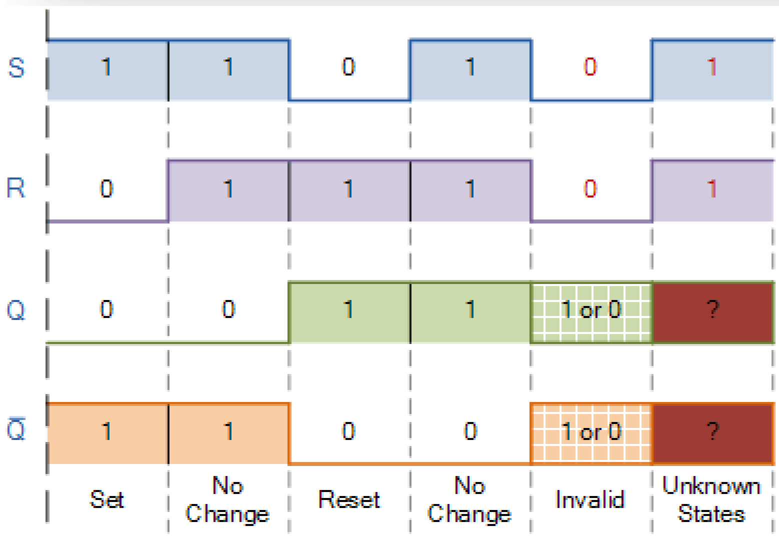
Reset State

In this second stable state, Q is at logic level “0”, (not Q = “0”) its inverse output at Q is at logic level “1”, (Q = “1”), and is given by R = “1” and S = “0”.

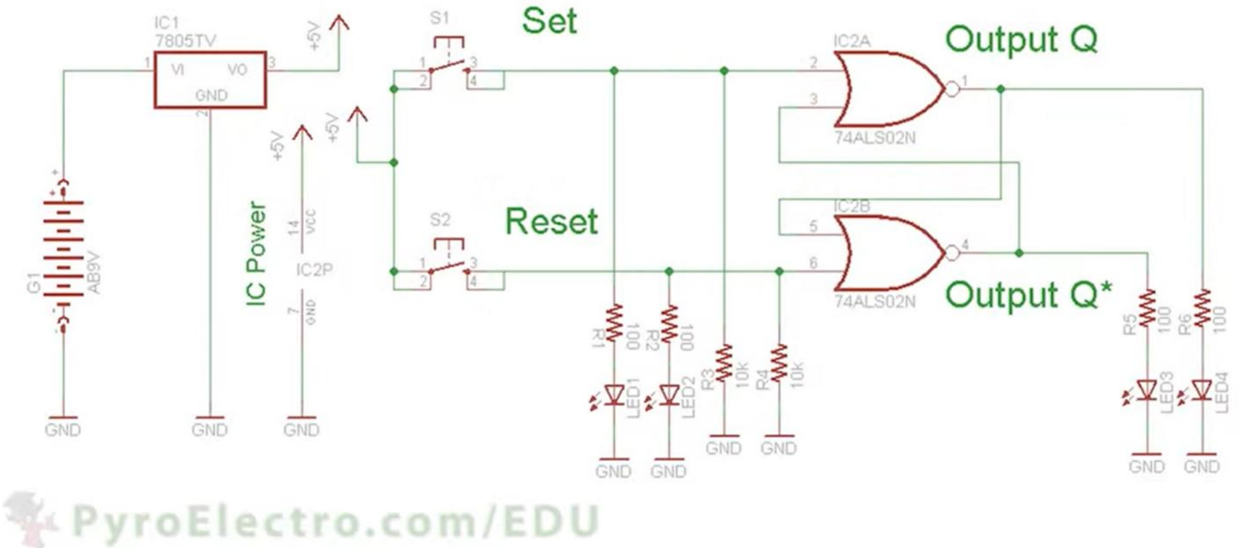
As gate X has one of its inputs at logic “0” its output Q must equal logic level “1” (again NAND gate principles). Output Q is fed back to input “B”, so both inputs to NAND gate Y are at logic “1”, therefore, Q = “0”.

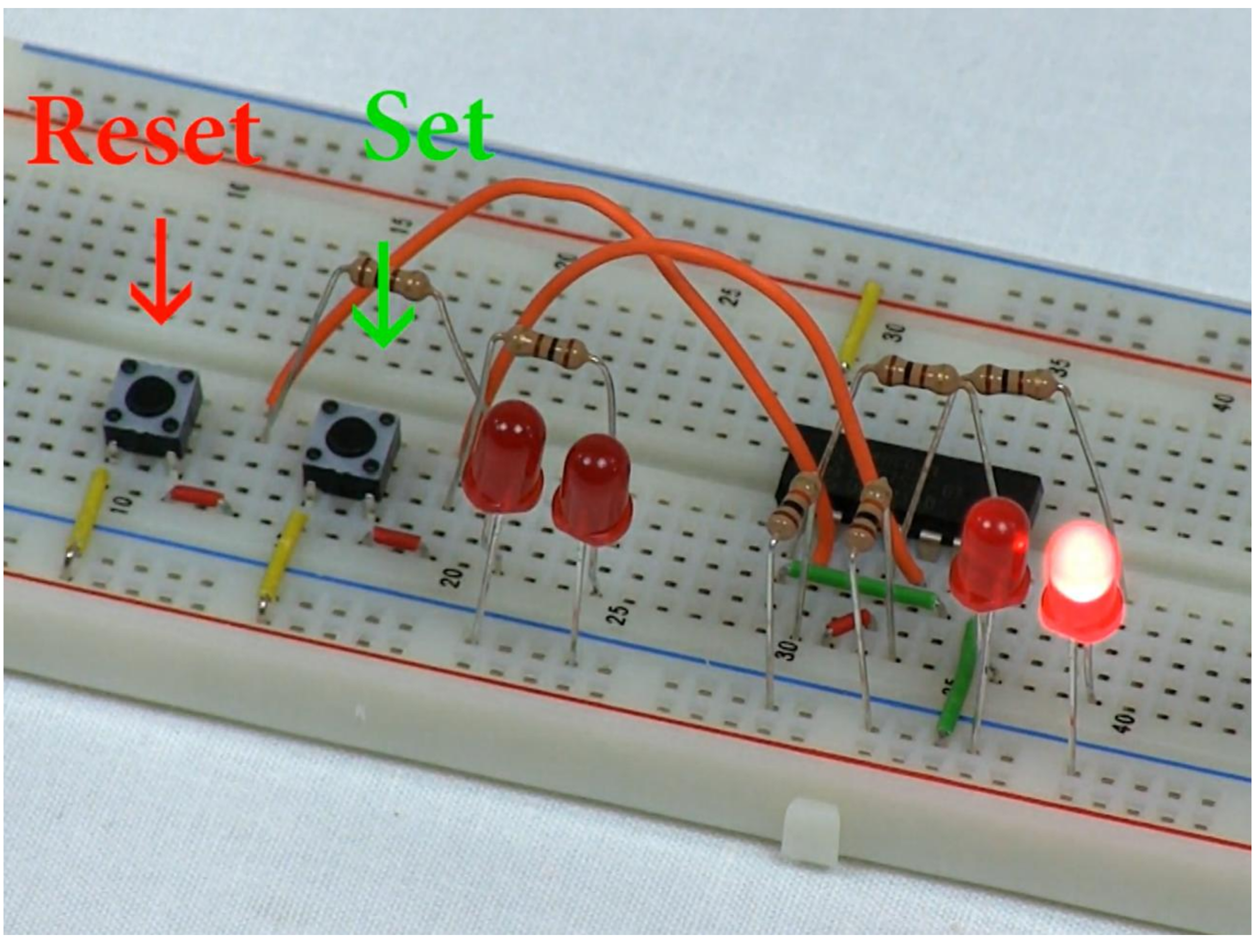
If the set input, S now changes state to logic “1” with input R remaining at logic “1”, output Q still remains LOW at logic level “0” and there is no change of state. Therefore, the flip-flop circuits “Reset” state has also been latched and we can define this “set/reset” action in the following truth table.

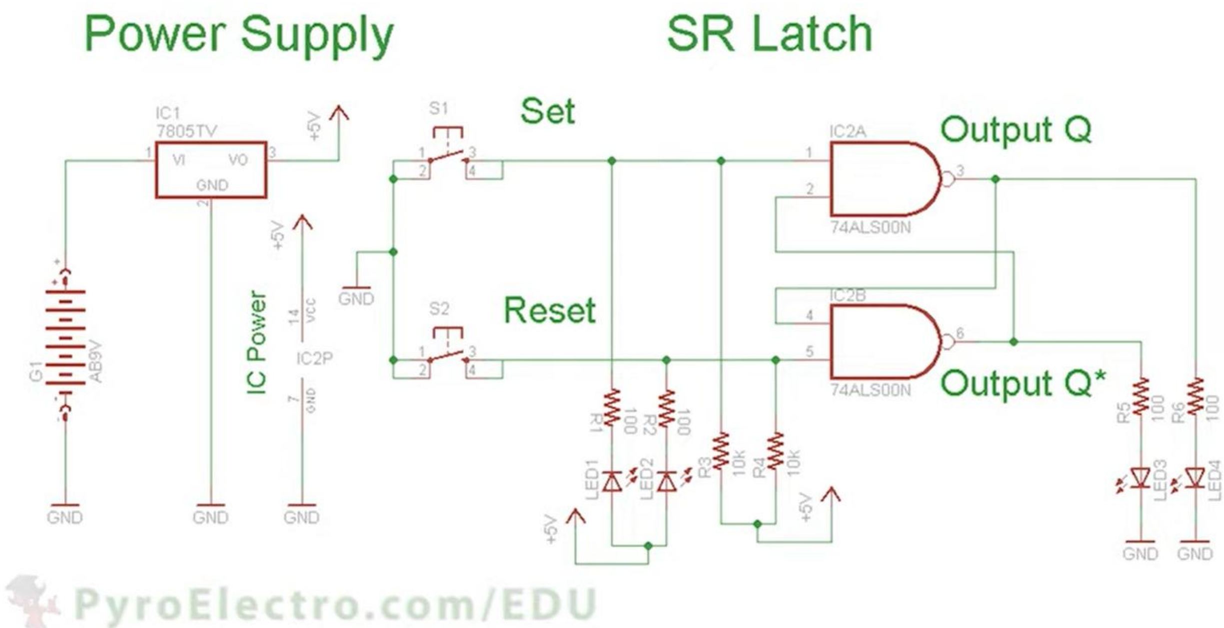
State	S	R	Q	$\overline{Q}$	Description
Set	1	0	0	1	Set $\overline{Q}$ » 1
	1	1	0	1	no change
Reset	0	1	1	0	Reset $\overline{Q}$ » 0
	1	1	1	0	no change
Invalid	0	0	1	1	Invalid Condition



SR Latch Experiment







Power Supply
SR Latch
IC1
7805TV
VI
VO
GND
+5V
G1
AB9V
IC Power
IC2P
GND
S1
Set
S2
Reset
IC2A
Output Q
74ALS00N
IC2B
Output Q*
R1
R2
R3
R4
R5
R6
100
10k
LED1
LED2
LED3
LED4
PyroElectro.com/EDU

Lesson 6 Flip-flops

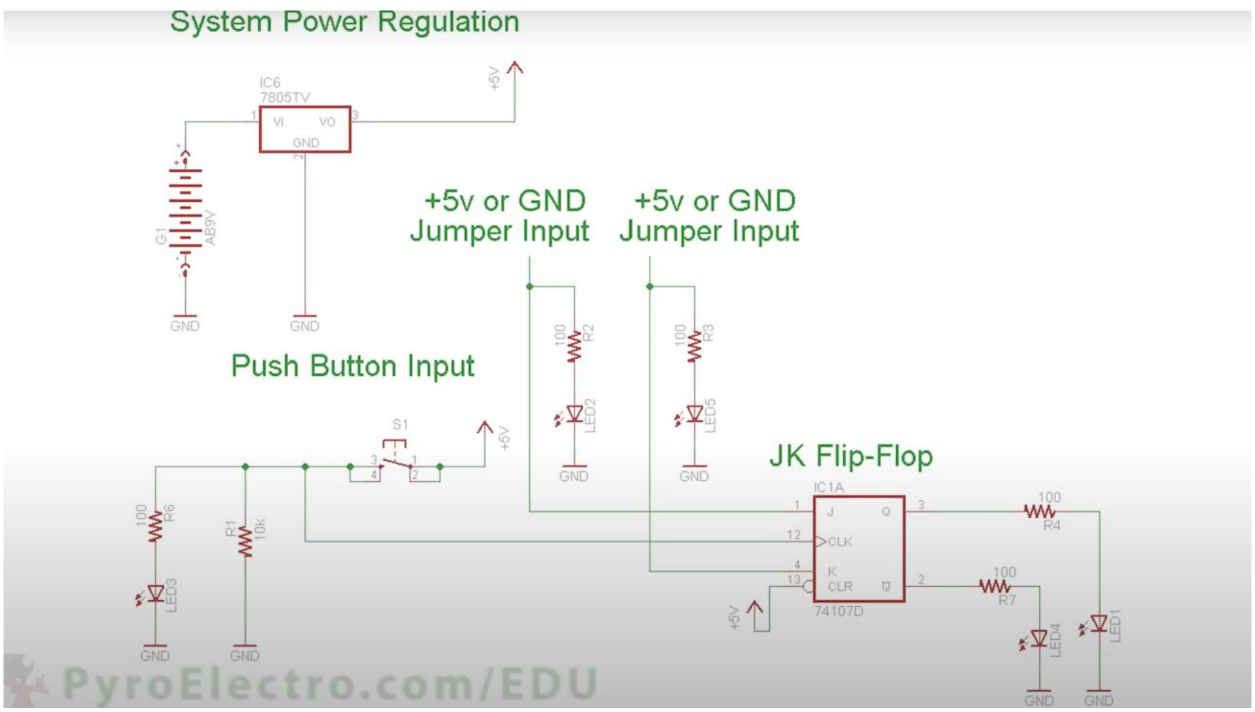
A flip-flop is a circuit with two stable states that can be used to store binary data. The stored data is typically changed by an edge trigger on a clock input along with one or more inputs.

JK Flip-Flop

The J input has effect only when the circuit is reset, and the K input has effect only when the circuit is set. In other words, the two inputs are interlocked, so that they cannot both be activated simultaneously.

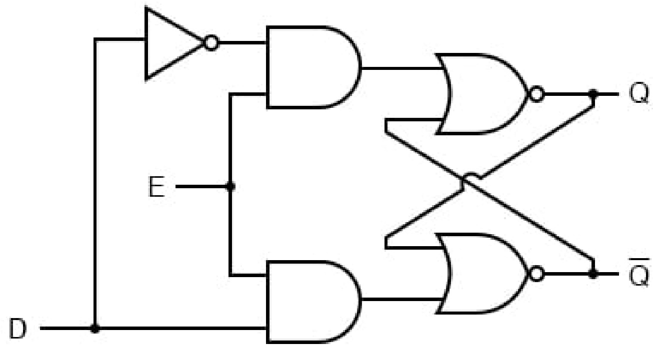
If the circuit is "set," the J input is inhibited by the 0 status of not-Q through the lower AND gate; if the circuit is "reset," the K input is inhibited by the 0 status of Q through the upper AND gate. Below is the logic diagram and truth table.

JK Flip-Flop Experiment



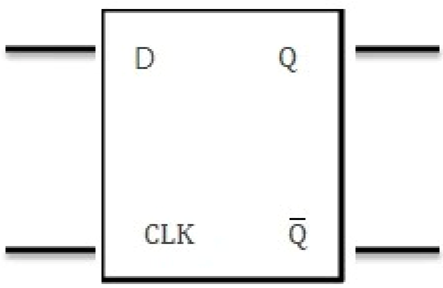
D Flip-flop

A D (or Delay) Flip Flop is a digital electronic circuit used to delay the change of state of its output signal (Q) until the next rising edge of a clock timing input signal occurs.



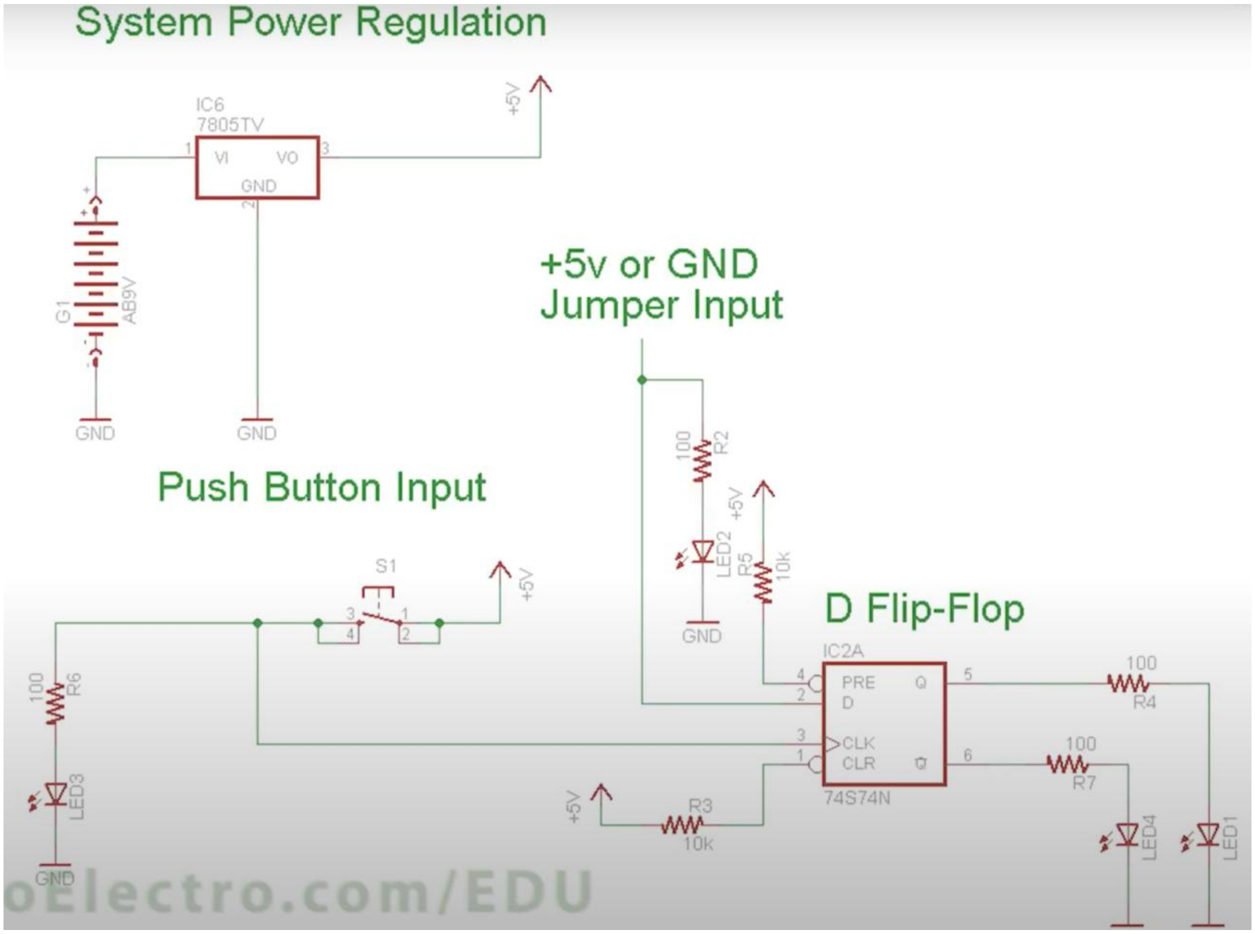
E	D	Q	$\overline{Q}$
0	0	latch	latch
0	1	latch	latch
1	0	0	1
1	1	1	0

The symbol used to indicate a D Flip-flop in a circuit is below.



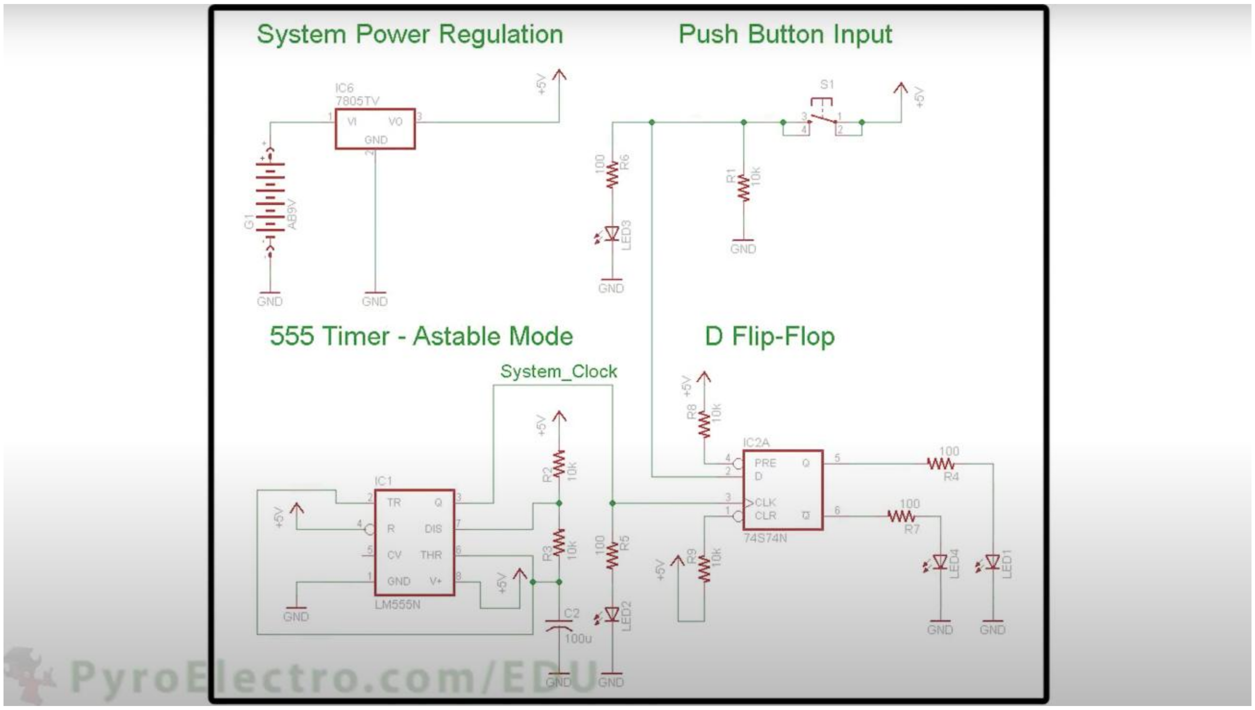
Flip_Flop Experiment

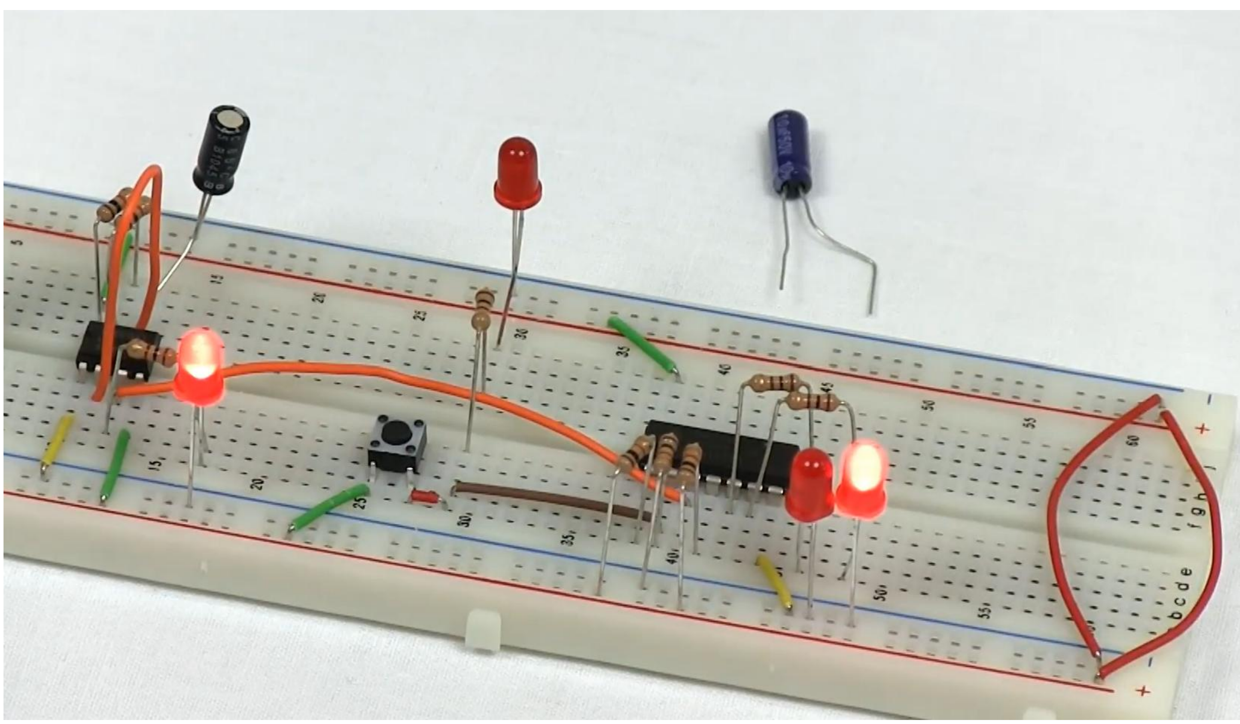
In the circuit below, a switch is used to act as a clock. Clear (CLR) and preset (PRE) are set to high (inactive).


System Power Regulation
IC6
7805TV
VI
VO
GND
+5V
G1
AB9V
GND
GND
+5v or GND
Jumper Input
R2
100
LED2
+5V
R5
10k
GND
Push Button Input
S1
+5V
R6
100
LED3
GND
D Flip-Flop
IC2A
PRE
D
CLK
CLR
Q
74S74N
R4
100
R7
100
R3
10k
+5V
LED4
LED1
oElectro.com/EDU

Lesson 7 Clocks and Oscillators

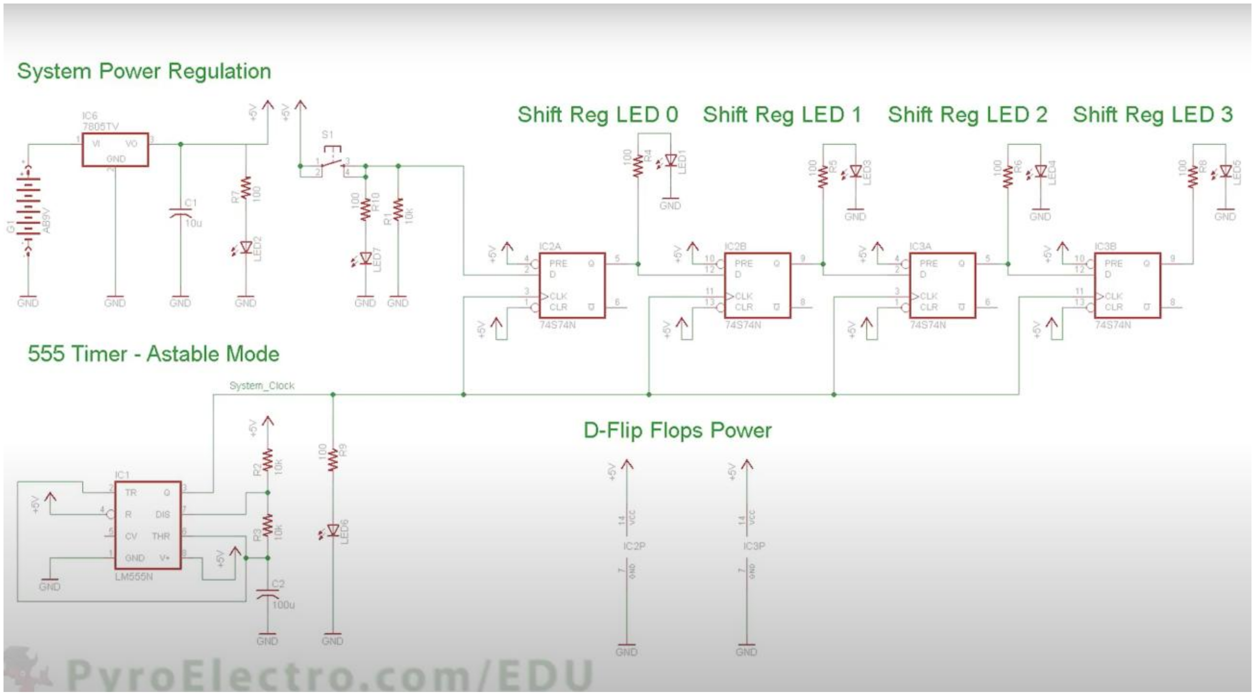
Clock Experiment

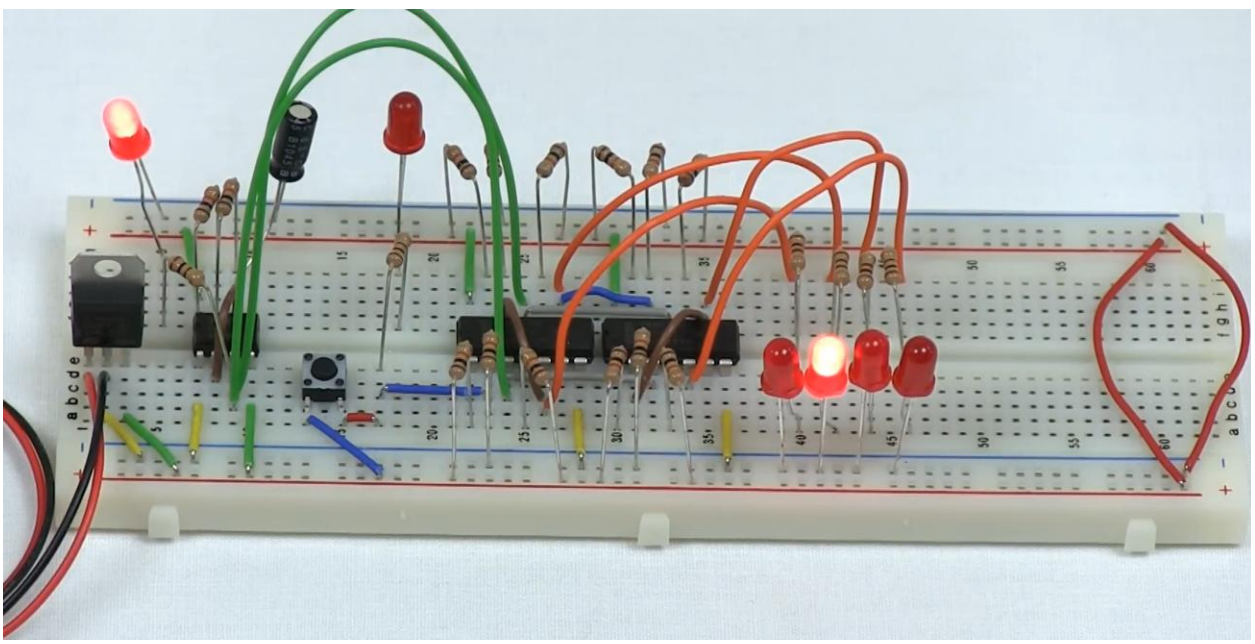




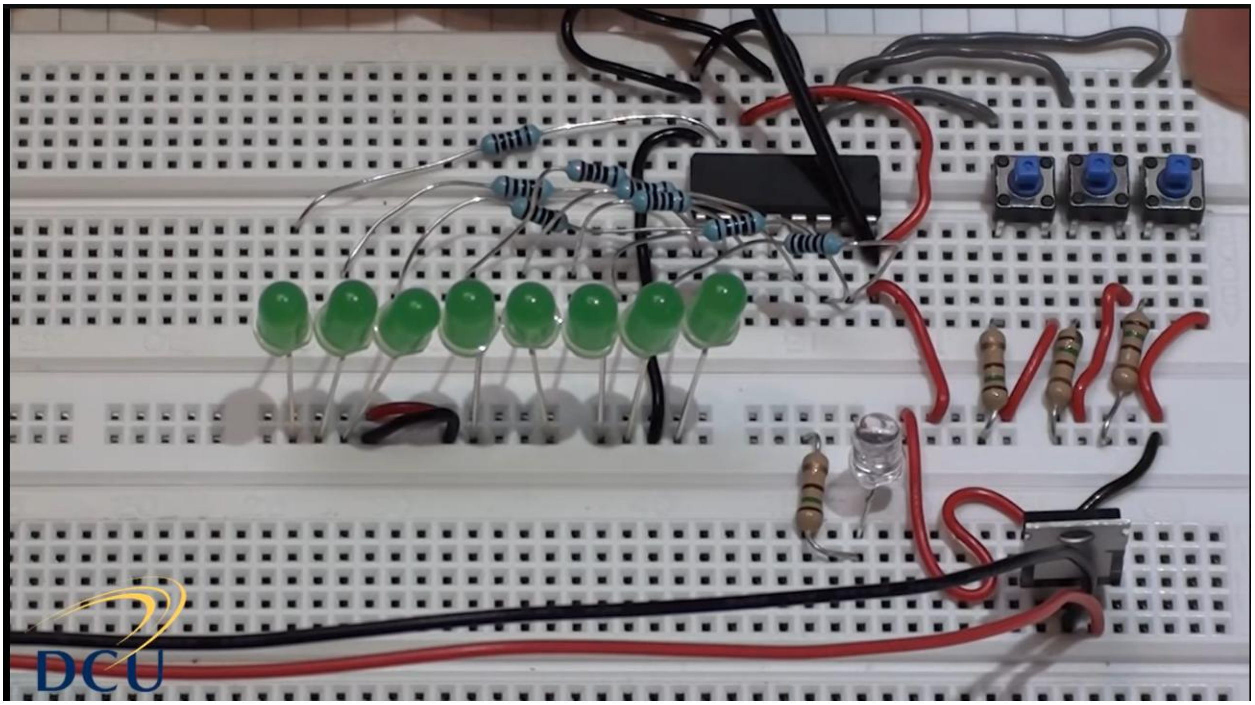
Oscillator Experiment

Lesson 8 4 Bit Shift Register

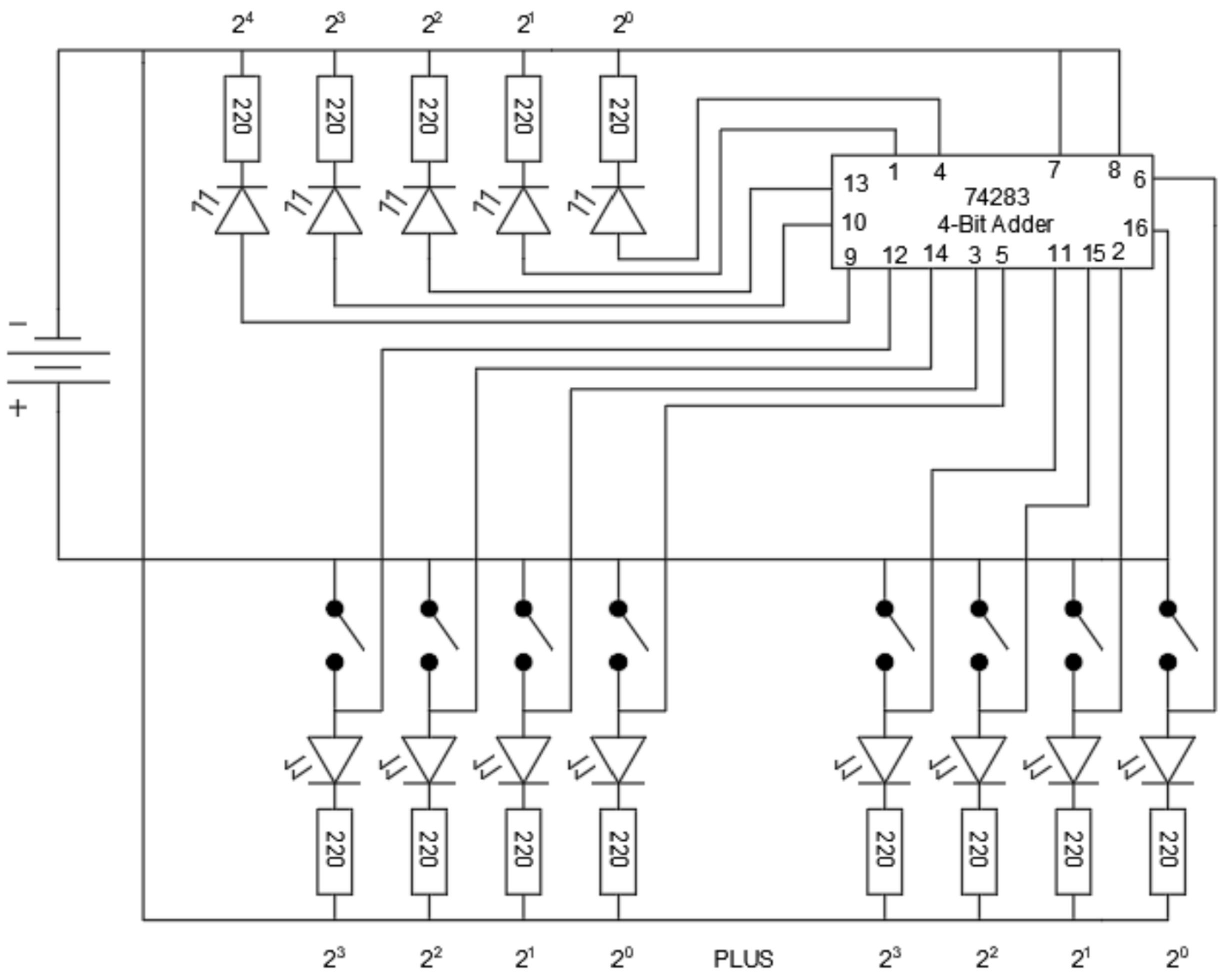




Lesson 3 to 8 Line Decoder (demux)



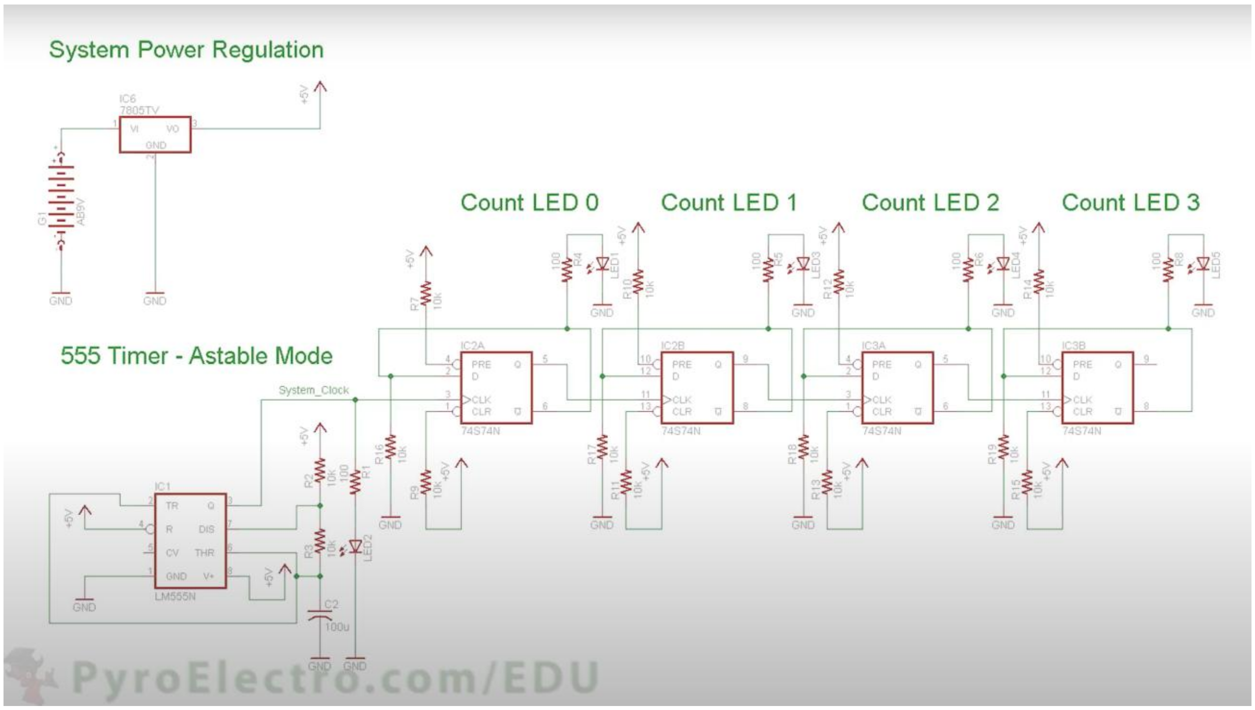
Lesson 4-Bit Added

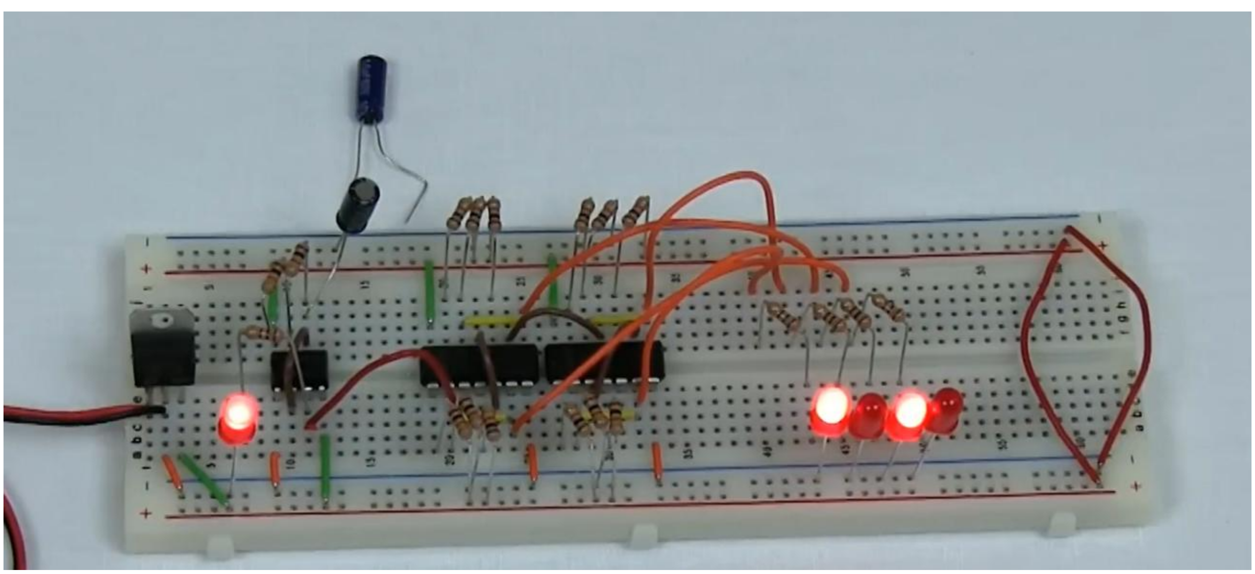


Lesson 9 4-Bit Counter

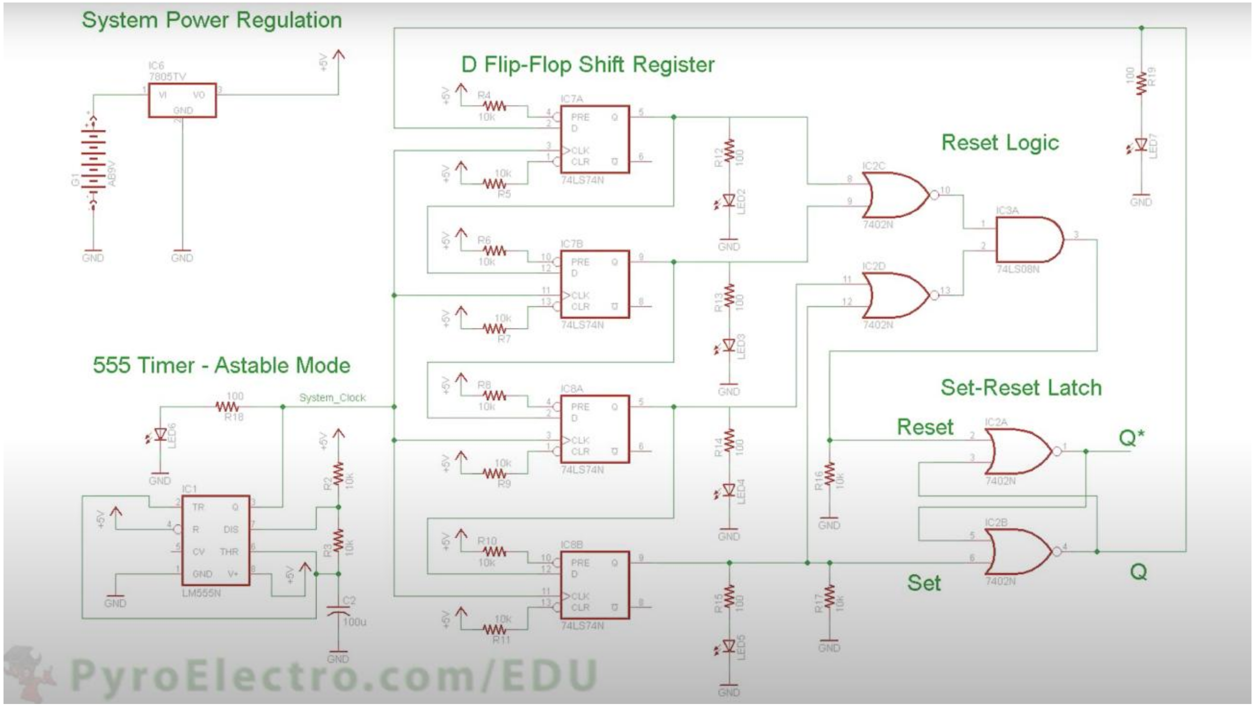
The

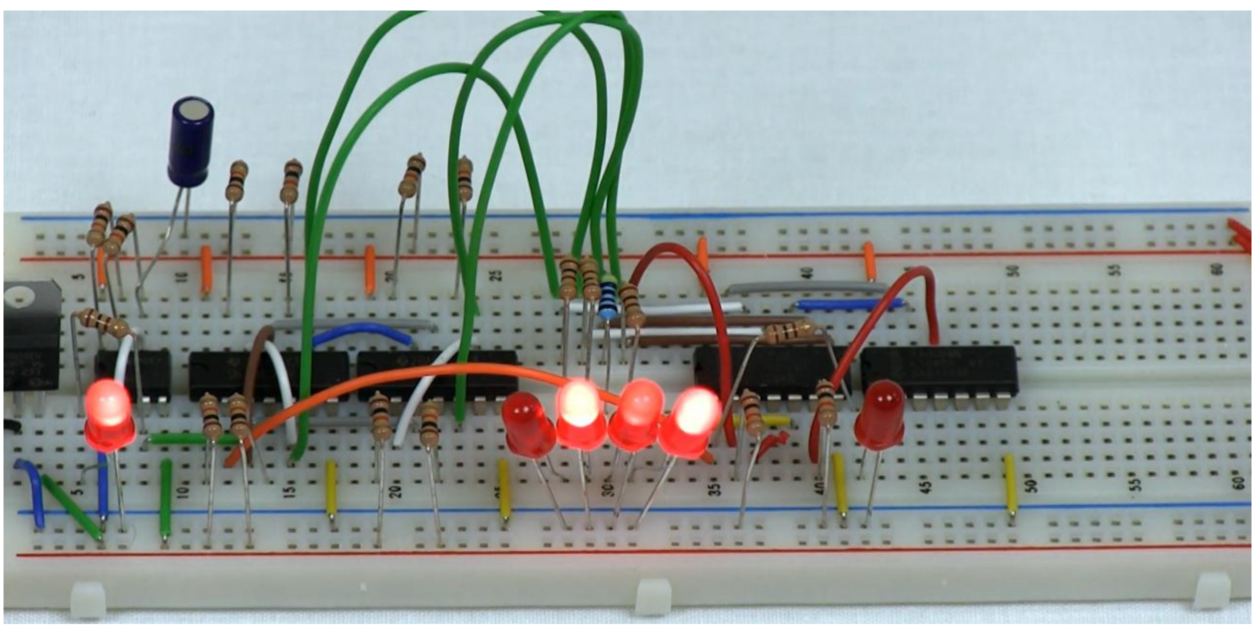
74HC74 D-Flip-Flop
Two D-Flip-Flop elements in a single IC!





Lesson 10 Design an LED Chaser





Lesson 11 7400 Logic ICs

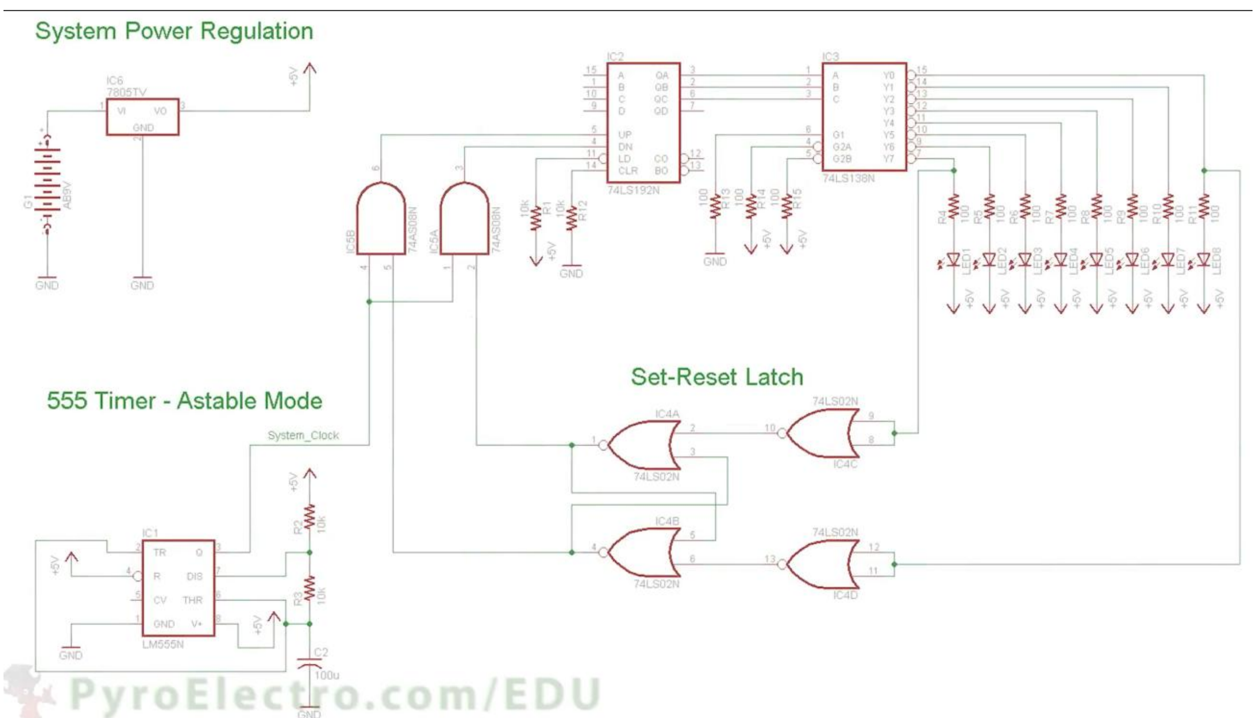
Truth table for 74192.

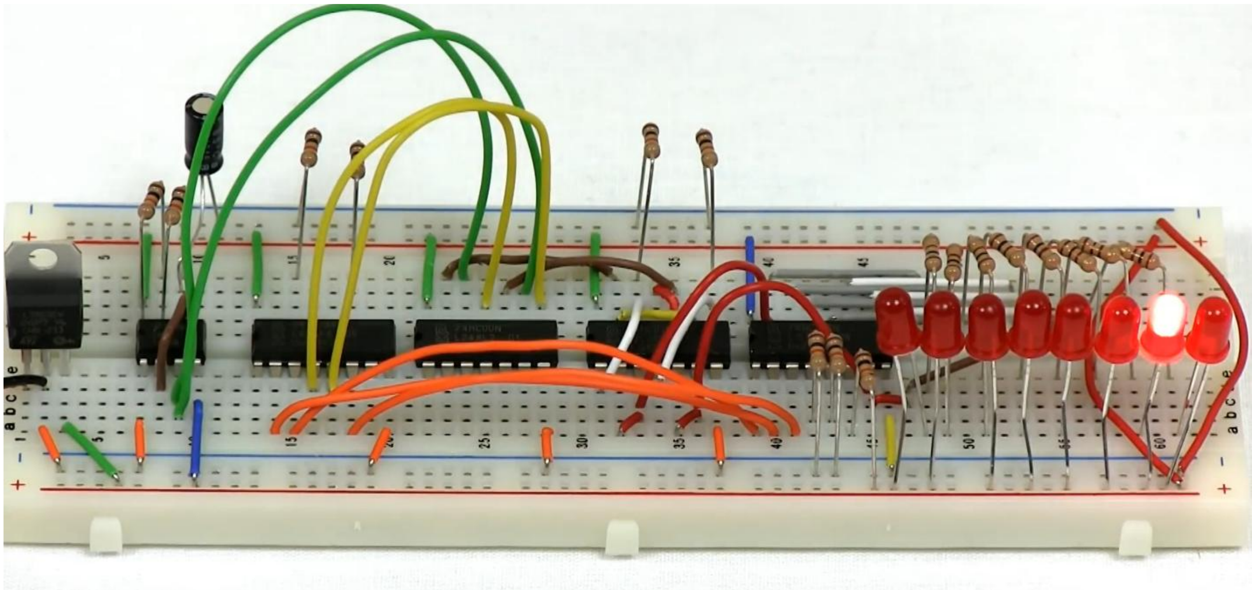
MODE SELECT TABLE

MR	$\overline{PL}$	CP_U	CP_D	MODE
H	X	X	X	Reset (Asyn.)
L	L	X	X	Preset (Asyn.)
L	H	H	H	No Change
L	H	↑	H	Count Up
L	H	H	↑	Count Down

L = LOW Voltage Level
H = HIGH Voltage Level
X = Don't Care
↑ = LOW-to-HIGH Clock Transition

The 74183 wiring shown the circuit has pins 4 and 5 for 74183 incorrect. They need to go to ground and pin 6 needs to go to VCC (+5V). The LEDs do go into the VCC slot because the output (Y0-Y7) go to active low.

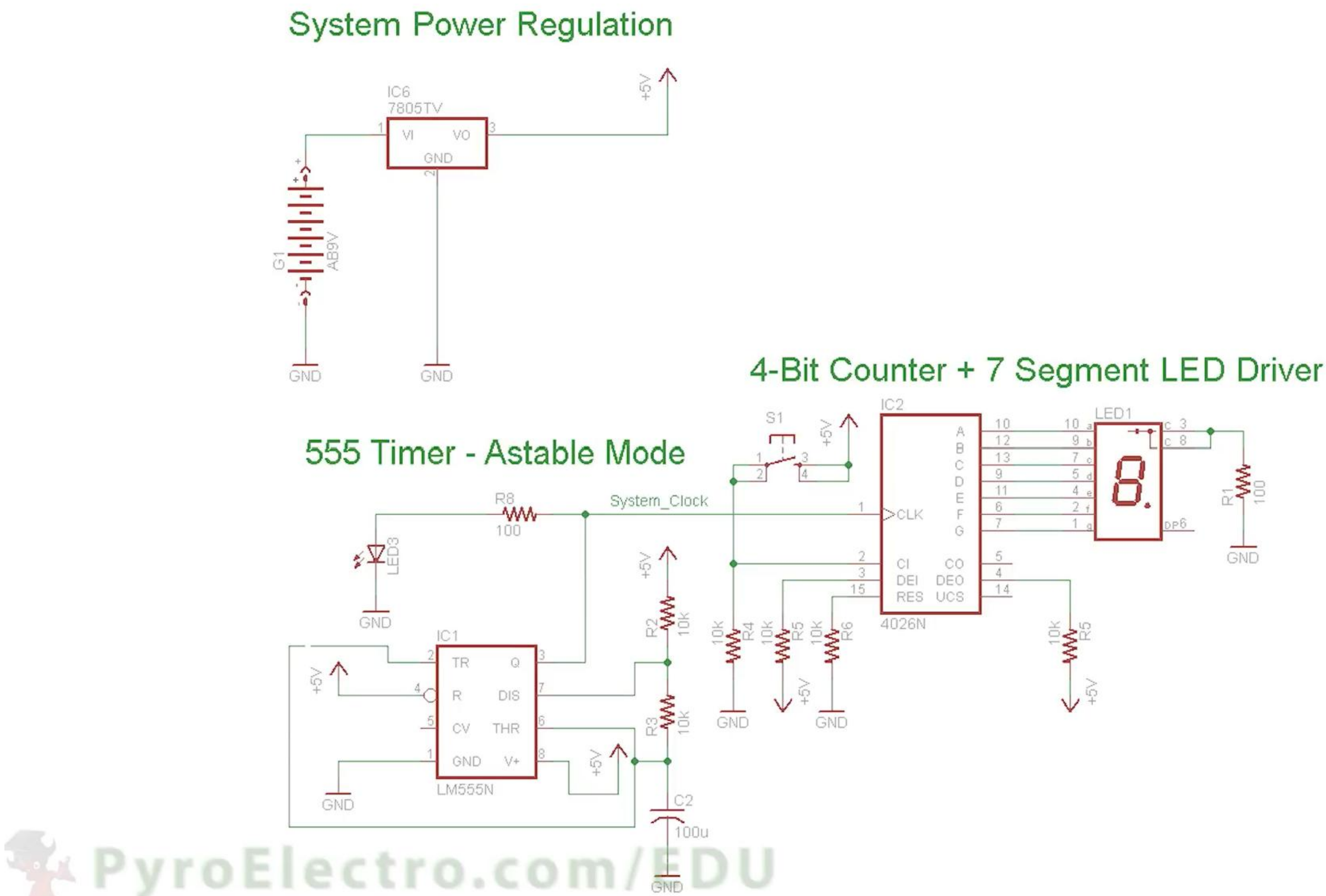


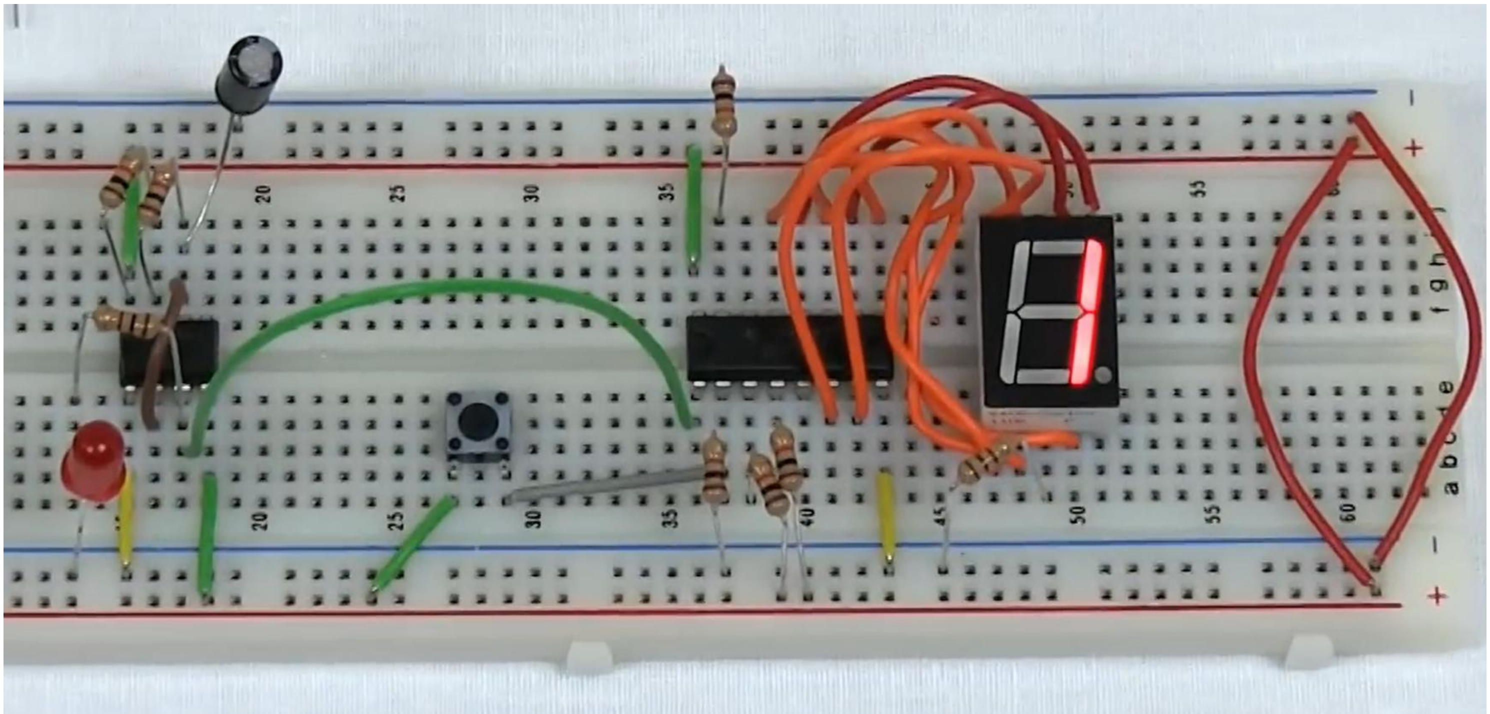


Lesson 12 4000 Logic ICs

4-Bit Counter and 7 Segment Display Experiment

Diagram missing ground on pin 8 and 5V on pin 16.





Lesson 13 Beeping Down Counter

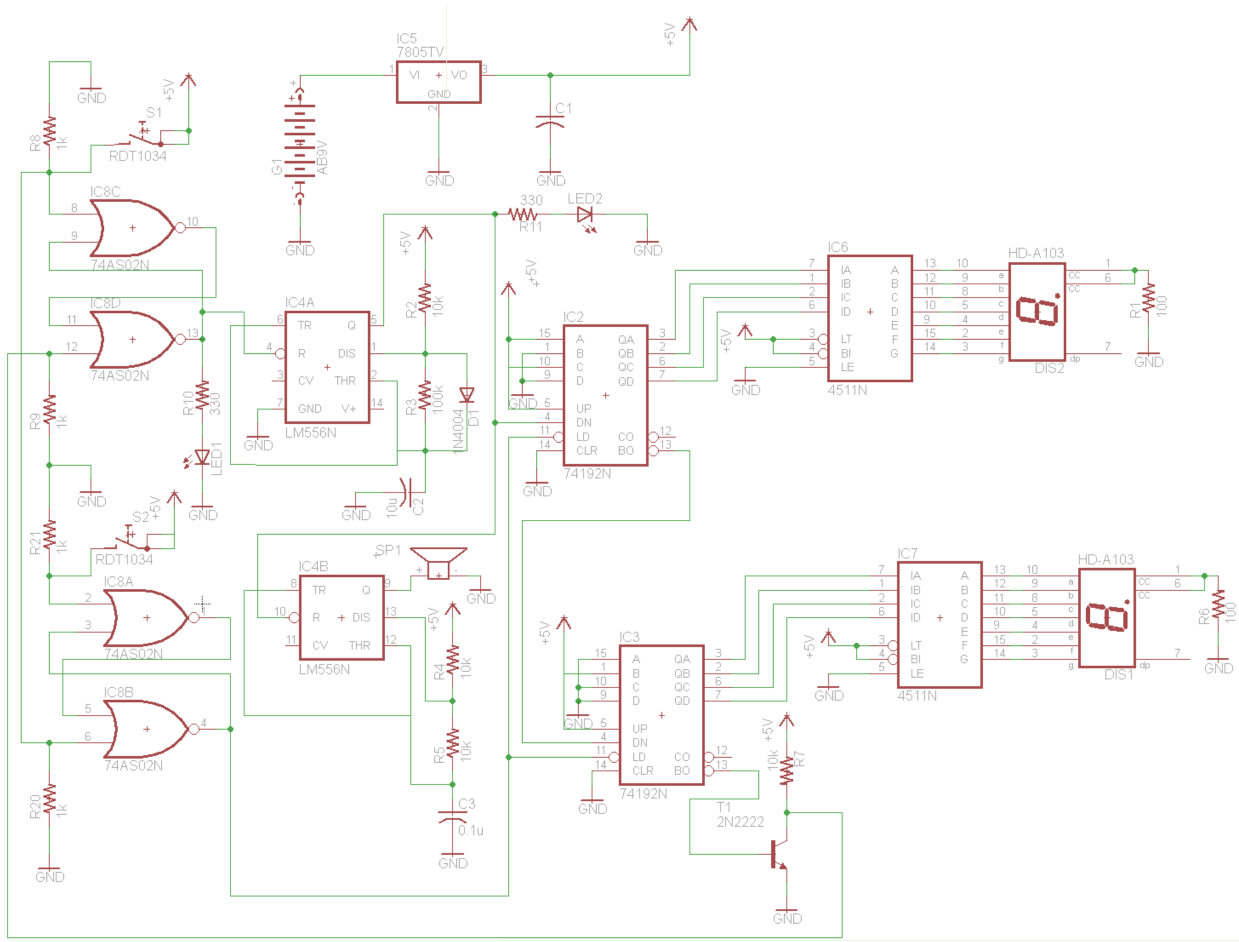
One of the most basic circuits in all digital electronics is the up/down counter with a 7-segment LED display. While you could easily build a similar circuit using all software and a microcontroller, understanding how to build the same circuit functionality entirely in hardware will give you an edge as a design engineer.

There are three key components that go into this design:

- A Down Counter With Dual 7 Segment LEDs
- A Push Button To Initiate The Down Counting
- A Quick 'Beep' Sound With Each Down Count

These goals will be accomplished by using a combination of 555 timers, 7400 series and 4500 series logic devices. The 555 timers will be used to drive the 'beep' sound and the main down counting. The 7400 devices will be used to control state outputs for the system and the 4500 devices will be used to set the current count value on the 7 segment LEDs.

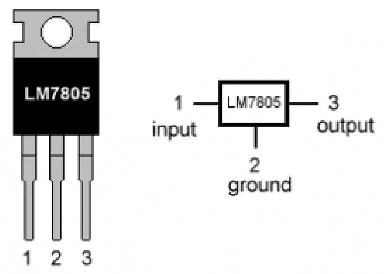
1	LM7805
1	Dual 7 Segment LED Display
1	NE556, Dual 555 Timer
2	74-192, 4-bit Decade Counter
2	4511, 7 Segment LED Driver
1	2n2222 Transistor
1	100kΩ Resistor
4	10kΩ Resistors
4	1kΩ Resistors
2	330Ω Resistors
2	100Ω Resistors
2	10uF Capacitors
1	0.1uF Capacitor
2	SPST Push Buttons
2	Green LEDs



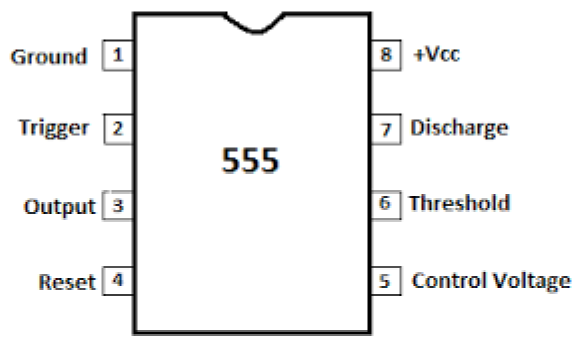
Appendix

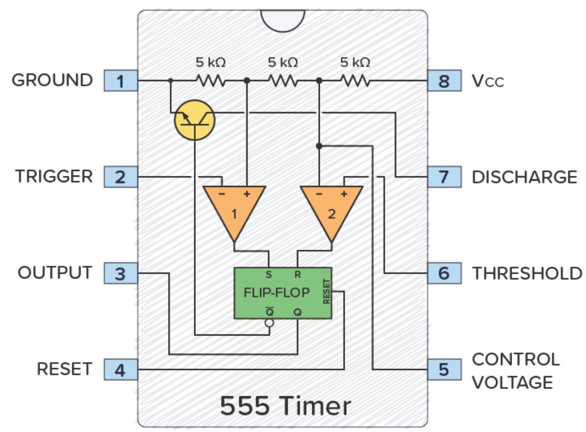
LM7805 5V Regulator

The LM7805 is a linear voltage regulator integrated circuit (IC) that provides a fixed output voltage of 5V.

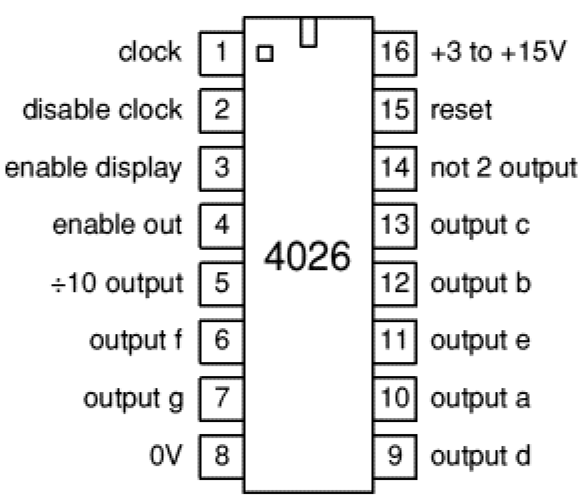


555 Timer



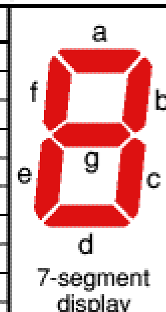


4026 Decade Counter/Divider with 7-Segment Display Outputs



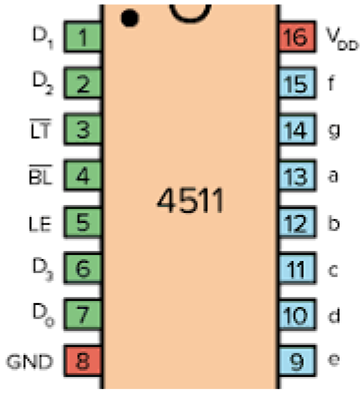
Outputs from the 4026 counter and display driver IC

Count	a	b	c	d	e	f	g	h
0	●	●	●	●	●	●		●
1		●	●					●
2	●	●		●	●		●	●
3	●	●	●	●			●	●
4		●	●			●	●	●
5	●		●	●		●	●	
6	●		●	●	●	●	●	
7	●	●	●					
8	●	●	●	●	●	●	●	
9	●	●	●	●		●	●	



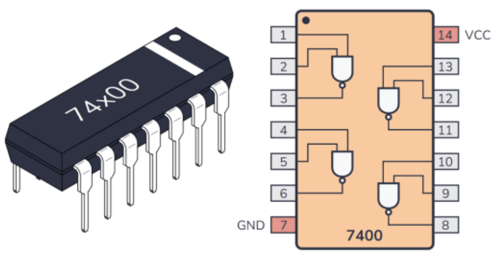
● = segment on. h is used to drive other counters.

4511



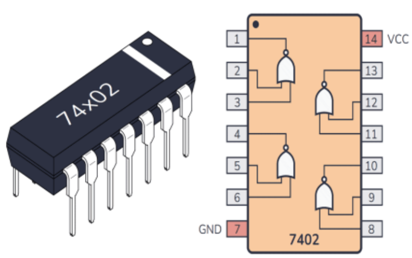
7400

Quad 2-input NAND gate: An IC with four standard NAND gates.



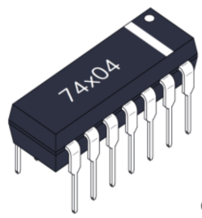
7402

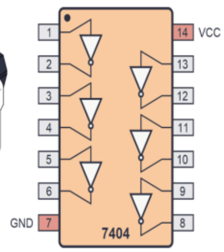
Quad 2-input NOR gate: An IC with four standard NOR gates.



7404

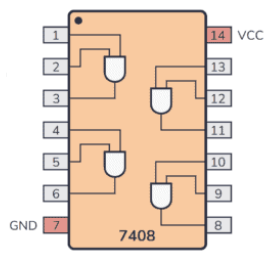
Hex inverter/NOT-gate: An IC with six inverters (or NOT-gates)





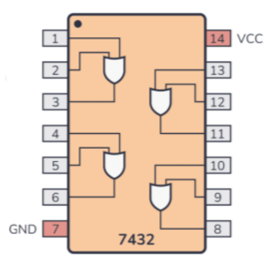
7408

Quad 2-input AND gate: An IC with four standard AND gates.



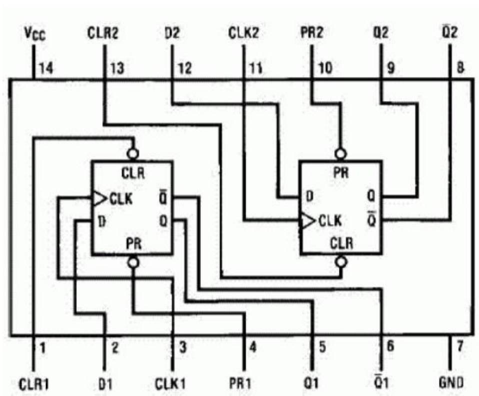
7432

Quad 2-input OR gates.: An IC with four basic OR gates



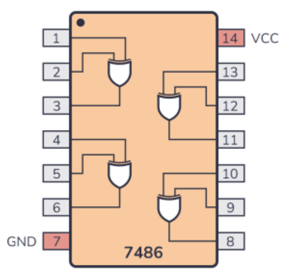
7474

Dual D Flip-Flop with individual D, Direct Clear, and Clock Pulse inputs. A low level at the preset (PRE) or clear (CLR) input sets or resets the outputs, regardless of the levels of the other inputs. When PRE and CLR are inactive (high), data at the data (D) input meeting the setup time requirements is transferred to the outputs on the positive-going edge of the clock pulse.



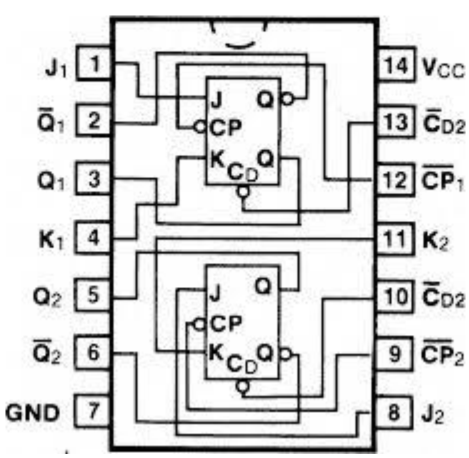
7486

Quad 2-input XOR gates.: An IC with four basic XOR gates

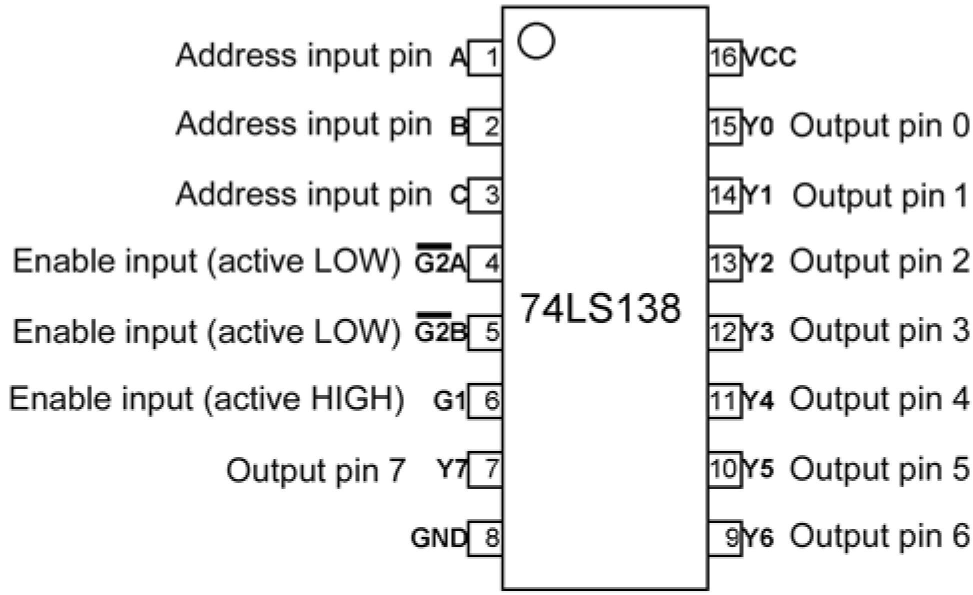


74107

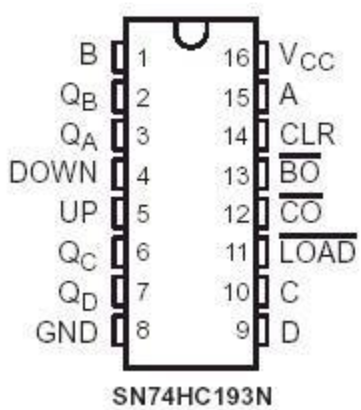
Dual JK Flip-Flop with individual J, K, Direct Clear, and Clock Pulse inputs.



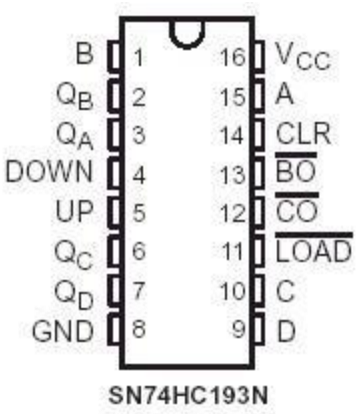
74138 3 to 8 Line Decoder



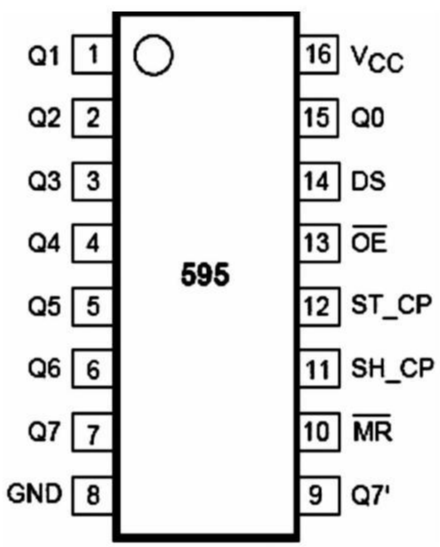
74193



74283


B
QB
QA
DOWN
UP
QC
QD
GND
1
2
3
4
5
6
7
8
16
15
14
13
12
11
10
9
VCC
A
CLR
BO
CO
LOAD
C
D
SN74HC193N

74595


Q1
Q2
Q3
Q4
Q5
Q6
Q7
GND
1
2
3
4
5
6
7
8
595
16
15
14
13
12
11
10
9
VCC
Q0
DS
OE
ST_CP
SH_CP
MR
Q7'

References

[i] https://technav.ieee.org/topic/digital-integrated-circuits
[ii] https://www.electronics-tutorials.ws/logic/pull-up-resistor.html
[iii] https://www.electronics-tutorials.ws/sequential/seq_1.html