First Year Laboratory

Phase 3

The Electronics Laboratory

(2013-2014)

Name.....

School of Physics and Astronomy

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The First Year Electronics Laboratory

The aim of this electronics laboratory is to introduce you to some basic electronics; electronics that may not only be useful for future experimental projects, but also electronics which provides an essential introduction to the second year electronics unit laboratory. Physicists need a basic knowledge of electronics if they are to make full use of the expertise of electronics technicians for research projects and if they are to collaborate fully with electronic engineers on major developments. The course consists of a number of lectures and two days (one on digital and one on analogue) in the first year laboratory.

Within each lab class you will be working in pairs of your choice. There is much ground to cover so you will need to work very conscientiously to complete all the exercises. However, do not regard the lab as a race; you must understand what you are doing as you are going along. Ask a demonstrator or a fellow student if you get stuck.

Analogue Electronics

Almost all of scientific measurements rely on the use of analogue electronics to convert data into electrical form, to control a physical system, or to present data to a digital computer. An understanding of analogue electronics is also required to make intelligent use of a wide variety of electronic instruments available and to understand the more subtle aspects of real digital systems.

Digital Electronics

Uses of digital electronics range from small-scale tasks that are possible with just a few logic gates up to the complexity of main frame computers.

Experimental Points

- Use sensible colour scheme for wiring all circuits (e.g. red for positive, black for negative, green for ground, yellow for signals). Connect components with short wires (to reduce pick up and stray coupling) in a way that you and a demonstrator can easily relate to the electrical circuit.

- On power supplies, the black terminal should be taken as signal ground or earth. Do not use the green terminal - it is connected to the supply's metal chassis. The black (0V) terminal on the power supply will of course be connected to the black terminal of the signal generator and the crocodile clip of the probe which is the oscilloscope ground.

- Get into the habit of using the oscilloscope for all measurements, including DC values.

Assessment

- Two laboratory notebooks will be required

- Notebooks must be handed in for marking at the end of each session. It is essential to make good notes during the experimental work. We are not looking for a beautiful write-up, but we do expect an intelligible working record of all experimental work and measurements. You should also check your results as you proceed; try plotting a rough graph (no great accuracy is needed) to see whether your measurements vary in a sensible way. Tidiness in note taking is encouraged, but intelligibility and completeness (e.g. inclusion of all relevant circuit diagrams) are more important than literary style. Notes and records on loose paper are not acceptable.

- Books will be divided between the demonstrators for marking using a numerical marking scheme described in your handbook.

Electronics Laboratory Reference Material

We have gathered together what we believe to be important points to help you make better use of your time in the electronics laboratory.

Care of components

In the laboratory we make use of 'breadboards' which have holes on a 0.1 inch pitch, with electrical connectors underneath. These breadboards are suitable for use with both integrated circuits and other components. However, some care is necessary.

1. Try to keep leads straight. If they do bend, straighten them (using pliers, carefully).

2. If you cut a lead to insert it into the breadboard, make sure that the end of the lead is smooth (i.e. not barbed).

Remember that the laboratory has to run a restricted budget, and the more careful you are with components, the wider and more interesting selection of components will be available.

'Ground', 'Earth' etc.

'Ground' and 'earth' are synonyms: they are often also used as synonyms for 'zero voltage'.

The power supplies in the laboratory have a green 'earth' terminal and a black 'zero voltage' terminal, which are electrically isolated from each other.

Use of coaxial cable etc.

Remember that the outside of the coaxial cable is invariably the earthly (or 'LO') side. In the case of 'scope probes the connection is to mains earth via the front panel connector.

If you are using a probe with your oscilloscope, make sure that the switch on the probe is correctly set.

Colour of leads

Whenever possible, and particularly when making connections to power supplies, use leads which are the same colour as the terminals to which they are connected.

Component values

The values of resistors, and of some capacitors, are shown by a banded colour code. You must learn this code - it is displayed in the laboratory.

Analogue Electronics

The operational amplifier

The operational amplifier is the basic building block of many useful electronic circuits ranging from simple amplifiers, voltage comparators, voltage- and current-sources, precision rectifiers to active filters and oscillators. The term "operational" refers to the various mathematical operations, such as addition, subtraction, integration and differentiation, that can be simulated using op-amplifiers in an analogue computer - the precursor to today's powerful digital computers. The current experiments are designed to provide an introduction to op-amps and to introduce a number of op-amp circuits that are likely to be useful for future experimental/project work.

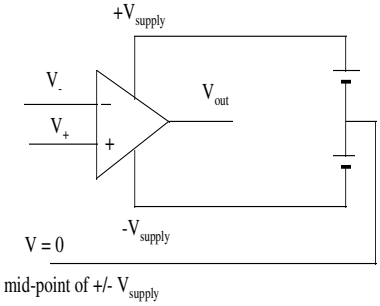


Figure 1 Schematic diagram of TL081 Op-amp

The operational amplifier is a packaged circuit, typically containing ~ 20 transistors, resistors and one capacitor (which defines the frequency response). We treat the op-amp as a "black box" and do not need to know anything about its internal circuitry. All we need to know is how the output voltage varies as a function of input voltages, how the overall gain of the op-amp varies as a function of frequency, and the magnitude of the input and output impedances, all of which we can look up in books describing the characteristics of specific op-amps.

All our experiments will be based on the widely used TL081 op-amp, with pin connections illustrated in figure 2. We will not be using the "offset balance" connections 1 and 5, or pin 8 which is not connected (NC) to the op-amp. The other connections are equivalent to the connections indicated in Figure 1 .

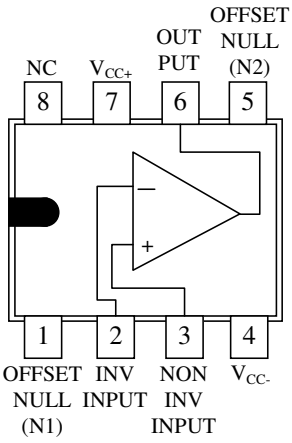


Figure 2 Pin connections for TL081 from above.

The op-amplifier is a "differential amplifier" - it amplifies the difference in voltage applied to the inputs V_+ and V_-. An idealised op-amp has an output given by

$$V_{out} = A\,(V_+ - V_-)\,,$$

where A is very large (~10^5-10^6 *at low frequencies*). That means that for changes of a few microvolts difference at the inputs the output voltage changes by ~1 V. In practice, the "open-loop" gain A is a function of frequency. The product of A and the frequency (the gain frequency product) is typically ~10^6 Hz. There is also an unavoidable

"offset voltage" of typically +/- several tens of mV, so that in practice V_{out}= A (V_+ - V_- + V_{offset}). As the gain and offset voltages are so large, op-amps are never used in isolation as amplifiers. To operate as an amplifier they are incorporated in circuits which involve negative feedback.

The TL081 has a very high input impedance, so that in analysing circuit performance we can ignore any current flowing into the input terminal. Nevertheless, there is always a small but finite current that flows into the inputs of the op-amp (~pA). **There must therefore always be a dc path to ground at each of the inputs**, otherwise the control gates of the input transistors will simply accumulate charge and acquire a voltage that will turn them off. The op-amp circuit will no longer operate after a few minutes! Never connect a capacitor as the sole input to an op-amp. The output impedance is small, so that for sufficiently small signals the output voltage is independent of any load resistor >100 ohms. However, the output transistors in the op-amp can only deliver a few mA of current, which can be a problem for large voltages on the output (current saturation). Moreover, no amplified signal can exceed the voltages of the positive and negative power supplies (voltage saturation).

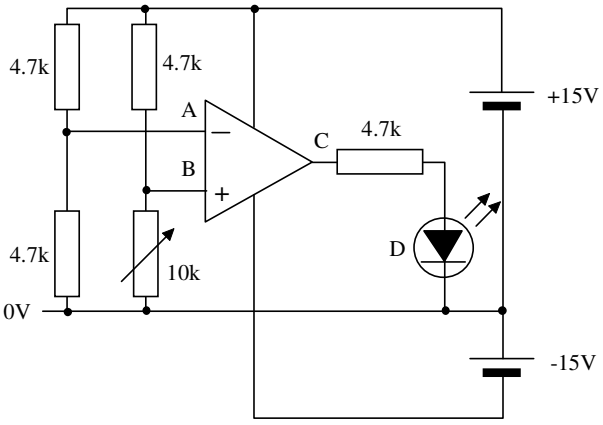
Op-amps can be used in many types of useful circuits. You will construct and determine the operating characteristics of a number of circuits using op-amps including:

a) without feedback as a voltage comparator
b) with negative feedback as a linear amplifier
c) with positive feedback as an oscillator.

Op-amp as a voltage comparator (spend no more than 1½ hour on this exercise)

- **Before connecting the power supplies to the circuit below, set the output voltages to ±15V**
- **Always turn the power supply off before making any changes to your circuit**

Construct the illustrated circuit on a breadboard using a TL081 op-amp. D is a light emitting diode. Note that op-amps are usually run off symmetric positive and negative power supplies of ±9V, ±15V, etc. For simplicity, the connections from the



positive and negative supply inputs to the op-amp are often omitted in circuit diagrams. **However, you must always remember to connect the op-amp chip to the power supplies, otherwise it will not work!**

The voltages V_+, V_- and V_{out} , at B, A and C respectively, are all measured relative to the mid-point of the power supplies (often referred to as the "ground" or "earth " potential). When connecting external equipment (i.e. an oscillator or oscilloscope) remember to connect the equipment's "earth" connection (generally the metallic casing of the apparatus or the "earth" return line of a coaxial cable) to the midpoint of the +/- V_{supply} . Note that connections of wires should always be indicated by a solid dot. Lines crossing without a dot are not connected together.

Measurements

1. Show that the LED can be turned on and off by suitable adjustment of the 10k variable resistor. This is an example of a voltage comparator. The op-amp compares the voltages at its inverting and non-inverting inputs and gives either a high positive or negative voltage output close to $\pm V_{supply}$ (the saturated states of the op-amp)
2. Use a DVM to measure the output voltages in the two "saturated" states and compare these voltages with the supply line voltages. Remember - all voltages are measured relative to the mid-point of the voltage power supplies.
3. Use your oscilloscope to monitor the dc-voltages at A and B while varying the 10k resistor to turn the LED on and off. Confirm that the op-amp switches from a positive saturated state to a negative saturated state, when the two voltages are approximately equal.
4. Replace the 10k variable resistor by a light dependent resistor (LDR) and show that output LED can be turned on and off depending on the light falling on the LDR. Does the light go on or off when light falls on the LDR? Does this make sense?

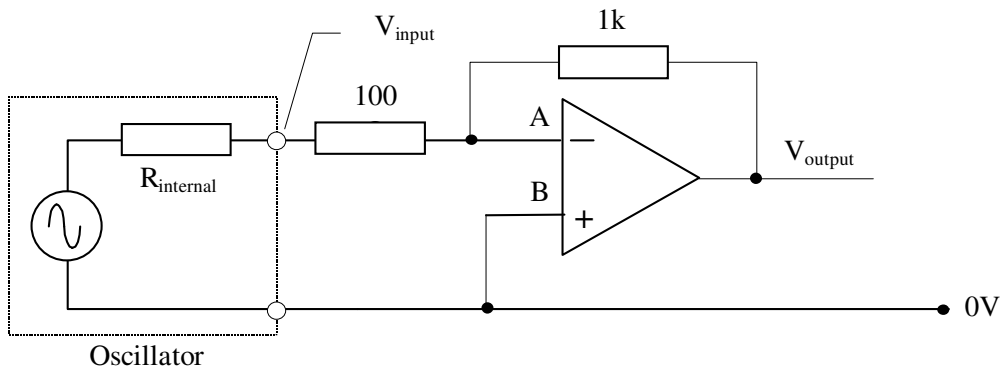
[The above circuit could be used as a light sensor - for example to turn on a security lamp (rather than the LED) in the hours of darkness. What might happen if the LED (or an even brighter light) was mounted too close to the LDR with the whole circuit shielded from external light?]

Amplifier circuits using op-amps (~ 2½ hours on the inverting and non-inverting amplifiers)

Because of the relatively large offset voltages and very large gain at low frequencies, op-amps are always used in amplifier circuits with negative feedback. You will construct and measure the frequency response of an inverting amplifier, a non-inverting amplifier and a "buffer" amplifier.

The inverting amplifier (~ 1½ hours)

Construct the following circuit and connect it to an oscillator as illustrated below. You will



monitor the input and output voltages on an oscilloscope.

We now follow the usual convention and do not indicate the +/- V_s power supply connections to the op-amp - but do make sure that you have made them, otherwise the circuit will not work!

The output connections are from the oscillator to the "ground" (i.e. mid-point of the op-amp's power supplies) and to the input of the op-amp circuit (the left-hand end of the 100 Ω resistor).

The oscillator is a source of sinusoidal emf, but also has an internal resistance (50 ohms to a few k ohms, depending on the oscillator used) just like a battery. The internal resistance of the oscillator is therefore in series with the 100 ohm input resistor. Connect probes across V_{input} and V_{output} as indicated in the diagram above. [V_{input} is different from the open circuit voltage from the oscillator, because the voltage drop across the oscillator's internal resistance when current flows.]

- ***Measurements***

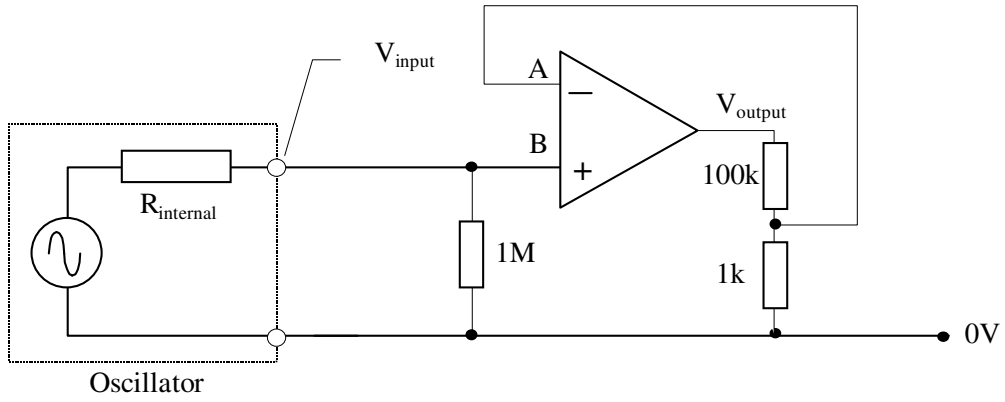
1. Use a dual trace oscilloscope to monitor the ac voltages at the input to the op amp circuit and its output voltage. Set the oscillator initially to a frequency of 1 kHz and an amplitude of ~ 0.1V
2. Measure the amplitudes of the input and output voltages.
3. What is the phase of the output voltage relative to the input?
4. Check that the amplification is what you would expect from "virtual earth" arguments (i.e. gain = - $R_{feedback}$ / R_{input}).
5. Measure the gain and phase of the output at 10Hz, 30Hz, 100Hz, 300Hz, etc. up to 1 MHz and plot your results as log(amplifier gain) vs log(frequency) on the log/log graph paper provided. This graph is called a Bode plot. Note that at high frequencies the gain is limited by the "open-loop" gain of the op-amp.
6. Replace the 1k feedback resistor by a 10k resistor and repeat these measurements plotting your results on the same log/log graph paper.
7. What do these measurements tell you about the open-loop gain of the operational amplifier as a function of frequency? Obtain a value for the gain-frequency product.
8. Making use of the "virtual earth argument", work out the input resistance (V_{in}/I_{in}) of the inverting amplifier.
9. You have been provided with a piezo-electric transducer (with a large internal resistance ~ 1MΩ), which generates a voltage when it is flexed. It has been attached to a small cantilever that you can "twang" to generate a voltage from the transducer. Monitor the piezo-electrically generated voltage on "twanging" the cantilever on your oscilloscope. Now use your inverting amplifier circuit to "amplify" the voltage from the piezoelectric transducer. Do you get a larger signal - **NO! Explain why not?**

- *The reason is that the transducer has a large internal resistance (~1MΩ) in series with the source of emf. The signal at the input of your amplifier, V_{input}, is therefore reduced by a factor (input impedance of amp)/(1MΩ +input impedance of amp) ~10^{-4}. The amplification is therefore much less than the attenuation of the voltage at the input, so that the net effect of connecting to the amplifier is to decrease the signal instead of increasing it!. This exercise should serve as a warning about the importance of source and input resistances in determining a circuit's performance. The inverting op-amp circuit should*

only be used to amplify signals from transducers or circuits that have a relatively low output resistance (i.e. another op-amp, a thermocouple, a magnetic coil pick-up, etc.)

Non-inverting and buffer amplifier (~ 1 hour)

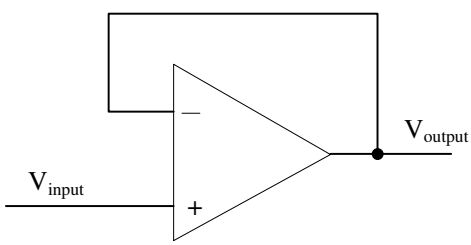
You will now construct a non-inverting amplifier circuit, which typically has an input resistance of up to 10^{12} ohms and can therefore be used to amplify signals from sources with a high source resistance (such as a piezo-electric transducer).



- Note again the use of the mid-point of the power supplies as the "ground" or 0V line.

- ***Measurements***

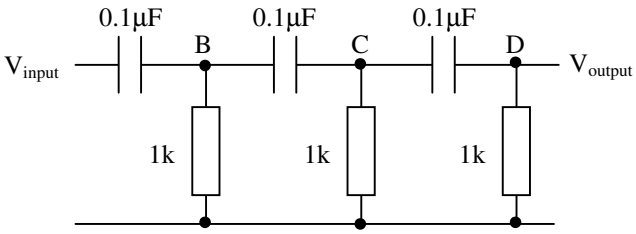
1. Measure the gain and phase at 10 Hz , 100 Hz, 1000 Hz , etc., up to 1MHz and plot your results as a Bode plot on the same graph that you drew for the non-inverting amplifier.
2. Reset the oscillator to 1 kHz and compare the gain with and without a 1M ohm resistor connected from your oscillator output to the input of the amplifier circuit. What does this tell you about the input resistance of the non-inverting amplifier?
3. Remove the extra 1MΩ resistor and connect the outputs of the piezo-electric transducer across the input of the non-inverting amplifier. Demonstrate that you now achieve appreciable gain. In this configuration the op-amp has a large input impedance ~ 10^6 Ω, set by the resistor from B to ground, and thus can be used to amplify signals from sources with high source resistances.
4. Reconfigure the above amplifier as a simple "buffer" amplifier, which is frequently used to "buffer" a source of emf with a high output resistance from the load of a following stage.



Use the full frequency range of the signal generator to check the gain and phase through the buffer amplifier. What are the values you obtained and is there any change with frequency?

Positive feedback oscillator (~ 1 hour on this exercise)

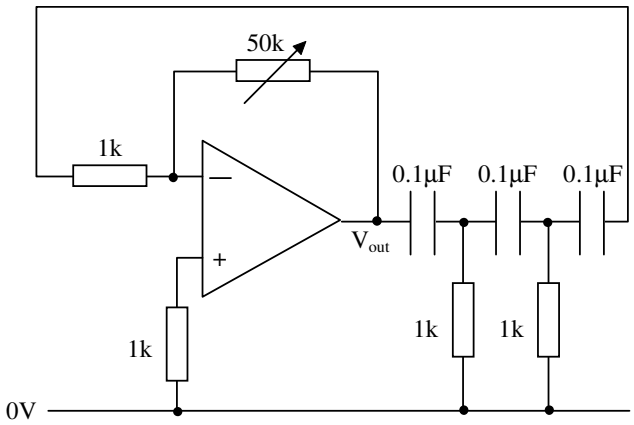
The final experiment illustrates the use of an op-amp with positive feedback to generate an oscillating ac signal.



First set up on your breadboard the phase-shifting circuit shown.

Measurements

1. Set the oscillator output to ~1V and use the two-trace facility on your oscilloscope to observe the output voltage and phase relative to the input as a function of frequency at 10 Hz,30 Hz,100 Hz, ...etc. (no accurate measurements needed). Make an **approximate sketch** of how the "filter gain" and the phase varies as a function of frequency. You will have to change the oscilloscope gain or increase the input voltage to observe signals over the full frequency range.
2. Show that at high frequencies the output voltage is close to the input voltage with no change in phase.
3. Use the oscilloscope in X-Y mode to make an accurate determination of the frequency at which the phase change is exactly 180^o. Determine V_{output}/V_{input} at this frequency.
4. Incorporate the above phase shifter (*a high-pass 3-pole filter* in electronics jargon) into the op-amp circuit shown below. Remember to connect the 0V connections to the mid-point of the power supplies.
5. The filter network will now change the phase of the signal at its output by 180^o at the frequency you determined above, and will also attenuate the signal. If the amplifier circuit provides a larger gain than the loss through the filter and also inverts the signal (180^o phase shift), then the net effect is to provide positive feedback. The amplifier gain more than compensates for the loss in amplitude through the



attenuating filter. Oscillations therefore build up in the circuit, limited eventually by non-linearities in the op-amplifier's performance (approaching saturation) at large amplitudes.

6. Vary the 50k variable resistor from a low value (low gain) to a high value and determine the minimum value of the resistor for the circuit to just oscillate. **You will have to remove the resistor from your circuit to measure its resistance with a multimeter.** Measure the frequency of the oscillations produced by the circuit.

7. Evaluate the expected amplification of the inverting amplifier for the measured value of resistance and show that the amplification is approximately that required to compensate for the amplitude loss through the filter network.

Digital Circuits

There is a wide range of digital integrated circuits (ICs) available commercially; these are normally built as mutually compatible members of logic "families" (circuits within a family have been designed to comply with a set of rules such that they behave properly when interconnected). We shall be using TTL, one of two families that are currently popular. TTL is transistor-transistor-logic, usually the 74LS series. [CMOS or complementary metal-oxide-semiconductor logic is the other even more popular family.]

TTL is always operated with a supply voltage of 5 volts (i.e. $V_{cc} = 5 \pm 0.25$ V); the negative supply pin is normally connected to ground. Within the family the voltage range corresponding to LOW and HIGH and the transitions between them is specified, but this is taken care of by the chip designer. In order to make full use of the capabilities of such devices you need to know about their internal circuitry, but they can be used as "black boxes", which is the approach we are going to take.

The aim of this experiment is to illustrate how easy it is to connect TTL - the outputs of one circuit are the inputs of the next. The objective of the experiment is for you to build a system using TTL to make a measurement of your reaction time.

Basic Logic Gates

The basic digital circuit is the logic gate, which may be thought of as a switch. The AND gate is like two (or more) switches in series, the OR gate like several switches in parallel. The simplest construction gives gates that invert the output so the common gates are actually NAND and NOR. Symbols for these basic gates are illustrated in figure 1.

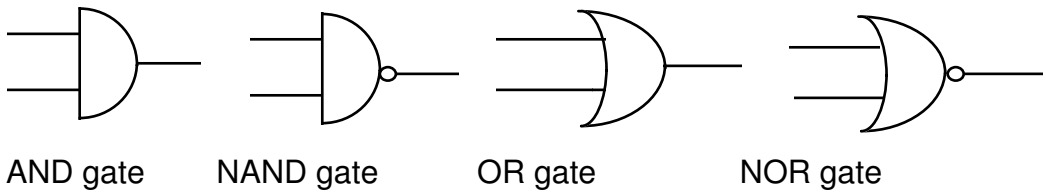


Figure 1 Symbols for basic logic gates

Note the inversion "bubbles" on the outputs of the NAND and NOR. In principle we can build up all other logic circuit elements out of NAND gates alone, or out of NOR gates alone. In practice we make very considerable use of more complicated circuits, such as flip-flops and counters, which we then treat as building blocks for even larger systems.

To analyse the operation of a logic circuit we may use its "Truth-Table". For example the truth-tables for 2-input AND and NAND gates are shown below. The inputs are denoted by A and B, the output by Q in each case.

AND gate

A	B	Q
0	0	0
0	1	0
1	0	0
1	1	1

NAND gate

A	B	Q
0	0	1
0	1	1
1	0	1
1	1	0

The value "0" corresponds to "OFF" or "LOW" or "FALSE" and the value "1" to the complementary state. In the truth-table all possible combinations of inputs are tabulated together with the expected output.

Exercise 0 Combinational Logic (Digital counting usually starts at 0!)

The aims of this exercise are to verify the truth table for NAND gates and to use some of them in 'combinational logic'. Combinational logic has no memory - the output only depends on the current values of the inputs.

Whilst an oscilloscope is the most powerful way of investigating the operation of a circuit, it is convenient to indicate digital logic levels with LED's (Light Emitting Diodes) that are 'on' for logic level 1.

- **Remember to turn off the power supply to your circuit when making adjustments.**

1. Connect all 6 of the circuits on a 74LS04 Hex Inverter as shown in figure 2 - you will need them all later. In this configuration they light on a level 1 input to the inverter. On untrimmed LED's the long leg should go to +V. (Note that with no connection the input to the inverter floats high and the LED lights.)

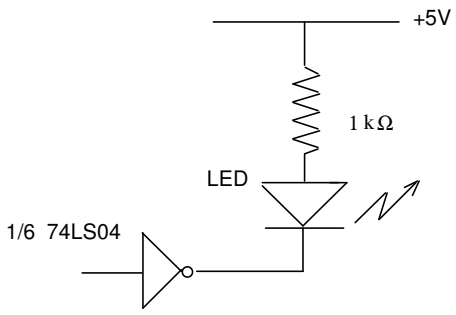


Figure 2 LED driver circuit

Please keep this circuit intact – you will use it later to determine which signals are level "0" or level "1".

- *If testing LED's between +5V and earth include a 1kΩ series resistor to limit the current, otherwise they burn out*

2. Power a 74LS00 (or 7400) Quad NAND gate; use wires to +5V via 1kΩ and to 0V as logic 1 and 0 inputs. Record the truth table for one of the NANDs, using LED's to indicate the levels on the inputs and output.

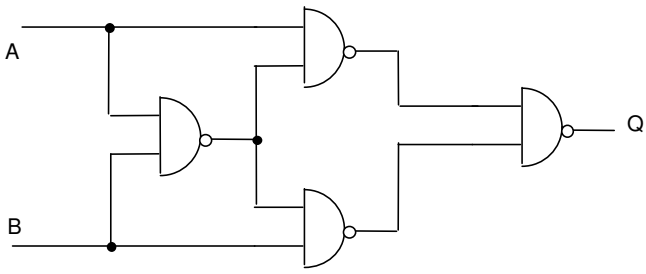


Figure 3 An XOR gate made from NANDs

3. Now use 4 NAND gates to build an exclusive OR gate (an XOR), an example of combinational logic. This gate gives a high out if either, but not both, of the inputs is high. One (of many) ways of making this is shown in figure 3. Again use inputs to A and B to find the truth table, indicating the levels with the LED's. Think about why the circuit works but do not spend too long. It is easy to analyse with Boolean algebra.

- *Dismantle the XOR but keep the LED circuits.*

Exercise 1 A /R-/S Latch

The next circuit is an example of 'sequential logic' which is logic that does have some memory of previous inputs. The circuit (shown below in figure 4) is a bistable, that is to say it has two stable states, one in which output Q is HIGH, and /Q LOW, and a second in which the states of the outputs are reversed.

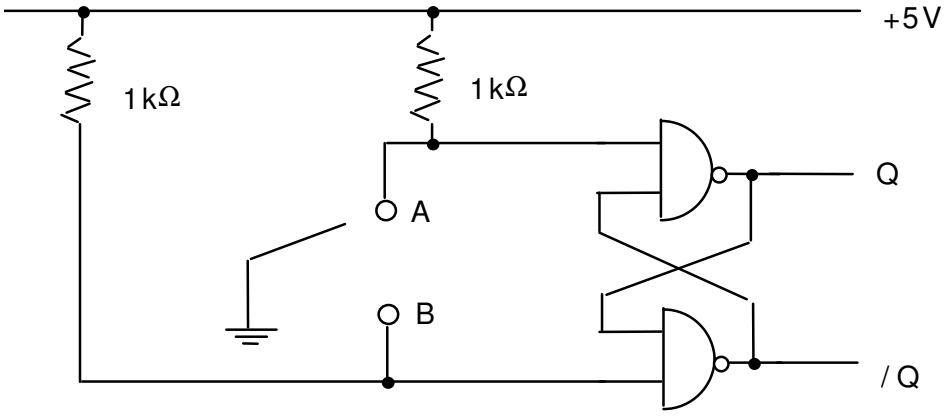


Figure 4 The /R - /S Flip-flop

The output Q is HIGH when the switch is in the position shown, and will remain HIGH until the switch contact touches input B, when Q will go LOW, and remain LOW until the switch again touches input A. The state of output /Q is the inverse of output Q when the circuit behaves normally (the / is a conventional label). Such circuits have memory in that the output depends on the last input (A or B) when the switch is between the two. It is also a useful 'anti-bounce' device as will be shown later.

1. First check that the output level should retain its previous value if both A and B are HIGH by using the truth-table of a NAND gate. Deduce the truth-table of the /R - /S latch and record it.

2. Now build and test the latch shown using a 74LS00 (or 7400) Quad 2-input NAND gate. Use two of the LED circuits to show Q and /Q. Initially use pieces of wire instead of the switch so that you can determine the outputs for all four possible input conditions. Compare the results with the predicted truth table.

3. Replace the wires with a push switch (figure 6 shows details of the switch) and check the behaviour of the circuit. Note which output in normally ON. Preserve the latch circuit as you will be using it again.(The S and R stand for SET and RESET.)

Exercise 2 A TTL Counter

For this exercise you are going to use a hexadecimal up/down counter (74LS193 or 74193). A hexadecimal counter counts from 0 to 15 before overflowing so requires 4 binary bits (there are 4 latches inside). The first aim is to check that it works as expected, using 4 LED's to display the outputs (Q_A-Q_D on pin-out). From the specification (copies of the data sheets are available) you will see that the chip 'counts' when the COUNT UP input goes from LOW to HIGH but only if the COUNT DOWN input is held HIGH, the LOAD input is HIGH and the CLEAR is LOW. The other inputs can be left floating, but it is good practice to tie them to the positive rail through a suitable resistor.

1. Connect the COUNT UP input to +5V via a 1kΩ and touch the input to ground with an extra wire. The input level is then held LOW. On breaking the ground contact the chip should count (as the input is pulled HIGH), but it will generally be found that the counting is erratic, as it is almost impossible to make or break the contact cleanly.
2. Mechanical switches usually display this effect, which is known as 'switch bounce', and is unacceptable in devices such as computer keyboards. The /R - /S latch is one (common) way to avoid the problem. Connect the normally OFF output of the latch to the COUNT UP input and verify that the chip counts properly. Be sure you understand why!
3. For display purposes it is more convenient to count in a scale of 10, not 16. A simple way to do this, using the '193, is to clear the counter to zero as soon as its output reaches ten. Devise a system of gates to do this automatically and check that it works. Record your circuit and results and show your working circuit to a demonstrator.

- *Keep the counter circuit and latch for later use.*

Exercise 3 TTL "Clock" Pulses

A logic level that switches regularly between 0 and 1, to give a square wave, is often used as a "clock" to give timing signals in a circuit. Here clock pulses will be used as the input to the counter so that the combination can be used as a timer. If your signal generator has a TTL output skip a) and proceed to b).

a) The square wave output from the signal generator is symmetric about 0 V. To make this compatible with TTL it should be positive going, with an amplitude of 3-5 V. Use the circuit shown in figure 5; there will still be some negative excursion (~ 0.7 V) but at an

acceptable level. [What is happening?] Set the amplitude and check the form of the pulse train using the 'scope (set on dc).

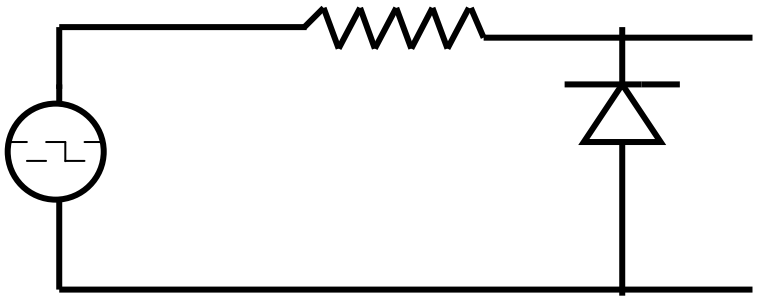


Figure 5 TTL from a square wave.

b) Use the 'scope to confirm that the signals are TTL (0 level less than 0.4 V, 1 level in the range 2.4 to 5 V) then connect to the COUNT UP input of the counter. Check that the lowest order bit of the counter output (Q_A) is changing at half the clock frequency, as expected in binary counting.

Exercise 4 Reaction-time Measurement

You now have a clock with adjustable frequency, a counter and an anti-bounce switch. With these it is possible to make a measurement of reaction-time.

1. First the /R - /S latch (in figure 4) must be modified to respond to two switches. One way to do this is shown in figure 6.

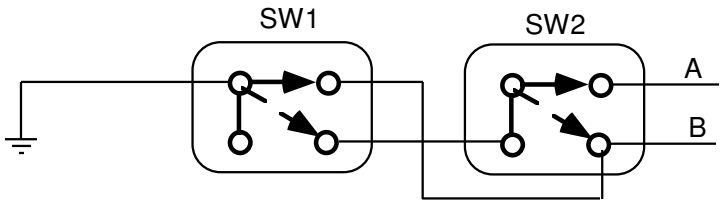


Figure 6 Switch circuit for reaction-time measurement

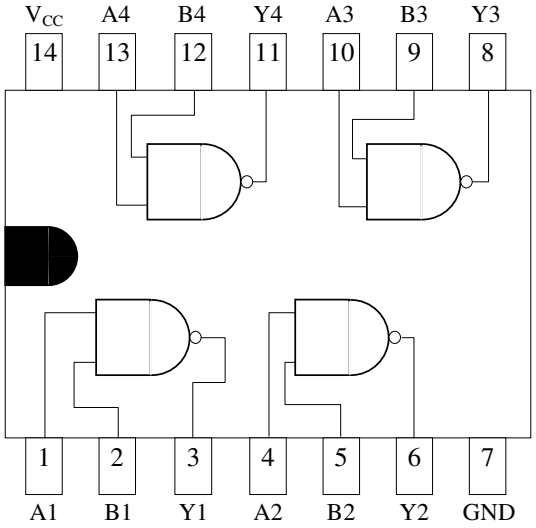
2. Wire up the switches to the latch and confirm that SW1 gives Q = $0 \rightarrow 1$ and, keeping SW1 down, SW2 gives $Q = 1 \rightarrow 0$.

3. The idea is to use Q to gate the clock pulses before they reach the counter. Use a spare NAND gate. One partner presses SW1 which should turn on an LED and allow pulses to reach the counter. The second partner presses SW2 as soon as the LED is seen to light, stopping any more pulses from reaching the counter. Try to adjust the frequency of the clock to make good use of the very limited range of the counter.

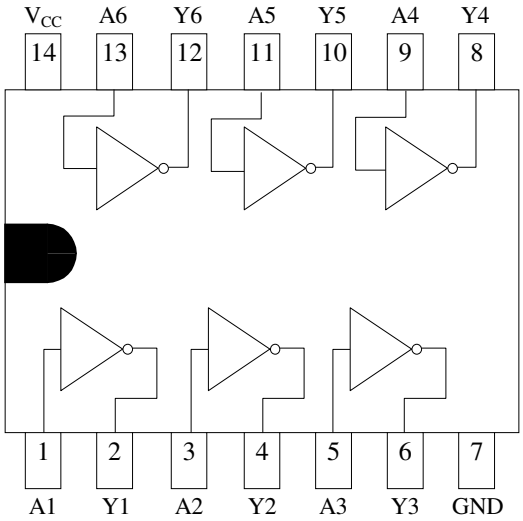
- If you find that the error in the measurement is dominated by the limited resolution of the counting system add a second counter chip to count the CARRY from the first one, and use a higher clock frequency. You can either wire up a second counter or, better, combine with another pair who have reached a similar stage and share counters.
- Do different people have significantly different average reaction times? How do you decide?

Connection Diagrams

7400



7404



74193

