EE 113 Introduction to Electrical Engineering Practice
2019-20/I
Expt 2: BJT and Opamp Circuit Applications (Ver1)

Objectives:

a) Familiarization with the Arbitrary Waveform Generator
b) BJT inverter circuit: to explore the basic modes of a BJT and observe its switching behaviour
c) Proximity sensor using LED-IR detector pair (Object sensor)
d) Hum amplifier using Opamp
e) Opamp difference amplifier for obtaining i-v characteristic of an LED and a Zener diode

Part A – Arbitrary Function Generator

Arbitrary Function Generator (AFG) is a special function generator which can choose a variety of waveforms (sine, square, ramp, arbitrary, etc) whose parameters, such as amplitude, frequency, offset can be adjusted. (Refer to the AFG.pdf for more details on usage of this instrument. You will be using the Arbitrary Function Generator in Part B, Sec 2.2.)

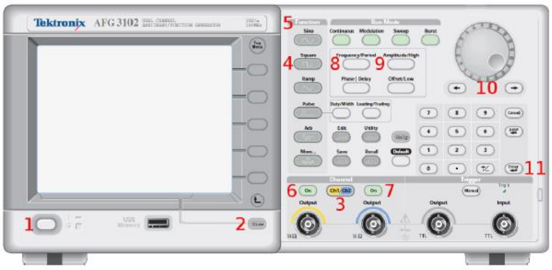


Fig. 2.1 Arbitrary Function generator Panel

<u>2.1 Experiment</u>:

a) Press ‘Output menu’. Choose ‘Load Impedance’ as ‘High-Z’

b) Adjust CH1 output of AFG to obtain a 1 kHz, square waveform going from 0 to +5V. Observe the waveform on the DSO. Learn the usage of X and Y cursors for making measurements.

Part B – BJT Inverter

2.2 BJT Modes of Operation and Voltage Transfer Characteristic

Wire the BJT inverter circuit of Fig. 2.2A using the BC547B NPN transistor. Choose R_C = 10 kΩ, R_B = 47 kΩ Refer to Fig. 2.2B for the BJT terminals. Use the +5 V supply of the Aplab DC Power supply as V_{CC}. Use the adjustable 0-30V supply as the input. The required range of the input voltage V_I for this experiment is 0 to +5V.

<u>Lab Preparation:</u> Draw the BJT inverter circuit diagram. Assume V_{BE} = 0.7 V, V_{CEsat} = 0.2 V and β_{DC} = 50. For the above BJT parameters and R_C = 10 kΩ calculate I_{Cmax} (the maximum theoretical value of I_C in mA). Also calculate V_{IH} (the input voltage at which the BJT just enters saturation).
(V_{OH}: Output high level; V_{OL}: Output low level; V_{IH}: Input high level; V_{IL}: Input low level).

<u>Experiment:</u> Vary V_I from 0 to +5V in small steps, especially between 0 to +1V (Use the ‘Fine’ control of the 0-30V supply along with the DMM to obtain finer steps). Measure all voltages using the DMM only. Altogether about 10 points between 0 to +5V is fine, but ensure that you have at least two points in the cut-off, active and saturation regions. For each V_I value measure V_{BE} and V_O . Sketch the voltage-transfer characteristic of the BJT inverter. Indicate clearly the break points (V_{IL}, V_{IH}, V_{OH} and V_{OL}). Make a table with V_I, V_{BE}, I_B, V_O, I_C, β values. Calculate I_B I_C and β for each V_I value.

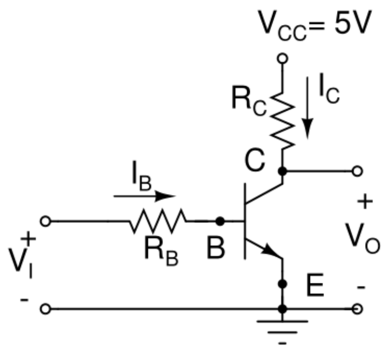


Fig 2.2A BJT inverter

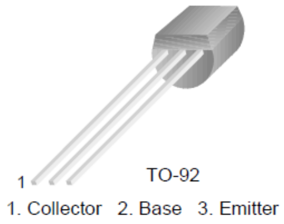


Fig 2.2B BC547B pinout

2.3 BJT Inverter – Switching Characteristics

Experiment: with R_C = 10 kΩ

i) Remove the 0-30 supply connections. (R_C = 10 kΩ, R_B = 47 kΩ). Connect the 1 kHz, 0 to +5V square waveform from the AFG as the V_I input to the BJT inverter. Observe the V_I input on CH-1 and V_O output on CH-2 of the DSO. Ensure that the circuit is working as an inverter.

ii) Without speed-up capacitor: Observe the V_O waveforms at 1 kHz, 10 kHz, 50 kHz and 100 kHz. For the 100 kHz V_I input, measure the rise-time (time taken from 0.1 V_O to 0.9 V_O), fall time (time taken from 0.9 V_O to 0.1 V_O), and the propagation delays (t_{PLH} and t_{PHL}). Sketch the V_I and V_O waveforms. Measure t_{PLH} and t_{PHL} and calculate the propagation delay t_P of the BJT inverter.
Note: t_{PLH} is the delay between 0.5 V_I (high-to-low transition) and 0.5 V_O (low-to-high transition); similarly t_{PHL} is the delay between 0.5 V_I (low-to-high transition) and 0.5 V_O (high-to-low transition); propagation delay t_P is the average of t_{PLH} and t_{PHL}. See Fig. 2.3 for a graphical representation of the above definitions.

iii) With speed-up capacitor: Connect a 0.1 µF capacitor as a speed-up capacitor across R_B. Repeat step (ii) above. Note the improvement in the V_O waveform. Sketch the V_I and V_O waveforms for the 100 kHz case. Measure t_{PLH} and t_{PHL} and calculate the propagation delay t_P of the BJT inverter.

iv) With R_C = 1 kΩ: Remove the speed-up capacitor. Change R_C value to 1 kΩ. Observe the V_I and V_O waveforms for 10 kHz, 50 kHz and 100 kHz. Sketch the V_I and V_O waveforms for the 100 kHz case.

v) Repeat step (iv) with a speed-up capacitor of 0.1 µF. Sketch the V_I and V_O waveforms for the 100 kHz case. Compare this result with the case when R_C was 10 kΩ.

vi) Comment on the waveforms you got for R_C = 10 kΩ and R_C = 1 kΩ, with and without the speedup capacitor. Explain the behaviour.

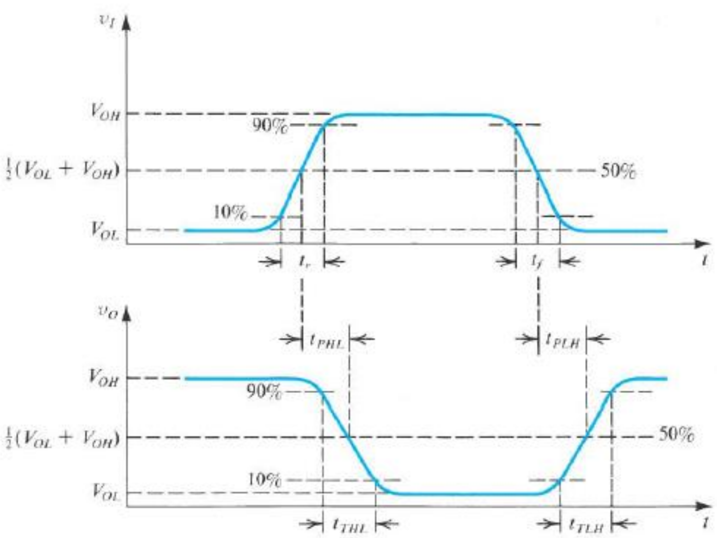


Fig. 2.3 Definitions of rise time, fall time and t_{PHL} and t_{PLH}

Part C – Proximity Sensor using IR LED-Photodetector Pair

2.4 LED-Photodetector Pair for Object Sensing

LED-photodetector pair is used in a variety of applications, such as optocoupler, IR sensor, remote control of appliances etc. Optocoupler is used in applications where electrical isolation is required, and where the ground of one system cannot be connected to the ground of the second system. In an optocoupler the LED is placed in front of a photodetector and the light signals from the first system are passed on to the second system through the photodetector without any electrical connection between the two systems (thereby ensuring electrical isolation). For use as an IR proximity or object sensor, the LED and photodetector are placed in such a way that light from the LED falls on the photodetector only by reflection from the target. In the remote control of a TV (or an electronic appliance) coded signals from the remote device is sent through air to the appliance where it is decoded so as to obtain the required setting. Another application of an LED-photodetector pair is in what is called as VLC (visible light communication) or optical wireless communication, where high speed digital signals are used to modulate a LED which is received by a photodetector located at a distance from the LED transmitter, and is processed n its receiver circuitry.

2.4.1 LED-Photodetector Pair (TCRT-5000) Testing

In our experiment we shall use the LED-photodetector pair (TCRT-5000) for sensing the presence or absence of an object.

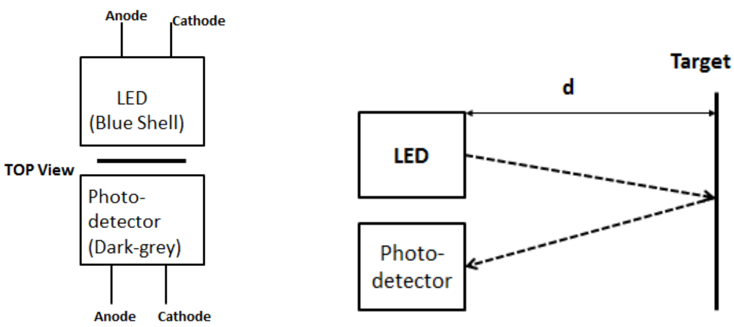


Fig. 2.4A LED-Photodetector pair IR LED-Photodetector (TCRT-5000)

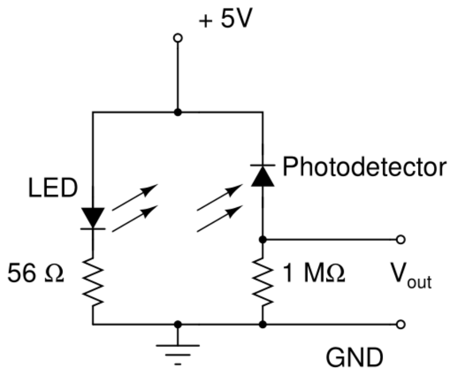


Fig. 2.4B LED-Photodetector Test circuit

<u>Experiment:</u>

Identify the LED and photodetector terminals of the given TCRT-5000 sensor and wire the circuit of Fig. 2.4B. Measure V_{out} for : i) no object /target in front of the sensor; ii) a reasonably bright target, such as a white paper kept close to the sensor.

2.4.2 LED-Photodetector Pair Interface Circuit using a BJT Inverter

The aim of this part is to build an interface circuit for the TCRT-5000 sensor so as to generate a pulse signal when a nearby target is detected.

<u>Experiment:</u>

Wire the circuit of Fig.2.4C. Measure BJT inverter output with and without a target.

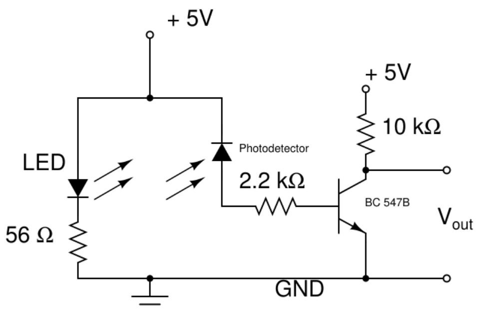


Fig.2.4C LED-Photodetector pair interface circuit

Part D – Opamp based Amplifiers (Hum and Signal)

2.5 Opamp Hum Amplifiers

The objective of this part of the experiment is to amplify hum (50 Hz pickup) and AFG signals by opamp amplifiers. Opamp circuit with higher input resistance would be affected most by such pickups. This also illustrates the need to keep wires short.

<u>Note:</u> The 741 opamp uses two power supplies, viz. +12V and -12V (V^+ = +12 V and V^- = -12V). Please note that Opamp has no GND connection in it. However your circuit should have a GND with reference to which everything is measured. Your circuit GND is the common terminal of the +12 and -12V power supplies.

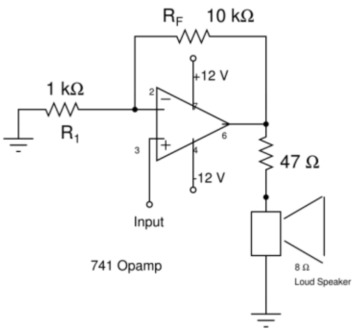
2.5.1 Hum Amplifier using a Non-Inverting Amplifier

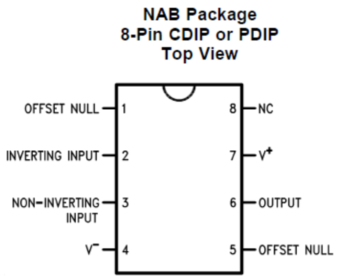
<u>Experiment</u>: Wire the non-inverting amplifier Opamp circuit of Fig.2.5A. R_1 = 1 kΩ and R_F = 10 kΩ.

i) Touch the non-inverting input with your fingers and listen to the hum (50 Hz) on the loud speaker.

ii) Connect the non-inverting input to GND and once again listen for any hum.

iii) Explain the observations in (i) and (ii).





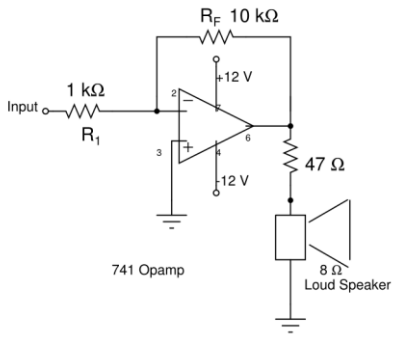


Fig. 2.5A Hum amplification using a non-inverting amplifier; Fig. 2.5B 741 pinout; Fig.2.5C Inverting amplifier

2.5.2 Hum Amplifier using an Inverting Amplifier

<u>Experiment</u>: Wire the inverting amplifier Opamp circuit of Fig.2.5C. R_1 = 1 kΩ and R_F = 10 kΩ.

i) Touch the input to the amplifier (the inverting input) with your fingers and listen to the hum (50 Hz) on the loud speaker. Could you hear any hum?

ii) Now make R_1 = 100 kΩ and R_F = 1 MΩ. Now listen to the hum on the loud speaker. Are you able to hear hum?

iii) Explain why you were able to hear hum for Sec 2.5.1 for the non-inverting amplifier (Voltage gain =11) while you could not hear for the inverting amplifier case (Voltage gain = -10) even though the voltage gain and the resistance values were roughly the same in both cases. However, you were able to hear hum for the inverting amplifier case when R_1 = 100 kΩ and R_F = 1 MΩ (Voltage gain = -10).

iv) Use 500 Hz and a 1 kHz, 0.5 sin ωt signals from the AFG as the input signal. Use R_1 = 1 kΩ and R_F = 10 kΩ and try using for both non-inverting and inverting amplifiers. Unlike the case for hum, you should get similar loudness for both non-inverting and inverting amplifiers.

v) Based on your observations, point out the major difference between a non-inverting amplifier and an inverting amplifier with same voltage gains (other than the phase difference). What is its significance? (Try to reason out what would happen when the above amplifiers are used to amplify the output of a sensor which has a very high (say 1 MΩ) Thevenin equivalent resistance. In such cases which one should be preferred – the non-inverting amplifier or the inverting amplifier? Justify your choice.
<u>Note:</u> An amplifier is a controlled source. In the above cases both were voltage amplifiers and were voltage controlled voltage sources.

vi) Think of a good application for the inverting amplifier. Can it be used to convert the output current (photo current) of the photodetector in Sec 2.4 to a voltage?

Part E – Opamp Difference Amplifier

2.6 V-I Characteristic of an LED and a Zener Diode using Opamp Difference Amplifier

<u>2.6.1 Difference Amplifier</u>

Connect the circuit of Fig. 2.6A. Instead of the AFG connect +5 V as the input to the LED circuit. Using the DMM measure the voltage across the 1 kΩ resistor. Measure the 741 opamp output voltage. Estimate I_D for both cases. Compare the results.

<u>2.6.2 V-I Characteristic of an LED</u>

Connect the circuit of Fig. 2.6A. Obtain a 1 kHz triangular waveform of amplitude -10 V to +10V from the AFG.

a) Observe the V_D (voltage across the diode) and I_D (diode current in mA) waveforms on the DSO with respect to time. Try to explain the voltage and current waveforms.
b) Change the display mode of the DSO to X-Y mode (Use the Display Menu > Format and choose Y-T mode or X-Y mode). Adjust the X (CH-1) and Y (CH-2) waveform settings such that the origin of the X-Y plot is at the centre. Chose CH-1 and Ch-2 settings to be 1 V/Div. Connect V_D waveform as X and I_D waveform as the Y. Measure the junction voltage V_{LED} (the voltage at which the LED starts conducting.

<u>2.6.3 V-I Characteristic of a Zener diode</u>

Replace the LED in Fig. 2.6A with the given Zener diode (3.6 V Zener). The anode and cathode connections of the Zener diode should be the same for the LED. Follow the same procedure as followed for the LED V-I characteristic in Sec 2.6.2. Try to explain the V_D and I_D waveforms you get in the Y-T mode. In the X-Y mode, measure the Zener breakdown voltage for I_Z = 4 mA. Also estimate the dynamic resistances of the Zener diode in the forward biased case and in the Zener region.

Question: What is the significance

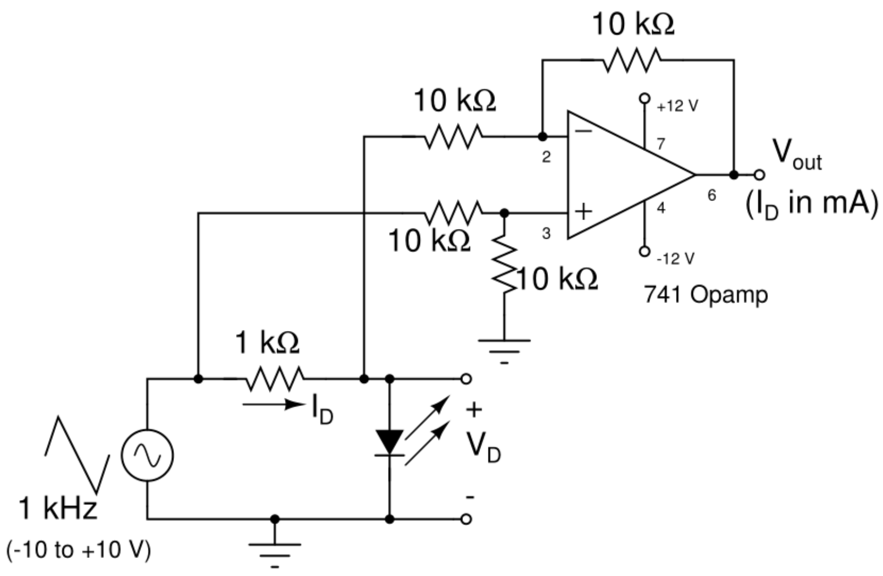


Fig. 2.6A Experimental setup for measuring the V-I characteristic