

EE 330 Laboratory 9

Bipolar Devices and Applications

Spring 2019

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Objective:

The objective of this laboratory is to develop measurement methods for extracting device parameters of the Bipolar Junction Transistor (BJT) and to investigate applications of discrete BJTs.

In this experiment, you will be measuring waveforms, operating points, and gains. All of these measurements should be made with the oscilloscope. The multimeter that is on the laboratory bench should not be used for any measurements in this experiment.

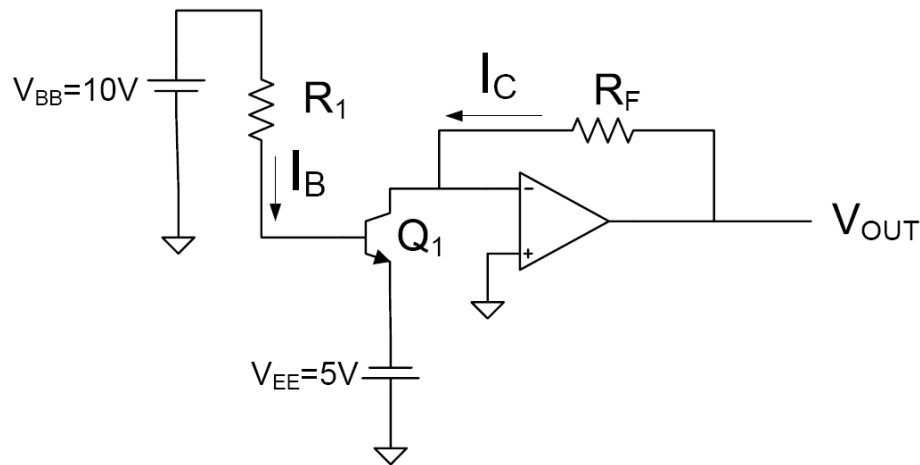
Components Needed:

PN2222 BJT, operational amplifier, LNA2903L Infra-red LED, PNZ323 Infra-red Photo Diode, and other standard electronic components. Data sheets for these components are posted on the EE 330 class web site.

Discussion:

-- Measurement of Small-Signal BJT Parameters

The measurement of parameters of devices is often facilitated with the use of simple op amp circuits. The circuit shown below is useful for measuring some parameters of the bipolar transistor. Although configured to facilitate measurement of parameters of npn transistors, some straightforward modifications can be used to make measurements of parameters of pnp transistors as well.



In this circuit the voltage V_{EE} is used to create a positive value for V_{CE} . The base current is given by

$$I_B = \frac{V_{BB} + V_{EE} - 0.6}{R_1}$$

The collector current is proportional to I_C . The component values R_1 and R_F can be chosen to establish the desired base current level and the desired output voltage level respectively.

Note: R_1 should be very large ($>1\text{ M}\Omega$) and R_F should be small ($<10\text{ k}\Omega$).

Datasheets for discrete transistors were very complete 25 years ago but with the limited use of discrete bipolar transistors today, details provided in the datasheets are often sketchy. In textbooks of the 60s and 70s, the small-signal parameters of the bipolar transistor were generally expressed in terms of h-parameters (hybrid parameters) rather than in terms of the conductance parameters that are more commonly used today. This is still reflected in the datasheets today. The relationship between the conductance parameters and the h-parameters are

$$\begin{aligned}\beta &= h_{fe} \\ g_{\pi} &= h_{ie} \\ g_o &= h_{oe}\end{aligned}$$

The key parameter g_m is generally not given directly in a datasheet but

$$g_m = \beta g_{\pi} = h_{fe} h_{ie}$$

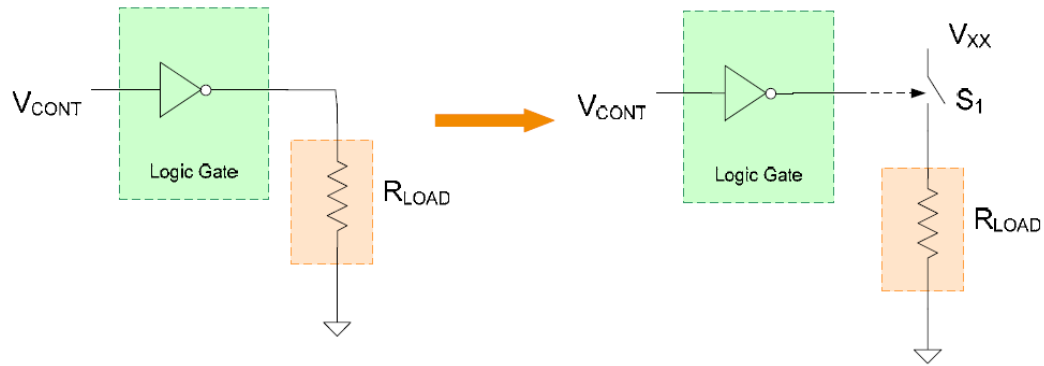
There is one other small-signal parameter that is given in some of the datasheets, h_{re} . This parameter was not discussed in class and characterizes the small amount of feedback that exists in the bipolar transistor from the collector to the base. By assuming the BJT is unilateral, we have neglected this effect.

It was shown in the device models that were established in the lecture portion of this course that the small signal parameters g_o , g_m , and g_{π} are strongly operating point dependent. Unfortunately, most manufacturer's datasheets do not directly reflect this dependence and simply give the small-signal h-parameters at a single operating point. This limits the direct usefulness of the small-signal model parameters that are given but since the functional relationship between operating point and small-signal parameters is known, the small signal parameter at different operating points can be determined if the value of that small signal parameter at one operating point is given .

To obtain V_{AF} (Early Voltage) use the parametric analyzer to obtain IV curve of your BJT and then fit an equation to the linear part of your curve. Solve the equation for x-intercept, $V_{AF} = |x - intercept|$. Note that this is very similar to what we did when characterizing an NMOS

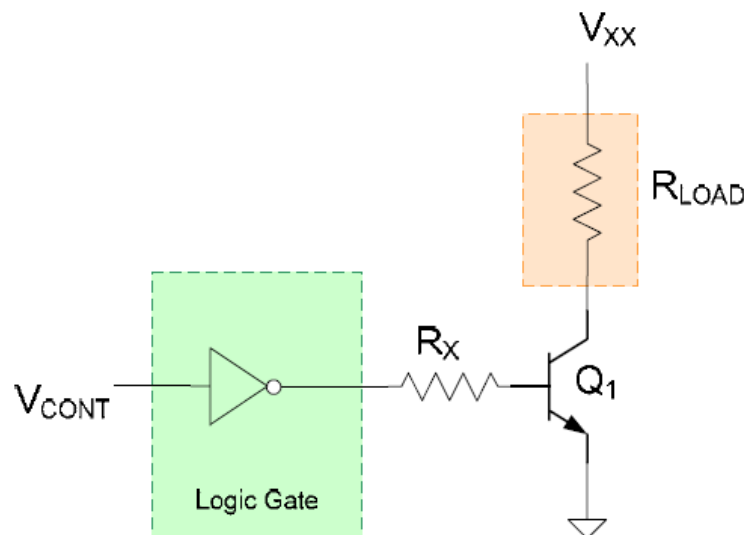
Application of BJT to driving large loads

One common task of an electronic circuit is to drive a rather large load (a load that requires a large current) based upon the Boolean status of a logic gate or based upon the output level of a comparator or an operational amplifier. Conceptually, a logic gate is depicted driving a load in the following figure.



Concept of driving load based upon condition of Boolean Variable

Although there are a small number of applications where this load can be driven directly as indicated in the figure, there are two major limitations that preclude this approach in most applications. The first is the voltage level that will be supplied to the load with this approach is the same as the high Boolean logic level which may not be the desired voltage that is to be applied to the load. The second is the current drive limitations of the Boolean gate or the comparator or op amp. The BJT is often used to serve as a switch when large loads need to be driven and this is one of the most common applications of discrete BJTs today. The use of a BJT as a switch is shown in the following figure.



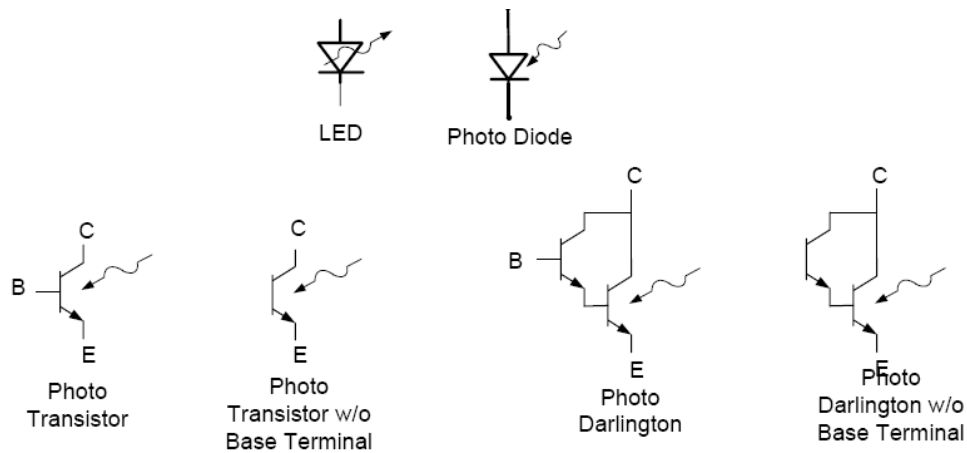
Use of a BJT as a switch

Because of the high current gain of most good BJTs, a small amount of dc current can be used to control a large amount of current in the collector. When used as a switch, the base current drive should be sufficiently strong so that the transistor will operate in cutoff when in the “OFF” state and in saturation when in the “ON” state. If the base current drive is not sufficiently strong to drive the transistor into the saturation region in the “ON” state, it will generally end up in the forward active region. Although the forward active region is widely used when building an amplifier, it is generally avoided when using the BJT as a switch. If insufficient base drive is not provided, two undesirable effects will be observed. First, the voltage at the load will not be at the desired level. And, second, since the CE voltage will not be small, excessive power dissipation will occur in the BJT and, depending upon the application, this could cause so much heating that the BJT will be destroyed.

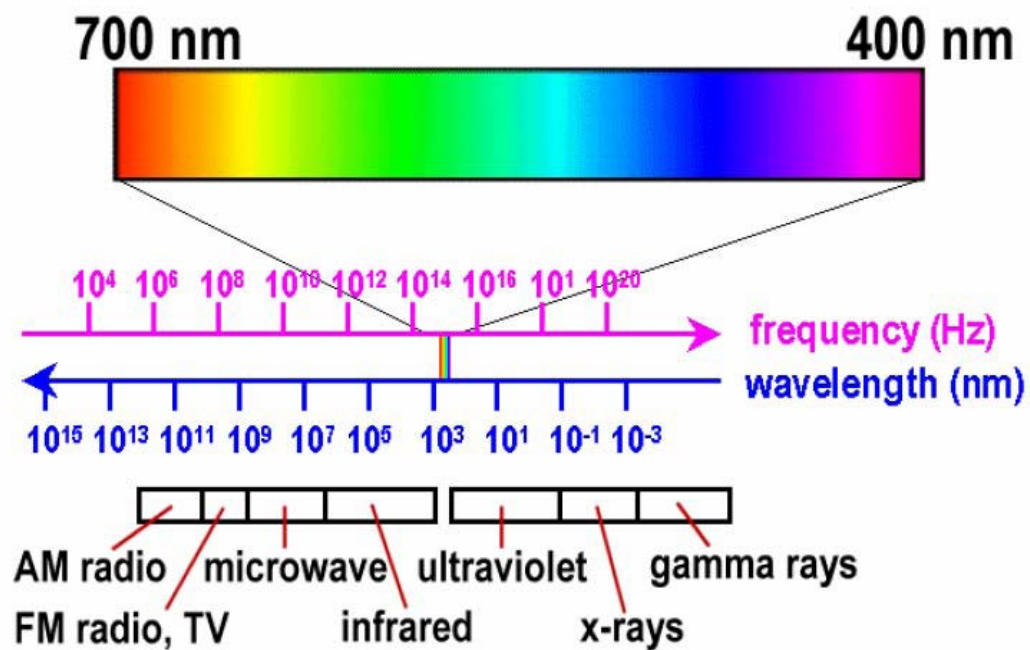
Application of BJT to optoelectronics

Many applications of bipolar transistors and diodes are in the greater optoelectronics area whereby light energy is emitted from semiconductor devices or whereby incident light is detected by semiconductor devices. Light emitting diodes (LEDs) and laser diodes are widely used as sources of light and photodiodes, photo-transistors and Darlington phototransistors are widely used as light detectors. Invariably the light sources will emit energy over a rather narrow spectral range and invariably photo-detectors will respond optimally over a limited spectrum and often little if at all at to other wavelengths of light. When transmitting light and detecting light, it is important that the spectral response of the transmitter and detectors be compatible. Optoelectronic devices operate over a wide frequency spectrum with some operating at speed up to 1GHz or higher thus making them useful for very high speed data communications.

The symbols for a LED, photo-diode, photo-transistor, and a photo-Darlington transistor are shown below. In the LED, the light emitted increases with the current flowing in the device. In a photo-diode, the reverse biased diode current increases with light intensity and in the photo-transistor and photo-Darlington structures, the collector current increases with light intensity. The photo-transistors can be used with or without a connection to the base lead and in some photo-transistors, the base lead is not even available. If a base current is input to a photo-transistor, the collector current is that sum of that due to photons entering the base region and that due to the base current.



Many light sources operate in the visible region with wavelengths between 400nm and 700nm whereas others operate in the much broader infrared region which is not visible to the human eye. The spectral bands of light are shown in the figure below.

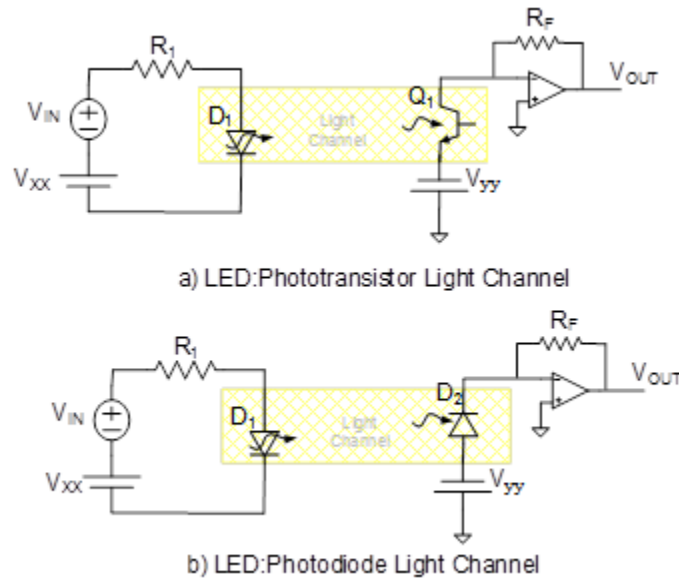


Spectral Bands of Light (obtained from WWB as site <http://groups.csail.mit.edu/graphics/classes/6.837/F01/Lecture02/sp>)

Some applications of optoelectronics include essentially all communications over fiber optic networks, the remote controllers used for TVs, CD players, etc, the detectors

in scanners, and imagers that are used in digital cameras and cell phone.

One application that will be considered in this experiment is an optical wireless link. Such a link can be used to transmit an audio signal over an air channel. A block diagram of a possible implementation of an audio link using a phototransistor (or photodiode) is shown below.



Optical Links

In these structures, a quiescent bias is maintained on both the LED and the phototransistor (or photodiode) so that reasonably linear operation is obtained when a small-signal input is present. The amount of light emitted from the LED and the amount of light received by the phototransistor (or photodiode) is strongly a function of the orientation of the devices, the radiation pattern for the devices, and the spectral region over which light is emitted and detected respectively.

Note: In both structures there has been a problem with the waveform coming out of the op-amp interfering with the signal it is attempting to amplify. If a later stage signal is interfering with an earlier signal it is often fixable with a buffer, we advise using a unity gain amplifier configuration.

Part 1

Extract and compare the small-signal model parameters g_m , g_0 , and g_π with those given in one of the data sheet for the PN2222. Remember you have to relate them through the h-parameters and can only make a comparison at one operating point since the parameters are only given at one operating point.

Part 2

Design a circuit that will drive a 500Ω load between 0V and 10V when a Boolean signal goes between 5V and 0V (notice that the output needs to be inverted).

Part 3

Design and test a wireless optical link that will transmit a signal over at least 6 inches. The signal must be recognizable at the far end of the circuit. Demo it to your TA.

Deliverables:

- Verification sheet
- Introduction:
 - Discuss what is done in lab
 - Discuss why is it useful
- Part 1 – BJT small signal parameters extraction:
 - Analytically explain how this circuit is useful to extract small signal parameters
 - Why is Collector connected to Null Port of the Op-Amp?
 - Show I-V plot from parametric analyzer and compare it to the one from MOSFET
 - Explain how you extracted β , g_m , g_π and g_0
 - You need to include plot for g_0
 - Compare extracted values against the one from datasheet
- Part 2 – Application of BJT to drive large loads:
 - Explain how your design works
 - Show a picture of both input and output on the oscilloscope
 - Analyze your output
- Part 3 – Application of BJT to optoelectronics:
 - Explain how the circuit works
 - Think of the diode model, what happens when it is forward biased, what happens when its reverse biased?
 - Explain your choices of V_{xx} , V_{yy} , R_F , and R_I
 - Show a picture of both input and output on the oscilloscope
 - Demonstrate this to your TA
- Conclusion:
 - Discuss what you learned in lab
 - Add any comments on what you liked or what would you want to see changed