School of Electrical & Electronic Engineering

E2002L Analog Electronics

Academic Year 2021-2022

L2002C

BJT Amplifier

Project Laboratory (S2-B4a-01/02)

Dress Code in the Laboratory

- **Work shirt that covers the upper torso and arms.**
- **Lower body clothing that covers the entire leg.**
- **Closed-toe shoes that cover the top of the foot.**

Laboratory Manual

BJT Amplifier

Name : ____

Group : ____

Date : ____

Last Reviewed: Aug 2021 Reviewed by: A/P Yvonne Lam

CONTENTS

1. INTRODUCTION

For this experiment, a discrete npn transistor is used. Figure 1 shows the pin-outs for 2N3904.

2. OBJECTIVES

The objectives of this experiment are:

(a) to measure the dc biasing conditions of the BJT amplifier;

(b) to evaluate the small signal gain of the amplifier;

(c) to analyse the effect of inclusion of an additional emitter resistor.

Notations adopted in this manual are:

v denotes ac node voltages
V denotes dc node voltages

3. EQUIPMENT AND COMPONENT LIST

The following equipment and components are required:

Signal generator
Oscilloscope
Digital multi-meter
Power supply
Breadboard

Transistor	2N 3904	x 1		
Resistors	75 Ω	x 1	2 kΩ	x 2
	150 Ω	x 1	20 kΩ	x 2
	560 Ω	x 1	220 kΩ	x 1
	1 kΩ	x 1	10 kΩ (variable)	x 1
	1.5 kΩ	x 1		
Capacitors	4.7 μF	x 1		
	22 μF	x 1		

4. **<u>DC CONDITIONS</u>** [Suggested Time: 30min]

A common-emitter amplifier using is given in Figure 2. Setup the amplifier circuit using the values given in Table 1

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Table 1

V_{CC}	20	V
R_1	220	kΩ
R_2 (variable)	10	kΩ
R_C	20	kΩ
R_E	0	kΩ
C_1	22	μF

Do not connect v_{in} under DC condition.

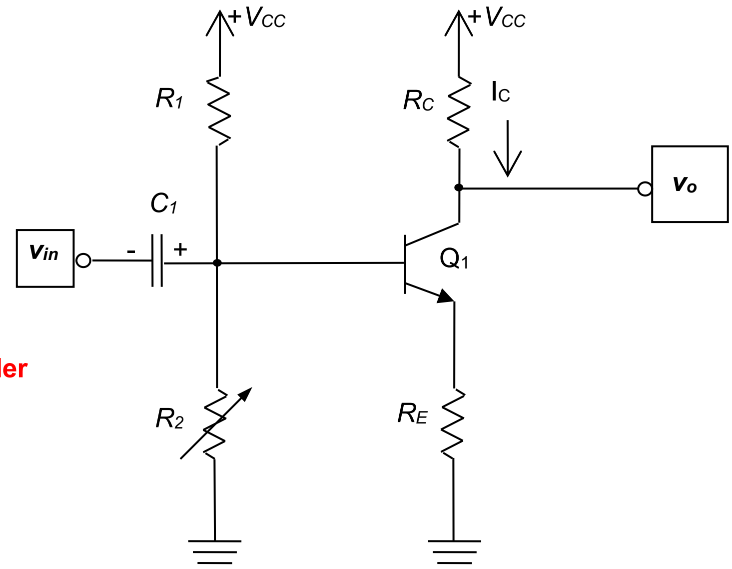


Figure 2 A Common-Emitter BJT Amplifier

The biasing of the circuit should be carefully adjusted until V_o attain a value of ½ V_{CC}.
Before any measurement, estimate the resistance R_2 and the collector current I_C that is required to set V_o to be ½ V_{CC}, and record them in Table 2. Now, adjust the variable port of R_2 until V_o reaches ½ V_{CC}.

Measure the values of R_2 and I_C (use ammeter for current measurement) and record them in Table 2. Does the measured value tally with your estimation?

Table 2

	Estimated values		Measured values	
Resistance, R_2	7.9	kΩ	7.8	kΩ
Collector current, I_C	Text	mA		mA
Output voltage, V_o	½ V_{CC}	V		V

5. SMALL SIGNAL RESPONSE

In this section, continue to use the circuit constructed in Section 4 to evaluate the small signal behaviour of the common-emitter amplifier.

5.1. Non-linear Gain of a Grounded-Emitter Amplifier [Suggested Time: 30min]

When R_E is set to zero, it is a special case of Common-Emitter amplifier, which is known as the Grounded-Emitter amplifier. The general gain of common-emitter amplifier can be approximated to $\frac{\text{Total collector resistance}}{\text{Total emitter resistance}}$.

By keeping all circuit components unchanged as in section 4 and applying a small triangular waveform of $v_{p\text{-}p}$ = 40 mV at 1 kHz to v_{in} of Figure 2. Use the oscilloscope to monitor and observe the voltage waveform at v_o. Do you observe an output waveform that looks like Figure 3? Why do you not get a triangular output waveform?

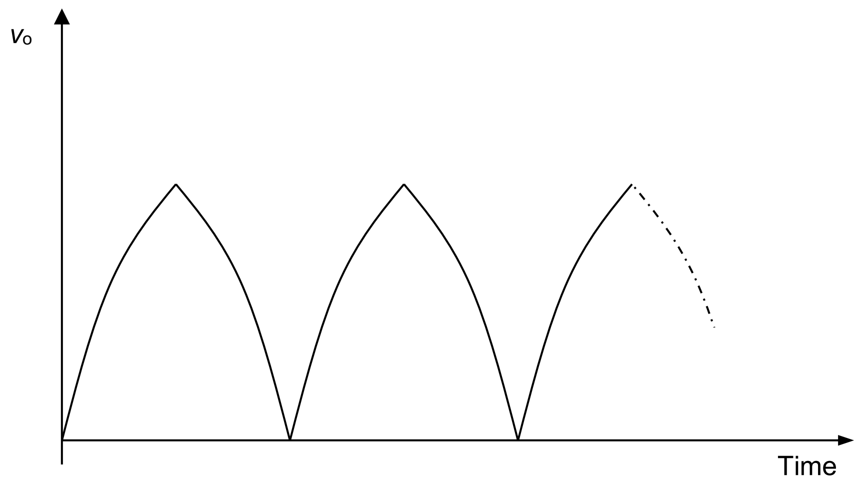


Figure 3 "Barn-roof" distortion from a Grounded-Emitter amplifier

If the gain of the amplifier is linear, one would expect an exact output waveform as the input waveform (except that the waveform is amplified). Although, there is no external emitter resistance connected to the circuit, there is an intrinsic emitter resistance, r_e, and its value can be approximated to $\frac{V_T}{I_C}$. As I_C varies while v_o moves, the gain changes. Therefore the distorted output is observed. How about verifying this behaviour by **calculating** the gain at various v_o (instantaneous value) and record them in Table 3 (assume V_T to be 25 mV)? [After completing section 5.4, student might like to verify the calculated gains, if time permits].

Table 3

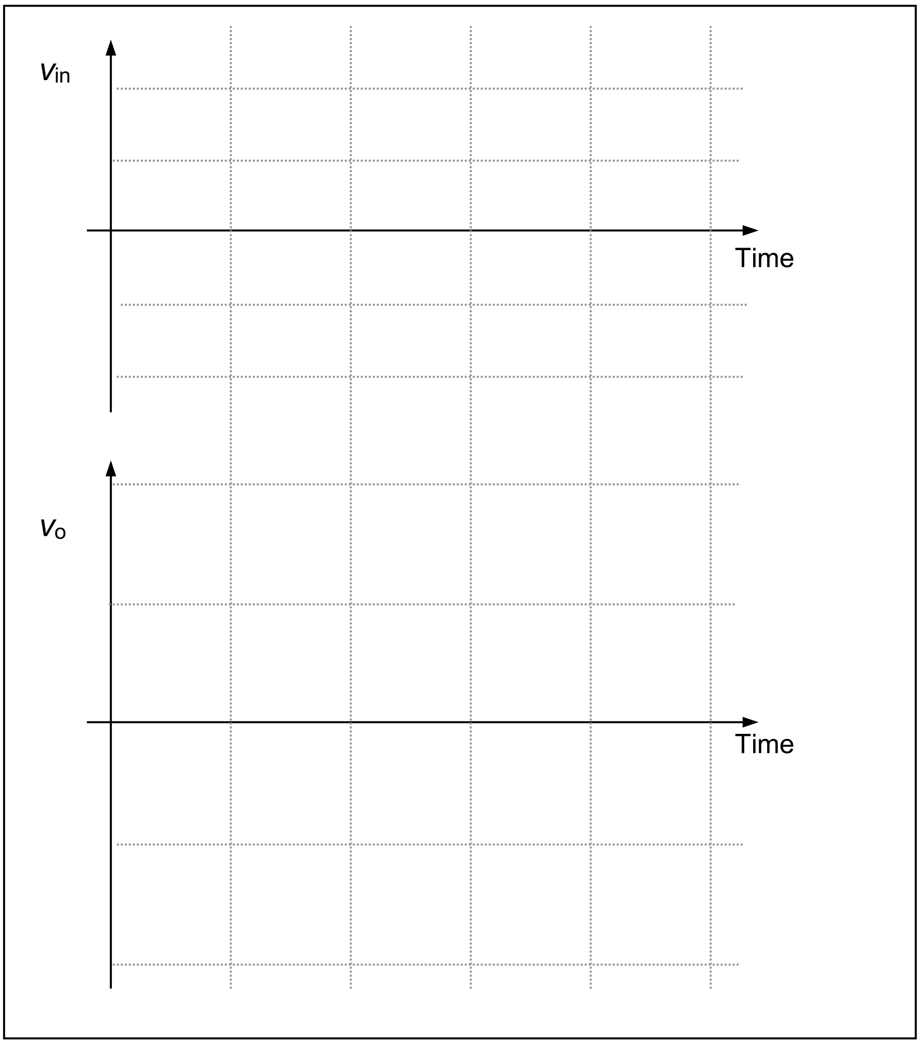
v_o / V	I_C / mA	r_e / Ω	Gain (V/V)
12.0			
10.0			
5.0			
0.5			

Do you see that the gain changes over a wide range of values as v_o changes?

What is the calculated gain of this amplifier? $\left.\frac{R_C}{r_e}\right|_{bias}$ = Text V/V.

What is the measured gain of this amplifier? $\frac{V_{o(p\text{-}p)}}{V_{in(p\text{-}p)}}$ = V/V.

What do you expect the output of a sinusoidal waveform to look like, after it is amplified by a non-linear amplifier? This can be observed by changing the input waveform to a sinusoidal waveform of $v_p = 20$ mV at 1 kHz. Observe the output voltage at v_o, sketch the input and output waveforms in Graph 1.



Graph 1 Input and output waveforms of Grounded-Emitter amplifier

5.2. **Inclusion of Emitter resistor** [Suggested Time: 40min]

As seen from Table 3 that the gain of the amplifier is dependent on r_e. The variation of r_e cannot be eliminated since it is intrinsic to the transistor. However, the effect of this variation can be minimised by adding an external R_E (which is constant). By taking a much larger value than the varying r_e will make the denominator of the gain equation almost constant.

Reconstruct the circuit shown in Figure 2 by using the values given in Table 4.

Table 4

V_{CC}	20 V
R_1	220 kΩ
R_2	20 kΩ
R_C	20 kΩ
R_E	2 kΩ
C_1	22 μF

Now, supply the input with a triangular signal of $v_{p\text{-}p}$=120mV at 1 kHz. Use the oscilloscope to monitor and observe the voltage waveform at v_o. Do you still observe a distorted "barn-roof" output waveform? If not, then it appears that the amplifier is amplifying at a constant gain. Is it true? Let us verify the gain variation of this amplifier by **calculating** the gain at various instantaneous, v_o, and record them in Table 5 (note that the gain for this amplifier is now $\frac{R_C}{R_E + r_e}$.

Table 5

v_o / V	I_C / mA	r_e / Ω	Gain (V/V)
12.0			
10.0			
5.0			
0.5			

Compare Table 3 and Table 5, what can you comment about the values of gain and its variation?

Lastly, change the input from triangular waveform to sinusoidal of v_p = 20 mV at 1 kHz. Observe the output voltage on an oscilloscope, do you notice any distortion as for the case of Grounded-Emitter amplifier?

Estimate the gain of this amplifier: $\left.\frac{R_C}{R_E + r_e}\right|_{\text{bias}}$ = V/V.

What is the measured gain of this amplifier? $\frac{V_{o(p\text{-}p)}}{V_{in(p\text{-}p)}}$ = V/V.

Increase the magnitude of v_{in} until just before the waveform starts to distort. What is the gain of the amplifier circuit at this point? Does it vary much from the previous gain?

So, by adding an emitter resistance to the circuit, we have introduced negative feedback to stabilise the circuit performance.

5.3. **Emitter capacitance to achieve higher ac Gain** [Suggested Time: 20min]

We have seen how the intrinsic emitter resistance affected the gain of the amplifier. We have also noted the remedy to bury the gain variation by adding a large external emitter resistor. Now, the next challenge is: what do you need to do if both stability and high gain are desired? The solution is to include R_E for DC biasing but diminish its effect for ac, i.e., include a bypass capacitor. In other words, add a C_E that is parallel to R_E. With this concept in mind, circuit in Figure 2 is modified to be one as shown in Figure 4.

Setup the circuit by using the values given in Table 6. By choosing a value of C_E whereby its reactance is negligible within the signal frequency has the effect of 'shorting' or reducing the value of R_E under ac operation. R_3 is included so that the ac gain can be adjusted.

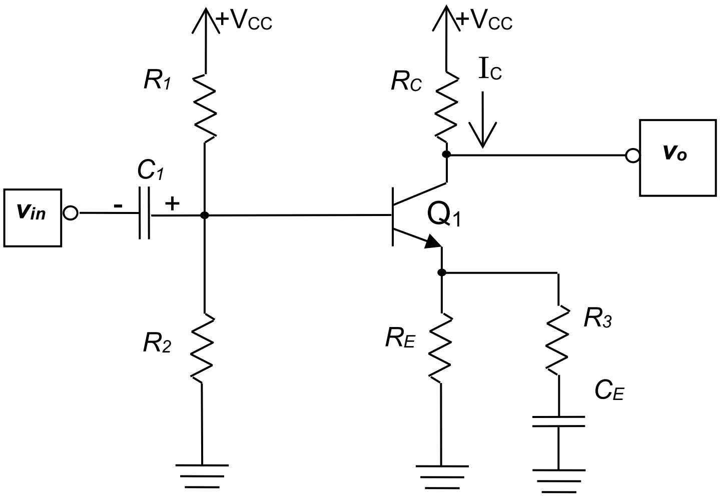


Figure 4 Common-Emitter amplifier with bypass capacitor

Table 6

R_1	220 kΩ
R_2	20 kΩ
R_3	75 Ω
R_C	20 kΩ
R_E	2 kΩ
C_1	22 μF
C_E	4.7 μF

Connect a sinusoidal waveform of v_p = 20 mV at 1kHz to the input v_{in}. What is the expected gain for the amplifier circuit?

Gain = V/V

What is the measured gain of this circuit? V/V

Increase the magnitude of input waveform until the distortion on output waveform is first observed. Do you expect the gain of the amplifier circuit to change?

What is the measured gain of your amplifier circuit? V/V

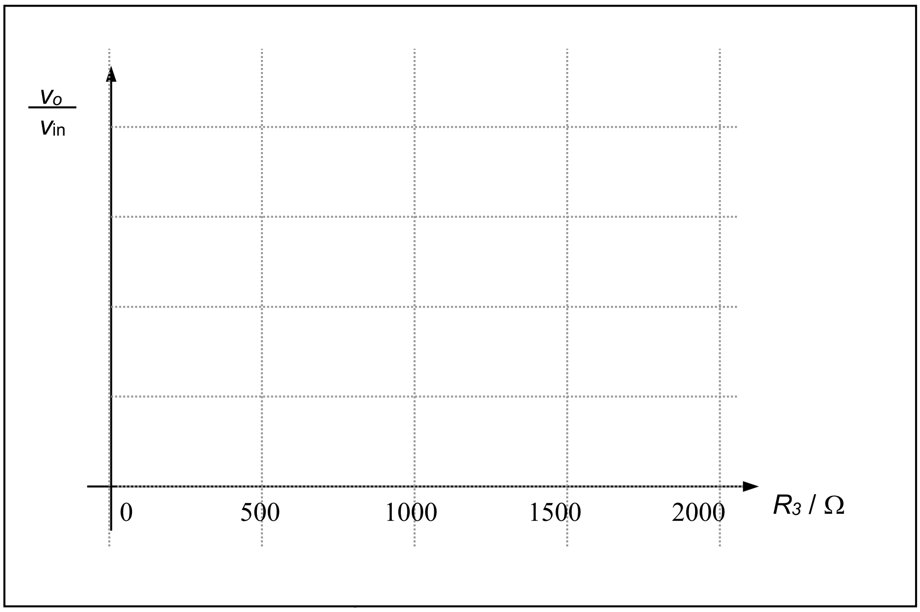
Suggest any reason(s) for the discrepancies between the calculated and measured gain, if any (e.g. effect of C_E).

5.4. **Effect of changing R_3 on ac Gain** [Optional]

Based on the results from earlier experiment, what value would you assign the value of R_3 if maximum ac gain were to be achieved? Verify your understanding with the following experiment if time allows. Change the value of R_3 according to the values listed in. Keeping $v_{in(p)}$ at 20 mV at 1kHz, measure the output voltage v_o and complete the missing data in Table 7 and plot the results in Graph 2. Students are strongly encouraged to estimate the expected gains first before proceeding to the measurements.

Table 7

R_3 / Ω	$v_{o(p\text{-}p)}$ / V	Measured Gain $\frac{V_{o(p\text{-}p)}}{V_{in(p\text{-}p)}}$
0		
75		
150		
560		
1000		
1500		
2000		



Again, suggest any reason(s) for the discrepancies between the calculated and measured gain, if any (e.g. effect of C_E).

6. DATASHEETS

FAIRCHILD SEMICONDUCTOR®

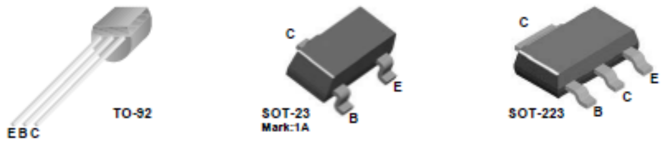
October 2011

2N3904 / MMBT3904 / PZT3904
NPN General Purpose Amplifier

Features

- This device is designed as a general purpose amplifier and switch.
- The useful dynamic range extends to 100 mA as a switch and to 100 MHz as an amplifier.

2N3904 MMBT3904 PZT3904



Absolute Maximum Ratings* T_a = 25°C unless otherwise noted

Symbol	Parameter	Value	Units
V_{CEO}	Collector-Emitter Voltage	40	V
V_{CBO}	Collector-Base Voltage	60	V
V_{EBO}	Emitter-Base Voltage	6.0	V
I_C	Collector Current - Continuous	200	mA
T_J, T_{stg}	Operating and Storage Junction Temperature Range	-55 to +150	°C

* These ratings are limiting values above which the serviceability of any semiconductor device may be impaired.

NOTES:

1) These ratings are based on a maximum junction temperature of 150 degrees C.

2) These are steady state limits. The factory should be consulted on applications involving pulsed or low duty cycle operations.

Thermal Characteristics T_a = 25°C unless otherwise noted

Symbol	Parameter	Max.			Units
		2N3904	*MMBT3904	**PZT3904	
P_D	Total Device Dissipation Derate above 25°C	625 5.0	350 2.8	1,000 8.0	mW mW/°C
$R_{\theta JC}$	Thermal Resistance, Junction to Case	83.3			°C/W
$R_{\theta JA}$	Thermal Resistance, Junction to Ambient	200	357	125	°C/W

* Device mounted on FR-4 PCB 1.6" X 1.6" X 0.06".

** Device mounted on FR-4 PCB 36 mm X 18 mm X 1.5 mm; mounting pad for the collector lead min. 6 cm^2.

2N3904 / MMBT3904 / PZT3904 — NPN General Purpose Amplifier

Electrical Characteristics T_a = 25°C unless otherwise noted

Symbol	Parameter	Test Condition	Min.	Max.	Units
OFF CHARACTERISTICS					
$V_{(BR)CEO}$	Collector-Emitter Breakdown Voltage	I_C = 1.0mA, I_B = 0	40		V
$V_{(BR)CBO}$	Collector-Base Breakdown Voltage	I_C = 10μA, I_E = 0	60		V
$V_{(BR)EBO}$	Emitter-Base Breakdown Voltage	I_E = 10μA, I_C = 0	6.0		V
I_{BL}	Base Cutoff Current	V_{CE} = 30V, V_{EB} = 3V		50	nA
I_{CEX}	Collector Cutoff Current	V_{CE} = 30V, V_{EB} = 3V		50	nA
ON CHARACTERISTICS*					
h_{FE}	DC Current Gain	I_C = 0.1mA, V_{CE} = 1.0V I_C = 1.0mA, V_{CE} = 1.0V I_C = 10mA, V_{CE} = 1.0V I_C = 50mA, V_{CE} = 1.0V I_C = 100mA, V_{CE} = 1.0V	40 70 100 60 30	300	
$V_{CE(sat)}$	Collector-Emitter Saturation Voltage	I_C = 10mA, I_B = 1.0mA I_C = 50mA, I_B = 5.0mA		0.2 0.3	V V
$V_{BE(sat)}$	Base-Emitter Saturation Voltage	I_C = 10mA, I_B = 1.0mA I_C = 50mA, I_B = 5.0mA	0.65	0.85 0.95	V V
SMALL SIGNAL CHARACTERISTICS					
f_T	Current Gain - Bandwidth Product	I_C = 10mA, V_{CE} = 20V, f = 100MHz	300		MHz
C_{obo}	Output Capacitance	V_{CB} = 5.0V, I_E = 0, f = 1.0MHz		4.0	pF
C_{ibo}	Input Capacitance	V_{EB} = 0.5V, I_C = 0, f = 1.0MHz		8.0	pF
NF	Noise Figure	I_C = 100μA, V_{CE} = 5.0V, R_S = 1.0kΩ, f = 10Hz to 15.7kHz		5.0	dB
SWITCHING CHARACTERISTICS					
t_d	Delay Time	V_{CC} = 3.0V, V_{BE} = 0.5V I_C = 10mA, I_{B1} = 1.0mA		35	ns
t_r	Rise Time			35	ns
t_s	Storage Time	V_{CC} = 3.0V, I_C = 10mA, I_{B1} = I_{B2} = 1.0mA		200	ns
t_f	Fall Time			50	ns

* Pulse Test: Pulse Width ≤ 300μs, Duty Cycle ≤ 2.0%

Ordering Information

Part Number	Marking	Package	Packing Method	Pack Qty
2N3904BU	2N3904	TO-92	BULK	10000
2N3904TA	2N3904	TO-92	AMMO	2000
2N3904TAR	2N3904	TO-92	AMMO	2000
2N3904TF	2N3904	TO-92	TAPE REEL	2000
2N3904TFR	2N3904	TO-92	TAPE REEL	2000
MMBT3904	1A	SOT-23	TAPE REEL	3000
MMBT3904_D87Z	1A	SOT-23	TAPE REEL	10000
PZT3904	3904	SOT-223	TAPE REEL	2500