Electrical Engineering Department

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Course: EE – 321 / Electronic Circuits

Project Title:

Active Band Pass Filter (BPF) using Transistors

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Abstract

The transistors have many applications as we know. Therefore, I will build an active band pass filter using a special type of transistor. This type is an NPN-BJT. However, analysis, diagrams, calculations, and applications will be provided for the project. Finally, we can use this filter to tune some device to take specific frequencies and to have a creative idea in this project, we can add a potentiometer to have a variable band as well. So, it can be applied in various communication applications.

Content

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1. Introduction

One of the most important skills for an electrical engineer is designing and analyzing circuits. Electronics 2 course focuses on this particular objective in its project. As a result, in this report, I will design a BPF using NPN-BJT (NPN Bipolar Junction Transistor) that serves specific functions within a certain range. I will discuss the theory briefly, the configuration precisely, and the frequency response in details.

A bandpass filter (BPF) is a circuit that enables frequencies within a certain frequency range to pass through while rejecting (attenuating) frequencies outside that range. A bandpass filter usually is a combination between a low pass filter and a high pass filter. The constructed filter using transistor is an active filter. An active filter is a type of analog circuit implementing an electronic filter using active components, typically an **amplifier**. So, as we know, the constructing elements of the amplifiers are transistors of any type; BJTs, MOSFETs, JFETs, etc.

2. Theory & Configuration

❖ Theory

A BJT circuit is usually an active BPF circuit, so continuing with the idea that states that the BPF is combined form a LPS and a HPF, we will have two frequency responses for the BJT circuit.

These two responses are related to specific capacitors, and the following figure demonstrates this.

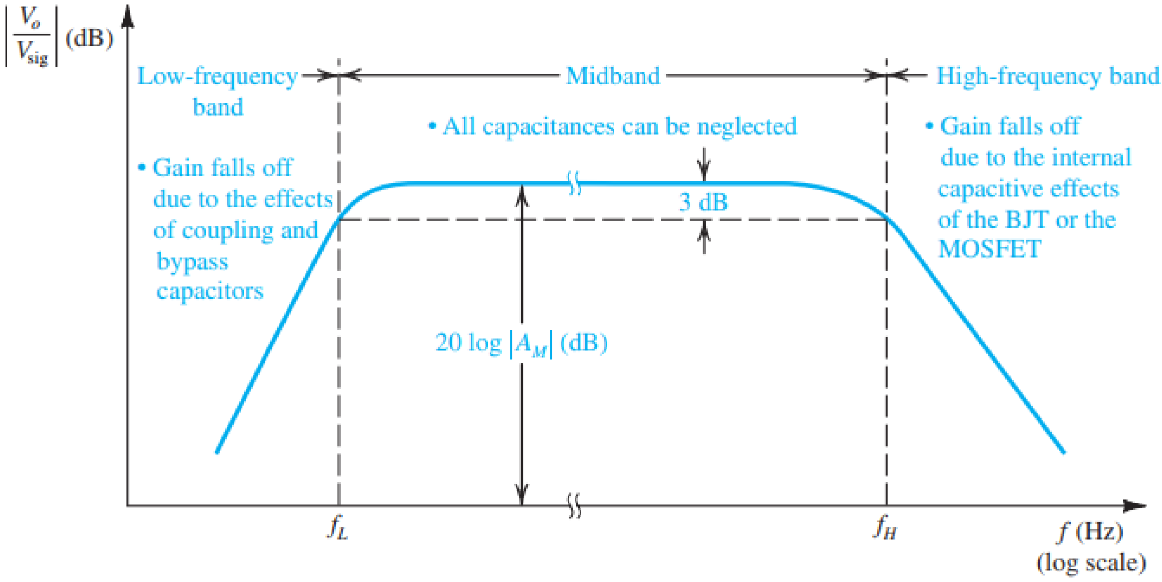

Figure 1 – Frequency responses due to capacitors

The main equation that is used to determine the frequency response is:

$$\boldsymbol{f = \frac{1}{2\pi RC}}$$

Where:

f = the frequency in HZ.

R = the equivalent resistance related to the specific capacitor in Ω.

C = the capacitor the affect the frequency response in F.

And we can determine the bandwidth (or passband) by:

$$\boxed{\text{bandwidth (BW)} = f_H - f_L}$$

Where:

f_H = high band frequency in Hz.

f_Z = low band frequency in Hz.

These frequencies depend on the type of the BJT circuit. So, I will discuss the low frequency response and the high frequency response equations in the Configuration subsection.

❖ Configuration

I will use a well-known NPN-BJT circuit called voltage divider common emitter configuration, and this circuit is shown in the following figure:

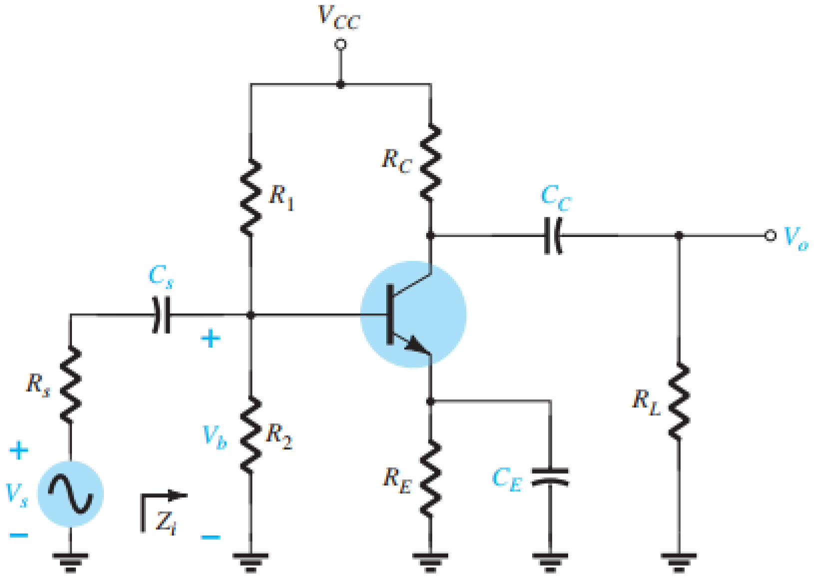

Figure 2 – Voltage divider common-emitter BJT circuit

The BJT circuit is an active BPF circuit, so continuing with the idea that states that the BPF is combined from a LPF and a high HPF, we can say that the BJT has two responses for each as mentioned. As a result, we will have two responses for this circuit:

1- Low Frequency Response: it is the greatest frequency response of a capacitor among the three bypassing and coupling capacitors (C_S, C_C, and C_E). $f_L = \max(f_S, f_C, f_E)$.

a) Frequency response of (Capacitor S):

$$\boxed{f_{L_s} = \frac{1}{2\pi(R_i + R_s)C_s}} \qquad \boxed{R_i = R_1 \,||\, R_2 \,||\, \beta_{r_e}}$$

Where:

β = is the DC current gain (I_C/I_B).

r_e = The dynamic resistance of the BJT (internal resistance) in Ω.

b) Frequency response of (Capacitor C):

$$\boxed{f_{L_C} = \frac{1}{2\pi(R_o + R_L)C_C}} \qquad \boxed{R_o = R_C \| r_o}$$

Where:

r_O = The output resistance of the transistor in Ω.

c) Frequency response of (Capacitor E):

$$\boxed{f_{L_E} = \frac{1}{2\pi R_e C_E}}$$

$$R_e = R_E \| \left(\frac{R'_s}{\beta} + r_e\right) \text{ and } R'_s = R_s \| R_1 \| R_2$$

2- High Frequency Response: it is the smallest frequency response of a capacitor among the two output capacitances (C_i, C_o). $f_H = \min(f_{Hi}, f_{Ho})$.

We will have a new representation of our circuit as shown in the next figure:

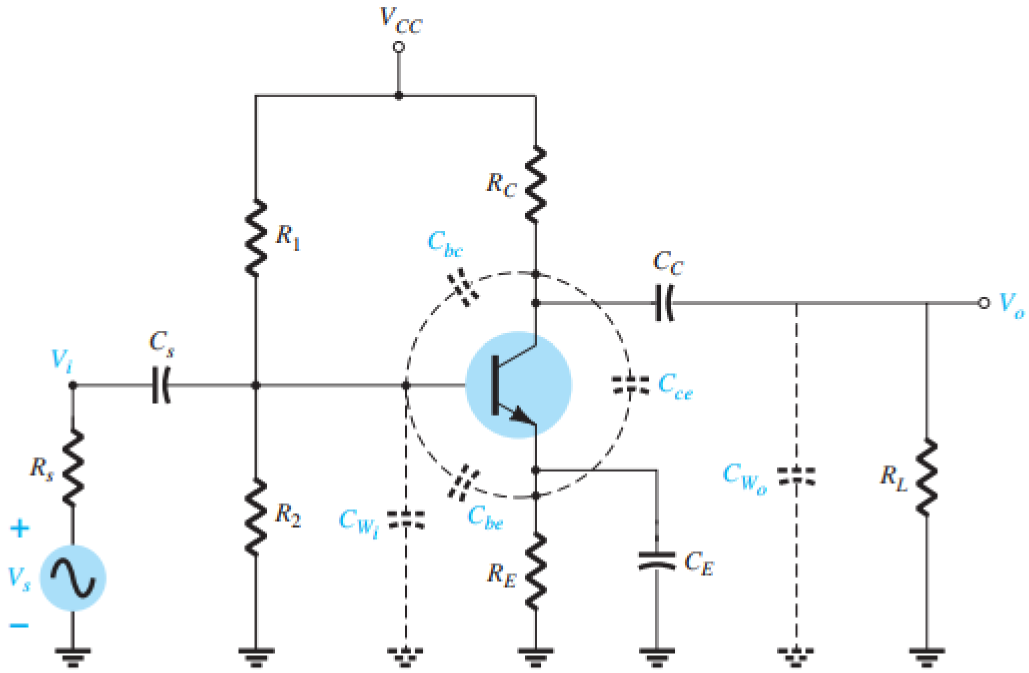

Figure 3 – Same BJT configuration with the effect of the output capacitance

i. Frequency response of C_i:

$$\boxed{f_{H_i} = \frac{1}{2\pi R_{Th_i} C_i}}$$

$$\boxed{R_{Th_i} = R_s \| R_1 \| R_2 \| \beta r_e}$$

$$\boxed{C_i = C_{W_i} + C_{be} + C_{M_i} = C_{W_i} + C_{be} + (1 - A_v)C_{bc}}$$

Where:

C_{Wi} = input wiring capacitance in F.

C_{be} = internal capacitance of the BJT form base to emitter in F.

C_{Mi} = input Miller effect capacitance in F.

A_V = voltage gain.

C_{bc} = internal capacitance of the BJT form base to collector in F.

ii. Frequency response of C_o:

$$f_{H_o} = \frac{1}{2\pi R_{Th_o} C_o}$$

$$R_{Th_o} = R_C \| R_L \| r_o$$

$$C_o = C_{W_o} + C_{ce} + C_{M_o}$$

$$C_o = C_{W_o} + C_{ce} + (1 - 1/A_v)C_{bc}$$

Where:

C_{Wo} = output wiring capacitance in F.

C_{ce} = internal capacitance of the BJT form collector to emitter in F.

C_{Mo} = output Miller effect capacitance in F.

A_V = voltage gain.

After calculating these frequencies, we can get the values for the low band and high band frequency. However, to find the gain of this amplifier we can use:

The total gain of the circuit:

$$A_{v_s} = \frac{V_o}{V_s} = \frac{V_o}{V_i} \cdot \frac{V_b}{V_s}$$

The gain of the amplifier:
(Without the effect of R_s).

$$A_v = \frac{V_o}{V_i} = \frac{-R_C \| R_L}{r_e}$$

The resulted gain:
(After adding R_s).

$$A_{v_{mid}} = \frac{\mathbf{V}_b}{\mathbf{V}_s} = \frac{R_i}{R_i + R_s}$$

3. Implementation & Analysis

This section will contain the simulation of the circuit with its bode plot and characteristics values of f_L and f_H. In addition, the analysis of the frequency response and a comparison between the practical and theoretical values.

❖ Implementation

I will use the previous circuit discussed in **Figure 2** with the parameters shown in the next Figure:

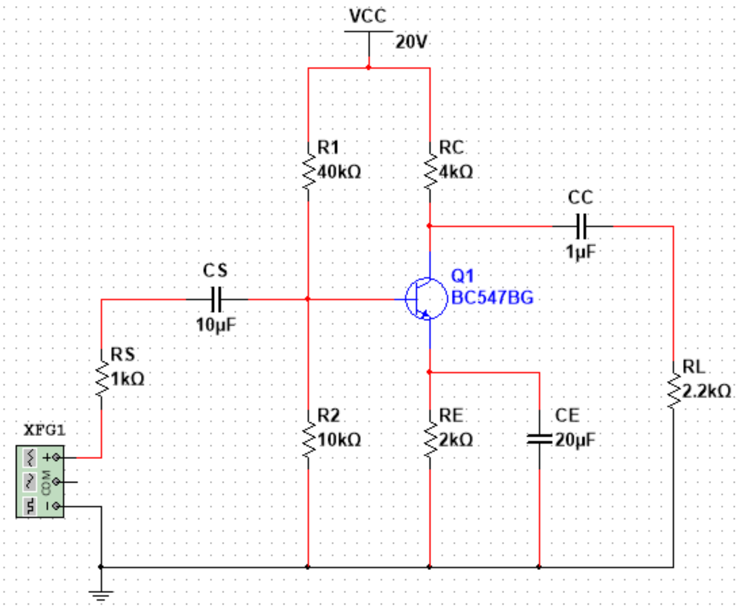

Figure 4 – S

So, now we can calculate the theoretical values to compare them later with the practical values.

1- Low Frequency Response:

A- Response of Capacitor S:

Using the following equations: (with **beta = 120** from **Figure 6** of the datasheet of BC547BG)

$$\boxed{f_{L_s} = \frac{1}{2\pi(R_i + R_s)C_s}} \qquad R_i = R_1 \,||\, R_2 \,||\beta_{r_e}$$

We get:

$$V_B \cong \frac{R_2 V_{CC}}{R_2 + R_1} = \frac{10\,\text{k}\Omega(20\text{ V})}{10\,\text{k}\Omega + 40\,\text{k}\Omega} = \frac{200\text{ V}}{50} = 4\text{ V}$$

from (DC analysis)

$$I_E = \frac{V_E}{R_E} = \frac{4\text{ V} - 0.7\text{ V}}{2\,\text{k}\Omega} = \frac{3.3\text{ V}}{2\,\text{k}\Omega} = 1.65\text{ mA}$$

$$r_e = \frac{26\text{ mV}}{1.65\text{ mA}} \cong \mathbf{15.76\ \Omega}$$, $$\beta r_e = 120*15.76 = 1.891\text{ k}\Omega$$

$$R_i = R_1 \| R_2 \| \beta r_e = 10\text{k}//40\text{k}//1.891\text{k} = 1.529\text{ k}\Omega$$

$$f_{Ls} = \frac{1}{2\pi(1.529k+1k)10\mu} = \boldsymbol{6.29\ Hz}$$

B- Response of Capacitor C:

Using the following equations:

$$f_{L_C} = \frac{1}{2\pi(R_o + R_L)C_C} \quad \text{with} \quad R_o = R_C \| r_o \cong R_C$$

Because r_O = 1 GΩ $\cong \infty$

$$f_{L_C} = \frac{1}{2\pi(R_o + R_L)C_C} = \frac{1}{2\pi(4k + 2.2k)1\mu} = \mathbf{25.67Hz}$$

C- Response of Capacitor E:

$$f_{L_E} = \frac{1}{2\pi R_e C_E}, \quad R_e = R_E \| \left(\frac{R'_s}{\beta} + r_e\right) \text{ and } R'_s = R_s \| R_1 \| R_2$$

Rs' = 889 Ω, R_e = 24 Ω

$f_{LE} = \frac{1}{2\pi(24)20\mu} = \mathbf{331.57\ Hz}$

- $f_L = \max(f_{LS}, f_{LC}, f_{LE}) = f_{LE}$ = **331.57 Hz**

2- High Frequency Response:

A- Response of C_i:

Using the following equations: (C_i = 10 pF, from the datasheet)

$$\boxed{f_{H_i} = \frac{1}{2\pi R_{\mathrm{Th}_i} C_i}} \quad \boxed{R_{\mathrm{Th}_i} = R_s \| R_1 \| R_2 \| \beta r_e}$$

$$\boxed{C_i = C_{W_i} + C_{be} + C_{M_i} = C_{W_i} + C_{be} + (1 - A_v)C_{bc}}$$

R_{Thi} = 605 Ω, C_i = 10 pF, $f_{Hi} = \frac{1}{2\pi(677)10p} = \mathbf{26.31\ MHz}$

B- Response of C_o:

Using the following equations: (C_o = 1.7 pF, from the datasheet)

$$\boxed{f_{H_o} = \frac{1}{2\pi R_{\mathrm{Th}_o} C_o}} \quad \boxed{R_{\mathrm{Th}_o} = R_C \| R_L \| r_o}$$

$$\boxed{C_o = C_{W_o} + C_{ce} + C_{M_o}}$$

R_{Tho} = 1419 Ω (taking r_O = 1 GΩ $\cong \infty$), C_o = 1.7 pF, $f_{Ho} = \frac{1}{2\pi(1419)1.7p} = \mathbf{65.98\ MHz}$

- $f_H = \min(f_{Hi}, f_{Ho}) = f_{Hi} = \mathbf{26.31\ \ MHz}$

3- The Voltage Gain:

$$\boxed{A_v = \frac{V_o}{V_i} = \frac{-R_C \| R_L}{r_e}} = \frac{-1419}{15.76} = \mathbf{-90.04}$$

$$\boxed{A_{v_{\text{mid}}} = \frac{\mathbf{V}_b}{\mathbf{V}_s} = \frac{R_i}{R_i + R_s}} = \frac{1529}{1529 + 1000} = \mathbf{0.60}$$

$$\boxed{A_{v_s} = \frac{V_o}{V_s} = \frac{V_o}{V_i} \cdot \frac{V_b}{V_s}} = -90.04 * 0.60 = \mathbf{-54.02}$$

- $dB\ Gain = 20\log(54.02) = 34.65\ dB$

Now, after calculating the theoretical values, using Bode Plotter, we can find the practical value from the bode plot of the circuit:

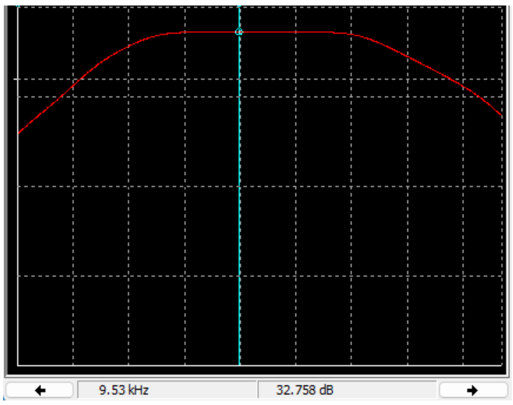

Figure 5 – a

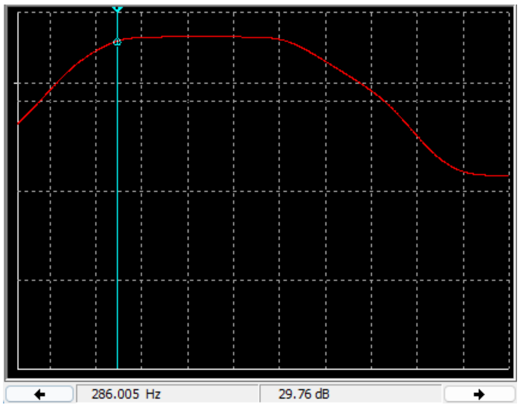

Figure 5 – b

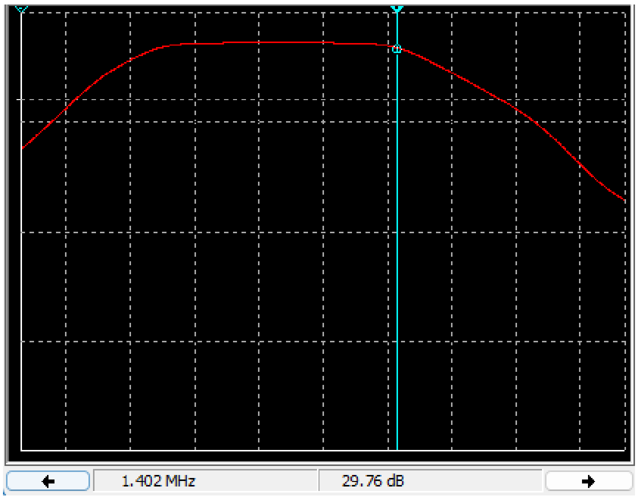

Figure 5 – c

Figure 5 – Bode Plot

Figure 5 – a: represents the overall bode plot of this BPF.

Figure 5 – b: represents the LPF at practical cutoff frequency of 286.01 Hz, by taking -3 dB from the mid band gain.

Figure 5 – c: represents the HPF at practical cutoff frequency of 1.40 MHz, by taking -3 dB from the mid band gain.

Finally, here is the phase plot:

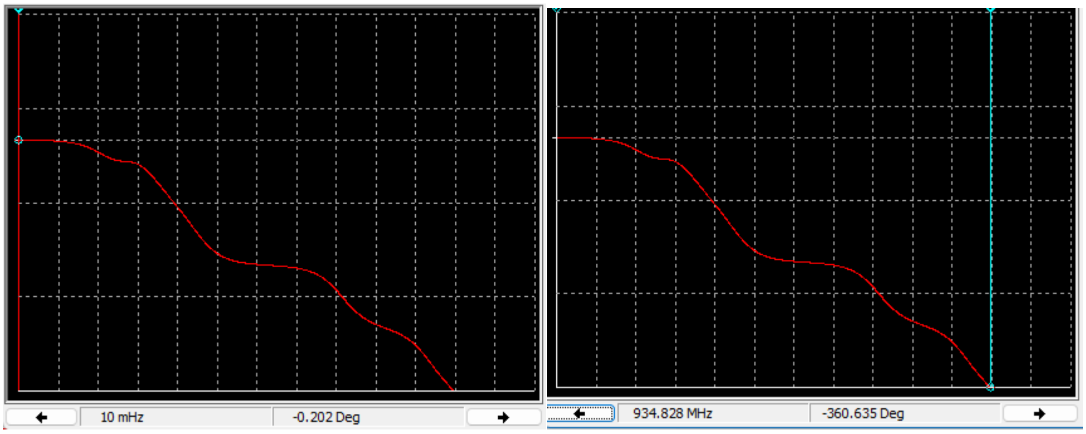

Figure 6 – Phase Bode Plot

❖ Analysis

In this section I will discuss the previous results using the following table:

Parameter	Theoretical	Particle	Error
Low Frequency	331.57 Hz	286.01 Hz	13.74%
High Frequency	26.31 MHz	1.40 MHz	High
Gain	34.65 dB	32.76 dB	5.45%

It is well known that frequency analysis differs excessively between practice and theory. However, here are some reasons of this percentages:

1- There could be some little noise.
2- There were a lot of approximations in the calculations.
3- These errors are for the values that are found and calculated on a logarithmic scale, so it is possible to have some extreme percentages for error.
4- For the high frequency calculation: the capacitance values of the wiring were neglected because we do not have these values, and it is known that when we have such a situation, we try to find the value of the high cutoff frequency only practically (because each type of wiring has its own internal capacitance value). "In the high-frequency region, the capacitive elements of importance are the interelectrode (between-terminals) capacitances internal to the active device and the wiring capacitance between leads of the network". (Boylestad, 2012, p. 574)

4. Conclusion

At the end, I have constructed and analyzed an active BPF circuit using voltage divider BJT network. In this project, I have applied an abundance amount of knowledge that I have learned in Electronics 2 course. Finally, the analysis shows that this application of BJT is very useful and has its own benefits & negatives.

5. References

Alldatasheet.com. (n.d.). *BC546 Datasheet(PDF) - on semiconductor*. ALLDATASHEET.COM - Electronic Parts Datasheet Search. Retrieved December 15, 2022, from https://www.alldatasheet.com/datasheet-pdf/pdf/11550/ONSEMI/BC546.html

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