EE430: Electronic Analog Circuits II

Electronics Project with Gerber Schematic Representation

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Introduction

The purpose of this project is to educate students on the characteristics of a Common Emitter (CE) Amplifier, as well as, list the real world applications that the amplifier can be used for. The amplifier is known as a circuit used to strengthen, or amplify an input signal that is deemed to be weak. This amplification can be observed in terms of voltage, current, or power. Most importantly, the original signal should remain the same while the only alteration is in the amplitude of the signal. The amplifier can be designed by using a Field Effect Transistor (FET) or a Bipolar Junction Transistor (BJT), and in this case a BJT in NPN configuration is used for the design. The observation of the amplifier characteristics will be completed by performing an AC small-signal analysis of the CE Amplifier.

Overview

The proposed project displays the AC small-signal analysis of a Common Emitter Amplifier. The characteristics being analyzed are the mid-frequency gain, low and high frequency poles, and small signal input and output of a Common Emitter Amplifier. The project is commenced by designing the amplifier with two different scenarios. One circuit with a bypass capacitor, and one without. This is done to understand the effect of the bypass capacitor on the circuit with regard to frequency response. With the finalized design of the CE Amplifier, the equivalent circuit was determined to continue onto the small-signal analysis of the circuit. The equivalent circuit was the primary resource for obtaining the theoretical results. In addition, this project displays the ways in which the amplifier can be used in the real world. This serves as the bridge between theory and practicality. As a result of this report, students should be able to understand the an NPN configured CE Amplifier with regard to the mathematical theory behind the development and characteristics of the circuit.

Problem Statement

The following diagram is the design we are evaluating, which is the frequency response of an NPN-based Common Emitter Amplifier. With the prior knowledge of AC and DC analysis, we will be evaluating what the necessary procedures are to solve this system's:

- Mid - frequency gain, $A_{MID\text{-}FREQ}$,
- Low frequency poles, F_L,
- High frequency poles, F_H,
- Small signal input resistance, R_{IN}, & the
- Small signal output resistance, R_{OUT}.

Further analysis, in greater detail, is thoroughly completed in our ***Mathematical Solution / Theory*** section of this report analysis. Below are schematic illustrations of the circuit diagrams of the design. The first analysis will be when the circuit includes a bypass capacitor, C2, and the second design analysis is when the circuit has the bypass capacitor, C2, removed.

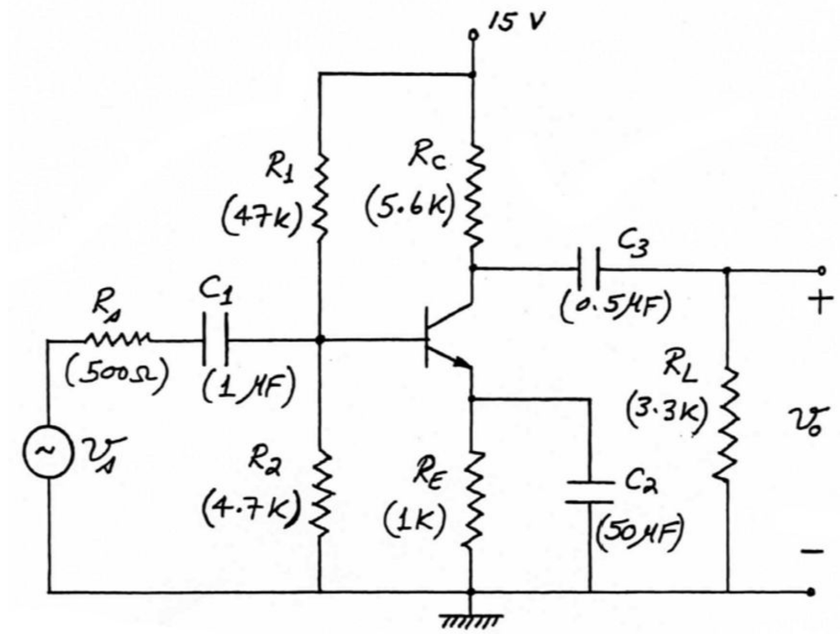

Figure 1: *This figure is the illustration of the frequency response schematic of a NPN-based common emitter amplifier with a bypass capacitor, C2, attached.*

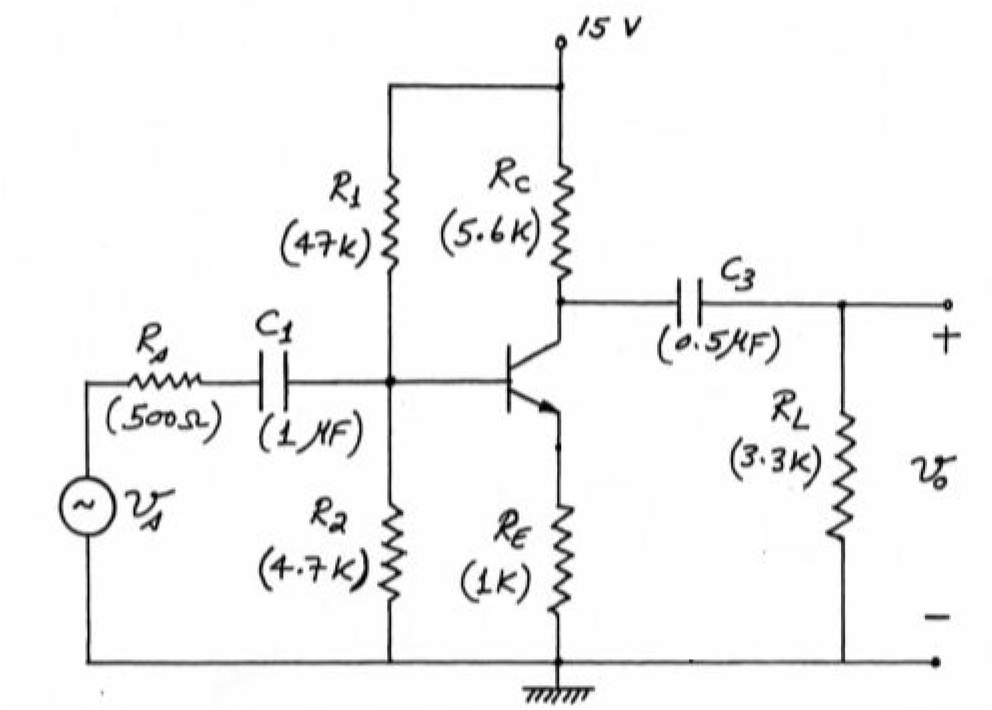

Figure 2: *This figure is the illustration of the same frequency response schematic of a NPN-based common emitter amplifier without the bypass capacitor, C2, attached.*

Mathematical Solution / Theory

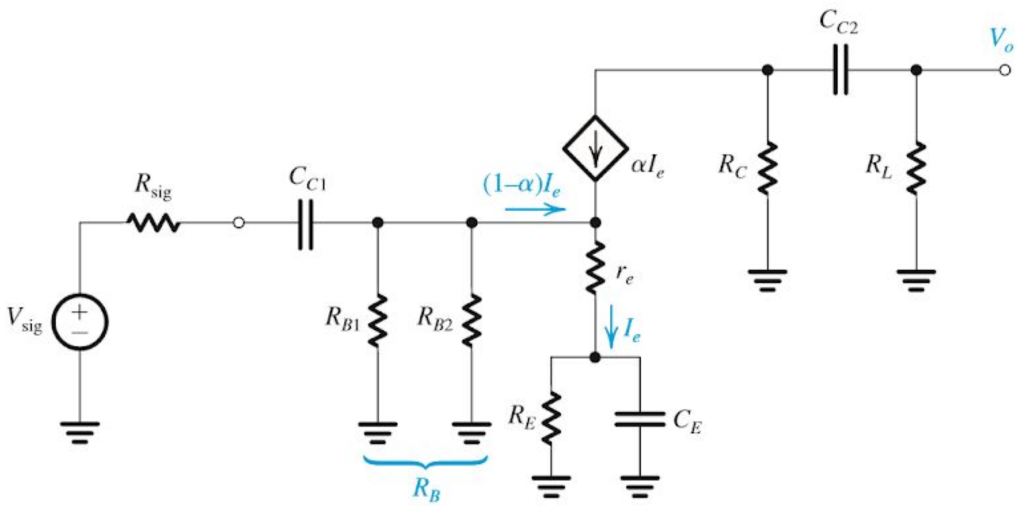

Figure 3: *Equivalent circuit of the CE Amplifier*

Initial Calculations:

Through AC analysis, the following values were used:

- B = 100
- $C_U = C_{bc} = 8pF$
- $C_\pi = C_{be} = 30pF$

They were assimilated into the following equations to solve the Mid-Frequency gain and the low-frequency gain. By first finding r_π , I_C , R_E , and Gm, we will have the variables needed to find the gains. For r_π , $r_\pi = B * V_T / I_C = 175.75\Omega$.

For I_C , $I_C = I_E = V_{CC} - V_{BE} / R_E = 14.3mA$.

$R_E = V_T / I_C = 1.74\Omega$

Input Resistance R_{in} = RS + (R1 || R2 || Rπ) = 668.806Ω 4

Output Resistance R_{out} = RC || RL = 2076.404Ω

Low Frequency Poles: We find the low frequency poles of the Common Emitter (CE) amplifier by the method of short-circuit time constants. We let Vsig=0 in the circuit from *Figure 3* so we can look at each capacitor individually. With Vsig=0, the circuit can be modeled by three different circuits containing one capacitor each, shown in *Figure 4*. The time constant equations are also given in *Figure 4*, for coupling capacitors C_{C1} , C_{C2} , and bypass capacitor C_E . The low frequency poles are the inverse of each time constant found. To find the 3dB low frequency cutoff we use the equation:

$$f_L = \frac{\omega_L}{2\pi} = \frac{1}{2\pi}\left[\frac{1}{C_{C1}R_{C1}} + \frac{1}{C_E R_E} + \frac{1}{C_{C2}R_{C2}}\right]$$

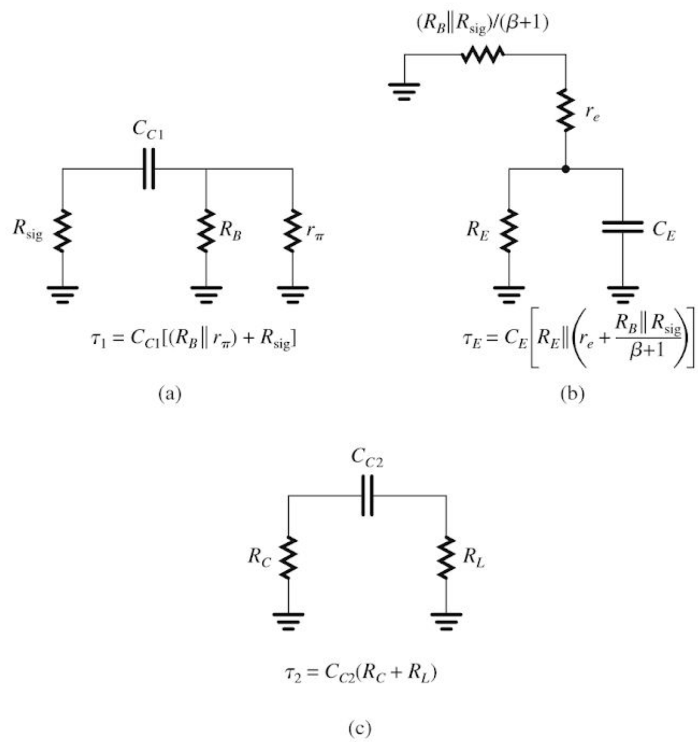

Figure 4: *Low frequency response time constant simplified circuits and equations*

Using the equations from *Figure 4* and values from *Figure 3* we get the low frequency pole frequencies: W_1= 234 Hz, W_2= 20 Hz, W_3= 224.79 Hz. The 3 dB low frequency cutoff of this amplifier is found by f_L = 1 / C3 * (RL + RC) = 224.72 Hz.

Midband Gain:

To find the midband gain of a CE amplifier, we use the high frequency response circuit in *Figure 5* and the equation:

$A_M = \frac{V_o}{V_{sig}} = -\frac{R_B}{R_B + R_{sig}} \frac{r_\pi}{r_\pi + r_x + (R_{sig} \| R_B)}(g_m R'_L)$ where $R'_L = r_o \| R_C \| R_L$. The final equation for high frequency amplifier gain using the midband gain from above is :

$\frac{V_o}{V_{sig}} = \frac{A_M}{1 + \frac{s}{\omega_H}}$. Using these equations we found the midband gain A_M to be 41 V/V.

High Frequency Poles:

To find the high frequency pole f_H we use the equivalent high frequency circuit and analysis shown in *Figure 5.* The equation for f_H is simply $f_H = \frac{\omega_H}{2\pi} = \frac{1}{2\pi C_{in} R'_{sig}}$. This high frequency pole is the 3dB cutoff range of the midband gain.

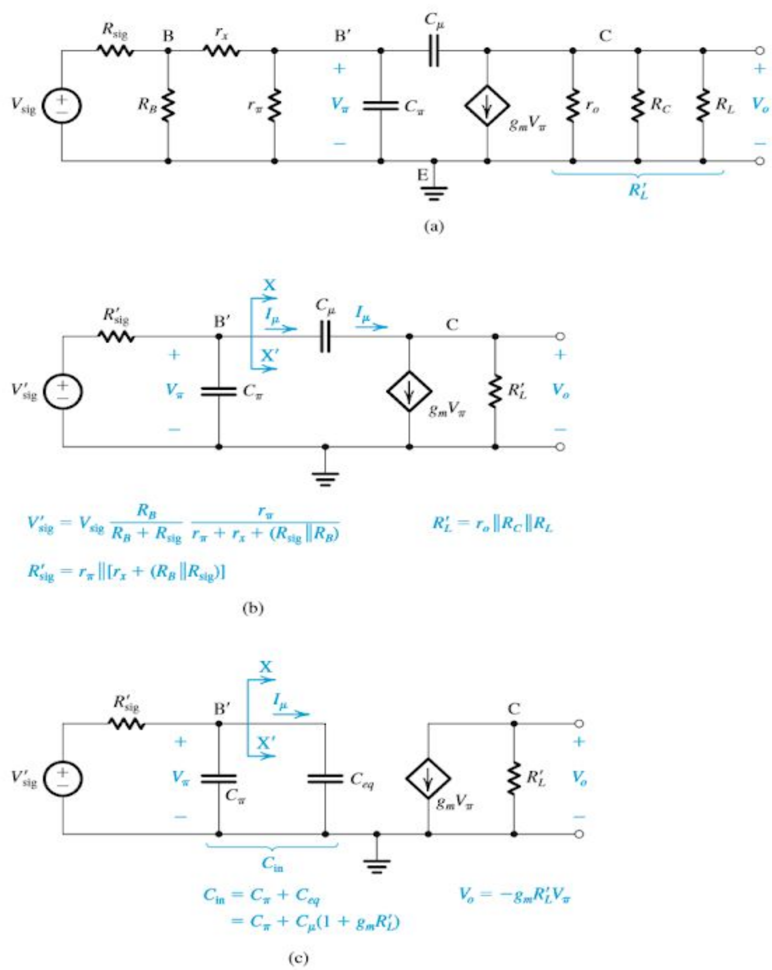

Figure 5: *High frequency response equivalent circuit simplified*

$R'_{sig} = r\pi \| (R_1 \| R_2 \| R_{sig}) = 126.2\Omega$

$R'_L = R_C \| R_L = 2076.4\Omega$

$C_{in} = C\pi + C\mu * (1 + G_m * R'_L) = 9.49\text{nF}$

$f_H = 1 / (2\pi * C_{in} * R'_{SIG}) = 1.1$ MHz

<u>Discussion</u>

Using the methods described above, we found the low and high frequency poles, cutoff frequencies, midband gain, output resistance, and input resistance. As part of our experiment we simulated a frequency sweep in PSpice of the circuit in *Figure 1* with a 100 mV input to show the values that we calculated are correct. The second part of this experiment was taking out the bypass capacitor in the circuit and simulating it again to show the effect of C_E. In *Figure 7* you can clearly see our high and low cutoff frequencies along with the midband gain in between the cutoff frequencies. In *Figure 8* you can see the effect of removing the bypass capacitor. The midband gain was greatly reduced without the capacitor and can be seen visually as about 1.5 V/V. In the low frequency band (below the lower cutoff frequency) the gain greatly drops due to the effects of the coupling and bypass capacitors. In the high frequency band (above the upper frequency cutoff) the gain drops off due to the internal capacitive effects of the BJT.

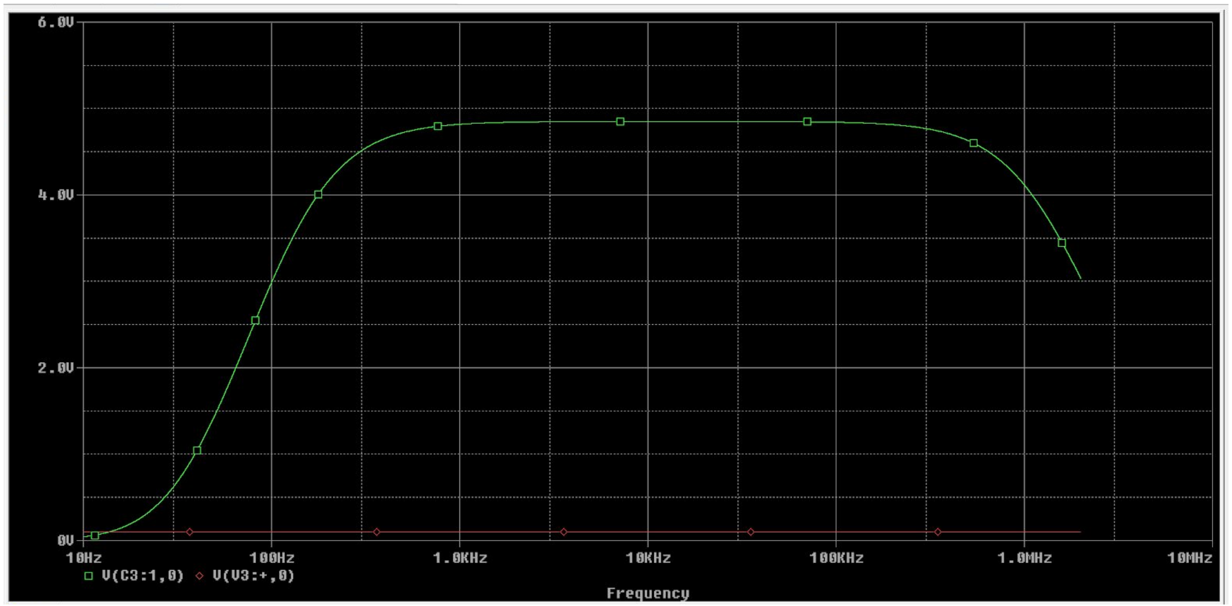

Figure 7: *AC sweep of the circuit with the bypass capacitor C4*

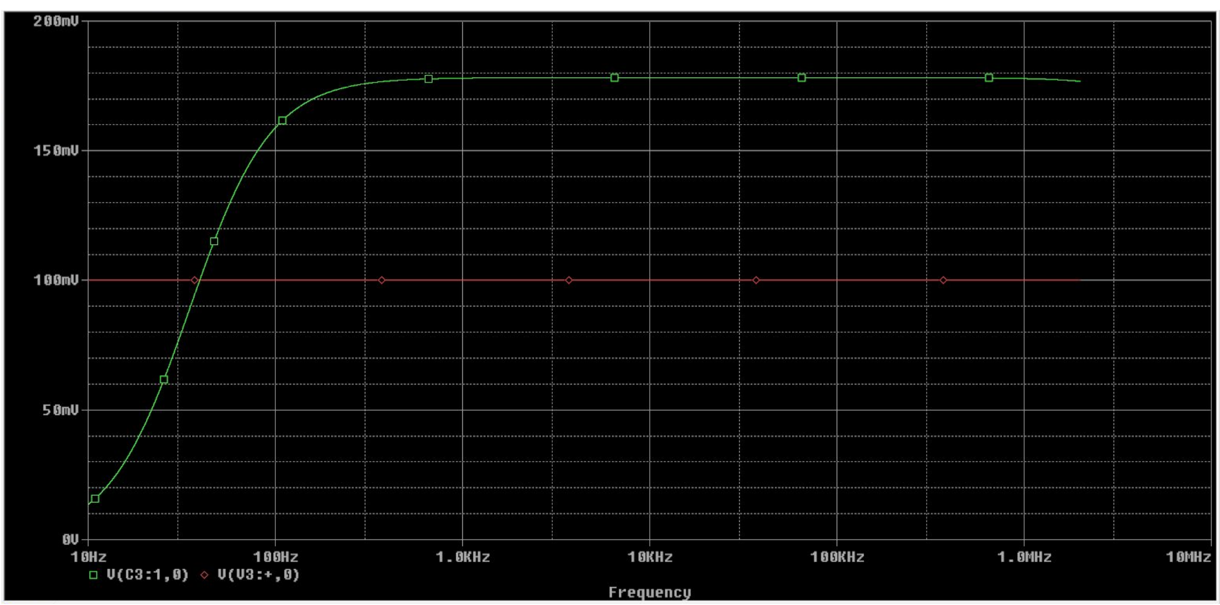

Figure 8: *AC sweep of the circuit with bypass capacitor C4 removed*

Real World Applications

Application 1:

One application that can use this schematic for circuit integration are radio frequency (RF) modules. RF modules are broken down between one being a transmitter, receiver, transceiver, or a system on a chip (SoC) module. RF modules are devices that allow for electronic communication to be sent to other devices and are often programmed to be used wirelessly. These devices implement the use of pre-designed schematics as integration into the system and will apply only changes that will suit the overall product and ultimately its functionality. Such common devices that are used today that incorporate the use of RF modules are monitoring systems, sensor application and smart technology based-devices.

Specifically, for our design of NPN-based common emitter amplifier, the effect this design does to RF modules is that it creates an inverted, but amplified output. This essentially creates a modulated signal that can take small input radio frequencies and extend them to cover longer distances with a signal that will be more easier to process by the receiving device. This will only be essentially help for low frequency emitting devices and not for high frequency to due to the Miller Effect. This is when the gain is directly affected the bypass capacitor, and in turn, directly affects the stabilization of the gain and limitation of the bandwidth. With a limiting bandwidth, the cutoff frequency produced by the transmitting portion of the module will be also be directly modified and will lower the chances of the signal to be properly processed.

Application 2:

Another application that the NPN common emitter amplifier can be used for are in low-noise amplifiers (LNA). Low-noise amplifiers are electronic amplifiers that take low-power signals that are just above the noise floor and amplify them without significantly degrading the signal-to-noise ratio (SNR).These LNA's are most commonly used in radio communications systems and electronic test equipment. The signal-to-noise ratio compares the level of the desired signal with the level of the background noise. It can also be understood as the ratio between the signal power to the noise power. In regards to the SNR, any ratio greater than a 1:1, meaning 0 dB, would mean that there is more signal present than noise. The noise floor is the measure of the signal that is comprised of the sum of all of the noise sources. In the area of radio communication, the most applicable use for the NPN CE amplifier, these noise sources can include thermal noise, cosmic noise, and atmospheric noise, just to name a few.

When receiving a radio signal, the receiver antenna often are the source of weak signals due to the cable loss. The coaxial cable that is connected in the system can affect the SNR based on the length and width of sed cable. To correct for this signal loss, a LNA is often placed at the antenna to supply a gain sufficient enough to offset the loss. This will enable the system to be able to read the desired signal without too much unwanted noise disturbing the system. It is often studied in communication systems that “front-end” electronic noise is present. That is why an LNA is a key component in reducing unwanted noise. By placing the LNA closer to the signal source, the noise from the ensuing stages of the receiver chain is reduced by the gain from the LNA. Although the LNA creates some noise itself, the signal now has more power, and the least amount of distortion possible, enabling the system to more effectively use the signal that is being transmitted.

In constructing the LNA, there are four parameters that create the building blocks of the system. Those four parameters are gain, noise figure, non-linearity, and impedance matching. The block that is of most importance is the gain parameter. In most of today’s LNA’s transistors, most effectively bipolar and field-effect, are the devices that provide the gain. When considering gain, it can come mostly from a compromise. Meaning if you have low gain, the acceptable bandwidth will be much larger, and if you desire a higher gain, the bandwidth will be much smaller. When a higher gain is desired, the designer would have to take into account higher level signals, and this can lead to more problems with non-linear mixing. While on the topic of gain, this would lead to the type of circuitry that is required. The input and output impedance needs to be taken into account because this will maximize the power transfer to the device. In terms of our application the common-emitter configuration would be desired for a medium source impedance, not too high or too low. To give perspective, for low source impedance, a common-base or common-gate configuration would be appropriate. For high source impedance, common-collector or common-drain configuration would be desired.

Conclusion

As seen throughout the project report, the CE amplifier was discussed to understand the theory behind it’s development, the analysis of its characteristics, and it’s real world applications. It can be noted that the CE Amplifier has many applications that contribute to technologies all around the world. The most common application that was founded was in the realm of radio and RF communication systems. This would be due to the fact that the CE amplifier deals with bandwidth and different frequencies, all of which are affected by the design of the circuit.

Referenced Sources:

Application 1:
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https://www.researchgate.net/publication/224349942_Analysis_and_development_of_a_localization_system_based_on_Radio_Frequency

https://www.youtube.com/watch?v=NizrzRKQqII

Application 2:
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https://en.wikipedia.org/wiki/Signal-to-noise_ratio

https://en.wikipedia.org/wiki/Noise_floor

Mathematical Solution/Theory:
Sedra, A. S., & Smith, K. C. (n.d.). *Microelectronic Circuits* (Seventh ed.).