Homework 8/9
Fundamentals of Electronics
EECE2412/3

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Abstract

The purpose of this document is to outline the design process for a common-emitter bipolar junction transistor (BJT) amplifier with specified characteristics. The design process involved creating a viable circuit, calculating expected results, and simulating to confirm expectations.

KEYWORDS: common-emitter, BJT, amplifier

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1 Introduction

Common-emitter amplifiers are some of the most ubiquitous components of radio-frequency (RF) circuitry. These components, which rely on bipolar junction transistors (BJTs) involve the amplification of a source signal, passed through the base of the BJT. The base is connected to the collector branch via a resistor. To improve stability of such circuits, capacitors are added after the input and before the output, which allows for better direct-current (DC) filtration. Such amplification is crucial in audio-based circuits, like speakers, and radios, specifically antennas.

2 Circuit Design

We may begin with our provided model:

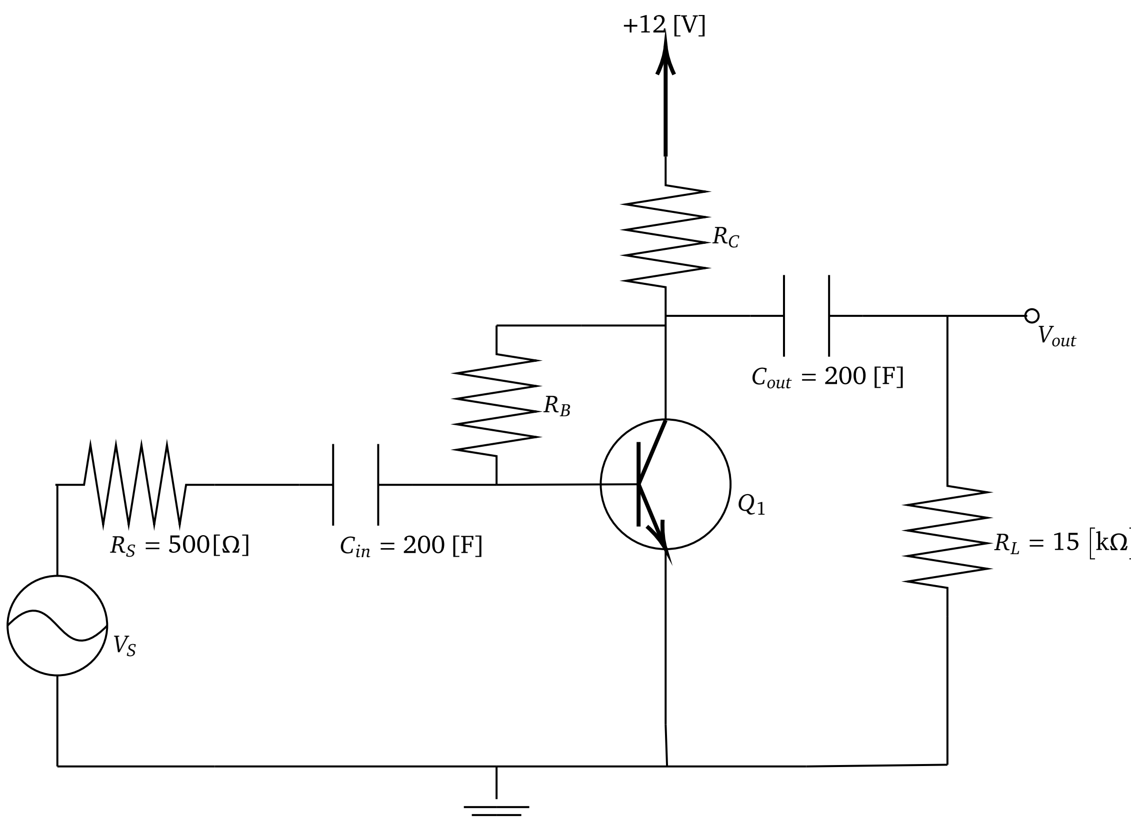

Figure 1: Standard Common-Emitter Amplifier

This, in tandem with the provided circuit example, will be the basis for our design.

2.1 Given Parameters

We are given the following parameters as a requirement for our amplifier:

$$\boxed{\begin{cases} \text{Assume:} & T = 300[\text{K}] \\ |A_{VS}| = \frac{V_o}{V_{in}} & \geq 80 \\ I_C & \leq 8[\text{mA}] \\ V_{CC} & = 12[\text{V}] \\ R_S & = 500[\Omega] \\ R_L & = 15[\text{k}\Omega] \\ R_i & \approx R_S \\ V_{FB} & = .7[\text{V}] \\ \beta & = 200 \end{cases}}$$

Finally, we want to ensure that there is a 7[V] peak-to-peak output signal swing without distortion. We begin by performing a DC analysis of the given circuit.

2.2 DC Analysis

The DC equivalent circuit may be constructing by taking all capacitors as open circuits. This gives us an equivalent circuit of:

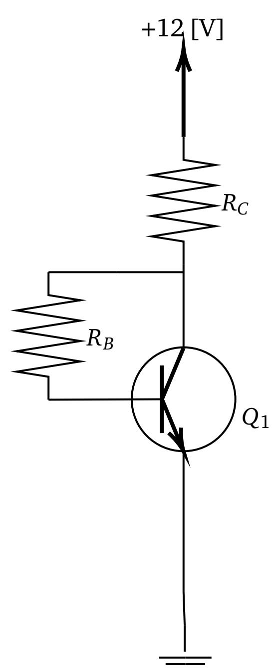

Figure 2: DC Equivalent Circuit

From this, we may use Kirchoff's voltage laws to write:

$$\boxed{12 - (I_B + I_C)R_C - R_B I_B - V_{BE} = 0}$$

We know β, which allows us to say:

$$200 = \frac{I_C}{I_B}$$
$$I_C = 200 I_B$$

Substituting this into the above, we get:

$$12 - I_B(201R_C + R_B) - .7 = 0$$

2.2.1 Worst-Case Assumption

Since $I_C \leq 8[\text{mA}]$, we know that:

$$I_B \leq \frac{I_C}{200}$$
$$I_B \leq 40[\mu\text{A}]$$

2.2.2 Finding Applicable R_B and R_C Values

Assuming worst-case (*i.e.* highest) values of the currents, we get $I_C = 8[\text{mA}]$ and $I_B = 40[\mu\text{A}]$. Plugging this in, we get:

$$11.3 = (40 \cdot 10^{-6})(201R_C + R_B)$$
$$282500 = 201R_C + R_B$$
$$\boxed{R_C = \frac{282500 - R_B}{201}}$$

We need R_B to be positive, which means $201R_C < 282500$. Let us take R_C as an arbitrary $\boxed{R_C = .9[\text{k}\Omega]}$, which gives us:

$$\boxed{R_B = 101.6[\text{k}\Omega]}$$

2.3 Small-Signal Analysis

We may redraw the circuit using the Hybrid-π Model to obtain the small-signal equivalent:

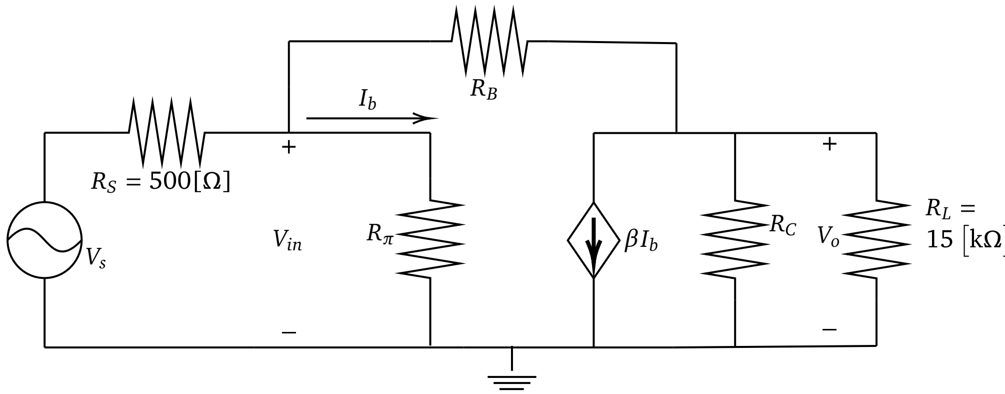

Figure 3: Small-Signal Equivalent Circuit

First and foremost, we must note that R_L' may be expressed as $R_C||R_L$. We can begin by finding:

$$g_m = \frac{I_C^{max}}{2V_T}$$

We take our quiescent collector current from the DC analysis to get:

$$g_m = \frac{8}{2(26)}$$

$$\boxed{g_m = .1538}$$

We then calculate R_π to get:

$$R_\pi = \frac{\beta}{g_m}$$

$$R_\pi = \frac{200}{.1538}$$

$$\boxed{R_\pi = 1.3[\mathrm{k}\Omega]}$$

2.3.1 Input Impedance Calculation

Let us stop to verify that the input impedance is roughly equal to R_s. From our equivalent circuit, we may obtain:

$$R_i = \frac{(R_B + R_L')R_\pi}{R_\pi + R_B + (\beta + 1)R_L'}$$

Let us get R_L' first:

$$R_L' = \frac{R_C R_L}{R_C + R_L}$$

$$\boxed{R_L' = 849.06[\Omega]}$$

We return to find the input impedance:

$$R_i = \frac{(101600 + 849.06)(1.3k)}{1.3k + 101600 + 849.06(201)}$$

$$\boxed{R_i = 486.85[\Omega]}$$

We see that, as intended, this is within 3% of the given value of R_S, and, thus, we may say that $R_i \approx R_S$.

2.3.2 Gain Calculation

From our equivalent circuit, we may conclude that the gain is:

$$|A_v| = \frac{R_L'(R_\pi - \beta R_B)}{R_\pi(R_L' + R_B)}$$

We substitute our values to get:

$$A_v = \frac{849.06(1300 - (200)(101600))}{1300(849.06 + 101600)}$$

$$\boxed{A_v = -129.53}$$

This meets the minimal gain requirement of $|A_v| \geq 80$. As such, our equivalent circuit becomes:

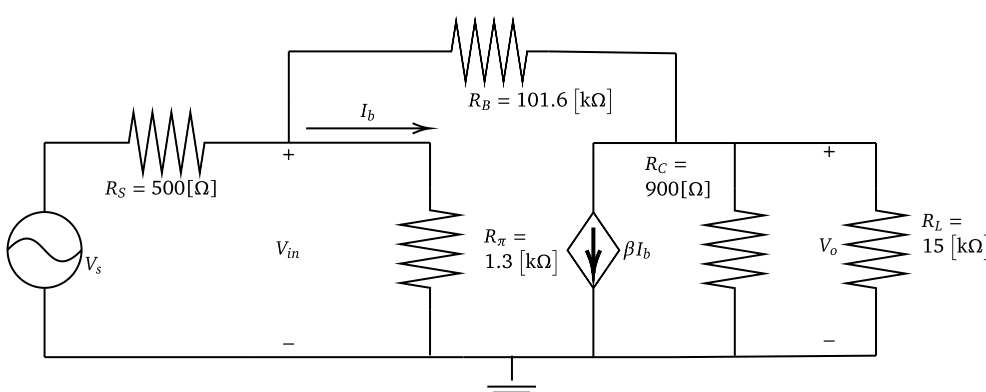

Figure 4: Small-Signal Equivalent with Values

This gives us our final circuit as:

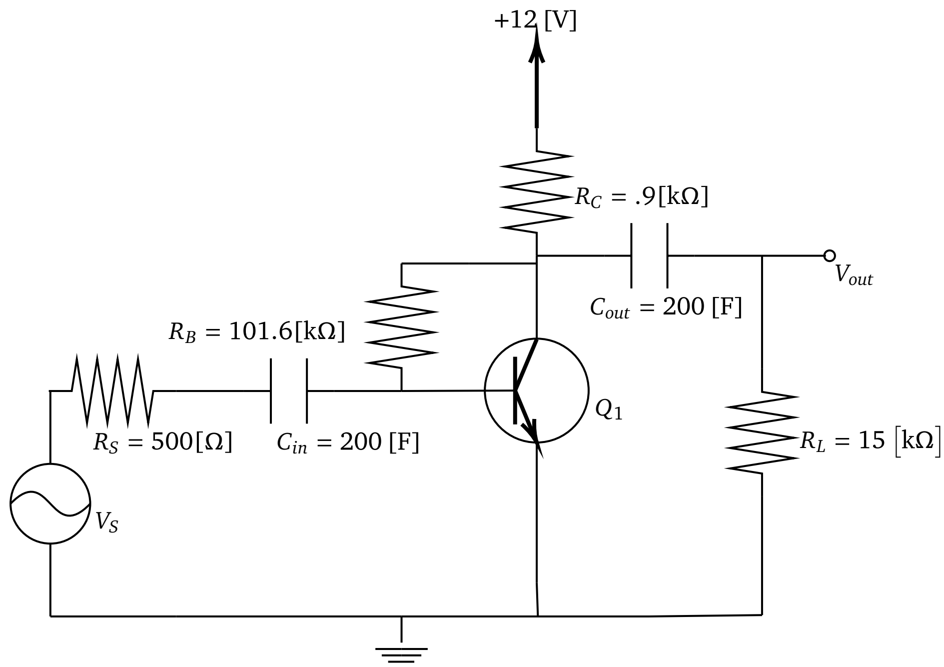

Figure 5: Final Common-Emitter Amplifier

2.3.3 Output Impedance Calculation

The final step is to calculate the expected output resistance. Based on the equivalent circuit in Figure 4, we get:

$$R_o = R_C || \left(\frac{R_B R_S + R_B R_\pi + R_S R_\pi}{(\beta + 1) R_S + R_\pi} \right)$$

We plug in known values to get:

$$\left(\frac{R_B R_S + R_B R_\pi + R_S R_\pi}{(\beta + 1) R_S + R_\pi} \right) = \frac{(101600)(500) + (101600)(1300) + (500)(1300)}{(201)(500) + 1300}$$

$$\left(\frac{R_B R_S + R_B R_\pi + R_S R_\pi}{(\beta + 1) R_S + R_\pi} \right) = 1802.8[\Omega]$$

Then, we calculate $R_C || 1802.8$:

$$R_o = \frac{(1802.8)(900)}{900 + 1802.8}$$

$$\boxed{R_o = 600.32[\Omega]}$$

3 Simulation

3.1 Bias Point Performance

Simulating in PSPICE, we obtain the following Bias Point Performance:

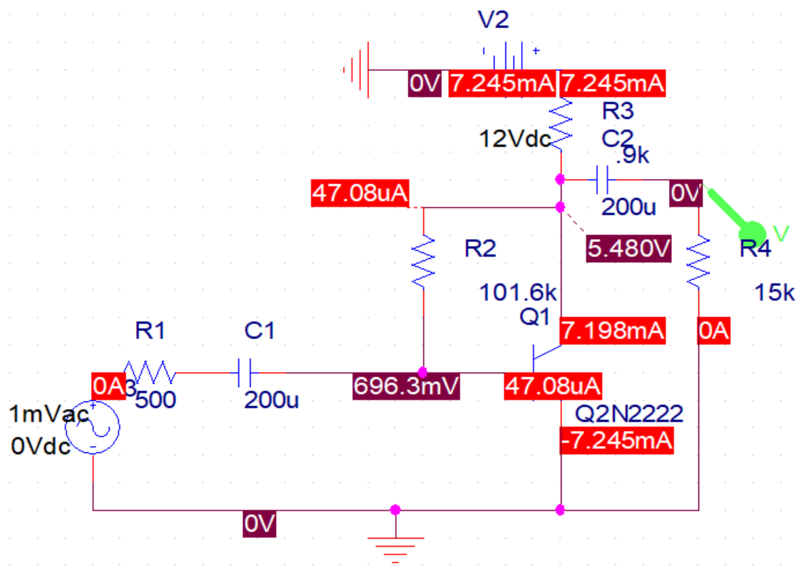

Figure 6: Bias Point Performance

We may observe, that, as calculated, the collector current, $I_C = 7.198[\text{mA}] \leq 8[\text{mA}]$.

3.2 AC Sweep

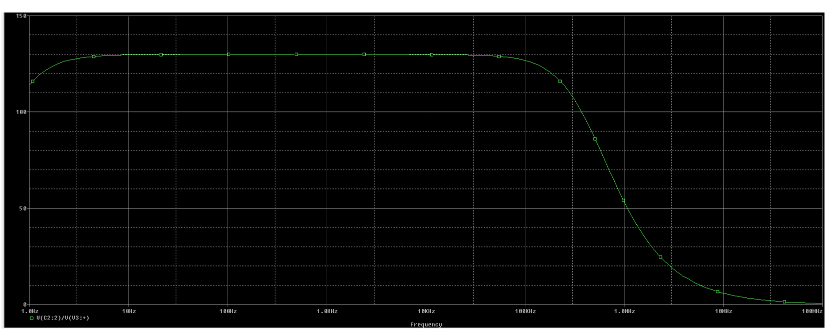

Figure 7: AC Sweep Gain Plot, Gain (A_{vs}) at 130

We may observe that the gain is right at the expected value, or approximately at a magnitude of 130 at midband values.

3.3 Input Resistance Sweep

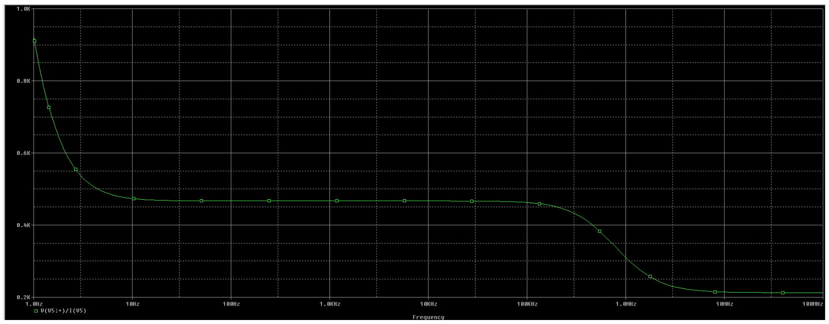

Figure 8: AC Sweep Input Impedance Plot, Approximately Z_i = .44[kΩ]

The resulting input impedance is very close to the calculated one. We may observe that the calculated impedance was .486[kΩ], while the simulated one is a bit less. These values are still quite similar, and, as such, close enough to the expected one at midband values.

3.4 Output Resistance Sweep

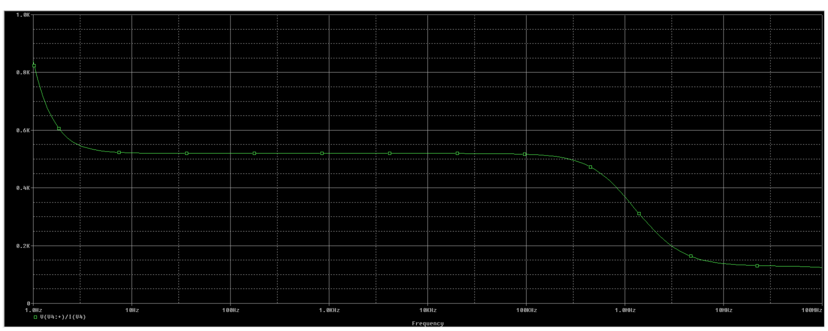

Figure 9: AC Sweep Output Impedance Plot, Approximately Z_o = .53[kΩ]

Once again, we see that the simulated value is a bit less than the calculated value. The calculated output impedance is .6[kΩ], while the one observed above is .53[kΩ] at midband values.

3.5 Transient Sweep

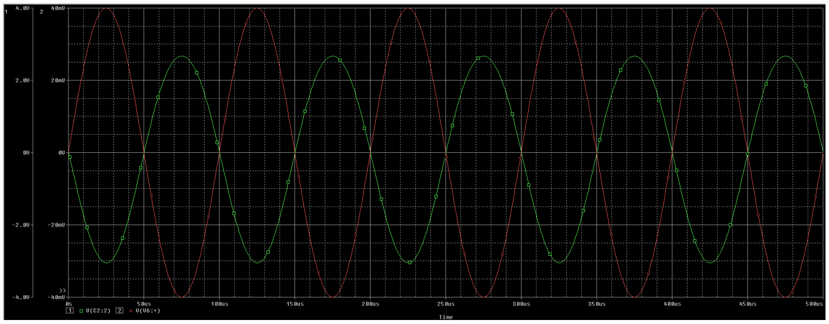

Figure 10: Transient Sweep, Peak-to-Peak Output: V_o = 6.2[V]

We may calculate the voltage gain as:

$$\boxed{A_{vs} = \frac{6.2}{.04} = 155}$$

We see that the transient simulation has a slightly higher gain than the AC sweep and the calculated one. Again, the values are close enough that nothing is too out of the ordinary.

4 Conclusion

We may observe the following obtained values:

Value	Specified	Calculated	Simulated	Requirement Met?
Gain (A_{vs})	≥ 80	129.53	130/155	✓
Input Z_i	$\approx 500[\Omega]$	$486.85[\Omega]$	$440[\Omega]$	✓
Collector Current (I_C)	≤ 8[mA]	≤ 8[mA]	7.198[mA]	✓

As such, we see that we were able to successfully meet and even exceed the given requirements.

5 References

Allan R. Hambley, Electronics, 2nd edition, Prentice Hall, 1999 1999