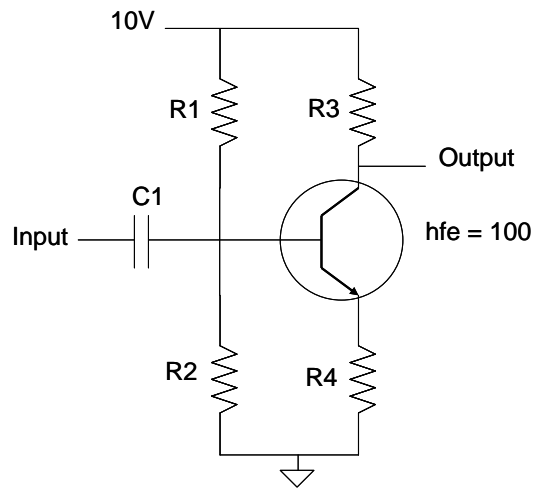


To determine if ChatGPT-4 is capable of solving hardware design problems we tested it with some design problems. This question is part of our interview process for hardware engineers. The question is to calculate the values of the resistors and capacitors for this single transistor amplifier circuit.

The following description of the circuit and the input and output conditions is provided to the model. It is important to accurately describe the input signal and provide the operating parameters of the transistor. It is also useful to have the model check itself by calculating the DC and AC results for some test conditions.



#### INPUT

*For this question the accuracy of the answer is important and will require mathematical calculations. Please double check the results of all calculations.*

*I am designing an amplifier circuit to amplify a 1V peak to peak 1kHz sine wave from a 50 ohm source presented at the INPUT into a 5V peak to peak sine wave at the Output. There are four resistors R1, R2, R3, R4, one capacitor C1 and an NPN transistor that has an hfe of 100 at a collector current of 5mA.*

*The components are wired as follows:*

*INPUT connects to pin1 of C1*

*Pin 2 of C1 connects to pin 2 of R1 and pin 1 of R2 and the base of the transistor*

*Pin 1 of R1 connects to a 10V power supply.*

*Pin 2 of R2 connects to ground*

*Pin 1 of R3 connects to 10V power supply*

*Pin 2 of R3 connects to the collector of the transistor and the OUTPUT.*

*Pin 1 of R4 connects to the emitter of the transistor.*







*Pin 2 of R4 connects to ground.*

*The OUTPUT will not be unconnected to a load.*

*Calculate the values for R1, R2, R3, R4 and C1 and then calculate the OUTPUT For these two conditions:*

1. *When a 0.5V peak to peak voltage 1kHz sinewave is applied to the INPUT*
2. *When the INPUT is left unconnected.*



ChatGPT-4's Response	Comments
<p>To design the amplifier circuit, we need to calculate the resistor and capacitor values based on the given specifications. The circuit is a common emitter NPN transistor amplifier, with capacitive input coupling. We'll determine the resistor and capacitor values based on the desired gain, biasing conditions, and input frequency.</p>	
<p>First, we'll calculate the desired voltage gain (<math>A_v</math>):            Desired output voltage = 5V peak-to-peak            Input voltage = 1V peak-to-peak  <math>A_v = (\text{Output voltage}) / (\text{Input voltage}) = 5V / 1V = 5</math></p>	
<p>1. Calculate the values for R1, R2, R3, R4 and C1:            We need to bias the transistor for optimal operation. A common rule of thumb is to set the collector current (<math>I_c</math>) to around 10% of the maximum collector current. In this case, <math>I_c = 5\text{mA}</math>.</p>	
<p>1.1. Calculate R4:            The emitter voltage (<math>V_e</math>) should be about 10% of the power supply voltage (<math>V_{cc}</math>) for proper biasing:  <math>V_e = 0.1 * V_{cc} = 0.1 * 10V = 1V</math>            We'll use the formula <math>V_e = I_c * R_4</math> to calculate R4:  <math>R_4 = V_e / I_c = 1V / 5\text{mA} = 1V / 0.005A = 200\Omega</math></p>	
<p>1.2. Calculate R3:            The collector voltage (<math>V_c</math>) should be about 50% of the power supply voltage (<math>V_{cc}</math>) for proper biasing:  <math>V_c = 0.5 * V_{cc} = 0.5 * 10V = 5V</math>            We'll use the formula <math>V_c = V_{cc} - I_c * R_3</math> to calculate R3:  <math>R_3 = (V_{cc} - V_c) / I_c = (10V - 5V) / 5\text{mA} = 5V / 0.005A = 1000\Omega</math></p>	
<p>1.3. Calculate R1 and R2:            To determine the base current (<math>I_b</math>), we'll use the formula <math>I_b = I_c / h_{fe}</math>:  <math>I_b = I_c / h_{fe} = 5\text{mA} / 100 = 0.00005A = 50\mu A</math>            The voltage divider formed by R1 and R2 will provide the base bias voltage (<math>V_b</math>). A common rule of thumb is to set the current through R1 and R2 to be about 10 times the base current (<math>I_b</math>). Let's call this current <math>I_{div}</math>:  <math>I_{div} = 10 * I_b = 10 * 50\mu A = 500\mu A</math>            We'll use the formula <math>V_b = V_e + 0.7V</math> (the 0.7V is the base-emitter voltage drop for an NPN transistor) to calculate <math>V_b</math>:  <math>V_b = 1V + 0.7V = 1.7V</math>            Now, we can calculate R1 and R2 using the voltage divider rule:  <math>R_2 = V_b / I_{div} = 1.7V / 500\mu A = 1.7V / 0.0005A = 3400\Omega</math></p>	



$R1 = (V_{cc} - V_b) / I_{div} = (10V - 1.7V) / 500\mu A = 8.3V / 0.0005A = 16600\Omega$	
<p>1.4. Calculate C1:</p> <p>To ensure the 1kHz signal is passed through the input capacitor with minimal attenuation, we'll choose a cutoff frequency (<math>F_c</math>) that is well below the input frequency (1/10th is a good rule of thumb). So, we'll set <math>F_c</math> to be 100 Hz.</p> <p>The capacitor C1, in conjunction with the input resistance at the base of the transistor, forms a high-pass filter. The input resistance at the base (<math>R_{in}</math>) is given by the parallel combination of R1, R2, and the resistance looking into the base of the transistor (<math>\beta * r_e</math>). The small-signal emitter resistance (<math>r_e</math>) can be approximated as:</p> <p><math>r_e = 26mV / I_e \approx 26mV / I_c = 26mV / 5mA = 5.2\Omega</math></p> <p>Since <math>I_c \approx I_e</math> for an NPN transistor, and <math>\beta = h_{fe} = 100</math>, we have:</p> <p><math>R_{in} = (R1 \parallel R2 \parallel (\beta * r_e)) \approx (16600\Omega \parallel 3400\Omega \parallel (100 * 5.2\Omega))</math></p> <p>To find the parallel resistance, we'll use the formula:</p> <p><math>1/R_{in} = 1/R1 + 1/R2 + 1/(\beta * r_e)</math></p> <p><math>1/R_{in} = 1/16600 + 1/3400 + 1/(100 * 5.2)</math></p> <p>Solving for <math>R_{in}</math>, we get:</p> <p><math>R_{in} \approx 2976.9\Omega</math></p> <p>Now, we can calculate the value of C1 using the formula for the cutoff frequency of a high-pass RC filter:</p> <p><math>F_c = 1 / (2 * \pi * R_{in} * C1)</math></p> <p>Rearranging for C1, we get:</p> <p><math>C1 = 1 / (2 * \pi * R_{in} * F_c) = 1 / (2 * \pi * 2976.9\Omega * 100Hz) \approx 5.36\mu F</math></p> <p>We can choose a standard capacitor value of 5.6<math>\mu F</math> for C1.</p> <p>So, the calculated values for the components are:</p> <p><math>R1 = 16600\Omega</math> <math>R2 = 3400\Omega</math> <math>R3 = 1000\Omega</math> <math>R4 = 200\Omega</math> <math>C1 = 5.6\mu F</math></p>	<p>✓</p> <p>✗ The resistance of the base is <math>(\beta * (r_e + R4))</math> not <math>(\beta * r_e)</math></p> <p>✗ <math>R_{in}</math> is not calculated correctly for the value of <math>r_e</math> given. It can solve this equation as shown below but it did not here.</p> <p>✓</p> <p>The two errors above somewhat cancelled each other such that the value of C1 will work.</p>
<p>2. Calculate the OUTPUT for these two conditions:</p>	<p>It does not appear that it calculated the results from the resistor</p>



	values but did provide a modest level of checking.
<p>2.1. When a 0.5V peak-to-peak voltage 1kHz sine wave is applied to the INPUT:</p> <p>The gain remains the same (<math>A_v = 5</math>), so the output voltage will be:  Output voltage = <math>A_v \times \text{Input voltage} = 5 \times 0.5V = 2.5V</math> peak-to-peak</p>	<p>✓</p> <p>Gain <math>A_v = R_3/R_4 = 1000/200 = 5</math></p>
<p>2.2. When the INPUT is left unconnected:</p> <p>When the input is left unconnected, there's no input signal. The output will be at the DC bias point, which is equal to the collector voltage (<math>V_c</math>) calculated earlier:</p> <p>Output voltage = <math>V_c = 5V</math> DC</p>	<p>✓</p> <p><math>V_b = 1.7V</math>  <math>V_e = 1V</math>  <math>i_{R3} = 1/200 = 5mA</math>  <math>i_{R4} = i_{R3}</math>  <math>V_c = 10V - 5mA \times 1000 \text{ ohms} = 5V</math></p>

Additional comments

The text highlighted in red above is an area where it did not generate correct results.

The base resistance should be:

$(\beta \times r_e) + (\beta \times R_4)$  and is often simplified to  $\beta \times R_4$  where  $R_4$  is the emitter resistor when the emitter resistor is much larger than  $r_e$  as the emitter resistor dominates. However, it then made a mathematical error and improperly calculated the value for  $R_{in}$ .

GPT-4 was asked to solve the equation below again to see if it could get the result correct.

GPT-4 Input

*Solve this equation.  $1/R_{in} = 1/16600 + 1/3400 + 1/(100 \times 5.2)$*

GPT-4's Response	Comments
<p>To solve this equation, you need to find the reciprocal of the sum of the reciprocals of the three terms on the right side of the equation.</p> <p>First, let's simplify the third term:  <math>1 / (100 \times 5.2) = 1 / 520</math></p>	<p>The result is close to correct though it took a long route to get</p>



<p>Now, the equation becomes:</p> $1 / R_{in} = 1 / 16600 + 1 / 3400 + 1 / 520$ <p>To find a common denominator for the three terms on the right side, we need to find the least common multiple (LCM) of 16600, 3400, and 520. The LCM is 859600.</p> <p>Now, we can rewrite the equation with the common denominator:</p> $1 / R_{in} = (859600 / 16600) / 859600 + (859600 / 3400) / 859600 + (859600 / 520) / 859600$ <p>Simplify the numerators:</p> $1 / R_{in} = 52 / 859600 + 253 / 859600 + 1654 / 859600$ <p>Now, we can add the numerators:</p> $1 / R_{in} = (52 + 253 + 1654) / 859600$ $1 / R_{in} = 1959 / 859600$ <p>Now, to find <math>R_{in}</math>, take the reciprocal of both sides of the equation:</p> $R_{in} = 859600 / 1959$ <p>Finally, divide 859600 by 1959:</p> $R_{in} \approx 438.69 \text{ (rounded to two decimal places)}$ <p>So, the approximate value of <math>R_{in}</math> is 438.69.</p>	<p>there. Calculating the result with a calculator result in 439.09</p>
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## Conclusion

The bottom line is that ChatGPT-4 made a lot of correct decisions and can provide useful output with a well-designed prompt but specific care should be paid to the math. The problem posed has many possible valid solutions and it did use some reasonable rules of thumb to make assumptions where input was not specified.

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