Objectives

When you have completed this exercise, you will be able to determine the \( dc \) operating conditions as well as the \( ac \) voltage gain and the input/output phase relationship of an RC coupled amplifier. You will be able also to determine the frequency response of an RC coupled amplifier by using measured values.

Part A- DC Operation
Introduction and Theoretical Background

Figure E7-1 shows the dc operation schematic for the RC coupled circuit on The TRANSISTOR AMPLIFIER CIRCUITS circuit. The circuit consists of two cascaded common-emitter NPN amplifier (Q1 and Q2). Coupling capacitor \( C2 \) connects the output of the first stage (Q1) at the collector to the input of the second stage (Q2) at the base.

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Fig. E7-1 RC coupled amplifier circuit for dc operation

- \( R1 \) & \( R2 \) provide the base current
- \( RE \) For bias stabilizer
- \( CE \) by pass capacitor
Capacitor C2 blocks the collector dc current of Q1 from the base current of Q2, preventing dc interaction and shifting of the Q-points of each amplifier. The term RC (resistance-capacitance) comes from capacitor C2 and the second stage (Q2) voltage divider circuit resistors R4 and R8.

The dc power supply (VA) is typically 15.0 Vdc. Both amplifiers (Q1 and Q2) have identical voltage divider circuits, collector resistors, and emitter resistors. Therefore, the dc bias for each amplifier is essentially the same.

As mentioned, coupling capacitor C2 prevents dc interaction between the Q1 collector current and the Q2 base current. If C2 were shorted Q1 collector voltage and Q2 base voltage would be the same, and the Q-points of each amplifier would not be optimum for ac operation.

Because the collector voltage of the first stage is normally more positive than the base voltage of the second stage, the polarity of the electrolytic capacitor C1 has to be observed for proper circuit operation.

Equipments Required

F.A.C.E.T Base Unit (AS9100-00)
TRANSISTOR AMPLIFIER CIRCUITS Circuit Board
Dual Power Supply 15 Vdc @1 A (Lab-Volt 1242)
Digital Multimeter (Volts/Milliampere/Ohms)
Signal Generator (Sine/Square Wave)
Oscilloscope (Dual Trace)

Procedure

1- Locate the RC COUPLING/TRANSFORMER COUPLING circuit block on the TRANSISTOR AMPLIFIER CIRCUITS circuit board. Connect the RC coupled amplifier circuit for dc operation, as shown in Figure E7-2.

2- What circuit component indicates that the amplifier circuit you just connected is RC coupled?

3- Measure and record the supply voltage (VA), with reference to ground.

4- Measure first-stage amplifier (Q1) dc voltages, with reference to ground. Record your results in Table 7-1.
Table 7-1

| VC1 | 0.65 |
| VBE | 1.86 |
| VEB | 1.21 |

active Region

| VC2 | 9.35 |
| VBE2 | 1.86 |
| VEB2 | 1.21 |

Table 7-2

Fig. E7-2 Connection diagram

5- Do the measurements taken in step 4 indicate that the base-emitter junction is forward biased?

6- Do the measurements taken in step 4 indicate that the base-collector junction is reverse biased?

7- Would you conclude that NPN amplifier Q1 is biased correctly? Yes

8- Is the amplifier operating in its active region? Yes

9- Measure the second stage amplifier (Q2) dc voltages, with reference to ground. Record your results in Table 7-2.
10. Do the measurements taken in step 9 indicate that the base-emitter junction is reverse biased? \( \checkmark \) \( \checkmark \) \( \checkmark \).

11. Do the measurements taken in step 9 indicate that the base-collector junction is reverse biased? \( \checkmark \) \( \checkmark \) \( \checkmark \).

12. Would you conclude that NPN amplifier Q2 is biased correctly?

13. Is the amplifier operating in its active region? \( \checkmark \) \( \checkmark \) \( \checkmark \).

14. Place CM switch in the ON position to short RC coupling capacitor C2. Did the dc bias of amplifier Q1 change?

15. Is amplifier Q1 still operating in the active region?

16. Did the dc bias amplifier Q2 change?

17. At what point is amplifier Q2 operating?

18. Is there dc interaction between the first- and second-stage amplifiers (Q1 and Q2) while coupling capacitor C2 is shorted?

**Discussion**

1. Two amplifiers are RC coupled when a capacitor and one or more resistors connect the first-stage output to the second-stage input.

2. RC stands for resistance-capacitance, which includes the capacitor and resistor in the connection circuit.

3. The connecting capacitor prevents dc interaction between amplifiers and permits maintenance of dc bias stability.

**Review Questions**

Set up circuit in Figure E7-1. Place CM switch in the ON position to change the value of \( R_5 \) from 1 k\( \Omega \) to 4.7 k\( \Omega \). Measure the dc voltages for first-stage amplifier Q1, with reference to ground. Record your results in Table 7-3.

| \( V_{C1} \) | \( 3 \) |
| \( V_{B1} \) | \( 1.31 \) |
| \( V_{E1} \) | \( 1.2 \) |

Table 7-3
With $R_5$ equal to 4.7kΩ, amplifier Q1 is:
- operating in the saturation region.
- at the cut-off point.
- operating in the active region.
- no longer RC couples to amplifier Q2.

2- Cascaded amplifiers are amplifiers that:
- operate in parallel.
- have the output of the first-stage amplifier connected to the input of the second-stage amplifier.
- have the base voltage of the first-stage amplifier used as the input of voltage for the second stage.
- are connected to have equal dc current gains.

3- The capacitor that connects RC coupled amplifiers:
- changes the dc bias for the first amplifier.
- changes the Q-point of the second amplifier.
- has no effect on the dc bias of either amplifier.
- reduces the beta ($β$) of the second amplifier.

4- In an RC coupled amplifier circuit, the collector-base junctions of each transistor:
- are biased differently.
- are both reverse biased.
- are both forward biased.
- have a voltage difference of 0.6 Vdc.

5- The purpose of having a voltage divider circuit for each transistor is to:
- prevent dc interaction between transistors.
- provide a return path for the first transistor emitter current.
- have equal collector currents.
- properly bias each transistor.

**Part B: AC Operation, Voltage Gain and Phase Relationship**

Introduction and Theoretical Background

Figure E7-3 shows the ac operation schematic for the cascaded two-stage RC coupled NPN common-emitter amplifier circuit on the TRANSISTOR AMPLIFIER CIRCUITS circuit board. A sine wave generator ($V_{gen}$) provides the ac input signal ($V_{i1}$) at the base of the first stage amplifier (Q1).
Fig. E7-3 RC coupled amplifier circuit for ac operation

The ac peak-to-peak output voltage \( V_{01} \) of the first stage amplifier (Q1) depends on the ac output load resistance \( R_{L1} \) of Q1. Because \( C2 \) passes ac signals, the first stage (Q1) ac load \( R_{L1} \) is not just the collector resistor \( R3 \) but the parallel resistance of \( R3, R4, R8, \) and \( (r_c+R10) \), as shown in Figure E7-4. The value of \( (r_c+R10) \) is very large, so you can neglect it when calculating \( R_{L1} \).

The voltage gain \( A_{V1} \) of the first stage (Q1) equals the voltage ratio of the input and output signals, which is approximately equal to the ratio of the ac load resistance \( R_{L1} \) to the emitter resistor \( R5 \):

\[
A_{V1} = \frac{V_{01}}{V_{i1}} = \frac{R_{L1}}{R5}
\]  
\[
(1)
\]

The ac output load \( R_{L2} \) of Q2 (Figure E7-4) is the collector resistor \( R9 \). The voltage gain \( A_{V2} \) of Q2 can be expressed by the following equations:

\[
A_{V2} = \frac{V_{02}}{V_{i2}} = \frac{R_{L2}}{R10} = \frac{R9}{R10}
\]  
\[
(2)
\]
Fig. E7-4 Q1 and Q2 output loads and signal phase relationships

The overall circuit voltage gain ($A_{VC}$) of a two-stage RC amplifier circuit is the ratio of the second stage output signal to the first stage input signal:

$$A_{VC} = \frac{V_{02}}{V_{i1}} \quad (3)$$

Because the output signal of Q1 ($V_{01}$) equals the input signal of Q2 ($V_{i2}$), the following equations show that the overall circuit gain ($A_{VC}$) equals the product of the gains for each stage:

$$A_{VC} = \frac{V_{02}}{V_{i1}} = \frac{-V_{01}}{V_{i1}} \times \frac{-V_{02}}{V_{i2}} = A_{V1} \times A_{V2} \quad (4)$$

In a two-stage RC coupled amplifier composed of two NPN common-emitter amplifiers, the output signal ($V_{02}$) is in phase with the input signal ($V_{i1}$) because of the phase inversion of each stage (Figure E7-4).

The overall voltage gain ($A_{VC}$) of the two-stage RC coupled stage (Q2) collector terminal at C4; the output load resistance ($R_{L2}$) becomes the parallel resistance of R9 and R12 (Figure E7-5). Because the load resistance is reduced, the gain is smaller.
Fig. E7-5 Q2 output load when R12 is connected in parallel with R9

The second circuit addition affects the second stage (Q2) emitter resistor (R10). The effect of the second stage 1K emitter resistor (R10) on the second stage output signal and gain can be greatly reduced when bypassed with C5 and R11 (100 Ω), as shown in Figure E7-6. This bypassing greatly increases the voltage gain of the second stage (AV2) and the overall circuit gain (Avc).

However, bypassing emitter resistor R10 slightly reduces the first stage output load (RL1) and, as a result, the first stage gain (AV1).

When C5 and R11 are connected to the Q2 emitter terminal, the emitter resistor is reduced from 1k to 91 because it is the parallel resistance of R11 and R10. When R10 is bypassed, the resistance of re (about 21) must be accounted for in the total emitter circuit resistance (91+21=112) when voltage gains are calculated.

Procedure

1- Locate the RC COUPLING/TRANSFORMER COUPLING circuit block on the TRANSISTOR AMPLIFIER CIRCUIT circuit board. Connect the RC coupled amplifier circuit for ac operation, as shown in Figure E7-7.
Fig.E7-6 R10 bypassed with C5 and R11

2- Measure and record the supply voltage (VA), with reference to ground.

3- Connect channel 1 of the oscilloscope to the base of Q1. Adjust the sine wave generator for a \(100 \text{ mV}\) peak-to-peak 1kHz ac input signal \((V_{i1})\).

4- Connect the channel 2 probe of the oscilloscope to the first-stage ac output signal \((V_{o1})\) at the collector of Q1. What is \(V_{o1}\)?

\[
V_{o1} = \frac{2.6 \text{ V}}{260 \text{ mV}} = 10
\]

5- In comparison to the input signal, is the output waveform distorted?

6- What is the phase relationship of \(V_{o1}\) to \(V_{i1}\)?

7- Calculate and record the voltage gain of Q1, using Eq.(1).

8- Connect the channel 1 probe to the second stage ac input signal \((V_{i2})\) at the base of Q2. What is \(V_{i2}\)?

\[
V_{o1} = 2.6 \text{ V} \quad A_{o1} = \frac{V_{o1}}{V_{i1}} = \frac{260}{100} = 2.6
\]
9- Is $V_{i2}$ equal $V_{o1}$? \( \neg \neq \searrow \) \[ V_{i2} \neq V_{o1} \]

10- Connect the channel 2 probe of the oscilloscope to the ac output signal ($V_{o2}$) of Q2 at the collector of Q2. What is $V_{o2}$? $1200\,\text{mV}$ (12 volts).

11- What is the phase relationship of $V_{o2}$ to $V_{i2}$? $180^\circ$

12- Calculate and record the voltage gain of Q2, using Eq.(2).

13- Connect the channel 1 probe to the base of Q1 ($V_{i1}$). What is the phase relationship of $V_{o2}$ to $V_{i1}$?

14- Calculate and record the overall circuit gain, using Eq.(3).

15- Does the measured overall gain ($AV_C$) equal the product of $AV_1$ (calculated in step 7) and $AV_2$ (calculated in step 12)?

16- At the output of Q2, connect load resistor (R12) to C4. For ac signals, R12 is in parallel with Q2 collector resistor R9. With a 100 mV peak-to-peak input signal ($V_{i1}$), measure and record $V_{o2(L)} = 560\,\text{mV}$.

\[
\frac{R_{12}}{R_g} = \frac{R_{\text{total}}}{40} \approx \frac{516\,\text{V}}{96} \approx 5.37\,\text{V}
\]
17. Calculate and record the loaded overall circuit gain.

\[ A_{ \text{ve}(L)} = \frac{V_{02}}{V_{i1}} \]

18. Is the loaded overall circuit gain \( A_{ \text{ve}(L)} \) less than the unloaded overall circuit gain \( A_{ \text{ve}} \) calculated in step 14?

19. Bypass emitter resistor \( R_{10} \) by connecting \( R_{11} \) and \( C_5 \) to the emitter of \( Q_2 \). Load resistor \( R_{12} \) should still be connected to \( C_4 \). With 100 mV peak-to-peak input signal \( (V_{i1}) \), measure and record \( V_{02}(L) \).

20. Calculate and record the loaded overall circuit gain

\[ A_{ \text{ve}(LB)} = \frac{V_{02(LB)}}{V_{i1}} \]

21. Did bypassing the emitter resistor greatly increase the gain?

22. Observe output signal \( V_{02} \). Set CM 13 switch in the ON position to change \( R_{12} \) from 4.7 k\( \Omega \) to 1k\( \Omega \), what happened to \( V_{02} \) (reduced)?

23. What caused the result of step 22?

**Discussion**

1. The voltage gain of a two-stage RC coupled amplifier is the product of the gains of each stage.

2. The output signal of a two-stage RC coupled NPN common-emitter amplifier is in phase with the input signal.

3. Connecting an external load across the output of an RC coupled amplifier reduces the voltage gain.

4. Using a capacitor to bypass the emitter resistor of the second stage greatly increases the voltage gain.

**Review Questions**

1. Set up the circuit in Figure E7-8. Observe the output signal \( (V_{02}) \) on the oscilloscope. Turn on CM switch 12 to change \( R_{11} \) from 100 to 390 . The RC coupled amplifier output signal \( (V_{02}) \) amplitude changed because the
a- output load \((R_{L2})\) was reduced
b- second stage emitter resistance was increased.
c- second stage emitter resistance was reduced.
d- first stage voltage gain was reduced.

Fig.E7-8 Connection diagram

2-When an ac input signal is applied, each common-emitter stage:
   a- changes the phase of its input signal by 90 degrees.
   b- acts as an independent amplifier circuit.
   c- changes the phase of its input signal by 180 degrees.
   d- has an output signal in phase with its input signal.

3- When the emitter resistor of the second stage is bypasses with a capacitor, the:
   i- voltage gain of the second stage increases greatly, but the gain of the first stage decreases slightly.
   ii- voltage gain of the first stage increases greatly, but the gain of the second stage decreases slightly.
   c- second stage amplifier goes into saturation.
   d- second stage emitter current decreases significantly.

4- Increasing the collector resistance of either stage:
   a- decrease the amplifier gain.
   b- increases the amplifier gain.
c- affects the input/output phase relationship.
d- has no effect on the overall gain.

Part C: RC Coupled Amplifier, Frequency Response
Introduction and Theoretical Background

The gain of an amplifier is not the same for all signal frequencies. The way in which the gain varies with frequency is called the frequency response (Figure E7-9).

The gain of the RC coupled amplifier used in this exercise starts to decrease at frequencies below 20 Hz and above 100 kHz, as shown in Figure E7-9. The bandwidth of an amplifier is the range of signal frequencies over which the audio amplifier falls off more than 15%, the end of the bandwidth frequency range has been reached. The frequency response curve for audio amplifiers should be flat between 15 Hz and 20 kHz.

Fig. E7-9 Frequency response and bandwidth

The size of the coupling capacitor (C2) can affect frequency response at the lower frequencies. Coupling capacitor C2 is 1.0 F in the RC circuit on the circuit board. The capacitive reactance (\(X_C\)) of a 1.0 F capacitor does not appreciably affect the magnitude of the second-stage ac input signal (\(V_{12}\)) at frequencies above 50 Hz. The second-stage input (\(V_{12}\)) equals the first-stage output (\(V_{02}\)).
However, if the capacitance is reduced by a factor of \( \frac{1}{100} \) (1.0 F to 0.01 F), the capacitive reactance \( (X_C) \) increases by a factor of 100. If \( C_2 \) is changed to 0.01 F, \( X_C \) and the input impedance of \( Q_2 \) act like a voltage divider (Figure E7-10), making \( V_{i2} \) significantly less than \( V_{o2} \) at frequencies less than 5kHz. As a result, the overall amplifier gain \( (A_{VC}) \) starts to decrease with signals less than 5kHz, causing a more narrow bandwidth.

Frequency dependent amplifier parameters and stray circuit capacitance limit the frequency response at frequencies above 50 kHz.

Procedure

1- Locate the RC COUPLING/TRANSFORMER COUPLING circuit block on the TRANSISTOR AMPLIFIER CIRCUITS circuit board. Connect the RC coupled amplifier circuit for frequency response measurements, as shown in Figure E7-11. Notice that R12 is connected to C4, but R11 is connected to R10.

![Voltage divider circuit](image)

Fig. E7-10 Voltage divider circuit formed by \( C_2 \) and the input impedance of \( Q_2 \) when \( C_2 \) equals 0.01 F.
6- Calculate the overall loaded circuit gain \( (A_{Vc(L)} = \frac{V_{o2}}{V_{i1}}) \) for each frequency. Record your results in Table 7-4.

![Frequency response curve and bandwidth with C2 = 1.0 F](image)

**Fig.E7-12** Frequency response curve and bandwidth with \( C_2 = 1.0 \, F \)

7- Figure E7-12 shows the typical form of a frequency response curve for the two-stage RC coupled amplifier (Figure E7-11). The points on the curve correspond to the frequencies at which you calculated the amplifier gains \( (A_{Vc(L)}) \), recorded in Table 7-4. On the Y-axis of the frequency response curve in Figure E7-12, record your calculated gains in the boxes next to the points corresponding to the frequencies. The X-axis of Figure E7-12 is a logarithmic scale for the wide range of input signal frequencies (10Hz to 1.0MHz).

8- Do the gains on the frequency curve increase sharply before a frequency of 20 Hz and decrease sharply after 100KHz?

9- Are the gains for frequencies in the audio frequency range of 20 Hz to 20 kHz generally within the bandwidth of the two-stage RC coupled amplifier?

10- If necessary, adjust the sine wave generator for a 1kHz, 100 mV peak-to-peak ac input signal \( (V_{i1}) \) at base of transistor Q1. In the next steps, you will...
To determine B & G:

x-axis \rightarrow \text{Freq}

y-axis \rightarrow \text{Gain}

and the value of \( f_0 \) Gm.

\begin{align*}
\frac{1}{10} & \quad 220 \text{ mV} \\
2 & \quad 500 \text{ mV} \\
5 & \quad 600 \text{ } \\
10 & \quad 600 \text{ ''} \\
50 & \quad 600 \text{ ''} \\
100 & \quad 4800 \text{ ''} \\
1M & \quad 40 \text{ mV} \\
2M & \quad 0
\end{align*}
observe the effect on lower frequency gains when the size of coupling capacitor 
C2 is reduced.

1- Set CM switch 3 in the On position to change the capacitance of C2 
from 1.0 μF to 0.01 μF. With CM switch 3 on, measure and record $V_{o2}$ 
for the frequencies shown in Table (2). Calculate $AVc(L)$ and record 
your results in Table 7-5.

<table>
<thead>
<tr>
<th>Frequency Hz</th>
<th>$V_{o2mV}$ peak-to-peak</th>
<th>$AVc(L) = \frac{V_{o2}}{V_{i1}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>1k</td>
<td></td>
<td></td>
</tr>
<tr>
<td>10k</td>
<td></td>
<td></td>
</tr>
<tr>
<td>100k</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 7-5 Gain versus frequency with C2 changed from 1.0 μF to 0.01 μF

12- Figure E7-13 shows the typical form of a frequency response curve 
for the two-stage RC coupled amplifier circuit (Figure E7-11) with C2 
equal to 0.01 μF. The points on the curve correspond to the frequencies 
at which you calculated the amplifier gains [$AVc(L)$], recorded in 
Table 7-5. On the Y-axis of the frequency response curve in Figure E7-
13, record your calculated gains at the points that correspond to the 
frequency of the gain.

Fig. E7-13 Frequency response curve and bandwidth with C2 = 0.01 μF

103
13. Compare the frequency response curves in Figures E7-12 and E7-13. At 1 kHz, is the gain with a 0.01 μF capacitor significantly lower than the gain with a 1.0 μF capacitor?

14. Are the gains at frequencies between 10 kHz and 50 kHz about the same for the RC coupled amplifiers with 0.01 μF and 1.0 μF capacitors (compare Figures E7-12 and E7-13)?

15. Refer to Figure E7-13. What is the low frequency limit of the bandwidth when the amplifier has a 0.01 μF coupling capacitor (C2)?

Conclusion

1. The way in which gain varies with frequency is the frequency response.

2. The range of signal frequencies over which the gain is relatively constant is the bandwidth.

3. The size of the coupling capacitor affects frequency response at lower frequencies.

4. The upper frequency limit of the bandwidth is affected by frequency-dependent amplifier parameters and stray capacitance in the circuit elements.

Review Questions

1. The way in which gain varies with frequency is the:
   a. bandwidth
   b. frequency response
   c. gain efficiency
   d. relative frequency.

2. The range of frequencies over which the amplifier gain is constant is the:
   a. bandwidth
   b. frequency response
   c. gain efficiency
   d. relative frequency.

3. The size of the coupling capacitor affects frequency response at:
   a. high frequencies
   b. middle frequencies
   c. low frequencies
   d. all frequencies
4. Amplifier gains start to decrease at higher freq. because:
   - The amplifier parameters change at high frequencies.

5. Increasing the size of the coupling capacitor in a two-stage RC coupled amplifier from 0.05 μF to 5 μF will:
   - Increase the BW

\[ BW = \frac{F_c}{Q} \quad \text{and} \quad F_c = \frac{1}{2\pi R_C} \]

Increased \( R_E \) → gain deu

Increased \( R_W \) → gain deu

Gain = \( \text{deu} \)