Study of Two Stage RC Coupled Transistor Amplifier Circuit

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A multi-stage amplifier circuit extensively used in electronic circuits. Here the individual stages of the amplifier are connected together using a resistor-capacitor combination.The successive stages amplify the signal and the overall gain is raised to the desired level. Much higher gain can be obtained by connecting a number of amplifier stages in succession.

RC coupling in amplifiers are most widely used to connect the output of first stage to the input of the second stage and so on. This type of coupling is most popular because it is cheap and provides a constant amplification over a wide range of frequencies. The main purpose of this circuit is pre-amplification that is to make weak signals to be stronger enough for further amplification. In this experiment, we design two-stage RC coupled common emitter transistor amplifier circuit and study its characterstics, including how it responds to different frequencies.

I. OBJECTIVE

To design a two stage RC coupled common emitter transistor (NPN) amplifier circuit and to study its frequency response curve.

II. THEORY

A single stage of amplification is often not enough for a particular application. The overall gain can be increased by using more than one stage, so when two amplifiers are connected in such a way that the output signal of the first serves as the input signal to the second, the amplifiers are said to be connected in cascade. The most common arrangement is the common-emitter configuration.

Resistance-capacitance (RC) coupling is most widely used to connect the output of first stage to the input (base) of the second stage and so on. It is the most popular type of coupling because it is cheap and provides a constant amplification over a wide range of frequencies. These R-C coupled amplifier circuits are commonly used as voltage amplifiers in the audio systems.

Circuit Design

The circuit diagram (Fig.1) shows the 2-stages of an RC coupled amplifier in CE configuration using NPN transistors. Capacitors C_1 and C_3 couple the input signal to transistors Q_1 and Q_2, respectively. C_5 is used for coupling the signal from Q_2 to its load. R_1, R_2, R_{E1} and R_3, R_4, R_{E2} are used for biasing and stabilization of stage 1 and 2 of theamplifier. C_2 and C_4 provide low reactance paths to the signal through the emitter.

Gain

The total gain of a 2-stage amplifier is equal to the product of individual gain of each stage. Once the second stage is added, its input impedance acts as an additional load on the first stage thereby reducing the gain as compared to its no load gain. Thus the overall gain characteristics is affected due to this loading effect.

The loading of the second stage i.e. input impedance of second stage is given by,

$$Z_{i2} = R_3 \parallel R_4 \parallel \beta r_{e2} \tag{1}$$

Hence, the loaded gain of the first stage is depends on the input impedance of the first stage, i.e.,

$$A_{V1} = -\frac{R_{C1} \parallel Z_{i2}}{r_{e1}} \tag{2}$$

And the unloaded gain of the second stage,

$$A_{V2} = -\frac{R_{C2}}{r_{e2}} \tag{3}$$

In the experimental circuit, the emitter resistor is split into two in order to reduce the gain to avoid distortion. So the expression for gain each stage is modified as,

$$A_{V1} = -\frac{R_{C1} \parallel Z_{i2}}{R_{E1} + r_{e1}} \tag{4}$$

$$A_{V2} = -\frac{R_{C2}}{R_{E2} + r_{e2}} \tag{5}$$

Frequency Response Curve

The performance of an amplifier is characterized by its frequency response curve that shows voltage gain plotted versus frequency. The frequency response begins with the lower frequency region designated between 0 Hz and lower cutoff frequency. At lower cutoff frequency, f_L , the gain is equal to 0.707 A_{mid}. A_{mid} is a constant mid-band gain obtained from the mid-band frequency region. The third,

the upper frequency region covers frequency between upper cutoff frequency and above. Similarly, at upper cutoff frequency, f_H, the gain is equal to 0.707 A_{mid}. Beyond the upper cutoff frequency, the gain decreases as the frequency increases and dies off eventually.

Applications

The application of RC coupled amplifiers in music systems, has excellent audio fidelity over a wide range of frequencies. Therefore, they are widely used as voltage amplifiers (preamplifiers). For example, in public address systems. They are also used in radio or TV Receivers as small signal amplifiers.

III. EXPERIMENTAL SETUP

Circuit components

1. 2 Transistors (CL100 or equivalent)
2. Power supply
3. 10 resistors of various specifications
4. 4 Capacitors
5. Function Generator
6. Oscilloscope
7. Multimeters
8. Connecting wires
9. Breadboard

Circuit Diagram

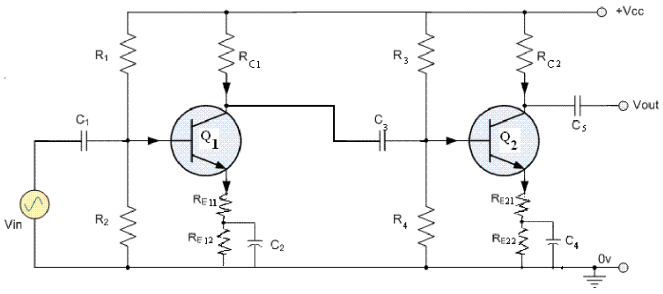

FIG. 1: Circuit diagram for the setup.

IV. OBSERVATIONS

Stage 1 (Q_1)	**Stage 2** (Q_2)
$\beta_1 = 189$	$\beta_2 = 184$
$R_1 = 26.48\,k\Omega$	$R_3 = 27.16\,k\Omega$
$R_2 = 4.900\,k\Omega$	$R_4 = 4.918\,k\Omega$
$R_{C1} = 3.835\,k\Omega$	$R_{C2} = 3.843\,k\Omega$
$R_{E11} = 0.590\,k\Omega$	$R_{E21} = 0.559\,k\Omega$
$R_{E12} = 0.466\,k\Omega$	$R_{E22} = 0.469\,k\Omega$
$C_1 = 1.036\,\mu$F	$C_4 = 83.1\,\mu$F
$C_2 = 1.014\,\mu$F	$C_5 = 99.0\,\mu$F

- $V_{CC} = 12$ V
- V_i (pp) = 200 mV
- $C_3 = 0.986\,\mu$F

We measured the following values from the D.C. analysis of the circuit.

	Stage 1 (Q_1)		Stage 2 (Q_2)	
Parameter	Computed Value	Observed Value	Computed Value	Observed Value
V_B (V)	1.874	1.835	1.839	1.808
V_E (V)	1.174	1.236	1.139	1.214
$I_C \approx I_E$ (mA)	1.11	1.17	1.11	1.17
V_{CE} (V)	6.57	6.26	1.59	1.26

TABLE I: D.C. analysis of the circuit

From this, the Q-point of stage is the found to be (6.26 V, 1.17 mA) and that of stage 2 is found to be (6.26 V, 1.17 mA).

The mid-frequency voltage gain (V_o/V_i) (at $f \approx 20$ kHz) was measured as follows.

	Stage 1 (Q_1)		Stage 2 (Q_2)	
Parameter	Computed Value	Observed Value	Computed Value	Observed Value
Unloaded Voltage Gain	6.26 (15.93 dB)	5.95 (15.49 dB)	6.61 (15.94 dB)	6.40 (16.12 dB)
Loaded Voltage Gain	2.19 (6.81 dB)	3.50 (10.88 dB)	-	-

TABLE II: Mid-frequency voltage gain at ∼20 kHz

V. CALCULATIONS & DATA ANALYSIS

Input and Output Impedances

For stage 1, $r_{e_1} = 26\text{mV}/I_{E1} = 26$ mV/1.17 mA $= 22.22\,\Omega$. Therefore,

$$\begin{aligned} Z_{i1} &= R_1 \parallel R_2 \parallel \beta_1 r_{e1} \\ &= \left(\frac{1}{26480} + \frac{1}{4900} + \frac{1}{189 \times 22.22}\right)^{-1} \\ &= 2.083\,k\Omega \end{aligned}$$

And output impedance,

$$\begin{aligned} Z_{o1} &= R_{C1} \parallel r_{o1} \\ &= \left(\frac{1}{R_{C1}} + \frac{1}{r_{o1}}\right)^{-1} \\ &\approx R_{C1} = 3.835\,\text{k}\Omega \end{aligned}$$

Since r_o is is the range of ~ 100 kΩ, we can ignore it.

Similarly for stage 2, $r_{e_2} = 26\text{mV}/I_{E2} = 22.22\,\Omega$. Therefore,

$$\begin{aligned} Z_{i2} &= R_3 \parallel R_4 \parallel \beta_2 r_{e_2} \\ &= \left(\frac{1}{27160} + \frac{1}{4918} + \frac{1}{184 \times 22.22}\right)^{-1} \\ &= 2.062\,k\Omega \end{aligned}$$

And output impedance,

$$\begin{aligned} Z_{o2} &= R_{C2} \parallel r_{o_2} \\ &= \left(\frac{1}{R_{C2}} + \frac{1}{r_{o2}}\right)^{-1} \\ &\approx R_{C2} = 3.843\,\text{k}\Omega \end{aligned}$$

Mid-frequency Gain

Using Eqs. (4) and (5), loaded gain of the first stage

$$\begin{aligned} A_{V_1} &= \frac{R_{C1} \parallel Z_{i2}}{R_{E1} + r_{e1}} \\ &= \frac{\left(\frac{1}{3835} + \frac{1}{2062}\right)^{-1}}{590 + 22.22} \\ &= 2.19 \text{ (or 6.81 dB)} \end{aligned}$$

unloaded gain of first stage,

$$\begin{aligned} A'_{V_1} &= \frac{R_{C1}}{R_{E1} + r_{e1}} \\ &= \frac{3835}{590 + 22.22} \\ &= 6.26 \text{ (or 15.94 dB)} \end{aligned}$$

unloaded gain of second stage,

$$\begin{aligned} A_{V_2} &= \frac{R_{C2}}{R_{E1} + r_{e1}} \\ &= \frac{3843}{559.3 + 22.22} \\ &= 6.61 \text{ (or 16.40 dB)} \end{aligned}$$

The overall computed gain of the 2 stage amplifier,

$$A_{V_{\text{comp}}} = A_{V1} \times A_{V2} = 14.48 \text{ (or 23.21 dB)}$$

Observed value of total gain,

$$A_{V_{\text{obs}}} = 19.75 \text{ (or 25.91 dB)}$$

Frequency Response Curve

Here is the plot of the frequency response curve of the circuit.

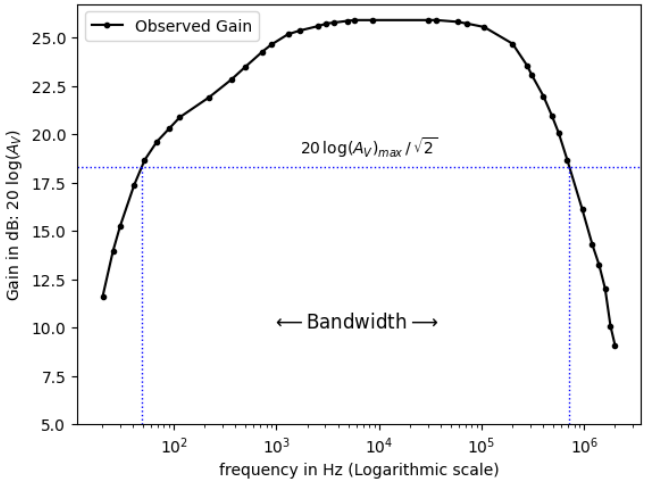

FIG. 2: Frequency response curve: A_V vs. frequency plot

From Fig. 2, we can estimate the following values,

- Mid frequency Gain: 25.91 dB (or $V_o/V_i = 19.75$)
- Cut-off frequencies: 48.46 Hz and 712.89 kHz and
- Bandwidth: 712.83 kHz

VI. ERROR ANALYSIS

1. **Error in Z_{i1}**

$$\begin{aligned} \Delta Z_{i1} &= \sqrt{\left(\tfrac{\partial Z_{i1}}{\partial R_1}\Delta R_1\right)^2 + \left(\tfrac{\partial Z_{i1}}{\partial R_2}\Delta R_2\right)^2 + \left(\tfrac{\partial Z_{i1}}{\partial \beta}\Delta\beta\right)^2 + \left(\tfrac{\partial Z_{i1}}{\partial I_{E1}}\Delta I_{E1}\right)^2} \\ &= 1.041\,\Omega \end{aligned}$$

2. **Error in Z_{o1}**
   Since $Z_{o1} \approx R_{C1}$, $\Delta Z_{o1} = 0.001\,k\Omega$
3. **Error in Z_{i2}**
   Similarly as Z_{i1}, $\Delta Z_{i2} = 1.054\,\Omega$
4. **Error in Z_{o2}**
   Similarly as Z_{o1}, $\Delta Z_{o2} = 0.001\,k\Omega$
5. **Error in A_{V_1}**

$$\begin{aligned} \Delta A_{V_1} &= \sqrt{\left(\tfrac{\partial A_{V_1}}{\partial c}\Delta c\right)^2 + \left(\tfrac{\partial A_{V_1}}{\partial Z_{i2}}\Delta Z_{i2}\right)^2 + \left(\tfrac{\partial A_{V_1}}{\partial R_{E1}}\Delta R_{E1}\right)^2 + \left(\tfrac{\partial A_{V_1}}{\partial I_{E1}}\Delta I_{E1}\right)^2} \\ &= 0.004 \end{aligned}$$

   $\therefore A_{V_1} = 2.190 \pm 0.004$

6. **Error in A'_{V_1}**

$$\begin{aligned} \Delta A'_{V_1} &= \sqrt{\left(\tfrac{\partial A'_{V_1}}{\partial c}\Delta c\right)^2 + \left(\tfrac{\partial A'_{V_1}}{\partial R_{E1}}\Delta R_{E1}\right)^2 + \left(\tfrac{\partial A'_{V_1}}{\partial I_{E1}}\Delta I_{E1}\right)^2} \\ &= 0.001 \end{aligned}$$

   $\therefore A'_{V_1} = 6.260 \pm 0.001$

7. **Error in A_{V_2}**
   Similarly to A'_{V_1}, $\Delta A_{V_2} = 0.01$.
   $\therefore A_{V_2} = 6.61 \pm 0.01$
8. **Error in $A_{V_{\text{comp}}}$**
   Since to $A_{V_{\text{comp}}} = A_{V_1} \times A_{V_2}$, $\Delta A_{V_{\text{comp}}} = 0.07$.
   $\therefore A_{V_{\text{comp}}} = 14.48 \pm 0.07$

VII. RESULTS AND DISCUSSION

We have successfully constructed a two stage RC coupled transistor amplifier circuit, and anaysed its frequency response curve. We found that the gain is maximum and stable in the mid-frequency range. The bandwidth of the frequency response came out to be from 48.46 Hz to 712.89 kHz.

Using data from the D.C. analysis of the circuit, the following values were calculated:

- Input Impedance of Stage 1

$$Z_{i1} = (2.083 \pm 0.001)\,\text{k}\Omega$$

- Output Impedance of Stage 1

$$Z_{i1} = (3.835 \pm 0.001)\,\text{k}\Omega$$

- Input Impedance of Stage 2

$$Z_{i2} = (2.062 \pm 0.001)\,\text{k}\Omega$$

- Output Impedance of Stage 2

$$Z_{o2} = (3.843 \pm 0.001)\,\text{k}\Omega$$

The theoretical value of the overall mid-frequency gain voltage gain was calculated as (14.48 ± 0.07) (or 23.21 ± 0.04 dB). The observed value of mid-frequency gain is 19.75 (or 25.91 dB). We can see that overall gain is close to the product of the voltage gain of both the individual stages. Hence, we have achived higher overall voltage gain by connecting two stages of an RC coupled transistor amplifier circuit.

The deviation in the values could be due to (i) error in measurement of the resistance/capacitance values, or (ii) the extra resistance offered by the connecting wires, or (iii) fluctuation in the source voltage.

VIII. PRECAUTIONS

1. Vary the input signal frequency slowly.
2. Connect electrolytic capacitors carefully.

[1] SPS. Lab manual. *Website*, 2023. `https://www.niser.ac.in/sps/sites/default/files/10_RC_coupled_two_stage_transistor_amplifier.pdf`.