Bandwidth Extension of BJT Amplifier using a Novel Cascade Topology

Rupjyoti Haloi
Department of Electronics and Communication Engineering, Gauhati University, Guwahati-781014, Assam, India

Kandarpa Kumar Sarma
Department of Electronics and Communication Engineering, Gauhati University, Guwahati-781014, Assam, India

ABSTRACT

In any amplifier design, it is always necessary to give utmost attention to its frequency response analysis. While applying frequency response for some application it is also important to extend the bandwidth of an amplifier. Increasing the bandwidth means increasing the upper 3 dB frequency and decreasing the lower 3 dB limit. Although there are different means by which this extension can be achieved, we have chosen the application of negative feedback for the purpose. We have derived some new topologies from these existing topologies which fulfill our bandwidth requirements. In this paper, we are presenting a new approach based on the individual standard topologies which extend the bandwidth of the standard amplifier by 30%.

Keywords: - Frequency response, bandwidth, negative feedback, 3 db frequency.

1. INTRODUCTION

Conventional BJTs have limited frequency response range. In any amplifier design, it is always necessary to give utmost attention to its frequency response analysis. While applying frequency response for some application it is also important to extend the bandwidth of an amplifier. Increasing the bandwidth means increasing the upper 3 dB frequency and decreasing the lower 3 dB limit. There are several approaches by which this range can be extended [1] [2]. An extended range allows use of the BJT based system for multiple applications. A simple approach to extend the bandwidth of the BJT amplifier is the use of negative feedback. Such works have already been explored and studied extensively [1] [2]. Another approach is to combine multiple feedback configurations and derive additional benefits. Here, we discuss such an approach. We have analyzed the detail frequency response provided by composite structures formed using combinations of known feedback topologies. The work includes detailed theoretical analysis of the proposed topology and responses to various parameter variations considered. The theoretical analysis show that the proposed approaches provides considerable improvement in bandwidth expansion and enables multiple frequency dependent applications. Experimental works suggest that cascade topologies provide improved performance. Especially series shunt - shunt shunt topology provides the best bandwidth expansion. Compared to series-shunt topology, the proposed approach provide 30% betterment while in comparison to shunt shunt topology, the improvement is 22%.

Some of the relevant literatures are [1] to [20]. The rest of the paper is organized as below: Secion 2 provides certain theoretical consideration. Section 3 includes the proposed model. Experimental details are included in section 4 and Section 5 concludes the paper.

2. THEORETICAL BACKGROUND

Most physical systems incorporate some form of the feedback. Feedback can be either positive (regenerative) or negative (degenerative). Negative feedback has the advantages of desensitizing the gain of the amplifier, reducing nonlinear distortion, reducing the effect of noise, controlling the input and output impedances and extending the bandwidth of the amplifier. In amplifier design negative feedback is applied to effect one or more of its above mentioned properties. Although based on the quantity to be amplified and on the desired form of output amplifier can be classified into four categories. For the present work we are using series-shunt and shunt-shunt type of feedback amplifiers. Figure.1 shows a common-emitter amplifier with series – shunt type of negative feedback.

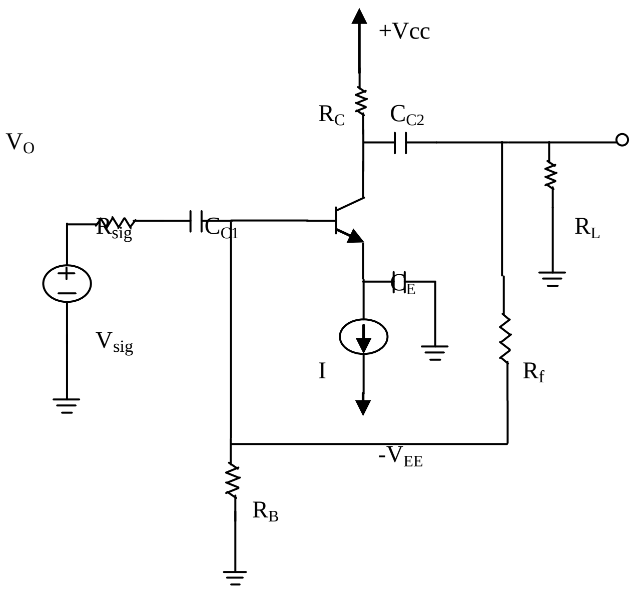

Figure 1: Series-shunt type of feedback amplifier

The high frequency equivalent circuit of the amplifier is shown in figure 2:

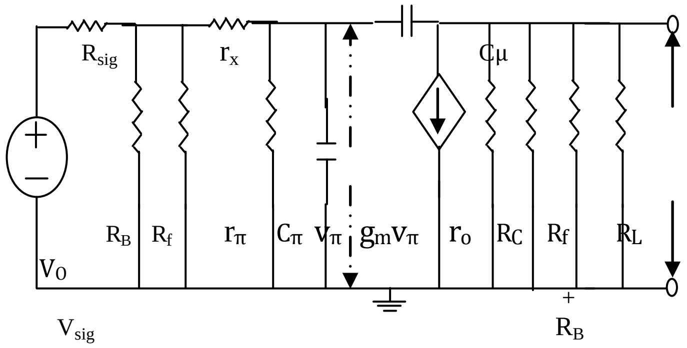

Figure 2: High frequency equivalent circuit

Figure 3 shows the common emitter amplifier with shunt-shunt type of negative feedback.

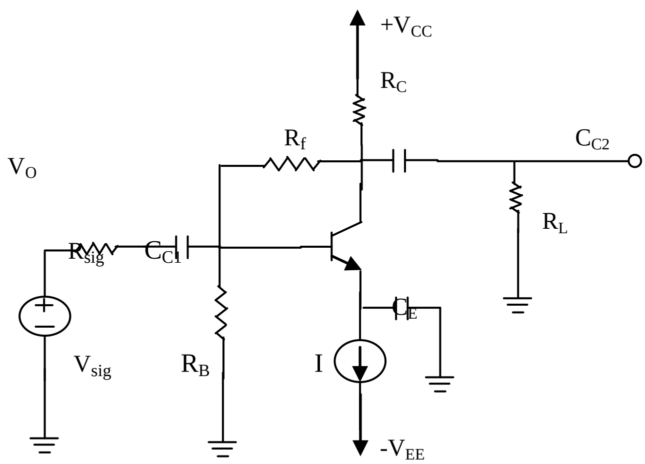

Figure 3: Shunt shunt type of feedback amplifier

The working of the system is already known. The high frequency equivalent circuit of this circuit is shown in figure 4.

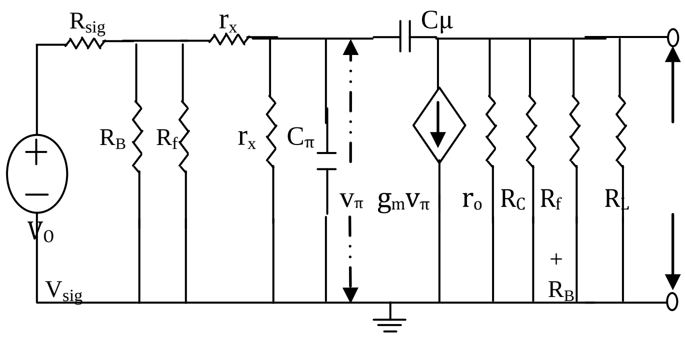

Figure 4: High frequency equivalent circuit

From these equivalent circuits, we can derive the mathematical
equations for calculation of the high cut-off frequency. The high frequency f_H can be calculated by using the following expression:

$$f_H = \frac{1}{2 \times \pi \times C_{in} \times R_{sig}{}'} \text{ .... (1)}$$

where input capacitance,

$$C_{in} = C_\pi + C_{eq}$$

$$= C_\pi + C_\mu\left(1 + g_m R_L{}'\right) \text{ .... (2)}$$

$$R_{sig}{}' = r_\pi II \left\{ r_x + \left(R_B{}' \mathbin{//} R_{sig} \right) \right\} \text{ ....(3)}$$

and, $R_B{}' = R_B \mathbin{//} R_f$

Again for low frequency analysis we are using the circuit shown in figure 5 with the dc sources eliminated.

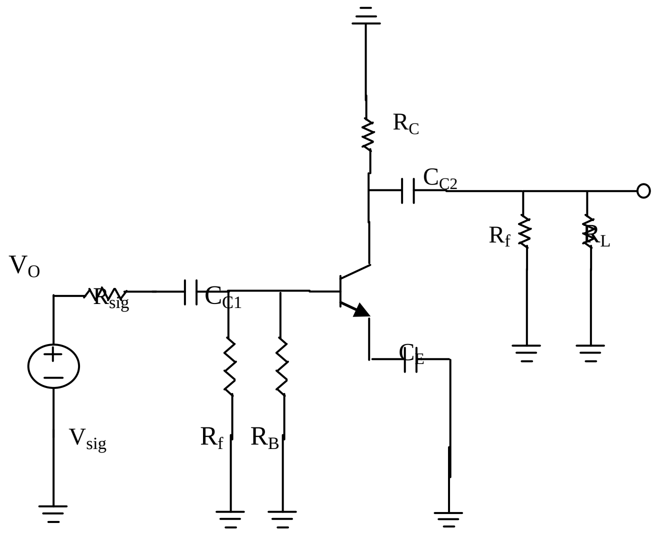

Figure 5: Amplifier circuit for low frequency analysis

We can perform the small signal analysis directly on the circuit. For this low frequency analysis, we can ignore C_π and C_μ since at such a low frequency their impedances will be very high and thus can be considered as open circuit. Also, in this analysis, we are neglecting r_x and r_π as their effects on the amplifier response at low frequency are very small.

For finding out the lower cut off frequency, we consider the three capacitances C_{C1}, C_{C2}, and C_E one at a time considering other two as perfect short circuits. By this procedure three break frequencies f_1, f_2 and f_3 are found. From these three break frequencies, we can calculate the low cut-off frequency by using the expression

$$f_L = \frac{1}{2 * \pi}\left[\frac{1}{C_{C1}R_{C1}} + \frac{1}{C_E R_E} + \frac{1}{C_{C2}R_{C2}}\right] \text{ ... (4)}$$

$$= f_1 + f_2 + f_3 \text{ .... (5)}$$

where C_{C1}, C_{C2} and C_E are the capacitances as shown in figure and R_{C1}, R_{C2}, R_E are the resistances as seen by C_{C1}, C_{C2} and C_E respectively. These resistances can be calculated by using the following expressions:

$$R_{C1} = \left(R_B \mathbin{//} r_\pi\right) + R_{sig} \text{ .... (6)}$$

$$R_E = r_e + \frac{R_B // R_{sig}}{\beta + 1} \quad \text{.................................. (7)}$$

$$R_{C2} = R_C + R_L \quad \text{...................................... ..... (8)}$$

3. PROPOSED MODEL

Based on the theoretical analysis stated above in Section 2, we propose here this new composite model. It is shown in figure 6.

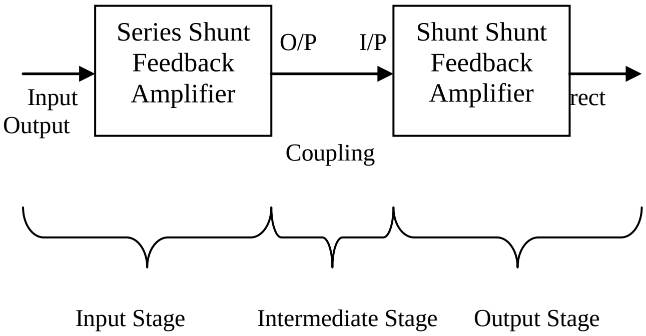

Figure 6: Block diagram of the proposed model

Here, we are cascading series-shunt and shunt-shunt type of feedback amplifiers. For cascading these two amplifiers, we are using here the method of direct coupling. Direct coupling connects two amplifier stages by taking the output of the first stage as the input of the second without the use of capacitors. The equivalent circuit for this cascaded topology is shown in figure 7.

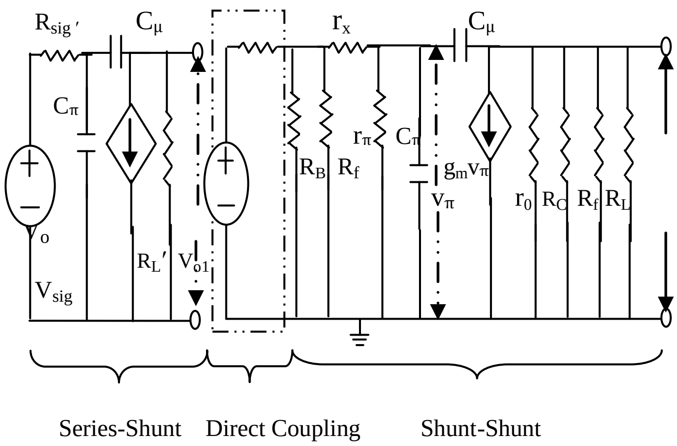

Figure 7: equivalent circuit of the proposed model

In this proposed model, the output voltage of the series-shunt amplifier will act as input to the shunt shunt type of feedback amplifier. From this equivalent circuit, the high frequency can be calculated by the expression

$$f_H = \frac{1}{2 \times \pi \times C_{in} \times R_{sig}{}'}$$

where,

$$R_{sig}{}' = r_\pi II \left\{ r_x + \left(R_B // R_f // R_L{}' \right) \right\} \quad \text{........... (9)}$$

In this expression, r_π, r_x, R_B , R_f and C_{in} are calculated from the output stage and R_L' is the equivalent output resistance of the first stage of the amplifier. We can calculate the low frequency by the expression

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

where,

$$R_{C1} = \left(R_B // r_\pi // R_f \right) + R_{sig} \quad \text{............... (10)}$$

$$R_E = r_e + \frac{R_B // R_{sig}{}'}{\beta + 1} \quad \text{............................... (11)}$$

$$R_{C2} = R_C + R_L \quad \text{....................................... (12)}$$

Here R_{sig}' is the output resistance of the first stage of the composite amplifier topology.

4. EXPERIMENTAL DETAILS AND RESULTS

For selecting the best possible 2's-configuration form, we calculate the input and output impedances of all the possible configurations. The behavior of those topologies based on these results are shown in Table 1. From Table 1, we can clearly select series shunt – shunt shunt type of cascaded topology to be the most suitable one. Here input and output impedances increases which leads to better performance.

Table 1. Characteristics of the possible two configuration form of the standard topologies.

Cascaded topology					Input Impedance	Output Impedance
Series	Shunt	-	Shunt	Series	Increases	Increases
Series	Shunt	-	Shunt	Shunt	Increases	Decreases
Series	Shunt	-	Series	Series	Increases	Increases
Shunt	Series	-	Shunt	Shunt	Decreases	Decreases
Shunt	Series	-	Series	Series	Decreases	Increases
Shunt	Shunt	-	Series	Series	Decreases	Increases

With the help of the equivalent circuits and the derived expressions, we have calculated f_H and f_L and also the bandwidth. The results are tabulated in Table 2. We see that the Series-Shunt Shunt-Shunt configuration with 1062 KHz provides 30 % bandwidth expansion compared to Series Shunt topology.

Table 2. Results of the bandwidth calculation

Feedback type	frequency f_L(Hz)	frequency f_H(KHz)	Bandwidth f_H - f_L(KHz))
Series- shunt	162	817	816
Shunt -Shunt	142	874	873
Series shunt Shunt shunt	137	1063	1062

For generating the results shown in Table.2 we assumed some standard values for all the necessary parameters like resistances and capacitances. From the above results, we see that the bandwidth of the cascaded topology is higher than the individual type of amplifier topologies. For better analysis of the frequency response of these amplifiers, we are presenting some tabulated data which show changes in bandwidth with different parameters changes. These are shown in Tables 3 to 5.

Table 3: Bandwidth for different resistances in series shunt topology

Resistances		series-shunt		
R_B	R_C	f_H	f_L	BW
100 K Ω	8K Ω	817.6K Hz	162 Hz	817.4KHz
100 Ω	10 Ω	135.9MHz	5.85K Hz	135.9MHz
300 K Ω	100 K Ω	538.7KHz	149 Hz	538.6KHz
500 K Ω	200 K Ω	523.4KHz	148 Hz	523.3KHz

Table 4: Bandwidth for different resistances in shunt shunt topology

Resistances		shunt - shunt		
R_B	R_C	f_H	f_L	BW (Hz)
100K Ω	8 KΩ	874.5 KHz	142 Hz	874.4 KHz
100 Ω	10 Ω	135.9 MHz	5.832 KHz	135.9 MHz
300 KΩ	100K Ω	608.4 KHz	130Hz	608.3 KHz
500K Ω	200K Ω	595.7 KHz	128Hz	595.6KHz

Table 5. Bandwidth for different resistances in series shunt - shunt shunt topology

Resistances		series shunt – shunt shunt		
R_B (Ω)	R_C (Ω)	f_H	f_L	BW (Hz)
100K Ω	8 KΩ	1063.5KHz	137Hz	1063.3 KHz
100 Ω	10 Ω	328.5MHz	50.2KHz	328.4 MHz
300 KΩ	100K Ω	630KHz	155Hz	629.8 KHz
500K Ω	200K Ω	611.3KHz	150Hz	611.2 KHz

The results conclusively show that cascade topologies provide improved performance. Especially series shunt - shunt shunt topology provides the best bandwidth expansion. Compared to series-shunt topology, the proposed approach provide 30% betterment while in comparison to shunt shunt topology, the improvement is 22%.

5. CONCLUSION

Here, we have presented a new topology that gives a higher bandwidth compared to the standard individual topologies. Also we have presented a detail theoretical analysis of the amplifier frequency response with respect to the different values of the amplifier's internal and external parameters. These analyses would help us in achieving better performance from the amplifier.

The theoretical analysis show that the proposed approaches provides considerable improvement in bandwidth expansion and enables multiple frequency dependent applications. Experimental works suggest that cascade topologies provide improved performance. Especially series shunt - shunt shunt topology provides the best bandwidth expansion. Compared to series-shunt topology, the proposed approach provide 30% betterment while in comparison to shunt shunt topology, the improvement is 22%.

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