



e-ISSN: 2319-8753 | p-ISSN: 2347-6710

IJIRSET

International Journal of Innovative Research in
SCIENCE | ENGINEERING | TECHNOLOGY

INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

Volume 11, Issue 8, August 2022

ISSN INTERNATIONAL
STANDARD
SERIAL
NUMBER
INDIA

Impact Factor: 8.118

 9940 572 462

 6381 907 438

 ijirset@gmail.com

 www.ijirset.com

Components Dependence and Error Analysis on the Output Response of the Circuits

Amit Sehgal

Associate Professor, Department of Physics and Electronics, Hansraj College, University of Delhi, Delhi, India

ABSTRACT: The aim of the present work is to demonstrate the variation in the results achieved by the analog circuits. The article focuses on the issues which students, researchers and amateur designers face while designing the circuits. The compromised performance of the circuits due to dependence on the components which are not of standard specifications and often deviate from its values leads to poor outcome of the circuit under consideration. In this article, a common emitter (CE) bipolar junction transistor (BJT) amplifier is studied and its performance is observed due to variation in the components present in the circuit based upon their tolerance limits. The theoretical results, simulated results and experimental results are found to be in good agreement to each other. Further, the theoretical analysis is extended to produce different results and thereby, predict the dependence of components on the output behaviour of the circuit under consideration.

KEYWORDS: Amplifiers, Tolerance, Gain response, Bandwidth, Error analysis

I. INTRODUCTION

Attributable to poor response of vacuum tubes-based triodes in World War II, Bardeen, Brattain and Shockley started experimenting on semiconductors as an alternative at Bell Laboratories. On December 16, 1947, they built the point-contact transistor, made from strips of gold foil on a plastic triangle, pushed down into contact with a slab of germanium [1]. Thereafter, there was no looking back. In 1951, the company known as Texas Instruments (TI) came into existence and applied to Bell Labs for a license to build transistors. TI managed to build the very first commercial silicon transistors under supervision of Gordon Teal in 1952 [2]. In 1957, Fairchild Semiconductor was founded by Robert Noyce and Gordon Moore and the new company started mass production of transistors [3]. In July 1968, Robert Noyce and Gordon Moore started a new company named Intel, acronym for Integrated Electronics [3]. In 1965, G. E. Moore gave a roadmap of advancement in the field of Integrated Chip (IC) industry with miniaturization of device size and thereby increasing packaging density [4]. Later, the roadmap became popular by the name of Moore's Law. As proposed by the Moore's Law, the IC technology has been advancing rapidly, still manufacturing of standalone transistors are required for several high voltage applications and small scale discrete component based circuits.

This article focuses on the dependence of all the parameters connected in the circuit and their impact on the performance of the circuit. The circuit under consideration is BJT common emitter amplifier. The need of analysis of the circuit was required to address the issues related to design of the circuit and deviation of performance in the experimental setup from the projected theoretical/simulated results. The problem faced during actual experiment's results is addressed in the section II. The complete circuit analysis along with its components is demonstrated in the section III. Section IV presents the graphs and discussion as an outcome based upon formulation deduced in section III for different conditions. Finally, section V presents conclusion.

II. ORIGIN OF PROBLEM

The transistors were primarily used in analog circuit applications such as amplifiers, oscillators. With the advancements in the integrated circuit technology, the feature size of the devices has reduced drastically. Still, small scale integration (SSI) based circuits are in use for commercial purposes in the field of laboratory instruments and high voltage/power applications. The BJT based amplifiers are one of common amplifier circuits still in use commercially and for education purpose. The design of BJT amplifier is studied and created based upon different requirements. Several authors have mentioned about these circuits and showcased about designing the circuits based upon different conditions. The design of the circuits comprises of DC biasing and AC analysis. But, often these analysis formulations are truncated or approximated under the specific conditions [5-7]. At times complete circuits with all parameters

dependence is not accounted to avoid complexity at the cost of marginal error in the final results. These approximations and reduced expressions at times avoids the dependence of the parameter/s too.

The students are introduced with basic transistorized amplifiers, oscillators and digital circuits as laboratory tasks. The students often face issues and challenges with design of amplifiers in the laboratories. The problem arises while comparison of the parameters done experimentally with their simulation and theoretical counterparts. The inconsistency in the experimental results with theoretical values is often answered as deviation in the values of components under the operating conditions due to experimental limitations. In this article, author proposed an analysis and the results achieved are an outcome of dependency of the parameters/ characteristics on all the possible components. The results obtained demonstrate a range of output values instead of a conventional behaviour due to components' value deviation from standard marked value.

III. METHODOLOGY

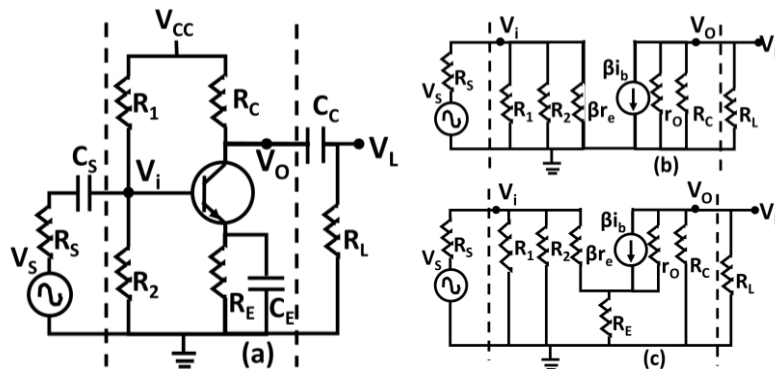


Fig.1 a) Voltage divider bias BJT Common Emitter (CE) Amplifier, b) Small signal AC equivalent circuit for bypassed emitter capacitor, c) Small signal AC equivalent circuit for un-bypassed emitter capacitor (emitter capacitor not present)

The Fig.1a shows the circuit under consideration, which comprise of voltage divider bias BJT CE amplifier. The circuit is designed to operate in Class A mode. The circuit is considered to have a figure of merit over other biasing configurations. The Class A mode of operation of amplifier works for complete cycle of operation and hence a single stage is sufficient for the analysis to be done. The formulation associated with the design of amplifier using small signal AC analysis for: i. Bypassed emitter capacitor and ii. Un-bypassed emitter capacitor is as follows:

i. Bypassed Emitter capacitor

The bypassed emitter capacitor configuration comprises of emitter capacitor C_E intact in the amplifier circuit. Due to this the emitter resistor R_E is reduced to a short-circuit for the small-signal analysis, as shown in Fig.1b. The advantage of this reduction of resistance in the output circuit arm is that it is not directly affecting the gain and other parameters of the amplifier. The middle section between dotted lines represents the CE BJT amplifier. The formulae are given as:

Input Impedance, Z_i : It is expressed as parallel combination of three resistors in the input section of amplifier (within dotted lines) and is as under

$$Z_i = R_1 \parallel R_2 \parallel \beta r_e$$

Output Impedance, Z_o : It is expressed as parallel combination of two resistors in the output section of the amplifier (within dotted lines) under the condition that there is no input signal present and associated signal in the circuit.

$$Z_o = r_o \parallel R_C$$

Voltage Gain, A_v : It is given by ratio of output load voltage (V_L) to applied voltage (V_s). The V_i and V_o are the input voltage and output voltage respectively of CE BJT amplifier and are measured at the two cross-section lines respectively.

$$A_v = \frac{V_o}{V_s} = \frac{Z_i}{Z_s + Z_i} \frac{R_L}{R_L + Z_o} \frac{V_o}{V_i} = \frac{Z_i}{Z_s + Z_i} \frac{R_L}{R_L + Z_o} \left(\beta \frac{Z_o}{Z_i} \right)$$

The gain is also a function of frequency and is dependent on the capacitors present in the circuit and also parasitic capacitances which come into action at high frequencies. And the associated cut-off frequencies are expressed as:

$$f_S = \frac{1}{2\pi(R_S + Z_i)C_S}, f_C = \frac{1}{2\pi(R_L + Z_o)C_C}, f_E = \frac{1}{2\pi\left(R_E \parallel \left(r_e + \frac{(R_S \parallel R_1 \parallel R_2)}{\beta}\right)\right)C_E} \text{ for low frequencies}$$

$$f_{Hi} = \frac{1}{2\pi(R_S \parallel Z_i)(C_{Wi} + C_{be} + (1 + A_v)C_{bc})}, f_{Ho} = \frac{1}{2\pi(R_L \parallel Z_o)(C_{Wo} + C_{ce} + (1 + 1/A_v)C_{bc})}, f_{\beta} = \frac{1}{2\pi\beta r_e(C_{be} + C_{ce})} \text{ for high frequencies}$$

Finally, the gain as function of frequency and all components is represented as:

$$A_v(f) = \frac{A_v}{\sqrt{\left(1 + \frac{f}{f_{Hi}}\right)^2 \left(1 + \frac{f}{f_{Ho}}\right)^2 \left(1 + \frac{f}{f_{\beta}}\right)^2 \left(1 + \frac{f_S}{f}\right)^2 \left(1 + \frac{f_C}{f}\right)^2 \left(1 + \frac{f_E}{f}\right)^2}}$$

ii. Un-bypassed Emitter capacitor

The un-bypassed emitter capacitor configuration comprises of emitter capacitor C_E not present in the amplifier circuit. Due to this the emitter resistor R_E is present for the small-signal analysis, as shown in Fig.1c. The advantage of presence of this resistance in the output circuit arm is that the gain of the amplifier is almost controlled by components other than the transistor parameters. The gain can be modified easily without replacing the transistor. The formulae are modified to incorporate the role of the emitter resistor and are given as:

Input Impedance, Z_{ie} : It is now expressed as nested combination of almost all resistors in the amplifier. The combination of resistors is investigated from input side of the CE BJT amplifier and is given as under

$$Z_{ie} = R_1 \parallel R_2 \parallel [\beta r_e + \{(\beta + 1)R_E\} \parallel \{\beta(r_o + R_C)\}]$$

Output Impedance, Z_{oe} : It is also not a simple network due to connecting resistor R_E which is complicating the mesh. The combination of resistors for the output impedance is solved from the output end with the condition that there is no input signal and associated signal present in the circuit and is expressed as:

$$Z_{oe} = R_C \parallel \left[r_o + \left\{ \frac{\beta R_E}{\beta + 1} \parallel \left(r_e + \frac{(R_1 \parallel R_2)}{\beta} \right) \right\} \right]$$

Voltage Gain, A_v : The expression of the voltage gain remains same with some revisions such as Z_i and Z_o are replaced by Z_{ie} and Z_{oe} . Also, in the frequency response due to f_E will not be present because of absence of emitter capacitor C_E in the circuit.

With reference to problem addressed in Section II and formulation explained in this section, it is observed that the small signal parameter gain $A_v(f)$ is dependent on many component values. The choice of these components is done based upon the circuit output requirements and still the output values are not achieved. Thus, a thorough investigation is done to study the variation of proposed values/response and the actual experimental values/response. The analysis is done for wide range of tolerance response in each component individually and their combination to yield maximum deviation from the desired output response.

IV. RESULTS AND DISCUSSION

Fig.2 demonstrate the Gain response of the circuit under consideration showcased in Fig.1. The results showcased are obtained from the expression stated in the section III as modeled results and are depicted as curves in the Fig.2a and Fig.2b for different gain values. The gain response are in agreement with simulated results represented by hollow diamond symbols. The simulated results are produced by Multisim software by National Instruments [8]. The experiment for the same set of components is also performed in the laboratory and the results are seen to be in close proximity to the theoretical and simulated results. The experimental results were deviating from the other traces and reasonably it is justified as the experimental errors. But, the quality and efficacy of the components used can also be the scope of the error, where the values of components chosen are not the same as required for the desired output response

i.e. the tolerance limit variation of the component or components is hampering the output performance of the circuit under consideration. Thus, an extensive investigation of results with tolerance limit need to be examined and is showcased in the other figures and tables.

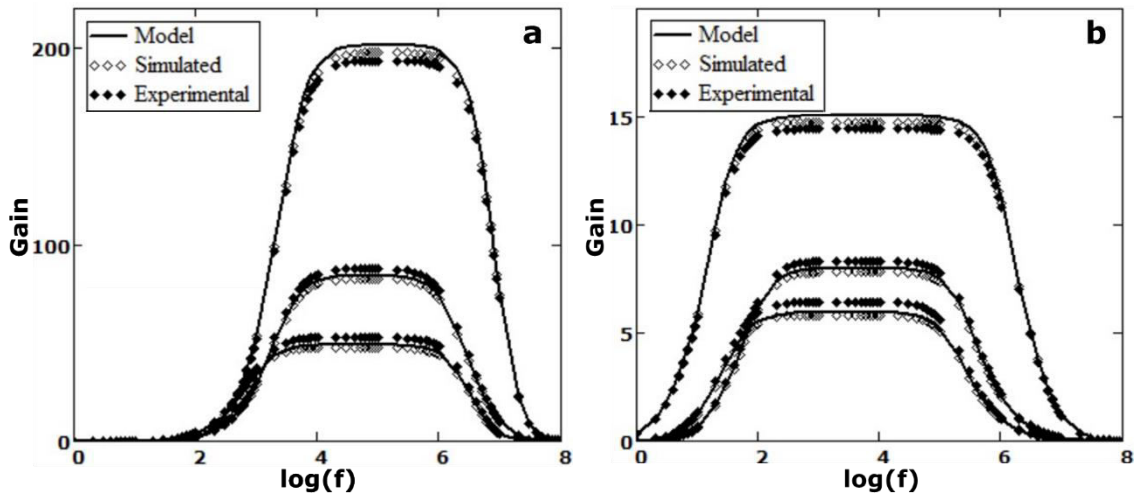


Fig.2 Voltage gain vs frequency graphs for BJT CE amplifier at different components values. (a) represents gain response bypassed for emitter resistance. (b) represents gain response for un-bypassed emitter resistance (Simulation done by NI simulator Multisim [8])

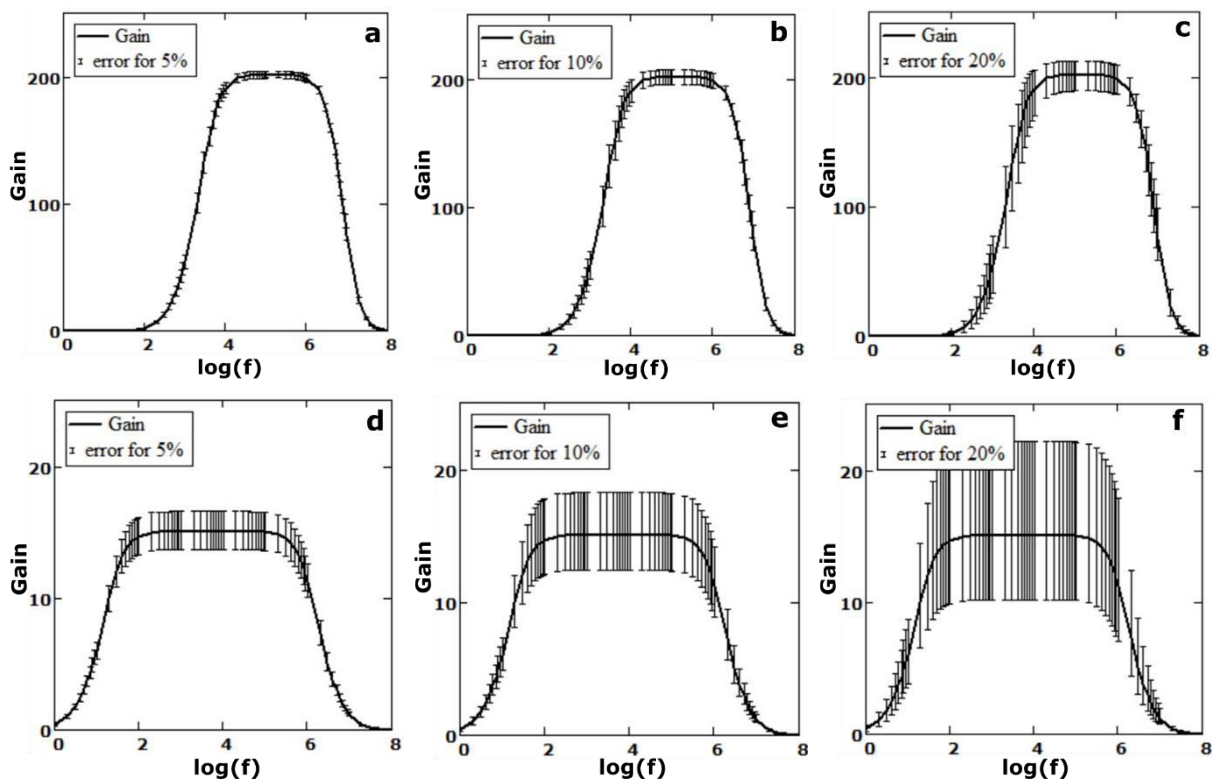


Fig.3 Voltage gain Vs frequency graphs for BJT CE amplifier. (a, b, c) represents gain and maximum deviation error for bypassed emitter resistance at tolerance 5%, 10% and 20%. (d, e, f) represents gain along and maximum deviation error for un-bypassed emitter resistance at tolerance 5%, 10% and 20%

Fig.3 graphs demonstrate the variation in the output performance (gain) with frequency for bypassed and un-bypassed CE BJT amplifier at different tolerance limits. The graphs plotted comprise of a gain response under zero tolerance condition as a continuous graph depicted by a smooth curve. It also showcases an envelope in each case as vertical



fluctuations which represents maximum possible gain response deviations for tolerance limit of the passive components connected in the circuit. The envelope plotted in each case is the outcome of model expressions. It is seen that the larger the tolerance limit the more is the expansion of the envelope which infers the scope of high deviation in the value of the gain response. These deviations can compromise the performance of the circuit as standalone or cascaded circuit. Also, the gain envelope can form a basis for observation where instead of a single curve response. An envelope can be realized as theoretical component tool for the verification of the results achieved in the laboratory.

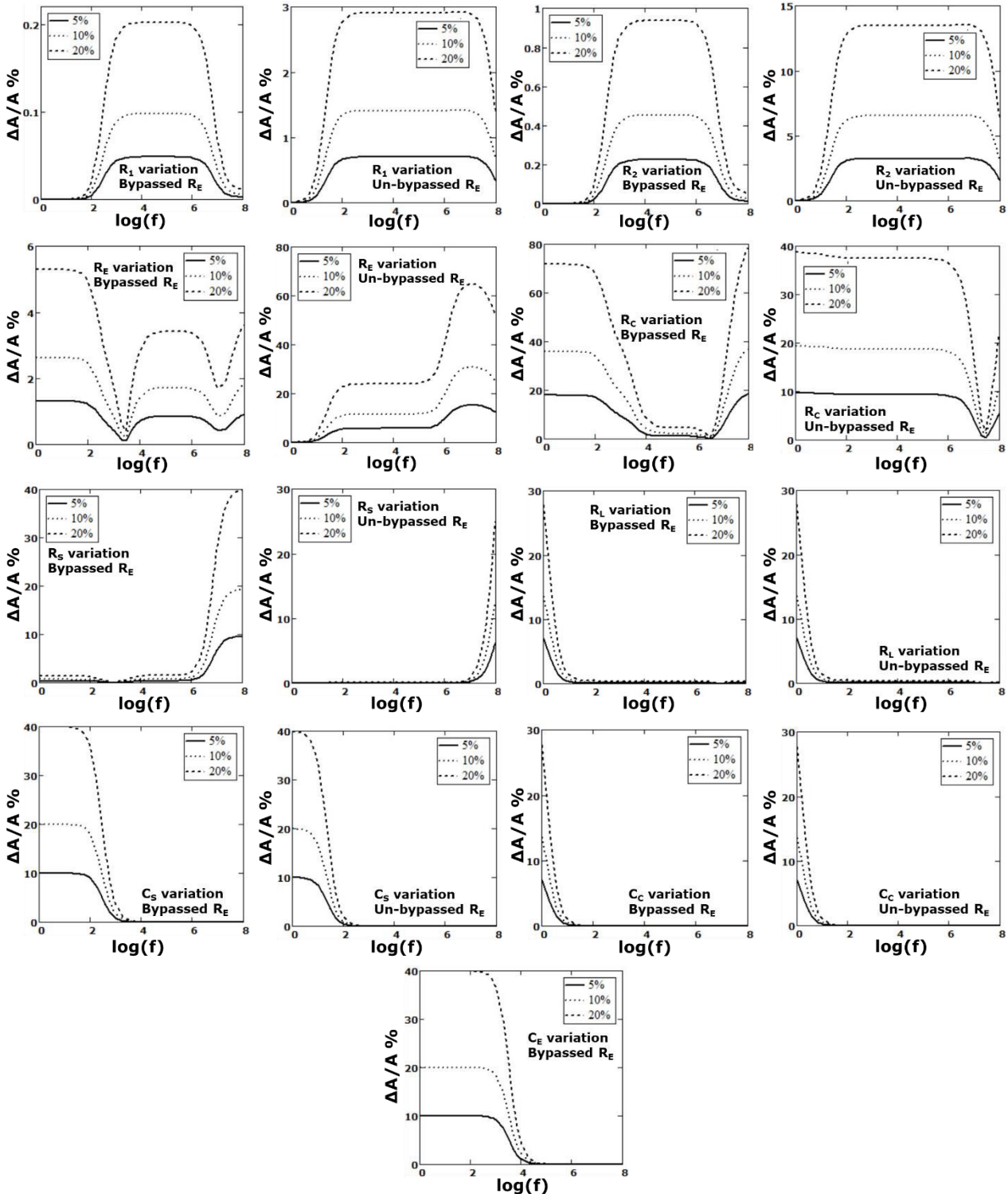




Fig.4 Differential Voltage gain (in percentage) Vs frequency graphs for BJT CE amplifier at tolerance 5%, 10% and 20%

Fig.4 represents differential voltage gain variation along the frequency variation for \pm tolerance value reported in the graphs. ΔA represents an absolute difference of positive tolerance and negative tolerance-based component value gain response and A represents the gain based upon components for the designed circuit. The plots are for a single device component deviation without the impact of other components. From stability point of view, the mid-range frequencies are of interest due to smooth response and is of also interest to the designers. The R_E and R_C components curves are showing noticeable in change values in the Fig.4. The other components are showing the impact too, but that is outside the mid-range frequencies where the gain is rolling-off. A key outcome came from the graphs that the feedback resistor R_E which works in the circuit for bias-stabilization is actually showing a significant deviation in the performance of the circuit.

TABLE I Percentage change in amplifier bandwidth

% change in bandwidth for bypassed R_E configuration									
Tolerance	$R_1=100k\Omega$	$R_2=21.56k\Omega$	$R_E=100\Omega$	$R_C=1k\Omega$	$R_S=20k\Omega$	$R_L=100k\Omega$	$C_S=1\mu F$	$C_E=10\mu F$	$C_C=1\mu F$
5%	0.046	0.214	0.0815	1.452	9.269	0.095	0	5.06E-3	0
10%	0.093	0.432	1.629	2.928	18.678	0.192	0	0.01	0
20%	0.192	0.889	3.258	6.054	38.526	0.397	0	0.021	0
% change in bandwidth for un-bypassed R_E configuration									
5%	1.39E-5	6.45E-5	9.616	0.406	5.65E-7	0	1.99E-4	-	0
10%	2.8E-5	1.299E-4	19.367	0.812	1.13E-6	0	4.01E-4	-	0
20%	5.78E-5	2.679E-4	39.844	1.623	2.26E-6	0	8.27E-4	-	0

Table I showcases the percentage change in the bandwidth value due to change in the value of the components connected in the circuit as shown in the Fig.1. It is seen that for the given set of components values the source resistance R_S is affecting the bandwidth followed by R_C and R_E resistors for bypassed configuration. Further, when the results for un-bypassed case are seen, the resistor R_E is seen to be only prominent candidate. The inference drawn from the results is that the emitter resistor which serves as feedback resistor to stabilize the circuit can serve as marginalizing the bandwidth of the circuit.

V. CONCLUSION

The dependence of various components on the output performance of the common emitter BJT amplifier is studied. It is observed that deviation in some of the parameters are noticeably altering the performance of the amplifier. In view of the existence of variation in the values of the components due to tolerance limit, a range of fluctuation that is envelope need to be account for as the result of the performance of the circuit instead of a single curve obtained from the theoretical or simulated results. It is seen that some of the components' variation i.e. R_E and R_C is affecting the performance of mid-range frequencies and hence, the choice of these components must be done wisely. The other parameters are also impacting the performance in the gain roll-off region and hence, contributing to deviation in the bandwidth of the amplifier.

REFERENCES

- [1] J.Bardeen, W.H. Brattain. "The Transistor, A Semiconductor Triode", Physical Review. American Physical Society, pp.230–231, Volume 74, No.2, 1948. doi:10.1103/physrev.74.230
- [2] J.Chelikowski. (2004) "Introduction: Silicon in all its Forms", p. 1 in Silicon: evolution and future of a technology. P. Siffert and E. F. Krimmel (eds.). Springer, ISBN 3-540-40546-1.
- [3] Transistorized! <http://www.pbs.org/>, ScienCentral, Inc, and The American Institute of Physics, Copyright 1999
- [4] G. E. Moore, "Cramming more components onto integrated circuits, Reprinted from Electronics, volume 38, number 8, April 19, 1965, pp.114 ff.," in IEEE Solid-State Circuits Society Newsletter, vol. 11, no. 3, pp. 33-35, Sept. 2006, doi: 10.1109/N-SSC.2006.4785860.
- [5] P. Horowitz, W. Hill, The Art of Electronics, Cambridge University Press, 1989.
- [6] J. D. Ryder, Electronic Fundamentals and Applications: Integrated and Discrete Systems, Prentice Hall India Learning Private Limited, 1975.
- [7] J. Millman and C. C. Halkias, Electronic Device and Circuits, McGraw Hill Inc., 1967.
- [8] Multisim Live Online Circuit Simulator, <https://www.multisim.com/>, National Instruments Corp., Copyright 2022



INNO SPACE
SJIF Scientific Journal Impact Factor
Impact Factor: 8.118



ISSN INTERNATIONAL
STANDARD
SERIAL
NUMBER
INDIA



INTERNATIONAL JOURNAL OF INNOVATIVE RESEARCH

IN SCIENCE | ENGINEERING | TECHNOLOGY

 **9940 572 462**  **6381 907 438**  **ijirset@gmail.com**



www.ijirset.com

Scan to save the contact details