A Method To Modify/Correct The Performance Of Amplifiers

Rohith Krishnan R, S. Krishnakumar, Reza Hashemian

Abstract: The actual response of the amplifier may vary with the replacement of some aged or damaged components and this method is to compensate that problem. Here we use op-amp Fixator as the design tool. The tool helps us to isolate the selected circuit component from rest of the circuit, adjust its operating point to correct the performance deviations and to modify the circuit without changing other parts of the circuit. A method to modify/correct the performance of amplifiers by properly redesign the circuit is presented in this paper.

Index Terms: Amplifiers, amplifier modification, amplifier re-design, biasing design, op-amp Fixators.

1 INTRODUCTION

NOW a days, digital revolution is at its full pace and its growth rate is beyond the Moore's law. At the same time, analog and mixed circuit techniques have high importance. Some may think that analog circuits are going to obsolete and digital technology is going to rule the electronics industry. Digital electronics does not exist without analog and analog never lose its importance. Analog electronics can model the real world, capture the analog information and help to digitally process the collected information. Analog technology has remarkable role in all major areas of electronics and it is essential to RF and microwave devices, cell phones, radar systems, image sensors and lot more. Now a day, analog research enters into different areas, including re-programmable analog circuits, micro electromechanical systems etc. Analog chips use up to many times less power than their digital counterparts and is essential in wireless devices. As the digital technology further develops, there will be a corresponding development for analog semiconductor and systems because, in a sense, every digital system is also an analog system. A detailed discussion on this topic is beyond the scope of this article but it is clear that modern analog technology will play an ever-increasing role in the quality of life. During the design of an analog circuit, biasing design is an important step [1]. The main problem in biasing design is to fix the operating point of nonlinear device [2] at the desired level.

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Once we find the operating points or critical specs for the nonlinear device/s, the next step is biasing design. Traditionally, the biasing design includes approximations and sometimes we have to neglect certain parameters, otherwise we require a number of iterations to reach at the final design. This is because traditional methods take the circuit as a whole with no separation between linear and nonlinear components; therefore, the design becomes complex [3]. Many times, we need to modify/correct and reuse some existing electronics circuits [4]. In some aged circuits, when one of the circuit components (e.g. BJT) is replaced with a similar one, the circuit performance may be changed and it causes distorted output. In some other situation, we need to keep some older skillful circuit designs by replacing aged components with new ones. For example, sometimes we need to modify the amplifier circuits by exchanging some components like BJTs with newer ones like MOS transistors. With traditional methods, solving these issues is difficult and time consuming. However, the proposed method offers a simple way to solve these problems. It uses op-amp fixators [3] as the tool to solve biasing tasks. With the proposed method, modification/correction of amplifier is a three-step process. The first step is to find the component that makes the performance deviations. If it is a linear component, it is easy to modify the circuit to correct the error; but if it is a nonlinear component, as the second step, we need to re-bias the component at the desired operating point. At the end of this step, we get the solutions to correct the error. At the last step, we just need to apply the results of second step to the circuit, i.e., modifying the circuit. The method offers us to isolate the component that makes the performance deviations and re-biasing it without changing other parts of the circuit. This is done by using the tool op-amp fixator. Hashemian [4] proposed a method to modify/tune amplifiers for a desirable performance and in that method, he uses partial local biasing (PLB). PLB allows us to locally modifying the Q-points of nonlinear components without affecting other parts of the circuit. It results in larger number of scattered DC sources. Voltage dividing, current mirroring and other source transformation techniques are used to reduce their number to one or two sources, but it is a time consuming and tedious task. Later, Hashemian [5] introduced a new technique to cut down the number of steps for a targeted biasing and it uses Fixator-Norator pairs. Fixators and norators are theoretical two terminal devices and are used in pairs. Circuit simulators like SPICE cannot directly model the pairs; therefore, ideal controlled sources with very high gain are used to model the pairs. The proposed method uses op-amp fixators. It doesnot require any theoretical parts like controlled sources and tests can be done either practically or using simulation software. Two important tools used here are voltage fixator and current fixator using op-amp [3]. Section 2 discusses about the designing tools. Four application examples are shown in section 3 and section 4 concludes the method.

2 DESIGNING TOOLS

The proposed method uses op-amp voltage and current fixators, where op-amp works as nullor, which is the combination of nullator and norator. Fixators [5] are theoretical two terminal devices with current through and voltage across them are fixed.Nullator is a theoretical two terminal device with both the current through and voltage across them are equal to zero. Thus, nullator is a special case of fixator. Norators are theoretical two terminal devices with both the current through and voltage across them are unspecific. Nullor have a special property, that is, if it is used in a circuit, the circuit around the nullor determines its output in such a way that its input forced to zero. That means nullor output can take any value so that its input equal to zero. This property of nullor is used in op-amp fixator to solve biasing issue that is to find the value of required bias supporting components. A bias supporting component may be a dc voltage source, dc current source or a power-conducting component (e.g. resistor). Two properties of op-amp [6], which make it a nullor are,

1. The input terminals of op-amp draw negligible current.
2. The differential input voltage between its input terminals is close to zero.

Schematics of op-amp voltage fixator and current fixator [3] are shown in Fig.3.

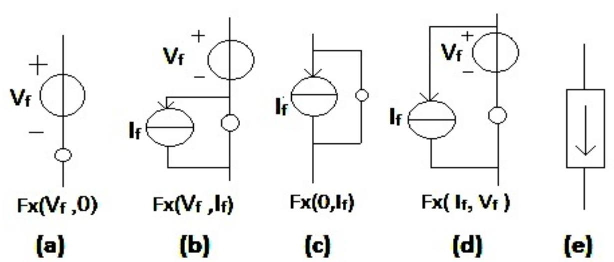

Fig.1. *Fixators; (a)&(b) Voltage fixators ; (c)&(d) Current fixators;*

(e) Symbol of a fixator.

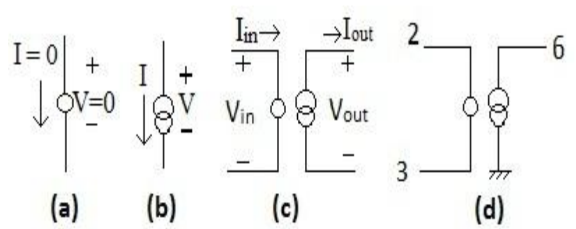

Fig.2. *(a) Nullator; (b) Norator; (c) Nullor; (d) Nullor model of op-amp.*

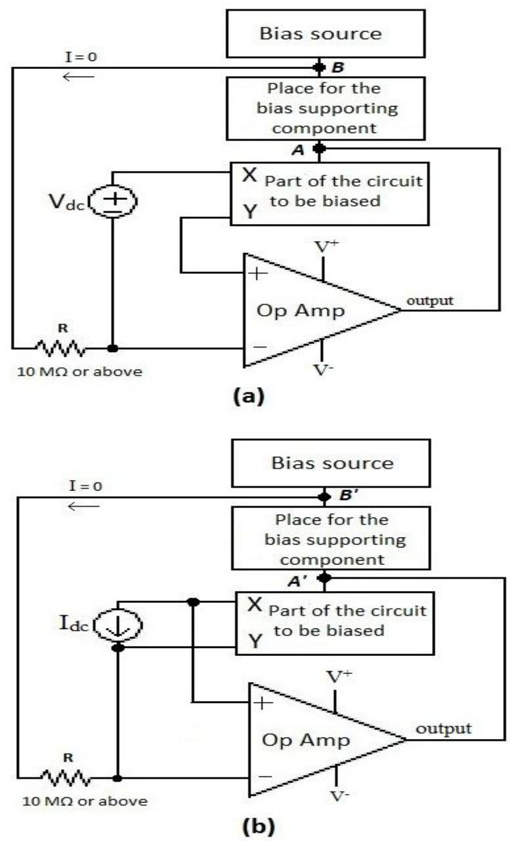

Fig.3. *(a) Op-amp voltage fixator; (b) Op-amp current fixator.*

The tool in Fig.3 (a) is used to fix the voltage between two nodes and to find the value of bias supporting component that satisfy the targeted bias. For example, to fix the voltage between node X and Y at V_f volts, we have to keep $V_{dc} = V_f$ volts and remove the existing bias supporting component if any. Resistor R is just a placeholder for one of the two terminals of bias supporting component and has no particular function at all. Output of op-amp gives the value of bias supporting component that if it used in the actual circuit will results a voltage of V_f volts between X and Y. Fig.3 (b) shows a current fixator, and it fixes current between two nodes X and Y.

Algorithm

1 Select the nonlinear device, which needs re-biasing one at a time.
2 For the selected nonlinear device, find the desired operating points for all the ports.
3 Properly apply op-amp fixators to all ports of the selected nonlinear device.
4 Using the output of op-amp, calculate the value of bias supporting component that meets the targeted design.

Now modify/replace the existing bias supporting component with the calculated value.

3 APPLICATIONS

Example 1: Consider a simple common emitter amplifier as shown in the Fig.4. Here the transistor is replaced with a similar one with different β value and it results in the deviation of output voltage swing of the amplifier. Using the traditional methods, we needs a number of iterations to redesign the circuit to keep the response unchanged. However, with the proposed method, it is much easy to adjust one of the bias supporting components and meet the required bias. In this example, we try to modify the value of resistor R_1 using the proposed method. Here, R_1 is only one of the choices we have made in our example and selection of any other bias supporting component is acceptable. However, the difference is that, each bias supporting component responds to the AC design differently. In this case, the output voltage swing must be 8 V_{P-P}; therefore, we have to fix V_{CE} = 4 V. Next, remove R_1 and instead use a voltage fixator to fix V_{CE} at 4 V. By analyzing the output of op-amp, we can calculate the required value of R_1, for that value of R_1, the circuit will results an output voltage swing of 8 V_{P-P}. The circuit arrangement is shown in Fig.5. Analyzing the circuit shown in figure, voltage at node B is observed as 1.873 V and I_{R1} = 389.1µA.

Therefore R_1 = (10-1.873)/389.1µA
= 20.88 KΩ

After changing the value of R_1 from 23 KΩ to 20.88 KΩ and on analyzing the circuit, we can observe that output voltage swing of the amplifier is 8 V_{P-P}.

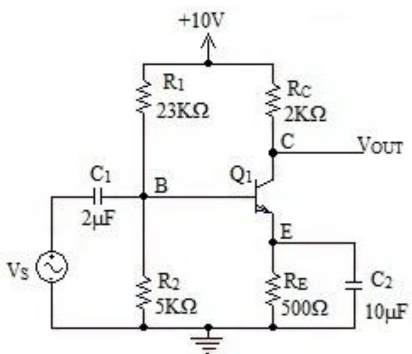

Fig.4. *Common emitter amplifier.*

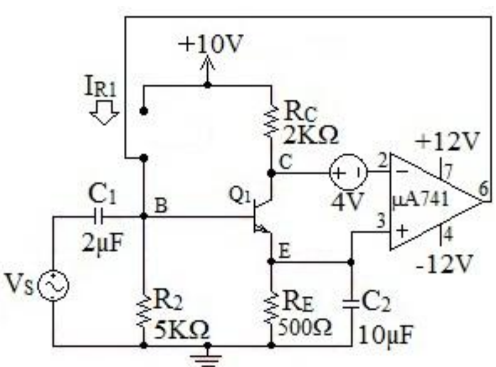

Fig.5. *Redesign of Common emitter amplifier.*

Fig.6 shows the practical circuit arrangement of Fig.5 and Fig.7 is the response of modified common emitter amplifier observed in the oscilloscope.

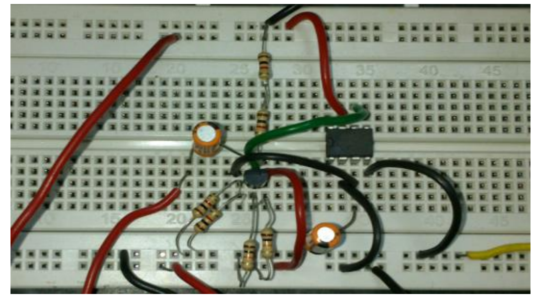

Fig.6. *Practical circuit arrangement of Fig.5.*

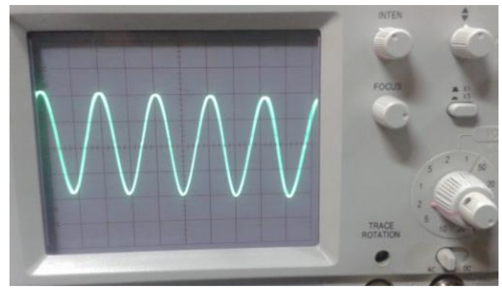

Fig.7. *Response of modified common emitter amplifier.*

Example 2: Fig.8 (a) shows a part of the circuit of MC1553 amplifier [4]. Replacement of the original BJTs with newer BJTs results in distorted output as shown in Fig.8 (b). With traditional methods, a number of trial and error attempts is required to remove the distortion and is time consuming. If the proposed method is used, the problem may be solved in few simple steps.

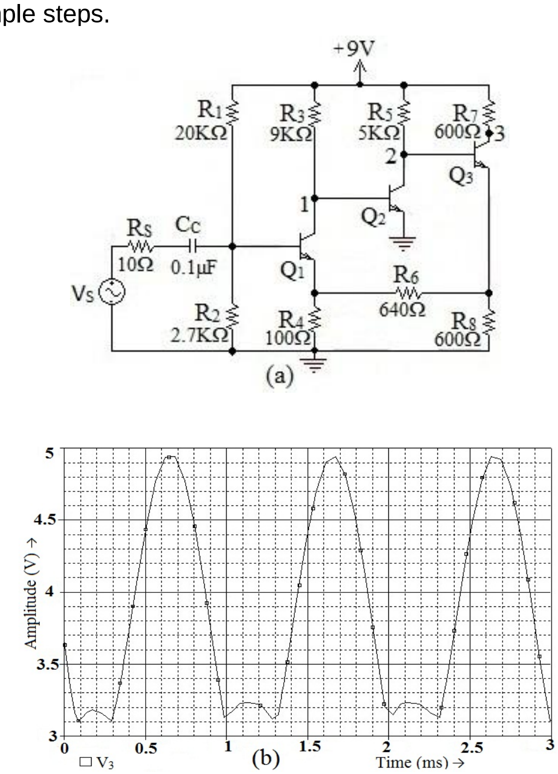

Fig.8.*(a) Part of MC1553 amplifier (b) Response of amplifier after component replacement.*

At first, find the transistor/s working at wrong operating points. In this example, it is noted that Q point of Q_1 is wrong and it causes unfaithful amplification. Next, find the desired operating point for Q_1 and apply fixators to input and output ports of Q_1. Table 1 shows the faulty operating points after component replacement and desired operating points of Q_1. It is necessary to apply fixators to input and output ports of Q_1 simultaneously. The circuit arrangement is shown in Fig.9.

TABLE 1
FAULTY AND DESIRED Q-POINTS OF Q_1

	Faulty	Desired
V_{CE}	201mV	366mV
V_{BE}	644.2mV	643.8mV
I_C	921.5µA	919µA
I_B	6.4µA	6.29µA

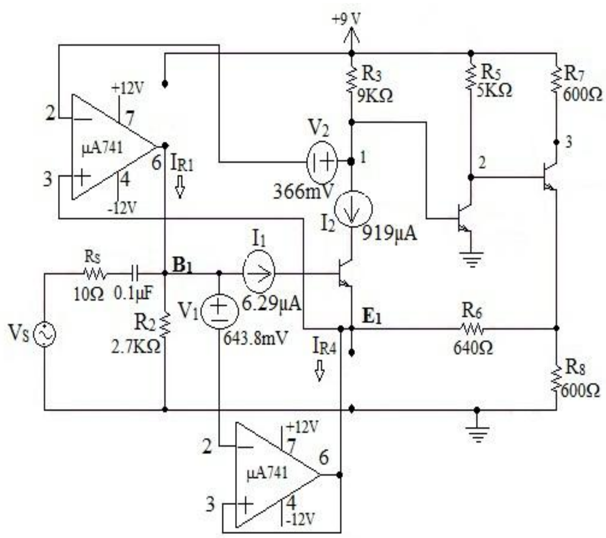

Fig.9. *Redesign of amplifier.*

If we setup and analyze the above circuit (Fig.9), we get voltage at nodes B_1 and E_1 as 916.7 mV and 273.2 mV respectively. Similarly, current I_{R1} and I_{R4} are observed as 351.4 µA and 2.786 mA respectively. Using these readings we get R_1 = 23 KΩ and R_4 = 98Ω. As the result of this modification, the response of amplifier is improved and we get undistorted output as shown in Fig.10.

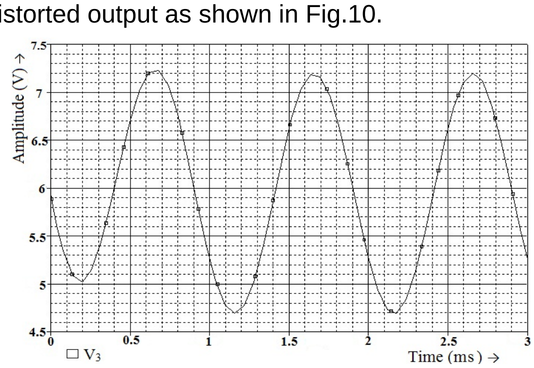

Fig.10. *Response of modified amplifier.*

Example 3: Here a cascaded CMOS amplifier [7] as shown in Fig.11 is taken to modify. Due to the replacement of nonlinear devices M_2 with another one, the output becomes distorted. Initially, nMOS M_2 has a width of 50µm, which is replaced with another nMOS of width 75µm. This change of component results the output to distort and to remove distortion, M_2 needs re-biasing. Desired operating points for M_2 is shown in table 2. We apply fixators to all ports of M_2 and redesign values of V_2 and R_1 for modifying its Q point. The circuit arrangement is shown in Fig.12.

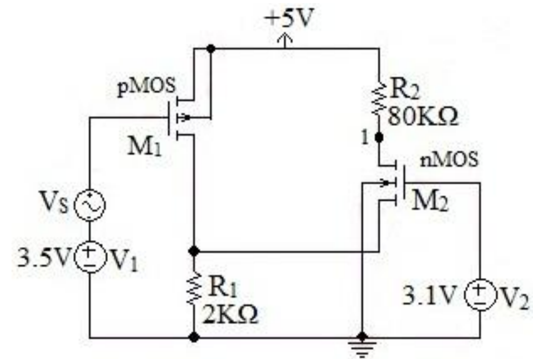

Fig.11. *Cascaded CMOS amplifier.*

TABLE 2
DESIRED Q-POINTS OF M_2

M_2	Desired Values
V_{DS}	1.8V
V_{GS}	1.3V
I_D	31.3µA

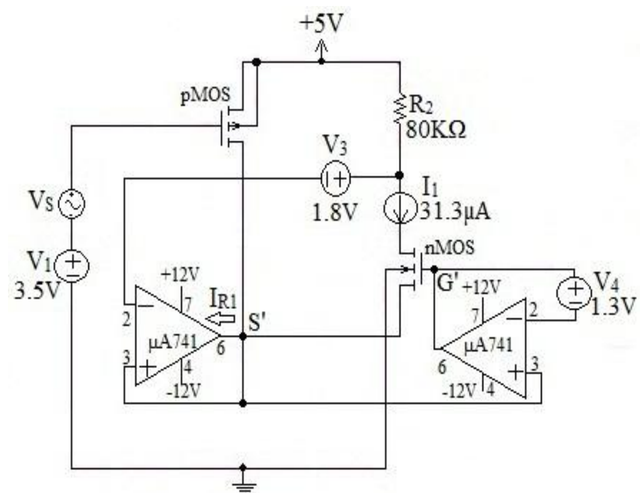

Fig.12. *Redesign of Cascaded CMOS amplifier.*

If we setup and analyze the circuit as in Fig.12, we get voltage at node S' and G' as 690 mV and 2 V respectively. I_{R1} is noted as 932 µA. Thus value of resistor R_1 =750 Ω and voltage source V_2= 2 V. The response of amplifier with modified values of components is shown in Fig.13 and the distortion is eliminated.

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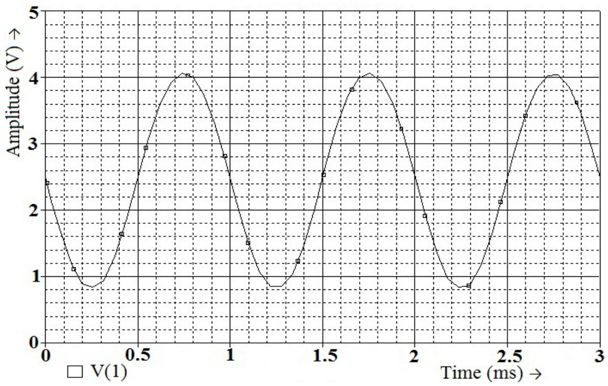

Fig.13. *Response of modified CMOS amplifier.*

Example 4: Next, we re-design a npn-pnp feedback amplifier [4] so as to replace existing BJTs with their equivalent MOS transistors by keeping the circuit structure and component values unchanged. Fig.14 shows the BJT amplifier and Fig.15 is its response. There is a lot of difference between the design of a BJT circuit and those of a MOS circuit. With the traditional methods, it is very difficult to keep the circuit structure and component values unchanged. Moreover, it requires a lot of effort to modify the BJT circuit to a MOS circuit. However, with the proposed method, the problem can be solved much easily by following the steps shown below.

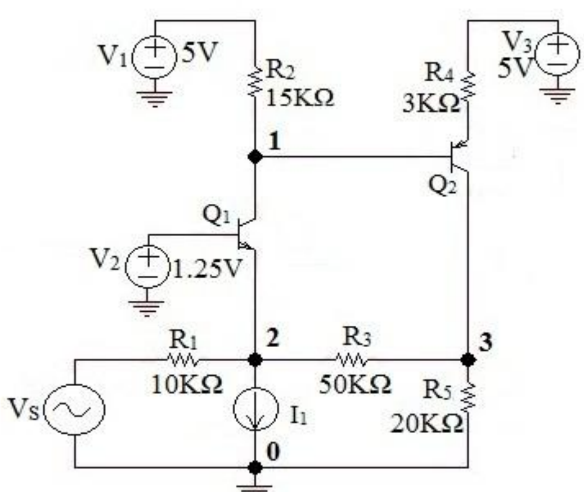

Fig.14. *BJT Feedback amplifier.*

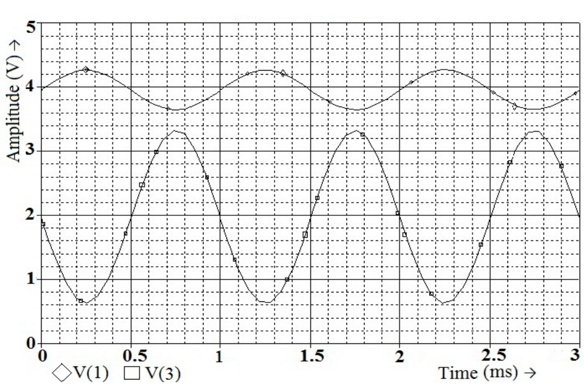

Fig.15. *Response of BJT feedback amplifier.*

1 Find the operating points of the MOS transistors, which we want to replace with BJTs.
2 Replace BJTs with corresponding MOS transistors and apply fixators to all ports of the MOS transistors.

Remember, the role of fixators is to find the values of bias supporting components. Thus, applying fixator to M_1 should redesign values of V_1 and V_2. Similarly, in the case of M_2, values of V_3 and I_1 are redesigned using fixators. Desired operating points for MOS transistors are shown in Table 3. Set up and analyze the circuit shown in Fig.16, we get voltage at nodes 1, 3 and 4 as 3.8 V, 5 V and 5 V respectively. That means, V_1 = 5 V, V_2= 3.8 V and V_3 = 5 V. Similarly, we can measure I_1 as 50 µA. Now, remove all the fixators and instead place the modified components. The modified circuit is shown in Fig.17 and the response of the redesigned amplifier is shown in Fig.18.

TABLE 3
Q- points for M1 and M2.

MOS	M_1	M_2
V_{DS}	2V	-2.646V
V_{GS}	2.8V	-1.646V
I_D	135.7µA	118µA

Response of the MOS amplifier is undistorted and acceptable, ignoring the slight reduction in the gain. The modified circuit has the advantage that it is a MOS circuit and therefore has the features of higher input impedance, current gain, less noise etc than its BJT version.

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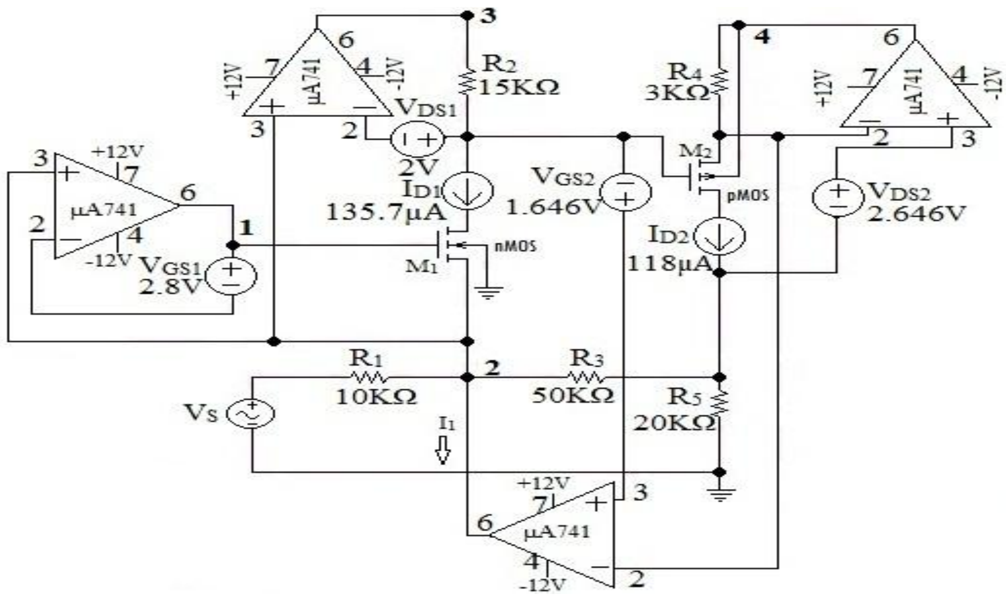

Fig.16. *Modification of feedback amplifier.*

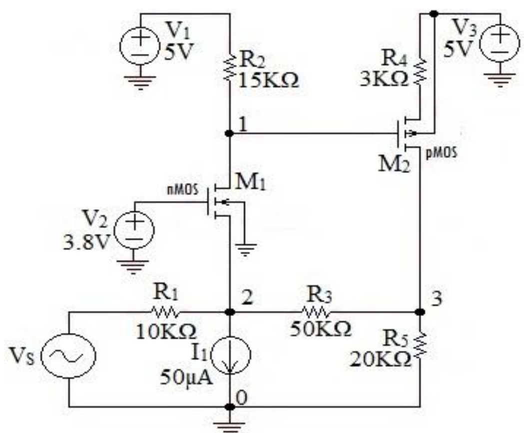

Fig.17. *Modified MOS feedback amplifier.*

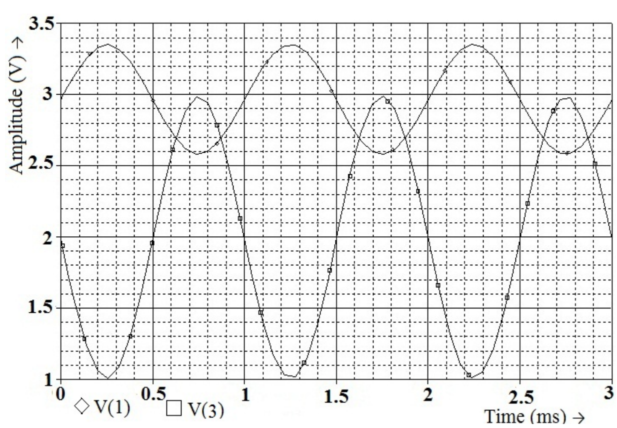

Fig.18. *Response of modified feedback amplifier.*

4 Conclusion

A new method for performing the modification and correction of analog circuit containing nonlinear devices has been presented. The method isolates the nonlinear device that needs re-biasing and uses op-amp fixators to find the appropriate bias supporting components that satisfies the new design. When compared with traditional methods, the proposed method has the advantage of less complexity and is simple. Four examples have been given that describe some of the application of the proposed method.

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