# Practical Biasing Design for Analog Circuits

Rohith Krishnan R[1] & S. Krishnakumar [2]
School of Technology & Applied Sciences
Mahatma Gandhi University Regional Centre
Edappally, Kochi, India

***Abstract*—A new method for the biasing design of analog circuits is presented in this article. In this method, the properties of operational amplifiers are well exploited, and it is useful for the biasing design of circuits containing non-linear components like diodes, BJTs, FETs etc. The method uses a combination of fixators, norators and nullators, where operational amplifiers are used as nullator plus norator (or simply nullor). As examples, a diode circuit, a BJT circuit and a JFET circuit are shown which are designed using the proposed method for some given critical specs. Application of current mirror as a current source, and its design using the proposed method are also discussed in this paper.**

***Keywords—Biasing design; current sources; fixators; nullors; operational amplifiers.***

## I. INTRODUCTION

The design of analog circuits involves two steps, viz. the AC performance design and DC biasing design. In performance design, active devices are replaced with their small signal model at the desired operating conditions. After the completion of AC design, DC biasing design should be done, which defines the DC supply values keeping operating conditions of the non-linear components and the circuit performance unchanged [1]. The proposed method is to ease the task of second step, which is biasing design.

The main point of biasing design is to fix those critical specs [1] at some required values. Critical specs means those parameters, which decide the operation of a circuit. For example operating point of a common emitter configuration is determined by collector current $I_C$ and collector to emitter voltage $V_{CE}$ [2]. Therefore, in the case of a common emitter amplifier, $I_C$ and $V_{CE}$ are the critical specs. However, the selections of critical design specs are purely depend on the circuit used. That is, in a multistage amplifier, more than one transistor has to be used and not all of them may be critical components. Therefore, the number of critical specs per transistors may not be two. All that is important is to decide which specs are critical and which are not. Knowledge and efficiency of the designer are checked at this stage. We have a number of critical specs while we are starting a circuit design. However, not all of them are bias based. Those parameters, which can avoid signal distortion and deal with nonlinearity, are considered as bias based specs.

Once we find the operating points or critical specs for a particular circuit operation, 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 non-linear components; therefore, the design becomes complex [1], [3-5]. In addition, traditional methods use one or two predefined DC sources and rest of the design are related with these sources i.e., global biasing. Our method separates the nonlinear components from the limitations of global biasing [3].

Verhoeven [6] presents a method for biasing amplifiers and in this method, biasing design is performed linearly until the end except for the transistors. Biasing of transistor is done separately at the last stage of the designing process. Controlled sources are used to isolate non-linear parts from rest of the circuit. There is a time consuming iterations to reach at the final design, and controlled sources are removed at this stage.



In the method proposed by Hashemian [3,4], non-linear devices are DC isolated and locally bias them for the desired operating conditions. 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. Hashemian [1,7] 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. Ideal controlled sources with very high gain are used to model the pairs.

In our method, operational amplifiers are used instead of ideal controlled sources. Two important tools used here are voltage fixator and current fixator using op-amp. We can model the non-linear device partially or completely [1,7]. For partial modeling, the non-linear device is placed in the circuit and using our tools, we fix those critical specs; after the design process, our tools are removed to obtain the final circuit. In this process, we actually freeze those port values at the desired level. For some applications, all the operating conditions of a non-linear device, viz. transistor the parameters such as $V_{CE}$, $V_{BE}$, $I_C$, and $I_B$ are critical. In such cases, we have to remove the transistor (i.e., non-linear device) from the circuit and instead place its fixator model. As the biasing design is completed, our tools are removed and they are replaced with original transistor. This is complete modeling. A mixture of partial and complete modeling is also possible.

The proposed method eliminates all the theoretical components and it does not require any circuit simulator. Circuits can be designed as simple as we do practical works in our electronics lab with familiar components. The added benefit is that we design the circuit using the actual components we like to use in our circuit and at the actual room temperature. So our design becomes more accurate. Operational amplifiers play the main role in the proposed method, which can represent nullator and norator (i.e. nullor). Operational amplifiers act as placeholders for bias-supporting components. For each critical spec, there should be a bias-supporting component (DC current source, DC voltage source or power conducting components like resistors) in the circuit, which can control that parameter. That means we can vary a parameter by simply adjusting the value of corresponding bias-supporting component. Sometimes more than one component has effect on the same parameter but the designer has to select the proper one based on the circuit requirements. The designer can select one component and adjust its value with the help of proposed method to meet the required design. As discussed, he/she has many other options than the selected one. However, the difference is that each component affects the AC performance design differently. The operational amplifiers and its supporting components are added in our method for designing only. They are removed as the design has been completed.

Section 2 introduces the proposed tools – voltage fixator and current fixator using op-amp. Their circuit arrangements and usage are shown with some discussions. Section 3 contains a diode circuit, a BJT circuit and a simple JFET circuit as examples. Section 4 explains how to use current mirrors as current sources in our method and its design. Section 5 checks the future scope of the proposed method and finally section 6 concludes the proposed method.

## II. DESIGNING TOOLS

The proposed method uses the concepts based on fixators, norators and nullators.

Fixators: These are theoretical two terminal devices with both, the current through and voltages across the components are specific. Thus, fixators can be a voltage source, a current source or a combination of both along with a series or parallel nullator. Nullators are theoretical two terminal components with both, the current through and voltage across them are equal to zero.

Norators: They are theoretical two terminal components with both, the current through and voltage across the components are unspecific.

Nullor : They are theoretical two port network with a nullator at its input port and norator at its output port.

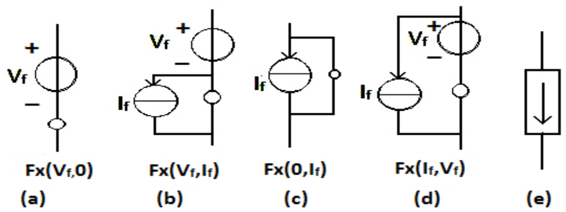


Fig.1. Fixators; (a)&(b) voltage fixators ; (c)&(d) current fixators; (e) symbol of a fixator.

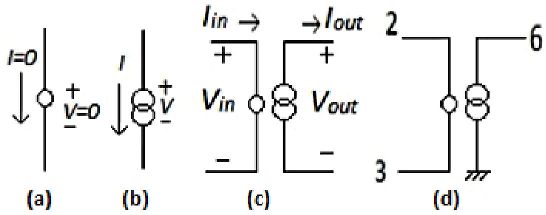


Fig.2. (a) nullator; (b) norator; (c) nullor; (d) nullor model of op-amp.

Nullor represents an ideal amplifier with infinite gain [6] and its input output behavior is,

$$\begin{bmatrix} V_{in} \\ I_{in} \end{bmatrix} = \begin{bmatrix} 0 & 0 \\ 0 & 0 \end{bmatrix} \begin{bmatrix} V_{out} \\ I_{out} \end{bmatrix}$$

In our method, operational amplifier is used as nullor. If it is used in a circuit, the circuit around the op-amp (nullor) determines the output of op-amp such a way that its input forced to zero. That means nullor output can take any value so that its input equals zero.

Using the basic structures of fixators in Fig.1, we can develop two new tools, voltage fixator and current fixator using op-amp. The usage of these tools in a circuit is as shown in Fig.3. These tools are based on the properties of op-amp and that of nullor [6]. The two properties of op-amp [8] that are the key factors of our tools are,

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

The tool in Fig.3 (a) can be used to fix the voltage between two nodes. In addition, this tool helps us to find the value of bias supporting component that satisfies the targeted design. For example, to fix 5 V between X and Y, we have to set $V_{dc}$ = 5 V, and remove the existing bias supporting component, if any. Resistor R is optional and it has no particular function at all. It is just a placeholder for one of the two terminals of bias supporting component. If it is using, its value must be ≥ 10 MΩ to make sure that the current flowing through it is close to zero. As mentioned earlier in this article, for every critical spec, there is a controlling voltage source, current source or power-conducting component in the circuit. In our method, op-amp output does exactly the same function what a bias-supporting component do. That is in this example; op-amp output takes the value to make its input equal to zero. By analyzing the output, we can easily find the value of required bias-supporting component, that if used in the actual circuit will satisfy the design, i.e., in our example fix 5 V between X and Y. Use of these tools are temporary. They are removed when the final design is obtained and instead place the appropriate bias-supporting component.

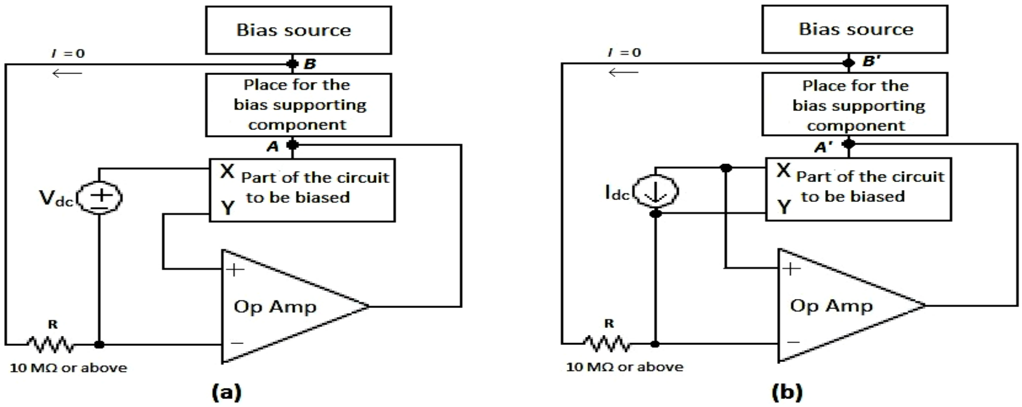


Fig.3. Usage of (a) Voltage fixator; (b) current fixator.

In Fig.3 (a), value of resistor R≥ 10 MΩ, therefore in this example, the circuit is source isolated. Thus, the solution obtained from our method can be used for calculating the value of bias-supporting component for any given bias source, providing the value of that source. That is, in this example, if the bias source is a +12 V DC voltage source, the solution of our method is useful even if the source voltage is changed to a different value. In Fig.3 (b), usage of a current fixator is shown and it fixes current between nodes X and Y. Rest of the arrangement is similar to that of Fig.3(a).

Another usage of the proposed method is shown below.

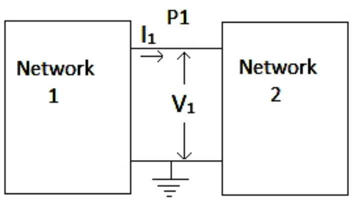


Fig.4. Network 1 and network 2 connected through port P1.

In Fig.4, network 1 contains the bias source and network 2 contains the non-linear device. Network 1 provides the required biasing for the non-linear device in network 2. Port P1 separates the two networks. Using fixators, we can nullify [3] port P1. Network 2 can be separated from network 1 without altering the operating point of non-linear device by adding $Fx(V_1, I_1)$ to input of network 2. If we want to preserve both the networks unchanged, we should add a similar fixator to output of network 2. Using this theory, a diode circuit is solved for a given design and is shown below.

In Fig.5 (a), a diode circuit is shown with unknown resistor $R_3$. We have to find value of $R_3$ such that current flowing through the diode must be 1 mA. If we remove $R_3$, we get two sub circuits, L.H.S is a powered network and network in R.H.S is an unpowered one. A powered network should contain one or more sources. In the next step, add current fixator of 1 mA to R.H.S network (Fig.5 (b)) to bias the diode $D_1$ at the desired operating condition. Analyze the circuit to find voltage at and current entering node A'. It should be 0.673 V and 1.135 mA. This means, in our original circuit (Fig.5 (a)), current entering $R_3$ must be 1.135 mA to get a diode current of 1 mA. Now place a current fixator of 1.135 mA to the output of L.H.S network as shown in Fig.5 (c). Analyzing the circuit, current to and voltage at node A' are 1.135 mA and 1.763 V respectively. Now we have enough data to calculate value of $R_3$.

$$R_3 = (1.763\text{-}0.673)/1.135 \text{ mA} = 960.35\ \Omega.$$

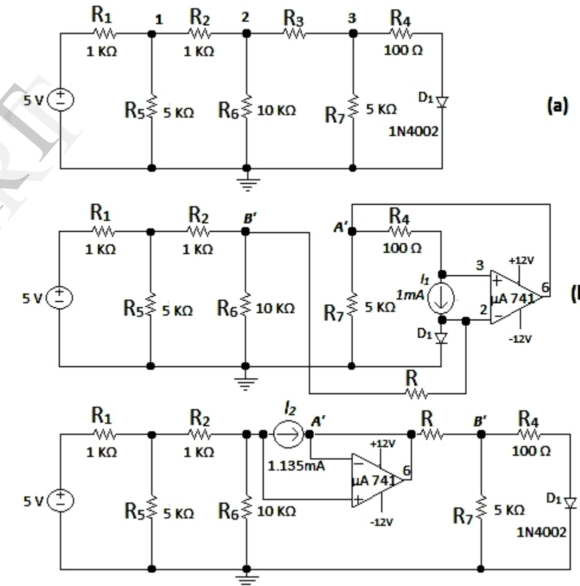




Fig.5. (a) A diode circuit; (b) Inserting current fixator to fix diode current at 1 mA; (c) Finding node 2 voltage for the required design.

## III. Implementation Of The Tools With Examples

a).Consider a simple diode circuit as depicted in Fig.6 (a). Here the design is to find the value of voltage source $V_1$ so that the current flowing through diode $D_1$ is 1 mA. Now the design process starts by inserting current fixator to the circuit, in such a way that the current flowing through the diode will freeze at 1 mA. The circuit arrangement is as shown in Fig.6 (b). The next step in our design procedure is to set up the circuit in a breadboard as in Fig.6 (b) and analyze the voltage and current values at all nodes. The resistor R in the above arrangement must be sufficiently high to get acceptable result. Results of the analysis are shown in tables 1.1 and 1.2.

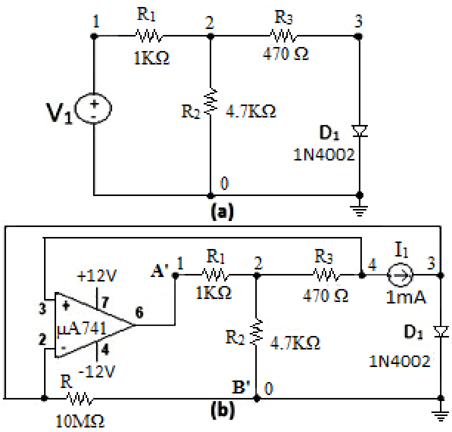


Fig.6. (a) A simple diode circuit; (b) Current fixator is added to fix current through diode at 1mA.

TABLE 1.1. ANALYSIS RESULTS OF DIODE CIRCUIT IN Fig.6(b)

| Voltage | Value (V) |
|---|---|
| Node 1 | 2.265 |
| Node 2 | 1.043 |
| Node 3 | 0.573 |

TABLE 1.2. ANALYSIS RESULTS OF DIODE CIRCUIT IN Fig.6(b)

| Current | Value (mA) |
|---|---|
| Node 1-2 | 1.22 |
| Node 2-0 | 0.22 |
| Node 3-0 | 1.00 |

The analysis indicates a voltage drop of 2.265 V across A'B' when 1 mA current flows through the diode. The last step in our design process is to remove current fixator and instead place $V_1$ = 2.265 V and the final circuit is as in Fig.7. Analyzing the circuit in Fig.7 with $V_1$ = 2.265 V, we can observe that diode current is 1 mA.

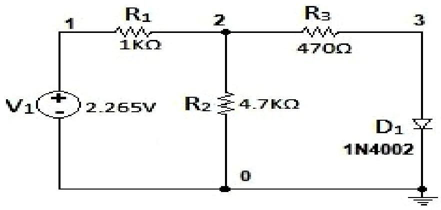


Fig.7. A voltage source of 2.265 V is placed as $V_1$.

b).Next, make some modifications to the arrangement in Fig.6 (a). Let $V_1$ = 2.5 V and still we needs the diode current fixed at 1 mA. As discussed previously in this article, for cases like this, we have to alter the value of one of the resistor but the selection of the resistor depends on the circuit itself. In this case, we are altering the value of resistor $R_2$. The selection of $R_2$ is only one of the choices we have made in our design and selections of any other resistors are also valid. Proceeding with the design steps, set up the circuit as shown in Fig.8 (a) and analyze. Analysis results are shown in table 2.1 and 2.2. Thus, we can calculate the value of $R_2$. Final circuit is shown in Fig.8 (b).



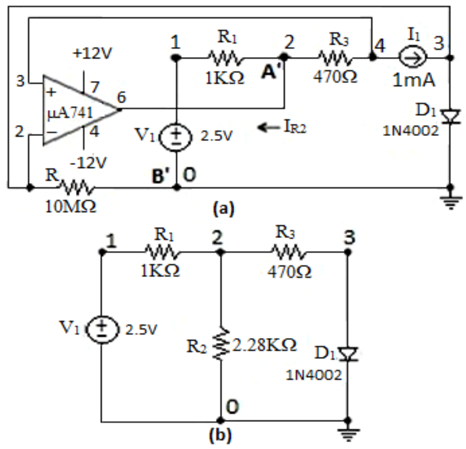


Fig.8. (a) finding value of $R_2$ using current fixator for a diode current of 1mA. (b) Value of $R_2$ changed to 2.28 KΩ.

TABLE 2.1. ANALYSIS RESULTS OF DIODE CIRCUIT IN Fig.8(a)

| Voltage | Value (V) |
|---|---|
| Node 1 | 2.500 |
| Node 2 | 1.043 |
| Node 3 | 0.573 |

TABLE 2.2. ANALYSIS RESULTS OF DIODE CIRCUIT IN Fig.8(a)

| Current | Value (mA) |
|---|---|
| Node 1-2 | 1.457 |
| Node2-0(i.e. $I_{R2}$) | 0.457 |
| Node 3-0(i.e. $I_{D1}$) | 1.000 |

$R_2$ = (1.043/0.457 mA) = 2.28 KΩ.

c). Consider the common emitter amplifier as shown in Fig.9 (a). The design criteria for this amplifier requires $I_C$= 1 mA, maximum output voltage swing = 8 $V_{P-P}$ and have a supply voltage $V_{CC}$ = 12 V. In other words the operating point must be such that $I_C$ = 1 mA and $V_{CE}$ = 4 V. In this case, we have to fix two parameters; $V_{CE}$ and $I_C$. So we have to use two fixators in this circuit; a current fixator is used to fix $I_C$ = 1 mA and a voltage fixator to keep $V_{CE}$ fixed at 4 V. Next step is similar to what we have done in previous cases. We have to choose two resistors such that they are the controllers of our targeted parameters. In this case, $I_C$ is a critical spec. We know that $I_C = \beta I_B$, where β is the current gain of the transistor. Resistor $R_1$ controls $I_B$ and hence $I_C$. In the case of collector to emitter voltage, collector resistor $R_C$ must take into consideration. As discussed earlier, selection of any other option (DC source or power-conducting component) is also acceptable, but the difference is that each component responds to AC design differently. The circuit arrangement for biasing design is as in Fig.9 (b). Add resistor $R_E$ as per the required $V_E$. Here a 1.2 KΩ resistor is added at the place of $R_E$ which gives $V_E$ = 1.2 V. Value of resistor $R_2$ is taken as 10 KΩ. Setup the circuit as shown in Fig.9 (b) and analyze the circuit. The result of analysis is shown in tables 3.1 and 3.2.

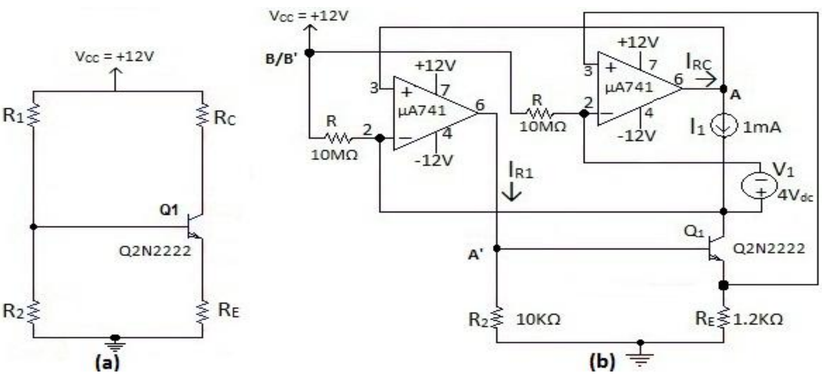


Fig.9. (a) Common emitter amplifier; (b) Fixing $I_C$ and $V_{CE}$ using current fixator and voltage fixator.

TABLE 3.1. ANALYSIS RESULTS OF Fig. 9(b)

| Voltage | Value (V) |
|---|---|
| $V_C = V_A$ | 5.21 |
| $V_E$ | 1.21 |
| $V_B = V_{A'}$ | 1.86 |

TABLE 3.2. ANALYSIS RESULTS OF Fig. 9(b)

| Current | Value (mA) |
|---|---|
| $I_C = I_{RC}$ | 1.000 |
| $I_E$ | 1.008 |
| $I_{R1}$ | 0.192 |

From the results, we can calculate values of $R_1$ and $R_C$, as,

$R_1$ = (12-1.86)/192 µA = 52.8 KΩ.
$R_C$ = (12-5.21)/1 mA = 6.79 KΩ.

Now in Fig.9 (a) put $R_C$ = 6.79 KΩ and $R_1$ = 52.8 KΩ. Again, analyze the circuit. Results of the analysis are shown below in table 4.

Fixators can also be used for complete modeling of non-linear devices. As mentioned earlier, complete modeling is employed when all the parameters of a device are seen to be critical. That means for a transistor used in Fig.9 (a), if $I_C$, $V_{CE}$, $V_{BE}$ and $I_B$ are critical, complete modeling can be used. The complete modeled circuit is shown in Fig.9.1.Here we fix $I_C$ at 1 mA, $I_B$ at 4 µA, $V_{BE}$ at 0.65 V and $V_{CE}$ at 4 V. If we setup a circuit as shown in Fig. 9.1 and measure the various voltages and currents, it gives measurements as shown in tables 4.1(a) and 4.1(b).

TABLE 4 RESULTS OF ANALYSIS WITH CALCULATED VALUES OF RESISTORS

| Parameter | Value |
|---|---|
| $V_E$ | 1.21 V |
| $V_C$ | 5.19 V |
| $I_C$ | 1.003 mA |
| $I_E$ | 1.009 mA |

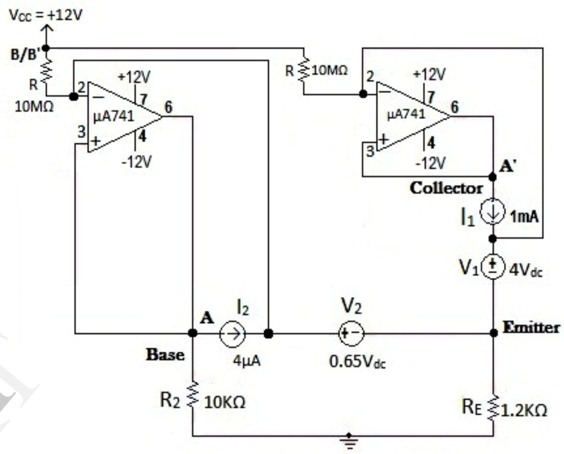


Fig.9.1. Complete modeling using fixators.

TABLE 4.1(a). ANALYSIS RESULTS OF COMPLETE MODELING

| Voltage | Value (V) |
|---|---|
| $V_E$ | 1.207 |
| $V_B$ | 1.857 |
| $V_C$ | 5.207 |

TABLE 4.1(b). ANALYSIS RESULTS OF COMPLETE MODELING

| Current | Value (mA) |
|---|---|
| $I_C$ | 1.0010 |
| $I_E$ | 1.0060 |
| $I_B$ | 0.0049 |
| $I_{R1}$ | 0.1897 |

Using the readings in tables 4.1(a) and 4.1(b), we can calculate $R_C$ and $R_1$ as,

$R_c$ = (12-5.207)/1.001 mA = 6.786 KΩ and,
$R_1$ = (12-1.857)/189.7 µA = 53.468 KΩ

These are close to the values of $R_C$ and $R_1$ obtained for circuit in Fig.9 (b).

d). Next example is a fixed biased JFET network as shown in Fig.10 (a). In this case, the only requirement of our design is to get a drain current of 5 mA. Therefore, we need a current fixator and which will determine the value of drain resistor $R_D$. We cannot choose $R_G$ because gate current of

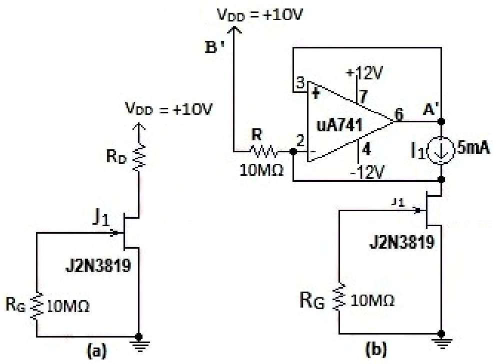


Fig.10. (a) JFET fixed biased circuit; (b) Fixing drain current using current fixator.

FET is theoretically zero. If we need to fix more parameters, we can add a source resistor or vary DC supply voltage $V_{DD}$ using fixators. Gate resistor $R_G$=10 MΩ because $I_G$ approximately equal to zero under DC conditions. The circuit arrangement for the biasing design is shown in Fig.10 (b).

Setup and analyze the circuit in Fig.10 (b). Analysis results are shown in table 5.

TABLE 5. ANALYSIS RESULTS OF JFET FIXED BIASED CIRCUIT

| Parameter | Value |
|---|---|
| $V_D$ | 0.734V |
| $V_G$ | 4.6µV |
| $I_D$ | 5mA |
| $I_S$ | 5mA |

From table 5, we can calculate $R_D$ as,

$$R_D = (10-0.734)/5 \text{ mA} = 1.85 \text{ K}\Omega.$$

Next put $R_D$ = 1.85 KΩ in Fig.10 (a) and analyze the circuit, we can observe that $I_D$ = 5 mA.

## IV. CURRENT SOURCES

For biasing designs using the current fixator, we need constant current sources. Voltage sources are easily available but current sources are not like that. The proposed tools are designed to do biasing designs easily, so there is a need for a commonly available current source. Current mirror can be used as a current source [1,8] and it needs only two BJT and a resistor (for the basic current mirror circuit). The value of current can be set using this resistor. The circuit for a current mirror arrangement is shown in Fig.11 (a).

In Fig.11 (a), Q and $Q_1$ are matched transistors. The base terminals and emitter terminals of both are connected together; it makes the same $V_{BE}$. Q is operating as a diode since its base is connected to its collector. This circuit works as a constant current source as long as the transistor operates in the active region [8], where the output terminals of current source are node 1 (+) and collector of Q1 (-). The current source in Fig.11 (a) makes use of the fact that as long as the transistor is operating in the active region, the collector current is relatively independent of collector voltage [8]. Current $I_{RC}$ (= $I_C$) flowing through Q results in a particular base emitter voltage. The base and emitter terminals of the two identical transistors (Q and $Q_1$) are interconnected so that a similar current flows through $Q_1$ (i.e. $I_{C1}$).

The value of output current can be controlled using $R_C$. We may think how to fix output current of the current source at a desired value. Again, fixator comes into usage. The difference from previous case is that here we employs a voltage fixator instead of a current fixator. The process starts with inserting a resistor with proper value R'. Then use voltage fixator to fix the voltage across resistor R' at a value $V_1$ such that $V_1$/R' = $I_{C1}$, which is the required current. For example, the designing process for a current source for an output current of 1 mA is shown in Fig.11 (b). Here we use R' as 100 Ω resistor and we need a voltage fixator to fix 100 mV across R'.

Setup the circuit as shown in Fig.11 (b) and analyze. Results of the analysis are shown in table 6. Based upon this observation, we can calculate $R_C$ as,

$$R_C = (12-0.642)/880 \text{ µA} = 12.9 \text{ K}\Omega.$$



We can verify the correctness of our current source by using it in circuit shown in Fig.6 (b). The new circuit obtained will be as shown in Fig.12. Setup the circuit (Fig.12) and analyze, we get the readings as shown in tables 7.1 and 7.2.

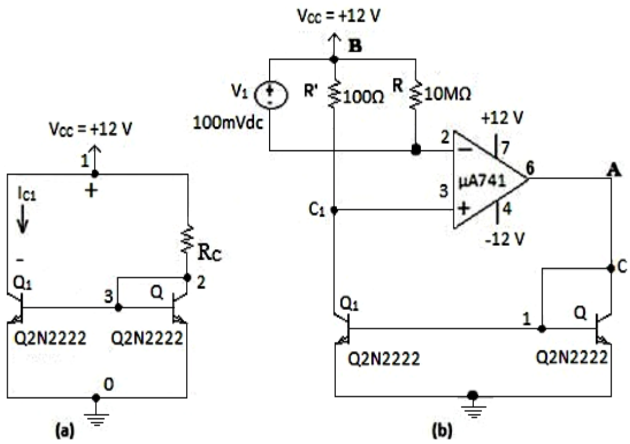


Fig.11. (a) Current mirror circuit; (b) Designing current source using voltage fixator.

TABLE 6. DESIGNING CURRENT SOURCE USING VOLTAGE FIXATOR: ANALYSIS RESUL

| Parameter | Value |
|---|---|
| $V_C$ | 0.642 V |
| $I_C$ | 880 µA |
| $I_{C1}$ | 1 mA |
| $I_{E1}$ | 1.006 mA |

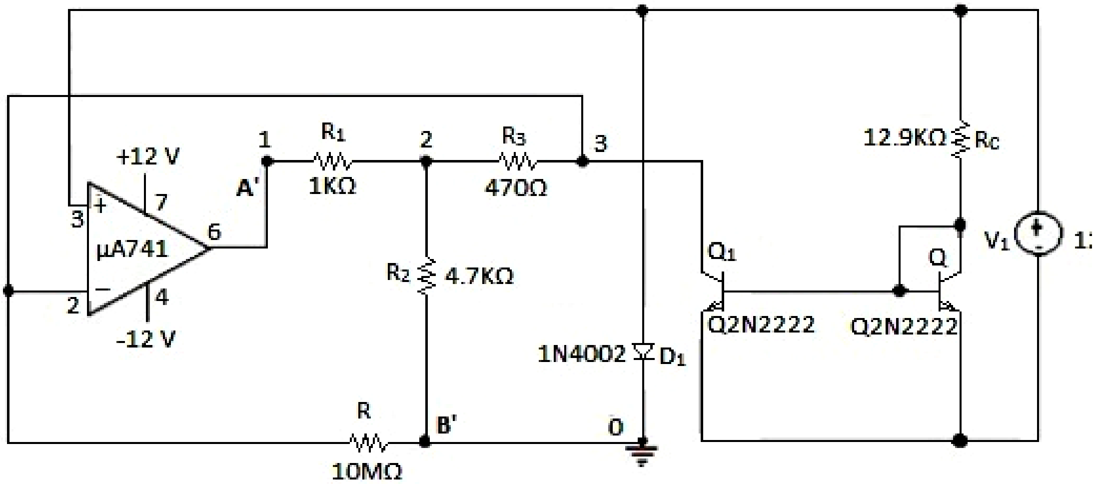


Fig.12. Current mirror is used as Current Source.

TABLE 7.1. CURRENT MIRROR IS USED AS CURRENT SOURCE: ANALYSIS RESULTS

| Voltage | Value (V) |
|---|---|
| Node 1 | 2.268 |
| Node2 | 1.044 |
| Node3 | 0.573 |

TABLE 7.2. CURRENT MIRROR IS USED AS CURRENT SOURCE: ANALYSIS RESULTS

| Current | Value (mA) |
|---|---|
| $I_{R1}$ | 1.224 |
| $I_{R2}$ | 0.222 |
| $I_{R3}$ | 1.002 |
| $I_{D1}$ | 1.002 |

The readings obtained using circuit in Fig.12 are very much close to values in tables 1.1 and 1.2. This test proves the efficiency of current mirror in our design.

## V. DISCUSSIONS

At present, biasing designs depend upon some approximations and sometimes we need to neglect certain factors. Why we take such approximations and why we avoid those small factors. It is just to make the design process easier and to minimize the number of iterations. If we can do those designs without taking any approximations and without avoiding any factors, it is advantageous. This is why the proposed tools have relevance in the present scenario.

Use of fixators for biasing design is a new concept. The scope of fixators is tremendous. This article presents their use in biasing design only. Fixators can be used to solve performance problems of amplifiers, oscillators, feedback networks, gain control of amplifiers and even to work with storage elements. The success of such tests depends on the way we use these tools and where we use them.

## VI. CONCLUSIONS

A new method for biasing design of analog circuit with practical components has been presented. The key elements of the method are voltage fixator and current fixator using op-amp. Advantage of this method is that it does not need any theoretical parts and any simulation software, but the designing can be done in our electronics lab with the original components, which we like to use in the circuit. This avoids needs for approximations and is very useful for designers. This method allows us to handle the non-linear device in an easier way and it avoids complexities associated with the biasing design of circuits containing non-linear devices. In addition, the proposed tools are able to bias the non-linear device individually and it provides the DC sources at the desired locations of the circuit. The scopes of the proposed tools are unlimited.



## ACKNOWLEDGMENT

Authors are thankful to Dr. Reza Hashemian, Life Senior Member, IEEE for his valuable suggestions, comments and inspiration in this research work.

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