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# Investigation of the Effects of Cascading Multistage JFET Common Source Amplifier on Gain and Bandwidth

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## *Abstract*

***In this work, a high gain broadband amplifier incorporating cascaded common source amplifier configurations for gain enhancement and bandwidth shrinkage is proposed.We investigated and reported the characteristics of N-channel BF245A JFET. We recorded its drain characteristics up to a drain voltage of 30V, and its mutualcharacteristics over a gate voltage of 0 to*** $-1.5V$***. A chain of four stage common source amplifier was used to study the effects of cascading on gain and bandwidth of the amplifier. Results from simulations revealed that for a single- stage, the gain was found to be*** $24dB$ ***while the bandwidth was found to be*** $0.59GHz$***. The two-stage cascade has a gain of*** $34dB$ ***and a bandwidth of*** $0.37GHz$***. The three-stage connection recorded a gain of*** $46dB$ ***and a bandwidth of*** $0.32GHz$ ***and finally for a four-stage cascade connection, the gain was obtained as*** $54dB$ ***while the bandwidth was obtained as*** $0.29GHz$***. In general, it was observed that as the number of stages was increased, there was a corresponding increase in the gain at the expense of the bandwidth.***

**Keywords:** Artificial Neural Network; Concrete; Washed gravel; Regression; Modelling

## 1.0 Introduction

The performance obtainable from a single stage amplifier is often insufficient for many applications. In most applications, a single-transistor amplifier will not be able to meet the combined specifications of a given amplification factor, input resistance and output resistance. Hence several stages may be combined to form a multistage amplifier. These stages are connected in cascade, that is, output of the first stage is connected to form input of the second stage, and so on. Cascading is done either to increase the overall small signal voltage gain or provide an overall voltage gain greater than unity, with a very low output resistance. High speed multistage amplifiers are widely used in optical communication systems as the main amplifier in a receiver [1, 2,3]. Multistage amplifier topologies often provides a remedy for circuits with low gain. To increase the gain of a single stage amplifier, up to three or four equivalent simple gain stages can be employed. In a gain boosted amplifier,since miller compensation is avoided, we do not rule out the possibility of bandwidth limitations exhibited by the cascading approach [4].

The primary function of an amplifier is to reproducethe applied signal and provide some level of amplification.Unipolar transistors can be used to achieve thisfunction.JFET and MOSFET are examples of unipolar amplifying devices. The *common-source amplifier* is the most widely usedFET circuit configuration. The inputsignal is applied to the gate-source and the outputsignal is taken from the drain-source. The source lead is common to both input and output. A common-source amplifier has a very good ratiobetween input and output impedance. Circuits of thistype are extremely valuable as impedance-matching devices.Common-sourceamplifiers are used almost exclusivelyas voltage amplifiers. They respond well in radiofrequencysignal applications [5].

The common-source amplifier has infinite input resistance and appreciable voltage gain. Both properties are useful and this is the most used of the FET linear circuits. Because of their low noise, FETs are often used in low-level audio frequency. applications, e.g. in microphone head amplifiers where the high input resistance makes such amplifiers particularly suitable for following capacitor and piezo-electric microphones[6].

In general, a field effect transistor (FET) amplifier will have greater bandwidth than equivalent BJT topologies. Since the input resistance for the FET is very large, modelled as infinity, the low frequency pole contributed by this resistance and $C_{in}$ will occur at low frequency. In addition, the device capacitances associated with FETs are generally smaller than those for a BJT. This has the effect of raising the upper cut-off frequency of FET amplifier relative to an equivalent topology BJT amplifier [7]. .

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This work intends to study the effects of cascading multistage common source amplifier on gain and bandwidth.

**CIRCUIT TOPOLOGY**

The common-source amplifier has characteristics similar to those of the common-emitter amp. However, the common source amplifier has higher input resistance than that of the common-emitter amplifier. The circuit for the common source amplifier is shown in Figure 1 [8].

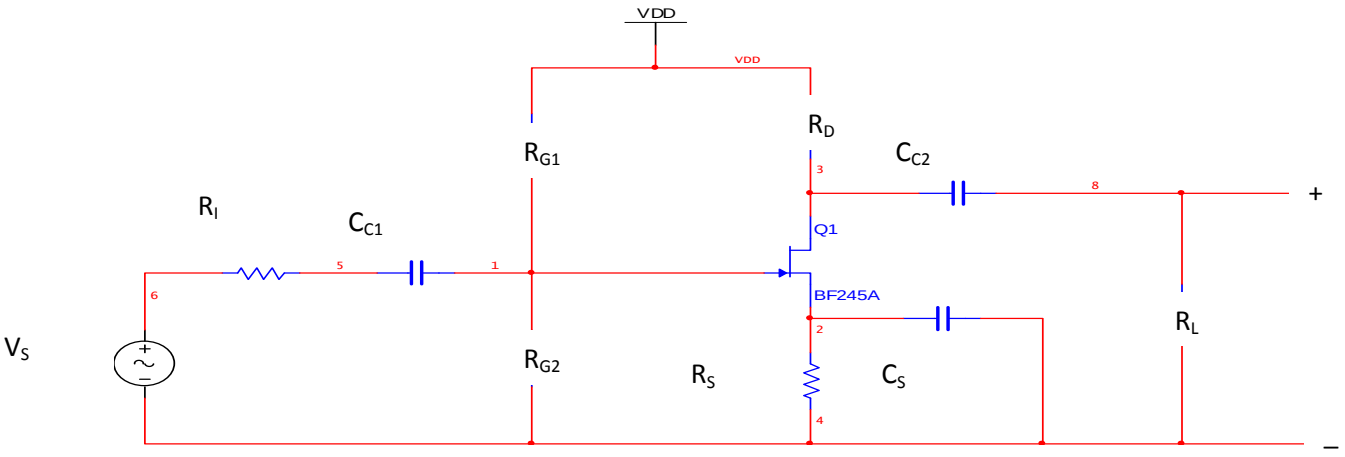


**Figure 1 Single Stage Common Source Amplifier**

The external capacitors $C_{C1}$ ,$C_{C2}$ and $C_S$ will influence the low frequency response. The internal capacitances of the FET will affect the high frequency response of the amplifier.

The midband gain, $A_{m,}$ is obtained from the midband equivalent circuit of the common source amplifier. This is shown in Figure 2 . The equivalent circuit is obtained by short-circuiting all the external capacitors and open-circuiting all the internal capacitances of the FET.

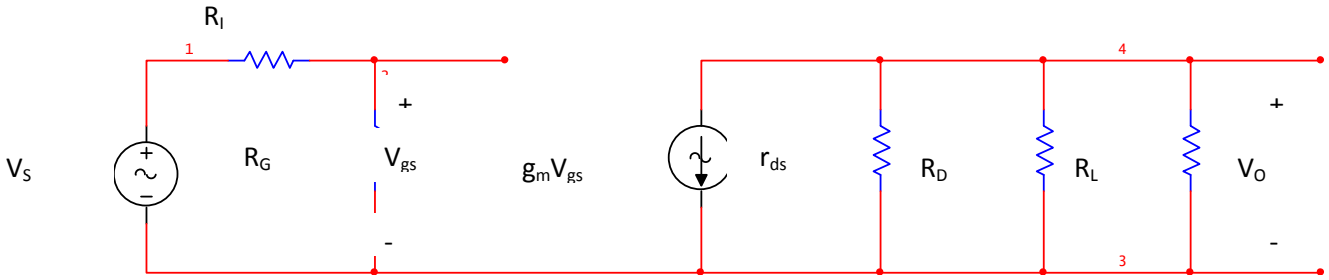


**Figure 2 Midband Equivalent Circuit of Common Source Amplifier**

Using the voltage division,

$$V_{gs} = \frac{R_g}{R_1+R_g} V_s \quad (1)$$

From Ohm's law,

$$V_s = -g_m v_{gs}(r_{ds} \| R_D \| R_L) \quad (2)$$

Substituting Equation (1) into (2) , we obtain the midband gain as

$$A_m = \frac{V_0}{V_s} = -g_m \left(\frac{R_G}{R_G+R_1}\right)(r_{ds} \| R_D \| R_L) \quad (3)$$

At low frequencies, the small signal equivalent circuit of the common source amplifier is shown in Figure 3.0

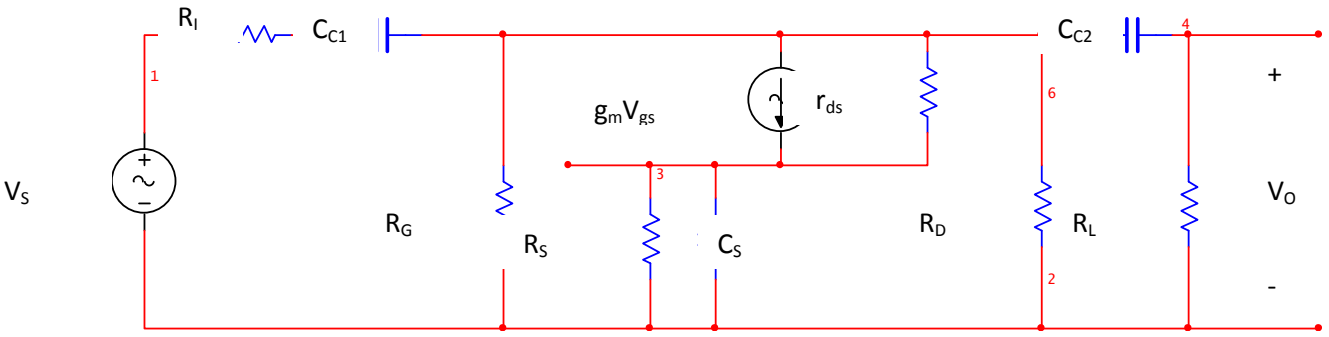


**Figure 3 Equivalent Circuit for Obtaining the Poles at Low Frequencies of Common Source Amplifier**

The low frequency poles due to $C_{C1}$ and $C_{C2}$ can be written as

$$\tau_1 = \frac{1}{w_{L1}} \cong C_{C1}(R_g + R_1) \quad (4)$$

$$\tau_2 = \frac{1}{w_{L2}} \cong C_{C2}(R_L + R_D \| r_{ds}) \quad (5)$$

Assuming $r_d$ is very large, the pole due to the bypass capacitance $C_S$ is given by

$$\tau_3 = \frac{1}{w_{L3}} \cong C_S\left(\frac{R_S}{1+g_m R_S}\right) \quad (6)$$

and the zero of $C_S$ is

$$w_z = \frac{1}{R_S C_S} \quad (7)$$

The 3-dB frequency at the low frequency can be approximated as

$$w_L \cong \sqrt{(w_{L1})^2 + (w_{L2})^2 + (w_{L3})^2} \quad (8)$$

For a single stage common source amplifier, the source bypass capacitor is usually the determining factor in establishing the low 3-dB frequency.

The high frequency equivalent circuit of common source amplifier is shown in Figure 4. In the figure, the internal capacitances of the FET ,$C_{gs}$ ,$C_{gd}$ and $C_{ds}$ are shown. The external capacitors are short-circuited at high frequencies.

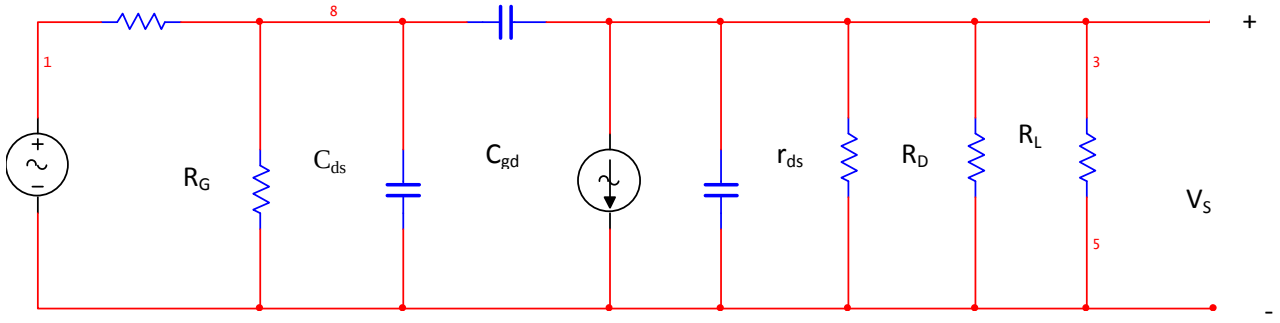


**Figure 4 High Frequency Equivalent Circuit of Common Source Amplifier**

Using the Miller theorem, Figure 4 can be simplified. This is shown in Figure 5.

The voltage gain at high frequencies is

$$A_V = \frac{V_0}{V_S} \cong -\left(\frac{R_G}{R_G+R_1}\right)\left(\frac{g_m R_L}{1+s(R_G \| R_1)C_1(1+sR_L C_2)}\right) \quad (9)$$

where

$$C_1 = C_{gs} + C_{gd}(1 + g_m R_L) \quad (10)$$

and

$$C_2 = C_{ds} + C_{gd} \quad (11)$$

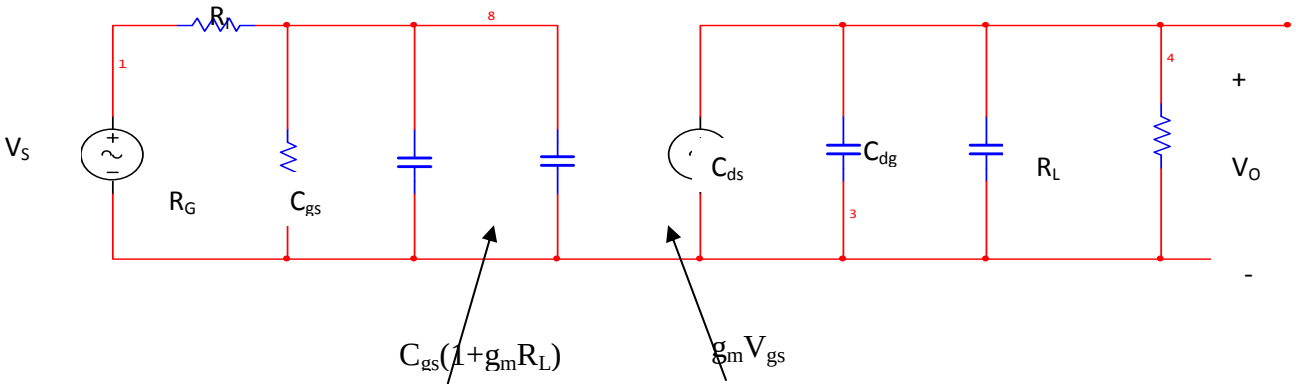


Figure 5 Simplified High Frequency Equivalent Circuit for common Source Amplifier

The high frequency poles are

$$w_{H1} = \frac{1}{C_1(R_G \| R_1)} \quad (12)$$

$$w_{H2} = \frac{1}{C_2(R_L \| R_D \| r_{ds})} \quad (13)$$

The approximate high frequency cut-off is

$$w_H = \frac{1}{\sqrt{\left(\frac{1}{w_{H1}}\right)^2 + \left(\frac{1}{w_{H2}}\right)^2}} \quad (14)$$

GAIN-BANDWIDTH CONSIDERATIONS

Consider a multistage amplifier with a DC gain $A_A$ and a $-3dB$ bandwidth$\omega_A$. Lets consider that the multistage amplifier is formed from a cascade of *n* identical stages, each with a single pole response [9, 10].

$$A_S(j\omega) = \frac{A_0}{1+j\frac{\omega}{\omega_B}} \quad (15)$$

where $A_0$ is the DC gain and $\omega_B$ is the $-3dB$ bandwidth of each stage. Assuming that there is no interaction among the stages, then the overall transfer function of the multistage amplifier is

$$A_A(j\omega) = \left(\frac{A_0}{1+j\frac{\omega}{\omega_B}}\right)^n, \text{ and} \quad (16)$$

$$A_A = A_0^n$$

The $-3dB$ bandwidth of the multistage amplifier $\omega_A$ is the frequency at which

$$|A_A(j\omega_A)| = \frac{A_A}{\sqrt{2}} = \frac{A_0^n}{\sqrt{2}} \quad (17)$$

Thus

$$\left[\frac{A_0}{\sqrt{1+\left(\frac{\omega_A}{\omega_B}\right)^2}}\right]^n = \frac{A_0^n}{\sqrt{2}}, \quad (18)$$

$$1 + \left(\frac{\omega_A}{\omega_B}\right)^2 = 2^{\frac{1}{n}}$$

where

$$\omega_A = \omega_B\sqrt{2^{\frac{1}{n}} - 1} \quad (19)$$

The above relation shows that the bandwidth of the multistage amplifier $\omega_A$ will be less than the bandwidth of the individual stages $\omega_B$. Increasing *n*, decreases $\omega_A$, whereas enlarging the bandwidth of each stage, increases the overall bandwidth of multistage amplifier.

In general a cascade of *n* identical gain stages, each having a bandwidth $\omega_B$, exhibits an overall bandwidth $\omega_A$

$$\omega_A = \omega_B \sqrt[m]{2^{\frac{1}{n}} - 1}, \quad (20)$$

where *m* is equal to 2 for first-order stages and 4 for second order stages. The gain $A_0$ and bandwidth $\omega_B$ of each stage can be written in terms of the overall gain $A_A$ and bandwidth $\omega_A$ as

$$A_0 = (A_A)^{\frac{1}{n}} \text{ and} \quad (21)$$

$$\omega_B = \frac{\omega_A}{m\sqrt{\frac{1}{2^{\frac{1}{n}}-1}}} \quad (22)$$

An amplifier normally operates with signal frequencies between $f_1$ and$f_2$.If the signal frequency drops below $f_{c1}$ , the gain and thus the output signal level drops at 20dB/decade until the next critical frequency is reached. The same occurs when the signalfrequency goes above $f_2$. The range (band) of frequencies lying between $f_1$ and$f_2$ is definedas the bandwidth of the amplifier, only the dominant critical frequencies appear in theresponse curve because they determine the bandwidth.

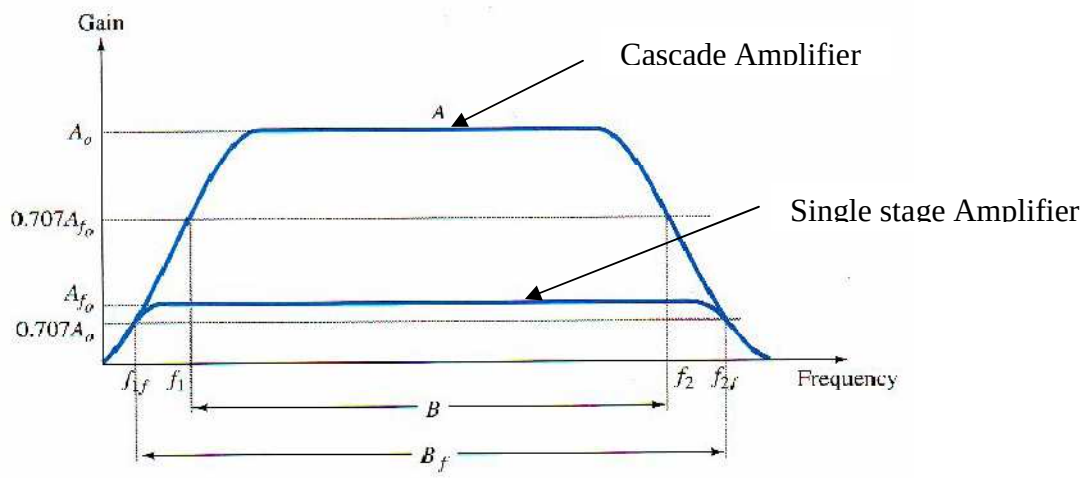


Figure 6 The frequency response

As the frequency response curve shows, the gain of an amplifier remains relatively constant across a band of frequencies. When the operating frequency starts to go outside this frequency range, the gainbegins to drop off. Two frequencies of interest, $f_1$ and $f_2$, are identified as the lower and uppercut-off frequencies[11].

The amplifier's bandwidth is expressedin units of hertz as[11]

$BW = f_2 - f_1$ (23)

For the purposes of this discussion, the bandwidth is defined as the lowest frequency at which the voltage gain drops by $\sqrt{2}$ or $3dB$. Accordingly this bandwidth is called the $3-dB$ bandwidth [12].

## Method and Materials

We applied computer simulation using MultiSim 8.0 to carry out this work. The drain and transfer characteristics data of JFET N-channel BF245A were obtained as described below.

For the transfer characteristics, the drain to source voltage ($V_{DS}$) was first adjusted to a suitable value of 10V and increased the gate to source voltage ($V_{GS}$) in small suitable steps of 0, -0.5, -1.0, -1.5, -2.0 and -2.5V. The corresponding value of drain current ($I_D$) was recorded for each step. A similar procedure was used for different values of $V_{GS}$= 20V and 30V. The data obtained were used to plot a graph of $V_{GS}$ along the horizontal axis and $I_D$ along the vertical axis as shown in figure 6.0. For the drain characteristics, the gate -to-source voltage ($V_{GS}$) was first adjusted to zero volts and the drain to source voltage ($V_{DS}$) was then increased in small suitable steps of 2, 4, 6…30V. The corresponding value of $I_D$ was recorded for each step. A similar procedure was used for different values of $V_{GS}$ = -0.5, -1.0, and -1.5V. The data obtained were used to plot a graph with $V_{DS}$ along the horizontal axis and $I_D$ along the vertical axis as shown in Figure 7.

From Figures 6 and 7, the values of $V_P$ , $I_D$ , $V_{DD}$ , $V_{DS}$ ,$V_{GS}$ were obtained at quiescent points.

The drain current in the pinch off region depends upon the gate to source voltage and is given by the relation [13]

$$I_D = I_{DSS}\left(1 - \frac{V_{GS}}{V_P}\right)^2 \quad (24)$$

The pinch off region is the normal operating region of JFET when used as an amplifier.

The bias line satisfied the equations [14]

$$V_{GS} = -I_D R_S \quad (25)$$

$$V_{GG} = \frac{R_2 V_{DD}}{R_1 + R_2} \quad (26)$$

and

$$R_G = \frac{R_1 R_2}{R_1 + R_2} \quad (27)$$

Equation 26 only determines the ratio of the resistors $R_1$ and $R_2$ but in order to take advantage of the very high input impedance of the JFET as well as reducing the power dissipation within the circuit, we need to make these resistor values as high as possible with values in the order of $1\ to\ 10M\Omega$ being common. [15]

The drain to source voltage of the output can be determined by applying Kirchhoff's law as follows [16]

$$V_{DS} + I_D R_D - V_{DD} = 0 \quad (28)$$

and

$$V_{DS} = V_{DD} - I_D R_D \quad (29)$$

To calculate the value of any coupling capacitor $C_1$ or bypass capacitor $C_S$, the standard formulas to be used are [17]

$$C_1 = \frac{1}{2\pi f R_{in}} \quad (30)$$

where $R_{in} = R_G$ and

$$C_S = \frac{1}{2\pi f R_0} \quad (31)$$

where $R_0 = R_D$

The equations above were used to obtain the relevant parameters needed to design the amplifier. A single stage common source amplifier was designed, and then cascaded to obtain a two-stage amplifier, three-stage amplifier and finally a four-stage amplifier. For a single stage amplifier, a sinusoidal input signal, $V_{in}$, $40mV$ with a voltage of $10mV$ peak-to-peak value at frequency of 100Hz was applied. The output voltage, $V_O$, was observed and recorded. At fixed input voltage of $40mV$, the frequency was increased as: 1KHz, 10KHz, 100KHz, 1MHz, 10MHz, 100MHz and 1GHz. In each case, a corresponding value of the output voltage was observed and recorded The gain in decibel for each variation of frequency was calculated from [18]

$$A_V = 20log\left|\frac{V_{out}}{V_{in}}\right| \quad (32)$$

. The data obtained were used to plot a graph of gain (dB) versus frequency (Hz) as shown in Figure 9. Origin 50 was used to plot the graph. In order to obtain the bandwidth, we used a screen reader from the menu of the origin to read values of lower cut-off frequency and upper cut-off frequency. The bandwidth is obtained as upper cut-off frequency minus the lower cut-off frequency. The same procedure was used for two, three and four stages amplifier. The input voltage ($40mV$) was constant at all frequency settings.

## RESULTS AND DISCUSSIONS

### CHARACTERISTICS CURVES

Figures 7 and 8 show the transfer and the drain characteristics of N-channel BF245A JFET. Values of $V_P$, $I_D$, $V_{DS}$, and $V_{DD}$ were obtained from them. Table1 is a summary of the various quantities usedin the design and their values.

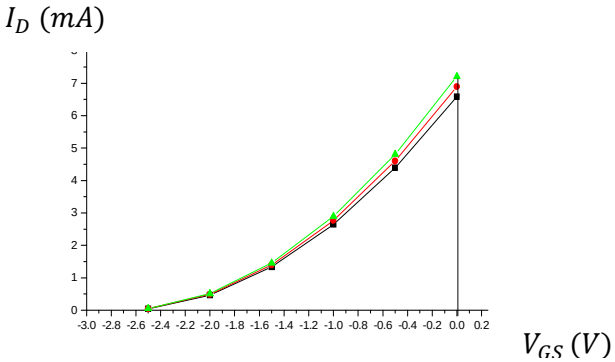


Figure 7 Transfer characteristics

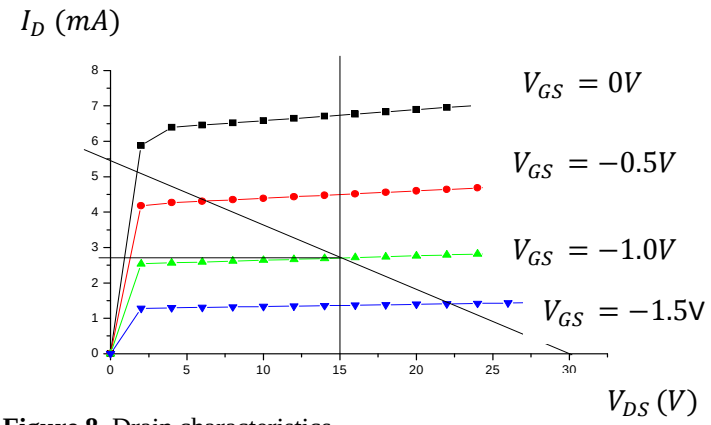


**Figure 8** Drain characteristics

**TABLE 1**

| SN | QUANTITY | SYMBOL | VALUE |
|---|---|---|---|
| 1 | Drain current | $I_D$ | $2.7mA$ |
| 2 | Gate pinch-off voltage | $V_P$ | $-2.5V$ |
| 3 | Gate-to-source voltage | $V_{GS}$ | $-1.0V$ |
| 4 | Drain-to-source voltage | $V_{DS}$ | $15V$ |
| 5 | DC-supply voltage | $V_{DD}$ | $30V$ |
| 6 | Drain resistor | $R_D$ | $5.6K\Omega$ |
| 7 | Source resistor | $R_S$ | $370\Omega$ |
| 8 | Resistor 1 | $R_1$ | $1M\Omega$ |
| 9 | Resistor 2 | $R_2$ | $10M\Omega$ |
| 10 | Coupling capacitors | $C_1$=$C_2$ | $1.5nF$ |
| 11 | Source capacitor | $C_S$ | $270nF$ |

SINGLE STAGE COMMON SOURCE AMPLIFIER: The graph in Figure 9 shows the gain versus frequency for a single stage common source amplifier. The gain was obtained to be $24dB$ and the bandwidth was found to be $0.59GHz$ . The gain is low at small frequencies, then rises as frequency increases, level off for further increases in frequency, and then begins to drop again at high frequencies. Response to a small signal - 100 Hz, and a large signal -1GHz sine waves are shown in Figures 10 and 11 respectively.

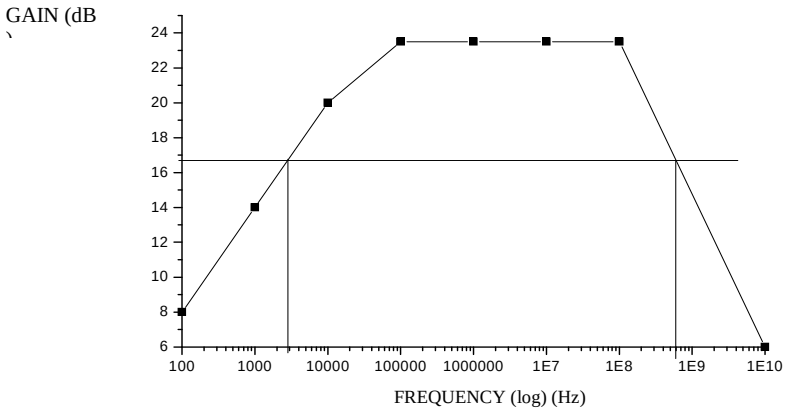


**Figure 9** Graph of Gain(dB) versus Frequency (Hz) for Single-stage CS Amplifier

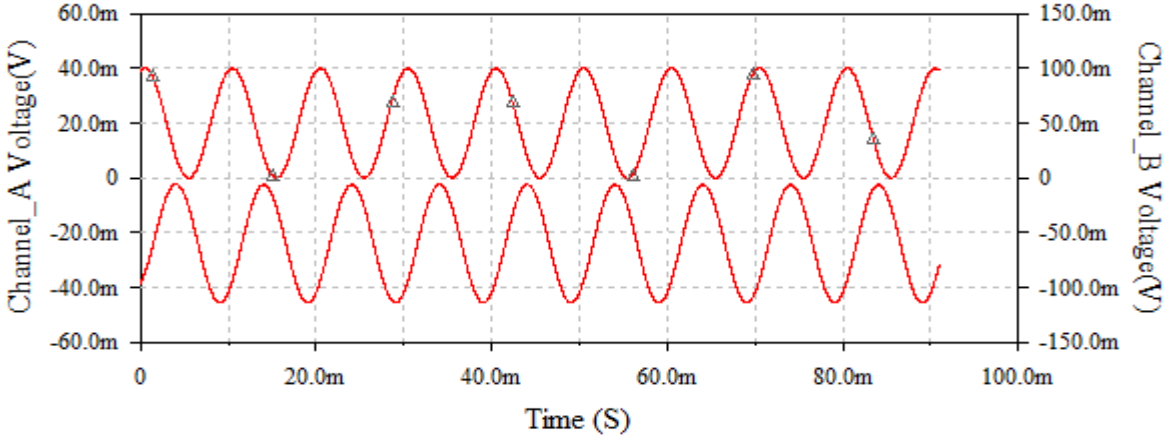


Figure 10 Single stage JFT common source amplifierResponse to a Small Signal - 100 Hz, sine wave

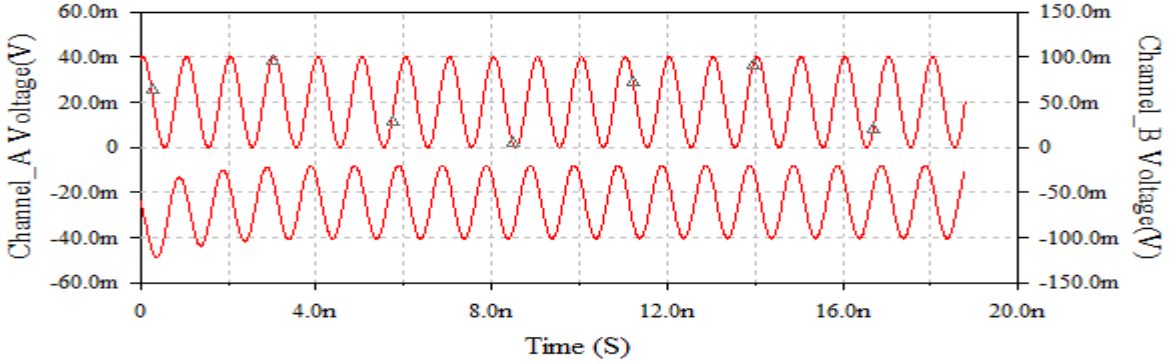


**Figure 11 Single stage JFT common source amplifierResponse to a large Signal – 1GHz, sine wave**

TWO-STAGE COMMON SOURCE AMPLIFIER: The graph in Figure 12 shows the gain versus frequency for a two-stage common source amplifier. The gain was obtained to be $34dB$and the bandwidth was found to be $\approx 0.37GHz$ . The gain is low at small frequencies, then rises as frequency increases, level off for further increases in frequency, and then begins to drop again at high frequencies. Response to a small signal - 100 Hz, and a large signal -1GHz sine waves are shown in Figures 13 and 14 respectively.

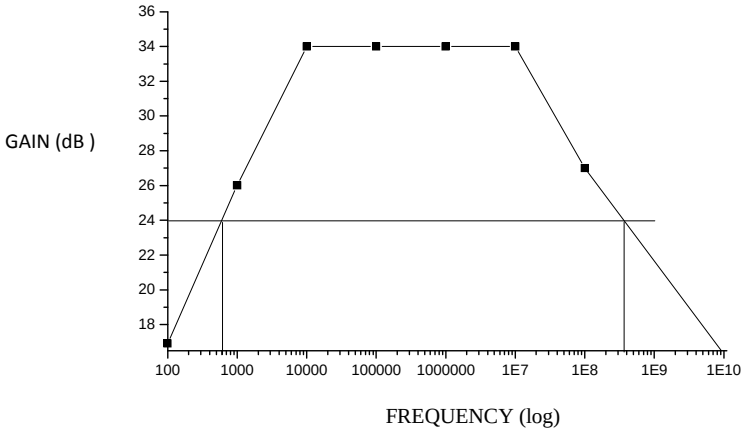


**Figure 12 Graph of Gain(dB) versus Frequency (Hz) for Two-stage CS Amplifier**

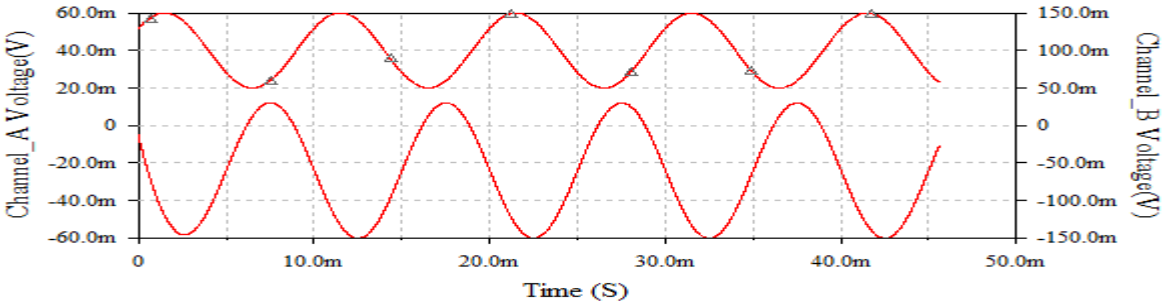


Figure 13 Two stage JFT common source amplifierResponse to a Small Signal - 100 Hz, sine wave

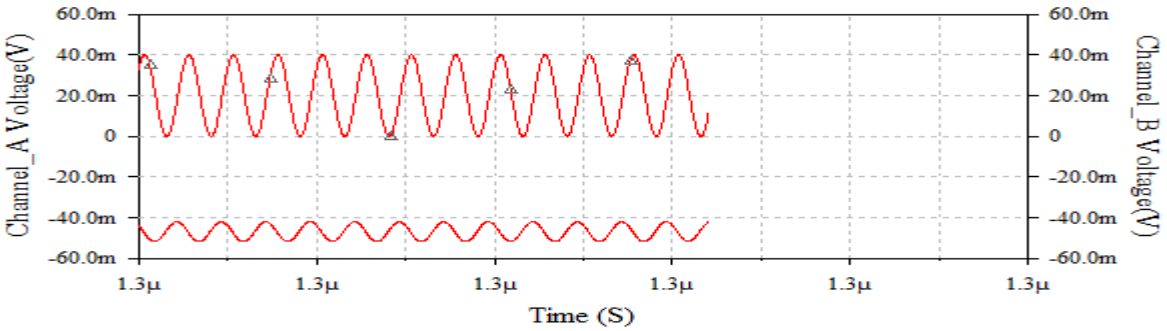


**Figure 14 Two stage JFT common source amplifierResponse to a Large Signal - 1 GHz, sine wave**

THREE-STAGE COMMON SOURCE AMPLIFIER: The graph in Figure 15 shows the gain versus frequency for a two-stage common source amplifier. The gain was obtained to be $46dB$ and the bandwidth was found to be $\approx 0.32GHz$ . The gain is low at small frequencies, then rises as frequency increases, level off for further increases in frequency, and then begins to drop again at high frequencies. Response to a small signal - 100 Hz, and a large signal -1GHz sine waves are shown in Figures 16 and 17 respectively.

GAIN (dB )

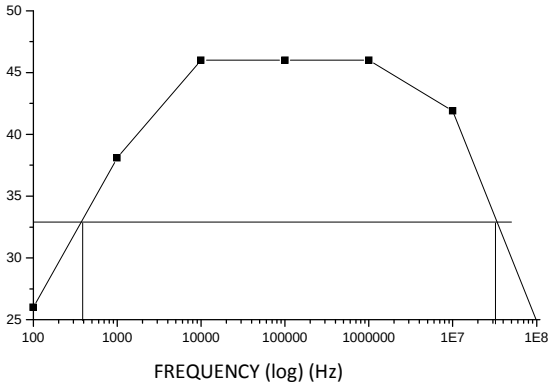


Figure 15 Graph of Gain(dB) versus Frequency (Hz) for Three-stage CS Amplifier

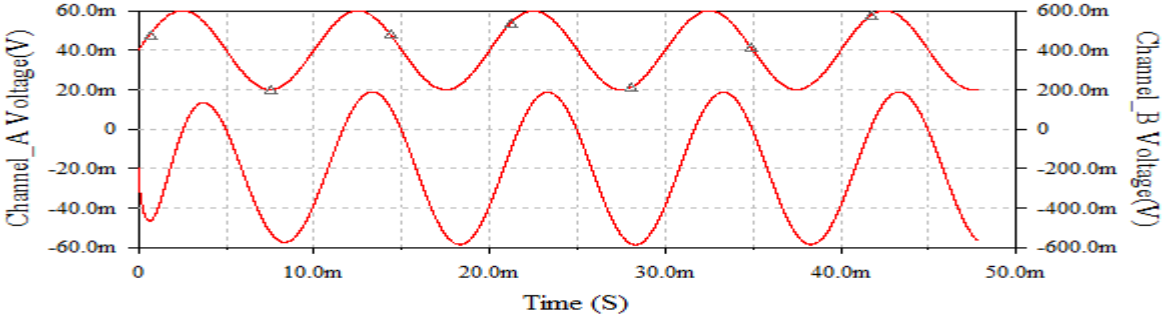


Figure 16 Three stage JFT common source amplifierResponse to a Large Signal – 100Hz, sine wave

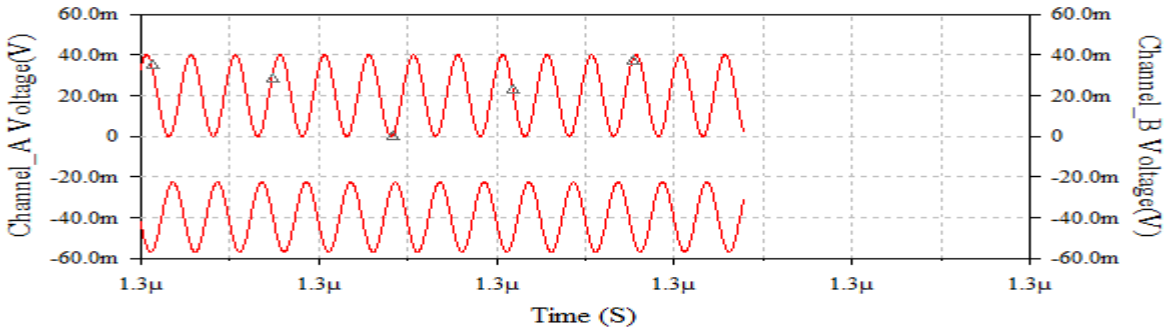


**Figure 17 Three stage JFT common source amplifierResponse to a Large Signal – 1GHz, sine wave**

FOUR-STAGE COMMON SOURCE AMPLIFIER: The graph in Figure 18 shows the gain versus frequency for a two-stage common source amplifier. The gain was obtained to be $54dB$ and the bandwidth was found to be $\approx 0.29GHz$ . The gain is low at small frequencies, then rises as frequency increases, level off for further increases in frequency, and then begins to drop again at high frequencies. Response to a small signal - 100 Hz, and a large signal -1GHz sine waves are shown in Figures 19 and 20 respectively.

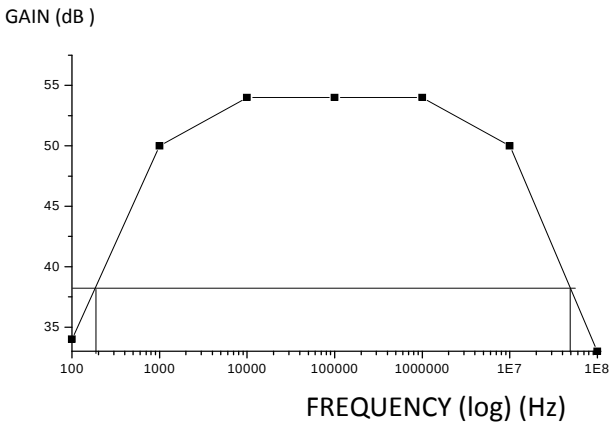


Figure 18 Graph of Gain(dB) versus Frequency (Hz) for Four-stage CS Amplifier

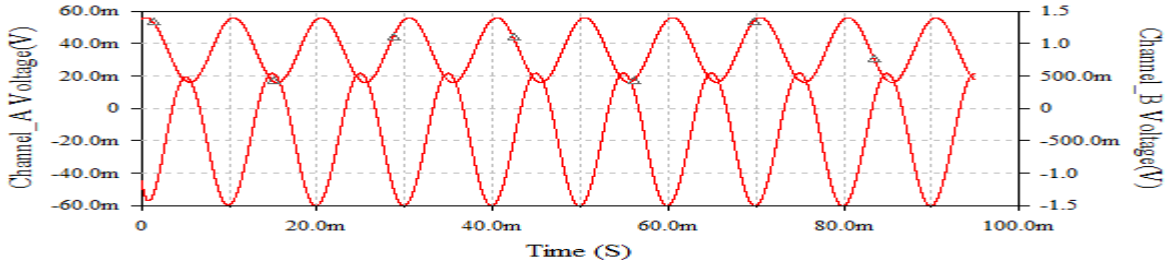


Figure 19 Four stage JFT common source amplifierResponse to 100Hz, sine wave

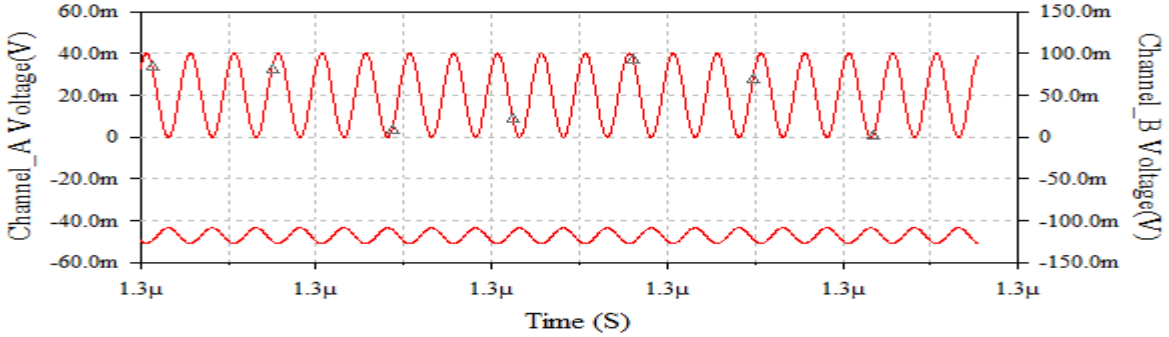


Figure 20 Four stage JFT common source amplifierResponse to 100MHz, sine wave

TABLE 2 SUMMARY OF RESULTS

| *Amplifier Mode* | *Single stage common source amplifier* | *Two stage cascaded common source amplifier* | *Three stage cascaded common source amplifier* | *Four stage cascaded common source amplifier* |
|---|---|---|---|---|
| *Gain (dB)* | *24* | *34* | *46* | *54* |
| *Lower cut-off Frequency (Hz)* | *2826.16* | *203458.90* | *389.11* | *188.6* |
| *Upper cut-off Frequency (Hz)* | *592619622* | *371308083* | *323929252* | *287332283* |
| *Bandwidth (Hz)* | *592616796* $\approx 0.59GHz$ | *371104624* $\approx 0.37GHz$ | *323928863* $\approx 0.32GHz$ | *287332094* $\approx 0.29GHz$ |

## Conclusion

In this work, a high gain broadband amplifier incorporating cascaded amplifier configurations for gain enhancement and bandwidth shrinkage is proposed. In a nutshell, by way of simulation using multiSIM8 Electronics Workbench and calculation using load line analysis and relevant equations, we were able to design a single stage common source amplifier, two-stage cascadedcommon source amplifier, three-stage cascadedcommon source amplifier and four-stage cascaded common source amplifier and studied their variation of output voltage with respect to frequency at constant input voltage of 40mV. We studied the effects of cascading on gain and bandwidth. We successfully showed that as the number of stages was increased, there was a corresponding increase in the gain at the expense of the bandwidth. This agreed with the theory that in a multistage amplifier, as the gain increases, the bandwidth decreases. Thus the decrease of bandwidth is proportional with the number of stages.

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