INVESTIGATION OF THE EFFECTS OF CASCADING MULTISTAGE JFET COMMON SOURCE AMPLIFIER ON GAIN AND BANDWIDTH

Bature, M.[1], Gidado, A. S.[2] & Sa'id, M.[3]
[1]Department of Physics,
Federal University of Technology, Minna
[2]Department of Physics, Bayero University Kano
[3]Department of Physics, Sa'adatu Rimi College of Education Kano
Emails: gidadoa4217@buk.edu.ng; mukhtarbature@yahoo.com
Phone No: +2348028276213, +2348025093289

Abstract
In this work, effects of cascading on a high gain broadband amplifier implemented with Junction Field Effect Transistors (JFET) cascaded in common source amplifier configurations for gain enhancement and bandwidth shrinkage is presented. The transfer characteristics of N-channel BF245A JFET was investigated, so also the drain characteristics up to a drain voltage of 30V, and its mutual characteristics over a gate voltage of 0 to $-1.5V$ *were recorded. 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* $0.29GHz$ *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. Electronics software called multiSIM 8.0 was used in carrying out this research.*

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 [1, 2].

The primary function of an amplifier is to reproduce the applied signal and provide some level of amplification. Unipolar transistors can be used to achieve this function. Junction Field Effect Transistors (JFET) and Metal Oxide Semiconductor Field Effect Transistors (MOSFET) are examples of unipolar amplifying devices. The *common-source amplifier* is the most widely used FET circuit configuration. The input signal is applied to the gate-source and the output signal is taken from the drain-source. The source lead is common to both input and output. A common-source amplifier has a very good ratio between input and output impedance. Circuits of this type are extremely valuable as impedance-matching devices. Common-source amplifiers are used almost exclusively as voltage amplifiers. They respond well in radiofrequency signal applications [3].

The common-source amplifier has infinite input resistance and appreciable voltage gain. Both properties are useful and they are the most used in 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 [4].

In general, a field effect transistor (FET) amplifier will have greater bandwidth than equivalent bipolar junction transistors (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.

This work intends to study of the effects of cascading multistage common source amplifier on gain and bandwidth [5].

Circuit Topology and Theoritical Considerations

The common-source amplifier has characteristics similar to those of the common-emitter amplifier of BJT's. 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 1.0 [6].

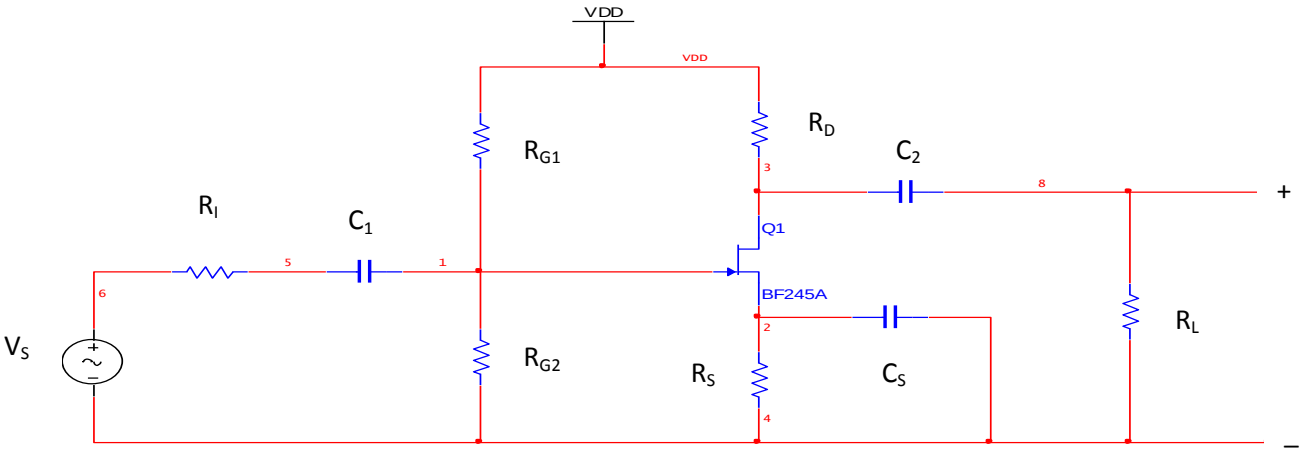


Fig. 1.0: Common source amplifier

The external capacitors C_1 ,C_2 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 Fig. 2.0. The equivalent circuit is obtained by short-circuiting all the external capacitors and open-circuiting all the internal capacitances of the FET.

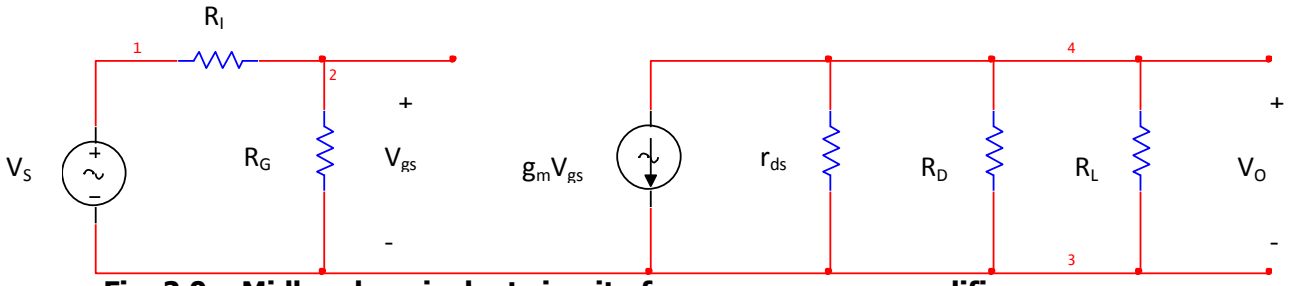


Fig. 2.0: Midband equivalent circuit of common source amplifier

Using the voltage division equation:

$$V_{gs} = \frac{R_G}{R_I + R_G} V_s \qquad (1)$$

From Ohm's law,

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

From Equation (1) and (2) the midband gain can be given 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

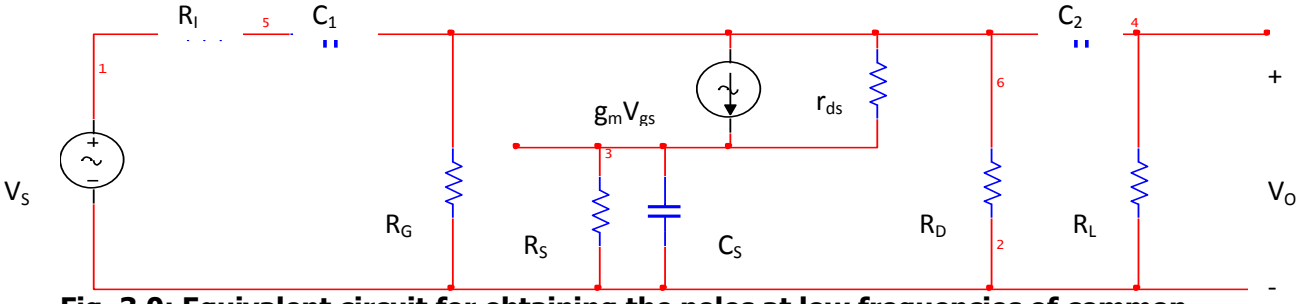


Fig. 3.0: Equivalent circuit for obtaining the poles at low frequencies of common source amplifier

The low frequency poles due to C_1 and C_2 can be written as

$$\tau_1 = \frac{1}{w_{L1}} \cong C_1(R_G + R_1) \quad (4)$$

$$\tau_2 = \frac{1}{w_{L2}} \cong C_2(R_L + R_D \| r_{ds}) \quad (5)$$

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

4.0. 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.

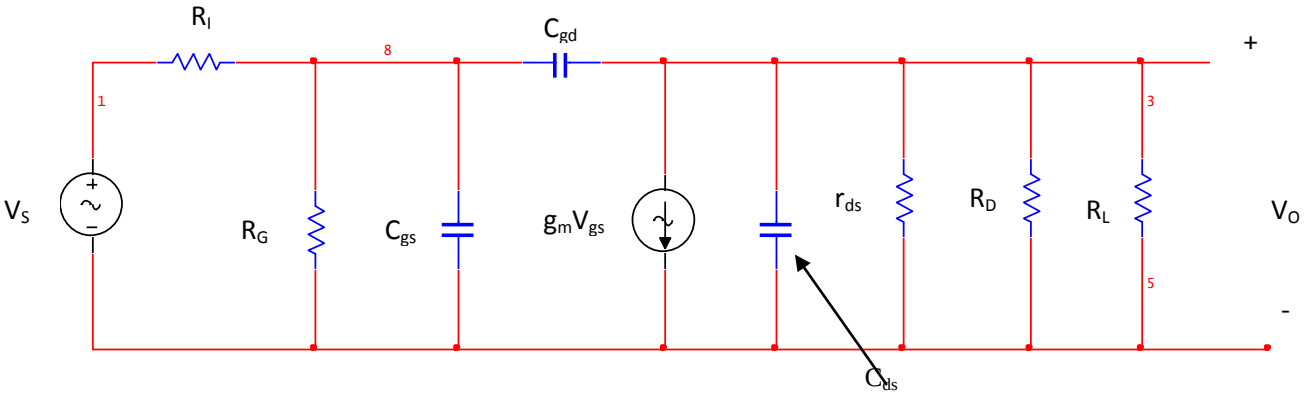


Fig.4.0 High **frequency equivalent circuit of common source amplifier**

Using the Miller theorem, Figure 4.0 can be simplified. This is shown in Figure 5.0.
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

$$C_2 = C \quad ' C_{\quad d} \quad (11)$$

R_I

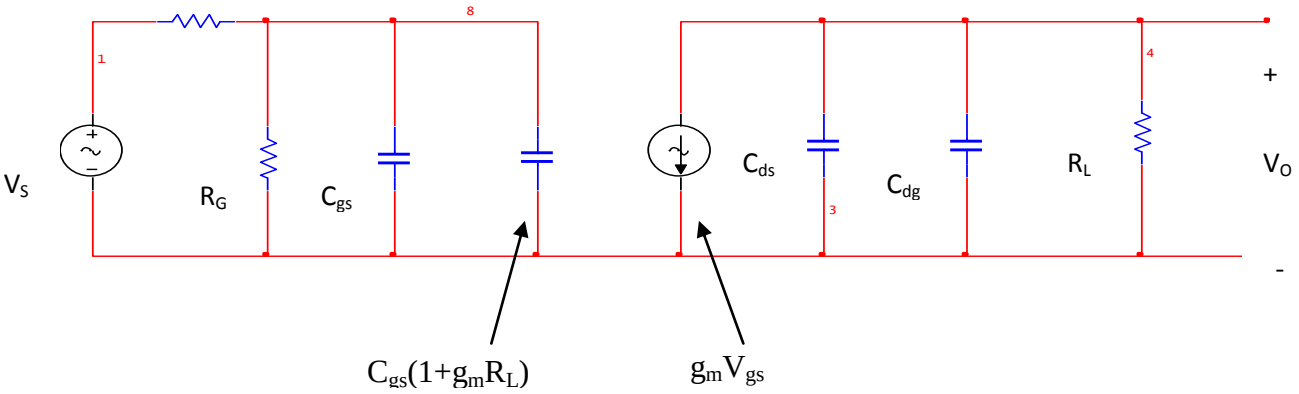


Fig. 5.0: Simplified high frequency equivalent circuit for common source amplifier

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_V and a $-3dB$ bandwidth ω_A. Let's consider that the multistage amplifier is formed from a cascade of *n* identical stages, each with a single pole response [7].

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

Where A_V is the DC gain and ω_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

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

And $A_V = A_v^n$

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

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

Thus

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

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

where

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

The above relation shows that the bandwidth of the multistage amplifier ω_A will be less than the bandwidth of the individual stages ω_B.

In general a cascade of *n* identical gain stages, each having a bandwidth ω_B, exhibits an overall bandwidth ω_A

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

where *m* is equal to 2 for first-order stages and 4 for second order stages. The gain A_V and bandwidth ω_B of each stage can be written in terms of the overall gain A_V and bandwidth ω_A as

$$A_V = (A_V)^{\frac{1}{n}} \qquad (21)$$

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

An amplifier normally operates with signal frequencies between lower cut off frequency (f_1) and upper cut off frequency (f_2). If the signal frequency drops below f_1, the gain and thus the output signal level drops at 20dB/decade until the next critical frequency is reached. The same occurs when the signal frequency goes above f_2. The range (band) of frequencies lying between f_1 and f_2 is defined as the bandwidth of the amplifier, only the dominant critical frequencies appear in the response curve because they determine the bandwidth. Figure 6.0 below shows a typical amplifier frequency response.

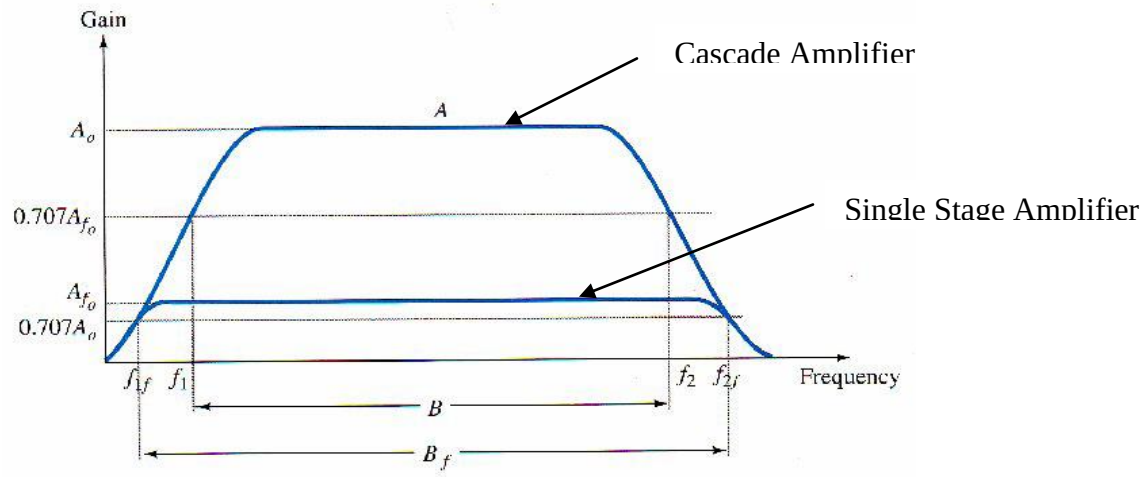


Fig. 6.0: The frequency response

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 gain begins to drop off. Two frequencies of interest, f_1 and f_2, are identified as the lower and upper cut off frequencies [8].
The amplifier's bandwidth is expressed in units of hertz as [8]:

$$BW = f_2 - f_1 \quad (23)$$

Method and Materials

In this research, a computer simulation using electronic software called MultiSim 8.0 was used. 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 reasonable value of 10V and the gate to source voltage (V_{GS}) was increased in small steps of -2.5, -2.0, -1.5, -1.0, -0.5 and 0V. The corresponding values of drain current (I_D) was recorded for each step. A similar procedure was used for different values of V_{DS} = 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 7.0. 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} = -1.5, -1.0, and -0.5V. 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 8.0.

From figures 7.0 and 8.0, the values of V_P , I_D , V_{DD} , V_{DS} ,V_{GS} were obtained at the quiescent points. The drain current in the pinch off region depends upon the gate to source voltage and is given by the relation [9]:

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

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

The bias lines satisfy the equations [10]:

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

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

and

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

Equation (27) 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, there is need to make these resistor values as high as possible with values in the order of $1\ to\ 10M\Omega$ being common [11].

The drain to source voltage of the output can be determined by applying Kirchhoff's law as follows [12]:

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

and

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

To calculate the value of coupling capacitor C_1 or bypass capacitor C_S, the standard formulas to be used are [13]:

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

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 for the design of single stage 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, the input voltage V_{in} and the output voltage V_o, were observed and recorded. At fixed input voltage of $40mV$, the frequency was increased step – wise to 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 [14]:

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

The data obtained were used to plot a graph of gain (dB) versus frequency (Hz) as shown in Figure 9.0. Origin 50 Software was used to plot the graph. In order to obtain the bandwidth, a screen reader from the menu of the origin to read values of lower cut-off frequency and upper cut-off frequency was used. The bandwidth is obtained as upper cut-off frequency minus the lower cut-off frequency. The same procedure was used for the two, three and four stage amplifiers. The input voltage ($40mV$) was constant at all frequency settings.

Results and Discussions

From this research some measured parameters and graphs were presented below**.**

Characteristics Curves

Figures 7.0 and 8.0 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. Table 1.0 is a summary of the various quantities used in the design and their values.

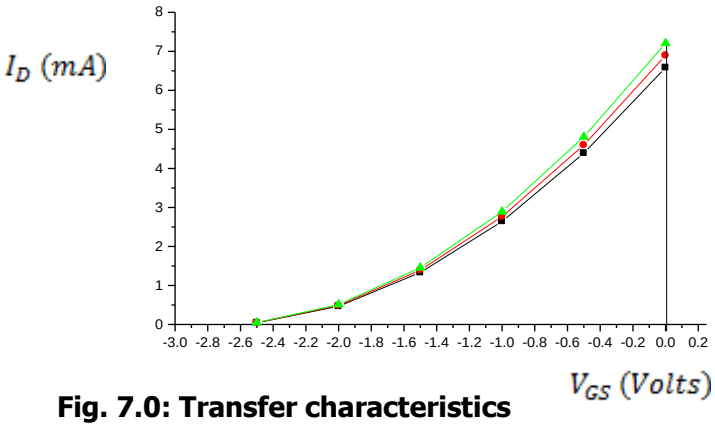


Fig. 7.0: Transfer characteristics

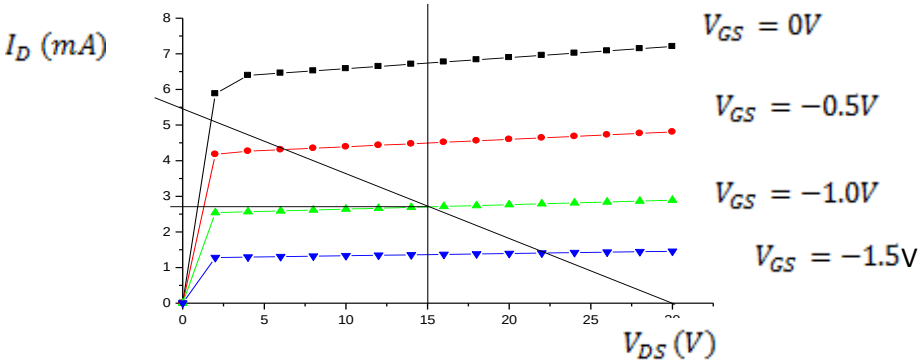


Fig. 8.0: Drain characteristics

Table 1.0: Calculated Parameters

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	370Ω
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 9.0 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, levels off for further increases in frequency, and then begins to drop at high frequencies. Response to a small signal - 100 Hz, and large signal -1GHz sine waves are shown in Figures 10 and 11 respectively.

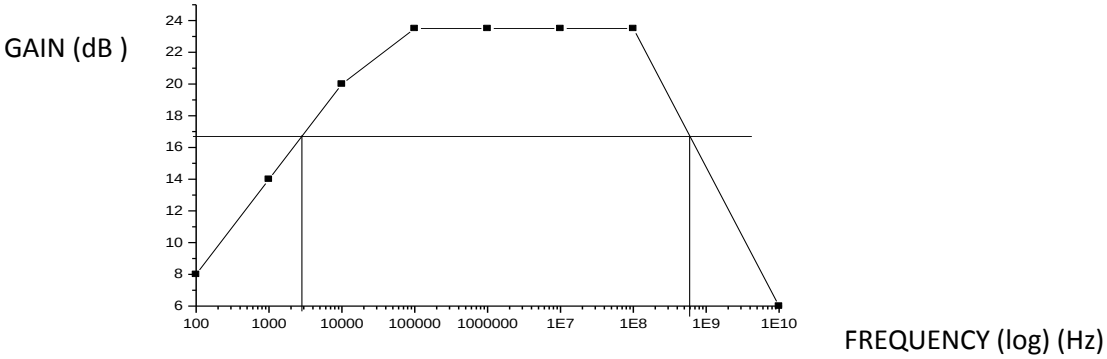


Fig 9.0: Graph of Gain (dB) versus Frequency (Hz) for Single-Stage CS Amplifier

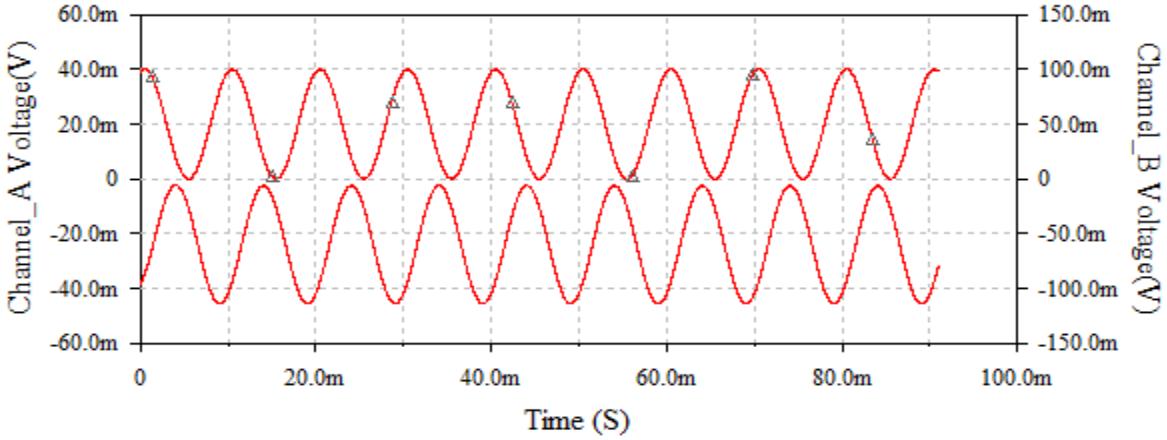


Fig 10: Single Stage JFT common source amplifier Response to a Small Signal-100Hz.

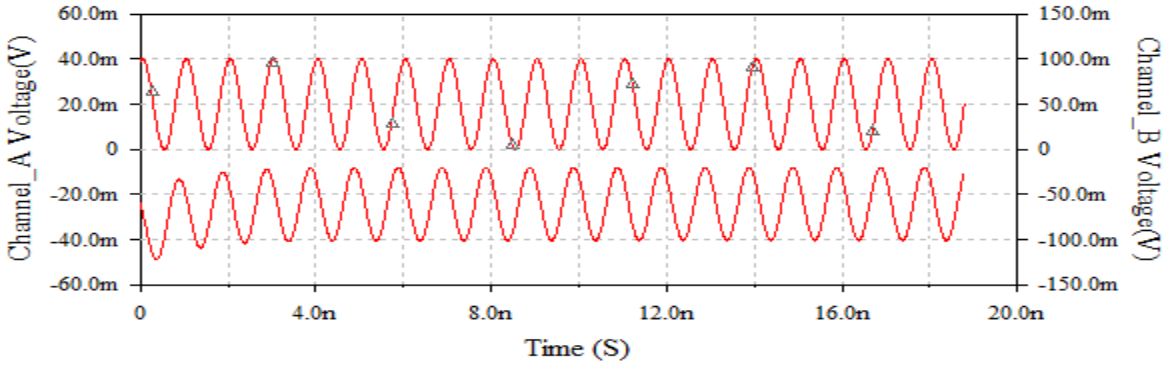


Fig. 11: Single stage JFT common source amplifier Response to a large Signal–1GHz.

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.

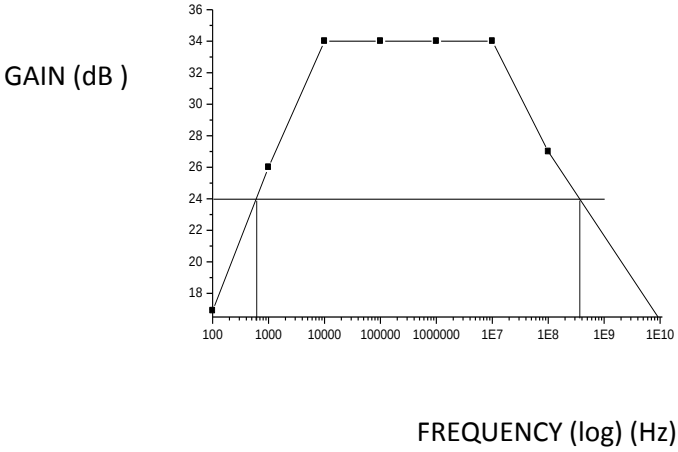


Fig. 12: Graph of Gain (dB) versus Frequency (Hz) for Two-stage CS Amplifier

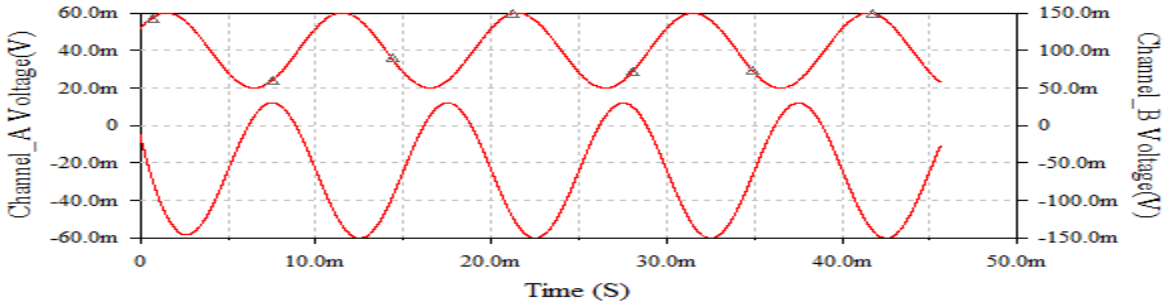


Fig. 13: Two Stage JFT common source amplifier Response to a Small Signal-100 Hz.

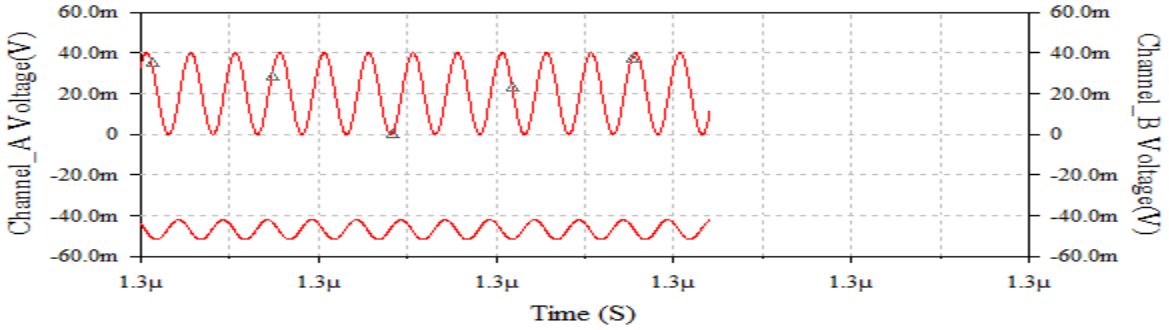


Fig. 14: Two Stage JFT common source amplifier Response to a Large Signal -1 GHz.

Three-Stage Common Source Amplifier

The graph in Figure 15 shows the gain versus frequency for a three-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.

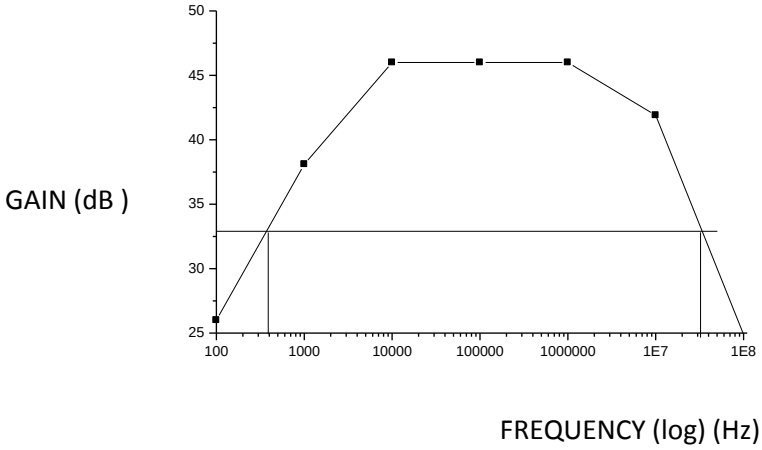


Fig. 15: Graph of Gain (dB) versus Frequency (Hz) for Three-Stage CS Amplifier

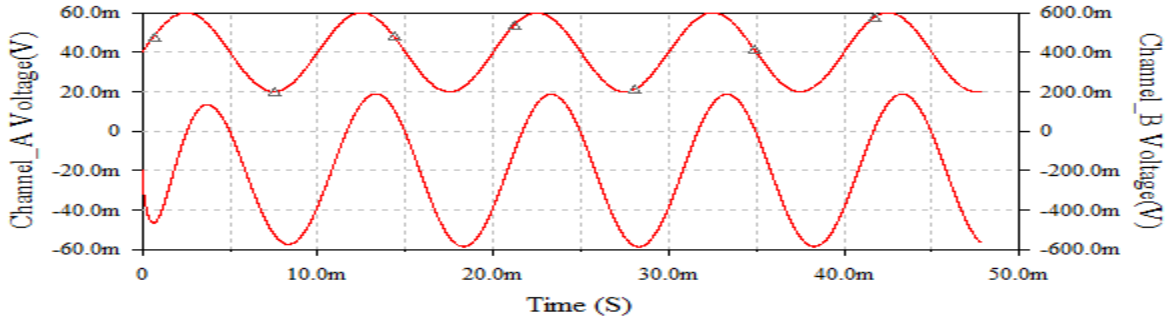


Fig. 16: Three Stage JFT common source amplifier Response to a Large Signal-100Hz

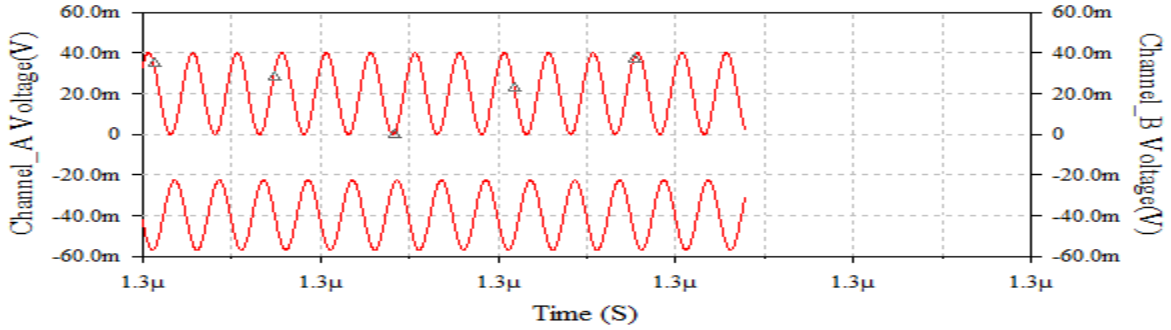
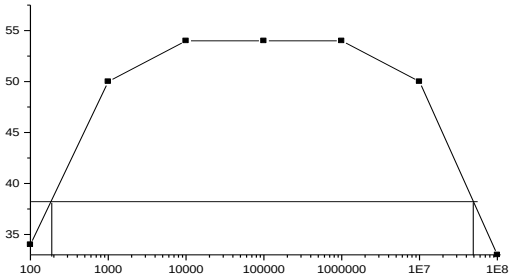


Fig. 17: Three Stage JFT common source amplifier Response to a Large Signal-1GHz

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.

GAIN (dB)



FREQUENCY (log) (Hz)

Fig. 18. Graph of Gain(dB) versus Frequency (Hz) for Four-Stage CS Amplifier

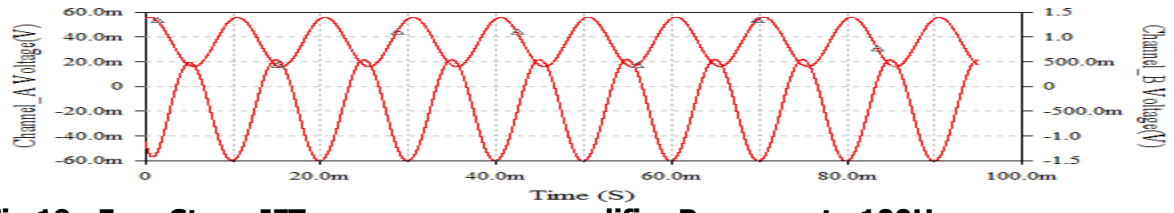


Fig 19: Four Stage JFT common source amplifier Response to 100Hz.

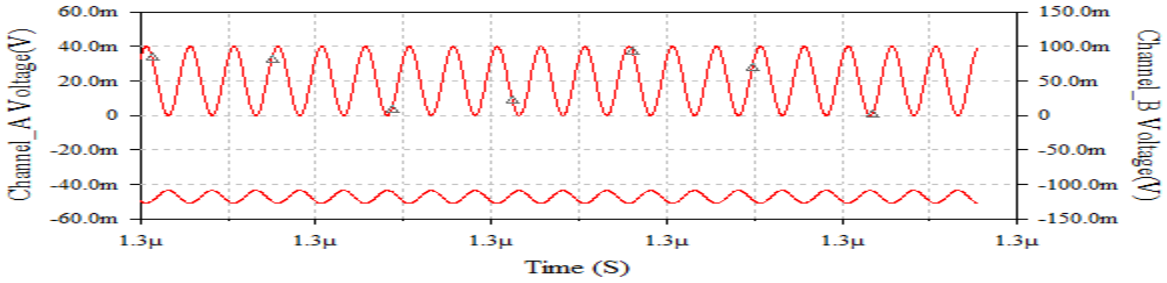


Fig. 20: Four Stage JFT common source amplifier Response to 100MHz.

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, investigation of the effects of cascading on a high gain broadband amplifier implemented with cascaded amplifier configurations for gain enhancement and bandwidth shrinkage is presented. In a nutshell, by way of simulation using multiSIM8 Electronics Workbench and calculation using load line analysis and relevant equations, the design of single stage common source amplifier, two-stage cascaded common source amplifier, three-stage cascaded common source amplifier and four-stage cascaded common source amplifier and studied the variation of their output voltage, with respect to frequency at constant input voltage of 40mV were achieved. The effects of cascading on gain and bandwidth were also realised. Study has shown 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.

References

htt://en.wikipedia.org/wiki/multistage_amplifier 14/05/2012

http://www.mhhe.com/engcs/electrical/neamen01/ch06.pdf 01/06/2012

Stephen, W. F. & Dale, R. (2008). *Electricity and electronics fundamentals.* 700 Indian Trail: Fairmont Press Inc. Pp.155-156

Stan, W. A. & Mike, R. J. (2000). *Principles of transistor circuits.* London: Clays Ltd Ives plc, 84-85pp http://www.eng.mu.edu/jacobyf/eece142/JFET_SSA_Design.pdf 23/09/2011.

Attia, J. O. (1999). Transistor circuits: *Electronics and circuit analysis using MATLAB.* Ed. John Okyere Attia Boca Raton: CRC Press LLC.

Qaiser, N. (2011). *Design of a wideband variable gain amplifier*. Unpublished M.Sc Thesis, Aalto University, School of Electrical Engineering pg 15-16 http://Lec%5C BJT_Amp_freq_resp.pdf (05/04/2009)

Sedha, R. S. (2005). *A textbook of applied electronics.* Nagar New Delhi: S. Chand & Company Ltd. Pp253-257.

Millman, J. & Halkias, C. (2004). *Integrated electronics, analog & digital circuits and systems.* New Delhi: Tata MCGraw-Hill Publishing Company Ltd. Pp. 337-338pp

(http://www.scribd.com/doc/23913837/4/COMMON-SOURCE-AMPLIFIER 07/03/2012

Boylested, R. L., Lous, N. & Kishore, K. L. (2006). *Electronic devices and circuit theory.* India: Dorling Kindersley PVT Ltd. pg387 http://sound.westhost.com/valves/preamps.html 09/02/2012

http://www.engga.uwo.ca/people/adounavis/courses/ece241b/labs/lab6.pdf 27/09/2011