

# A Design Implementation of Single Stage Amplifiers using HEMT Technology

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**Abstract** - The capacity of Si-CMOS scaling down to deliver improved performance has recently come into interrogation. The transfer properties of definite III-V compound semiconductors make HEMT to work smart for high frequency. HEMTs operation has been verified using several materials, especially AlGaAs/GaAs and AlGaN/GaN. This paper provides a CS amplifier and a source follower design tuned to 100GHz with three different substrate materials.

**Key Words:** CMOS; HEMT, CS Amplifier, source follower, GaAs, GaN, Gain.

## 1. INTRODUCTION

Semiconductor industry is based on the silicon material from the time of its innovation. It is the material chosen when compared to germanium because of its advantages of being easily available in nature and less expensive. Silicon dioxide grown is a very good insulator which shrinks processing complexity. This oxide is also soluble in water. These features supports in fabricating MOSFETs [1]. The revolution which took place in microelectronics has been described by "miniaturized is superior". Accordingly the present-day progress is rigorous in dropping the device size, in order to consume low power and to work with extraordinary performance and swiftness. The scaling capacity of Si CMOS to get down the transistor size although providing an enriched performance has recently come into query [2]. The scaling of transistor demands to reduce operating voltage. For last few generations, in order to achieve enhancement in performance, the operative voltage is brought down to 1V. This margin of practical voltage poses a severe warning to further development.

Far-out a new material with a much higher carrier velocity was familiarized which allowed further scaling in voltage, with continuity in enhanced performance. A favorable material which helped in scaling is III-V compound semiconductors. III-Vs semiconductors are recognized for their distinctive nature of working for high frequencies. Integrated circuits on the basis of compound semiconductors such as gallium- arsenide (GaAs), gallium-Nitride (GaN) or Silicon Germanium (SiGe) can be used up to the GHz ranges.

This paper is arranged as follows; in section II, the type's heterostructure are discussed. Section III, details about HEMT construction along with the energy band diagram when two different materials are placed in contact. Section IV presents analysis i carried out for CS amplifier, Source follower using HEMT. Finally, the Conclusion along with the references is reflected respectively.

## 2. HETEROSTRUCTURE PHYSICS

The heterostructure progress offered the prospect for incredible evolution in the performance of microwave transistors. A two or more different semiconductor materials grown on one another is commonly referred as heterostructure.[3] MOCVD or MBE epitaxial techniques are normally used to grow the heterostructure. The Fig-1 shown below details about three different types of heterostructure consisting of two different materials.

The energy bandgap are diverse i.e. conduction band and valence band boundaries are discontinuous at the heterointerface. The energy gaps between two band edges at the interface are called offsets  $\Delta E_c$  and  $\Delta E_v$ . Fig-1.(a) is the most shared. In this heterostructure, the sum of both band edge discontinuities is the same as the energy bandgap difference  $\Delta E_g$ . In type II structure shown in Fig-1.(b), the discontinuities have unlike signs. The discontinuity is the difference between the two band edges. In type III heterostructure focused in Fig-1. (c), the band structure is such that the top of the valence band in one material lies directly above the conduction band bottom of the other substantial [4].

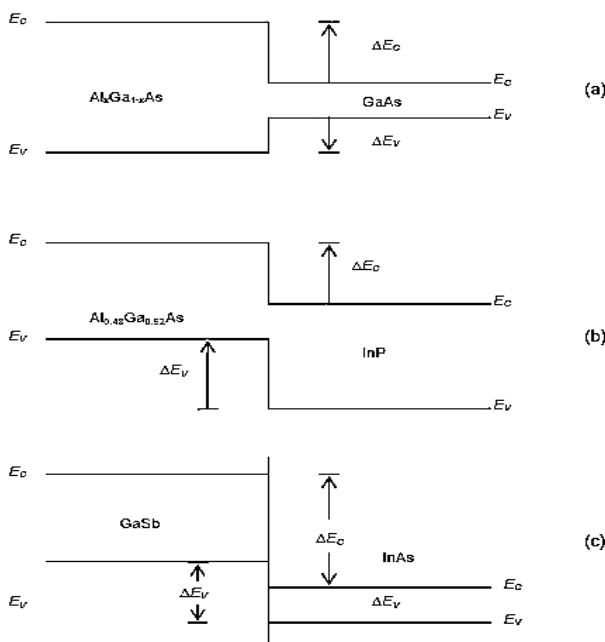


Fig -1: Categories of Heterostructure

### 3. HIGH ELECTRON MOBILITY TRANSISTOR [HEMT]

The HEMT is a heterostructure field effective device. This device gains an advantage of the larger transport properties of electrons i.e. high mobility and high carrier velocity [5]. The Fig-2 exposed is a cross sectional view of HEMT structure. The variance in conduction band energies of two materials produces a quantum well on one side of the heterojunction. Due to which the electrons concentrate and form a two dimensional electron gas (2DEG). Similar to MESFET, the three terminals namely, source, gate and drain are arranged on the surface of the semiconductor structure to have the connection.

The HEMT structure differs significantly from MESFET structure in terms of semiconductor layers. The AlGaAs has a longer band gap than GaAs, making it superior to GaAs. To fix the strain problem, the AlGaAs is grown to just below its thickness limit and a thin layer of GaAs is full-sized on top. The GaAs relieves the strain and allows another layer of AlGaAs to be developed.[6] For the HEMT structure, the width of both the n-type AlGaAs and the undoped AlGaAs spacer layer are critical in determining the device behavior.

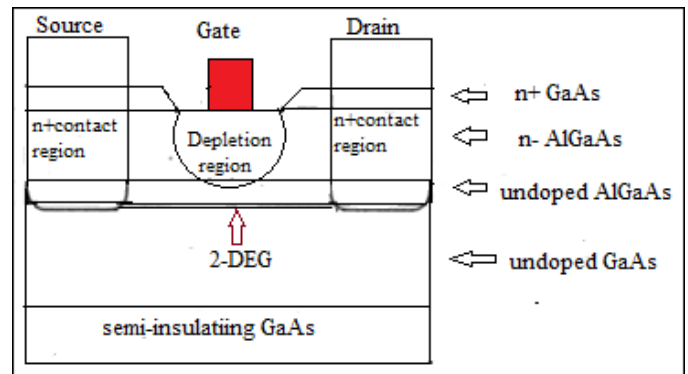


Fig -2: A cross-sectional view of HEMT device.

When the two different semiconducting materials i.e., AlGaAs/GaAs or AlGaN/GaN is placed in contact, in order to align the Fermi level, the electrons are transferred from the AlGaAs layer having wider bandgap into the GaAs of narrow bandgap.[7] The electrons tend to occupy the lowest energy state. The energy band plan of the HEMT device is presented in Fig-3.

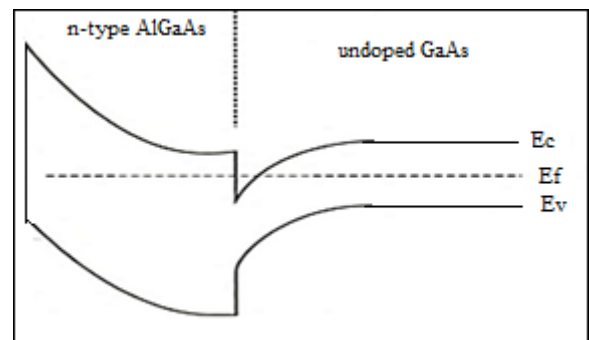


Fig -3: Energy band diagram of the conventional HEMT device

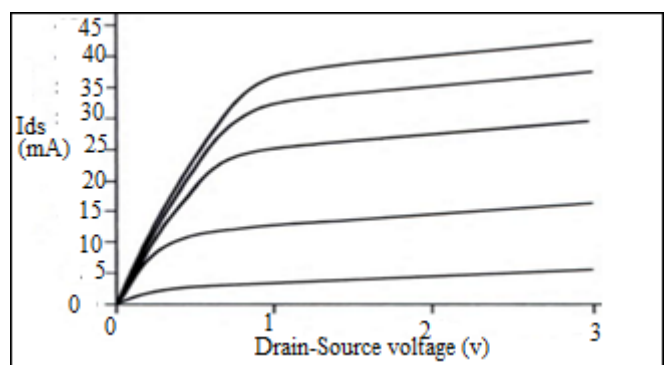


Fig -4: I-V characteristics of HEMT

The current- voltage characteristic of HEMT is presented in the Fig -4. The characteristic are similar to those of MESFET devices. The HEMT a main device for high speed, higher frequency operation [8]

## 4. PROPOSED DESIGN WITH MATERIAL COMPARISON

### 4.1 Si [Silicon] :

The single stage RF- Common source amplifier using Si-CMOS is designed in order to verify the operation of the device. The schematic representation and transient analysis of a CS Amplifier is shown in Fig -5 and Fig - 5.1.This amplifier is tuned to 100GHz using tuning circuit. The gain of CS amplifier drops to -9.35dB as presented in gain curve Fig- 5.2.

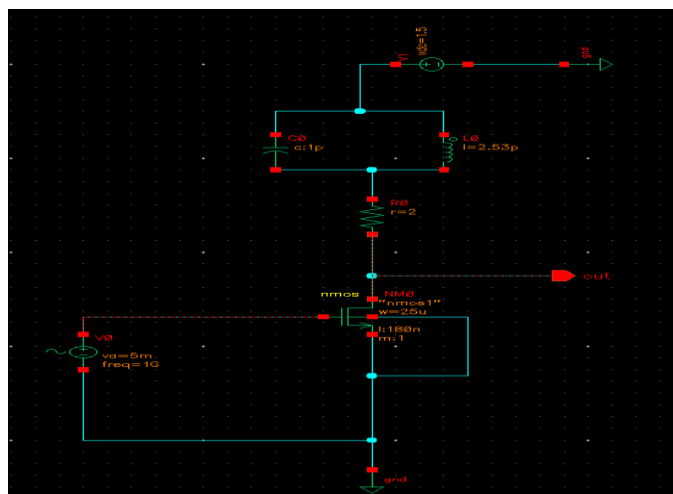


Fig -5. CS amplifier using Si

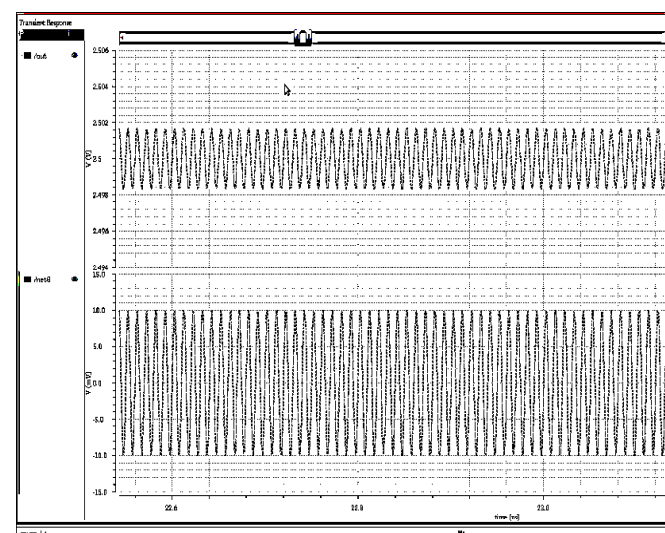


Fig-5.1. Transient response of CS amplifier

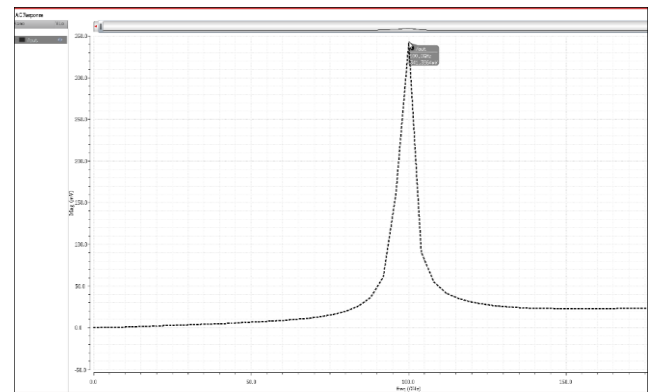


Fig -5.2. The AC response of CS amplifier showing -9.35db

The source follower also known as common drain amplifier, the input signal is fed at the gate as in case of CS amplifier but the output is noticed at the source terminal. The schematic representation of common drain amplifier using Si is shown in Fig -6.the gain curve of the source follower is displayed in Fig -6.1. The silicon transistor works as a source follower at low frequencies when compared to CS amplifier i.e. up to 10GHz.

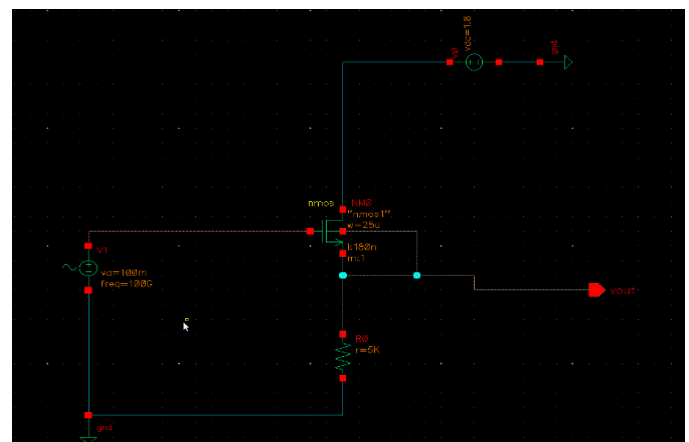


Fig -6. Schematic view of source follower using Si

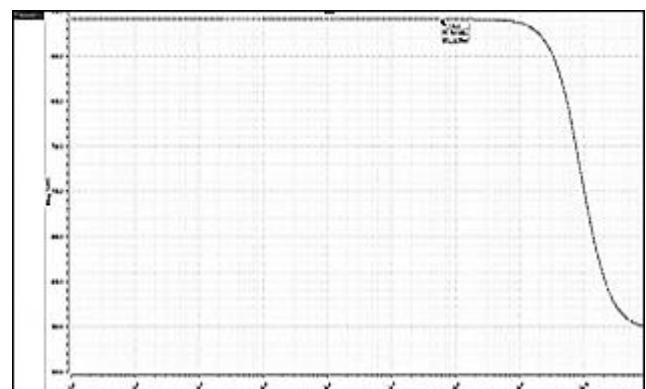


Fig - 6.1. AC response of source follower amplifier

#### 4.2 GaAs [gallium Arsenide]:

The GaAs HEMT- CS amplifier designed in Fig-7 is tuned to 100GHz. The gain remains high and is equal to 44.17dB as shown in the gain curve Fig -7.1. The transient analysis is shown in Fig -7.2. It is noticed that the output signal is slightly distorted with respect to the input signal. The GaAs HEMT common drain amplifier presented in figure8 works at high frequencies in the order of Tera hertz. The gain curve is shown in Fig -8.1

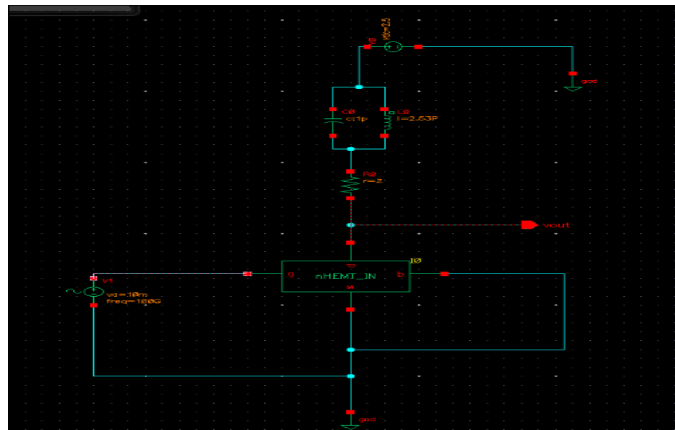


Fig - 7: CS amplifier using GaAs

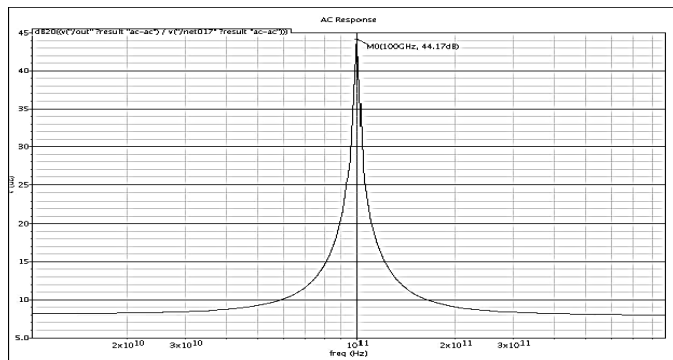


Fig -7.1. AC response presenting 44.17dB

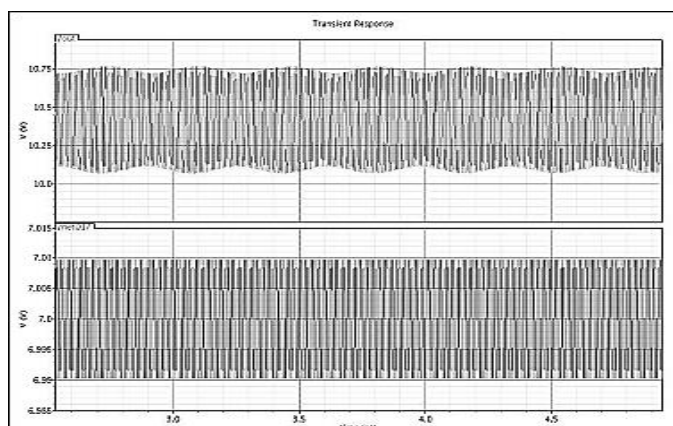


Fig - 7.2 Transient response of CS amplifier using GaAs

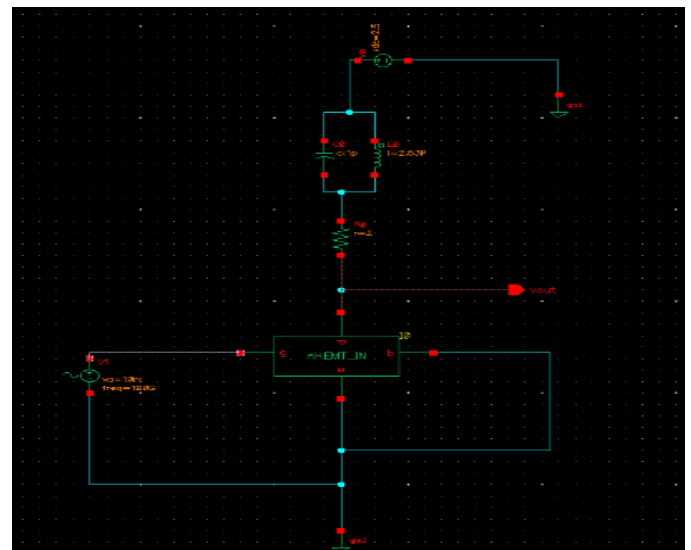


Fig - 8.Source follower using GaAs

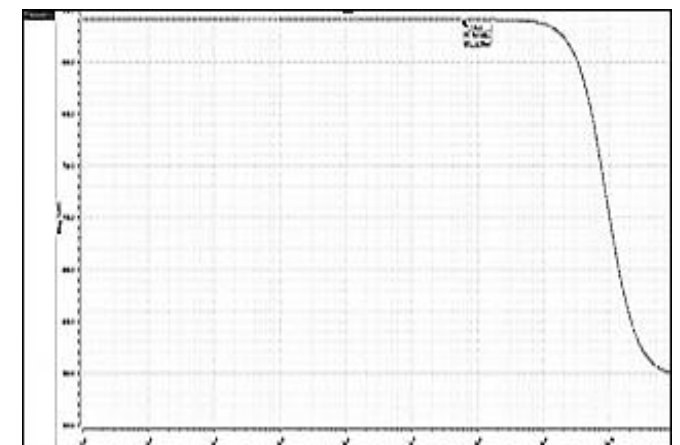


Fig - 8.1. Gain curve of source follower

#### 4.3 GaN [gallium nitride]:

The GaN HEMT CS amplifier works at very high frequencies in order of Tera Hertz. The gain is minimized to 16.64dB when compared to GaAs HEMT CS amplifier, but the output is a faithful reproduction of the input signal. The schematic representation of CS Amplifier using GaN and common drain amplifier is displayed in Fig -9 and Fig -10. The source follower using GaN HEMT behaves in a similar way as described for GaAs HEMT Source follower. The transient analysis of CS amplifier is shown in Fig -9.1. The gain curves for both CS amplifier and CD amplifier us shown below in Fig -9.2 and 10.1.

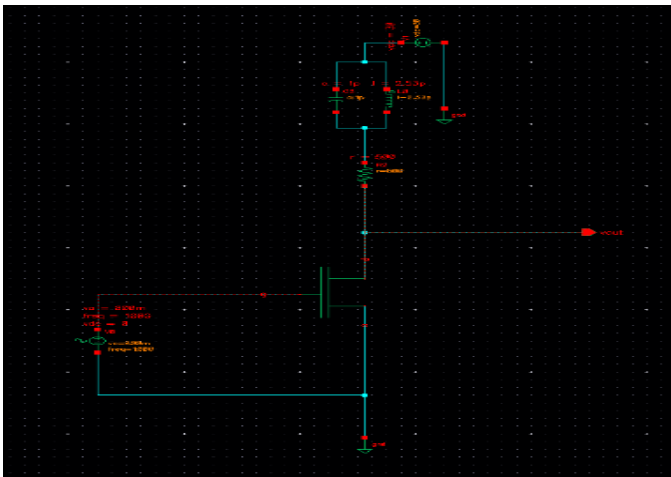


Fig - 9. CS amplifier using GaN

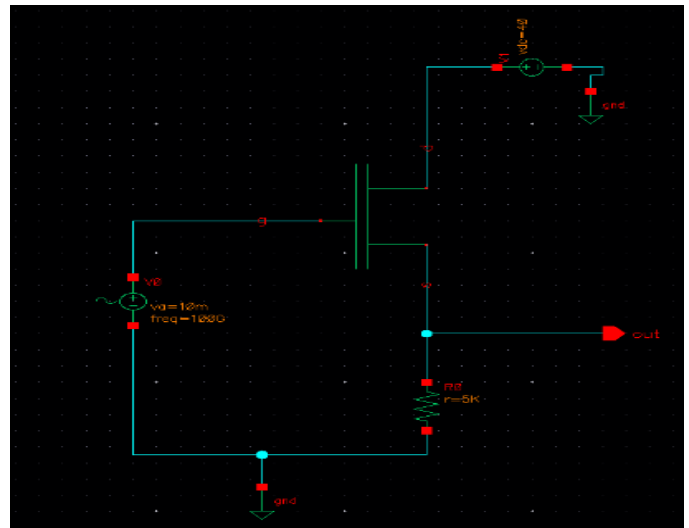


Fig -10 Source follower using Gallium Nitride

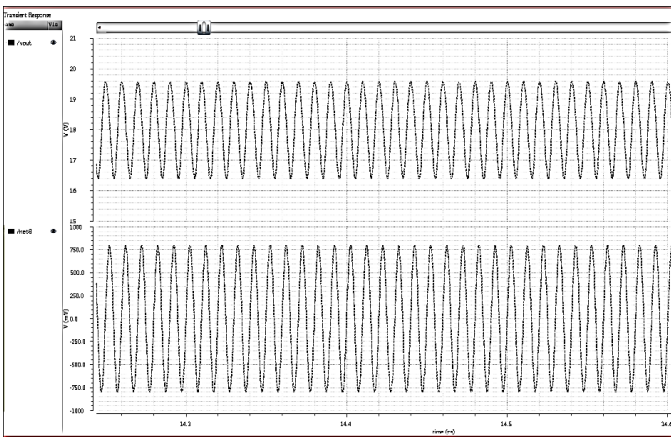


Fig -9.1 Transient response of CS amplifier

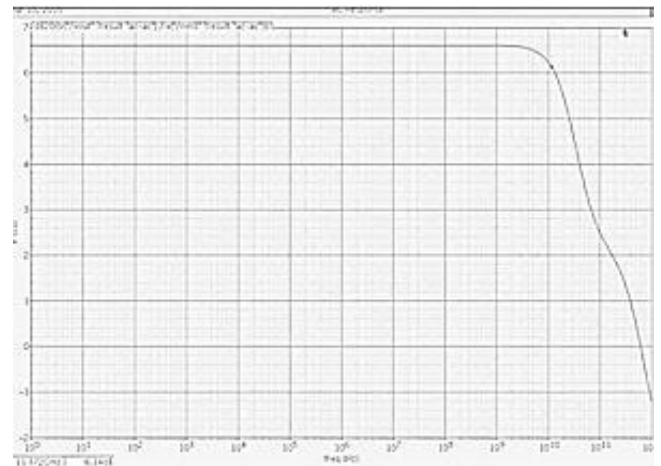


Fig -10.1 AC response of source follower using GaN

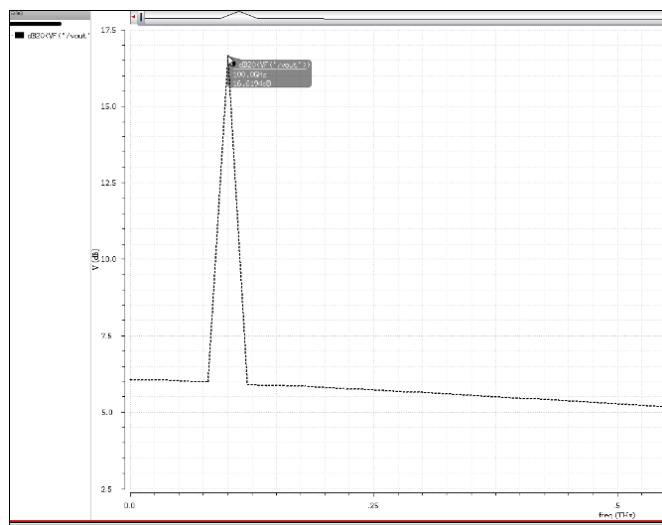


Fig -9.2 Ac response of CS amplifier with gain of 16.64dB

Table -1: comparison of parameters obtained for the proposed CS amplifier using CMOS & HEMT

| Parameters          | CMOS    | HEMT     |         |
|---------------------|---------|----------|---------|
|                     | Si      | GaN      | GaAs    |
| Operating Frequency | 100GHz  | 100GHz   | 100GHz  |
| Supply Voltage      | 1.8V    | 30V      | 30V     |
| Gain                | -9.35dB | 16.64 dB | 44.17dB |

## 5. CONCLUSIONS

The knowledge on HEMT device and the heterostructure physics provides the main idea in the analysis of the design. The operation of AlGaAs/GaAs HEMT device along with the energy band diagram is explained. With the satisfactory literature study and the thorough knowledge on HEMT, CS amplifier and source follower are constructed using Si, GaAs and GaN n-HEMT devices. CS amplifier using HEMT shows improved gain when compared to CMOS RF amplifier. With the comparison of the three materials it is noticed that GaN provides a better performance.

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