Design A Darlington Amplifier with Improved Gain and Slew Rate

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Abstract
In current trend of technology enhancement, the demand for Darlington pair amplifier for high data rate communication system has been considered as of paramount importance. The use of Darlington pair amplifier has been suggested in a condition, where requirement of high gain at a low frequency is applicable. Recently, Darlington pair amplifier has been testified with high gain bandwidth product for current applications. This paper presents a slew rate enhancement technique for Darlington pair amplifier. A three stage Darlington amplifier with proposed improvement are designed and implemented on 180nm technology. A slew rate booster circuit is connected to a three stage Darlington pair amplifier. The designed circuit is applicable in Wireless Sensor Network (WSN). After applying slew rate booster, the gain becomes 26 dB and the positive slew rate is recorded at 28.4 µV/S and negative slew rate is recorded at -28.4µV/S. Therefore, this paper highlights the use of slew rate enhancement technique to improve the gain of Darlington pair amplifier.

Keywords
Broadband Darlington Amplifier, Circuit, Gain Enhancement, Multi-stage Amplifier, Slew Rate Booster, Transistor

I. Introduction
With reference to some applications, during switching on a transistor, the output of input current available has been found to be very low. Thus, it may be observed that a single transistor is unable to pass sufficient current essential by the load. In recent, the transistor gain has beenrecommended to get enhanced, if it's not possible to increase the input current. Such achievement in transistor can be done by using a Darlington pair amplifier only[1-10].

Load current= Input current X Transistor gain

Darlington pair amplifier may be defined as the transistor in which two transistors are kept inside a single packet and whole configuration has high gain and high input impedance [10-30]. The emitter of the first transistor is coupled to the base of second transistor in such a way that second transistor amplifies the signal which is already amplified by the first transistors and collectors are common[5-10, 30-34].

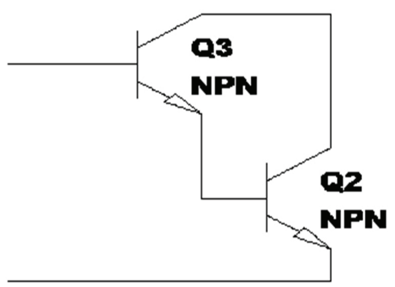

Fig. 1: Basic Circuit of Darlington Pair Amplifier

Fig. 1 shows the basic circuit of single stage Darlington pair amplifier.

$$\beta_D = \beta_{Q1} \cdot \beta_{Q2} \quad (1)$$

β_D = current gain of whole unit.
β_{Q1} = current gain of first transistor.
β_{Q2} = current gain of second transistor

Above equation shows that gain Darlington pair amplifier is just double or we can say that product of gain of two transistors. The voltage required to switch on a Darlington pair amplifier is two times compared to one transistors, reason is that there are two base emitter junctions. In this case second transistor should be capable to handle high level of current [10-20]. Darlington pair amplifier has larger phase shift at greater frequency compared to one transistor, which will stop the circuit and circuit become unstable if used in negative feedback [1].

A single transistor in the common source configuration is used as the transconductance stage in broadband amplifier. Other gain stages are cascade amplifier, emitter follower, and the cherry- Hooper amplifier. Darlington amplifier provides broad bandwidth performance up to microwave frequencies. So it is applicable in broadband amplifiers. So, Darlington pair amplifier is used in implementation of broadband amplifiers, distributed amplifiers, low noise amplifiers, trans-impedance amplifier, and power amplifier. A cascade amplifier with linearizing circuit and active self bias is used to improve bandwidth. Other circuit used to improve bandwidth is mirror doubler and inductive peaking technique. The three stage Darlington pair amplifier is designed to improve the Gain Bandwidth Product (GBW) of amplifier [1-10].

II. Techniques used in Darlington Pair Amplifier

A. Slew Rate Enhancement
The small variation of voltage per unit time is called as slew rate. Slew rate is well-defined as the change of voltage per unit time.

It is expressed as volts/seconds and the formula is presented as below:

$$SR > 2\pi f V_{pk} \quad (2)$$

f = operating frequency
V_{pk} = peak voltage
Additionally, small variation of voltage according to time is expressed as slew rate.

$$SR = \max([dv_{out}(t)/dt]) \quad (3)$$

Slew rate is used to calculate some parameters of amplifiers like amplitude and maximum input frequency, which helps to get enhanced output of amplifiers and possibly not the distorted one [25-34].

B. High Electron Mobility Transistor (HEMT)

It is a type of Field Effect Transistor (FET), which integrates junction in the middle of two material with not the same band gaps as the channel in its place of a duped region. A material arrangement used is GaAs with AlGaAs which depend on the applications. Device shows the better performance if it is incorporating with more indium. GaN-HEMT attracted because of high power performance. HEMT transistors are capable to operate at huger frequency compared to other transistors. Applications of HEMT are satellite receiver, low power amplifiers, cell phone etc. Advantages of HEMT are high gain, high speed, and low noise [1-9].

III. Applications of Darlington Pair Amplifier

Darlington amplifiers are basic building blocks of high speed communication system, imaging and wide band instrumentation. A single transistor in common source configuration is used as a transconductance stage in broad band amplifiers. A broad band Darlington pair amplifier plays an important role in both the transmitting andreceiving sites of communication systems. It provides excellent characteristics with high input impedance and low impedance. Darlington amplifier is used In Scientific and Medical (ISM) for Gigabyte per second wireless network solution, Wireless Sensor Network (WSN), point to point communication and short range automotive radars, wide band [1-15]

Present Darlington pair amplifier has disadvantages when operated at a large bandwidth and under large signal. It has been found that the bias current can increase or decrease with related to change in input power due to operation of transistor under a large signal. When transistors are under large signal conditions, it has been suggested that even number of order products can be generated within transistor. The DC bias condition related to power level is varied by DC component which is included in even order products. This disadvantage is removed in Darlington pair amplifier, which results in unacceptable big changes in the bias current.
The pair amplifier has disadvantage that it produces worst frequency response when amplifier is operated at higher frequency, although pair amplifier is used in applications of high speed just because of compact chip size and broadband performance of pair amplifier [15-30].

Because of the slew rate of amplifier in the single stage and directly related to bias current source, there is a report that power dissipation of the circuit can be increased. The main objective of the presentstudy focused on to increase the slew rate having low input power. At the same time, other parameters of the amplifier will be remaining constant. The main factor which is responsible for slew rate in amplifier is its internal architecture. Amplifiers are unable to lead nonlinear operation because of limited bandwidth and linear phenomenon [15]. An amplifieris connected in unity gain configuration. In case of limitation is found on its dynamic performance as thefinite amplifier bandwidth, then output would be expected from the follower [20-34].

Below is the equation of unity gain Amplifier and its transfer function.

$$Vo/Vt = 1/1+s/Wt \qquad (4)$$

Here, it shows the low pass STC response referenced over a time constant 1/Wt.

Hence, in the next step, the step response is presented as.

$$Vo\ (t) = V\ (1-e^{-wt}) \qquad (5)$$

Positive slew rate and negative slew rate have different value due to different arrangement of circuits of amplifier. Different arrangement of the pair amplifier has different slewing conditions [16]. For pull up and pull down amplifier should have outputs which are compliments with each other.I.e. the configuration does not have same at two sides [5-12].

III. Circuit Analysis

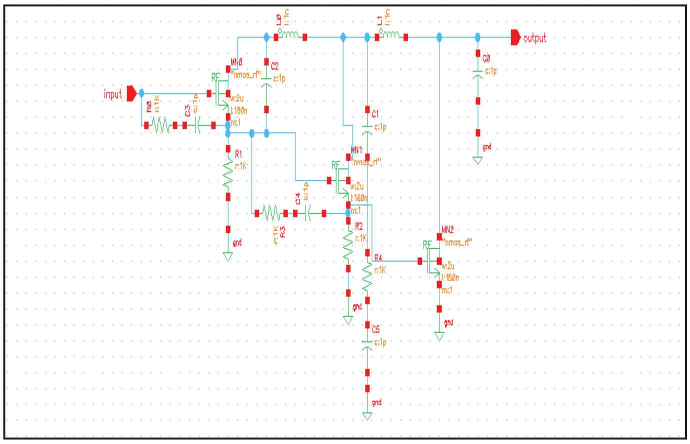

Fig. 3: Three Stage Darlington Pair Amplifier

Circuit diagram shows the three stage Darlington pair amplifier drawn at 180nm. The two inductances Lm1 and Lm2 separate the drain terminals of the transistors. Their values should be optimized to minimize the transconductance roll off with frequency. It is observed that the minimum roll-off of the transconductance is obtained when both inductances are used and all transistors have the same width. In this circuit diagram,when W2/W1 is increased, the bandwidth is increased in a condition that inductance is not used. On the other hand, in the presence of inductance, peak frequency is almost unchanged while gain variations in the frequency band are increased. The inductance should be optimized based on the width ratio of two transistors, parasitic capacitances, and the frequency band of interest [1-5].

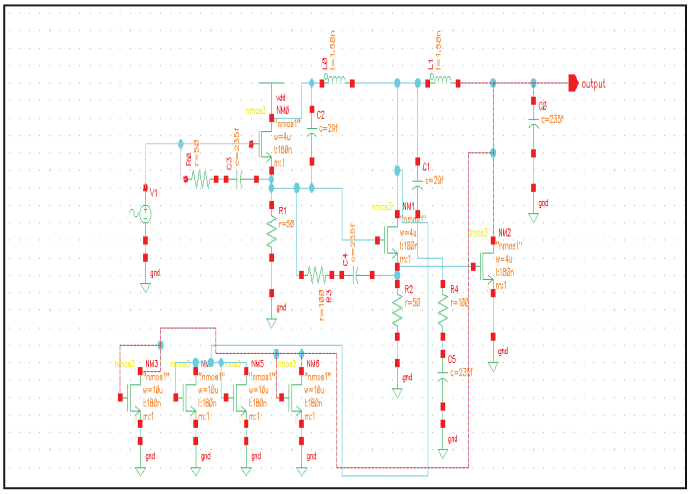

Fig. 4: Three Stage Darlington Amplifier Connected with Positive and Negative Slew Rate Booster.

In fig. 4, that triple Darlington pair amplifier is connected to positive slew rate booster and negative slew rate booster. Positive slew rate is defined as the slew rate when output is increasing with time. Negative slew rate is defined as the slew rate when output is decreasing with time. A negative sign should be there when it is decreasing. The slew rate when output voltage is increasing need not be the same as the decreasing slew rate[8-12].

IV. Result Analysis

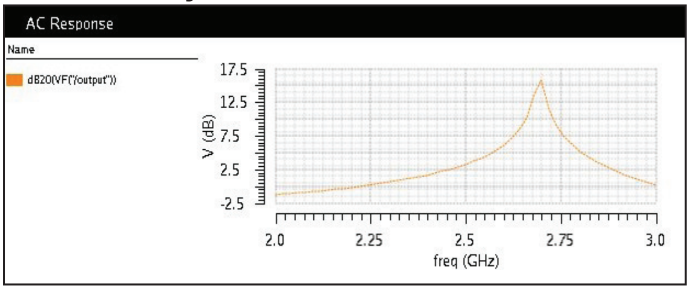

Fig. 5: AC Response of Triple Darlington Pair Amplifier

As shown in fig. 5, graph presents gain response of triple Darlington amplifier without slew rate booster. It shows that gain of the circuit is 15dB. This response is obtained by simulating the circuit diagram in fig. 3.

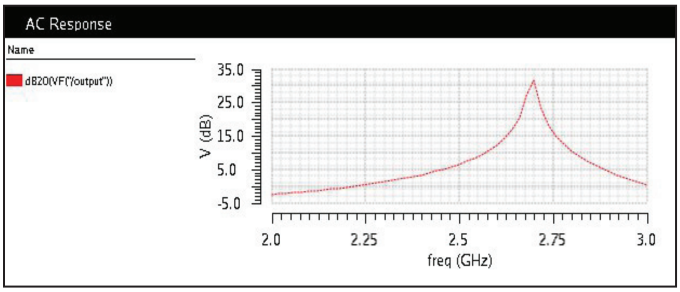

Fig. 6: AC Response of Triple Darlington Pair Amplifier With Slew Rate Booster

Above Fig. 6 shows the gain response of triple Darlington amplifier with positive and negative slew rate booster. It shows that gain of the circuit is 30dB. This response is obtained by simulating the circuit diagram in fig. 4.

V. Conclusion

Table. 1: Parameters Comparison With Slew Rate Booster and Without Slew Rate Booster

Parameter	Proposed Work Three Stage		Proposed Work With Slew Rate Booster	
Gain(dB)	15		30	
Bandwidth (GHZ)	0.9-27.4		1.9-26.7	
Slew Rate (μV/S)	Positive slew rate=8.1	Negative slew rate = -8.1	Positive slew rate= 28.4	Negative slew rate = - 28.4
Process	180nm GPDK		180nm GPDK	

From the analysis of data presented in Table 1, it is concluded that gain of three Darlington pair amplifier with slew rate booster is just double as compared to slew rate of Darlington without booster. The slew rate is also increased by using booster which is around more than 3 times. We can apply this design in wireless sensor network, high data rate communication system and optical fiber etc. Additionally, the bandwidth of the circuit is also increased by using slew rate booster circuit. Hence, these data suggest the use of slew rate technique for the improvement of gain and bandwidth of Darlington pair amplifier.

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