Qualitative and Tuning Performance of MOSFET Based Small-Signal Darlington pair Amplifiers

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Abstract: Two different circuit models of RC coupled small-signal amplifiers are developed using identical power MOSFETs in Darlington pair configuration. Proposed circuits successfully eliminate the poor frequency response problem of Darlington pair amplifiers at higher frequencies. An additional biasing resistance R_A, ranging from 1KΩ to 100KΩ, is to be essentially used in the proposed circuits to maintain their voltage/current amplification property. In presence of R_A, proposed amplifiers crop considerably high voltage gains, moderate range bandwidths and sufficiently high current gains in 1-10mV input signal range at 1 KHz frequency. Both the circuits can be tuned in specific audible frequency range, extending approximately from 130Hz to 55KHz. Tuning performance makes these amplifier circuits suitable to use in Radio and TV receivers. The qualitative and tuning performance offer a flexible application to these amplifiers to be used as high voltage gain, high power gain and tuned amplifiers. Variations in voltage gain as a function of frequency and different biasing resistances, temperature dependency of performance parameters, bandwidth and total harmonic distortion of the amplifiers are also perused to provide a wide spectrum to the qualitative studies.

Keywords: Small Signal amplifiers, Darlington amplifiers, MOSFET Amplifiers, MOSFETs in Darlington pair

I. Introduction

A Darlington pair contains two identical BJTs in CC-CE connection and its application range in day-to-day electronics is almost extended from small-signal amplifiers to power amplifier circuits [1]-[3]. Principally, with high input resistance, low output resistance and voltage gain just greater than unity, the current gain factor of Darlington pair (β_D) is treated as approximately equal to the product of current gains of the individual transistors ($\beta_D \approx \beta_{Q1} x \beta_{Q2}$)[1],[3]. However, as a major drawback, its frequency response exhibits poor response problem at higher frequencies [1]-[4]. A number of modifications in Darlington's composite unit or in respective amplifier circuits are suggested by researchers to conquer this problem [2]-[11]. These efforts include the use of devices different than BJTs or hybrid combination of devices (e.g. BJT-JFET or BJT-MOSFET etc.) in Darlington's topology and, moreover, using some additional biasing components in respective amplifier circuit [7]-[11].

Though the MOSFETs are frequently used to configure high speed switching circuits in present day electronics, but Common Source MOSFET amplifiers with high input impedance, low output impedance, high current gain and significant voltage gain (greater than unity) had already proved its authenticity to process small-signals [1], [8]-[9]. The present investigation is focused around a Darlington pair which uses two identical MOSFETs (IRF 150 connected in CD-CS configuration) in its composite unit. This pair with appropriate biasing components is explored to develop two different circuit models of small-signal amplifiers suitable to use in radio and TV receiver stages.

II. Experimental Circuits

The present exploration discusses the qualitative and tuning performance of two MOSFET based Darlington pair amplifier circuits which are respectively depicted in Fig.1 and Fig.2. An additional biasing resistance R_A [6]-[9] is introduced in the proposed circuits to maintain their voltage/current amplification properties in the present context. Position of bypass capacitor is also changed in the 'Proposed amplifier-2' (Fig.2).

Amplifier circuits under discussion use potential divider biasing methodology [4],[6]-[7]. Values of passive biasing components are so selected to provide proper DC biasing to the respective circuits. Component details of the respective amplifier circuits are summarized in TABLE I.

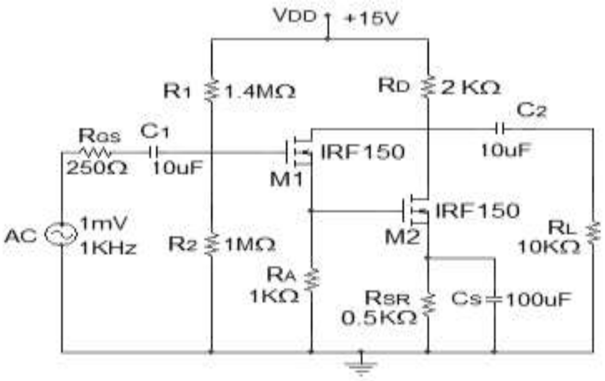

Fig.1. Proposed Amplifier-1

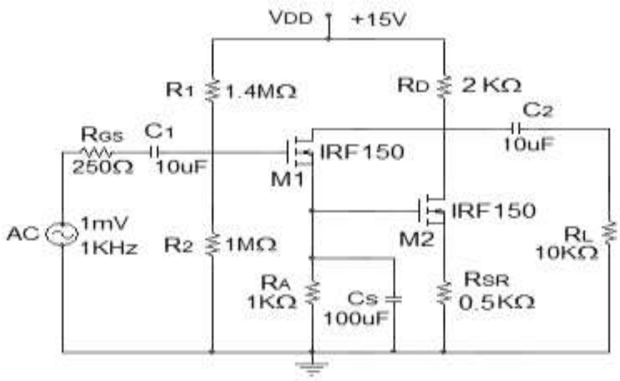

Fig.2. Proposed Amplifier-2

PSpice simulation (Student version 9.2) is performed to carry out present investigations [12]. Observations are procured by feeding the amplifier circuits with 1V AC input signal source, from which, a small-distortion-less AC signal of 1mV at 1KHz frequency is drawn as input for amplification purpose.

TABLE I
COMPONENT DETAILS OF THE CIRCUITS UNDER DISCUSSION

COMPONENTS	DESCRIPTION	Proposed Amplifier-1 and Proposed Amplifier-2
M1	N-Channel MOSFET (V_{TH}=2.831)	IRF150
M2	N-Channel MOSFET (V_{TH}=2.831)	IRF150
R_{GS}	Gate-Source Resistance	250Ω
R_1	Biasing Resistance	1.4MΩ
R_2	Biasing Resistance	1MΩ
R_D	Drain Biasing Resistance	2KΩ
R_{SR}	Source Biasing Resistance	0.5KΩ
R_A	Added Biasing Resistance	1KΩ
R_L	Load Resistance	10KΩ
C1	Coupling Capacitors	10 μF
C2	Coupling Capacitors	10 μF
C_S	Source/Emitter By-pass Capacitor	100μF
Biasing Supply	DC Biasing Supply	+15V DC
AC Signal	Input AC Signal range for distortion-less output at 1KHz input frequency	1-10mV (1KHz)

III. OBSRVATIONS AND DISCUSSIONS

A. Qualitative Performance

Proposed amplifiers of Fig.1 and Fig.2 are found to provide fair and distortion-less results for 1-10mV AC input signals respectively at 1 KHz input frequency at +15V DC biasing voltage. Amplifier of Fig.1 produces 132.743 maximum voltage gain (peak output voltage 132.841mV), 7.764K maximum current gain (peak output current 13.284μA) and 48.494 KHz bandwidth (lower cut-off frequency f_L=129.217Hz and upper cut-off frequency f_H=48.624 KHz). However, the amplifier of Fig.2 produces 239.487 maximum voltage gain (peak output voltage 235.153 mV), 13.943K maximum current gain (peak output current 23.53μA) and 61.493KHz bandwidth (f_L=231.325Hz and f_H=61.725KHz). Thus, the changed position of bypass capacitor in the circuit of Fig.2 results in an enhanced voltage and current gain with enlarged bandwidth.

Total Harmonic Distortion (THD) percentage is also calculated for 10 significant harmonic terms using established rules [1],[11],[13]. It is found that the Proposed amplifier-1 shows 1.205% THD whereas the Proposed amplifier-2 shows 1.817% THD. THDs of both the amplifiers can be significantly reduced by increasing load resistance R_L; but this simultaneously reduces the voltage and current gains of the respective amplifiers.

Both the amplifiers of Fig.1 and Fig.2 invert phase of voltage or current in amplification mode [1]-[9],[11]. In fact, MOSFETs in paired unit of proposed amplifiers hold CD-CS configuration [14]. Independently, a CD configuration do not show any phase shift between applied input and amplified output signals whereas CS configuration produces an amplified output having 180^o phase difference with input [14]. Therefore the resultant paired unit of CD-CS MOSFETs reverts the phase of output waveform.

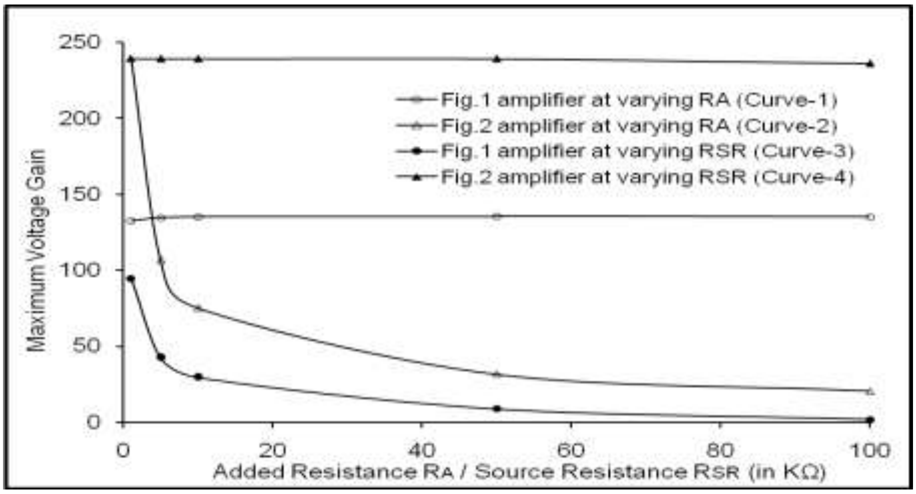

Fig.3. Variation of Maximum voltage gain with R_A and R_{SR}

Performances of proposed amplifiers highly depend on the presence of additional biasing resistance R_A. Variation of A_{VG-MAX} with R_A is depicted in Fig3. The voltage gain of the Proposed amplifier-1 increases a bit with increasing values of R_A from 132.74 (at 1KΩ) to 135.36 (at 100KΩ). However for Proposed amplifier-2 it decreases almost exponentially from its maximum value 239.48 (at 1KΩ) to the minimum value 20.57 (at 100KΩ). The factor which seems to be responsible for such a decrement in voltage gain for the circuit of Fig.2 is the changed position of by-pass capacitor C_S. The by-pass capacitor C_S which is available across the R_{SR} in circuit of Fig.1 bears almost consistent value of current at increasing R_A (73.36µA at 1KΩ and 74.30µA at 100KΩ) whereas it witnesses a significant fall in current at increasing R_A (when attached across the biasing resistance R_A) in the circuit of Fig.2 (139.09µA at 1KΩ and 13.21µA at 100KΩ). In addition, if R_A is removed from the circuit configuration of proposed amplifiers, the A_{VG-MAX} of proposed amplifiers reaches below unity to a value 0.773 for Fig.1 amplifier and .000093 for Fig.2 amplifier. Therefore, the presence of additional biasing resistance R_A in the proposed circuits is essential to explore the 'MOSFET Darlington pair unit' suitable for amplification of small-signals.

Apart from curves corresponding to R_A, Fig.3 simultaneously depicts the variation of maximum voltage gain as a function of source resistance R_{SR}. The nature of curve obtained for Proposed amplifier-1 corresponding to R_{RS} (Curve-3) seems to be similar to that of Proposed amplifier-2 for R_A (Curve-2) and the same relationship is observed between the Curve-1 (for Fig.1 amplifier at varying R_A) and Curve-4 (for Fig.2 amplifier at varying R_{SR}). Almost inverted voltage gain curves corresponding to R_A and R_{SR} for both the amplifiers can be correlated with the position of C_S. When C_S is attached across R_A (Fig.2 amplifier) the voltage gain of the respective amplifier becomes independent of any variation in R_{SR} and when it is attached across R_{SR} (Fig.1 amplifier) the amplifier becomes independent of any change in R_A.

Variation of voltage gain with DC supply voltage is depicted in Fig.4. Maximum voltage gain for proposed amplifiers has a nonlinear rising tendency at increasing values of DC supply voltage up to +15V. Mounting values of voltage gain with supply voltage for respective amplifiers in the range of $+10V<V_{CC}<+15V$ is well in accordance of the usual behaviour of small signal amplifiers [2], [9], [13]. However, beyond the critical point of +15V, voltage gain of proposed amplifiers reduces rapidly and above +20V of V_{CC}, it seizes to a non-significant value. The factor which is responsible for this behaviour is the significant reduction in drain to source voltage of the composite unit of MOSFETs in Darlington pairs at increasing or decreasing values of V_{CC} (other than +15V). This reduces the effective voltage gain of the respective amplifiers at supply voltages above or below +15V.

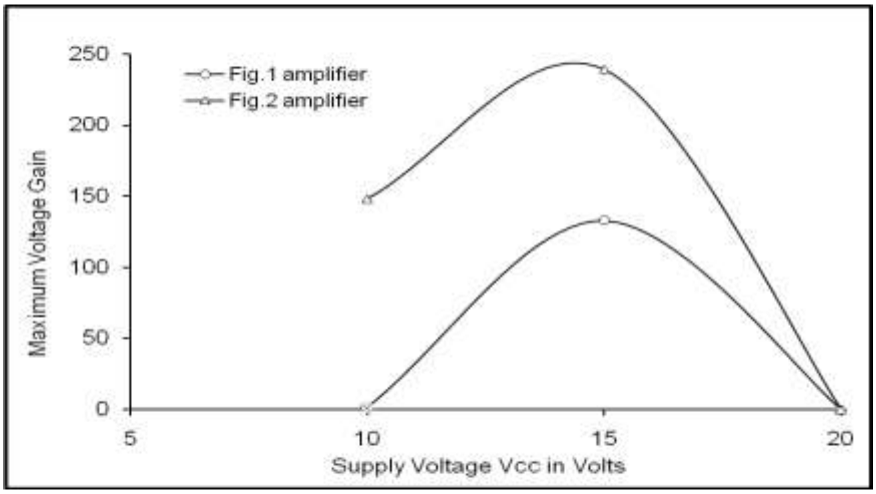

Fig.4. Variation of Maximum voltage gain with V_{CC}

Variation of voltage gain, current gain and bandwidth with temperature is also measured and listed in Table II. It is noticed here that both variety of gains gradually decreases at increasing temperature for respective amplifiers. This outcome can be associated with the positive temperature coefficient property of Drain-Source resistance [14]. Perhaps Drain-Source resistance of the composite unit rises with temperature which in turn reduces the drain current and thus the effective voltage / current gains [14]. Similarly, the bandwidth of respective amplifiers also reduces with raising temperature. At increasing temperature, perhaps the effective drain to source capacitance of composite MOSFET unit decreases and causes significant reduction in the bandwidth [14].

TABLE II
VARIATION OF MAXIMUM VOLTAGE GAIN (A_{VG-MAX}), CURRENT GAIN (A_{IG-MAX}) AND BANDWIDTH WITH TEMPERATURE

Temperature (°C)	Fig.1 Amplifier			Fig.2 Amplifier		
	A_{VG-MAX}	A_{IG-MAX}	Bandwidth (KHz)	A_{VG-MAX}	A_{IG-MAX}	Bandwidth (KHz)
-30	139.826	8.1733 K	54.710	278.413	16.173K	67.719
-20	138.411	8.0915 K	52.203	270.473	15.703K	66.620
-10	137.079	8.0146 K	52.397	263.067	15.271K	65.509
0	135.821	7.9420 K	50.387	256.140	14.883K	64.396
10	134.631	7.8734 K	50.196	249.647	14.518K	63.279
27	132.743	7.7647 K	48.494	239.487	13.943K	61.493
50	130.426	7.6317 K	46.330	227.254	13.246K	59.192
80	127.736	7.4778 K	43.589	213.464	12.454K	56.106

Variation of maximum voltage gain with drain resistance R_D and load resistance R_L is also observed but not shown in form of figure. Voltage gain for both the amplifiers increases almost linearly with increasing R_D in the range of $0.5K<R_D<2K$. Beyond this range of R_D output corresponding to respective amplifiers suffer from distortion. Similarly, voltage gain gradually rises up to 100KΩ value of R_L for both amplifiers and then acquires a sustained level at higher R_L. This rising and saturation of the voltage gain with R_L is well in accordance of the usual behaviour of small signal amplifiers [2], [6]-[9].

B. Tuning Performance

Radio or TV receiver type systems frequently use tunned amplifiers in its design [1]. To design such amplifiers a parallel tuning network at their output or input section are introduced. If central frequency of the response is so adjusted to match with the frequency of a particular channel, desired signal can be received. Motayed et.al.[15] had explored the tuning performance of a small-signal CC-CE Darlington pair amplifier. The idea of Motayed et.al. is successfully tested here for the proposed MOSFET Darlington amplifiers to explore them as tuned-amplifiers.

The tunning performance of the proposed amplifier is established in two steps- first, with C_S which is made available across R_{SR} in amplifier of Fig.2 and across R_A in amplifier of Fig.1 and second by introducing a tunning capacitor C_L in respective amplifiers across the load resistances R_L.

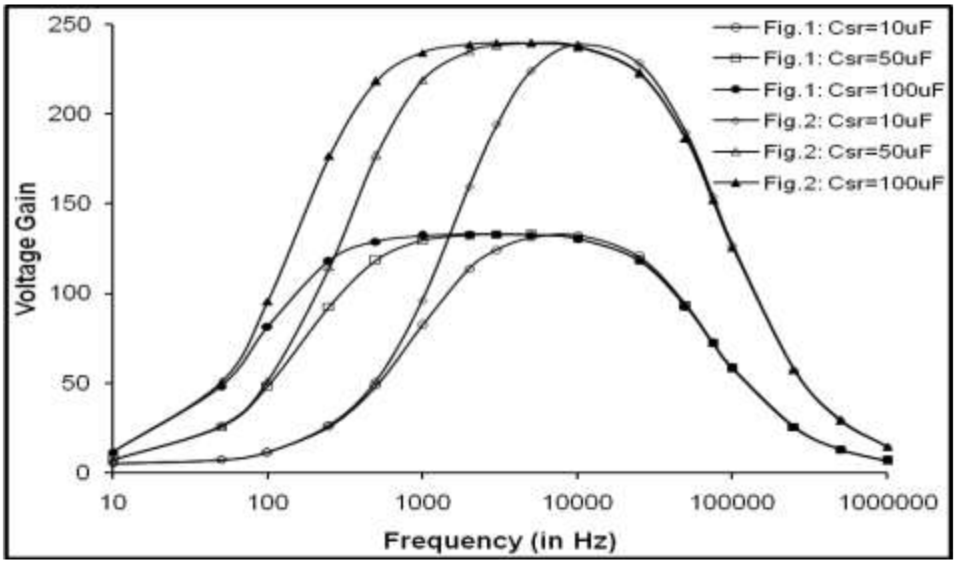

Fig.5. Variation of voltage gain with frequency at various source capacitors C_{SR}

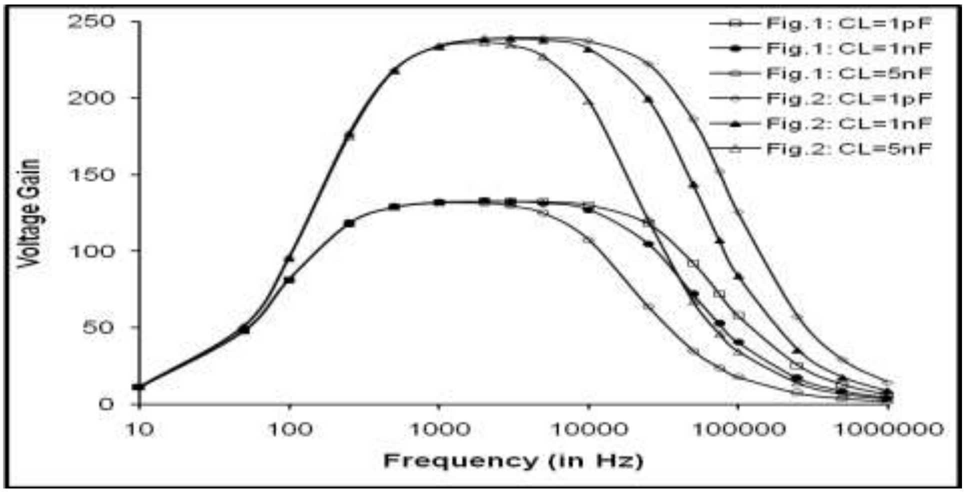

Fig.6. Variation of voltage gain with frequency at various load capacitors C_L

Both the proposed amplifiers show tunning performance for corresponding variations in C_{SR} between 10µF and 100µF. Respective observations are graphically presented in Fig.5. Changes in the C_{SR} merely create any variation in voltage gain, whereas it plays a significant role in adjusting the mid-band width. Corresponding to proposed amplifier-1, mid-band width extends between f_L=1.2574KHz and f_H=50.068KHz for C_{SR}=10µF, between f_L=252.469Hz and f_H=48.767KHz for C_{SR}=50µF and between f_L=129.217Hz and f_H=48.624KHz for C_{SR}=100µF. Similarly, ccorresponding to proposed amplifier-2, mid-band width extends between f_L=2.238KHz and f_H=63.834KHz for C_{SR}=10µF, between f_L=460.838Hz and f_H=60.971KHz for C_{SR}=50µF and between f_L=231.325Hz and f_H=61.725KHz for C_{SR}=100µF. Thus, the upper cut-off frequency remains unchanged for both the amplifiers with varying C_{SR} whereas the lower cut-off frequency shifts towards lower values with increasing C_{SR}.

Similarly the inclusion of capacitor C_L across load resistance R_L also plays an important role in adjusting mid-band frequency range for proposed amplifier. Fig.6 shows the respective response curves. Tunning is obtained for variations of C_L between 1pF and 5nF. Corresponding to proposed amplifier-1, mid-band width extends between f_L=129.244Hz and f_H=48.615KHz for C_L=1pF, between f_L=126.244Hz and f_H=32.365KHz for C_L=1nF and between f_L=126.395Hz and f_H=13.986KHz for C_L =5nF. Similarly, corresponding to proposed amplifier-2, mid-band width extends between f_L=231.325Hz and f_H=61.707KHz for C_L=1pF, between f_L=230.152Hz and f_H=37.808KHz for C_L=1nF and between f_L=224.79Hz and f_H=15.031KHz for C_L =5nF. Hence, the lower cut-off frequencies of the proposed amplifiers remains unchanged whereas upper cut-off frequencies shift towards lower values (from MHz to KHz range) on the frequency axis with increasing C_L.

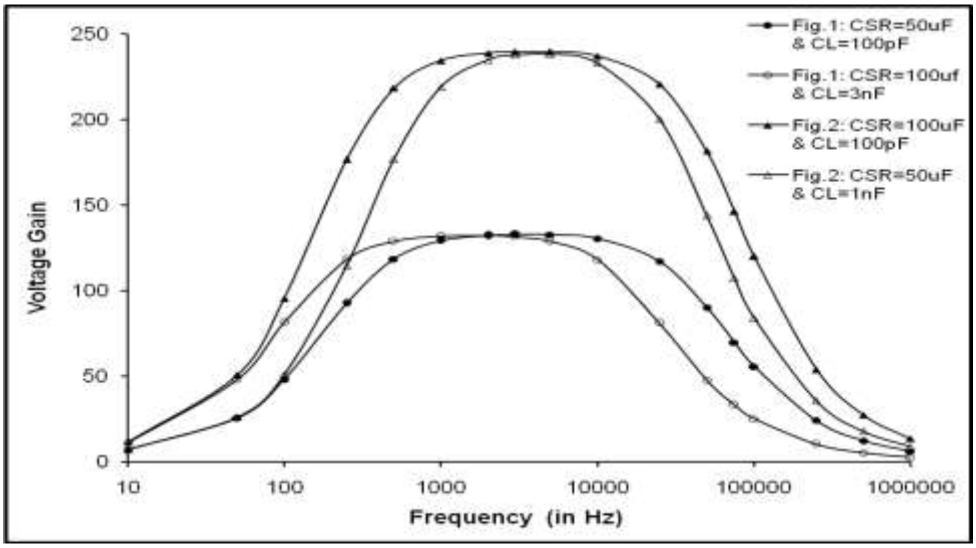

Fig.7. Tuned frequency response of MOSFET Darlington pair amplifiers at two different combinations of C_{SR} and C_L

Thus, an adjustment of C_{SR} and C_L will lead to a tunning which finally ascertain the frequency response of proposed amplifiers to peak around the desired frequency. This may enable the centre frequency of the response to coincide with the frequency of a desired communication channel. This tunning idea is depicted in Fig.7 for two different combinations of C_{SR} and C_L. The explored idea of tuning in Fig.5 leads to a conclusion that CD-CS combination of MOSFET Darlington pair in presence of R_A can be applied to receive signal of a specific channel, and to filter or to attenuate those of others.

CONCLUSIONS

Small-signal MOSEFT amplifiers normally hold high current gain as its prominent feature with a voltage gain just greater than unity but here as a novel approach, two identical MOSFETs are used in Darlington pair to explore the proposed circuits as small-signal high voltage gain amplifier. The proposed amplifiers provide optimum performance on +15V DC biasing supply and can be tuned in permissible audible frequency range approximately extended from 130Hz to 55KHz. The additional biasing resistance R_A (ranging in between 1KΩ to 100KΩ), is to be essentially included in the proposed circuits to maintain its voltage/current amplification property. In absence of R_A, voltage and current gain of both the amplifiers fall-down below unity and make them purpose-less. These amplifiers can effectively process small-signals ranging in 1-10mV at 1KHz input frequency and is free from the problem of poor response of conventional small-signal Darlington pair amplifiers at higher frequencies. Therefore, the proposed amplifiers may be a good replacement of conventional small-signal Darlington pair amplifiers in day-to-day electronics. The proposed amplifiers show considerable response for R_D and R_L almost in the same way as is usually observed for small-signal RC coupled Common Source MOSFET amplifiers. Moreover, low order harmonic distortion percentage of proposed amplifiers in the respective class of small-signal amplifiers is another feather in their cap.

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