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Qualitative Analysis of Darlington pair Based Modified Small-Signal Amplifier

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ABSTRACT: Modified version of small-signal amplifier using Darlington pair is proposed with inclusion of an additional biasing resistance. Proposed modification brings considerable improvement in voltage gain and widening of bandwidth. Proposed amplifier successfully removes poor frequency response problem of conventional Darlington pair amplifier at higher frequencies. Small-signal AC analysis, variation of maximum voltage gain with biasing parameters and temperature dependency of performance parameters are analyzed on the qualitative scale. Proposed amplifier circuit is found capable of amplifying small signals in 1-25mV range and can be used in various analog communication applications.

KEYWORDS: Circuit design, Circuit simulation, Darlington pair, Small signal amplifier,

I. INTRODUCTION

Amplification of weak and medium range signals through BJT and its compound units (e.g. Darlington pair, Differential Amplifier etc.) is observed as all time important phenomenon for electronics industry[1]-[6]. Various communication circuits use Darlington pair as one of the significant element for amplification of small-signals [1] [3]-[6]. In Darlington pair, current gain of the composite unit β_D is considered to be the product of current gains of individual transistors i.e. $\beta_D=\beta_{Q1}.\beta_{Q2}$. Input resistance of Darlington pair amplifier is found much higher and output resistance is lower than that of a single-stage Emitter Follower. However at higher frequency small-signal Darlington pair amplifier produces poor frequency response [1], [5]-[9]. A number of books and research papers are available to explain the usefulness of Darlington pair amplifier but the efforts are still continued to develop its modified versions [5]-[7]. In the present manuscript, authors proposed various modifications in small-signal Darlington pair amplifier circuit and observed some fabulous results that may be useful for various communication applications.

II. CIRCUIT DETAILS

For present investigations, conventionally used small-signal NPN Darlington pair amplifier is selected as Reference Amplifier (Fig.1). However, Proposed amplifier (Fig.2) is obtained by adding an extra biasing resistance R_A between emitter of Q1 and ground of the Reference amplifier.

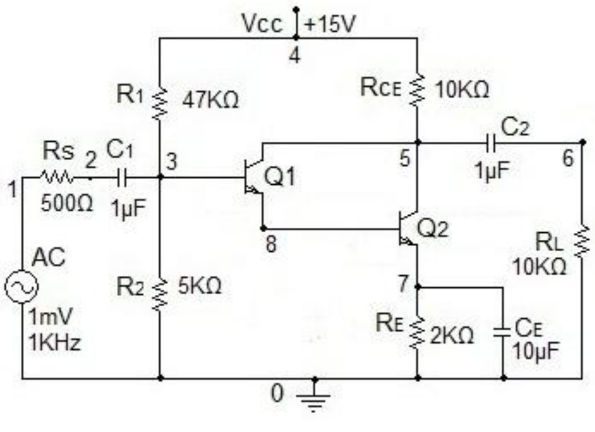

Fig.1. Conventional Small-signal Darlington pair amplifier (Reference Amplifier)

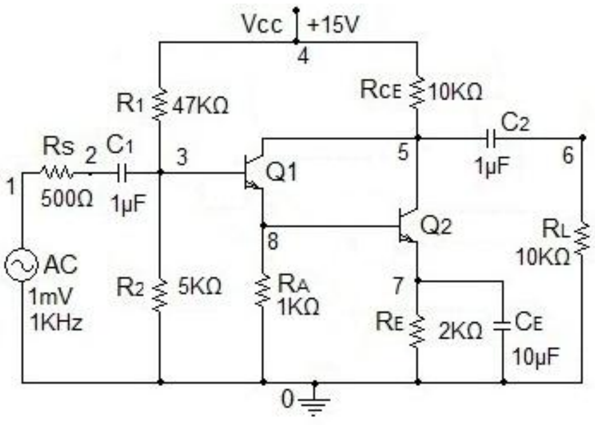

Fig.2. Proposed Small-signal Darlington pair amplifier (Proposed Amplifier)

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Reference and proposed amplifiers (Fig.1 and Fig.2) use NPN transistor (Q2N2222 with β=255.9) in respective Darlington units. Other biasing parameters and DC biasing supply used to design respective circuits are as depicted in Fig.1 and Fig.2. Both the circuits are fed with 1V AC input signal but respective observations are received for 1mV, 1KHz input AC signal through PSpice simulation software [10] (Student version 9.2).

III. RESULTS AND DISCUSSIONS

Various qualitative features of respective amplifiers are measured on the basis of simulation results and the outcomes are listed in TABLE-I for a quick qualitative comparison. Refer TABLE-I. Despite of enhanced voltage gain, current gain and bandwidth of the proposed amplifier, both the circuits generates 180^{O} out of phase output waveform. Reference amplifier successfully amplifies 1-15mV range input AC signals at 1KHz frequency. However this range for proposed amplifier is 1-25mV at similar frequency. Instead, Fourier analysis of respective amplifiers suggests an appearance of higher THD for proposed amplifier.

TABLE-I: QUALITATIVE FEATURES OF AMPLIFIERS AT 27^{O}C TEMPERATURE

Performance Parameters	Reference amplifier	Proposed amplifier
Maximum Voltage Gain (A_{VG})	16.98	20.56
Maximum Current Gain (A_{IG})	8.517	10.031
Band Width (B_W)	102.058KHz	2.833MHz
Lower Cut-off Frequency (f_L)	79.913Hz	77.419Hz
Higher Cut-off Frequency (f_H)	102.138KHz	2.8337KHz
Peak Output Voltage (V_{RL}) Across Load R_L	17.92mV	21.41mV
Input Signal Voltage used for present observations (V_I)	1mV (at 1KHz)	1mV (at 1KHz)
Input Signal Voltage range for purposeful amplification	1mV to 15mV (at 1KHz)	1mV to 25mV (at 1KHz)
Peak Output Current (I_{RL}) Across Load R_L	1.79 µA	2.14 µA
Input Current across R_S	192.17 nA	197.45 nA
Output Phase Difference θ^o	180^{O}	180^{O} (approx.)
Total Harmonic Distortion (THD)	0.62%	0.82%

Clearly the inclusion of added resistance R_A in proposed amplifier (Fig.2) is responsible for simultaneous enhancement in voltage gain and bandwidth [7]-[9]. Permissible range of R_A for successful amplification is observed to be $0.5K\Omega \leq R_A \leq 80K\Omega$. Minimum of A_{VG} (1.77) is obtained at R_A=500Ω whereas maximum of A_{VG} (24.66) is received at R_A=80KΩ. Moreover, circuit configuration of proposed amplifier (Fig.2.3) effectively removes the poor frequency response problem of conventional small-signal Darlington pair amplifier (Reference amplifier) at higher frequencies.

In addition to observed qualitative features of the proposed amplifier (Fig.2), if another bypass capacitor C_A=10µF is added across R_A in circuit of Fig.2, resultant configuration produces enhanced voltage gain A_{VG}=64.80, higher current gain A_{IG}=23.79, reduced bandwidth B_W=1.0249MHz (lower cut-off frequency f_L=149.162Hz and higher cut-off frequency f_H=1.0251MHz) and increased harmonic distortion THD=1.50%. However, if both the BJTs of Darlington unit of Fig.2 (proposed amplifier) are replaced by PNP transistors (Q2N2907A with β= 231.7), respective circuit comes up with A_{VG}=10.44, A_{IG}=5.15 and B_W=4.02MHz (with f_L=44.225Hz and f_H=4.02MHz) and THD=1.45%.

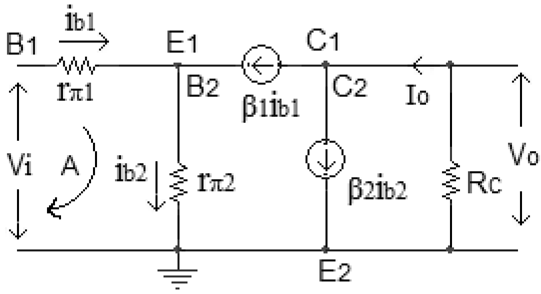

Fig.3. Small-signal AC equivalent circuit of Fig.1 (reference amplifier)

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Small-signal AC equivalent circuit [1] of the Fig.1 (reference amplifier) is depicted in Fig.3. Observed values of important device parameters for independent transistors of reference amplifier (Fig.1) are found as- $r_{\pi1}$=1.58MΩ, $r_{\pi2}$=22.4KΩ, r_{o1}= 65.9MΩ, r_{o2}=464KΩ, β_{ac1}=79.2 and β_{ac2}=160. Due to considerably high values of collector-emitter resistance r_{o1} and r_{o2} of respective transistors in Fig.1, these parameters hardly draw any impact on device performance. Therefore, small-signal AC equivalent circuit (Fig.3) of reference amplifier is drawn without taking r_{o1} and r_{o2} into the account. Analysis of Fig.3 reveals following approximated expression for small-signal AC current gain of the Fig.1amplifier (reference amplifier)-

$$A_I \approx \beta_1\beta_2 + \beta_1 + \beta_2$$

Similarly, approximated expression for small-signal AC Voltage gain of the reference amplifier is-

$$A_V \approx \frac{-R_C(\beta_1\beta_2 + \beta_1 + \beta_2)}{r_{\pi1} + r_{\pi2} + \beta_1 r_{\pi2}}$$

In addition to above analysis, small-signal AC equivalent circuit [1] of the Fig.2 (proposed amplifier) is depicted in Fig.4. Observed values of important device parameters for independent transistors of reference amplifier (Fig.1) are found as- $r_{\pi1}$=5.66KΩ, $r_{\pi2}$=36.7KΩ, r_{o1}= 101KΩ, r_{o2}=811KΩ, β_{ac1}=170 and β_{ac2}=139. A quick comparison of the device parameters of transistors in Fig.1 and Fig.2 suggests that the inclusion of additional biasing resistance R_A comes with a significant variation in parameter values of respective transistors in Fig.2. These variations ultimately emerge with proposed amplifier (Fig.2) in form of better qualitative features. Still due to higher values of r_{o1} and r_{o2}, small-signal AC equivalent circuit of proposed amplifier does not include r_{o1} and r_{o2} in Fig.4.

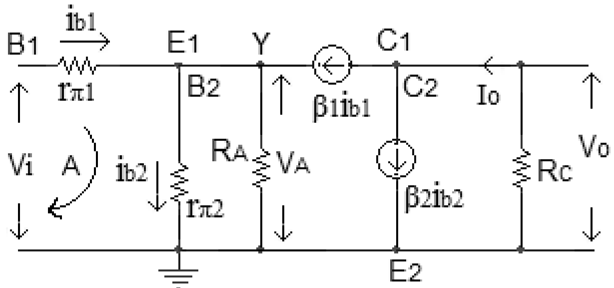

Fig.4. Small-signal AC equivalent circuit of Fig.2 (proposed amplifier)

Analysis of Fig.4 reveals following expression for small-signal AC current gains of proposed amplifier-

$$A_I = \beta_1 + \frac{\beta_2(\beta_1 + 1)}{\left(\frac{r_{\pi2}}{R_A} + 1\right)}$$

Similarly, approximated value of small-signal AC Voltage gain of the proposed amplifier is-

$$\boldsymbol{A_V = \frac{-R_C\left[\beta_1\left(\frac{r_{\pi2}}{R_A} + 1\right) + \beta_2(\beta_1 + 1)\right]}{\left[r_{\pi1}\left(\frac{r_{\pi2}}{R_A} + 1\right) + (\beta_1 + 1)r_{\pi2}\right]}}$$

TABLE-II: α AND β PARAMETERS BASED ON SIMULATION RESULTS

Circuits	Q1			Q2			Darlington Unit	
	β_{DC}	α_{DC}	V_D	β_{DC}	α_{DC}	V_D	β_{DC}	α_{DC}
Reference Amplifier (Fig.1)	51.525	0.9809	1.44V	157.1145	1.000	0.97V	8303.9641	0.999
Proposed Amplifier (Fig.2)	138.2987	0.9928	1.42V	137.9016	0.9928	0.78V	19347.813	0.999

On the basis of simulation results, small-signal amplification parameters α and β for BJT's in respective Darlington pair units of reference amplifier (Fig.1) and proposed amplifier (Fig.2) are observed using $\beta = \beta_{Q1}.\beta_{Q2} + \beta_{Q1} + \beta_{Q2}$ and $\alpha=\beta/(1+\beta)$following expressions. The resultant outcomes are listed in TABLE-II.

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Observed α and β values in TABLE-II corresponding to respective amplifiers are found adequately in accordance with the prescribed range for small-signal amplifiers [1],[3],[11]. It is to be noted that the default values of β, α and transistor's turn-on voltages V_T as defined in PSpice model of NPN transistor Q2N2222 transistor are β=255.9, α=0.996 and V_T=0.75 [10].

TABLE-III: VARIATION VOLTAGE GAIN, CURRENT GAIN AND BANDWIDTH WITH TEMPERATURE

Temperature (°C)	Reference Amplifier (Fig.1)			Proposed Amplifier (Fig.2)		
	A_{VG}	A_{IG}	B_W (KHz)	A_{VG}	A_{IG}	B_W (KHz)
0	13.511	6.773	121.085	14.227	6.927	4232.744
10	14.865	7.452	113.138	16.669	8.1217	3523.138
20	16.139	8.091	106.723	19.002	9.264	3131.729
25	16.747	8.396	104.425	20.124	9.815	2935.225
50	19.534	9.795	93.533	25.284	12.349	2231.007
80	22.382	11.224	80.434	30.562	14.950	1713.187

Variations of maximum voltage gain, current gain and bandwidth with temperature are also measured and listed in TABLE-III. For reference (Fig.1) and proposed (Fig.2) amplifiers, both variety of gains increases but bandwidth decreases with rising temperature. This perhaps happens because of the generation of more carriers with temperature elevation. This observation verifies the usual behaviour of transistor parameter h_{FE} with temperature [12].

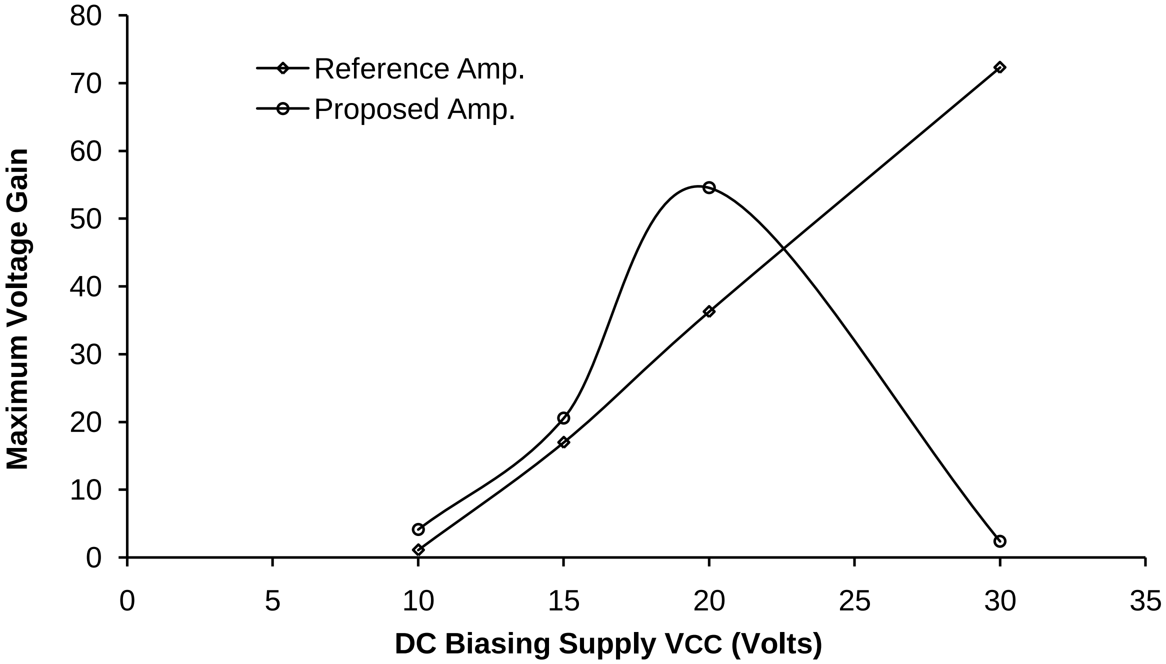

Fig.5. Variation of maximum voltage gain with DC supply V_{CC}

Variation of A_{VG} (maximum voltage gain) with DC supply voltage V_{CC} is also observed and resulting curves are depicted in Fig.5. Refer Fig.5. Maximum voltage gain increases almost linearly with V_{CC} for reference amplifier. However for proposed amplifier it reaches at maximum for V_{CC}=20V and thereafter decreases sharply till the amplifier generates purposeless response beyond 30V. Moreover, both the amplifier systems are found to switch ON at 10V.

Maximum voltage gain (A_{VG}) raises slowly up to 100KΩ value of R_L for both the amplifiers thereafter it acquires a sustained level. This rising and saturation of the voltage gain with R_L is well in accordance of the usual behaviour of CE amplifier [10].

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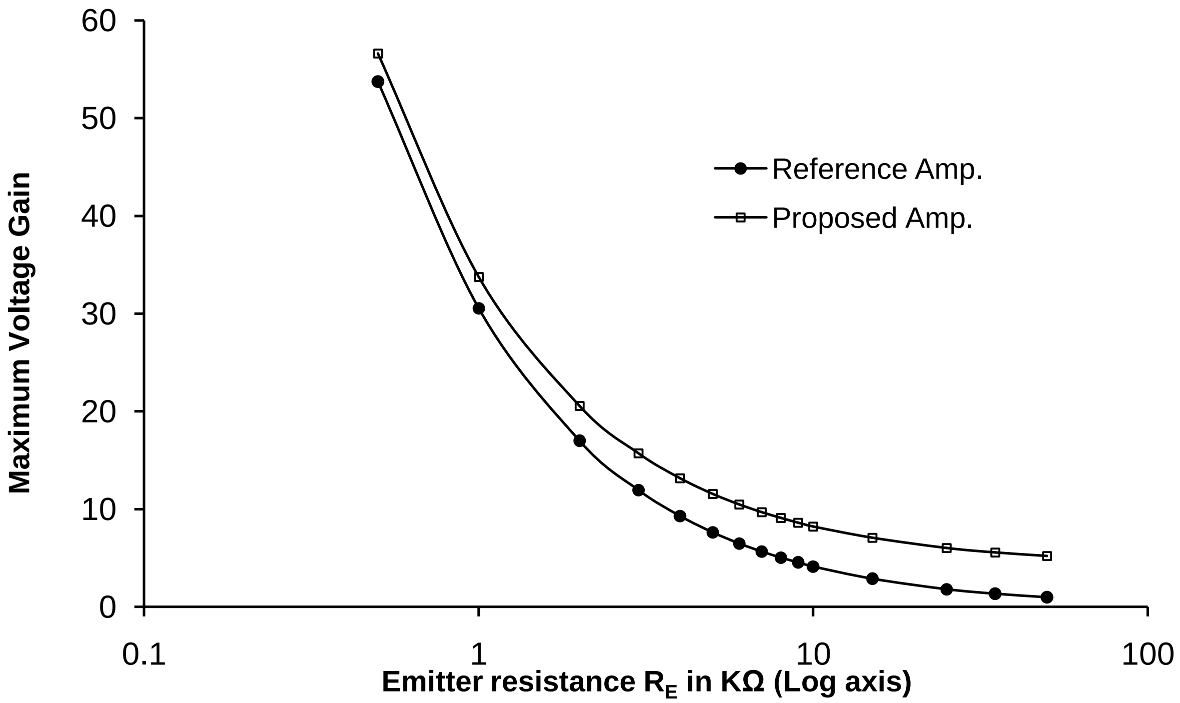

Fig.6. Variation of maximum voltage gain with load resistance R_E

Variation in maximum voltage gain with R_E is shown in Fig.6. Voltage gain is found to decrease exponentially with rising values of R_E.

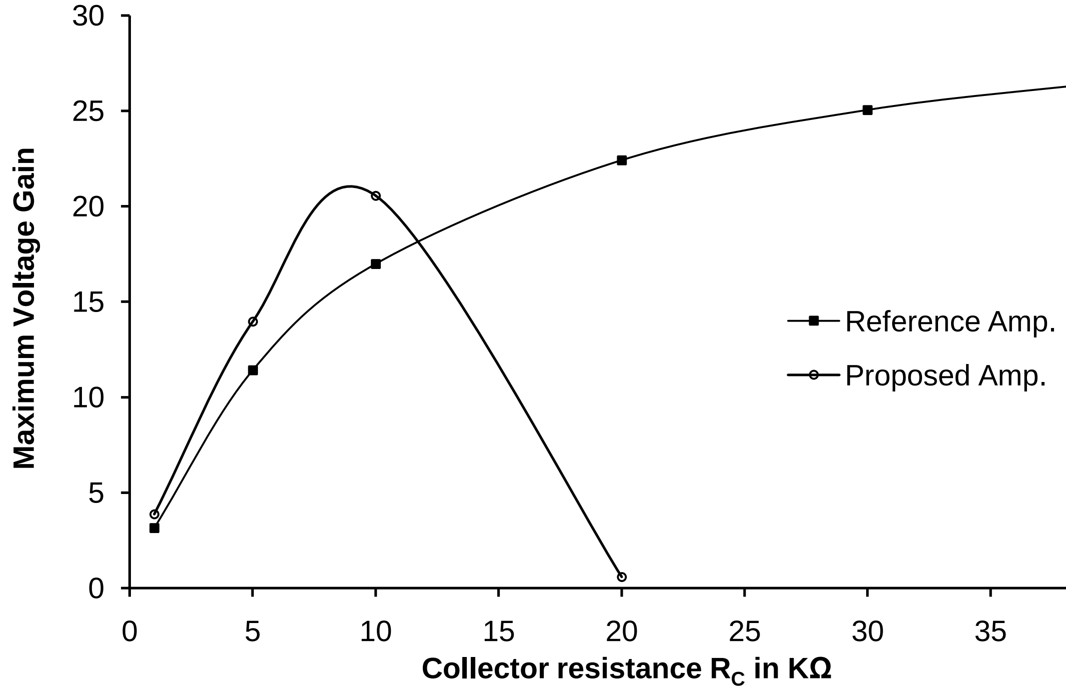

Fig.8. Variation of maximum voltage gain with load resistance R_C

Variations of maximum voltage gain with R_C for respective amplifiers are observed and the outcomes are recorded in form of Fig.8. Maximum voltage gain (A_{VG}) of the reference amplifier (Fig.1) increases almost exponentially with R_C

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up to 40KΩ and thereafter the amplified output signal suffers from heavy distortion. However A_{VG} of the proposed amplifier (Fig.2) rises up to10KΩ (A_{VG}=20.56) thereafter rapidly falls down to A_{VG}=0.59 at 20KΩ of R_C.

IV. CONCLUSIONS

Proposed circuit configuration successfully removes the poor response problem of conventional small-signal Darlington pair amplifier at higher frequencies. For best results the proposed amplifier should be fed with 15-20V D.C. supply. It produces high voltage gain and wider bandwidth for R_A=2KΩ. This amplifier configuration with R_A=2KΩ can be used for those applications where simultaneous high voltage gain and wide bandwidth would be the prime requirement. The emitter resistance R_E and collector resistance R_C significantly affects the performance of the proposed amplifier.

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