IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)
e-ISSN: 2278-1676,p-ISSN: 2320-3331, Volume 10, Issue 2 Ver. I (Mar – Apr. 2015), PP 77-80
www.iosrjournals.org

Analysis of Darlington Pair in Distributed Amplifier Circuit

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Abstract: *This paper presents the analysis of the Darlington pair as an element in a distributed amplifier (DA) configuration. The Darlington pair circuit with the input and output inductor of the DA transmission line are included in the analysis of the circuit, this is also simulated. The inherent problem of poor performance is reduced by the inductors. The overall result shows that high power gain at high frequency is achievable with Darlington pair as the stage element of a given DA.*
Keywords: *Distributed amplifier, Darlington pair topology*

I. Introduction

Amplification is one of the most important concept and application of electronic, almost all electronic; analog, digital, or mixed analog and digital system requires amplifier [1] [2] [4]. **Fig. 1** shows the conventional Darlington pair amplifier configuration. Amplifying signal through Darlington pair is an important phenomenon of electronic, mainly it is made of up two identical Bipolar junction transistor in common collector – common emitter connection and its applications ranges from small – signal amplifier to power amplifier circuits [3][5]. However at high frequency the performance of the Darlington pair become very poor [5] [6] [7].

Attempts are being made in order to overcome the poor performance of the circuit at high frequency. [6] and [9] attempted to overcome this problem by adding some extra biasing resistor at the emitter of the first transistor and by using triple Darlington pair topology in cascade respectively. The work of [6] would suffer reduction in gain while that of [9] would suffer bandwidth shrinkage.

Use of the Darlington pair in a distributed amplifier configuration solved the the above problems. As such, this work presents the analysis of the Darlington pair in distributed amplifier configuration.

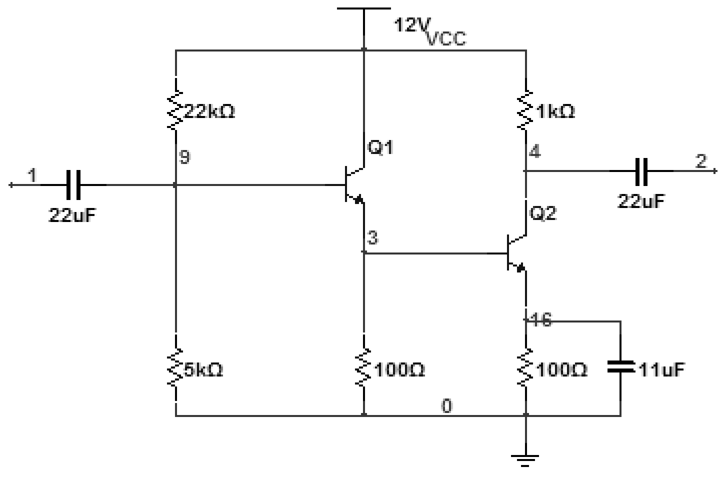

Figure 1: Schematic diagram of the conventional Darlington pair amplifier

II. Circuit Detail

Distributed amplification is widely used technology in broadband amplifier design. Wideband amplifiers are the basic building block of broadband communication [8]. A distributed amplifier is made up of two transmission lines and multiple of conventional amplifiers providing gain through multiple signal paths that amplifies forward travelling signal. Each amplifier in the system adds power in phase to the signal at each tap point on the output line. Each path way provides some gain and therefore the whole distributed amplifier is capable of providing better gain and bandwidth than the conventional amplifier [10]. **Fig. 2** shows the distributed amplifier.

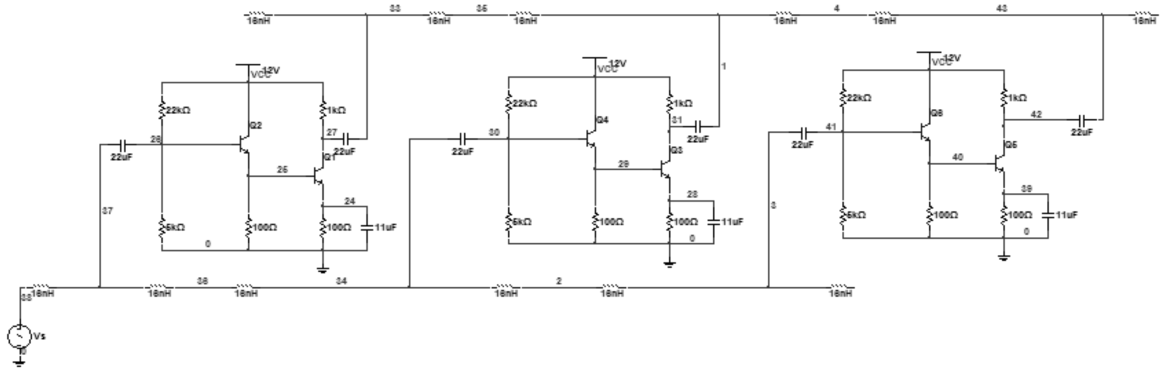

Figure 2: Schematic diagram of the distributed amplifier.

III. Circuit Analysis

The circuit analysis is performed by replacing the transistor in the distributed circuit with its high frequency hybrid – π model of the BJT. **Fig. 3** shows the high frequency AC equivalent circuit of the distributed amplifier. From the AC equivalent circuit we write the current equation at the nodes V_1, V_2, V_3, and V_o. And we obtain equation (1), (2), (3) and (4).

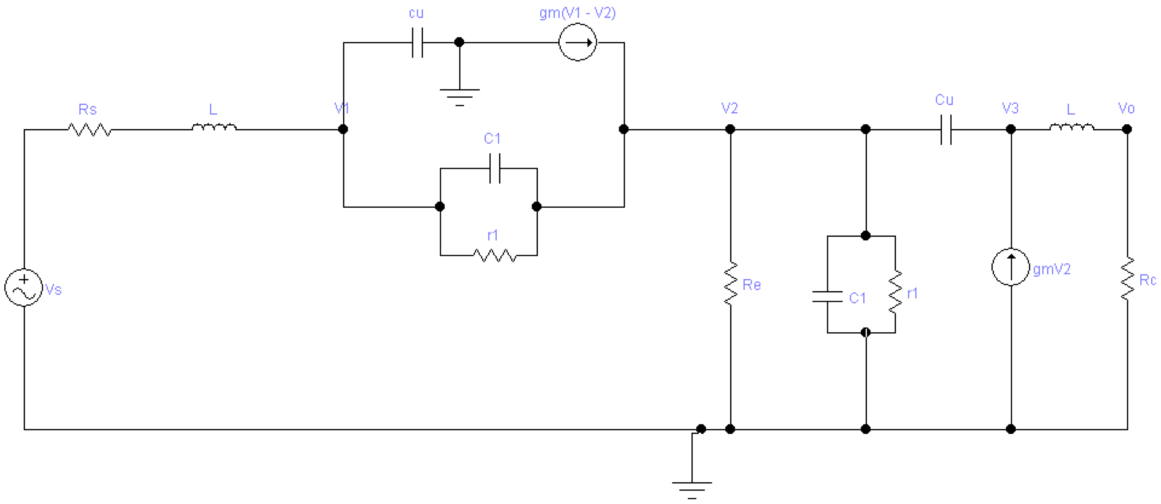

Figure 3: Ac Equivalent Circuit for the Proposed Distributed Amplifier

$$\frac{V_1 - V_S}{Z_S} + \frac{V_1 - V_2}{Z_{C_1}} + \frac{V_1}{X_{C_\mu}} = 0 \qquad (1)$$

$$\frac{V_2 - V_3}{X_{C_\mu}} + \frac{V_2}{Z_e} + g_m(V_2 - V_1) + \frac{V_2 - V_1}{Z_{C_1}} = 0 \qquad (2)$$

$$\frac{V_3 - V_2}{X_{C_\mu}} + g_m V_2 + \frac{V_3 - V_O}{X_L} = 0 \qquad (3)$$

$$V_O = \frac{R_C}{X_L - R_C} V_3 \qquad (4)$$

Where

$Z_S = R_S + X_L$ $\quad Z_1 = r_1 \,//\, X_{C_1}$ $\quad Z_e = R_e \,//\, r_1 \,//\, X_{C_1}$ $\quad X_L = i\omega L = SL$ $\quad X_C = \frac{1}{i\omega C} = \frac{1}{SC}$

$r_1 = r_\pi$ $\quad C_1 = C_\pi$

Using equation (1) through (4) the transfer function A_v of the circuit of **fig. 3** is found to be equation (5) where S is the frequency parameter:

$$A_V = \frac{-SLR_C r_\pi [SC_\mu - g_m][SC_\pi r_\pi - g_m r_\pi - 1]}{\mathbf{AB}SLR_C\,[g_m - SC_\mu] + [S^3L^2C_\mu + S^2LC_\mu R_C + SL][SC_\pi r_\pi + g_m r_\pi + 1][SL + R_S][SC_\pi + 1]} \qquad (5)$$

$$\mathbf{A} = \frac{\left[2SC_{\mu}R_{e}r_{\pi} + SC_{\pi}R_{e}r_{\pi} + 2R_{e} + g_{m}R_{e}r_{\pi} + r_{\pi}\right]\left[S^{3}L^{2}C_{\mu} + S^{2}LC_{\mu}R_{C} + SL\right] - S^{2}LC_{\mu}R_{C}R_{e}r_{\pi}\left[g_{m} - SC_{\mu}\right]\left[SL + R_{S}\right]}{SLR_{C}R_{e}r_{\pi}\left[g_{m} - S_{\mu}\right]}$$

$$\mathbf{B} = 2S^{2}\,LC_{\pi} + S\left[2C_{\pi}R_{S}r_{\pi} + R_{S} + r_{\pi}\right]$$

IV. Result

The values of the components use for the analysis are shown in **Table 1.** The frequency response of the Darlington pair in the DA configuration that is characterized by the flat voltage gain and wide bandwidth for the simulation and the calculated result is shown in **fig. 4** and **5.** The maximum gain and bandwidth for the simulation was found to be 47dB and 237MHz respectively. The analysis result was obtain from **equation (5),** the transfer function gain is shown in equation (6) and it is plotted using MATLAB R2010a, from the plot we obtain the gain and bandwidth for the analysis to be 229dB and 336MHz.

Table 1: Component detail of the circuit analysis

component	Description	Value	Unit
R_c	Collector biasing resistance	1	KΩ
R_e	Emitter biasing resistance	100	Ω
r_{π}	Dynamic emitter resistance	300	Ω
C_{π}	Dynamic emitter capacitance	1	pF
C_{μ}	Collector base transition capacitance	3.5	pF
L	Inductor	16	nH
g_m	Transconductance	0.2	Ω^{-1}

If these values in **Table 1** are substituted in equation (5) we obtain the gain function to be:

$$\mathbf{A_V} = \frac{S^{3}(5.2\times10^{-12}) - S^{2}(7.6\times10^{-11}) + S(5.95)}{S^{6}(1.7\times10^{-38}) + S^{5}(2.6\times10^{-27}) + S^{4}(1.3\times10^{-16}) + S^{3}(7\times10^{-7}) + S^{2}(1.6\times10^{3}) + S(1.6\times10^{6}) + 4.1\times10^{5}} \quad \textbf{(6)}$$

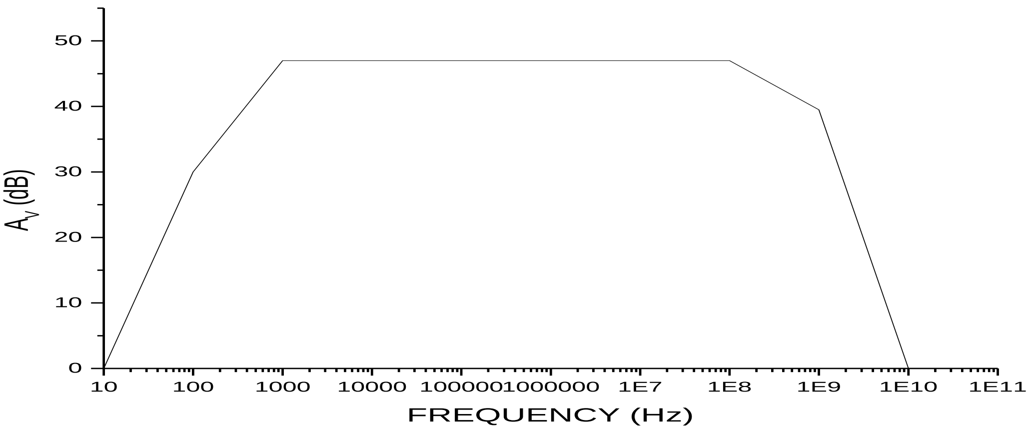

Figure 4: Frequency Response of the Distributed Amplifier (Simulation)

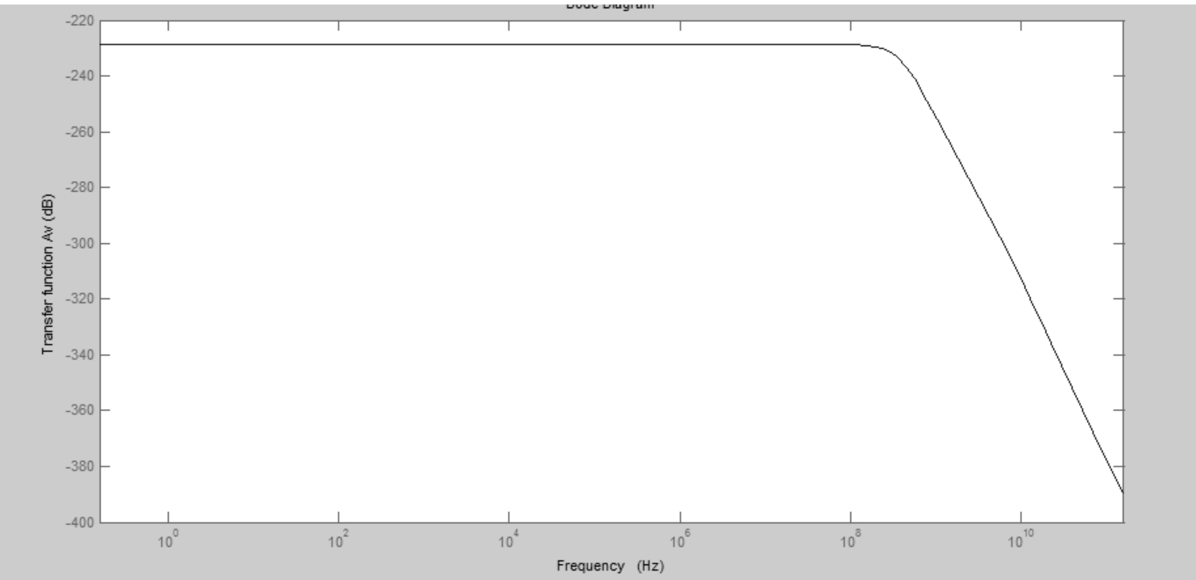

Figure 5: Frequency Response of the Distributed Amplifier (Theoretical)

V. Discussion

We found that the use of conventional Darlington pair amplifier as an element of distributed amplifier has a great improvement in both the gain and bandwidth as compared to the conventional Darlington pair topology. This is seen from both the simulation and the calculated result. DA with Darlington pair as its gain element can be use in modern wireless communication system. Conventional Darlington pair topology as the gain stage of the distributed amplifier solves the problem of poor response of the topology at high frequency. Considering the fact that broadband communication demand high data rate and large coverage, the propose amplifier has great potential for broadband application and its can be used in transceivers for vast application such as WiMAX, Wi – Fi, surveillance equipments etc.

VI. Conclusion

A novel approach is used in the distributed amplifier by using the conventional Darlington pair amplifier as an element of gain stage. It was observed that frequency response of the conventional Darlington pair amplifier was improved. The proposed Darlington pair amplifier will be of utmost important in vast area of modern wireless communication systems.

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