A Proposed Design for the Broadband Microwave Distributed Amplifiers

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Abstract − **In this paper, a new method for the design of the broadband RF/microwave amplifiers employing distributed amplification is presented. It proposes to use stages with asymmetric lumped elements (inductances and capacitances) in the gate and drain circuits of the amplifier instead of symmetric elements in order to control the frequency response and to achieve a flat gain over a large bandwidth. The need for impedance matching problems is also solved. Simulation result obtained demonstrates that the new design gives better frequency response as compared to the conventional distributed amplifiers even without optimization.**

Index Terms − **Microelectronics, Microwave amplifier, Broadband Amplification.**

I. INTRODUCTION

The principal of distributed amplification was suggested in 1948 and originally applied to vacuum tubes [1]. With the development of the P-N technology, the vacuum tubes were replaced by the transistors. It is based on the idea to separate the parasitic capacitors of the active devices by means of artificial transmission lines. As a result, the effect of the capacitors will be absorbed in to LPF segments of the transmission lines then it is possible to obtain amplification over much wider bandwidth than is achievable with traditional cascaded multi-stage amplifiers, therefore the distribute amplification is the best method and most widely applied for broadband microwave applications. Large amounts of publications proved the importance of the field [2]-[5]. The basic distributed amplifier (DA) structure is shown in Fig.1. It has two, lumped element, artificial transmission lines represented by the drain and gate lines, which are made up of a series of inductors with the corresponding parasitic capacitances (C_{gs} and C_{ds} of the transistors).

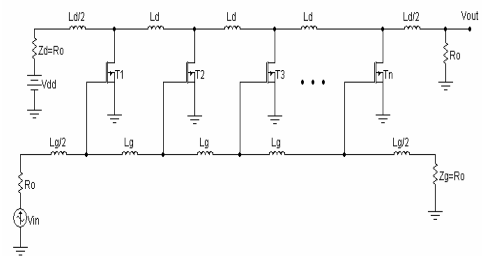


Fig.1 Structure of an n-stage DA

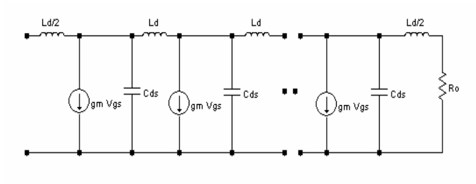
The input signal (V_{in}) is traveled down the gate line to the terminated end (Z_g), where it is absorbed. As the signal travels down the line, it will be amplified at each stage and transferred to the drain line through the transconductance of the transistors. The signals on the drain line add in the forward direction as they arrive at the output. For the ideal case of a lossless amplifier, the power gain is given by [6]:

$$G = (g_m)^2 Z_d Z_g n^2 / 4 \quad (1)$$

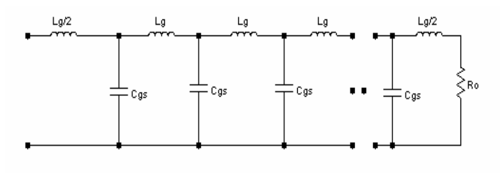
where n is the number of sections and g_m is the transconductance of the active devices. The bandwidth of a DA is determined by the L-C ladder circuit. As shown in Fig.2, if $L_g = L_d = L$ and $C_{gs} = C_{ds} = C$ (1), then

$$\omega_c = 2 / \sqrt{LC} \quad (2)$$

(1) C_{ds} is smaller than C_{gs} therefore it is necessary to add a capacitance to the drain of each stage in order to counterbalance the value of C_{gs}.



(a) Drain line



(b) Gate line

Fig.2 Simplified equivalent circuit of the DA

The above topology is based on the image parameter method of LPF design since it consists of a cascade of identical two port networks formed by the constant-k T-section filters. The constant-k section has input image impedance equal to the output image impedance, which is given by [7]

$$Z_i = \sqrt{\frac{L}{C}}\ \sqrt{1-(\frac{\omega}{\omega_c})^2} \qquad (3)$$

From equation (3), it is seen that the impedance of the line is frequency dependent especially when (ω) is near (ω_c). This is a limitation of the filter since the image impedance will not match a constant source or load impedance, and always there is a deviation in the ideal flat behavior. The matching networks on the terminals can be improved by using m-derived half section with m = 0.6 [8]. The feature of m-derived filter is that it exhibits identical image impedance, which is matched to $R_0 = \sqrt{L/C}$ .The use of such circuit will increase the complexity of the system. Another problem in the design using the image parameter method is that, although the procedure is relatively simple, the design of the filter often must be optimized and iterated many times to achieve the desired response.

II. THE PROPOSED DESIGN METHOD

The insertion loss method is another way of the filter design, which uses network synthesis techniques and allows a high degree of frequency response control [9]. By this way the amplifier L-C segments will be different in values according to the response specification. Maximally flat or Butterworth characteristic provides the flattest possible passband response, which represents the desired goal in the amplifier circuits. The proposed design procedure can be summarized as in the following.

A. Circuit Topology

Fig.3 shows the new topology, which illustrates that the proposed design method is based upon:

1) The omission of m-derived buffer stage from the conventional DA circuit.
2) The use of filter with different element values between the amplifier stages.

Fig.4 shows a simplified model for both the drain and gate circuits. It is similar to ladder low-pass filter circuit with N reactive elements. N represents the order of the filter, which can be found from the following equation:

$$N = 2n - 1 \qquad (4)$$

where n is the total number of the amplifier stages. The element values for Butterworth LPF prototypes (R_0=1 , ω_c = 1) are given in Table I [9]. The value of C_1 is represented by (C_{g1} + C_{gs1}) in the gate transmission line and (C_{d1} + C_{ds1}) in the drain line. While L_2 is represented by L_{g1} and L_{d1} and so on.

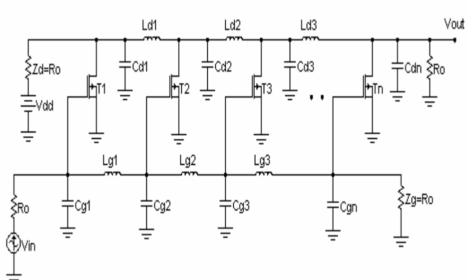
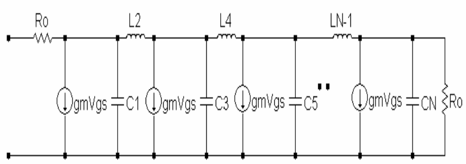
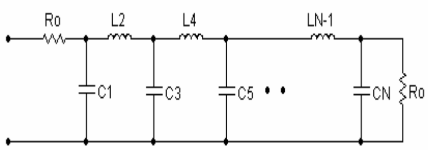


Fig.3 The new structure for the DA



(a) Drain line



(b) Gate line

Fig.4 Equivalent circuit of the new DA

TABLE I
ELEMENT VALUES FOR BUTTERWORTH LPF PROTOTYPES

Element	N=3	N=5	N=7	N=9
C_1	1	0.618	0.445	0.3473
L_2	2	1.618	1.247	1
C_3	1	2	1.8019	1.532
L_4		1.618	2	1.8794
C_5		0.618	1.8019	2
L_6			1.247	1.8794
C_7			0.445	1.532
L_8				1
C_9				0.347

B. Gain and Bandwidth Considerations:

Equation (1) is still valid for power gain computation of the proposed DA design since no massive charge occurred to the conventional DA circuit. The bandwidth of the proposed DA equals to the passband of the LPF, i.e it is equal to the cutoff frequency of the filter (ω_c), which depends to a high extent upon the element values of the filter, therefore it is necessary to scale the series inductance and shunt capacitance of the prototype filter according to the new (required) cutoff frequency which can be performed according to the following equations:

$$\left.\begin{aligned} L_{new} &= \frac{R_0 L_{old}}{\omega_c} \\ C_{new} &= \frac{C_{old}}{R_0 \omega_c} \end{aligned}\right\} \qquad (5)$$

III. DESIGN EXAMPLE

To demonstrate the theoretical viability of the new design method, Fig.3, a four-stage amplifier with R_0=50Ω has been designed for 14 dB power gain and 10 GHz bandwidth. From equation (1), the required g_m is :

$$g_m = \frac{2\sqrt{G}}{nR_0} = 0.05\ \Omega^{-1} \qquad (6)$$

The order (N) of the filter for such circuit can be evaluated by using equation (4) to be 7. Hence the corresponding prototype element values can be taken from Table I scaled according to equation (5) – see Table II.

TABLE II
THE SCALED AND UNSCALED VALUES OF THE FILTER ELEMENTS

Element	Prototype value	Scaled value
C_1	0.445	0.142 pf
L_2	1.247	0.993 nH
C_3	1.8019	0.574 pf
L_4	2	1.592 nH
C_5	1.8019	0.574 pf
L_6	1.247	0.993 nH
C_7	0.445	0.142 pf

Microwave office program simulation results of the proposed design schematic are illustrated in Fig.5 where as Fig.6 illustrate the result of the same structure when using the image parameter method. It is clear that the proposed design give flat gain of 14 dB over the range (0-10 GHz) while, the other method gave gain of 14 dB with (10 dB p-p) ripple over the same bandwidth. On the other hand, the reflection losses S_{11} and S_{22} of the new method are lower than those obtained by the old method. These results simply lead to the superiority of the proposed design method over the other one.

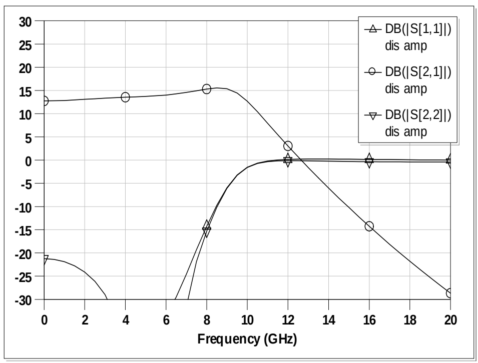


Fig.5 S-parameters in 4-stage insertion loss DA

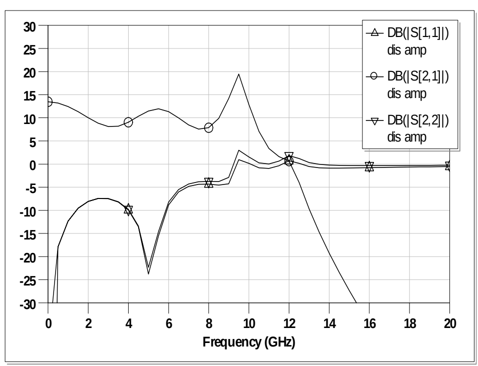


Fig.6 S-parameters in 4-stage image parameter DA

IV. CONCLUSION

In this paper, a new method for the distributed amplifiers design has been presented. The image parameter with cascading constant k-filter sections was replaced by the insertion loss method. The performance of the new technique is dependant on stagger tuning and shaping of the frequency response. The amplitude roll-off due to a low frequency pole in one stage can be compensated in the next stage and so on. Maximally flat or Butterworth filter provide flattest frequency response. The new method has been demonstrated to offer considerable performance improvement over the old method. It provides flat response over the bandwidth range even without optimization.

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