On Distributed Amplifiers with Bandpass Filter Structure

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Abstract

It is very important to increase the maximum frequency of operation of a distributed amplifier, and using the bandpass filter structure in place of the lowpass may be a good solution for some applications not needing DC operation. In this paper, some important points of a distributed amplifier with bandpass filter structure are studied by using a model of a distributed bandpass transmission line. The BP structure used in this work is different from the reported one and gives much better results. At the same time, effects of the input parasitic resistance (Ri) of transistors on the performance are illustrated on the relevant characteristics with SPICE simulations.

1.Introduction

In distributed amplifiers (DA) there are two artificial lines [1-8]. These artificial transmission lines are constructed with parasitic capacitances at the input and output of the active components (mostly FET) and inductances added to the DA. The schematic diagram of a conventional DA is given in Figure 1.

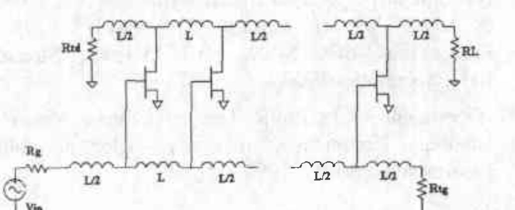


Figure 1 A conventional distributed amplifier

The artificial transmission lines in a DA show a lowpass filter characteristic. Therefore, we can easily think of using an alternative for the DA: bandpass filter structure [6,7,8]. By using this alternative, we can shift the band of operation to a higher frequency range and this is very important for some applications not needing DC operation.

Minnis has made some works on a DA with bandpass (BP) filter structure and has presented a different BP filter structure to increase the upper frequency limit of a conventional DA [7,8]. In his works, the classical approach (artificial transmission line approach) has not been used for the DA. The works have been made by using a different technique (Exact Synthesis) [8].

In this work, a model for a distributed bandpass transmission line is given with basic analyses and formulas. Then, by using the results of this model, a DA with BP structure is considered in ideal case and it is given in comparison with the BP structure used by Minnis. In the last step, the most important problem of a conventional DA which is the parasitic resistance of active components is taken into account and the relevant characteristics are given. These results were not given by Minnis because of his different approach.

2.Distributed BP Transmission Line

The model of a distributed bandpass transmission line is shown in Figure 2.

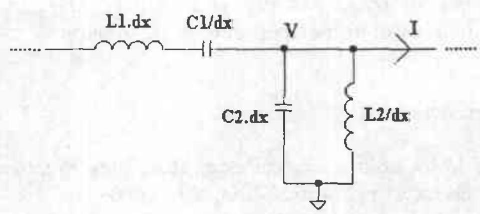


Figure-2 A distributed bandpass transmission line

By using this model, the basic equations for voltages and currents through the line can be easily written,

$$-\partial V=(sL_1+1/sC_1).\ \partial x.I \qquad (1\text{-a})$$

$$-\partial I=(1/sL_2+sC_2).\ \partial x.V \qquad (1\text{-b})$$

From these equations, one can obtain a differential equation for the voltage

$$\partial^2 V/\partial x^2=Z.Y.V \qquad (2\text{-a})$$

$$Z=sL_1+1/sC_1 \quad Y=1/sL_2+sC_2 \qquad (2\text{-b})$$

In general, this equation is the same as the differential equation obtained in the lowpass case. The solution of Eq. 3 for $V=V_0\, e^{\gamma x}$ gives us a known result,

$$V=Ae^{-\gamma x}+Be^{\gamma x} \qquad (3)$$

As known, A and B are the incident and reflected waves respectively through the line. Then, two basic parameters of the transmission line are obtained after routine analyses: γ (propagation coefficient) and Z_0 (Characteristic impedance). By using Eq. 1, 2 and 3 one can easily obtain the equations of these basic parameters,

$$Z_o = \sqrt{\frac{Z}{Y}} \qquad \gamma = \sqrt{ZY} \tag{4}$$

After the routine analysis, it is seen that Z_0 is constant under the condition of

$$\frac{L_1}{L_2} = \frac{C_2}{C_1} \tag{5}$$

At the same time, under this condition the frequency (ω_o) that gives γ=0 is only one. For this condition we obtain the equations of

$$Z_0 = \sqrt{\frac{L_1}{C_2}} = \sqrt{\frac{L_2}{C_1}} \tag{6}$$

$$\gamma = j\frac{\omega^2 L_2 C_2 - 1}{\omega}\frac{1}{\sqrt{L_2 C_1}} \tag{7}$$

$$\omega_0 = \sqrt{\frac{1}{L_2 C_2}} = \sqrt{\frac{1}{L_1 C_1}} \tag{8}$$

3.The DA with BP Structure

As in the lowpass case, when changing the distributed BP structure into lumped BP structure, the equations of Z_0 and γ are valid for a limited band. The central frequency of this band is ω_0 and its width is $1/\pi\sqrt{L_2 C_1}$ as in the lowpass case.

Considering all these results, we obtain some information about a DA with BP structure,

i) Provided the condition of $L_1/L_2=C_2/C_1$ is satisfied, Z_0 is approximately constant in the band.

ii) The bandwidth of a DA with BP filter structure is equal to that of a DA with lowpass filter structure and the central frequency is ω_0.

iii) The phase response is approximately linear in the band.

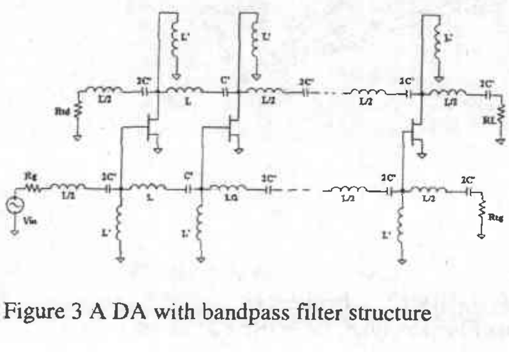


Figure 3 A DA with bandpass filter structure

The results given above show that the BP filter structure may be a good way to increase the upper frequency limit of a conventional DA. The schematic diagram of a DA with the bandpass filter structure is given in figure 3.

4.A Comparison with the structure used by Minnis

Minnis has used a different bandpass filter structure.In this BP filter structure, there is only a parallel inductance (L_2) to parasitic input and output capacitances in addition to lowpass case and C_1 is not used. But, in that case, when obtaining the equations for this BP structure in distributed case as done above, we see that Z_0 can not be kept constant against frequency. At the same time, the bandwidth of a DA using this structure narrows in the lumped case as the lower frequency limit increases. After all these results one can say that this structure does not give a good performance change. The characteristics obtained on the same conventional amplifier in ideal case (i.e. the effects of the parasitic resistances are not taken into account) by using both structures are given in Figure-4. These characteristics show that the above given information about the structure used by Minnis is valid and therefore the structure is not a good alternative.

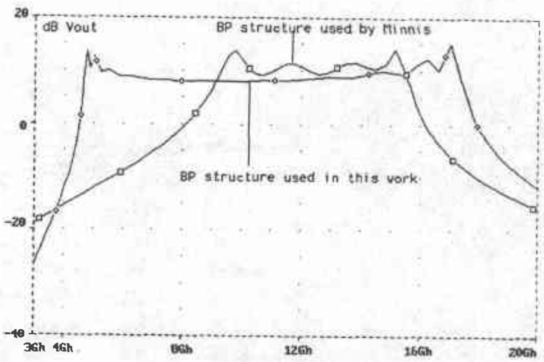


Figure 4 The comparison between the BP structures in ideal case.

5.The Effects of the Parasitic Resistance (Ri)

One of the important problems in a DA against wide-band amplification is the parasitic resistance (Ri) at the input of the transistors. Figure 5 gives the simplified model of a FET including Ri.

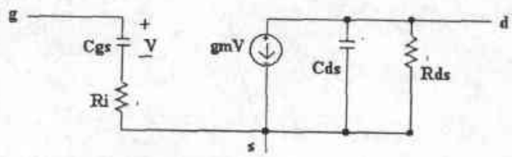


Figure 5 Simplified FET model

This parasitic resistance causes the signal to weaken through the artificial transmission line. But, the main problem is that the conductance which appears because of Ri through the input line (gate-line in a FET) rapidly increases near the cut-off frequency[1,2]. Therefore, the upper frequency limit of a conventional DA can not be equal to the cut-off frequency (fc). The same gate-line loading exists in a DA with BP filter structure too, because the BP filter structure does not change the input parasitic capacitance and resistance and the gate-line loading depends only on Ri, C_{gs} and frequency. Finally, the performance of a DA with BP filter structure depends mostly on the input parasitic resistance.

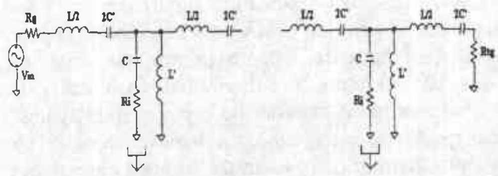
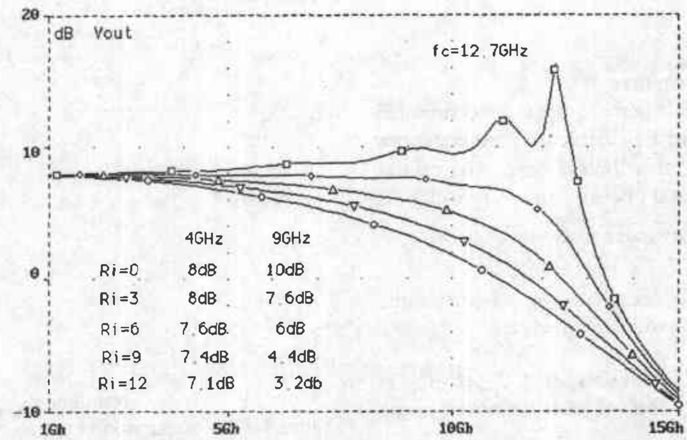


Figure 6 The input line of a DA with BP structure

Some simulations have been made on a DA with BP filter structure by using SPICE. The characteristics obtained at the end of the simulations give us the opportunity of observing how the performance of a DA with BP filter structure is affected by Ri. The DA used in the simulations includes five transistors and the gain of each transistor is unity. Rds is taken as ∞. The values of the other components are given in Table 1. The effect of Ri on the DA with BP filter structure is illustrated in Figure 7, 8 and 9. As known, actually Cds is smaller than Cgs. In practice, it is aimed that the characteristic impedances and the delays of the input and output lines be equal to each other. Therefore an extra capacitance is used to make Cds equal to Cgs.

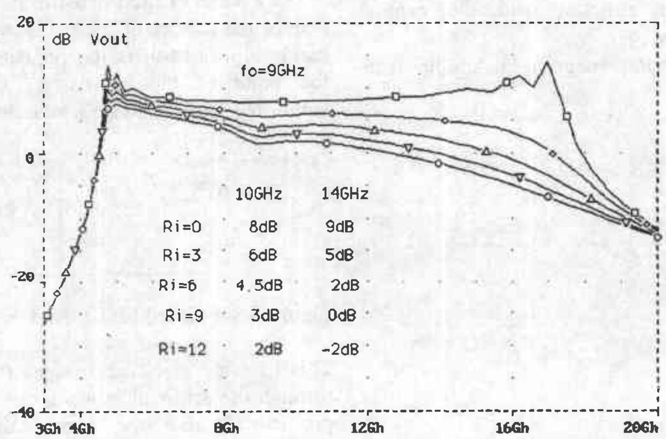
Table-1 The values of elements

LP,	**fc=12.7GHz, Zo=50**
Cgs	0.5pF
Cds	0.5pF
L	1.25nH
gm	40mS
BP,	**fo=9GHz, Zo=50**
C'	0.25pF
L'	.625nH
BP,	**fo=12.7GHz, Zo=50**
C'	0.125pF
L'	.3125nH



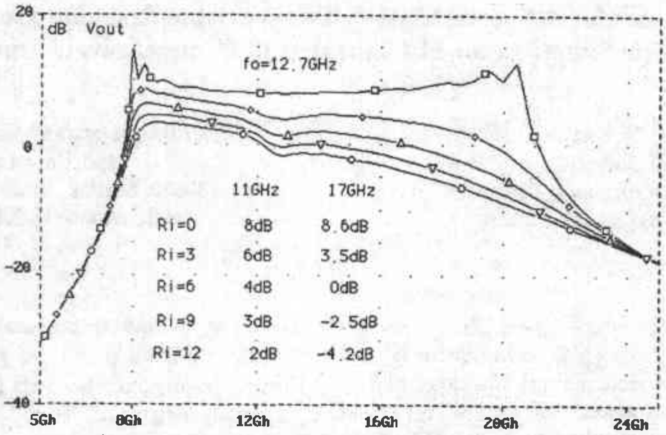
□□ Ri=0, ◊ ◊ Ri=3, Δ Δ Ri=6, ∇ ∇ Ri=9, o o Ri=12 frequency

Figure 7 The gain of the DA with lowpass filter structure



□□ Ri=0, ◊ ◊ Ri=3, Δ Δ Ri=6, ∇ ∇ Ri=9, o o Ri=12 frequency

Figure 8 The gain of the DA with bandpass filter structure, fo=9GHz.



□□ Ri=0, ◊ ◊ Ri=3, Δ Δ Ri=6, ∇ ∇ Ri=9, o o Ri=12 frequency

Figure 9 The gain of the DA with bandpass filter structure, fo=12.7GHz

When looking at the characteristics, one can see that the band of operation of the DA with BP filter structure is shifted to a higher frequency range. But, both the gain and the bandwidth of the DA decrease as Ri increases and we can not achieve a greater than 1.5:1 increase in the maximum frequency of operation of a distributed amplifier for great values of Ri.

In spite of the bad effect of Ri, using the BP filter structure in a DA appears to be a good way to increase the maximum frequency of operation. On the other hand, when using this way, we sacrifice some gain to the higher maximum frequency of operation.

CONCLUSION

In this work, a DA with bandpass filter structure is investigated by means of a distributed bandpass transmission line. When compared to the structure used by Minnis, the performance of the BP filter structure used in this work is a much better way to increase the maximum frequency of operation of a conventional DA. Additionally the effect of the input parasitic resistance in transistors (Ri) is an important problem in conventional distributed amplifiers and the effects of this parameter on a DA with BP filter structure are given in this paper. The results of this work shows that under the condition of $L_1/L_2=C_2/C_1$, using the BP filter structure is a good way to increase the maximum frequency of operation of a conventional distributed amplifier. On the other hand, Ri strongly affects the performance of the DA and therefore we may use this way in a limited range.

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