Performance Amelioration of 2x4 and 3x4 Matrix Amplifiers

G. Moradi[1] **A. Abdipour[2]**

1- Civil Aviation Technology College, Mehrabad Int'l Airport, Tehran,Iran
2- Electrical Engineering Dept., Amirkabir University of Technology Tehran, Iran

Abstract: Some considerable factors for optimizing the signal and noise performances of a matrix amplifier for broadband applications have been discussed. It is shown that proper loading of both external (i.e. input and output) lines and also the middle electrodes improves the device performances. Besides, due to discrepancy between the phase velocities of different lines, the capacitive compensation of these electrodes has a considerable influence on the behavior of the device. Also it is shown that using a tier of HBTs at the output of the matrix amplifier is effective in increasing the power gain of the device. The proposed technique is applicable in improving the performance of Microwave and mm-wave ICs.

Keywords: Matrix amplifier, Wideband amplifier, Electrode loading, Phase synchronization

1. INTRODUCTION

There are many active devices suitable for microwave and mm-wave applications, which have good signal characteristics [1]. Combining some of these active elements in a circuit may cause to a better performance. One structure for improving the signal performances of solid-state amplifiers is a distributed amplifier [2]. Another structure for improving both the signal and noise performances of amplifiers is the traveling wave amplifier (TWA), which uses a few transistors in a single tier. This structure is also used for increasing both the bandwidth and also the power handling capability of the device [3]. The other important structure is matrix amplifier [4], which has more than one tier of solid-state devices [4-5]. In this type, the active elements located in a column are used to increase the gain, and the elements in a tier increase the bandwidth. Matrix amplifier can use different active elements (i.e. HEMT or HBT) for each tier. The best selection is a matrix structure having HEMTs in the first tier and HBTs in the last tier. This leads to lower DC power consumption, better input and output impedance and higher gain respect to other configurations.

This paper merging our recent conference papers [6-7], proposes a method for improving the performance of linear matrix amplifiers. For modeling the noise sources of the active devices, the common noise models have been used [8-10]. Also, the Rizzoli's general approach has been used for the noise analysis [11]. The developed routine can be applied to nonlinear travelling wave amplifiers and mixers.

2.NOISY MODEL OF A MATRIX AMPLIFIER

Here, we discuss the algorithmic approach for simultaneous signal and noise performances of a matrix amplifier. The schematic diagram of noisy two-tier and three-tier matrix amplifiers have been shown in Fig. (1). The current noise sources in this figure are the equivalent noise sources of the active elements, which can be obtained after setting a suitable noise model (e.g. the Pospiezalski noise model) for these elements. Also the thermal noise sources of the resistive loads are included in these sources.

The signal analysis of the circuit is straightforward. For noise analysis, the Rizzoli's approach [9] is used. First, the circuit is partitioned into two passive and active parts. Then for each part, the noise correlation matrix (NCM) is calculated. The overall noise correlation

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matrix of the circuit is expressed by:

$$C_Y = H_N C_L H_N^{*t} + H_J C_J H_J^{*t} \qquad (1)$$

in which, H's are functions of circuit elements [11].
CL and CJ in equation (1) are the noise correlation matrix (NCM) of the passive part and the NCM of active part, respectively. CL is simply related to the admittance matrix (i.e. Y) of the circuit, i.e.:

$$C_L = 4KT\Delta f .real(Y) \qquad (2)$$

On the other hand, the overall NCM of the active part (i.e. CJ) contains the NCM of each active element. It is easy to prove that the NCMs for the HEMT and HBT can be expressed by (3) and (4) respectively.

(3)

$$C_{FET} = \frac{1}{T_0(1+\omega^2 C_{gs}^2 R_i^2)} \begin{bmatrix} T_g(\omega^2 C_{gs}^2 R_i) & T_g(j\omega C_{gs} R_i) \\ -T_g(j\omega C_{gs} R_i) & T_g(g_m^2 R_i) + T_d(1+\omega^2 C_{gs}^2 R_i^2) G_{ds} \end{bmatrix}$$

$$C_{BJT} = \frac{1}{4K T_0 \Delta f} \begin{bmatrix} 2 q_e I_b \Delta f & 0 \\ 0 & 2 q_e I_c \Delta f \end{bmatrix} \qquad (4)$$

It is noticeable that for calculating CFET and CBJT, we have used simple noise models of the active parts as shown in Fig. 2.
After calculating the CY (i.e. equation 1), the noise figure of the amplifier is calculated by (5), in which H and are functions of the circuit parameters [11].

$$NF = 1 + \frac{\vartheta^{*t} H C_Y H \vartheta}{\mathrm{Re}(Y_S)} \qquad (5)$$

3.THE PROPOSED OPTIMIZATION TECHNIQUES

To have a wide band amplifier, the circuit either single port or multiport should be properly matched. For a matrix amplifier there are two accessible ports as input and output ports. Surely these ports are matched to reduce the input and output VSWRs of the circuit. By the way, the other ports should be properly loaded so that the unwanted reflections are minimized. It is obvious that a matched port has less frequency sensitivity than an unmatched one. The influence of the proper loading on improving the signal and noise performances of matrix amplifiers will be verified in the next section.
Our study shows that the performance of a matrix amplifier can be further ameliorated by phase synchronization of the different lines. We know that in a transmission line having at least two different structures, the propagation characteristics such as the phase velocities and the phase constants are different. This means that wave propagating in this hetero-structure system will be dispersed and therefore the bandwidth of the circuit will be very low. Hence using a capacitor parallel to the line having higher phase velocity will reduce the dispersion. In the next section, we will show the validity of this technique, by increasing a capacitor parallel to the drain or collector ports of the FETs or BJTs, respectively.
The other technique that is effective in improving the performance of the circuit is using more elements in each row or column. Of course this increment is limited due to the saturation and other nonlinear characteristics of the active elements. Finally, using active elements or active structures with higher transconductance leads to higher gain for the circuit.

4.RESULTS

The procedure explained in section 2 has been used to calculate the signal and noise analysis of both two-tier and 3-tier matrix amplifiers. The data of the transistors are extracted from [5-6]. As our recent paper, the feedback capacitor (i.e. Cgd and C) are taken into account. It is noticeable that although the influence of these capacitors is not seen in the NCM, they are reflected in the NF through the signal parameters of the device.
The results of the analysis for 2-tier and 3-tier matrix amplifiers have been shown in Figs. 3-7. Fig 3 shows that although we have considered the feedback capacitance, the results are close to that of [5].
As shown in Fig. 4.(a, b), for increasing the bandwidth of the 2-tier amplifier, the first line must be terminated by a proper load. This is obvious because the effective matching of each line with proper loads leads to a structure having a traveling wave mode, which inherently has higher bandwidth. This shows that it is not suitable to leave the electrode to be open circuit. Fig. 4(c, d) shows that similar results are obtained for loading the

second electrode. The same is correct for the third line. The simulation has been repeated for a three-tier matrix amplifier. Again, as it is seen in Fig. 5, for increasing the bandwidth of the circuit, all of the lines must be terminated by a proper load. For instance, it is shown in Fig. 5.a that causes to better signal and noise performances respect to and .It should be noted that in deriving the results of the Fig. 4 and Fig. 5, we have studied the effects of one of the loads while using matched loads for the other ports.

The influence of phase synchronization capacitance on the device performances of the 3-tier matrix amplifier has been presented in Fig. 6. As this figure shows, the capacitance of the first line must be as low as possible to improve the device performances. This is predictable because it synchronizes the phase velocity of the first line with those of the other lines. Although, it is noticeable that due to the parallel connection of Cds and C , the influence of Cds on the device performances is not considerable, however a value of Cds in the order of 20 fF improves the performance of the device. This is the same value, which is used for simulations in [5]. On the other hand, we can use HBTs having lower value of C to synchronize the phase velocity of the different electrodes. Fortunately physical implementation of the synchronization capacitor is straightforward.

The similar results are obtained for other structures having more active elements in each tier or row. It is interesting to note that for a matrix amplifier having more active elements in each tier, the performance of the device is more sensitive to the diagonal elements. This shows that when applying these structures in modern microwave simulators, the device data and the extrinsic elements of the diagonal elements must be as accurate as possible.

The results have been extracted by a simple software written in Matlab simulator. However, they are completely matched with the results of a modern simulator (i.e. Libra). These results can be used in optimized realization of matrix amplifiers. Note that due to the full similarity of the results using Libra and those of using our Matlab-based software, we have merely focused on our results.

The analysis is repeated for the case in which all three tiers of the matrix amplifier are in FET structure. The results have been shown in Fig. 7. Again, it is seen that both phase synchronization and proper electrode loading has a considerable influence on the device performances. Comparing the results of this structure with that of previous one (i.e. Fig. 5) shows that higher gain is achieved for the matrix amplifiers using HBTs in the last tier.

To show the sharing of passive and active parts in the overall noise figure, we have calculated these two parts separately. It should be noted that here we have used a lossy model for the transmission line connecting the active elements. To remove the sharing of passive elements on the noise performance, we have easily set the noise temperature of the lossy transmission lines to be zero Kelvin. It is obvious that using a lossier model leads to a higher noise figure. Fig. 8 shows that the noise performance of passive part is less important in higher frequencies. This is because in higher frequencies the reactive (inductive and capacitive) elements dominate the resistive parts. Therefore, the passive section is approximately reactive and does not generate noise. It is noticeable that, the descending behavior of noise figure versus frequency in passive part and the ascending function of the active part lead to a nearly flat response for the noise figure.

5.CONCLUSION

It has been shown that suitable loading of electrodes may increase the gain and decrease the noise figure of the device. Also it has been shown that phase synchronization of different lines may lead to travelling wave mode, which in turn improves the device characteristics. Besides, the advantage of using proper combination of HBT and HEMT has been discussed. At last, the sharing of passive and active part in overall noise performance of the matrix amplifier has been studied. Although we have focused on and structures in deriving the simulation results, it is believed that the ideas proposed in this paper are valid for any matrix amplifier. These ideas can be used in optimized implementation of wideband MMICs.

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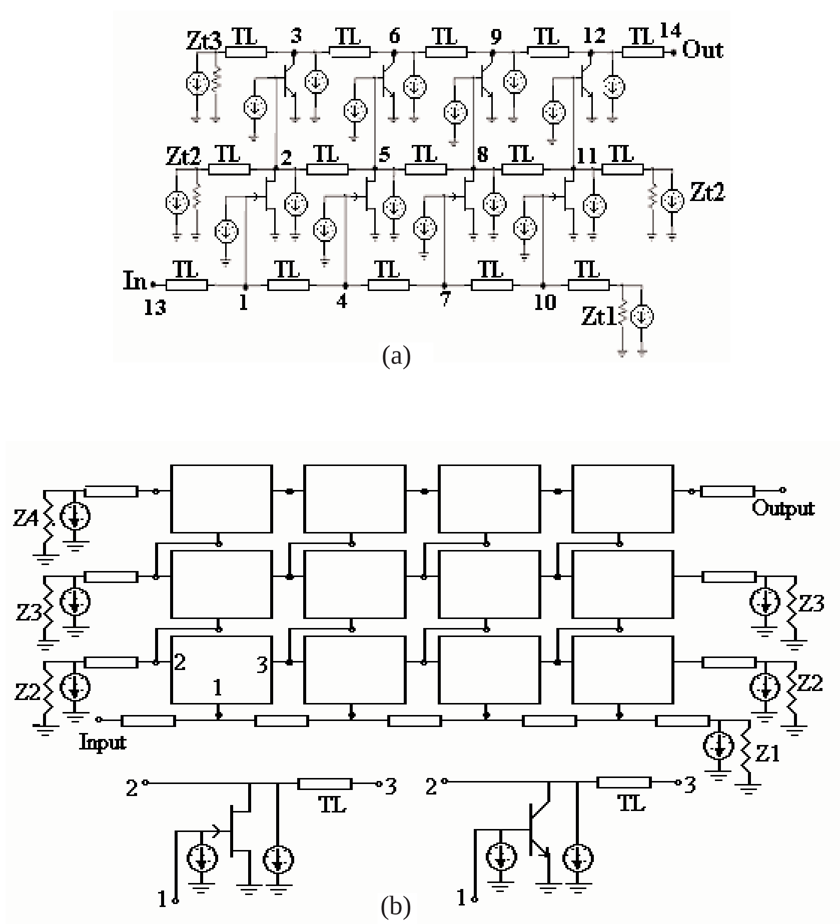
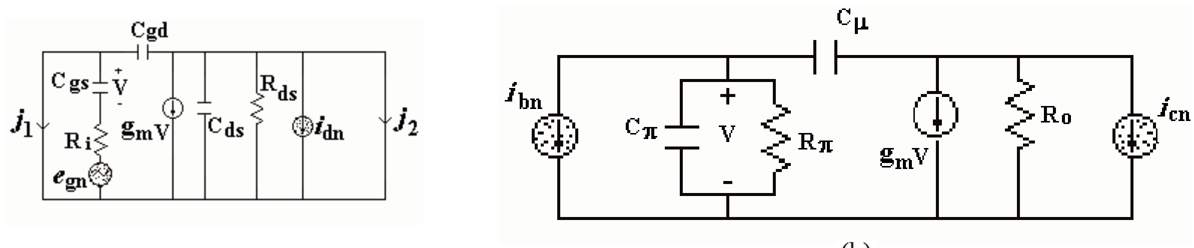


Fig. 1. Schematics of noisy (a) 2-tier and (b) 3-tier matrix amplifiers



(a) (b)

Fig. 2: Simple noise model of (a) a HEMT and (b) an HBT

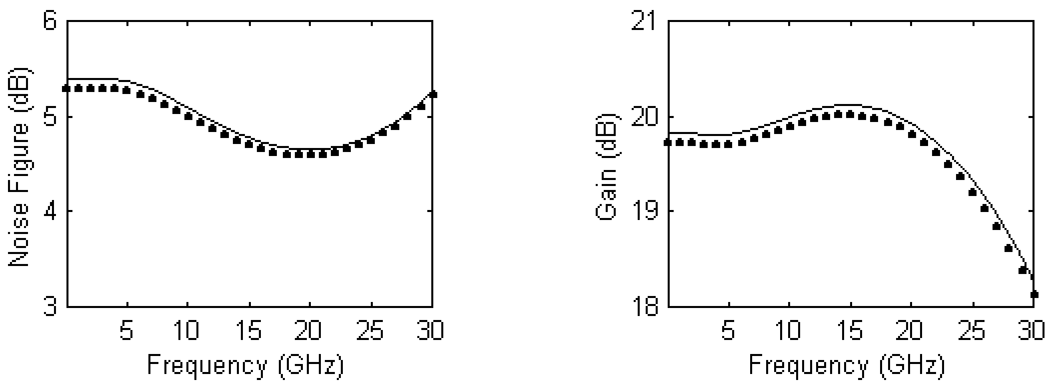


Fig. 3: Comparison of the noise figure and conversion gain of a 2-tier matrix amplifier for our simulation results (solid lines) with that of [5] (dashed lines).

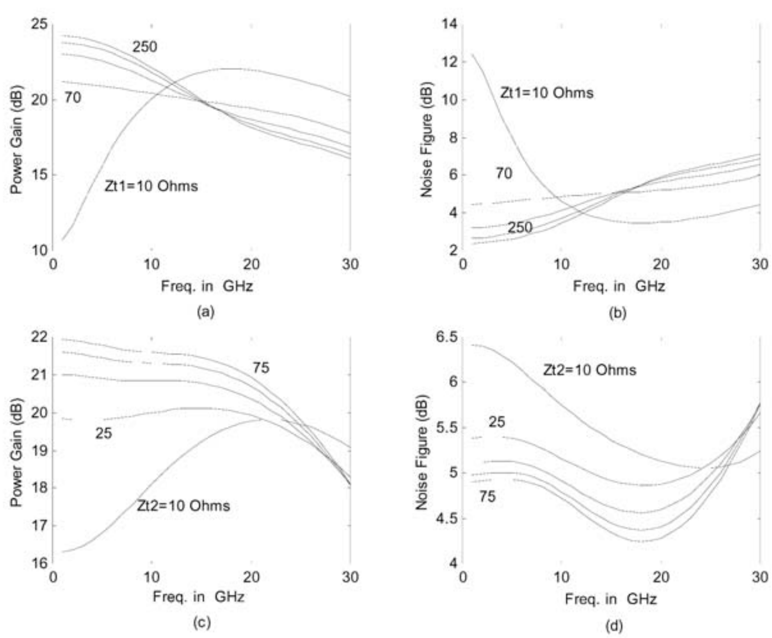


Fig. 4: Power gain and noise figure spectrum for different configurations of the electrodes' terminations.
(a) and (b): Influence of the load of the first line (Zt1) on power gain and noise figure.
(c) and (d): Influence of the load of the second line (Zt2) on power gain and noise figure.

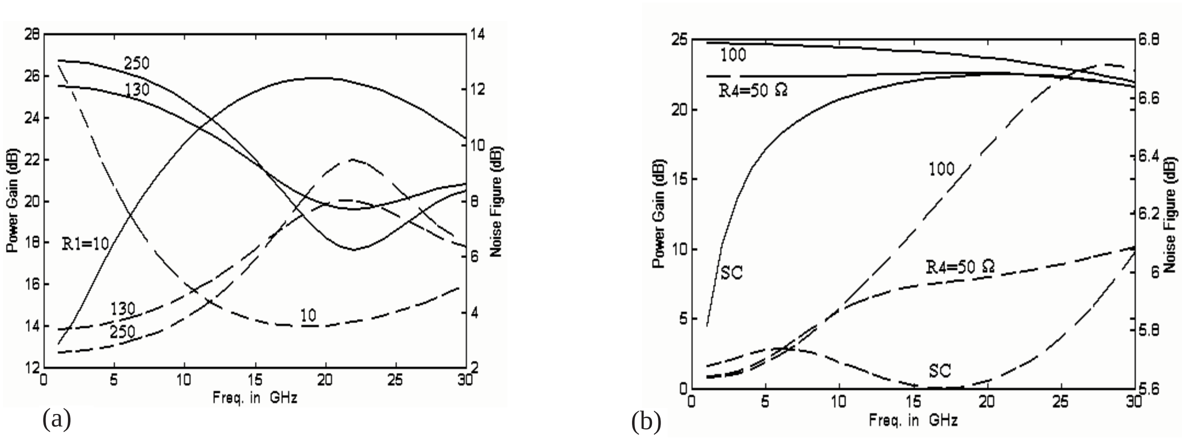


Fig. 5. Power gain (solid line) and noise figure spectrum (dashed line) for different configurations of the electrodes terminations in the HEMT-HEMT-HBT matrix amplifier
(a): Influence of the load of the first line (R1) (b): Influence of the load of the fourth line (R4).

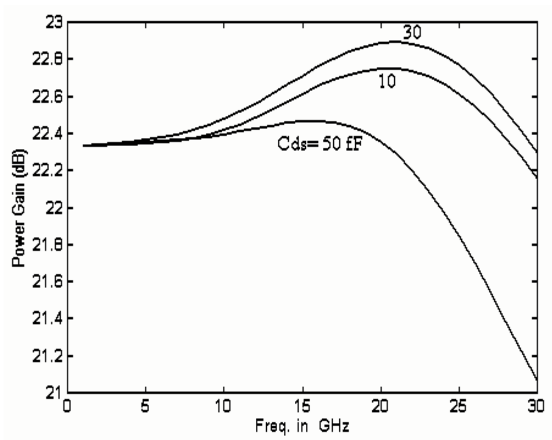


Fig. 6. Influence of (HEMT) drain capacitance on signal performance of the HEMT-HEMT-HBT matrix amplifier

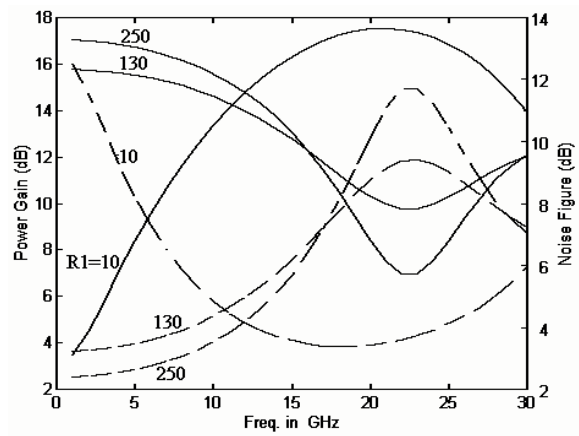


Fig.7. Influence of loading of the first line on signal performance (solid lines) and noise performance (dashed lines) of the HEMT-HEMT-HEMT matrix amplifier

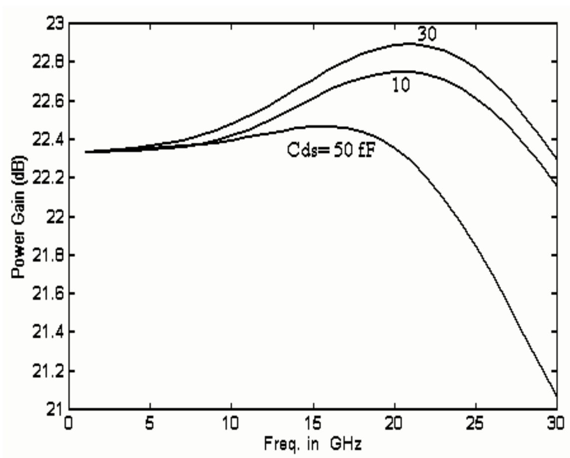


Fig.8. Influence of the passive and active parts on the noise performance of a two-tier matrix amplifier. Dashed line curve refers to the case where the passive elements are assumed noiseless.