TWO STAGE DOUBLE LAYER MICROSTRIP SPATIAL AMPLIFIERS

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ABSTRACT

Several two stage spatial amplifiers are presented. The amplifiers were constructed on double layer back to back microstrip circuits with a shared ground plane. The ground plane provides an effective isolation between the receiving antenna array and the transmitting antenna array. Furthermore, it serves as a heat sink in high power amplifier design. The coupling between the two stages is accomplished through microstrip to slot transitions, therefore there is no electrical contact from one layer to another. This facilitates monolithic fabrication of such amplifiers. The measured gain of a 3x3 spatial amplifier at 9.95 GHz is 18.0 dB.

INTRODUCTION

In order to increase the output power of solid state amplifiers at millimeter wave frequencies the output power from many devices must be combined. Due to the guiding wave losses at millimeter wave frequencies conventional power amplifier design techniques which use Wilkinson type combiners or four port hybrids become inefficient. The efficiency of these types of power combining amplifiers degrades as the number of devices that are power combined increases. This is due to the fact that larger lengths of guides are required to interconnect more devices. In order to alleviate guides wave losses in combining circuits, one can couple the waves into and out of an array of solid state amplifiers in free space. Recently there has been an increased interest in the area of spatial and quasi-optical power amplification [1-8]. The first demonstration of a grid amplifier was reported in [1]. Subsequently larger grid amplifiers were reported in [2]. A quasi optical amplifier based on an integrated horn antenna is presented in [3]. In [4] a quasi-optical transmission amplifier is demonstrated. In [6] a reflection type amplifier which uses folded slot antennas fed by coplanar waveguides is presented. In [7] a new approach which places unit cells of a quasi optical amplifier in short sections of square waveguide is investigated

Several single stage spatial amplifiers were reported in [8] which employed double layer microstrip circuits coupled to one another through via holes. In this paper we present several two stage spatial amplifiers on double layer back to back microstrip circuits with a shared ground plane. The coupling between the two stages is accomplished through microstrip to slot transitions, therefore there is no electrical contact from one layer to another. This facilitates monolithic fabrication of such amplifiers. The common ground plane plays two important roles. It provides a very effective isolation between the receiving antenna array and the transmitting antenna array and it serves as a heat sink in high power amplifier design. Separating the two stages may also play an important factor when the excess heat density is of concern. This type of structure allows the circuit designer to reduce the device density by spreading the devices between the two layers, thereby reducing the thermal power density. Therefore, this paper presents a new approach which has the potential to address the heat flow, the isolation between input and output ports and MMIC compatibility problems simultaneously.

DESIGN

A perspective view of a two stage double layer back to back microstrip spatial amplifier is shown in Fig. 1. The first stage of the amplifier is fabricated on layer one while the second stage is placed on layer two. The receiving and transmitting antennas are isolated from one another by the common ground plane. The output of the first stage is coupled to the input of the second stage via microstrip to slot transitions, therefore the two stages of the spatial amplifier are electrically isolated. Experiments show that the slot transition is essentially transparent to the amplifiers.

Figs. 2a, b show the unit cell of the two stage spatial amplifier. A slightly modified version of a broadband slot-coupled double sided microstrip interconnect [9] is used to couple two microstrip layers to one another. The diagram of a slot coupled double sided interconnect is shown in Fig. 3. To determine the insertion loss of this transition ,quarter wave transformers are used to match the slot impedance to 50 ohms transmission lines. The slot and microstrip dimensions are chosen such that they are easily realizable. The measured insertion loss and return loss for three different slot widths are shown in Fig. 4. The insertion loss of the transition with a slot width of 5 mils was measured to be better than 0.2 dB at the center frequency. As can be seen the insertion loss is not a strong function of the slot width. A slot width of 5 mils was chosen in the design of the two stage spatial amplifiers presented herein.

The unit cell of a 10 GHz spatial amplifier shown in Figs. 2a, b employes microstrip patch antennas to receive the input signal and to recombine the output power into free space. To design the amplifier the simultaneous conjugate match susceptances are provided to the input and the output of the active devices by open circuited stubs. Then the input conductances of the microstrip antennas (input and output ports) and microstrip to slot line transition (interstage coupling) are transformed into simultaneous conjugate match conductances using quarter wave transformers. Thus the simultaneous match conditions are fulfilled. The design was performed using a commercial microwave circuit analysis program Libra TM.

In order to verify the effect of a slot transition on the amplifier's performance prior to the construction of the spatial amplifier, a two-stage amplifier circuit in a 50 ohm system was designed and fabricated (the amplifier was identical to the one shown in Figs. 2a, b except that the microstrip antennas were replaced with quarter-wave transformers matching the amplifier's input and output impedances to 50 Ohms). The same amplifier was also fabricated on a single layer microstrip circuit (hence removing the slot transition). Plots of the measured gain versus frequency for the test amplifiers are shown in Fig. 5. As can be seen the two curves are almost identical. This demonstrates that the broadband slot transition does not degrade the amplifier's performance. The active devices used were Fujitsu FHX06LG HEMTs. Devices were biased at 2 volts with the drain current of 10 mA. The circuits were built on RT/Duroid with $\varepsilon r = 2.33$ and thickness of 31 mils.

In the next step a unit cell of a two stage double layer spatial amplifier was fabricated (Figs. 2a, b). The spatial amplifier's gain was calculated using the method outlined in [4]. A maximum gain of 18.5 dB was determined at 9.8 GHz. A plot of the unit cell two stage spatial amplifier's gain versus frequency is shown in Fig. 6. Measured and calculated E and H plane antenna patterns are given in Fig. 7. Subsequently a 1x3 two stage spatial amplifier was designed and fabricated. The measured gain was 18 dB at 9.8 GHz.

Figs. 7 shows the gain plot of a 3x3 two stage amplifier. There are a total of 18 HEMTs used in this structure. Maximum gain of 18 dB was measured at 9.95 GHz. Calculated and measured E plane patterns of the 3x3 amplifier array are compared in Fig. 8.

CONCLUSIONS

Several two stage spatial amplifiers were demonstrated. The amplifiers were constructed on double layer back to back microstrip circuits with a shared ground plane. The ground plane provides an effective isolation between the receiving antenna array and the transmitting antenna array as well as serving as a heat sink in the design of high power amplifiers. The coupling between the two stages is accomplished through microstrip to slot transitions, therefore there is no electrical contact from one layer to another. This facilitates monolithic fabrication of such amplifiers.

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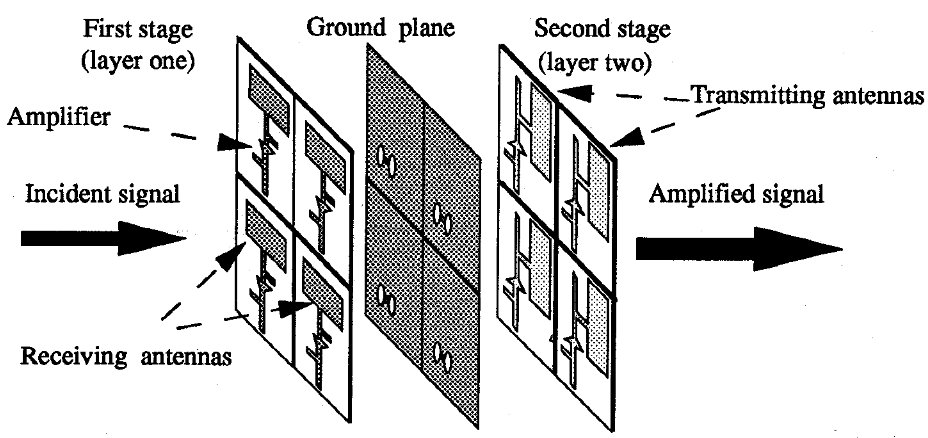

Figure 1. Perspective view of a two stage double layer back to back spatial amplifier.

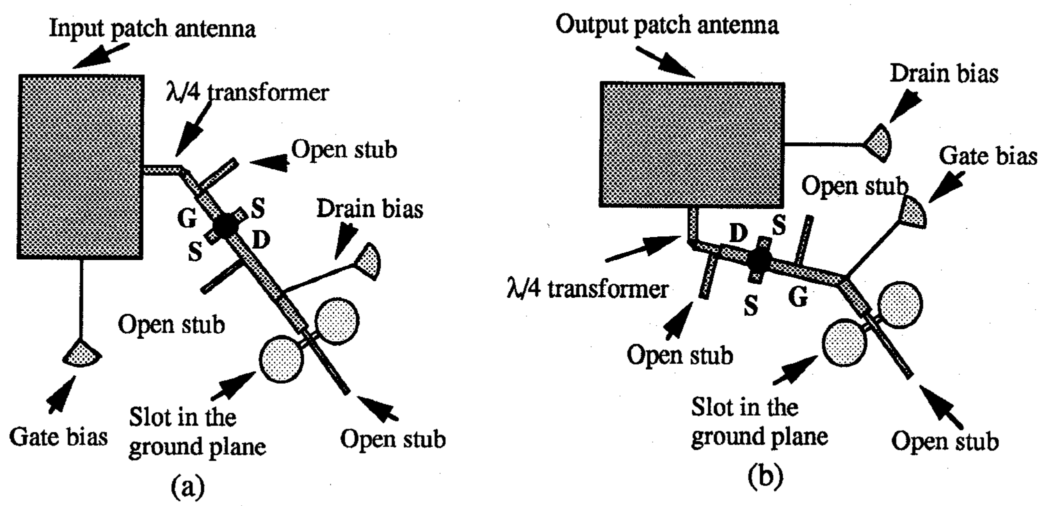

Figure 2. Layout of the unit cell. (a) input layer, (b) output layer

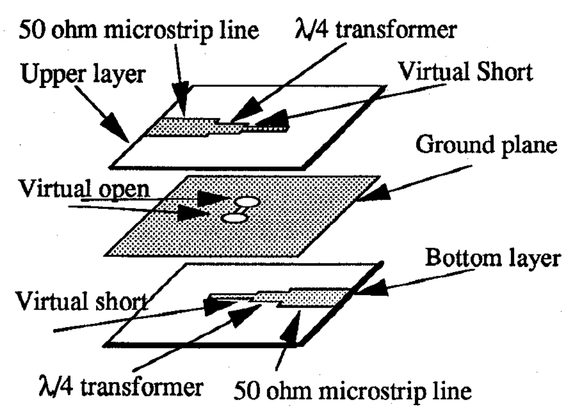

Figure 3. Slot-coupled double sided interconnect

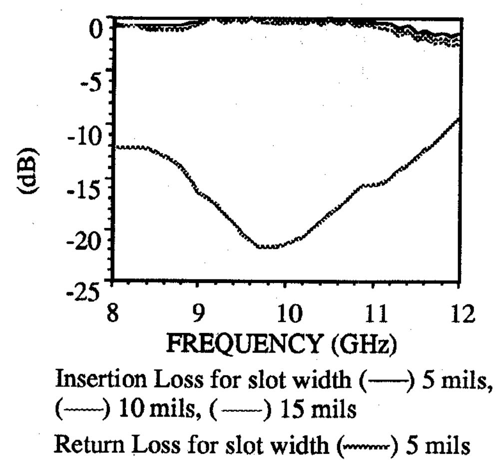

Figure 4. Insertion and return loss of slot-coupled double sided interconnect

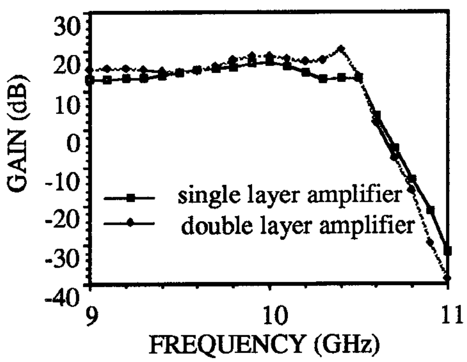

Figure 5. Gain versus frequency responce of a single and a double layer two stage amplifier .

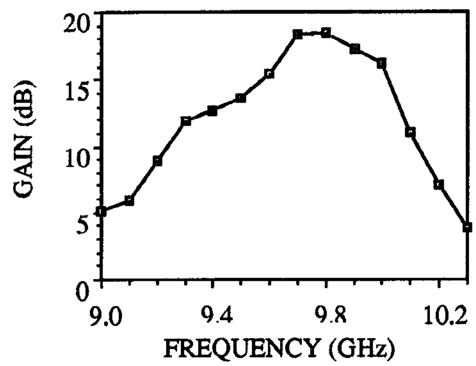

Figure 6. Gain versus frequency plot of a two stage double layer spatial amplifier's unit cell.

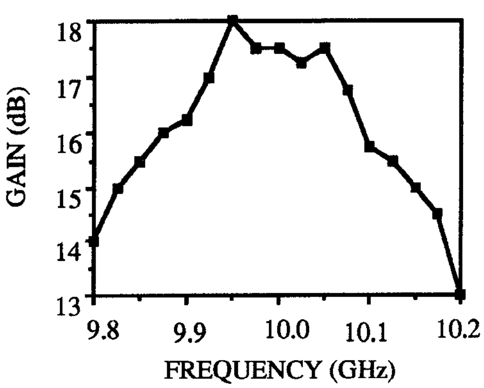

Figure 7. Gain versus frequency plot of a 3x3 two stage amplifier array.

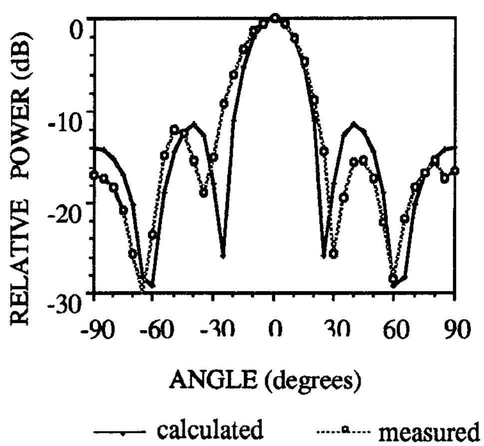

Figure 8. Measured and calculated E-plane patterns of a 3x3 two stage amplifier array.