QUASI-OPTICAL TRAVELING WAVE AMPLIFIERS

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ABSTRACT

Previously reported quasi-optical amplifier arrays have limited bandwidth and suffer from poor input/output isolation. These problems can be solved by using traveling wave antennas and distributed amplifier techniques. FDTD simulations of a linearly tapered slot array topology demonstrate very broadband quasi-optical transitions are feasible with small unit-cell aperture. Experiments using a single-element low frequency prototype exhibit a 50% fractional bandwidth at 3.5GHz using Vivaldi-type slots and a hybrid microstrip MESFET TWA circuit.

INTRODUCTION

While the reliability of solid state devices is high their output decreases at high frequencies. Increased circuit losses make quasi-optical power combining attractive, particularly at mm and sub-mm wavelengths. A number of researches have devoted significant time in developing amplifiers for quasi-optical systems [1-6]. A single element consists of a receiving antenna, an active device and a transmitting antenna. These modules are integrated in a 2-dimensional array for efficient power combining. Some investigators prefer a dense grid [1] approach whereas others chose a more sparse design [2]. Lack of space prevents the use of broad band antennas such as bow-ties and spirals.

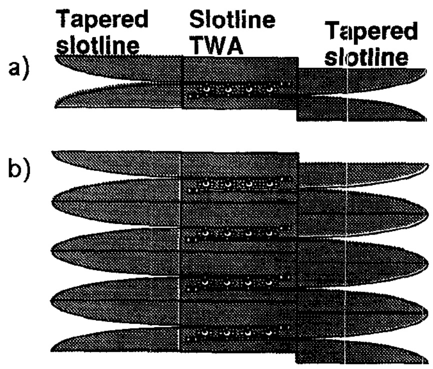

Figure 1 - Quasi-optical TWA **a)** single element **b)**Array

Narrow band antennas (patches and slots) coupled to single devices have been used with the expected limitations in bandwidth. Typical quoted 3dB bandwidths are on the order of 10-15% [1,3]. We suggest the use of distributed power amplifiers, or traveling-wave amplifiers (TWAs), coupled to "Vivaldi" type slot line antennas for wideband performance. Input/output isolation is greatly improved by this approach due to the traveling-wave character of the system, and consequently co-polarized antennas can be used. Figure 1 illustrates how a number of these units can be incorporated in a planar structure and therefore compatible with standard MIC technology.Since the antennas have a broadband resistive impedance equivalent to the characteristic impedance of the feed line, they can be integrated directly with off-the-shelf 50Ω TWA MMICs. A number of

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substrates can then be stacked to form a high power 3 dimensional amplifier array (fig.2).

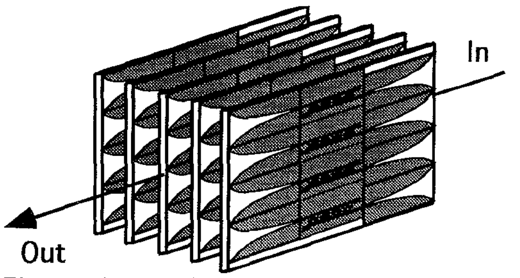

Figure 2 - 3-Dimensional array concept

AMPLIFIER

Slotline antennas have shown broad band characteristics [7-9]. Linear, exponential and other tapers have been examined [8]. These radiators exhibit narrow beamwidths and rotationally symmetric patterns over a large frequency range, even though they are planar structures. The use of slotline antennas in a quasi-optical array leads to a unit cell that is distributed along the beam direction rather than transverse to it. This topology is still planar and can be monolithically fabricated; a large number of these arrays can be stacked to create a high power three dimensional structure (fig 2). The additional substrate space along the beam direction allows integration of larger and more complicated active elements.

To match the wide bandwidths afforded by the traveling wave antennas, distributed circuit amplifiers (TWAs) must be used. An important advantage of TWAs is the tolerance to device parameter variations, which is important for successful monolithic designs. For a FET TWA, the input and output consists of high impedance transmission lines periodically loaded with gate and drain capacitances respectively. The capacitive loading effectively reduces the line impedance to 50Ω. The bandwidth of these circuits is primarily limited in the upper end by the low pass filter behavior of these distributed transmission lines [10]. Distributed power amps do not provide optimum gain, power and efficiency per device as compared to single-tuned designs, but the broad bandwidths and robust design favor their use in many applications.

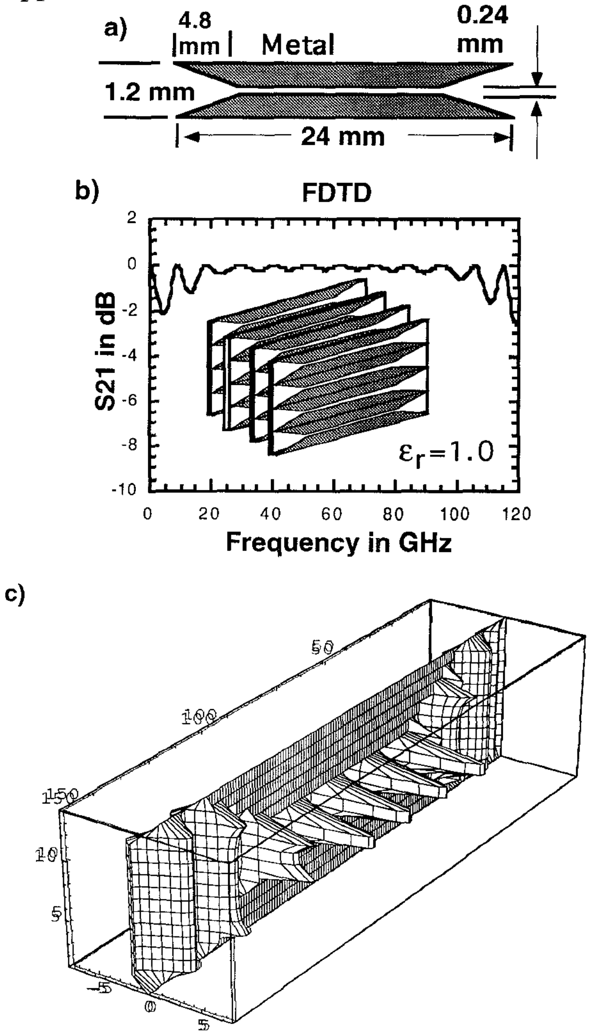

Figure 3- **a**)Dimensions of single element **b**)Theoretical (FDTD) results versus frequency **c**) FDTD simulation fields plot (80 GHz sinusoidal excitation)

"Vivaldi" type antennas tend to be electrically long and require large apertures (about half free space wavelength for the lowest frequency of operation) in order to exhibit their broad band behavior. Some concern might arise about compactness in the case of a tapered slotline quasi optical array. In the case of an array, we have found that mutual coupling between the array elements allows a smaller unit cell aperture to be used, much like the quasi-optical grid concept [1]. This was verified by theoretical FDTD simulations [11] for a free standing (ε_r=2.2) passive slotline array excited by a normally incident uniform plane wave. The geometry and the transmission vs frequency are shown in Figure 3.

The simulation (fig.3b) shows broadband transmission from 20-80GHz using a 1.2mm aperture size; an isolated tapered slot in this frequency range would require an aperture of at least 7mm.

19 unit cells (fig. 3a) were fabricated on 30 mil thick duroid (ε_r=2.2). 16 substrates were stacked on top of each other. To account for air gaps between the substrates a dielectric constant of 1.8 was used in the simulation. Comparison between theoretical and experimental results at Ka-band is shown below

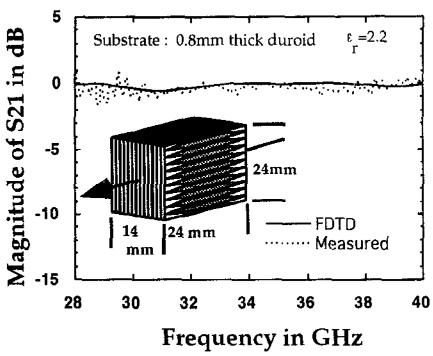

Figure 4- Ka-band results for a 16 x 19 passive array

MEASUREMENTS

A single element low frequency prototype was designed and tested (Fig. 5). Two tapered slotline antennas (15 cm long and 8 cm wide) were build on 65 mil thick (ε_r = 2.2) Duroid. Each one was fitted with a coax SMA launch. A microstrip TWA with ~11 dB gain (4 Volts Bias) up to 4.5 GHz was placed between them.

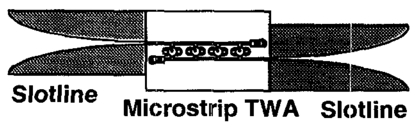

Figure 5-Single element prototype

The receiving and transmitting antennas were orthogonally polarized to simplify the measurement (Fig. 6)

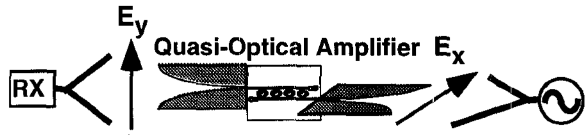

Figure 6- Measurement setup

The Friis transmission equation was used to determine the Effective Isotropic Power Gain [3] (EIPG = $G_{amplifier}\, G^2_{antenna}$).

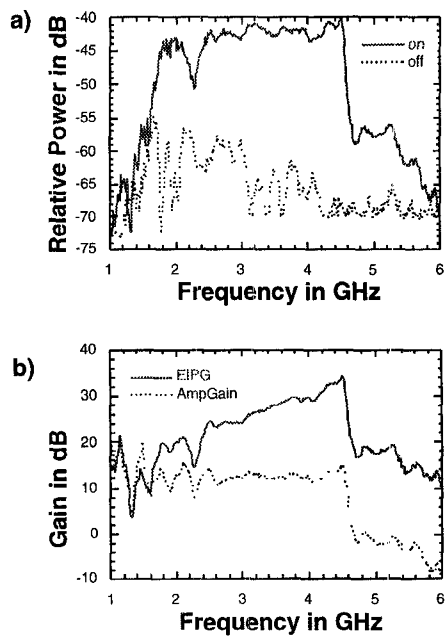

Figure 7- **a)**Cross-pol transmission with amplifier on /off vs frequency **b)** Amplifier EIPG and gain vs frequency

A separate measurement was performed to determine the gain of the tapered slots (G^2antenna).

This was subtracted from the EIPG (dB) in order to extract the amplifier gain. The on/off states along with the amplifier gain and EIPG can be seen in Figure 7. A 50% bandwidth at 3.5 GHz was been observed.

The low frequency cutoff is due to the antennas; a larger aperture would extend the low frequency performance. We are currently in the process of building a quasi-optical TWA array.

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