TE SURFACE WAVE POWER COMBINING BY A PLANAR 10-ELEMENT ACTIVE LENS AMPLIFIER

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ABSTRACT

This paper presents power combining of TE surface waves in a dielectric slab by a planar active lens amplifier. An amplifier gain greater than 7 dB over a 56% bandwidth has been demonstrated. Measurements of output power versus input power and surface wave field patterns are also presented.

INTRODUCTION

Quasi-optical amplifiers have the potential for efficient power combining of large numbers of solid-state devices. Most previous work has focused on three-dimensional approaches, such as the wave beam type [1], grid type [2], microstrip coupling type [3], and lens type [4]. A quasi-optical structure based on the dielectric slab-beam waveguide (DSBW) [5] is two-dimensional and therefore more amenable to planar fabrication technologies. An oscillator [6] and several amplifiers [7-9] based on the DSBW have been reported. These structures excited an electric field parallel to the slab ground plane. Such a mode has very low loss but is difficult to excite cleanly with no perturbation or scattering loss. Dielectric lenses were used to focus and constrain the quided waves in [7-9]. Yagi-Uda slot antenna arrays, fed by microstrip lines, were used to efficiently excite the dominant DSBW mode with the electric field normal to the slab ground plane in [10]. A two-dimensional quasi-optical amplifier with reasonable gain and bandwidth was demonstrated.

A drawing of the 10-element TE mode slab-beam lens amplifier discussed in this paper is shown in fig.1. In this work, dipole antennas, fed by microstrip to twin strip transitions, are used to excite TE modes in a thick dielectric slab with no ground plane. Microstrip delay lines are used to focus the quided waves in a manner similar to that reported in [4] and [10]. Delay line length is analogous to thickness of a conventional dielectric lens. Commercial gain blocks are used to amplify the RF signals. Measurements of amplifier gain, output power versus input power, and surface wave field pattern radiated by the dipole antenna are presented. An amplifier gain greater than 7 dB over a 56% bandwidth centered at 5.6 GHz has been recorded. Gain is measured from input to output connector to facilitate comparisons with more conventional amplifiers.

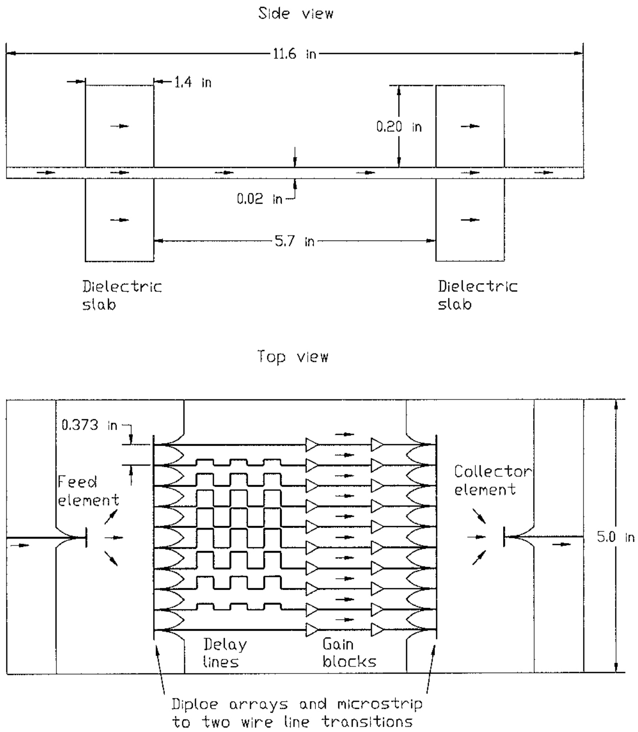

Fig. 1. TE mode slab-beam lens amplifier. Gain blocks and microstrip lines are on top side of thin substrate sandwiched between dielectric slabs. Microstrip ground planes and exponential tapers are on bottom. Half of dipole is on top side and the other half is on the bottom side.

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TE MODE SLAB-BEAM LENS AMPLIFIER

A thin substrate and thick homogeneous dielectric slabs are the basic components of the TE mode slab-beam lens amplifier of fig. 1. Microstrip lines and gain blocks are on the top side of a thin substrate. On the bottom of this thin substrate are the microstrip ground planes and exponential tapers to balanced two strip line. Dipoles, with arms on opposite sides of the thin substrate, are used to either receive or transmit TE slab-beam modes. Thick dielectric slabs sandwich the thin substrate and just cover the dipole elements. In this way the dipole radiated fields are drawn primarily into the high dielectric constant slabs. A feed element illuminates a 10-element slab-beam active lens which both amplifies and focuses the signal onto a collector element. Microstrip delay line lengths are such that the total phase delay from feed to collector element is identical for each lens element. The dielectric slabs and thin substrate sandwiched in between are RT/Duroid 6010 (ε_r = 10.2, tanδ = 0.002). Hewlett Packard MGA-64135 GaAs MMIC amplifiers are used as the cascadable gain blocks shown in fig. 1. Two gain blocks cascaded together produce 20.5 dB gain at 7.0 GHz.

Directive excitation of the dielectric slabs was achieved with a balanced twin strip fed dipole. Planar excitation, compatible with planar fabrication technology, of the dielectric slabs has been achieved. Coupling into the slabs was maximized by choosing the thickness such that the initially intended center operating frequency of 8.0 GHz corresponds to 90% of the cutoff frequency of the third order TE mode; dipole excitation of the second order TE mode is negligible as this mode has a null at the slab center. Initially, the dipole length was selected as one half wavelength in the dielectric media at 8.0 GHz. Experimental optimization of the dipole length resulted in a design with a SWR < 2.0 over a 20.7% bandwidth centered at 7.3 GHz.

EXPERIMENTAL RESULTS AND DISCUSSION

Gain of the slab-beam lens amplifier was measured from the feed element microstrip line to the collector element microstrip line. Microstrip-to-coaxial SMA connectors were used to interface with a network analyzer. Measured gain was greater than 7 dB over a bandwidth of 56% centered at 5.6 GHz (fig. 2). With no bias, the gain dropped below -30 dB over the entire frequency range measured. Peak response of a passive lens was -11.7 dB at 7 GHz with a 3 dB bandwidth of 11.2%. The passive lens has through lines instead of gain blocks. At 7 GHz the active lens gain was 8.5 dB. Difference between the active lens and passive lens response is 20.2 dB, close to the measured 20.5 dB gain of two cascaded gain blocks. Bandwidth of the active lens amplifier is much greater than for the passive lens. Gain of the cascaded gain blocks increases at lower frequencies and compensates for the decrease in response for the passive lens. Output power is plotted against input power for three frequencies (5, 6, and 7 GHz) in fig. 3. Output power at 1 dB gain compression is 17.1 and 17.6 dBm at 6 and 7 GHz, respectively. At 5 GHz this power falls to 14.4 dBm due to increased losses of the passive lens.

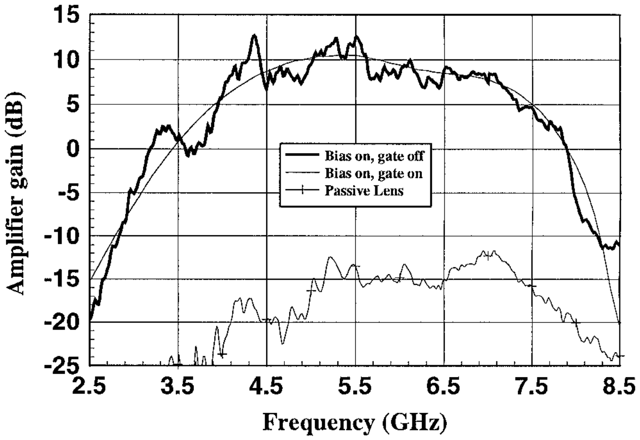

Fig. 2. TE mode slab-beam lens amplifier gain versus frequency. Gain is greater than 7 dB over a 56% bandwidth centered at 5.6 GHz. Insertion loss of a passive lens is included for reference.

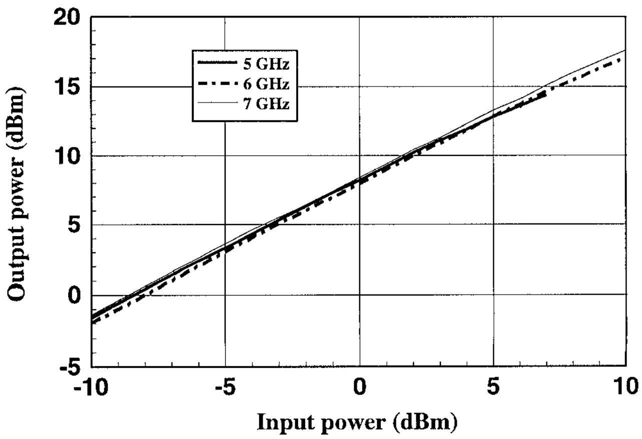

Fig. 3. Output power plotted against input power. Output power at 1 dB gain compression is 14.4 , 17.1, and 17.6 dBm at 5, 6, and 7 GHz, respectively.

A loss budget for the passive lens is presented in table 1. Direct measurement or calculation of each of the deduced losses in table 1 is not trivial and has not yet been performed. Array mutual impedance effects should be small since dipoles spaced end to end should not couple strongly. Further optimization of the dipole input match should reduce the mismatch losses to negligible values. Four of the dipole antennas would be expected to account for 7.9 dB of loss in a further optimized system. Therefore the loss due to a single dipole could be made to be about 2 dB. A waveguide to slab-guide transition, similar to the one described in [9], should have very low losses. If waveguide transitions were used to collect the lens output power the combining efficiency would be 63%.

Table 1. Passive lens losses at 7 GHz.

Total measured loss	**11.7 dB**
Dipole antenna mismatch losses (measured) **Input return loss = 10 dB** **Mismatch loss = 0.46 dB** **0.46 dB × 4 antennas = 1.8 dB**	**-1.8 dB**
Microstrip line losses (0.2 dB/in) (measured) **0.2 dB/in × 10.0 in = 2.0 dB**	**-2.0 dB**
Deduced losses (spillover, radiation, and mutual coupling)	**7.9 dB**

Recall that the slab-beam lens output power at 7 GHz was 17.6 dBm at 1 dB gain compression. To compute the power output by the ten output gain blocks, one should add the loss due to two dipole antennas and that due to the microstrip lines between the cascaded gain block output and the lens amplifier output. Therefore, the output gain blocks are producing 23.0 dBm. Typical output power of the Hewlett Packard MGA-64135 gain blocks is quoted as 12.4 dBm at 1 dB gain compression at 7 GHz. Ten of these amplifiers should yield 22.4 dBm if each gain block was driven equally to 1 dB compression. Amplitude taper on the lens causes the amplifiers in the middle of the lens to be driven harder than those at the edges. Elements in the lens center put out more power than those on the edges and are driven beyond 1 dB compression when the overall active lens amplifier is driven to 1 dB compression.

The power pattern of the fields incident on the lens amplifier were measured by constructing only one half of the circuit shown in fig. 1, i.e. only the input element and a single linear dipole array. Transmission measurements were performed from the input element to each of the ten elements in the linear dipole array. The amplitude patterns are shown in fig. 4. A large amplitude taper is observed to exist. Waveguide feeds could be used to realize better illumination. Phase data (not shown) from these measurements was used to design time delay lines for the passive and active lenses. To test the delay line design, the time domain feature of the network analyzer was used to transform the frequency domain data of the active lens amplifier with bias on (see fig 2). The results are plotted in fig. 5 and confirm the delay line design. Ripples in the time domain response for time greater than 4 ns are due to multiple reflections. If the data for time greater than 4 ns is gated out and the remaining data transformed back to the frequency domain the result is the data in fig. 2 labeled gate on. Notice the smoothness of the response. Tapered terminations of the type described in [5] applied along the edges of the slab where the dipole antennas are absent would reduce the reflections. Use of waveguide feeds should also reduce the problem.

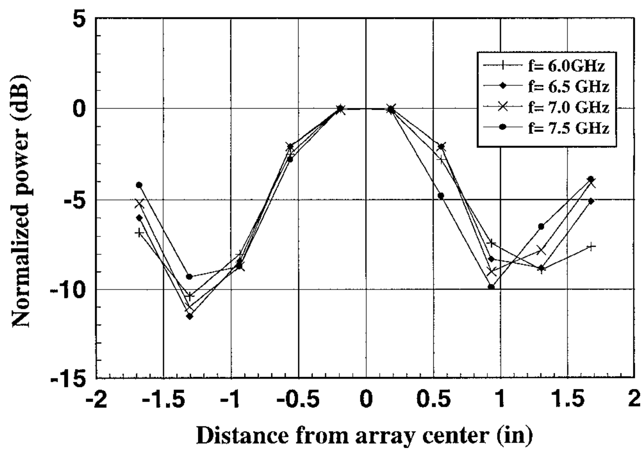

Fig. 4. TE surface wave field pattern incident on the active lens input array of fig. 1.

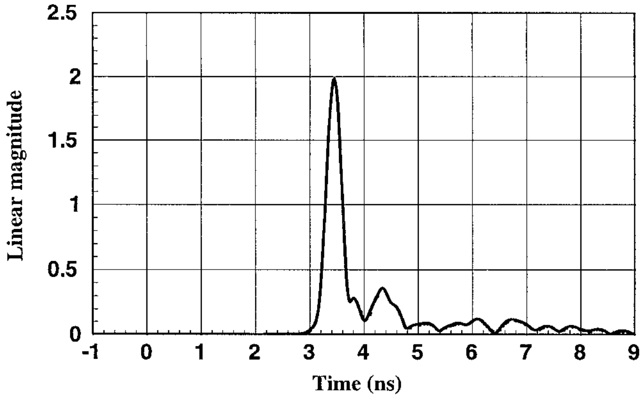

Fig. 5. Time domain response of the active lens amplifier of fig. 1. Single narrow pulse demonstrates proper function of true time delay lines. Gating this data at 4 ns and transforming back to frequency domain yields the data in fig. 2 labeled gate on.

CONCLUSION

A two-dimensional slab-beam lens amplifier has been developed for efficient quasi-optical power combining of large numbers of solid-state devices. An uncommonly large bandwidth of 56% with system gain greater than 7 dB has been demonstrated. At 7 GHz power combining with the active lens at 1 dB gain compression and the individual array element amplifiers in deep compression was demonstrated. Fabrication of the slab-beam lens amplifier is compatible with planar fabrication techniques.

ACKNOWLEDGMENT

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