A PLANAR ACTIVE LENS OSCILLATOR ON A DIELECTRIC SLAB

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ABSTRACT

This paper presents power combining of TM surface waves in a dielectric slab by a planar active lens oscillator. An output power of 15.4 dBm at 8.16 GHz was measured at the oscillator output connector. Measurements of surface wave field patterns radiated by the active lens oscillator are also presented.

INTRODUCTION

Quasi-optical amplifiers and oscillators 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 [7-10] 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 guided 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 [11]. Reasonable gain and bandwidth were obtained. In this work the amplifier described in [11] is turned into the oscillator shown in fig. 1. Microstrip delay lines are used to focus the guided waves in a manner similar to that reported in [4] and [11]. Delay line length is analogous to thickness of a conventional dielectric lens. Commercial gain blocks are used to amplify the RF signals. Measurements of the oscillator output spectrum and surface wave radiation pattern are presented. An oscillator output power of 15.4 dBm at 8.16 GHz has been recorded. Output power is measured at the oscillator output connector to facilitate comparisons with more conventional oscillators.

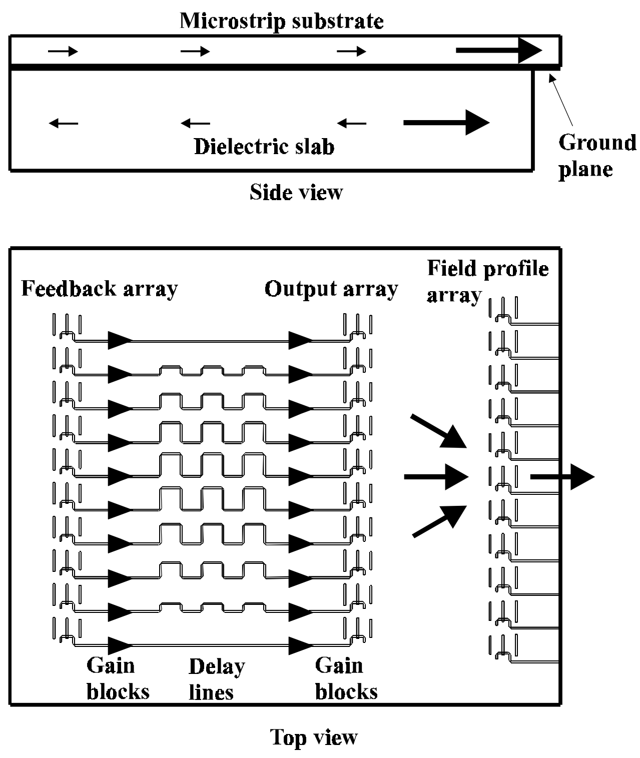

Fig. 1. Slab-beam lens oscillator. Gain blocks and microstrip lines are on top side of thin substrate on top of dielectric slab. Yagi-Uda slot arrays are on the common ground plane.

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TM SURFACE WAVE LENS OSCILLATOR

The TM surface wave lens oscillator is shown in fig. 1. Microstrip lines and gain blocks are on the top side of a thin substrate on top of a thick dielectric slab. Microstrip fed Yagi-Uda slot antenna arrays on the common ground plane are used to either receive or transmit slab-beam modes. The TM surface wave amplifier described in [11] is turned into an oscillator by rotating the Yagi-Uda antenna elements in the feedback array 180 degrees as shown in Fig. 1. Microstrip delay line lengths are such that the round trip feed back loop phase delay for a signal emanating from and returning to a point centered between the input and output antenna arrays in the dielectric slab is identical for each lens element. Oscillation is possible if the feed back loop phase delay is an integer multiple of 360 degrees and the loop gain is greater than unity. Separation in oscillation frequencies due to the phase condition is about 0.6 GHz. An 11-element field probing array is spaced a distance corresponding to the active lens focal length (f = 1.4 in). Spacing between the active lens feedback and output arrays is double the focal length. The array element spacing is 0.325 in and corresponds to 0.65 surface wave wavelengths in the dielectric slab. Back lobe radiation from the output array is used to provide feedback to ensure oscillation. Most of output array radiated power is focused to the center element of the field-probing array as the Yagi-Uda slot array antenna has a front-to-back ratio greater than 10 dB. The dielectric slab (0.20 in thick) and thin substrate (0.020 in thick) on top of it 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 18 dB of gain at 8.25 GHz. A key feature of the lens oscillator is that the active devices used are unconditionally stable and do not oscillate individually.

An important component of the active lens oscillator is the microstrip fed Yagi-Uda slot array antenna for directive surface wave excitation in the dielectric slab. As reported in [11] and [12] an input SWR<2.0 and front-to-back ratio greater than 10 dB over a 5% bandwidth has been experimentally demonstrated. The antenna input return loss and front-to-back ratio are important parameters for the oscillator design and are plotted as a function of frequency in Figs. 2 and 3, respectively. Recall that the oscillation phase condition gave an oscillation frequency spacing of about 0.6 GHz. Examination of Figs. 2 and 3 indicate the antenna pass band will allow one and at most two oscillation frequencies. Unfortunately, the back lobe radiation pattern of the antenna was not measured. It is important that the antenna have a well-formed back lobe pattern to provide proper feedback for the active lens oscillator. Numerical calculation of the fields radiated by the antenna has been performed. The calculated far-field TM mode surface wave radiation pattern is shown in Fig. 4 and shows symmetric back lobe radiation. Integration of the far-field patterns show that 85% of the power radiated is launched as a TM surface wave in the forward lobe. A front-to-back ratio greater than 10 dB results in 9.0% of the device output power being used to overcome the losses in the feedback loop and sustain oscillation.

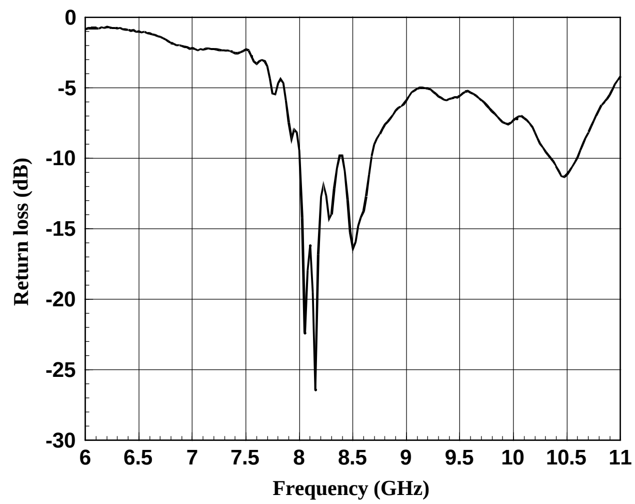

Fig. 2. Yagi-Uda slot array input return loss versus frequency. Return loss is better than 10 dB over a 0.68 GHz bandwidth centered at 8.3 GHz.

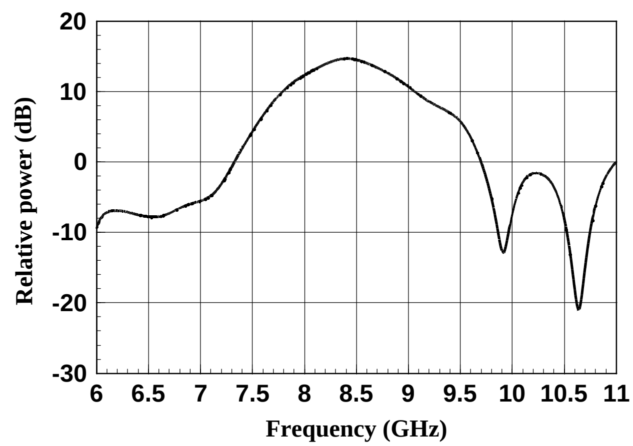

Fig. 3. Yagi-Uda slot array antenna measured front-to-back ratio versus frequency. Front-to-back ratio is greater than 10 dB over the return loss bandwidth of Fig. 2.

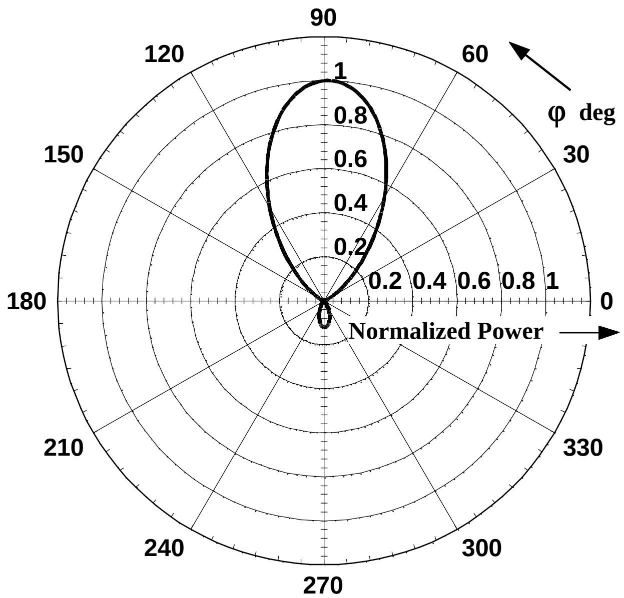

Fig. 4. Yagi-Uda slot array antenna element calculated far-field surface wave radiation pattern. Back lobe is symmetric and well formed.

EXPERIMENTAL RESULTS AND DISCUSSION

Initially only one channel of the active lens oscillator was biased on and no output signal was detected by a spectrum analyzer. This demonstrates that the gain blocks do not oscillate individually. With the six center channels biased on no oscillations were observed. Oscillations were observed with the central eight channels biased on. With all ten channels biased on the output spectrum shown in Fig. 5 was recorded. A flexible cable with 2.5 dB loss was used to connect the oscillator output (center element of field probing array of Fig. 1) to the spectrum analyzer. Output power was therefore 14.7 dBm at 8.60 GHz. An output power of 15.4 dBm at 8.16 GHz was obtained by placing the spectrum analyzer in max hold and applying pressure to force the slab and microstrip substrates together. Elimination of air gaps between the dielectric slab and microstrip substrate ground plane is mandatory for proper function of the Yagi-Uda slot array antenna element. An output power of 15.4 dBm seams reasonable since the 1 dB gain compression output power for the active lens amplifier of [11] was 16 dBm.

Unfortunately, the oscillator suffered from mechanical instability and the output power and frequency varied in a somewhat random manner over time. Oscillator operation requires surface wave propagation in the dielectric slab underneath the active devices. However, the active devices must be grounded and this perturbs surface wave propagation in the dielectric slab. Also, waste heat from the active devices cause the thin microstrip substrate to lift and separate from the dielectric slab. Employing platted through hole fabrication technology can rectify the grounding problem. Also, techniques exist to properly bond the microstrip substrate to the slab.

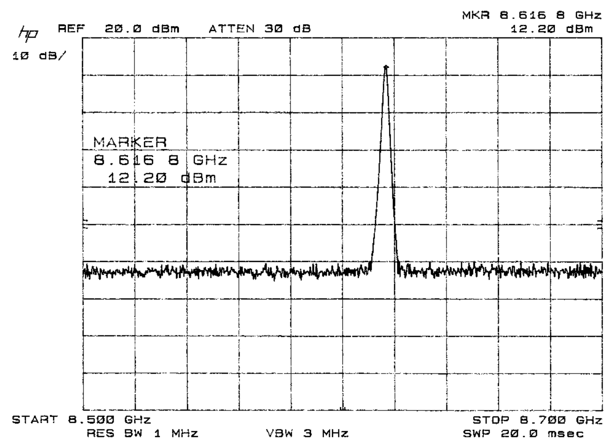

Fig. 5. Active lens oscillator output spectrum. Cable connecting the oscillator and spectrum analyzer has 2.5 dB loss. Oscillator output power is 14.7 dBm at 8.60 GHz.

Measurements of the surface wave field profile radiated by the output array were performed with the oscillator operating at 8.8 GHz. The power was sampled at every other element, including the center element, of the 11-element field-probing array. The elements are physically to close to place connectors on all the microstrip field probe lines simultaneously. Output power at the center element was 9.7 dBm. Ideally the field profile would have been performed when the output power was 15.4 dBm. This was not possible due to the mechanical instability problems discussed previously. Output power is plotted as a function of distance from the center element in Fig. 6. The power is not focused tightly onto the central element and is consistent with the lower output power.

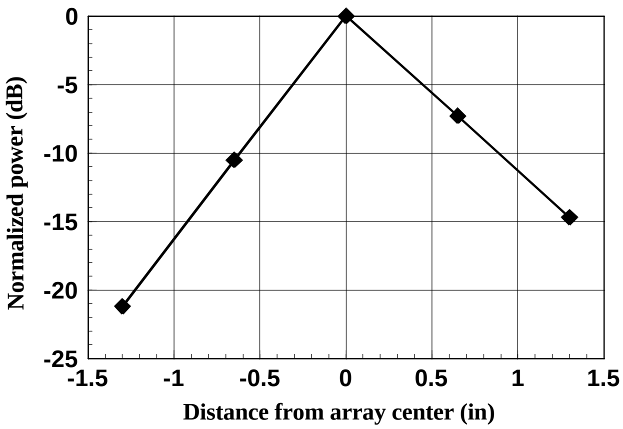

Fig. 6. Surface wave power pattern radiated by the active lens oscillator.

CONCLUSION

A two-dimensional lens oscillator on a dielectric slab is being developed for efficient quasi-optical power combining of solid-state devices. An output power of 15.4 dBm at 8.16 GHz was recorded. The structure is compatible with high quality factor resonators, which could be used to obtain a quasi-optical oscillator with low phase noise.

ACKNOWLEDGMENT

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