THREE-DIMENSIONAL POWER COMBINERS

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Abstract— **Conventional free-space power combiners consist of an array of solid-state devices loading a two-dimensional grid. Here the concept is extended to three dimensions, in which multiple grids are placed in parallel in a Fabry-Perot cavity. The advantage of this approach is that a large number of devices can be combined to produce more output power, while simultaneously improving the heat sinking and power-handling capabilities since the power is distributed over several grid surfaces. Experimental results are presented for a 5 GHz double grid oscillator with an effective radiated power 3 dB larger than that of a single grid.**

1 Introduction

Quasi-optical power combining is an attractive means of generating power at millimeter-wave frequencies. In this approach, the output power from a large number of solid-state devices is combined in free space, eliminating the losses associated with power-combining circuitry. The power is distributed among all of the devices, thus overcoming limitations on the power-handling capability of an individual device.

Power-combining grid oscillators reported to date are two-dimensional structures consisting of an array of devices loading a periodic grid [1, 2]. To achieve high power levels, it is necessary to increase the surface area of the grid to accomodate a larger number of devices, but this complicates the heat-sinking problem and causes the self-locking to become more difficult.

In this paper, we extend the concept of free-space power combining to three dimensions, in which multiple planar grids are placed in parallel in a Fabry-Perot cavity. In addition to delivering more output power, heat-sinking and power-handling capabilities are improved since the power is distributed over several grid surfaces. We report experimental results for a double grid oscillator with an effective radiated power (ERP) 3 dB larger than that of a single grid. The double grid demonstrates approximately 15% efficiency at 5 GHz, and delivered about 2 dB more output power than the single grid with a 3% increase in efficiency.

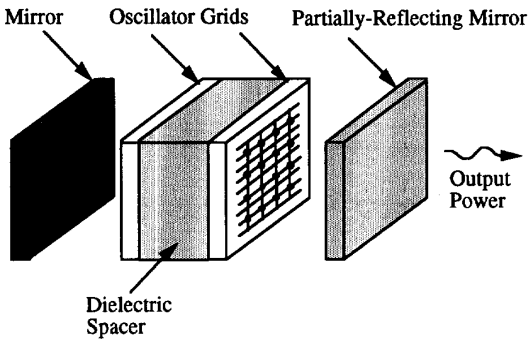

Figure 1: A three-dimensional power combining oscillator. Two planar oscillator grids are placed back-to-back against a dielectric spacer. The two mirrors form the Fabry-Perot cavity.

2 Configuration

An example of a three-dimensional power-combining oscillator is shown in Figure 1. It consists of two back-to-back planar oscillator grids separated by a dielectric spacer which enhances the coupling between the devices. The grids are placed in a Fabry-Perot cavity formed by a pair of mirrors, one of which is partially reflecting.

The metallic grid pattern for a single grid was designed using the EMF method as described in [1]. The period of the grid is 8 mm with 1 mm wide leads. Each grid is printed on a 2.5 mm thick Rogers' *Duroid* substrate with $\epsilon_r = 10.5$. The grids are placed back-to-back on either side of a dielectric spacer, which is a 25 mm thick slab of *Stycast HiK* (Emerson and Cumming) with $\epsilon_r = 9$. Copper tape is placed on the top and bottom edges of the spacer to prevent slab mode radiation. The transistors are Hewlett-Packard ATF-35576 pseudomorphic HEMTs which are typically used in low-noise applications from 2–18 GHz. Fifteen transistors are loaded on each grid, and all of the devices are identically biased with a common power supply. The partially-reflecting mirror, made from the same substrate material as the oscillator grid, provides 55% power reflectivity at 5 GHz.

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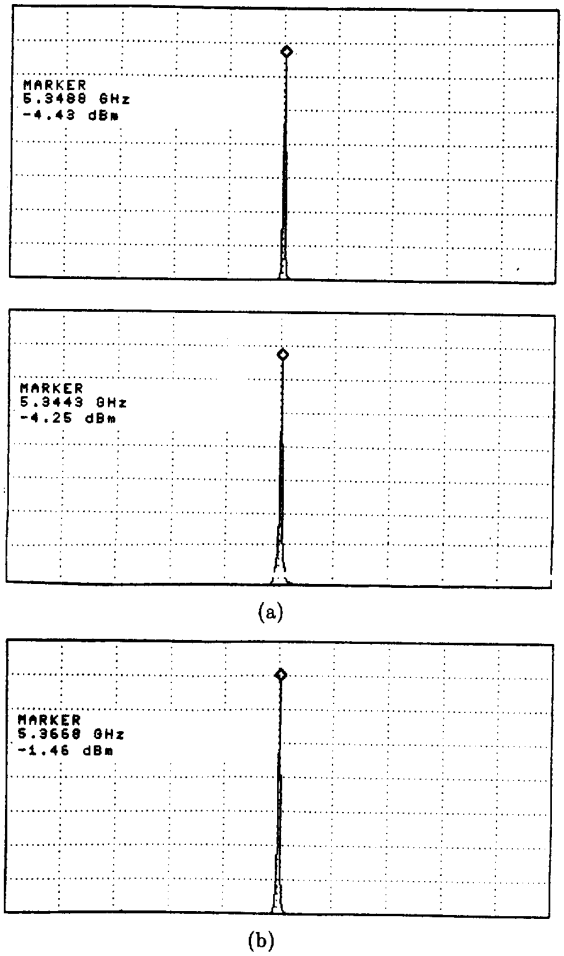
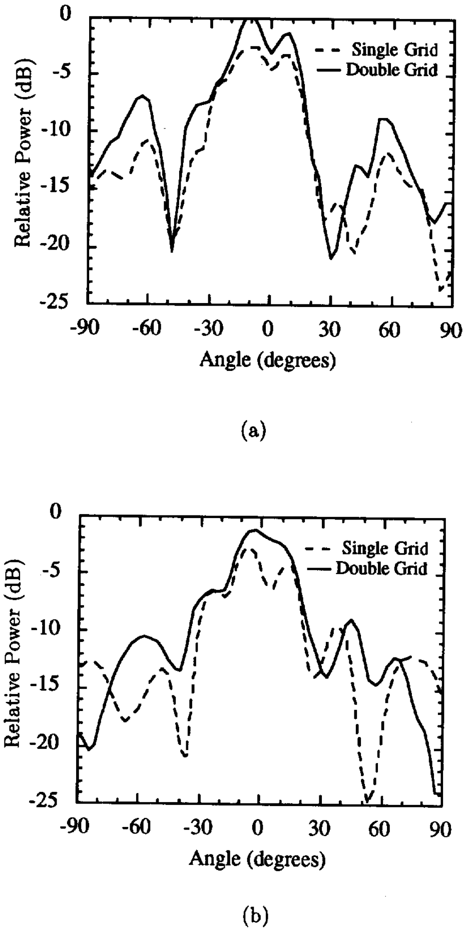


(a)

(b)

Figure 2: Spectra of (a) the two single grid oscillators at the same bias point ($V_{ds} = 3V$, $V_{gs} = -1V$) and mirror distances, and (b) the double grid oscillator ($V_{ds} = 3V$, $V_{gs} = -1.5V$). The power levels shown represent the power received by a low-gain horn antenna 66 cm away from the partially-reflecting mirror. Horizontal: 10 MHz/div; Vertical: 10 dB/div; Resolution Bandwidth: 10 kHz.



(a)

(b)

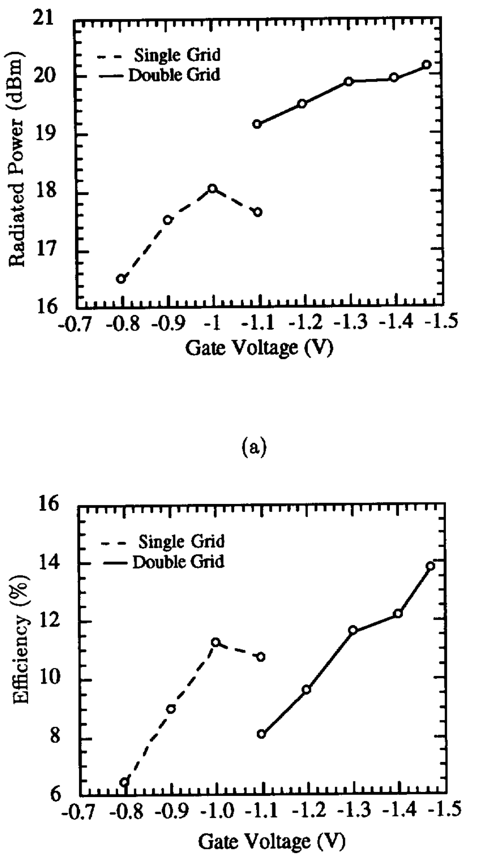
Figure 3: Measured far-field radiation patterns of the single and double grid oscillators in the (a) H-plane and (b) E-plane.

3 Experimental Results

Individually, each grid oscillates at the same frequency and power level for the same bias condition and mirror distance, as shown in Figure 2. The 5.34 GHz oscillation frequency is in close agreement with the theory in [1]. In the double grid configuration, the frequency shifts to 5.37 GHz, which is less than a 1% change. This is advantageous for design purposes, since a three-dimensional combiner can be designed on the basis of a two-dimensional one. The remaining design parameter is the coupling between the grids, which is provided by the dielectric slab separating the grids. This spacer is essential in maintaining a high-power locked mode.

The far-field radiation patterns of the single and double oscillator grids are shown in Figure 3. The pattern is very similar for the two cases. Based on these measurements, the estimated directivity of the single grid is $D_1 = 14.7\,\text{dB}$, while that of the double grid is $D_2 = 15.6\,\text{dB}$.

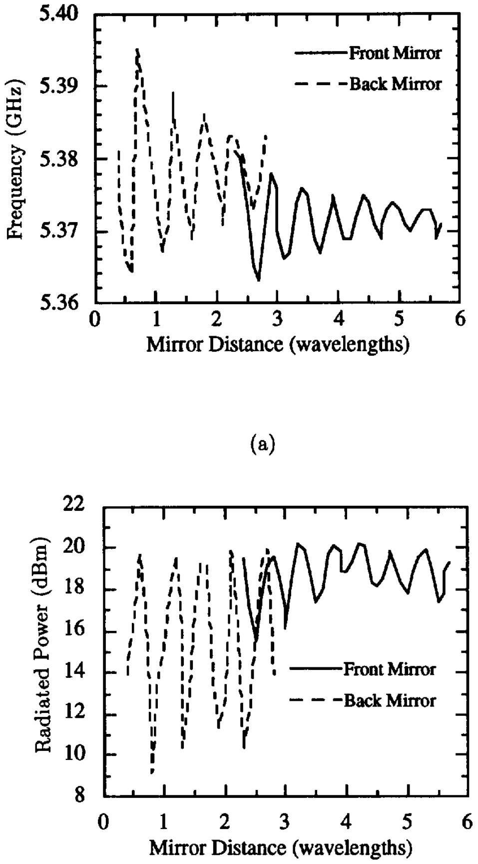
The highest effective radiated power (ERP) obtained from a single grid was 1.9 W, corresponding to an estimated radiated output power of $ERP/D_1 = 64\,\text{mW}$. The highest ERP for the double grid was 3.8 W, corresponding to a radiated output power of approximately $ERP/D_2 = 104\,\text{mW}$. At this power level, the dc-to-rf conversion efficiency was around 15%. The cross-polarized component was 22 dB below the co-polar one, the second harmonic was -33 dBc, and the third harmonic was -45 dBc.



(a)

(b)

Figure 4: Effect of gate bias tuning on the (a) radiated power and (b) dc-to-rf conversion efficiency. The drain voltage was 3 V.



(a)

(b)

Figure 5: (a) Frequency and (b) power tuning as a function of mirror distance. For front (partially-reflecting) mirror tuning, the back mirror was positioned at 0.6λ. For back mirror tuning, the front mirror was positioned at 3.2λ.

The effect of gate bias tuning on the radiated power and dc-to-rf conversion efficiency is shown in Figure 4. Measurements were only taken over the gate bias regime where the oscillator is locked. At the bias where the greatest power level is obtained, the double grid gives about 2 dB more output power and is approximately 3% more efficient than the single grid. The higher efficiency is a result of the devices becoming more saturated due to the higher gate bias.

Figure 5 shows frequency and power tuning as a function of mirror distance. Mirror tuning had little effect on the oscillation frequency (less than 1% frequency tuning) but had a substantial effect on the radiated power. The totally-reflecting mirror has a stronger effect than the partially-reflecting mirror, tuning the output power by as much as 11 dB. The oscillator unlocks when the partially-reflecting mirror is placed within two wavelengths of the active grid.

A second pair of identical grids was fabricated with 25 transistors each. As single grids, each one oscillated at 5.05 GHz, while in the double grid configuration, the frequency shifted to 5.03 GHz. The highest effective radiated power obtained from a single grid was 2.7 W. For the double grid, the ERP nearly doubled to 5.3 W.

4 Conclusion

Three-dimensional power combiners have been demonstrated. Compared to two-dimensional combining methods, higher power levels can be obtained since multiple grids can be stacked in parallel. At the same time, heat-sinking and power-handling capabilities are improved since the power is distributed over several surfaces. The dc-to-rf conversion efficiency increases due to the higher device saturation caused by the active feedback.

Acknowledgement

This work was supported by the U.S. Army Research Office through an ASSERT grant, and the National Science Foundation's Research Experience for Undergraduates Program. The authors are grateful to Hewlett-Packard and Rogers for their generous equipment and substrate donations.

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