

A 16-ELEMENT REFLECTION GRID AMPLIFIER

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ABSTRACT

We present a 16-element hybrid grid amplifier. This is the first successful grid amplifier to use a reflection architecture, which should provide thermal performance superior to transmission grids. The grid uses custom-made differential-pair chips with TRW InP Heterojunction Bipolar Transistors (HBTs) as the active devices. We measure a peak gain of 15 dB at 10.2 GHz. Gain, tuning, and angular measurements are consistent with theoretical predictions.

I. INTRODUCTION

A grid amplifier [1]-[5] is an array of closely spaced differential transistor pairs. All grid amplifiers to date have used a transmission architecture, as shown in Figure 1(a). In this paper, we present a new type of quasi-optical grid amplifier based on reflection. The approach is illustrated in Figure 1(b). The amplifier array is mounted on a reflective mirror, which can double as a large metal heat sink. Otherwise, the operation of reflection grid amplifiers is identical to their transmission cousins. The input and output beams remain cross-polarized, reducing the possibility of oscillations. This new reflection architecture holds a number of advantages. The most

obvious advantage is its superior heat sinking. Each unit cell can conduct heat directly through the substrate to the heat sink, thereby avoiding large temperature rises in the center of the array. This is especially important for large, high-power arrays. Another advantage is the reflection amplifier's compact size. Granted, one does lose the flexibility provided by the independent input and output tuning polarizers. However, through recent strides made in computer-aided-modeling of grid arrays [7], one can design a grid that does not require independent input and output tuning polarizers. Finally, the reflection amplifier can be used as an "active mirror" that is conformal to the surface of parabolic and other reflectors common in many radar and communications systems.

II. AMPLIFIER DESIGN AND FABRICATION

The differential-pair chips were custom fabricated by TRW in Redondo Beach, CA. The active devices are InP HBTs with a single emitter finger of area $1.5 \times 10 \mu\text{m}^2$. A chip schematic and layout are shown in Figure 2. The chip is designed to operate with a collector voltage of 3V. The base bias is provided by a resistive divider. The emitter current is set by the common-mode emitter resistor. This resistor is bypassed with a capacitor to improve common-

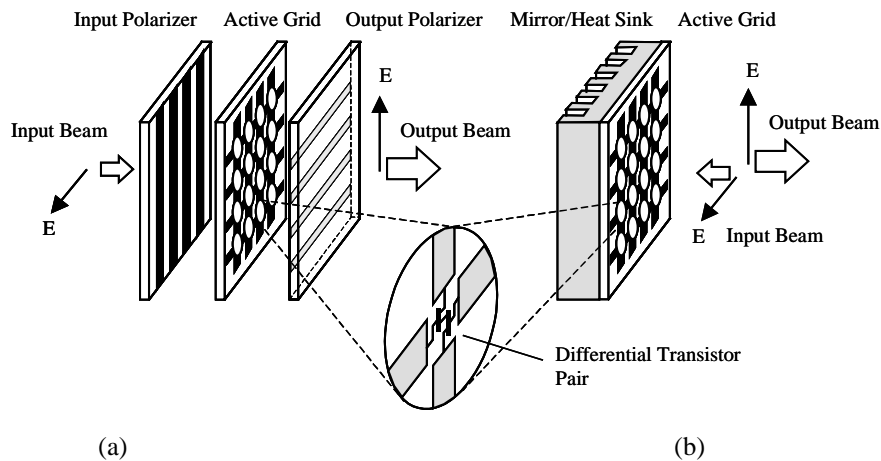


Figure 1. Transmission (a) and reflection (b) quasi-optical grid amplifiers. The reflective approach has been used in non-grid quasi-optical amplifier arrays [6].

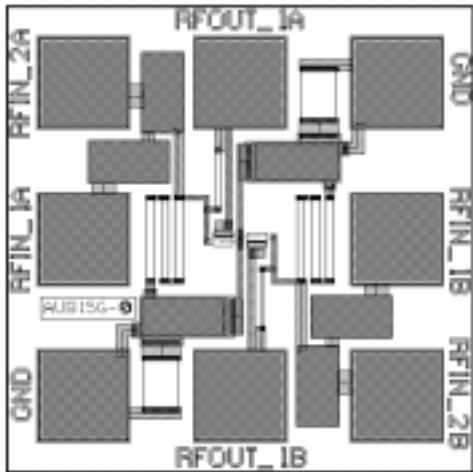
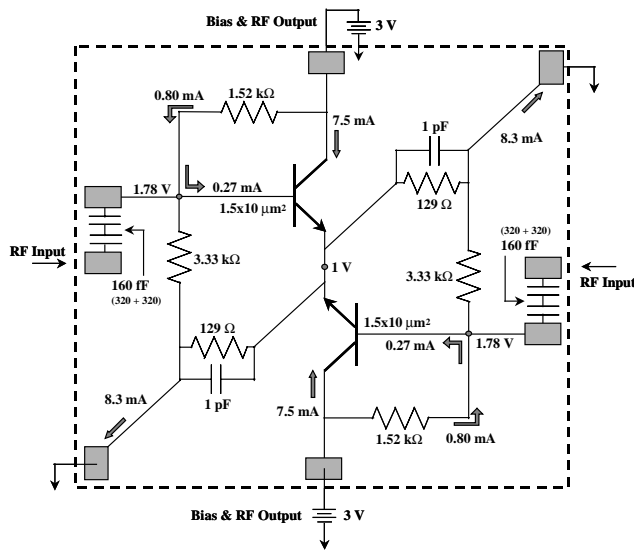


Figure 2. Schematic (top) and layout (bottom) of TRW InP HBT differential-pair chip. The chip is 400 μm on a side.

mode stability [8]. The input is coupled to the base through a pair of on-chip tuning capacitors.

Figure 3 shows the unit cell and array. The cell is 5.81 mm on a side. As a proof of the reflection concept, we fabricated a 16-element array on a Rogers *Duroid* substrate with a relative dielectric constant of 2.33 and a thickness of 1.8 mm. Figure 4 shows the assembled grid and transmission-line equivalent circuit. Various substrates and air gaps appear in the equivalent circuit as transmission lines. We use a *Duroid* ($\epsilon_r = 2.33$) tuner to improve the gain. To determine the input and output coupling networks, we use the computer-aided modeling procedure developed by Preventza at Caltech [7].

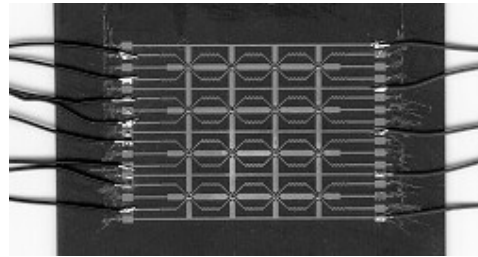
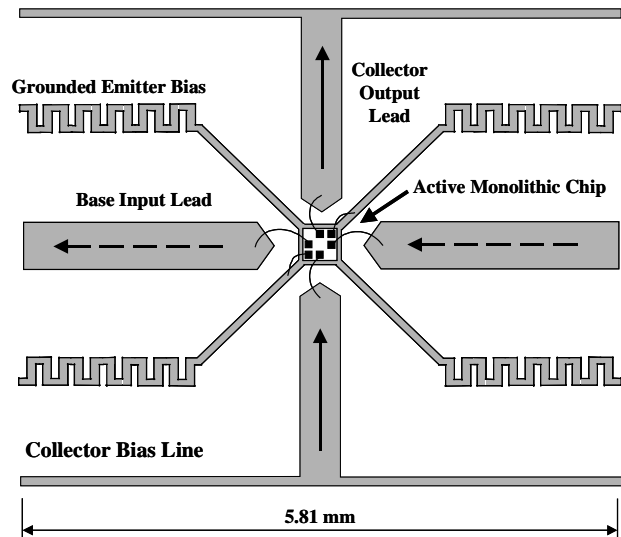


Figure 3. Reflection amplifier grid unit cell (top). Arrows indicate the directions of rf currents. Photograph of the assembled 16-element grid amplifier (bottom).

Originally, the grid was designed with the mirror mounted directly on the back of the substrate. This configuration resulted in oscillations, however, and a substrate-mirror air gap had to be introduced to stabilize the array. For applications where thermal performance is important, this air gap could be replaced with a thermally conductive dielectric.

III. MEASURED RESULTS

The small-signal gain of the grid was measured by placing the grid in the far field of two cross-polarized horns. The input and output horns were mounted at an angle of 20° off axis to reduce coupling between the horns. The measured gain is shown in Figure 5. The peak gain is 15 dB at 10.2 GHz. This is the highest gain reported for a grid amplifier. The 3-dB bandwidth is 530 MHz (5%). The modeled gain is also plotted; the agreement is reasonable considering the small size of the array. The measured gain is within 2 dB of the chip's maximum available gain. Figure 6 shows the gain as a function of mirror position. Again, the

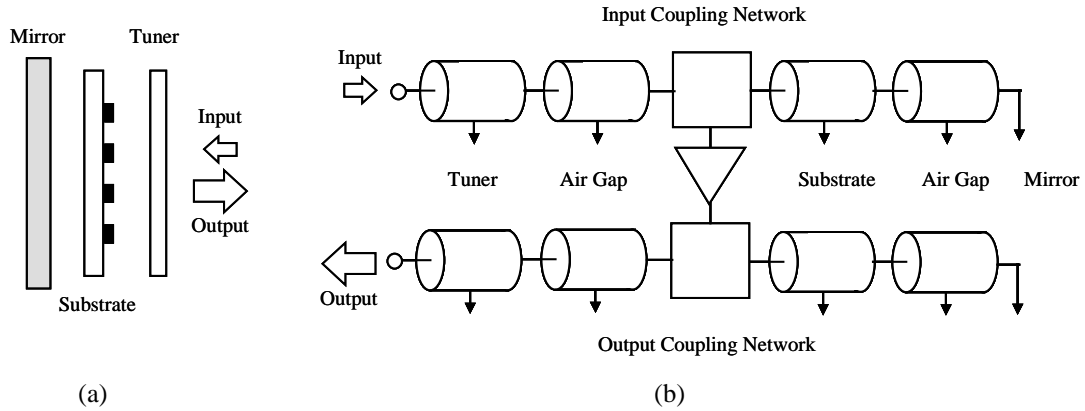


Figure 4. The assembled reflection amplifier (a) and its transmission-line equivalent circuit (b).

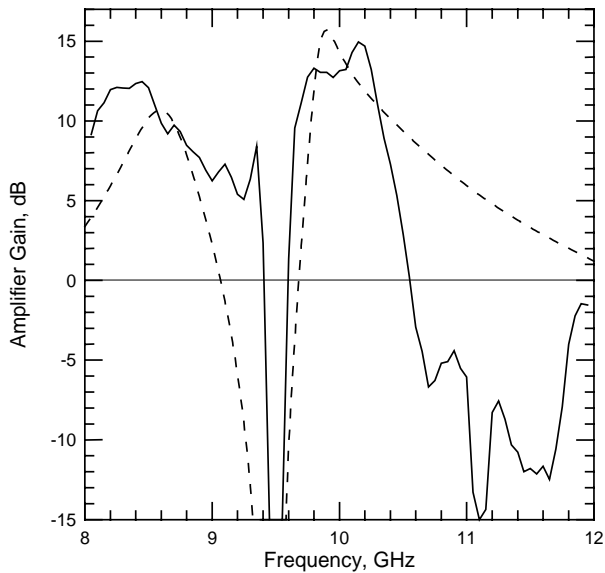


Figure 5. Measured (solid line) and modeled (dashed line) small-signal amplifier gain.

agreement with theory is reasonable considering the array's size.

Figure 7 shows the gain as a function of bias current. The current was varied by changing the collector voltage. The entire grid drew 370 mA at a voltage of 3 V. This current is about 40% higher than expected, which means some devices are drawing more current than intended. Nevertheless, these results show that further increases in bias current would be unlikely to result in higher gain.

The output of the reflection amplifier can be separated from the input because the two signals are cross polarized. For some applications, however, a spatial input/output separation may be desired. This can be achieved by

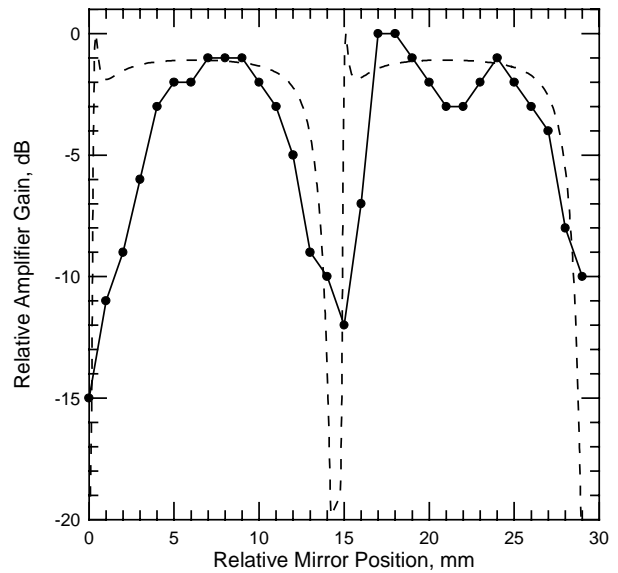


Figure 6. Measured (solid line) and modeled (dashed line) relative gain at 10.2 GHz as a function of relative mirror position.

illuminating the array at non-normal incidences. Transmission amplifiers have been shown to preserve the angle of incidence [1], [2]; this implies that the output beam in a reflection array should occur at the specular angle. If the gain is calibrated assuming a constant area, the gain reduction should follow a $\cos^2\theta$ obliquity factor. This accounts for the foreshortening of the array's input and output area. Figure 8 shows the measured results. The measured gain is within 3 dB of $\cos^2\theta$; differences may be attributed to the increased grid-mirror distance. Nevertheless, if a 3-dB gain reduction can be tolerated, the input and output beams can be separated by 70° . These results indicate that the reflection architecture should work well as an active mirror.

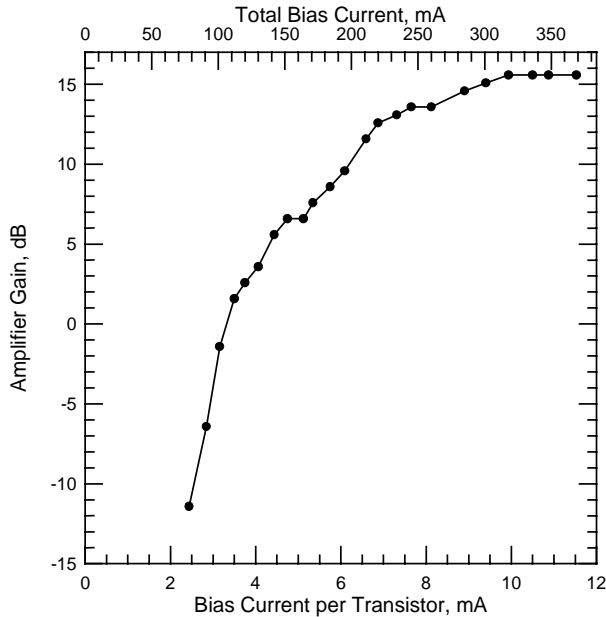


Figure 7. Measured amplifier gain at 10.2 GHz as a function of bias current.

IV. CONCLUSION

We have presented the first successful results from a reflection grid amplifier. The reflection approach should enable very efficient heat removal. The grid has a peak gain of 15 dB at 10.2 GHz. The gain, tuning, and angular dependence agree with theoretical predictions.

V. ACKNOWLEDGEMENTS

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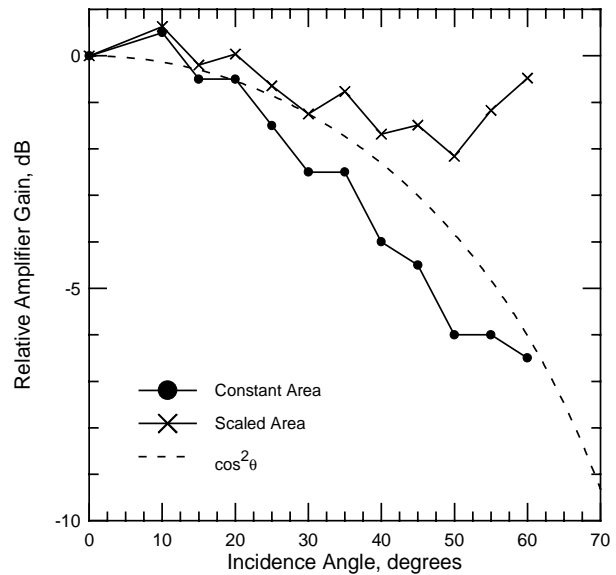


Figure 8. Measured amplifier gain at 10.2 GHz as a function of incidence angle. The output is taken at the specular angle. For calibration, the array's area is fixed to the physical area of the grid. A second curve shows the gain calibrated using an area scaled by $\cos^2\theta$.

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