A 16-ELEMENT REFLECTION GRID AMPLIFIER WITH IMPROVED HEAT SINKING

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ABSTRACT

We present a 16-element hybrid grid amplifier with improved heat sinking. This is a higher-power version of a previously reported reflection grid amplifier. The grid uses custom-made differential-pair chips with TRW InP Hetero-junction Bipolar Transistors (HBTs) as the active devices. We measure a peak gain of 15 dB at 8.4 GHz. Measured gain is consistent with theoretical predictions. The grid was able to dissipate up to 4 W of dc bias power without any apparent thermal damage. Measurements on passive resistor arrays demonstrate this architecture's superior thermal performance.

I. INTRODUCTION

A grid amplifier [1]-[5] is an array of closely spaced differential transistor pairs. Most grid amplifiers to date have used a transmission architecture, as shown in Figure 1(a). In [6], we presented a new type of quasi-optical grid amplifier based on reflection. The approach is illustrated in Figure 1(b). The amplifier array is mounted in front of 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 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 sink, thereby avoiding large temperature rises in the center of the array. This is especially important for large, high-power arrays.

The amplifier reported in [6] was a prototype of the reflection architecture, built primarily to demonstrate rf gain. We used small, low power transistor pairs. Thermal concerns were largely ignored: The grid was built on Rogers *RT/Duroid*, a notoriously poor thermal conductor; furthermore, an air gap had to be introduced between the substrate and the mirror/heat sink to suppress oscillations and to tune the gain. In this paper, we report on an array using higher-power

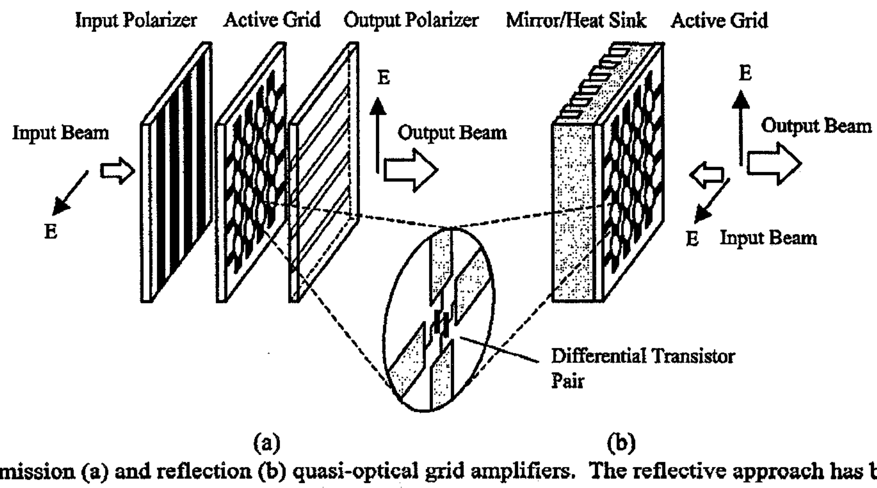
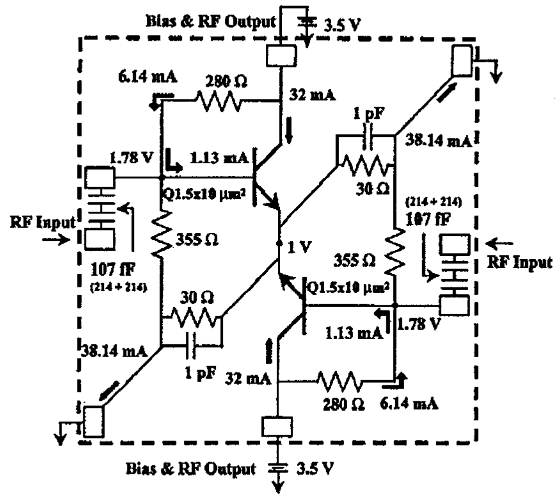
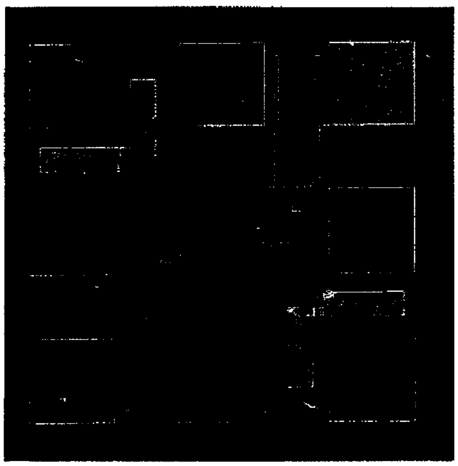


Figure 1. Transmission (a) and reflection (b) quasi-optical grid amplifiers. The reflective approach has been used in non-grid quasi-optical amplifier arrays [7].

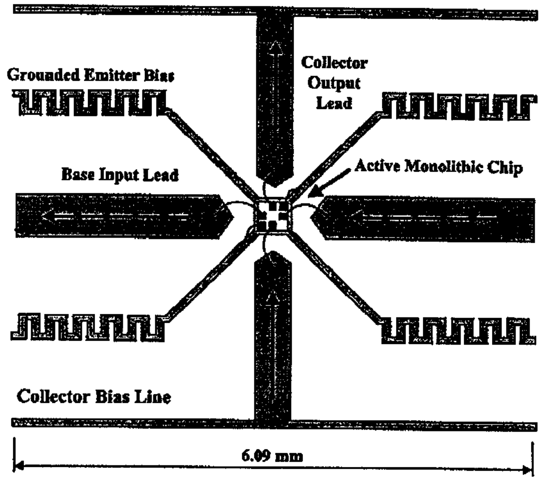


(a)

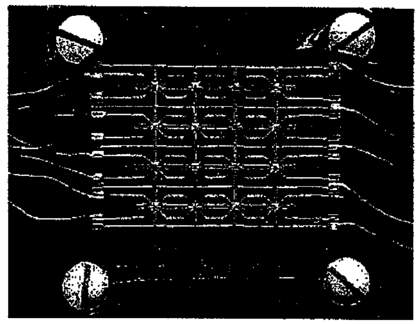


(b)

Figure 2. Schematic (a) and photograph (b) of TRW InP HBT differential-pair chip. The chip is 400 µm on a side, and has an emitter area four times greater than the chip reported in [6].



(a)



(b)

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

devices with four times the emitter area. In this case, thermal issues are paramount. We present a reflection amplifier structure that achieves good thermal and electrical performance while allowing the grid to be constructed on inexpensive *Duroid,* as well as retaining the flexibility of a moveable mirror.

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 four emitter fingers, each of area 1.5x10 μm^2. A chip schematic and layout are shown in Figure 2. The chip is designed to operate with a collector voltage of 3.5 V. 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-mode stability [8]. The input is coupled to the base through a pair of on-chip tuning capacitors.

Figure 3 shows the unit cell. The cell is 6.09 mm on a side. We fabricated a 16-element array on a *Duroid* substrate with a relative dielectric constant of 2.33 and a thickness of 2.8 mm. The unit cell was designed to achieve gain in the X-band, using the approach detailed by Preventza and others [9].

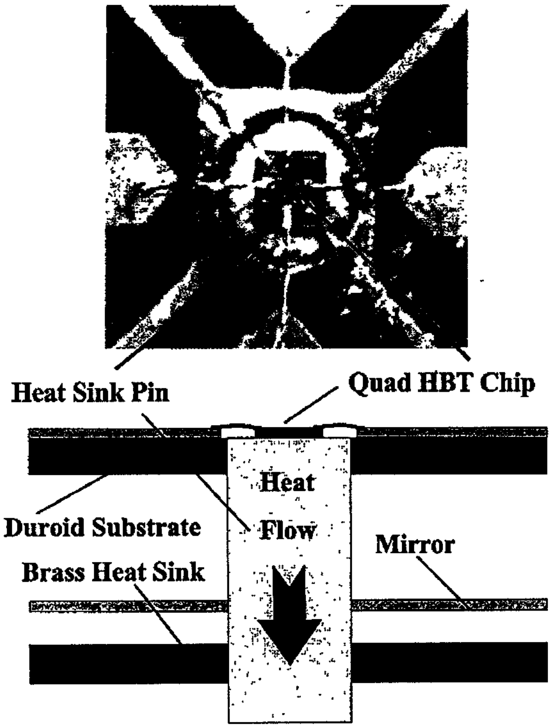


Figure 4. Heat sinking approach: top view (above) and cross section (below). The chip's heat is conducted to the sink via a copper pin

The first reflection amplifier reported in [6] was made with small devices, dissipating relatively little power, and thermal performance was therefore not a concern. The devices used in this array, however, will dissipate four times more power, and heat sinking is a major consideration. Figure 4 shows our heat sinking approach. Heat from the device is conducted through a 0.8-mm-diameter copper pin to a brass heat sink located behind the mirror. This allows the mirror position to be adjusted. The thermal conducting pins have little effect on the electrical performance of the array. Figure 5 shows a photograph of the assembled amplifier array, with the heat sink and copper pins visible.

III. THERMAL MEASUREMENTS

Our measurements indicate that the active grid is able to dissipate up to 4 W of dc bias power without any apparent effects. To further test the thermal performance of the array, we have fabricated two passive resistor arrays. These arrays are identical to the active arrays, except the transistor pairs are replaced by chip resistors. One array has the resistors mounted onto the copper pins with the brass heat sink, the other array does not use the thermal pins. Measurements with a ThermaCam PM290 infrared imaging system quantify the temperature rises. Fig. 6 shows the results. The array using our heat sinking approach is over three times more effective at removing heat than the array without. These measurements show that if the each cell were to dissipate the entire 270 mW of bias power, the

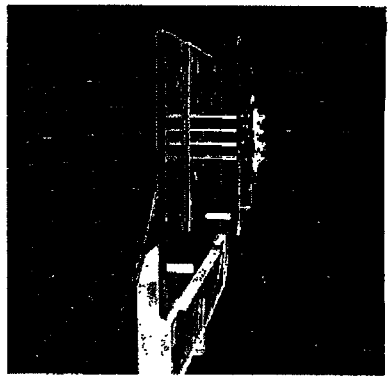


Figure 5. Photograph of the back of the assembled amplifier. The heat-conducting pins and brass heat sink (with thermal grease) are visible.

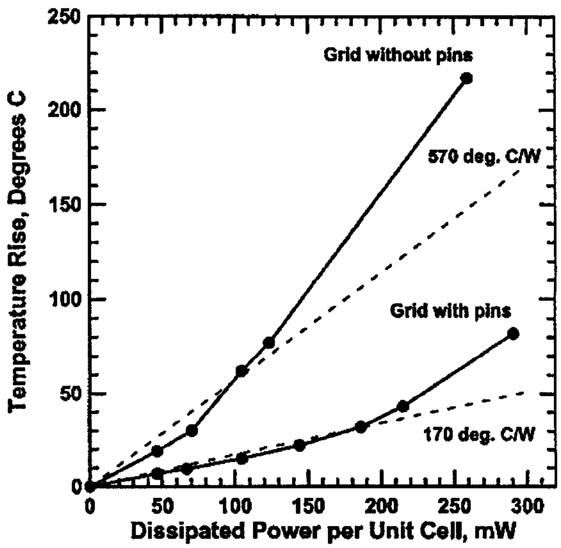


Figure 6. Measured temperature rise of a central element on two passive resistor arrays.

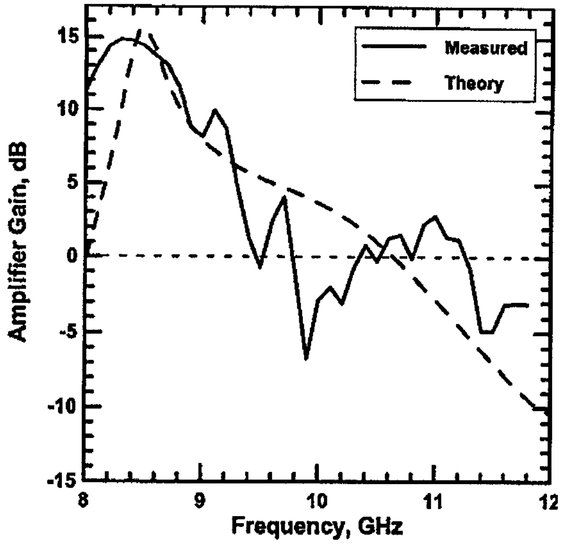


Figure 7. Measured (solid line) and modeled (dashed line) small-signal amplifier gain.

temperature rise would be a moderate 70°C with the improved heat sinking; an array without heat sinking would suffer a dangerously high temperature rise of over 220°C.

IV. ELECTRICAL MEASUREMENTS

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 7. The peak gain is 15 dB at 8.4 GHz; the peak frequency is lower than the result in [6] because of the larger devices. The peak measured gain is within 3 dB of the chip's maximum available gain. The 3-dB bandwidth is 750 MHz (9%). The modeled gain is also plotted; the agreement is reasonable considering the small size of the array. The theoretical gain is calculated using the approach detailed in [6] and [9].

We did not have a source powerful enough to saturate the array in our far-field setup. Attempts to measure the array's third-order intercept point using a two-tone measurement were limited by the noise floor of our spectrum analyzer. Nevertheless, our measurements indicate that the output third-order-intercept of the array is at least 0.5 W.

V. CONCLUSION

We have presented successful results from a reflection grid amplifier. Measurements show that our reflection approach does enable very efficient heat removal. The grid has a peak gain of 15 dB at 8.4 GHz, in agreement with theoretical predictions.

VI. ACKNOWLEDGEMENTS

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