A ROBUST 3W HIGH EFFICIENCY 8-14 GHz GaAs/AlGaAs HETEROJUNCTION BIPOLAR TRANSISTOR POWER AMPLIFIER

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ABSTRACT

A monolithic power amplifier has been developed using GaAs/AlGaAs HBT technology. This amplifier uses Cascode HBTs and provides ~3W CW from 8 to 14 GHz with a power added efficiency of ~40% and a gain of ~15dB. The cascode HBT is designed to be free of burnout problems associated with current collapse. Spurious signals at the output of the MMIC are kept ~-50dBc, worst case, and phase noise 1 KHz from the carrier is -130 to -140 dBc/Hz, better than that of comparable PHEMT amplifiers.

INTRODUCTION

Monolithic microwave power amplifiers employing GaAs/AlGaAs Heterojunction Bipolar Transistors (HBTs) have demonstrated impressive power and power added efficiency, especially over broad bandwidths [1-6]. Northrop Grumman has previously reported 1-2 W GaAs/AlGaAs HBT power amplifiers covering the 5-10 GHz [1], the 7-15 GHz [2], the 8-14 GHz [3] and the 6-18 GHz [4] bands. These amplifiers were implemented using HBTs in the common-emitter (CE) configuration. This paper reports the results of a recently developed power amplifier using cascode HBTs. This amplifier provides ~3W CW over 8-14 GHz with ~40% power added efficiency and ~15dB gain from a single stage. The measured phase noise, -130 to -140 dBc/Hz at 1 KHz from the carrier, is better than that of a typical PHEMT amplifier of comparable output power.

The advantage of using HBTs in the cascode connection is that these devices can be designed to be virtually free of problems stemming from the current collapse phenomena [7] and in this configuration breakdown voltage of the device is significantly higher than that in the Common Emitter (CE) connection (since BV_{CBO} is greater than BV_{CEO}). The same degree of ruggedness is difficult to achieve with CE designs and a significant penalty is usually imposed on the power, efficiency, bandwidth and other parameters of the CE amplifier to assure its survival in the field. Cascode amplifier design is simpler and more compact since interstage matching networks are eliminated.

The most significant disadvantages of Cascode HBT amplifiers, and which have precluded its widespread use, are the instabilities and spurious signals often observed in these circuits. These spurs can, however, be minimized and often eliminated with proper design. Another instance where Cascode HBTs are not a good choice is when the available operating voltage is low, e.g. below 5V as in battery operated systems. This is because the device knee voltage in this configuration is higher than for CE connections (~2V for Cascode HBT vs ~ 0.5V for CE HBT) which compromises power and efficiency at the lower collector voltages.

POWER AMPLIFIER DESIGN AND PERFORMANCE

Figure-1 shows a photograph of the 2.4mm x 4.6mm GaAs/AlGaAs HBT power MMIC. The technology used to fabricate this amplifier has been reported previously [3] and it provides the active and passive structures available from a typical power MMIC process, namely: active devices (HBTs), bulk and thin film resistors, MIM capacitors, local and global (air-bridge) interconnect metalizations and via holes through the 100 µm thick substrate. The MMIC is fully matched on chip, with 50 Ω input/output port impedances, and is therefore amenable to on-wafer testing and screening to a given performance specification.

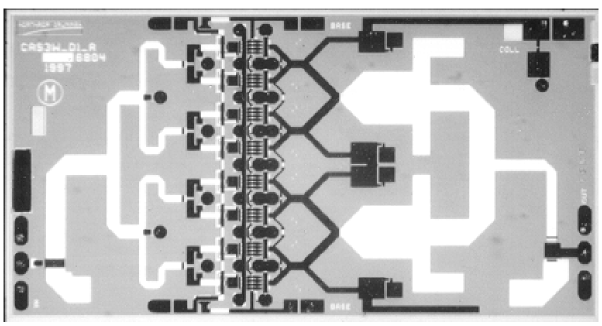

Figure 1. A photograph of the 2.4mm x 4.6mm 3W Cascode HBT power amplifier.

Figure-2 shows details of the 0.4W, multi-finger, cascode HBT unit cell; eight such cells are needed in the 3W MMIC. This cascode unit cell is designed to resist current collapse under practical operating conditions by the simple technique illustrated in Figure-3 and explained below. This approach was first discovered, utilized and patented by Ramachandran and Podell in 1991 [8] and was rediscovered in 1997 by Salib and Bayraktaroglu [9].

Figure-3a shows the conventional cascode connection between a multi-finger CE HBT and a multi-finger common base (CB) HBT; all collector contacts of the CE HBTs and all emitter contacts of the CB HBTs are tied together as shown. In this case, the CB HBT, which is the one operating under high power conditions, will suffer from current collapse under sufficiently high power dissipation. Any emitter finger of the CB HBT can hog the entire current available from the CE HBT. This will happen eventually because of the negative temperature coefficient of base-emitter turn-on voltage, the relatively high thermal resistance of GaAs HBTs and the inevitable non-uniformity in the multi-finger CB HBT.

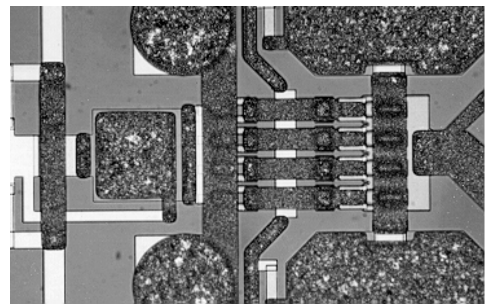

Figure-2. A photograph of the 0.4W Cascode HBT unit cell. There are eight 1.8µm x 19.8µm emitters in four pairs for both the CE and the CB transistors.

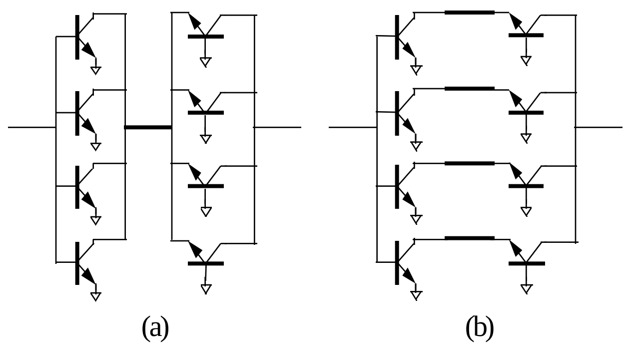

Figure 3. Two alternative Cascode HBT connections. The approach shown in (b) is preferred since it prevents current collapse in the CB HBT under practical operating conditions.

Figure-3b shows an alternate connection between the CE and the CB HBTs where current in each emitter of the CB HBT is regulated by the current in the corresponding CE HBT. In this case, as long as the total current is shared equally amongst the emitters of the CE HBT, the CB HBT will be forced to do the same irrespective of the power dissipation in this transistor. Since the CE HBT is operated at a low collector voltage (<3V), it does not suffer from current collapse even at the highest current levels and this keeps the CB HBT from current collapse as well.

The 0.4W unit cell used in the 3W MMIC employs four sub-cells, each with 71µm^2 emitter area. DC I-V characteristics of a typical device are as shown in Figure 4. In this measurement the base of the CB HBT is held at 3.2V, typical for the application described in this paper, while the CB collector voltage and CE base current are swept. Note the 2V knee voltage and the absence of any current collapse tendency. The high knee voltage is typical of the Cascode connection and limits this approach to applications where the collector supply voltage is 10V or greater. The typical performance of this device at 11 GHz is: 26 dBm output power, 19dB associated gain and 55% power added efficiency.

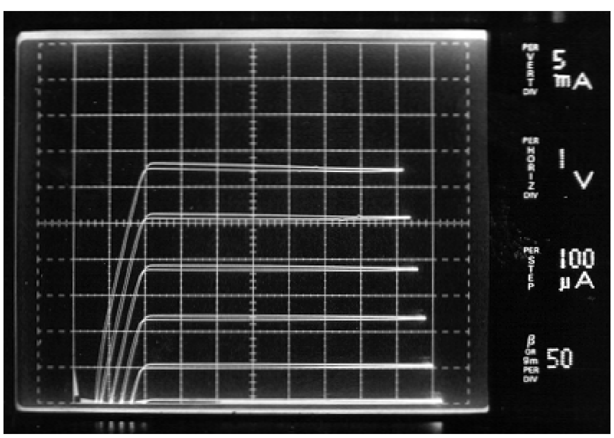

Figure 4. DC I-V characteristics of the 0.4W Cascode HBT unit cell. The base of the CB HBT was held at 3.2V during this measurement.

The CW power and efficiency performance of a typical MMIC in a 50 ohm fixture is shown in Figure-5. For a fixed input power of 19.7 dBm, the output power exceeds 34.8dBm (3W) over significant portions of the band. The MMIC is biased Class AB with 10V at the collector, 3.2V at the base of the CB HBTs and ~1.4V at the base of the CE HBT.

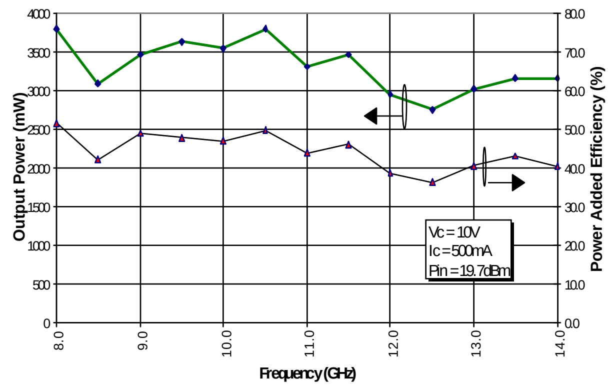

Figure 5. Output power (CW) and efficiency performance of a typical MMIC in a 50 ohm fixture.

The output signal is free of spurious signals for relatively good matches (VSWR <3:1). Output mismatches, both in-band and out-of-band can produce spurious signals, typically below 50dBc as illustrated in Figure-6 for one set of conditions. The phase noise close to the carrier does not seem to be affected by these spurious signals and is measured to be -130 to -140 dBc/Hz 1KHz away from the carrier. This performance is comparable to or better than that of amplifiers with similar output power made with MESFET and PHEMT technologies.

SUMMARY

This paper has reported the performance of a 3W HBT power MMIC covering 8-14 GHz with a power added efficiency of ~40% and power gain of ~15dB. The most significant feature of this amplifier is the use of Cascode HBTs designed to be virtually free of burnout problems related to current collapse. This is accomplished by means of an innovative device design.

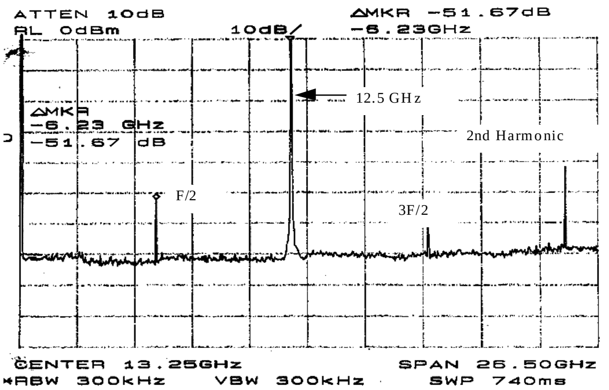

Figure 6. Output mismatches, both in-band and out-of-band can produce spurious signals, typically below 50dBc as illustrated here for one set of conditions.

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