Ultra-Efficient X-Band and Linear-Efficient K-Band Power Amplifiers using Indium Phosphide Double Heterojunction Bipolar Transistors (DHBTs)

T. Quach*, W. Okamura**, A. Gutierrez** , T. Jenkins*, E. Kaneshiro**, L. Kehias*, A. Oki**, D. Sawdai** , P. Watson*, R. Welch*, R. Worley*, and H.C. Yen**
* Air Force Research Laboratory, 2241 Avionics Circle, BLDG 620, Wright-Patterson AFB, Ohio 45433
* *TRW Electronics and Technology Division, One Space Park, Redondo Beach, CA 90278

OBJECTIVES: InP Double Heterojunction Bipolar Transistors (DHBTs) have shown excellent efficiency and linearity performance due to the inherently low knee voltage, high current density, low turn-on voltage, and intrinsic intermodulation characteristics. These features suggest that the InP DHBT technology is an excellent candidate for both military and commercial applications. For military systems, the recent focus towards space applications requires a shift in the critical parameters where the paramount specification is circuit efficiency with output power being secondary. Likewise for commercial systems, efficiency is related to talk time and advanced digital formats require linear amplifiers. We report on the first high efficiency X-Band power amplifier using InP DHBT technology. This circuit achieved a record of 61.5 % PAE, 20 dBm output power and 11 dB gain at 10 GHz. For commercial communication systems, the critical parameters are linearity and cost. We report on a compact power amplifier demonstrating excellent linearity and efficiency with 44% PAE, 26 dBm Pout, and 9 dB linear gain at 23 GHz. The same circuit yielded –30 dBc at 20 dBm output power.

APPROACH / RESULTS: The ultra-high efficiency power amplifier suitable for space applications was designed at 10 GHz and the linear efficient power amplifier was designed at 23 GHz. The X-band circuit employed a second harmonic termination at the output of the device using a pre-matched InP DHBT cell (Figure 1). The DHBT device is 1.5 µm X 30 µm X 4 fingers with Ft of 78 GHz and Fmax of 150 GHz. The device material profile consists of InAlAs/InGaAs/InP emitter-base-collector layers grown on a 3-inch InP substrate using molecular beam epitaxy (MBE). The double heterojunction (emitter and collector) reduces the offset voltage of the DC I-V characteristics. This is critical to improving efficiency due to the reduction of voltage and current overlap, which in turn reduces the I^2R loss of the intrinsic device. An alternative Class-E mode of operation was devised that produced higher efficiency than the classical approach [1]. In this paper, we extend that work by demonstrating a high efficiency circuit based on the load impedance for optimum efficiency. Thus the output matching circuit is designed to present the load condition for the alternative Class-E mode which has an impedance of 45.7 $\angle 68.5°$ Ohms. The input circuit is conjugately matched to S-parameters measured at the expected collector current. The final circuit implementation is a hybrid circuit approach (Figure 2). Small signal measurements of the circuit show 16 dB linear gain and better than 2:1 input / output VSWR (Figure 3). Load pull measurement of the pre-matched cell resulted in 73% PAE when the load is tuned to the alternative Class-E operation. The hybrid circuit has input / output substrate losses of approximately 0.5 dB, which equates to about 9% loss in circuit efficiency. In addition, the total connector loss is about 0.15 dB, further reducing the circuit PAE to ~ 61%. Figure 4 shows the Large-signal measurement of the X-band hybrid circuit tested in a 50 Ohm scalar system. The circuit yielded 61.5% PAE, 20 dBm output power, and 11 dB gain at a bias of Vce=4V and Ic=37 mA. The circuit efficiency may be improved in a MMIC implementation, which also will be presented. The K-band amplifier combines four 1.5 µm X 30 µm X 2 finger devices [2] (Figure 5). Small signal measurements indicated a peak linear gain of 11 dB at 23 GHz with the input VSWR better than 2:1 (Figure 6). The power amplifier delivered 26 dBm of output power and 44% of PAE (Figure 7). For linear class AB operation, the circuit yielded 22% PAE, 20 dBm output power, 8 dB gain, and an IM3 of –30 dBc at 23 GHz. Figure 8 shows IMD3 and PAE vary as a function of the bias voltage Vce.

CONCLUSION: This paper reports on microwave / mm-wave power amplifiers with excellent efficiency and linearity performance using the InP DHBT technology. We have also shown the DHBT technology will critically impact both military and commercial systems ranging from microwave to mm-wave operations. Furthermore, comparison between deep Class-AB and Class-E/F MMICs at X-band and linear efficient power operation at K/Ka Band will be presented.

REFERENCES:
[1] P. Watson et. al., "Ultra-High Efficiency Operation Based on an Alternative Class-E Mode", 2000 IEEE GaAs IC Symposium, pp 53-56, Nov. 2000.
[2] W. Okamura et. al., "K-Band 76% PAE InP Double Heterojunction Bipolar Power Transistors and a 23 GHz Compact Linear Power Amplifier MMIC", 2000 IEEE GaAs IC Symposium, pp 219-222, Nov. 2000.

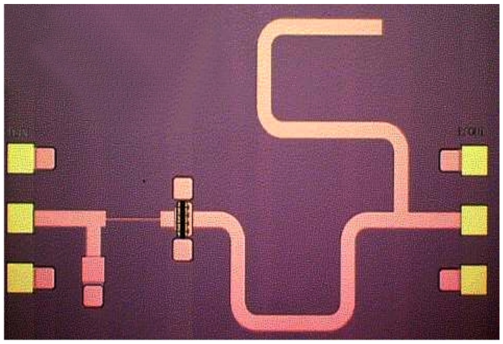

Figure 1: Pre-matched InP DHBT cell

Figure 2: High efficiency circuit using the pre-matched cell

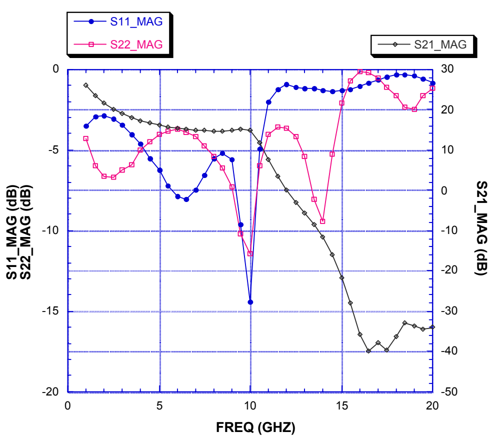

Figure 3: Measured S-parameters of the high efficiency circuit

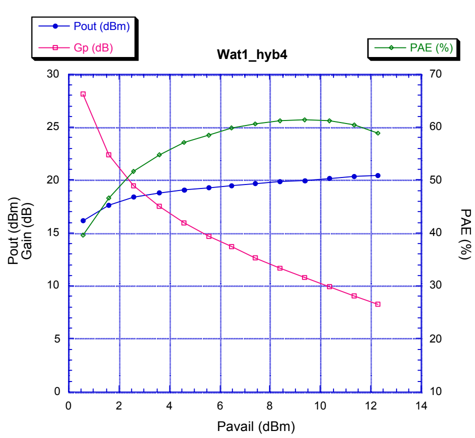

Figure 4: Power measurement of the high efficiency circuit showing 61.5 % PAE

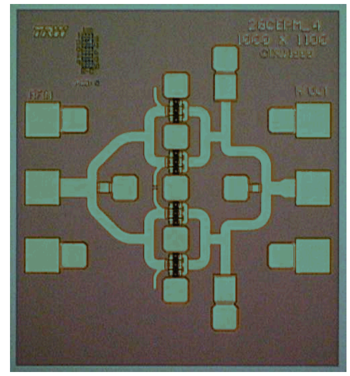

Figure 5: A linear power amplifier cell

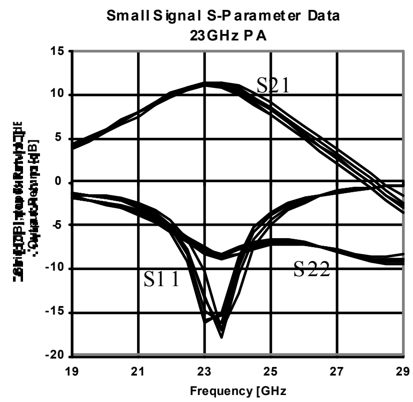

Figure 6: Measured S-parameters on 6 sites

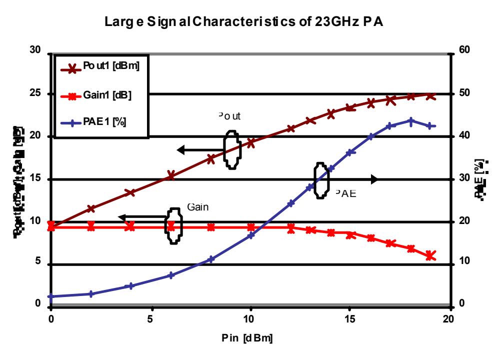

Figure 7: Power characteristics of the linear power cell measured at 23 GHz

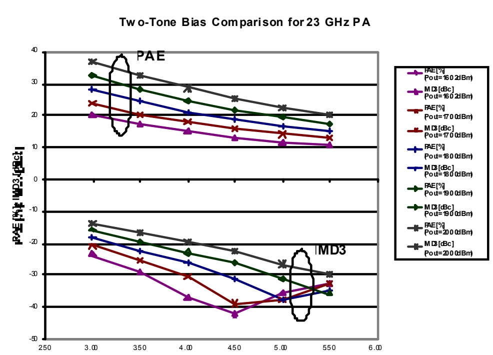

Figure 8: IMD3 and PAE as a function of output power at various Vcc