# 0.1–42 GHz InP DHBT distributed amplifiers with 35 dB gain and 15 dBm output

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An InP double hetero-junction bipolar transistor (DHBT) distributed power amplifier MMIC with 35 dB gain, 42 GHz bandwidth and 15 dBm output power is reported. This represents the highest power and largest gain reported over this bandwidth from a single chip HBT amplifier. A lumped preamplifier with a novel distributed output is used to obtain high gain and wide bandwidth at these power levels.

*Introduction:* Multi-decade bandwidth microwave power amplifiers have applications in phased-array radars, broadband communication systems and microwave instrumentation. They use distributed amplifiers that obtain wide bandwidth by splitting the amplifier into smaller parallel cells and absorbing the transistor input and output capacitances into synthetic transmission lines. With the device capacitances accounted for, the bandwidth is limited by the frequency-dependent losses associated with the loaded transmission lines [1]. Increasing the net device periphery increases the loaded line losses. Hence distributed power amplifiers (DPAs) have limitations on the net device periphery that can be used when designing for a given bandwidth [1]. This is one factor limiting the maximum output power obtainable over a specified bandwidth from a given device technology. Techniques such as capacitive division [2], resistive degeneration, and parallel coupling of DPAs [1] have been used to obtain higher power. Additionally, cascode (common-emitter–common-base) cells are often used to improve the input–output isolation and to decrease the loaded line losses at the output. In this Letter, we report a novel distributed stage employing common-collector–common-base (CC–CB) cells. This topology provides the benefits of capacitive division while also providing some of the advantages of a cascode output.

Distributed power amplifiers have been demonstrated using MESFET (GaAs), HEMT (InP, GaAs) and HBT (SiGe, InP, GaAs) technologies. Among the reported amplifiers with significant output power over 40 GHz bandwidth (Table 1), HEMT-based technology has typically obtained higher power and bandwidth. We report an InP double hetero-junction bipolar transistor (DHBT) power amplifier with 42.3 GHz bandwidth and 15 dBm output power at 1 dB compression. Reported DPAs (Table 1) typically have <20 dB gain. Multi-chip DPA modules have obtained large gain at the cost of increased size, complexity and packaging cost [3]. Our single chip solution achieves a high mid-band gain of 34.9 dB by using a broadband lumped preamplifier to drive the distributed stage.

**Table 1:** Comparison of amplifiers with highest power reported over 40 GHz bandwidth in various device technologies

| Device technology | Output power (dBm) | Output voltage** (V) | Gain (dB) | Bandwidth (GHz) | Reference |
|---|---|---|---|---|---|
| InP HEMT | 5 | | 17.5 | 0.06–48 | [3] |
| GaAs MESFET | 11 | | 10 | 1–40 | [4] |
| GaAs HEMT | 23 | | 12.5 | 1–40 | [5] |
| GaAs PHEMT | 21.5* | 7.5 V | 26 | 50 | [6] |
| GaAs MHEMT | 11 | | 13.4 | 65 | [7] |
| InP DHBT | 13.5* | 3 V | 15 | 58 | [8] |
| | **15** | | **34.9** | **0.1–42.3** | **this work** |
| SiGe HBT | 8.5 | | 9 | 0.1–50 | [9] |

*Estimated output power based on peak-to-peak output voltage reported
**Peak-to-peak single-ended voltage swing reported

*Device technology:* InAlAs/InGaAs/InP DHBT technology with a carbon doped base for improved reliability at high current density is used. $1 \times 3\ \mu m^2$ emitter area devices exhibit a typical current gain of 40 with 8 V breakdown ($V_{br}$), 140 GHz $f_t$ and 160 GHz $f_{max}$. The high $f_t V_{br}$ product is key to realising broadband power amplifiers. Commercial 4 inch GaAs HBT wafer processing techniques were used for the two layers of interconnect metal with polyimide dielectric, $0.36\ fF/\mu m^2$ $Si_3N_4$ MIM capacitors, $50\ \Omega$/sq resistivity NiCr resistors and co-planar waveguide (CPW) wiring environment.

*Circuit design:* The preamplifier uses alternating trans-admittance (TAS) and trans-impedance (TIS) stages (Fig. 1). Low inter-stage impedance in this architecture provides wide bandwidth. The preamplifier was designed for 23 dB gain, 48 GHz bandwidth and has a current-mode-logic (CML) interface with 50 Ω termination. The distributed cell design is based on the CC–CB pair: Q2–Q3 (Fig. 1). The CB device (Q3) provides RC degeneration for the CC device (Q2). This reduces the capacitance seen at the base of Q2 by half, allowing us to use devices of twice the emitter area. Higher power is obtained for the same bandwidth. An additional emitter-follower (Q1) further decreases the capacitive loading on the input transmission line while providing level-shifting. The CC–CB pair also mitigates the Miller effect just like the cascode pair, but without decreasing the voltage headroom available for the output transistor in the DPA. Additionally, this quasi-differential pair topology offers easy biasing through current sources. The 10 cell distributed amplifier was optimised for best power performance. Harmonic balance simulations showed that about 3 dB of gain peaking at 40 GHz obtained a flat response at high powers, and was incorporated in the design.

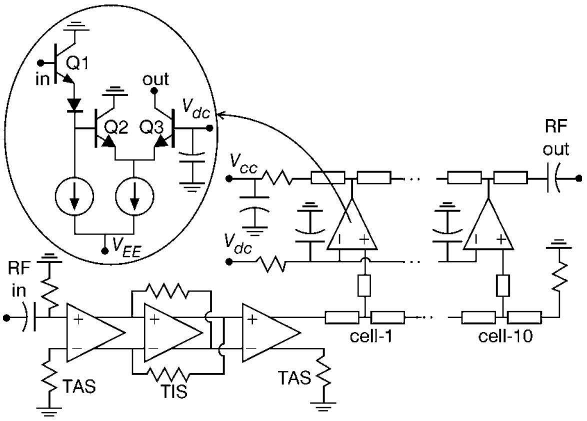

**Fig. 1** *Schematic diagram of broadband power amplifier with simplified view of distributed amplifier cell*

*Results:* The power amplifier IC measures $3.3 \times 1.5\ mm^2$ (Fig. 2) and operates from +3.3 and −5 V supplies, consuming 2.2 W. Measured *S*-parameters (Fig. 3) show 34.9 dB mid-band gain, 42.3 GHz bandwidth, and lower than 10 dB return losses over the bandwidth. Measured power response (Fig. 4) shows about 15 dBm of output power at 1 dB compression up to 40 GHz, and good linearity with >16.5 dBm saturated power at 20 GHz.

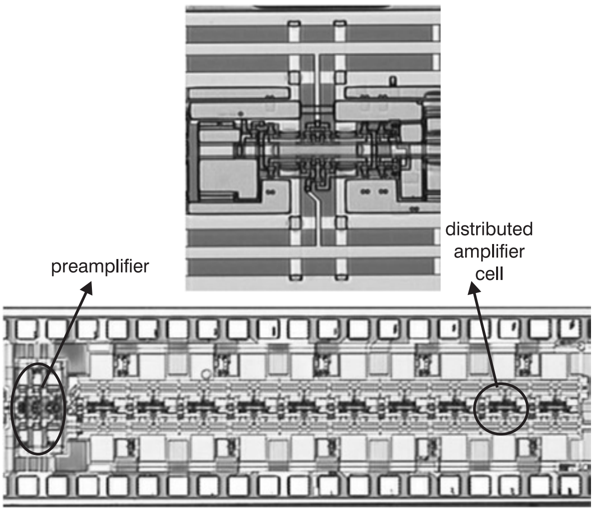

**Fig. 2** *Micro-photograph of broadband power amplifier IC with magnified view of distributed amplifier cell*

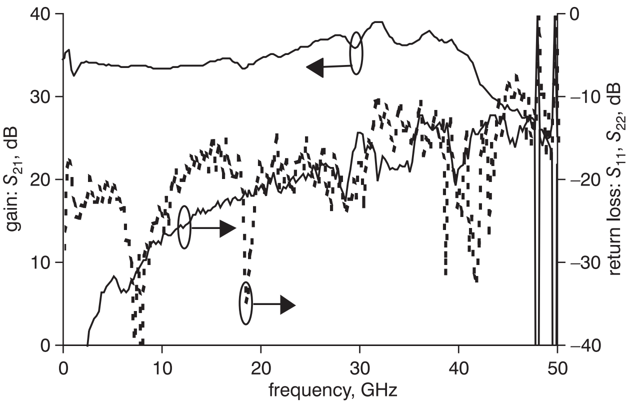

**Fig. 3** *Small-signal frequency response of broadband power amplifier*

——— $S_{21}$ (dB)
——— $S_{11}$ (dB)
- - - $S_{22}$ (dB)

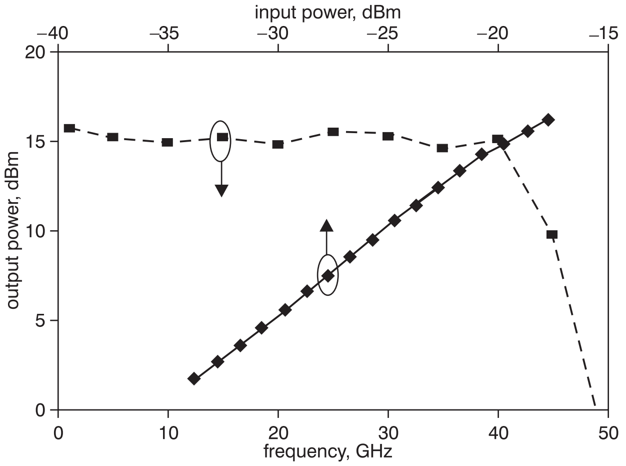

**Fig. 4** *Output power response of broadband power amplifier*

- -■- - frequency response of output power at 1 dB compression
—◆— measured output power against input available power at 20 GHz

*Conclusion:* We have demonstrated an InP DHBT distributed power amplifier with 15 dBm output power and 2.3 THz gain–bandwidth product by combining broadband high gain trans-admittance–trans-impedance preamplifier stage with a novel common-collector–common-base distributed output stage. To the best of our knowledge, this represents the highest power and largest gain over this bandwidth reported for a single chip HBT amplifier.

*2 August 2003*
*Electronics Letters Online No: 20031020*
*DOI: 10.1049/el:20031020*

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