A 50-MHz–55-GHz Multidecade InP-Based HBT Distributed Amplifier

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***Abstract*— This letter reports on a 50-MHz–55-GHz multidecade bandwidth InP-based heterojunction bipolar transistor (HBT) MMIC distributed amplifier (DA) which achieves the widest bandwidth and highest frequency of operation so far demonstrated for a bipolar amplifier. The HBT MMIC DA was fabricated using a high-speed 1-μm InAlAs/InGaAs-InP HBT base-undercut technology with peak f_T's and $f_{\max}$'s of 80 and 200 GHz, respectively, in order to obtain broad-band gain. Key to this work is the successful employment of HBT active load terminations used on both the input and output DA transmission lines in order to extend the low-frequency gain performance down to baseband. With only 82 mW of dc power consumption, the amplifier obtains measured gains of 7.6 dB at 50 MHz, 5.7 dB at 30 GHz, 5.8 dB at 50 GHz, and 3.1 dB at 55 GHz. Simulations of a monolithically integrated InGaAs p-i-n photodetector predicts a baseband 47-GHz photoreceiver response with an effective transimpedance of 38-dBΩ. The baseband millimeter-wave capability of the InP-based HBT DA and its compatibility with InGaAs photodetectors makes this technology attractive for future generation (>40 Gb/s) high-data-rate light-wave applications.**

***Index Terms*—HBT, InP, OEIC, photoreceiver.**

I. Introduction

THERE is an increasing trend toward the application of the distributed amplifier for high-data-rate (>40 Gb/s) lightwave communications [1]–[6] due to their inherently high bandwidth. Previous works have suggested that InP-based heterojunction bipolar transistors (HBT's) and HEMT's are preferred technologies for implementing future generation high-speed optical-electronic integrated circuits (OEIC's) due to their material compatibility with 1.55-μm p-i-n photodetectors and inherently higher electron velocities compared to GaAs-based technologies. While HEMT's have demonstrated pre-amplifiers and baseband amplifiers with performance as high as 100 GHz using the distributed design approach [4]–[6], they lack the good threshold voltage uniformity and low-phase jitter properties that HBT's have for supporting the monolithic integration of clock and data recovery IC functions which follow the photodetector. This may hinder HEMT's from providing optimum system performance in a single integrated receiver-clock-and-data-recovery chip, which is the ultimate goal for an OEIC implementation. On the other hand, HBT's are analog-bipolar devices which possess excellent threshold uniformity, low $1/f$ noise characteristics, and high output impedances and have been the preferred technology for high-speed digital and analog applications. While HBT's enable high-speed clock and data recovery performance using these well-established bipolar architectures, the conventional analog-bipolar direct-coupled pre-amplifier approach is limited in frequency performance due to their complex pole–zero nature, which is heavily influenced by interconnect and device layout parasitics that can cause premature roll-off or excessive peaking response. This warrants the adoption of a bipolar distributed amplifier approach which absorbs the device and interconnect parasitics into the design and results in a well-behaved low-pass roll-off response.

Previous work on an InP-based HBT distributed amplifier based on high-performance base-undercut HBT's has demonstrated record frequency operation in a 2–50-GHz HBT DA [7], however passive R-C load terminations have prevented them from achieving baseband performance. Active load techniques for extending the lower frequency response have been described and separately demonstrated [8] using a less-aggressive InP-based HBT technology. In this work, we present the first results of an InP HBT distributed amplifier which combines both the active load and advanced base-undercut HBT technology and demonstrates over three decades of bandwidth performance from 50 MHz to 55 GHz. In addition, this letter presents simulations of the InP HBT DA integrated with a monolithic InGaAs p-i-n diode which predicts a monolithic receiver performance from base-band to 47 GHz.

II. Multidecade InP HBT Distributed Amplifier

The detailed schematic of the InP-HBT distributed amplifier design with integrated active load terminations is given in Fig. 1. A similar design has been previously demonstrated in [7] except for the additional employment of the HBT active load terminations. The amplifier consists of a five-section distributed amplifier which employs HBT cascode devices with resistive feedback. The cascode is comprised of two 1×4 μm^2 single-emitter HBT's Q_1 and Q_2, biased at a nominal collector current of $I_{\rm ce} = 3$, mA which is close to the device's peak $f_{\max}$ condition. The small devices are biased at low collector currents to reduce the effective input capacitance of the HBT's so that a broader 50-Ω input transmission line bandwidth could be synthesized with the inductive CPW transmission lines. The cascode HBT topology is used to obtain higher broad-band gain. Negative feedback is utilized

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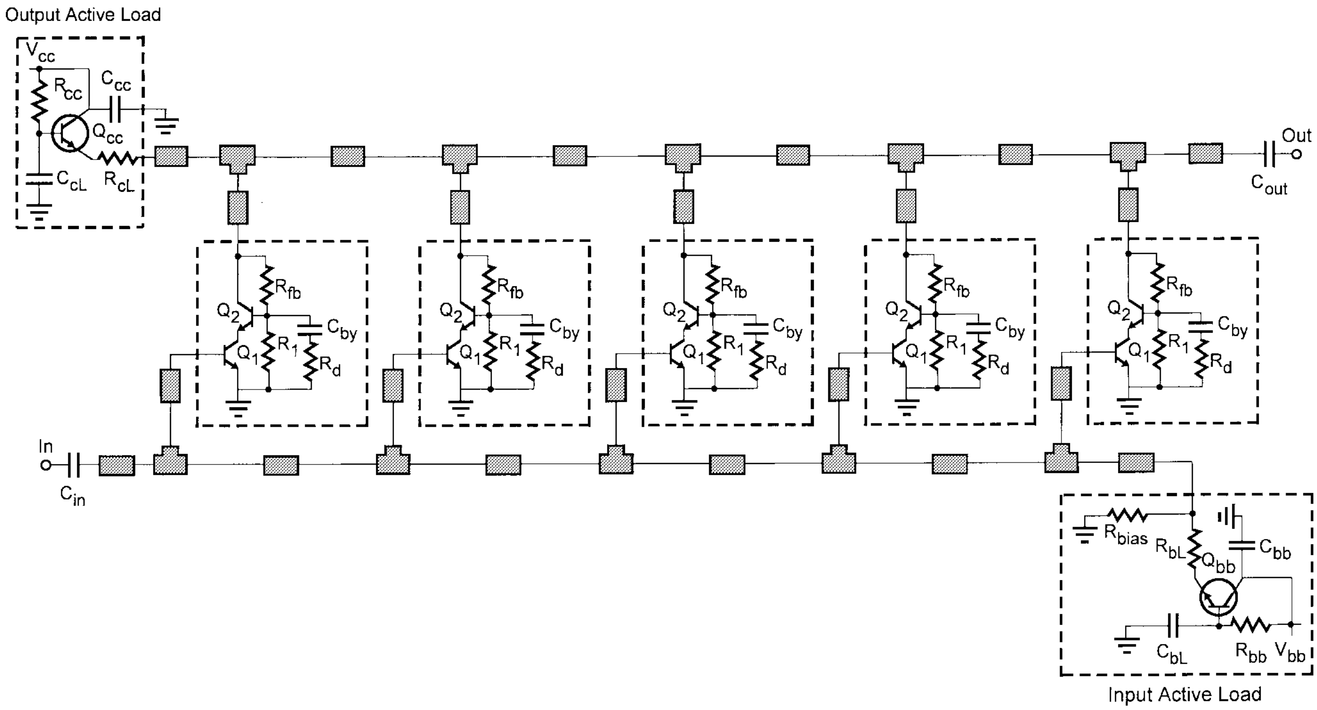

Fig. 1. Detailed schematic of the InP-HBT distributed amplifier design with integrated active load terminations.

in order to ensure stable operation with the high-gain cascode HBT's. The cascode feedback resistor R_{fb} used in this design is $\approx$600 Ω. Significant upper frequency gain performance is also achieved from the use of an advanced HBT base-undercut technology which has been previously described [7].

In many of the lightwave communication systems, the low-frequency response of the preamplifier must accommodate baseband performance, which is a function of the system configuration. In order to extend the lower frequency response of the HBT distributed amplifier, active load terminations were employed on both the input and output DA transmission lines. Where typically a combination of small on-chip and large off-chip bypass capacitors are used to extend the lower frequency response of conventional DA's to baseband frequencies, this implementation often results in L-C resonances which fall within the passband response of the DA. This problem becomes especially challenging for DA's requiring baseband to millimeter-wave frequency bandwidth performance. These effects can result in gain ripple due to standing-waves in either of the input or output distributed transmission lines and can affect the DA's amplitude and phase characteristics. The HBT active loads help eliminate the self-resonance problem by requiring smaller on-chip bypass capacitors which effectively get multiplied in value by the low-frequency ac beta of the HBT active load device. Referring to Fig. 1, the active loads consist of an HBT common-collector device $(Q_{\text{bb}}, Q_{\text{cc}})$ which transforms the shunt bypass capacitance $(C_{\text{bL}}, C_{\text{cL}})$ on the base, to an effectively larger load capacitance when looking into the emitter. In this way an ac ground can be extended to lower frequencies using active HBT's without incurring large capacitors which tend to self-resonate in-band. Active load transistor Q_{bb} is biased at $\approx$2 mA while Q_{cc} is biased at the total amplifier current of $\approx$20 mA. R_{CL} and R_{bL} are adjusted to provide a broad-band resistive impedance in combination with the impedance of the active load transistors. The theory and operation of this HBT active load has been previously described in detail [8] and was fabricated and tested with a less-aggressive HBT DA design (more feedback) and more-conservative HBT process (no base-undercut).

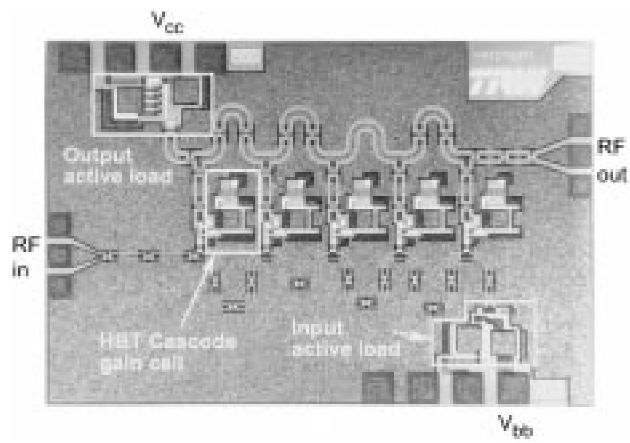

Fig. 2. Microphotograph of the HBT DA MMIC. Chip size of 1.8 $\times$ 1.2 mm^2.

Fig. 2 shows a microphotograph of the HBT DA MMIC with active load terminations. The amplifier is designed in a CPW environment with a total chip size of 1. 8 $\times$ 1. 2 mm^2. Coplanar waveguide simplifies the process (no backside vias required) and minimizes the chip area and simplifies the modeling of the DA design. The total dc power of the HBT MMIC is 85 mW which includes the active load bias.

Fig. 3 gives the broad-band gain and return-loss performance of the HBT distributed amplifier. The gain extends from below 50 MHz up to 55 GHz and is reasonably flat. Gains of

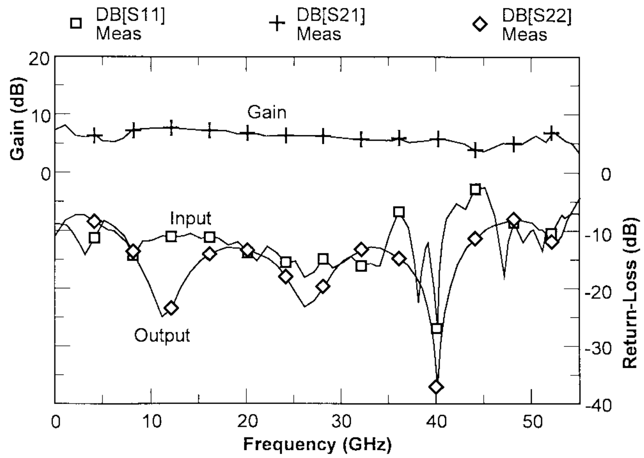

Fig. 3. Broad-band gain and return-loss performance of the HBT distributed amplifier.

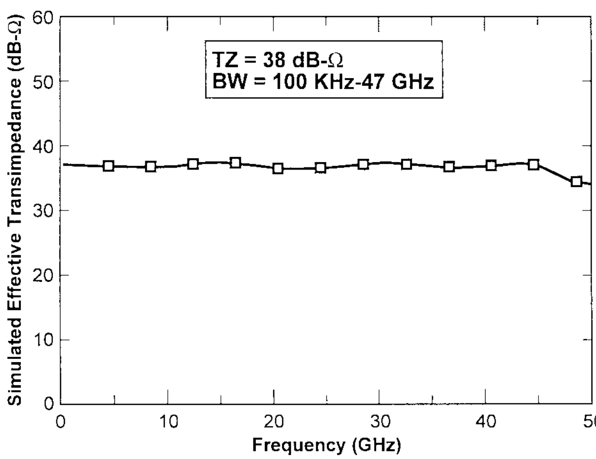

Fig. 4. Broad-band receiver response of a 10 × 10 μm^2 InGaAs p-i-n photodetector monolithically integrated with the InP HBT distributed amplifier.

7.6 dB at 50 MHz, 5.7 dB at 30 GHz, 5.8 dB at 50 GHz, and 3.1 dB at 55 GHz are achieved. Typical return-losses of >10 dB are also obtained across the band. Simulations indicate that the low frequency gain can be extended down to a few kilohertz by employing HBT's biased for higher current gains.

Fig. 4 gives the simulated broad-band receiver response of a 10 × 10 μm^2 InGaAs p-i-n photodetector monolithically integrated with the InP HBT distributed amplifier. The InGaAs p-i-n diode has a epitaxy thickness of 7000 Å and was processed from the same HBT epitaxy structure (wafers) as the DA. The diodes were separately characterized and modeled and obtain a responsivity of ≈0. 57 A/W with a transit-time limited bandwidth of around 45 GHz. The diodes are expected to handle as much as 1 mA of photo-induced current. The receiver of Fig. 4 illustrates a bandwidth from 100 kHz to 47 GHz with an effective transimpedance of 38 dB Ω. The bandwidth achieved from this simulation is 74% wider than the highest measured state-of-the-art bandwidth reported for an integrated photo-receiver MMIC [9]. These results reveal the broad-band OEIC receiver capability of the InAlAs/InGaAs-InP HBT distributed amplifier for high-data-rate lightwave applications.

III. Conclusion

Here we demonstrated a 50-MHz–55-GHz multidecade bandwidth InP-based HBT MMIC distributed amplifier (DA) which achieves the widest bandwidth and highest frequency of operation so far demonstrated for a bipolar amplifier. The design features the successful employment of HBT active load terminations with performance capability below 50 MHz. This lower frequency band edge can be significantly reduced with higher dc current-gain HBT active load devices. Simulations of a monolithically integrated InGaAs p-i-n photodetector predicts a baseband 47-GHz photoreceiver response with an effective transimpedance of 38 dBΩ. The results of this work reveals the potential of InP-based HBT OEIC's for next-generation high-data-rate (>40 Gb/s) lightwave communication systems.

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