Two-Tone Third-Order Intermodulation Distortion Characteristics of an HBT Optoelectronic Mixer Using a Two-Laser Approach

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Abstract

The third-order intermodulation distortion characteristics of a three-terminal InP/InGaAs HBT optoelectronic mixer are reported for the first time. The SFDR was 94 dB (1 Hz) in down-conversion (3.682 GHz to 300 MHz), and 96 dB (1 Hz) in up-conversion (3.682 GHz to 7.064 GHz).

Introduction

Heterojunction bipolar transistor (HBT) optoelectronic mixers (OEMs) find applications in microwave/millimetre wave fibre-radio systems [1] by simultaneously photodetecting an intensity modulated laser beam and frequency translating the detected signal to a higher and/or lower frequency. To deploy an HBT OEM successfully, one needs to know its conversion gain, frequency response, noise performance and distortion characteristics. The authors have previously demonstrated both two-terminal down-converting (2.5 GHz to 500 MHz) and three-terminal down-converting (3 GHz to 100 MHz) HBT OEMs with 7 dB and -6 dB conversion gain advantages, respectively, over a hypothetical 100 % quantum efficient photodiode and a zero conversion loss microwave mixer in a 50 Ω system [2,3]. Recently Gonzalez et al. [4] reported an HBT OEM in which an intensity modulated light was up-converted from 0.2–2.5 GHz intermediate frequency (IF) to 30 GHz ± IF with ± 3 dB variation in the output electrical signal powers. Urey et al. [5] reported a higher signal-to-noise ratio (S/N) for an HBT OEM compared to HEMT and JFET OEMs. In this paper, the measurement of the two-tone third-order intermodulation distortion characteristics of an InP/InGaAs HBT OEM will be described and results presented. To the authors' knowledge, these are the first published linearity measurements for an HBT OEM.

In general, the linearity of a fibre-optic link may be limited by the laser diode or the external modulator rather than the photodetector itself. Therefore when the photodetector is the subject of a distortion characteristic investigation, it is important that the measured distortion products are generated by the photodetector itself, but not the optical source. Liu et al. [6] previously measured the two-tone third-order intermodulation (IM) products of their MSM photodiode OEM by modulating a single laser diode with two microwave sources and concluded that the measured IM products were actually due to the nonlinearity of the optical source. The approach in the present investigation is to modulate separately two laser diodes at two slightly different frequencies. The two-tone test signal is then formed by combining the two laser beams in free-space before being focused on the HBT. This two-laser approach ensures that the IM products are generated by the photodetector, rather than the optical source.
In the following sections, the fabrication and structure of the HBT being investigated will first be described. The experimental arrangement will then be explained and the results presented. Finally a conclusion will be given.

**HBT fabrication and structure**

The HBT epitaxial layers were grown on a semi-insulating InP substrate by a compact metal-organic molecular beam epitaxy system [7]. The emitter Ti/Pt/Au metal served as a mask for wet etching of the emitter mesa. Self-aligned non-alloyed Pt/Ti/Pt/Au contacts were evaporated on the base and collector mesas. A 5×6 \( \mu \)m\(^2\) opening in the base metallisation served as an optical window. Ti/Au pads were evaporated after polyimide passivation and a curing process at 300°C for 1 hour. The polyimide layer covering the optical window was 450 nm thick. The cross-section of the HBT with doping levels is shown in Figure 1.

To perform optoelectronic measurements, the HBT die was secured in the middle of a custom-designed brass mount with 1 cm long, 50 \( \Omega \) characteristic-impedance microstrip transmission lines on both sides. The base and the collector were connected to the transmission lines using single bond wires estimated to be no longer than 0.5 mm each. The emitter was similarly connected to a neighbouring brass step serving as the signal ground. SMA connectors were then attached to both ends of the mount so that the HBT could be accessed electrically using conventional microwave cables. To enable optical access to the device, the mount was placed on an x-y-z micro-positioner so that the HBT optical window could be aligned with the laser beam.

**Experimental arrangement**

The basic experimental arrangement is shown in Figure 2. Lasers 1 and 2 were two very low-noise GEC-Marconi LD-6804 60mW laser diodes emitting at around 1550 nm wavelength, and were separately modulated, with 22 \% modulation depth, at \( RF - 5 \) kHz and \( RF + 5 \) kHz, respectively, where \( RF = 3.682 \) GHz. The wavelengths of the two lasers were sufficiently offset so that the beat signal (above 20 GHz) did not interfere with the measurements at lower frequencies. The two beams were combined in free space in a beam splitter cube. One of the emergent beams from the splitter was focused onto the HBT and the other was coupled to a fibre and monitored with a lightwave signal analyser (LSA). Equal amounts of incident optical power from each laser on the HBT were maintained by monitoring the primary photocurrent generated due to each laser in the HBT (by setting \( V_{BE} = 0 \) V). Optical isolators were employed to suppress optical reflections. Since the third-order IMD product powers were very low, a low-noise amplifier was used before the spectrum analyser to increase the output signal strength. However when the HBT was pumped by a -4 dBm local oscillator (LO) at the base at \( f_{LO} = 3.382 \) GHz, the LO leakage at the collector was so large that the amplifier was saturated. Therefore, two
bandstop filters based on microstrip commensurate-lines and coupled-lines, respectively, were inserted between the HBT collector and the amplifier in order to suppress the LO fundamental and second harmonics. Higher harmonics of the LO were small enough not to saturate the amplifier.

By varying the amount of optical power incident on the HBT through optical attenuation and slight misalignments, the fundamental output signals and third-order IM products were measured. The equivalent electrical input power per tone $P_{RF, \text{Elec}}$ was used as the independent variable in this measurement and is calculated from

$$P_{RF, \text{Elec}} = \left( \frac{m q \lambda_{opt}^2}{\hbar c} \right)^{50} \frac{50}{2}$$

where $m$ is the intensity modulation depth of the incoming optical beam, $P_{opt}$ is the mean incident optical power, $q$ is the electron charge, $h$ is the Planck's constant, $c$ is the speed of light and $\lambda$ is the wavelength. Therefore $P_{RF, \text{Elec}}$ is equal to the ac electrical power delivered by a 100% quantum efficient photodiode to a directly attached 50 $\Omega$ load.

**Experimental results**

The third-order IM distortion product characteristics in down- and up-conversions are shown in Figure 3 and Figure 4, respectively. The power levels shown are those at the HBT collector, not at the output of the amplifier. The IM products increased 3 times as fast with $P_{RF, \text{Elec}}$ as the fundamentals because of the third-order nature. The third-order intercept point (IP3) at the output was +2 dBm for the down-conversion and -14 dBm for the up-conversion. The system conversion gain, defined as the ratio of the output fundamental power to $P_{RF, \text{Elec}}$, was -6 dB for down-conversion and -17 dB for up-conversion. It is mainly the difference in the system conversion gain in the two processes which led to a much lower IP3 for up-conversion than for down-conversion.

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Figure 3: Third-order intermodulation distortion product characteristics in down-conversion. LO = 3.382 GHz at -4 dBm. CF = 300 MHz, $df = 5$ kHz. Only distortion products at CF-3CF were measured. $V_{ds} = 0.75$ V, $V_{gs} = 1.5$ V, HBT ext. quantum efficiency = 17.6 %

Figure 4: Third-order intermodulation distortion product characteristics in up-conversion. LO = 3.382 GHz at -4 dBm. CF = 7.064 GHz, $df = 5$ kHz. Only distortion products at CF-3CF were measured. $V_{ds} = 0.75$ V, $V_{gs} = 1.5$ V, HBT ext. quantum efficiency = 17.6 %

Also shown in Figure 3 and Figure 4 are the corresponding output noise floors in the two processes. The noise floors were measured with 70 $\mu$W unmodulated light (with RIN < -160 dB/Hz) incident on the HBT under the same electrical bias and LO drive power. With the knowledge of the noise floors, the spurious-free dynamic-range (SFDR) defined as the difference between the fundamental signal power and the IM product power when the IM product power and the noise floor are the equal, was measured to be 94 dB (1 Hz) for the down-conversion, and 96 dB (1 Hz) for the up-conversion. Microwave subcarrier
multiplexed (SCM) links connecting a satellite earth station and its antennas require a typical SFDR of 90 to 96 dB (1 Hz) [8] and therefore the up-converting HBT OEM should find applications in such a system.

The third-order IM product characteristics and SFDR of the HBT configured as a direct photodetector were also measured and are shown in Figure 5. The SFDR was 109 dB (1 Hz). The system signal gain, defined similarly to the system conversion gain but without frequency conversion, was 0 dB and the IP3 was +13 dBm. The system signal gain, IP3 and SFDR for direct detection were all higher than those for down- and up-conversions because of the linear operation of the HBT. If optoelectronic mixing is carried out with the HBT direct photodetector and an external microwave mixer requiring a 10–13 dBm LO with typical 7 dB conversion loss and 7 dB single-sideband noise figure, the calculated SFDR will be 107 dB (1 Hz). The SFDR penalties for the HBT optoelectronic mixer compared to this HBT/external mixer configuration will be 13 dB (down-conversion) and 11 dB (up-conversion). However, the present HBT optoelectronic mixer requires only a low -4 dBm LO drive, is simpler and therefore an attractive option.

Conclusion

The measurement of the two-tone third-order intermodulation distortion characteristics of an InP/InGaAs HBT optoelectronic mixer has been described and results presented for the first time. The spurious-free dynamic range (SFDR) was 94 dB (1 Hz) for the down-conversion (3.682 GHz to 300 MHz), and 96 dB (1 Hz) for the up-conversion (3.682 GHz to 7.064 GHz). The obtained SFDR for the up-conversion is high enough to satisfy the typical requirement of SCM links connecting a satellite earth station and its antennas.

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References


