Use of Surface Passivation Ledges and Local Negative Feedback to Reduce Amplitude Modulation Noise in AlGaAs/GaAs Heterojunction Bipolar Transistors

Damian Costa, *Member, IEEE,* and Ali Khatibzadeh, *Member, IEEE*

***Abstract*— It is shown that the use of surface passivation ledges and local negative feedback with an unbypassed emitter resistance reduce the AM noise of AlGaAs/GaAs heterojunction bipolar transistors (HBT's). The simultaneous use of both techniques improves the AM noise by 9 dB at 100 Hz offset. The correspondence between reductions in baseband noise and AM noise are described.**

I. Introduction

In modern communication and electronic warfare systems, in which small signals must be recovered in the presence of single or multiple carrier signals, low amplitude modulated (AM) and phase modulated (PM) near-carrier noise are of prime importance. These near-carrier noise sidebands are generally believed to arise from the up-conversion of 1/f (baseband) noise to the carrier frequency via the nonlinearities of the circuit. Thus, the most effective means for reducing near-carrier noise is to minimize the 1/f noise and linearize the active device.

While excellent low-harmonic distortion and phase-noise performance have been achieved with AlGaAs/GaAs heterojunction bipolar transistors (HBT's) [1], [2], the AM-noise performance of AlGaAs/GaAs HBT's has not been reported. Furthermore, while the incorporation of surface passivation ledges has been used to improve the baseband-noise performance of AlGaAs/GaAs HBT's [3], [4], the resulting improvement in up-converted noise performance has not been demonstrated. In this letter, we report the use of depleted AlGaAs surface passivation ledges (over the extrinsic-base surface) and local negative feedback with an unbypassed emitter resistance to reduce the AM noise of AlGaAs/GaAs HBT's. The correlation between reductions in baseband noise and AM noise are presented.

II. Baseband Noise Characterization

Fig. 1 shows the schematic cross sections of the conventional (with unpassivated, exposed extrinsic-base surface) self-aligned (SA) HBT (Fig. 1(a)) and the non-self-aligned with surface passivation ledge (NSAL) HBT (Fig. 1(b)) compared in this study. The AlGaAs emitter was 1400 Å thick and doped at [Si] $= 2 \times 10^{17}$ cm^{-3} and the base–emitter junction was nominally abrupt. The incremental current gains (h_{fe}) of SA and NSAL HBT's with four emitter fingers, each with dimensions 3.5 μm $\times$ 30 μm, were 60 and 100, respectively at a collector current of $I = 30$ mA. The low-frequency collector noise spectral density of each device, biased in the common-emitter configuration and base-terminated with 10 $K\Omega$, was measured using a HP 3561A signal analyzer. The measured collector noise spectrum was then transformed to an equivalent noise current spectral density at the base ($S_{Ib}(f)$) using the measured current gain and input resistance of the device and the known load resistance [5]. Fig. 2 compares $S_{Ib}(f)$ of the unpassivated SA HBT to that of the passivated NSAL HBT at $I_c = 30$ mA and $V_{ce} = 3$ V. As can be seen, $S_{Ib}(f)$ of both devices falls approximately as 1/f over the frequency range of 10 Hz to 10 KHz, but tends to flatten slightly from the 1/f dependence between 10 and 100 KHz. S_{Ib} (100 Hz) of the NSAL HBT is 7 dB lower than that of the SA HBT, in agreement with other studies [3], [4], which have demonstrated the role of surface passivation ledges in improving the 1/f noise performance of AlGaAs/GaAs HBT's.

III. AM Noise Measurement Method

Fig. 3 shows the AM noise test set. A California Microwave 2.24 GHz synthesizer was used to provide a clean signal in order to drive the HBT's under test. An HP 11729C diode detector demodulated the AM noise sidebands and the demodulated (baseband) sidebands were measured with a HP 3561A. Measurements were first conducted with the tuners and the HBT replaced with a thru line. The detector was calibrated by injecting a single sideband spur. The magnitude of the spur was set at -40 dBc relative to the carrier at 10 KHz offset. Once the detector constant was calibrated, the spur was removed and the AM noise was measured to establish the noise floor of the system. HBT's were mounted on alumina substrate carriers with 50Ω transmission lines. The AM noise added by the HBT was then determined by inserting the device, along with input/output tuners. The HBT was operated under small-signal drive (weakly nonlinear) conditions with an input carrier power of - 6 dBm. The tuners were adjusted in order to match the input/output impedances and maximize the power gain.

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The authors are with Central Research Laboratories, Texas Instruments, Dallas, TX 75206.
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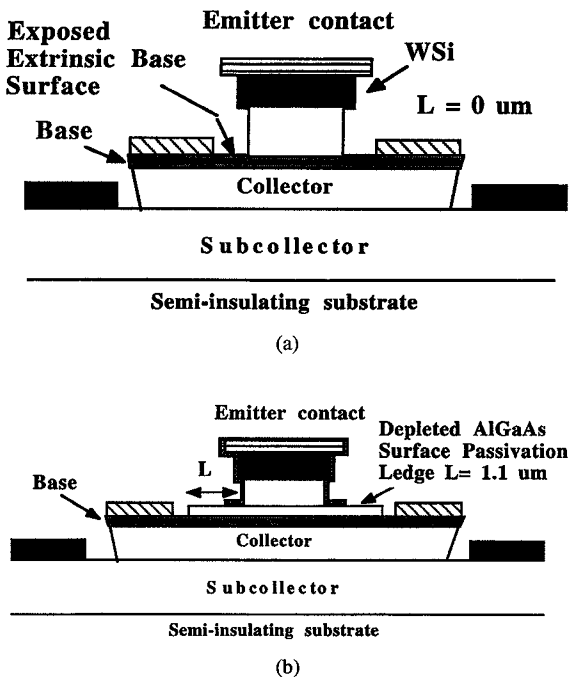

Fig. 1. Schematic cross sections of (a) SA HBTand (b) NSAL HBT.

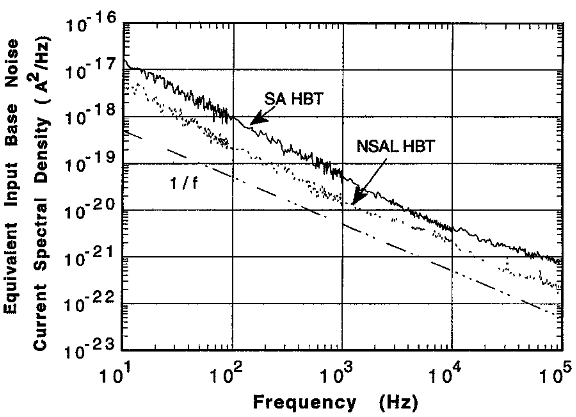

Fig. 2. Baseband equivalent input base noise current spectral density for the unpassivated SA HBT and the passivated NSAL HBT, each at $I_c = 30$ mA and$V_{ce} = 3$ V.

IV. AM Noise Measurement Results

Fig. 4 is a comparison of the added AM single sideband noise power spectral density (relative to the carrier) of the unpassivated SA HBT and the passivated NSAL HBT with and without an emitter feedback resistor. Both SA and NSAL HBT's were biased at the same dc operating point as used in the 1/f noise measurements ($I_c = 30$ mA and $V_{ce} = 3$ V). The AM noise with only the California Microwave synthesizer is also shown for reference. As with $S_{Ib}(f)$, the AM noise spectral density falls approximately as 1/f (10 dB/decade) over the frequency range of 100 to 1000 Hz (offset), but then flattens more dramatically than $S_{Ib}(f)$ from 1 to 100 KHz (offset) because of the additive noise contribution. As can be seen from Fig. 4, the surface passivated NSAL HBT exhibits lower up-converted AM noise than the unpassivated SA HBT. At 100 Hz offset, the AM noise of the NSAL HBT is 4 dB

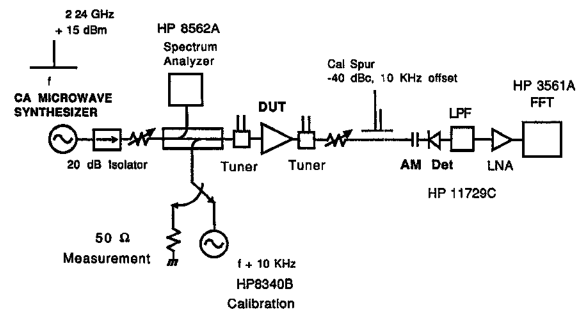

Fig. 3. AM noise measurement setup.

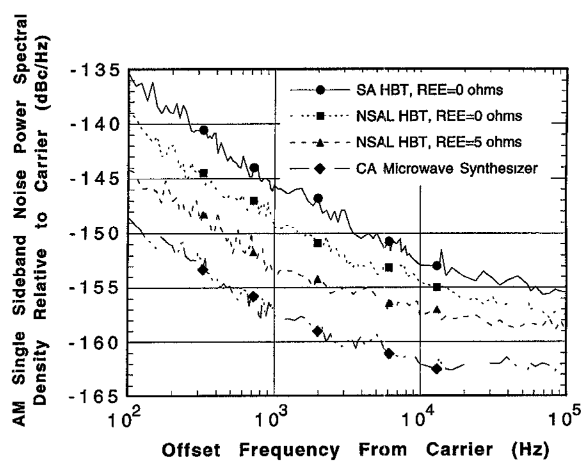

Fig. 4. Added AM single sideband noise power spectral density (relative to the carrier) of the unpassivated SA HBT and the passivated NSAL HBT with and without series emitter feedback resistance. The dc operating point is $I_c = 30$ mA and$V_{ce} = 3$ V for each case.

lower than that of the SA HBT. In comparison, S_{Ib} (100 Hz) of the NSAL HBT is 7 dB lower than that of the SA HBT. These results clearly demonstrate that surface passivation ledges, not only improve the baseband noise of AlGaAs/GaAs HBT's, but also favorably impact the up-converted AM noise, although there is not a strict one to one correspondence between the improvement at baseband and microwave (about the carrier) frequencies.

It is well established that the use of local negative feedback with an unbypassed emitter resistance linearizes the base–emitter junction and gain of bipolar transistors, leading to a reduction in phase noise [6] and nonlinear distortion [7], [8]. In order to investigate the effect of series feedback with an emitter resistance (REE) on HBT AM-noise performance, values of $R_{EE} = 5\ \Omega$ and $I_c = 30$ mA were chosen as a compromise between increasing the feedback loop gain and degrading the power gain. Fig. 4 shows that the AM noise of the NSAL HBT with $R_{EE} = 5\ \Omega$ is lower than that of the NSAL HBT with $R_{EE} = 0\ \Omega$. At 100 Hz offset, AM noise(NSAL, $R_{EE} = 5\ \Omega$)/AM noise(NSAL,$R_{EE} = 0\ \Omega$) $= -5$ dB. Thus, analogous to intermodulation distortion and PM noise, the use of series local negative feedback with a unbypassed emitter resistance, decreases the AM noise of bipolar transistors. As can be seen from Fig. 4, by using the combination of surface passivation and local negative feedback, the AM noise of our AlGaAs/GaAs HBT's was reduced by 9 dB at 100 Hz offset compared to the unpassivated HBT with no feedback.

V. Conclusion

The AM noise characteristics of AlGaAs/GaAs HBT's have been described. Reduction of the baseband noise by 7 dB at 100 Hz with the incorporation of surface passivation ledges resulted in 4 dB reduction in AM noise at 100 Hz offset. Linearizing the device with an unbypassed emitter resistance allowed a further reduction of 5 dB in AM noise at 100 Hz offset. These results indicate that in order to optimize the near-carrier noise performance of AlGaAs/GaAs HBT's, both the 1/f noise and device nonlinearities must be reduced simultaneously.

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