Extended Abstracts of the 2002 International Conference on Solid State Devices and Materials, Nagoya, 2002, pp. 122-123

G-1-6

A Study on Bias Dependence of IMD Asymmetry in HBT Using Nonlinear Large-Signal Model

Hyun-Min Park and Songcheol Hong

Dept. EECS, Korea Advanced Institute of Science and Technology (KAIST)
373-1, Guseong-dong, Yuseong-gu, Daejeon, 305-701, Republic of Korea
Phone: +82-42-869-5471 Fax: +82-42-869-8560 E-mail: hmpark@eeinfo.kaist.ac.kr

1. Introduction

Most recent researches addressed baseband termination effect on inband linearity characteristics through Volterra series analysis which is applicable to only weakly nonlinear system with sinusoidal stimuli [1]-[3]. The most important thing to note from these studies is that lower and upper intermodulation terms deviate from each other under certain conditions. Since they are dependent on so many factors in a sophisticated manner, such as frequency, biases, and matching condition, some simplifying assumptions should be accompanied to draw any useful conclusions with Volterra analysis. Despite that, the conditions for IMD asymmetry occurrence [4] in HBT were verified qualitatively by Wang et al. [5] where they concluded the asymmetry is greatest when baseband termination has a dominant reactive part.

This paper will further address on prediction of IMD asymmetry in HBT using large-signal model. At first, the measured asymmetry as a function of tone spacing is analyzed in conjunction with the measured baseband termination for different bias current level. The device is then measured again as a function of bias current level to reveal any specific bias condition for asymmetry occurrence.

2. Experiments

Two-tone measurements at 1.8 GHz were accomplished with two signal generators, input and output power meters, and output spectrum analyzer. The termination conditions for fundamental and higher harmonics were set to 50 Ω to concentrate on baseband termination effect. The measurements were done on-wafer and the same bias networks were employed in both base and collector terminals. As a first step, the S-parameters of input and output feeding networks were measured from 0.1 to 100 MHz with vector network analyzer. Only the measured impedance of input network is shown in Fig. 1 since output network is not very different from input network. It starts to have a dominant reactive part after a few MHz. The device used in this study is 2finger InGaP/GaAs single HBT with each finger having an emitter area of 60 μm^2. A parameter extraction procedure is explained in great detail in other literature [6].

3. Measurements with a Variation in Tone Spacing

The measurement data were obtained with a tone spacing ranging from 0.05 to 100 MHz when bias current level was

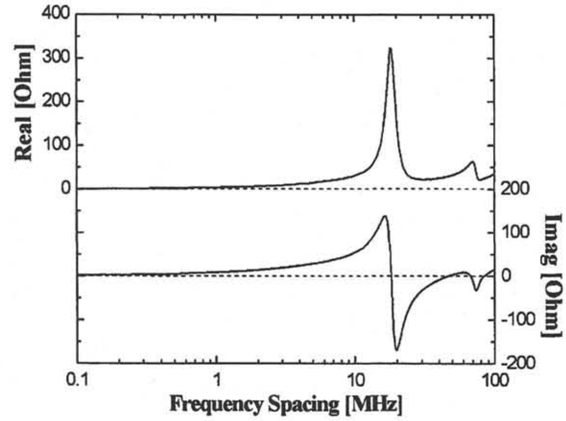
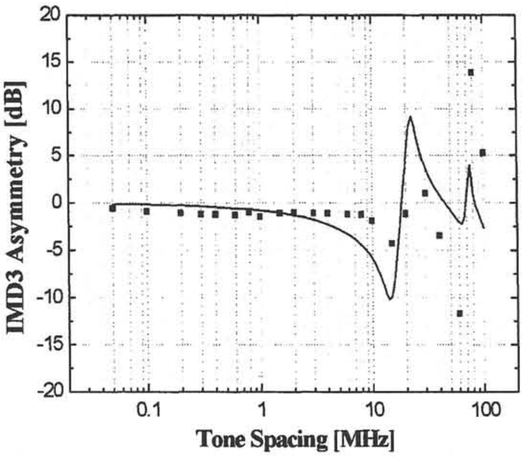


Fig. 1. Measured impedance of input network.

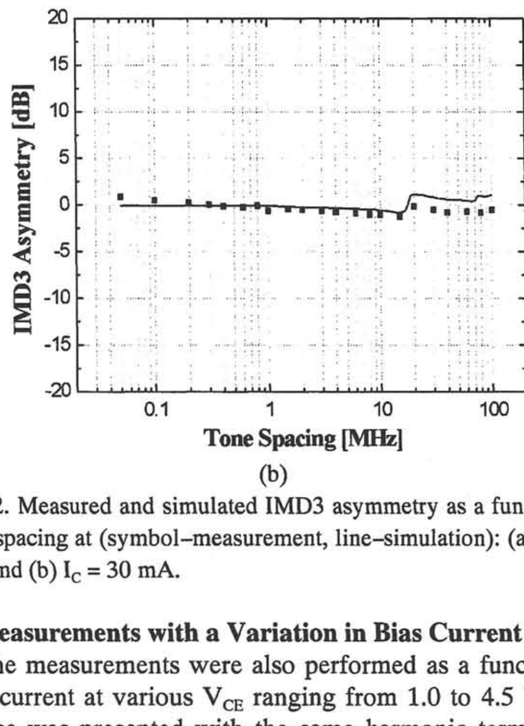
set to I_C = 3 and 30 mA which correspond to deep class AB and class A operation, respectively. For both cases, collector bias was set to V_{CE} = 3.5 V. The input power level was carefully chosen as –19 dBm/tone so that the asymmetry is not masked by dominant 3rd order nonlinearity [4]. It is found both in measurement and simulation that the asymmetry disappears as output power is increased even though occurrence conditions are met, which is a clear sign that the asymmetry is also sensitive to output power level.

Fig. 2(a) shows the measured and simulated IMD3 asymmetry for class AB bias condition. The asymmetry is not important until Δf = 3 MHz beyond which the reactive part of baseband termination rapidly increases. It is important to note that every time the reactive part crosses zero axis, the asymmetry also changes its sign accordingly. However, when the device is biased for class A operation as in Fig. 2(b), the asymmetry is greatly reduced for most tone spacing. Even at this bias condition, the asymmetry shows the steepest change around 20 MHz again where the reactive part resonates hence travels from its positive to negative peak.

It is known that when the device is biased for class AB operation, the bias point is modulated at envelope frequency if it is located in the pass-band of thermal network [7]. This means that an additional signal component can be generated inside the device at the envelope frequency. According to Sevic's analysis, lower and upper IMD terms experience a different transfer function in terms of phase, which induces magnitude imbalance for individual IMDs [3]. It is suggested that interactions between aforementioned mechanisms determine the value of IMD asymmetry. For class A operation, the bias point is still modulated with the envelope frequency. But at this time, the bias current is already high so that the disturbance effect is essentially negligible. This weak signal component at envelope frequency, together with lowered nonlinearity due to increased bias level, constitutes a reason for relaxed IMD asymmetry.



(a)



(b)

Fig. 2. Measured and simulated IMD3 asymmetry as a function of tone spacing at (symbol–measurement, line–simulation): (a) I_C = 3 mA and (b) I_C = 30 mA.

4. Measurements with a Variation in Bias Current

The measurements were also performed as a function of bias current at various V_{CE} ranging from 1.0 to 4.5 V. The device was presented with the same harmonic termination conditions. To see only the bias effect on IMD asymmetry, the tone spacing was set to 2 MHz where the envelope termination is characterized by relatively small imaginary part but not too small to leave a room for asymmetry occurrence. With this condition, the asymmetry would not be dominant for most cases, but for some special bias conditions, the asymmetry would dominate.

Fig. 3 shows the measured and simulated results of difference between lower and upper IMD3 and IMD5 (notated as IMD3D and IMD5D) at V_{CE} = 4 V. A first thing to note from measurement is that IMD3D exhibits a single dip at I_C = 7 mA, while IMD5D exhibits two dips with each occurring at 5 mA and 15 mA. These dips correspond to sweet spot where both lower and upper IMDs suddenly improve. It is known that the asymmetry appears in a great extent in IMD sweet spots where direct 3rd order mixing terms are cancelled and therefore become negligible [4]. Simulation result for IMD5D indicates that there should be an additional dip occurring at a very low current level, which was very hard to measure in practice. It is clear that large-signal model is very effective in predicting these sweet spots hence the IMD asymmetry. It should be also noted that sweet spots are fairly immune to V_{CE} change, which is a direct consequence of full depletion after a relatively small collector bias voltage.

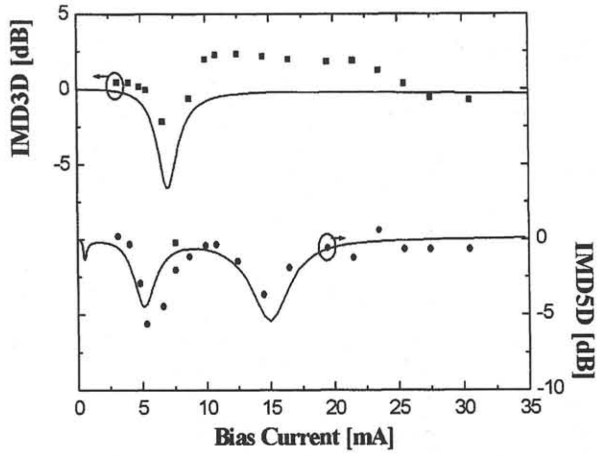


Fig. 3. Measured and simulated IMD3 and IMD5 asymmetries as a function of bias current (symbol–measurement, line–simulation).

5. Conclusion

A large signal model approach for IMD asymmetry prediction in HBT is presented in this paper. The baseband termination effect on the asymmetry has been verified both in measurement and simulation. It was also found that the asymmetry is sensitive to bias current level and maximizes at small-signal sweet spot. With this technique, it is expected that the optimum conditions for baseband termination and bias level can be determined for improved linearity performance through harmonic balance analysis.

Acknowledgments

This work was partially supported by KOSEF under the ERC program through the MINT research center at Dongguk University, and by the Intelligent Microsystem Center under Grant MS-01-231-01.

References

[1] B. Wang, *Proc. APMC,* (2001) p. 306.
[2] V. Aparin, *IEEE IMS Symp. Dig.*, (1999) p. 977.
[3] J. F. Sevic, *IEEE IMS Symp. Dig.*, (1998) p. 723.
[4] N. B. Carvalho, *IEEE IMS Symp. Dig.*, (2000) p. 445.
[5] Y. Wang, *Proc. IEEE GaAs IC Symp.*, (2001) p. 201.
[6] H.-M. Park, *IEEE IMS Symp. Dig.*, (2002).
[7] K. Lu, *IEEE IMS Symp. Dig.*, (1996) p. 1373.