Small-Signal Modeling for SiGe HBTs Characterizations

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A Dissertation

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Abstract

We have developed an extraction method for the small-signal modeling of SiGe HBTs which have been extensively used in monolithic microwave integrated circuits. Applying the small-signal modeling results, we successfully explained the anomalous dip in S-parameters of SiGe HBTs and developed a systematic extraction method for the current noise of SiGe HBTs. The thesis is therefore organized as two major parts. Firstly, to develop the direct extraction method for small-signal modeling of SiGe HBTs, it is better to investigate the small-signal modeling of III-V HBTs first since small-signal modeling of III-V HBTs where the substrate network has negligible effect on the performance is much easier as compared to that of SiGe HBTs. We derived close form representations of intrinsic circuit elements of HBTs and presented

a novel approach for parameter determination of HBT small-signal equivalent circuit. Assuming that the equivalent circuit is valid over the interested frequency range of the measurements, the extrinsic elements are determined by minimizing the variance of the intrinsic elements as an optimization criterion. The proposed method leads to a good fit between the measured and calculated S-parameters.

Applying the derived close-form representation on the small-signal modeling of SiGe HBTs, we found that the modeling results are not so successful, possibly due to the complicated extrinsic circuit such as the conductive substrate network. Most conventional methods for the extraction of substrate network were based on the use of frequency behavior of $Y_{22} + Y_{21}$. However, we found that the feedback signal through the internal circuit elements makes the conductance of the substrate network underestimated while makes the susceptance of the substrate network overestimated. If conventional methods are directly performed on large area SiGe HBTs, a negative effective substrate resistance will be extracted. In the first part of the thesis, a new extraction method for the substrate network parameters of SiGe HBTs is proposed. When extracting the substrate network parameters, the feedback signal through internal circuit elements is considered. All the circuit elements of substrate network are extracted from Y_{sub} instead of $Y_{22} + Y_{21}$. The extracted substrate network parameters show a different bias dependence as compared to the conventional methods. By using a simple n^+-p junction, we successfully explained the extracted bias dependent substrate network parameters. We developed a series linear regression equation to extracted the intrinsic circuit elements from the ABCD parameters. Compared with the conventional methods which extracted the circuit elements from Y-parameters or Z-parameters, the proposed method is much simple and easy to implement in the computer programs.

The extracted small-signal modeling results were applied on the analysis of the anomalous dip of S_{12}. A simple analytical representation of S_{12} in terms of lumped circuit elements is successfully derived. The derived equation can well represent the frequency behavior as compared to the dual-feedback methodology which is widely used in the analysis of the anomalous dip of S_{11} and S_{22}. The derived equation is divided into two parts, the output impedance ration and feedback network. Through the pole zero approximation, we found the anomalous dip is caused by the interaction between two poles in the output impedance ration and one zero in the feedback network. Analyzing the relation between the zero and lumped circuit elements, we successfully explained the phenomena that the anomalous dip of S_{12} is more obvious in large base current.

The second part of the thesis is to discuss the extraction technique for the intrinsic current noise of SiGe HBTs. We developed first a computation method for the four noise parameters from the measurement results from ATN NP5B using genetic algorithm. Compared with conventional method, the computer-time of proposed genetic search is independent on the number of measured source impedance Applying the calculated four noise parameters, we develop a complete extraction procedure for the intrinsic current noise of SiGe HBTs. By using the four-port S-parameters de-embedding and noise de-embedding theory, we simplify the problem to simple calculations of four-port Y-parameters ([Y_{ee}], [Y_{ei}], [Y_{ie}], and [Y_{ii}]). The proposed procedure prevents the complicated calculation through the use of correlation matrices. Four operands are defined before the calculation of four-port Y-parameters. Their values are calculated through the use of corresponding operands following the definition of the [Y_{ee}], [Y_{ei}], [Y_{ie}], and [Y_{ii}]. Finally, the base current noise, collector current noise and their correlation are extracted after removing the noise contribution from extrinsic circuit elements. The proposed four-port Y-parameters calculation method is much simpler and easy to implement in the mathematic program.