# Low Noise, Low Interference Automated Bias Networks for Low Frequency Noise Characterization Set-Up's

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*Abstract* — **The present paper reports on the implementation of electromechanical bias networks to be employed in an automated experimental set-up for the low frequency noise characterization of bipolar transistors. The obtained bias networks allowed to improve the automatization degree of the experimental set-up, reducing therefore the time and the efforts for the systematic characterization necessary for the identification of non-linear low frequency noise models. The electromechanical bias networks were successfully applied to the systematic characterization at wafer level of microwave GaInP/GaAs heterojunction bipolar transistors.**

## I. Introduction

The extraction of non-linear, low frequency noise models requires extensive and time consuming characterizations. A full automated experimental set-up can largely reduce the time and the efforts devoted to this hard task. Traditionally, the fabrication of a full automated experimental set-up for low frequency noise characterizations has always unsuccessfully faced the difficulty of the implementation of automated bias networks. They should indeed introduce magnitudes of noise and interferences low enough to be compatible with the necessary characterization accuracy. Stabilized power suppliers can not indeed be employed, because of the 50Hz interferences. Similarly, the use of active electronic devices to control the bias point of the Device Under Test (DUT) is not allowed, even if battery powered, because they may introduce a low frequency noise level higher or comparable with that of the DUT. For this reason, the battery powered bias networks traditionally present in the low frequency noise experimental set-ups were always manually driven.

Aim of the present work was the implementation of automated bias networks suited for the full automatization of a low frequency noise experimental set-up.

## II. Implementation

The bias networks have been developed for an experimental set-up based on the short-current representation of a noisy four-poles [1]. In the past, a comprehensive description of the experimental set-up was presented [2], where the main limitation was the use of traditional manually driven bias networks.

In the present work, this limitation has been overcome by replacing the operator with stepper motors to control the DUT bias point. The application in the practice of this basic idea required the implementation of electromechanical and software solutions, that will be described in the follows.

### *A. Electromechanics*

In the traditional practice, that is when the bias networks are manually operated, the operator acts on the shaft of a potentiometer to control the DUT bias point.

In the present work, the operator has been replaced by a stepper motor mechanically coupled through an Oldham coupling to the potentiometer shaft of the bias network. Two stepper motors were introduced: one for the base current bias network (see Figure 1) and the other one for the collector-emitter voltage bias network.

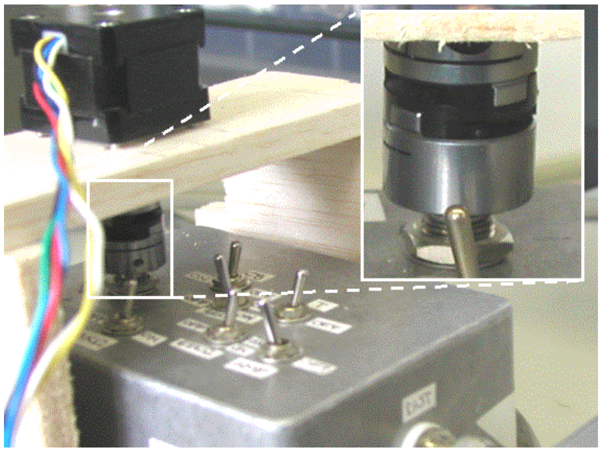

Fig. 1. Stepper motor mounted on the base current bias network. The insert details the Oldham coupling between the potentiometer and the motor shafts.

The use of an Oldham coupling was chosen, in order to guarantee a regular transmission of the rotary motion between the shaft of the potentiometer and the shaft of the stepper motor even in the presence of an imperfect alignment between them. In addition, the disk in the middle of the coupling (see insert in Figure 1) is made of insulating material. This disk is useful, because it breaks the electrical continuity between the motor and the potentiometer shafts avoiding that interferers captured from the environment by the winding of the motors can reach the bias network. The motion of the stepper motors has been obtained by using a National Instrument™ MID7602 2-axis stepper motor drive controlled through a GPIB interface by a LabView™ code running on a personal computer. Figure 2 shows the motor drive connected to the stepper motors mounted on the bias networks when the experimental set-up is configured for packaged DUT's.

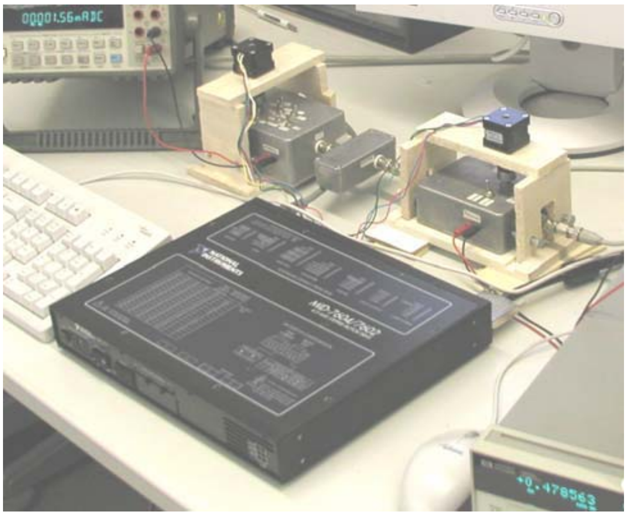

Fig. 2. The MID7602 2-axis stepper motor drive connected to stepper motors mounted on the base (on the left) and collector (on the right) bias networks. The box in the middle contains the packaged DUT.

*B. Software aspects*

Once the stepper motors were mechanically coupled to the potentiometer in a reliable way, the second step was to integrate in the software [2] the routines to control the DUT bias point.

A first difficulty to be faced was the electrical delay due to the large decoupling capacitors present in the bias networks. These capacitors exhibit high capacitance, because they should guarantee an AC coupling between the DUT and the low noise transimpedances (refer to [1] for a detailed description of the principle of operation of the experimental set-up) on the whole 10Hz-100kHz frequency band of interest. At the beginning of the characterization, that is when the DUT is biased for the first time, these capacitors are discharged and therefore the DUT exhibits a high delay to reach the desired final bias point. This large delay should be taken into account, in order to avoid that the polarization system becomes instable and that potentially dangerous biases can be applied to the DUT.

A second difficulty was the choice of the strategy to explore all the bias points on which to perform the low frequency noise characterization and the choice of the strategy to de-bias the DUT. Even in this case, the main goal was to avoid potentially dangerous biases for the DUT.

These difficulties were overcome by introducing suited algorithms acting on the base current and on the collector-emitter voltage acquired by the control program from multi-meters (visible in upper-left and in the lower-right corners in Figure 2) connected to the personal computer via the GPIB interface.

An overview of the bias point research algorithm is briefly reported in Figure 3. Two identical control loops were implemented: one for the base current ($I_B$), on the left in Figure 3, and one for the collector-emitter voltage ($V_{CE}$), on the right in Figure 3. The $I_B$ control loop is first executed and then, once the desired base current value $I_{B0}$ has been reached within a given error $\varepsilon_B$ specified by the user, the $V_{CE}$ control loop is executed. Once the desired collector-emitter voltage $V_{CE0}$ has been reached within a given error $\varepsilon_C$ specified by the user, the algorithm checks again the base current providing the required regulations. Only when the $I_B$ and $V_{CE}$ values result close enough to the desired values $I_{B0}$ and $V_{CE0}$, respectively, without requiring further regulations, the low frequency noise characterization takes place. In each of the two control loops the number of pulses to be sent to the stepper motor are computed from the actual error $|I_B - I_{B0}|$. In this way, the approach velocity to the final desired bias point ($I_{B0}$, $V_{CE0}$) decreases with reducing the errors $|I_B - I_{B0}|$ and $|V_{CE} - V_{CE0}|$ ensuring good stability. In the fact, usually the algorithm converges on the desired bias point without oscillation and only sometimes few re-iterations were observed.

Another important feature implemented in the algorithm of Figure 3 are the software limit switches. Limit switches are need, in order to avoid that the MID7602 drive forces the stepper motors when the potentiometers touch their rotation range limits. A traditional hardware limit switch would have complicated the interface between the drive, the bias networks, and the personal computer. A less traditional software implementation has therefore been preferred. For its implementation a variable A algebraically counting the pulses sent to the stepper motor and a variable B specifying the actual number of pulses to be sent to the stepper motor have been introduced in both the control loops. In each control loop it is possible to note two control sections. The upper section checks A avoiding that B assumes a value that can leads the stepper motor beyond their rotation limits. The lower control section checks again A, in order to evaluate if there is still room to move the motor shafts. If not, the software limit switches are activated and the program ends, meaning that the desired bias points ($I_{B0}$, $V_{CE0}$) is unreachable. The control algorithm of Figure 3 is controlled at its turn by an upper level algorithm, which passes to the algorithm of Figure 3 the bias point to be measured. The bias points are transferred following a given sequence, that explores the grid of the bias points following a well defined trajectory described on the DUT output characteristics plane. Figure 4 shows the turn-on trajectory followed to explore the bias point grids during the low frequency noise characterization. The DUT is gradually biased on until the highest bias point is reached. The main advantage offered by this trajectory is that the base current changes are minimized, reducing in this way the time required to get the desired bias point. The transients associated with changes in the bias base current are indeed longer than those due to changes in the collector-emitter voltage. Figure 4 depicts also the trajectory applied to turn off the DUT. First the collector-emitter voltage and then the base current are reduced to zero. In this way it is ensured that the base-collector junction does not face high reverse voltage, that may degrade the DUT.

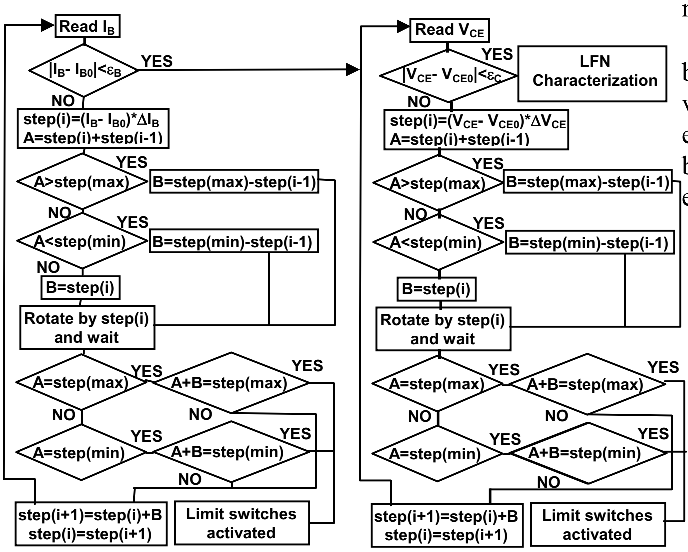


Fig. 3. General overview of the bias point research algorithm. The low frequency noise characterization takes place only after $I_B$ and $V_{CE}$ are close enough to the desired bias point ($I_{B0}$, $V_{CE0}$).

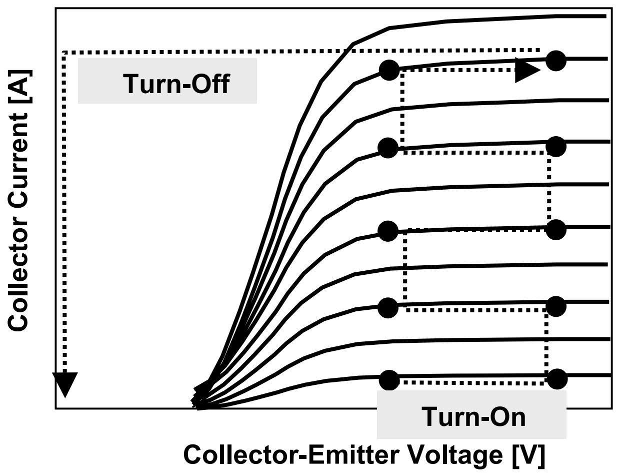


Fig. 4. Turn-on and turn-off trajectories on the DUT output characteristic plane.

## III. APPLICATION

The automated bias networks were applied to the systematic low frequency noise characterization at wafer level of GaInP/GaAs Heterojunction Bipolar Transistors (HBT's). The experimental set-up depicted in Figure 2 was mounted on a microwave R&D probe station. The DUT was contacted using a couple of Be/Cu GSG 150µm coplanar probes.

A 4x3 matrix of bias points were introduced in the control program: the base current spanned from 20µA to 80µA by steps of 20µA, and the collector-emitter voltage spanned from 1V to 3V by steps of 1V. The program was configured so that on each of these bias points, a full low frequency noise characterization was carried out in terms of the spectrum of the base current fluctuations $S_{IB}$, of the spectrum of the collector current fluctuations $S_{IC}$, and of their cross-spectrum $S_{IBIC^*}$ [2]. Figure 5 reports the $S_{IB}$ spectra measured at a fixed collector-emitter voltage of 1V and for the base current spanning on the investigated range.

Figure 6 reports the $S_{IB}$ spectra measured at a fixed base current of 20µA and for the collector-emitter voltage spanning on the investigated range. As one can expect, the $S_{IB}$ magnitude increases with increasing the bias base current while it is independent of the collector-emitter voltage.

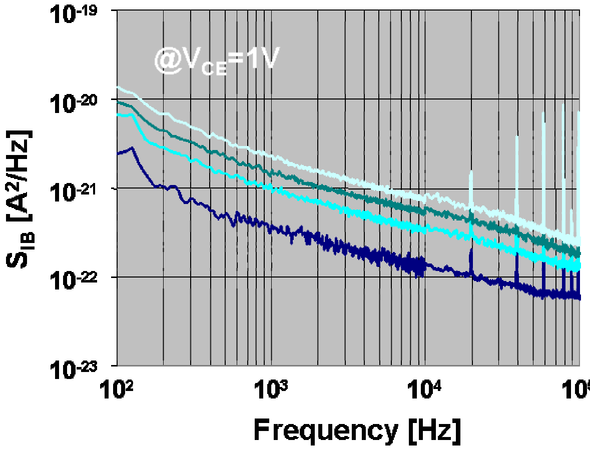


Fig. 5. $S_{IB}$ spectra measured at $V_{CE}$=1V and for the base current ranging from 20µA to 80µA by steps of 20µA.

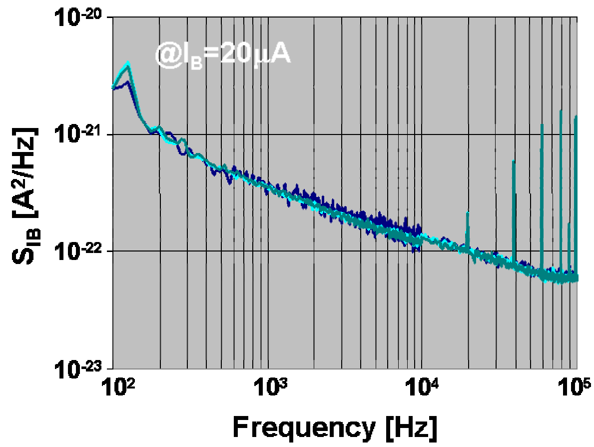


Fig. 6. $S_{IB}$ spectra measured at $I_B$=20µA and for the collector-emitter voltage ranging from 1V to 3V by steps of 1V.

The $S_{IB}$ spectrum exhibits a lorentzian bump in the last decade of the investigated frequency whereas in the lower frequency ranges the flicker component is dominant.

Figure 7 depicts the $S_{IC}$ spectra measured at the fixed collector-emitter voltage of 1V and for the base current spanning from 20µA to 80µA. The spectra are dominated by a large lorentzian component. As in the case of $S_{IB}$, even in the present case the spectrum magnitude increases with increasing the base current while no relevant changes were observed when the collector-emitter voltage changes.

Eventually, Figure 8 shows the $S_{IBIC^*}$ cross-spectra measured at the fixed collector-emitter voltage of 1V and for the base current spanning from 20µA to 80µA.

Again, the spectrum magnitude increases with increasing the base current while no changes were observed when the collector-emitter voltage changes.

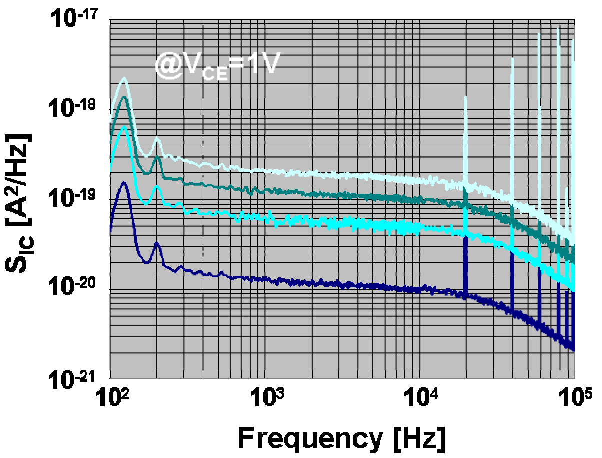


Fig. 7. $S_{IC}$ spectra measured at $V_{CE}$=1V and for the base current ranging from 20µA to 80µA by steps of 20µA.

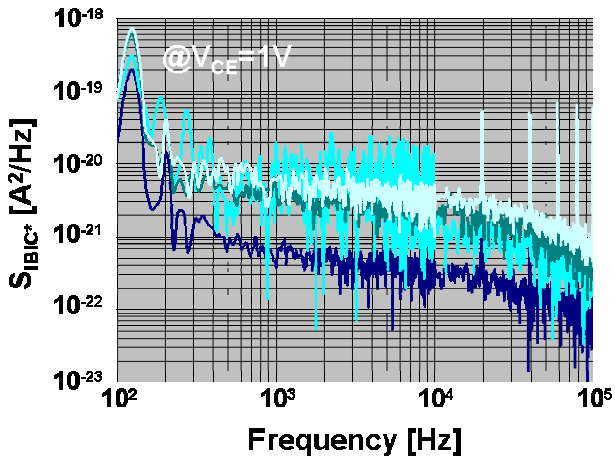


Fig. 8. $S_{IBIC^*}$ cross-spectra measured at $V_{CE}$=1V and for the base current ranging from 20µA to 80µA by steps of 20µA.

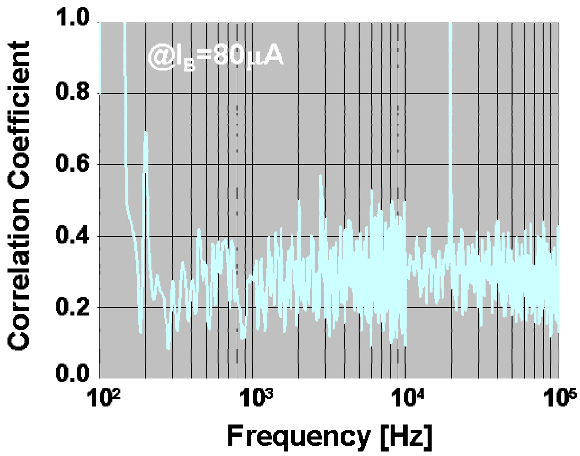


Fig. 9. Correlation coefficient spectrum measured at $I_B$=80µA and $V_{CE}$=1V.

To complete the low frequency noise characterization of the investigated GaInP/GaAs HBT's, Figure 9 reports the spectrum of the correlation coefficient.

The spectrum in Figure 9 was measured at $I_B$=80µA and $V_{CE}$=1V but very similar spectra were observed also for the other investigated bias points. The correlation coefficient value is around 0.3 on the whole frequency range. This low value indicates a low correlation degree, suggesting that several noise sources are present inside the DUT. In addition, the fact that this values does not change by changing the bias point suggest that, in the investigated bias range, there is never a dominant noise source even for the highest or the lower bias points.

## IV. Conclusion

In the present work low noise, low interference automated bias networks suitable to be employed in a low frequency noise experimental set-up devoted to the characterization of bipolar transistors were developed.

The measured $S_{IB}$, $S_{IC}$, $S_{IBIC^*}$, and correlation coefficient spectra changed regularly with changing the bias points indicating that the bias networks correctly work. It is worth stressing out that not the operator but the stepper motors have changed the bias points during the extensive LFN characterization on the twelve bias points.

The basic but original idea of making remote controllable the DUT bias point through stepper motors have made possible to overcome the traditional limits of the bias networks employed in the low frequency experimental set-ups. Thanks to the introduction of this solution the automatization degree of the experimental set-up has been improved. The involvement of the operator during the measurements has been therefore reduced at the minimum, making an extensive characterization a less hard and time consuming task.

The achieved high level of automatization allowed to get in a short time the experimental data necessary to identify the non-linear, extrinsic and intrinsic low frequency noise models of the investigated DUT.

## Acknowledgement


The present work was carried out in the frame of the national Italian research program COFIN entitled "Non-linear noise models and design of low-phase-noise oscillators for high performance communication systems".


## References


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