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Hot carrier effect on the bipolar transistors' response to electromagnetic interference

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ABSTRACT

Damage of bipolar transistors (BJTs) during the mission could affect their response to electromagnetic interference (EMI) and change the Integrated Circuit (IC)'s electromagnetic susceptibility (EMS). This work investigated the effect of hot carrier stress on BJT's response to EMI. The experimental results demonstrate that the base current increases under EMI and the amplitude enlarges after hot carrier stress. The variation of EMI induced collector current shift after hot carrier stress depends on the base supply resistance Rt. When Rt = 0, I_C shift in presence of EMI is not affected by hot carrier stress whereas in the case of Rt ≠ 0, the EMI induced I_C increment reduces or even reverses in variation direction. When the base terminal is biased by a current source, the voltage across the emitter-base junction drops more significantly after hot carrier stress.

1. Introduction

As the trend of ICs goes towards high integration, low power and high frequency, electronic devices are getting more susceptible to electromagnetic interference. Therefore much attention should be paid to the electromagnetic compatibility (EMC) of ICs. BJTs and BJT-containing ICs are very sensitive to EMI [1–3]. When ac signal is injected, the quiescent point of a BJT would change due to rectification effects of the p–n junction [4]. The p–n junction's rectification characteristic increases the collector current (I_C) while the ac crowding and nonuniformity of gain across the emitter decreases it. The final change of I_C depends on the circuit topology. When the base is biased by a voltage source, and a low base supply resistance is employed, I_C increases under the effect of EMI. But in the case where a high base supply resistance is employed, or a current source is applied to the base, I_C decreases as a result of EMI [3]. It is not just the collector current that is affected by EMI. The dc current gain, ac current gain [1] and the BE (base-emitter) voltage would also be decreased by EMI [5].

Recent studies have shown that damage of the transistors could increase the EMS of ICs without influencing their normal functions. For example Li et al. [6] have reported normal performance of a phase locked loop (PLL) device after accelerated life tests, nevertheless the EMS of the voltage controlled oscillator degraded significantly, increasing the failure risk of the whole PLL. They ascribed the change of EMS to the variation of MOS transistors' response to EMI after stress. Another study by the same authors found out that aging does change the characteristics of a MOSFET under EMI [7]. Doridant et al. [8,9] have also recently investigated the effect of gamma radiation on BJT's response to EMI. They observed that when a base supply resistance of 1 MΩ was employed, the EMI caused I_C to increase before radiation while the I_C decreased under EMI after radiation [8]. When a Rt = 20 KΩ was configured, the variation direction of I_C under EMI did not change, but the increasing extent reduced [8,9]. They considered this phenomenon as a consequence of the decrease of low frequency input impedance h_{ie} (which is defined as dV_{be}/dI_B).

The work mentioned demonstrates that degradation of device performance leads to a variation of their EMI response. From previous research we also know that besides gamma radiation, hot carrier stress due to high power microwave injection [10], reverse biased BE junction [11,12] and BC junction [13], high forward BE junction current [12,14] could damage BJTs. The motivation of this paper is to investigate the effect of reverse-biased BE junction stress on BJT's response to EMI. The hot carrier effect on BJT's response to EMI was first investigated by experiments, and then a theoretical model was used to explain the experimental results in detail.

2. Experiments

Two kinds of BJTs, BCW72 and BC850B were employed in our experiments. They were low frequency transistors with a peak

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transition frequency of about 100 MHz. The maximum current gain was about 290. The two kinds of transistors were mounted in SOT23 plastic packages. The transistors were placed on a FR4 substrate and biased as a common-emitter amplifier during the EMI test. The EMI test circuit is shown in Fig. 1. In the experiment, the base terminal was either biased through a voltage source and a supply resistance Rt, or a current source. Four Rt values-0 Ω, 200 K Ω, 510 K Ω, 1 M Ω were chosen. A current source could also be regarded as a voltage source with an infinite supply resistance.

The bias tee served to isolate the dc supply source and the ac power source while allowing the dc and ac signal to superpose in the base terminal. During the hot carrier stress, the emitter-base (BE) junction was reverse biased by a constant current source, with the collector being open. The stress current was 50 μA. The stress level was chosen in order to obtain observable damage in the device in a reasonable time. The hot carrier stress, the power supply and measurements during the EMI tests were performed by a 4200-SCS semiconductor parameter analyzer. All the tests were repeated on at least three devices to guarantee the repeatability of the results. The experimental results of BCW72 and BC850B were very similar, thus only the results of BCW72 were shown in the following part.

3. Experimental results and discussions

3.1. EMI effects on the characteristics of BJT

At the beginning, the EMI effects on BJT's Gummel and output characteristics were measured. The Gummel characteristic under EMI is shown in Fig. 2. The interference power Pi mentioned in the graphs means the power value set on the ac signal generator. From Fig. 2 it could be seen that the base current and collector current increases under EMI. Fig. 3 illustrates the dc current gain under EMI. It is shown that the dc current gain decreases under EMI. The gain degradation indicates that the increasing in base current is more significant than the collector current.

EMI effect on the output characteristic is illustrated in Fig. 4. Fig. 4 shows that under EMI the collector current decreases in the active region and increases in the vicinity of $V_{CE} = 0$ V. This phenomena is corroborated by the results reported by Hattori et al. [15].

3.2. Hot carrier effects on the characteristics of a BJT

The Gummel characteristics during the stress process are shown in Fig. 5. I_C remains unchanged after hot carrier stress while the I_B increases, especially at low V_{BE}. This occurs because the hot carriers damage the oxide above the BE junction, generating oxide trap charges and interface traps. As a result the recombination rate in the BE space charge region increases [12]. This is typical phenomenon after hot carrier stress.

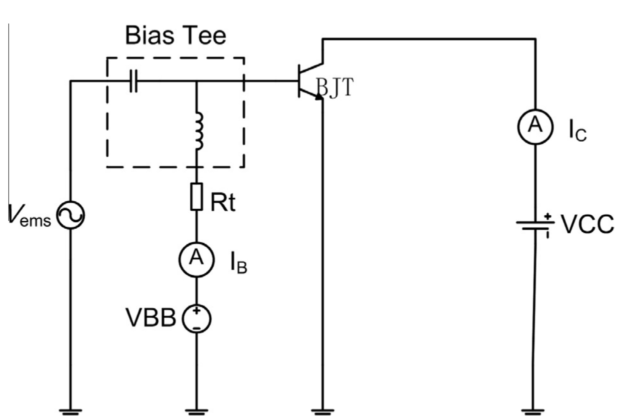

Fig. 1. EMI test setup.

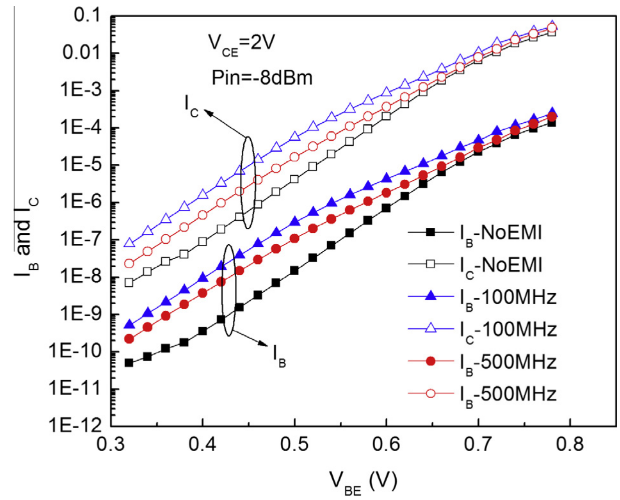

Fig. 2. EMI effect on the Gummel Characteristic of BCW72.

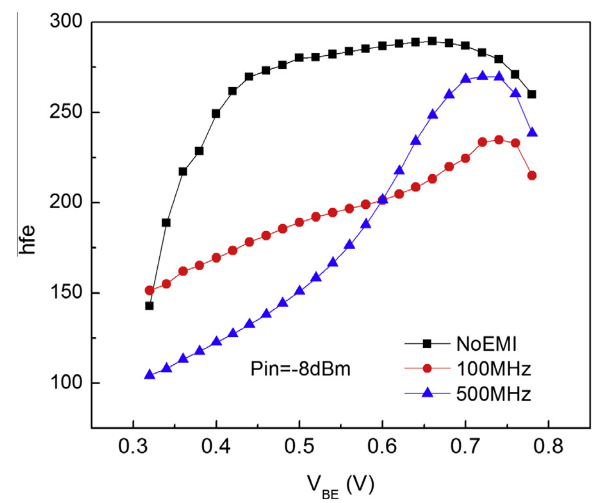

Fig. 3. EMI effect on the dc current gain of BCW72.

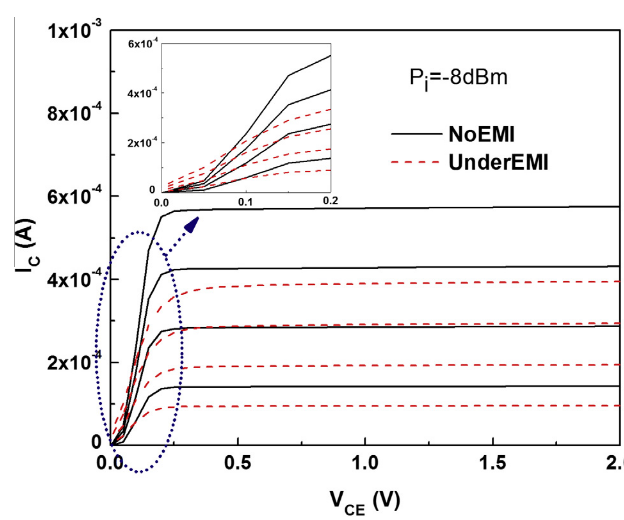

Fig. 4. EMI effect on the output characteristic of BCW72. During the measurement, IB was set to 0.5 μA to 2 μA, with a 0.5 μA increment.