How I simulate the radiation effect on BJT

Introduction

Space is a hostile environment, the temperature goes as low as +4K above the absolute zero, the Sun emits blast of alfa, beta and X-ray and gamma-ray, the magnetic field of the earth creates an ionized area of protons and electrons called the Val Allen belt, and the pressure is almost null.

Designing for a harsh environment like this is very difficult. There are a number of constraints to bear in mind.

Constraints on the temperature, as the temperature inside the satellite goes from -30 ^{0}C to + 90^{0}C every 90 minutes or so (depends from the orbit).

Constraints on the package and on the PCB's pads and on the mechanics, as the electronic needs to survive the lunch of a missile.

Constraints on the orbits and the number of year of the mission, as this dictate the Total Ionization Dose.

In this articles we'll talk only about how I simulate the Total Ionization Dose effect on NPN BJT.

The physics of TID on NPN BJT

Let's see how a particle can change the structure of an NPN transistor and let's have a quick discussion on TID effects. In Figure 1 you can see the theoretical structure of a NPN transistor. The box in blue represent the oxide SiO_2.

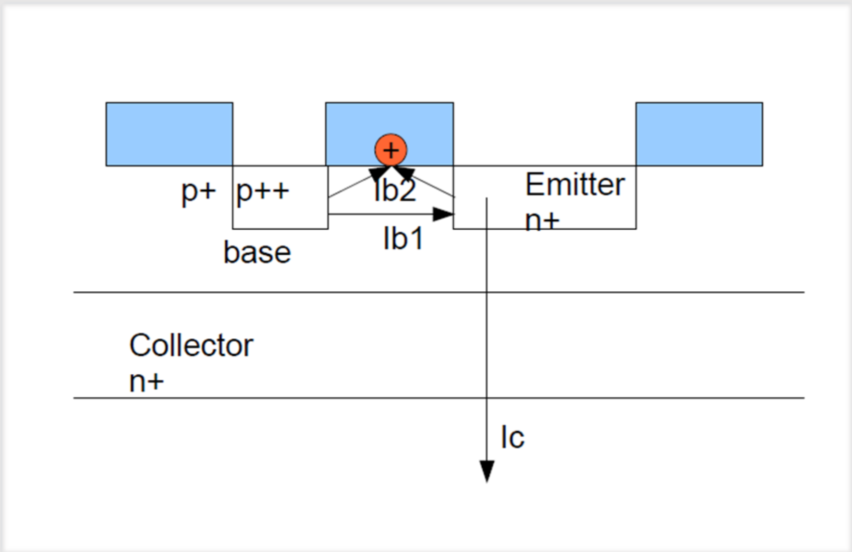

Figure 1 NPN cross section with emphasis on the hole in the SIO2 oxide.

When a particle (mostly Gamma rays) with enough energy hit the SiO_2, it may create a couple electron - positron. While the electron has a higher mobility it will eventually escape from the SiO_2. The positron, which has a lower mobility, will get trapped between the interface Oxide <-> BE and will create a positive charge. The higher the thickness of the oxide, the higher number of charges will get trapped. As the number of the trapped charges increase, a current Ib_2 will start to flow between the base and emitter (because the resistivity of the SiO_2 will get lower). The larger the charge trapped in the interface SIO2 – BE the higher the Ib_2 current will be. With reference to figure 1, in a transistor that has not been subject to radiation, Ib_2= 0 and therefore $HFE_0 = \frac{IC}{I_{b1}}$. However, as the radiation increase the number of positive charges below the oxide will increase Ib_2 will be not negligible, and the base current Ib = Ib_1+Ib_2 will increase and therefore we will have a reduction of the ratio Ic/Ib:

$$HFE_r = \frac{IC}{I_{b1} + I_{b2}} \quad 1]$$

β vs I_{C0} with and without radiation

Let's see now how the β-Ic characteristic of a NPN transistor varies with the TID radiations.

The characteristic β-Ic of a transistor is well known (see figure 2). We know that the current gain is almost constant for Ic <= Ic_{max} and then eventually declines.

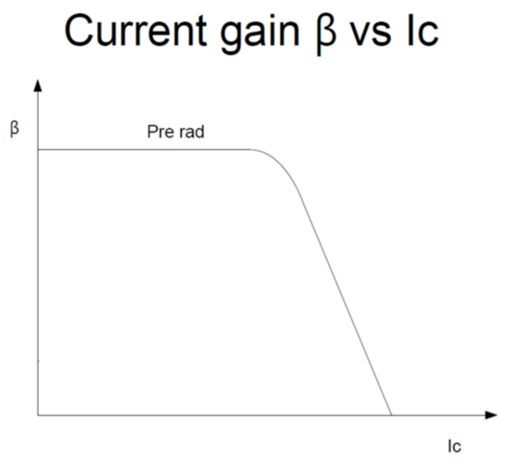

Figure 2 Beta vs Ic of a typical NPN BJT

Let's see what's happen to the beta after radiation. As the TID raises the current Ib2 will raise as well. From the equation 1] we can easily understand that for lower current we will have the worst degradation of the beta. And therefore we should expect a graphic like:

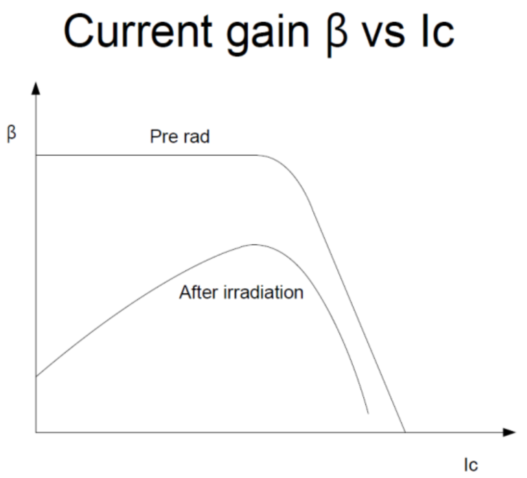

Figure 3 effect of radiation on the Beta, please notice that at lower current we have the worst degradation

Design tip: *In order to minimize the TID effect, you need to polarize the transistor where you have the pick of the β (see figure 3), you can get this information by looking at the radiation data.*

Understanding the TID test report.

When you read the total ionization dose report you need to be careful of a parameter called *radiation dose rate,* the radiation dose rate can be set during the test.

Why this is important?

It is very important because the space is a low radiation rate environment. To recreate the same radiation rate in a lab is not always possible, imagine you have a 10 mission space with 1 krad(Si)/year. If you want to try to simulate the same environment, then you need to test the transistor in the lab for 10 years. What is usually done is to give a faster radiation dose, to have, let say 10krad(Si)/week. So you have in a week the same TID you have in 10 years in the space. The problem with that, is that the lower the radiation dose rate the worst will be the damage. Keep this in mind when you get the radiation result from the test house.

Now, let's see some example of radiation report;

In a radiation report, usually you have the beta vs different Ic values and different radiation level. For example:

CTR = Current TRANSFER RATIO = Ic / Ib

0 krad	DUT#1	DUT#2	DUT#3	DUT N
CTR @ 0.1 mA	100	120	115	101
CTR @ 1.0 mA	124	140	120	120
CTR @ 10 mA	147	161	156	140
CTR @ 40 mA	180	192	187	160

5 krad	DUT#1	DUT#2	DUT#3	DUT N
CTR @ 0.1 mA	95	110	99	96
CTR @ 1.0 mA	110	130	110	115
CTR @ 10 mA	130	150	140	129

CTR @ 40 mA	160	170	170	157

20 krad	DUT#1	DUT#2	DUT#3	DUT N
CTR @ 0.1 mA	70	70	56	54
CTR @ 1.0 mA	90	81	88	73
CTR @ 10 mA	130	125	125	115
CTR @ 40 mA	150	160	162	142

Now let's assume that in your mission the TID is 5 krad, and you have the data for 5 krad and 20 krad. Use the beta (CTR) from the 20 krad, the reason is that in the lab your test was done with a fast radiation rate.

Simulating with SPICE

When you are doing the spice simulation, what I would recommend is to create 2 models for the same transistor, for example let's assume you are using the 2N2222 and the spice model for this transistor is:

.model 2N2222 NPN(IS=1E-14 VAF=100 ***BF=200*** *IKF=0.3 XTB=1.5 BR=3 JC=8E-12 CJE=25E-12 TR=100E-9 TF=400E-12 ITF=1 VTF=2 XTF=3 RB=10 RC=.3 RE=.2 Vceo=30 Icrating=800m mfg=NXP)*

Then you can create a new model called 2N2222_20krad and change the BF

model 2N2222_20KRAD NPN(IS=1E-14 VAF=100 ***BF=90*** *IKF=0.3 XTB=1.5 BR=3 JC=8E-12 CJE=25E-12 TR=100E-9 TF=400E-12 ITF=1 VTF=2 XTF=3 RB=10 RC=.3 RE=.2 Vceo=30 Icrating=800m mfg=NXP)*

So, now you know how to simulate the effect of radiation (TID) on a BJT. The same concept can be applied to PNP, however in PNP there are other issues not covered in this article.

What we have learned?

We learned that a BJT in space is subject to radiations. That radiation damages the SiO_2 oxide between the base and emitter. Due to the charge at the interface oxide- BE channel the base current Ib will increase and therefore the β will reduce.

The β due to TID can be estimated by looking at the radiation data from the testing results at various currents. The polarization current should be chosen to be as high as possible.

In the next issues…

- Why Shielding may damage your electronics!
- How to simulate SEE

About the author:

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