How to simulate Single Event Effect (SEE) on a transistor with SPICE

When charged radiation passes through a material, it slows down and loses kinetic energy. Part of this energy is lost due to Columbian forces and part of the energy loss is due to radiation losses. Therefore, we can write the total energy loss per unit of length as:

$$\left(\frac{dE}{dx}\right) = \left(\frac{dE}{dx}\right)_{col} + \left(\frac{dE}{dx}\right)_{rad}$$

The first term $\left(\frac{dE}{dx}\right)_{col}$ is also called Linear Energy Transfer (LET) and represent the energy lost in the material due only to Columbian forces. In the space industry the LET is defined in respect of the material density as well, and therefore the unit is [MeV cm²/mg].

Now you need to know that the energy required to create an electron hole depends on the material irradiated, and I prepared a small table that shows that.

Material	Air	Silicon (Si)	Germanium (Ge)	Silicon Dioxide (SiO$_2$)
Energy to create a couple electron hole	34 eV	3.6 eV	2.8 eV	17 eV

So for example by looking at the table above we can see that Germanium is more sensitive to LET compared to Silicon as it only needs an energy as low as 2.8 eV to create a couple electron hole.

So let's see how we can simulate a SEE with SPICE, and let's assume to have a LET = 100 [MeVcm²/mg], and let's assume the irradiated material is Silicon.

1. Calculate the number of ions created n = LET/3.6
2. If we multiply the above by the charge of an electron we have the total charge per unit of length per material density (remember that $1.6 \ 10^{-19}$ C is the charge of an electron) $\frac{q_{tot}}{\delta \ dx} = 1.6 \ 10^{-19} \frac{LET}{3.6}$
3. Then, If we multiply the above by the material density (for the silicon δ =2300mg/cm³), we obtain the total charge per unit of length: $\frac{q_{tot}}{dx} = 2300 \ 1.6 \ 10^{-19} \frac{LET}{3.6}$
4. To evaluate the worst case scenario, we need to consider the worst case path length in your BJT. You should do this for the emitter-collector, emitter-base, collector-base.

$$q_{tot} = X \ 2300 \ 1.6 \ 10^{-19} \frac{LET}{3.6}$$

5. Now, a particle in the Si will travel at a relativistic speed (33% of the speed of the light) therefore by knowing the geometry of the transistor we know the pulse duration dt
6. We can finally calculate the current $i = \frac{dq}{dt}$

Therefore, we can simulate the effect of the LET by adding a current generator in shunt to the BJT. the amplitude of the current is given by the step 6, while the time is given by the step 5. (Please notice that the current direction can be any).

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