A Central Force Model of the Semiconductor Junction

By
William H. Clark II, P.E.,MSE

ABSTRACT

The principles of Celestial Mechanics are applied to the physics of the transistor junction, as the process of transferring charge from one discrete location to another. The common aspects between the Three Body Problem in Celestial Mechanics and the Ebers-Moll Equations describing the solid state junction are paralleled. The result is a presentation of a complete model for the movement of charge from emitter to collector across the base, one electron at a time. Instead of a generalized movement of charge across the base of the transistor in the statistical language of energy bands and Fermi Levels, there is the analogous process in Celestial Mechanics of a small body (eg a satellite) making the orbital transfer from an inner planet of the solar system to an outer planet. Both processes have a similar mathematics and many similar functions and characteristics. The mathematics of the Three Body Problem is extremely well developed, and there are a number of potential applications of this theory to the study of the exact mechanisms that take place within the transistor

Introduction

One of the major technological challenges to the continued enhancement of the speed and the reduction of the size of the semiconductor junction is the quality of the base. The processes taking place there are extremely complex. This paper proposes a new model for the junction itself that offers the potential for a very detailed discrete - versus statistical - model.

The model is based upon the Three Body Problem of Celestial Mechanics: the influence of gravity from two massive bodies upon a third small body. This model is applied to the process by which a single electron leaves the emitter, crosses the base, and arrives at the collector junction. The analogous process in Orbital Mechanics is a satellite escaping the orbit of one planet, traveling across the inner solar system, and arriving at another planet. The mathematics and processes are similar, and the physics of the orbital analog is more detailed than existing solid state semiconductor models. Thus, the model has the potential of leading to a more effective understanding of the transistor, and hence more effective design of the base junction.

Interplanetary Orbit Transfer

It is presumed that the reader is more familiar with the physics of solid state devices than the mechanics of gravitational phenomena. Thus, the fundamentals of Orbital Mechanics will be reviewed, in as much as they apply to the transistor junction.

A practical problem in Orbital Mechanics is the travel from one planet to another. The satellite is first put into a circular parking orbit around Earth. A thrust is applied in this orbit, moving the satellite into a hyperbolic orbit, with Earth at the focus. Once the satellite is outside the Earth's gravitational field, the satellite is in an elliptical heliocentric orbit with the Sun at the focus. As the objective planet, say Mars, nears the satellite is again in a hyperbolic orbit, with Mars at the new focus.

The Hohmann Transfer is the most efficient path by which this can be done. The only energy expended is a thrust applied at Earth to enter the hyperbolic escape trajectory and another near Mars, to enter a circular parking orbit around that planet. In between these thrusts the path is an ellipse, with the hyperbolic segments patched on either end so the satellite describes the expected motion under the influence of the nearest, most massive celestial object; i.e. Earth, Mars, or the Sun. Though not an exact solution, it is accurate enough for mission planning and is mathematically concise, as the motions are all as expected under the influence of a central force; e.g. conic sections.

Electron Orbit Transfer

The solid state version of this orbital transfer is quite similar conceptually. The third, small body is the electron and it is going across the base of the junction in an elliptical path. At either end are massive bodies in which it experiences a more stable state, orbiting around a nucleus. The parking orbits on either end are simply circular orbits around these nuclei and the "inter-stellar" space is the conduction band as the electron traverses the base junction.

The electron does not make this journey of its own volition. It must have energy supplied at either end of its trajectory in the form of biasing applied to the junction (i.e. voltage), analogous to the thrust applied to the satellite in the Orbital Mechanics corollary. This voltage or electromagnetic thrust is sufficient to break the chemical bond of the electron, or in terms of Fermi probabilities, it is the energy needed to overcome the potential barrier and achieve the energy level sufficient to make the trip across the base of the junction diode.

Emitter and Collector

The simplest model of the transistor junction has a base with two exponential diffusion rates, at the emitter and collector base junctions. This is identical to one side of an hyperbolic trajectory; i.e. a full hyperbola can be patched together from two exponential paths. Consequently, a rough approximation of the charge of carrier density with distance from the junction is an inverse squared function.

Now, the change of gravity with distance from a massive celestial object is also inverse squared. Over short distances it can be approximated as an exponential function.

The diffusion equation and Newton's Laws of Motion are looking at the same phenomena from different vantage points. Orbital Mechanics bases the equations upon the massive body, whereas the diffusion equation is based upon a coordinate system that moves along with the carriers. That is, if gravity were assumed to be comprised of charged carriers, the quantity of these carriers would diminish by the inverse of the distance squared from the source. That is, the entities "GmM" and p(x) are equivalent mathematically, and dimensionally.

The Model

The diffusion equation applied to the simple transistor junction is a second order differential equation for the change in number of charged carriers versus distance from the junction. Just as the law of motion is a second order differential equation for the change in applied force with distance from a massive celestial object.

As a model, the circuit equivalent of the Ebers-Moll Equations has the equivalent aspects of the celestial problem, as an electronic model for the Hohmann Transfer. In particular, the following aspects are noted:

1. The bias voltages are the thrusts that characterize the minimum energy Hohmann Transfer
2. The relative value of the emitter and collector currents are consistent with the relative values of the velocity (and thus the energy) of an object in an elliptical orbit around a massive object
3. The base current is analogous to energy lost due to the perturbing influence of nearby celestial objects in transit
4. Recombination in the solid state junction is similar to the processes that cause the development of stable Lagrange points in the restricted Three Body Problem
5. The mathematics of the Three Body Problem generates a map of gravitational flux in the plane of the orbits, called zero velocity curves. Presumably, a similar distribution of energy will exist within the conduction band for the transistor junction

It is typical to model the emitter and collector as diodes coupled with a current source. The current source implies a steady, constant influence, as the Sun exerts upon an object transiting a Hohmann Transfer. Conversely, the diode influence is stronger, but sporadic: the influence of the planets on either end of the trajectory. When no bias is applied, both of these processes are subdued, and the electron remains in a stable Fermi orbit.