EEE105 - Electronic Devices
Lecture 1

Introduction

Much of Electronic Engineering ultimately relies on one type of material, and one material in particular. The type is a SEMICONDUCTOR and the material is SILICON (Si). This material forms the engine of computers and microchips that appear in virtually every modern device from a TV to a toaster.

It is possible to treat microchips as black boxes that perform a particular function, or even to design digital circuits using gates, without ever needing to think about what is happening in the underlying semiconductor material. However, in order to understand the limitations of the system it is important to also understand how the various devices work.

This is what we will be concentrating on in this course.

What is an Electronic Device?

In electronics we are interested in how we can manipulate currents flowing through devices and across them. Electronic devices allow us to do this. Current is produced when electrons move around. A summary of what this module is about is understanding how electrons move about in a solid and how we can control this.

Electric Fields

(CAL: fieldsim-Electric fields and potential, vac1-electrons in a vacuum1&2)

Before we start looking at the case of solids we will first consider electrons moving in a vacuum (or free-space). The motion of an electron can be changed if an electric field is present. Thus the first issue is to define what we mean by a field.

As Electric and Gravitational forces behave similarly let us for simplicity start with a gravitational field. In such a field objects are attracted due to their mass and the force on an object can be given by

$$F = \frac{GMm}{r^2}$$

where…………

The acceleration due to gravity , g can be given by GM/r^2

Consider the earth and a ball. If I take the ball away the earth's gravity is still present. Thus we can say that there is a gravitational ***FIELD*** around the earth pulling any object towards it. When the object comes near the earth it experiences an attractive ***FORCE***. The pull is in a particular direction, which can be represented using a ***VECTOR***. Similarly the field also must have direction and we call the field a ***VECTOR*** field.

Now when the ball falls it gains Energy.

So when it was raised up it had Energy.

The potential energy is equal to mgh, where h is the height the ball has been raised, or more particularly *the difference in distance away* from the centre of the earth that the ball has been moved.

This difference between two points in space exists even if the ball is not present, and we say that there is a difference in potential between these points. In this (special case) the ***potential difference*** will be given by gh.

Each point in space has a ***POTENTIAL***, V associated with is where V is a ***SCALAR*** quantity related to the objects energy. Each point also has a field, E, associated with it, which is a vector quantity related to the direction of attraction of the force produced by gravity.

Relationship between *E* and *V*

We can show that at a point

$E = \frac{GM}{r^2}$ and $V = \frac{GM}{r}$

Looking at these there is a simple relationship between them:

Hence --→

Now charges in an electric field move in the same way as particles in a gravitiational field. Electrons are attracted to positively charged objects. We can think of this as there being an ELECTRIC field around the positively charged object which gives a force on any other charged particle close to it. Similarly there is a potential field in the same way.

The Electric Field is given by $E = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q_1}{r^2}$ and

the Potential Field is given by $V = \frac{1}{4\pi\varepsilon_0} \cdot \frac{q_1}{r}$

If we place a charge q_2 in the field it will have an energy Vq_2 and will experience a force $\underline{E}q_2$

Potential and Voltage

Potential and Voltage are closely related: The voltage between two points is simply the difference in potential between the points. The ***POTENTIAL DIFFERENCE*** (or ***VOLTAGE***) is a much more useful concept than the ***POTENTIAL*** as in order to measure the potential at a point we would need to reference it to a point where the potential is zero (which occurs an infinite distance away from the charged object creating the potential field).

The potential comes from the presence of the charge q_1

Poisson's Equation

Poisson's equation is a way for us to relate the potential to the charge(s) present. The details of this equation will be discussed in EEE220 (Electric and Magnetic Fields) next year. However for the present we will assume it and only use it in One Dimension.

In 1-D we have: $\frac{d^2V}{dx^2} = -\frac{\rho}{\varepsilon}$

Where --------------------------

Now we also know that $E = -\frac{dV}{dx}$ so an alternative way of writing this equation is $\frac{dE}{dx} = \frac{\rho}{\varepsilon}$

This tells us that the rate of change of electric field with distance is equal to the mean charge density, ρ, in that region of space divided by the permittivity.

In free-space the permittivity is given by the fundamental constant (Permittivity of Free-Space), ε_0. In a material we need to take account of the relative permittivity, ε_r, where $\varepsilon = \varepsilon_0 \varepsilon_r$.

Force on an Electron

Let us consider an electron in a vacuum

An electron in an electric field will move under a force, $\underline{F} = -q\underline{E}$

Where q is the charge on the electron = $1.6\text{x}10^{-19}$ C.

NOTE: As the charge is negative the force is in the opposite direction to the field.

The field has units of Vm^{-1} (or V/m)

The particles will move due to a force on the object by the usual relationship: --------------→

Thus is the particle was at rest at t=0, then at some time, t the velocity will be given by $v = \frac{-qt}{m} E$

As long as E is present, and remains constant the velocity keeps increasing with time. We can say that the electron gains energy from the field in the form of Kinetic Energy (KE) = $\frac{1}{2} mv^2$

We will see later that in a solid this energy can be used to produce heat (whether we like it or not!!!)

Key Points to Remember:

1. We can consider there to be a field around any charge.
2. The Electric field is a vector field and characterises the force that a particle will experience.
3. The Potential field is a scalar field and characterises the energy we can extract from (or need to put in to) a particle in moving it from one position to another
4. Voltage is the difference in Electric Potential between two points
5. ***We can relate Electric Field, Potential and charge using Poisson's Equation.***
6. ***This equation is very important and we will need to use it work out how a diode behaves.***
7. If a field is present a charged particle in a vacuum will continually accelerate.

EE105 - Potential and Potential Difference (Supplement to Lecture 1)

These two concepts can cause confusion, so here is a quick summary, using the gravitational case as an example.

If we raise an object from the floor to a height, *h*, we give it Potential Energy, *PE=m.g.h*. (where m is the mass of the object raised, and g is the acceleration due to gravity at the earth's surface).

Strictly speaking what we are actually doing is ***increasing its Potential Energy by an amount equal to m.g.h.*** After all if there was a hole in the floor it could fall further and hence release more energy. Thus the potential energy is the energy that can be gained (or lost) in the object moving from one point to another.

Now in the above equation the only term that depends on the object is its mass, m. The other terms are *g.h*, which will affect all objects by the same amount. In raising the object we have increased its potential energy. Therefore we can say there is a potential difference between the start position and the raised position. As we increase the height from the start position we will increase the potential difference and hence increase potential energy of any object that we can raise by that amount. We can write the equation:

$$PE = m.V \qquad [1]$$

Where V is the difference in potential between the start position and finish position.

Now in the above case we made the approximation that h, the height we raised the object, is small compared to r, the radius of the Earth. Clearly this only applies close to the earth's surface, and would fail if we were considering a rocket leaving the earth's surface. In such a case as the earth's gravitational field is weaker at height, h, so the gravitational force acting on the rocket will be weaker and so the change in potential energy will not rise linearly with height.

In this case the potential energy of the rocket when it reaches a height *h* can be more generally given by.

$$PE = m\left[\frac{GMr}{r^2} - \frac{GM(r+h)}{(r+h)^2}\right] \qquad [2]$$

where, g was replaced with GM/r^2. This represents the potential at the earth's surface minus the potential at height, *h* multiplied by the mass of the rocket, *m*.

This formula can be simplified to

$$PE = m\left[\frac{GMh}{r^2 + rh}\right] \qquad [3]$$

and it is simple to show that the approximation *m.g.h* will hold if $h << r$.

Consider equation [2]. The potential difference,

$$V = \left[\frac{GM}{r} - \frac{GM}{(r+h)}\right] \qquad [4]$$

which is literally the difference in potential the two points. **The formula for potential at any point away from the earth is *GM/x*** where *x* is the distance away from the earth's surface.

Note that the potential at a point will decrease with distance away from the earth, but that from some arbitary start point (e.g. 'A') the potential difference will increase if the relative distance away from the earth from that point increases. This can be seen in the plot of potential against distance below: