CHAPTER
15

SOLID STATE DEVICES

15.1 INTRODUCTION

The solid-state devices of interest in microwave and RF circuits are made from materials called semi-conductors. The materials are crystals formed from atoms which come from the middle columns of the period table, i.e., columns 3,4, and 5. Silcon (Si) which is located in the 4th (IV) column of the period table is an example of a well known semi-conductor material. Gallium Arsenide (GaAs) is an example of a semiconductor which consists of atoms from the third (III) and fifth (V) column of the period table. To understand why semiconductors are important one needs to consider the characteristics of charge (electrons) movement in various materials. The conductivity, σ, is proportional to the number of free charges and their mobility. Crystalline solids consist of an orderly array of atoms referred to as a lattice. Electrons play two important roles when one consisters charge mobility. First electrons provide the boniding mechanism for the attoms in the lattice, i.e., the atoms share electrons which results in the crystal maintaining its integretity as a solid. Secondly, electrons which are not critical to the bonding process are free to move about the lattice and their motion consitites negative charge moving. Such electrons are referred to as *conduction electrons*.

Sometimes a crystal may have atoms in its structure with insufficient electrons to perform the bonding fucntion. Electrons involving in the bonding process are referred to as *valence electrons*. Situations where an electron is needed to complete the bonding are referred to as a hole, i.e., it is as if a hole is available to be filled by a passing electron. A hole-electron pair can be created by thermal energy due to the temperature of the material. In this case the thermal energy kicks the electron away from the veciinty of its atom and it becomes free to roam throughout the crystal. This process is referred to as *generation*, i.e., an electron-hole pair has been generated. The hole may likewise move in the crystal if a bonding elecgtron from a neighboring atom moves to take up the bonding position orignally vacated by the electron. In this way a hole can move throughout the crystal. Because a hole represents the absence of an electron from an otherwise neutral atom its net charge is positive. Therefore a hole can be though of as a positive charge which is mobile.

While less likely a mobile electron may stumble into a hole an become captured. When this happens this is called *recombination*. In this case the charge is neutralized andis no longer mobile. The number of electron-holes is determined by an equilibrium process. As the number of electron-hole paris generated by thermal energy increases then the more likely it becomes that holes and electrons will recombine. The number of free (mobile) electrons is designated by "n" and the number of holes is designated by "p." Because of the equilibrium process the number of free electrons times the number of holes is equal to a constant which is a function of temperature. In the example above the number of electrons would equal the number of holes. If the number of electrons equals n_i then the product of electrons and holes would be given by $np = n_i^2$.

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If electrons were added to the material so that the new number of electrons was $n' >> n$ then the equilibrium would be thrown out of balance and the recombination process would increase until the equilibrum was restore. If the number of recombinations to restore equilibrium is designated as "r" then

$$(n'-r)(p-r)=n_i^2$$

and

$$r^2-(n'+p)r+n'p-n_i^2=0$$

$$r=\frac{1}{2}\left[(n'+p)\pm\sqrt{(n'+p)^2-4(n'p-n_i^2)}\right]$$

$$r=\frac{1}{2}\left[(n'+p)\pm\sqrt{(n'-p)^2-4n_i^2}\right]$$

figure 15.1

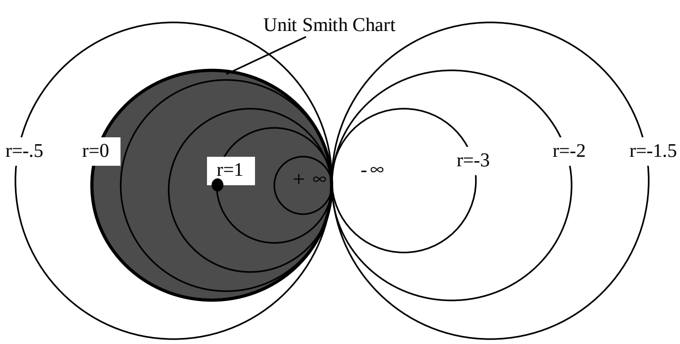

Figure 15.1. Smith Chart circles showing curves of constant resistance for positive and negative resistance.

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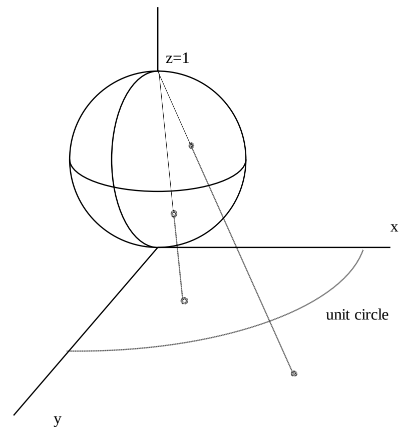

Figure 15.2. Illustration of the stereographic projection of the complex plane.

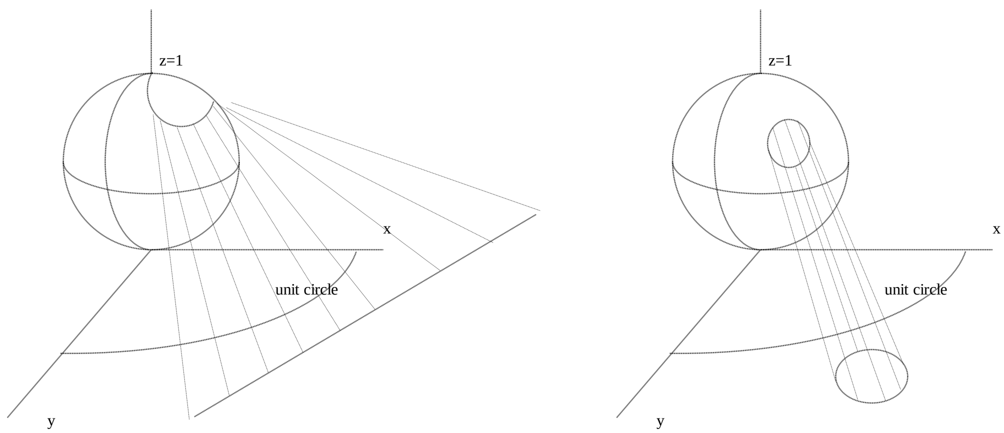

Figure 15.3. Line and circle in the plane map to circles (only) on the sphere..

TWO PORT STABILITY AND DEFINITION OF m

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