Introduction

How Can Frequencies be Managed?

Everywhere, all the time, we are bathing in a "field" of radio waves. The whole universe is covered by these waves. It maintains the everlasting trace of the initial "big bang" as a very weak radio noise which recreates a picture of the cosmos, at its very beginning for us.

Since discovering the laws of electromagnetism, during the 19th century, which are described by the set of Maxwell's equations, and inventing technical devices to produce and use these waves predicted by theory, man has added his own man-made waves to the natural ones.

Radio waves are electromagnetic waves whose frequency is low compared to others such as optical waves, X-rays or Gamma rays.

The radioelectric waves can be imagined as a shock, a vibration of space which spreads in all directions from a transmitter, traveling at the speed of light. These waves meet obstacles which absorb or deflect them and they weaken as the distance grows. After having traveled some way, they progressively mix with the radioelectric noise which exists all around, being created by innumerable wave sources, natural or man-made. Progressively, more and more sophisticated techniques are required to extract from this general noise a particular radio signal which weakens when propagated from the transmitter. If a radio link is established between a transmitting and a receiving station, the receiver must be installed in a place where, according to its sensitivity, it can separate the useful signal from the noise and process it.

Engineers have found ways to shape the completely immaterial but completely real radio waves and map them in the three dimensions of space. If the exact

location of each transmitter is known with its radio characteristics, if the obstacles met by the waves are evaluated, if the propagation conditions are assessed, we can design a map of the radioelectric field, at every place, often exactly and at least in a statistical form.

Moreover, if the radioelectric noise can be described and modeled, if well defined receivers are installed, the useful range of any particular radio system can be calculated and designed. It is important to note that a radio system (transmitter, propagation medium, receivers) should be seen as a whole. Any part cannot be considered without reference to others. In fact, radio engineers must generally manage whole systems rather than transmitters alone. Their objective is to implement everywhere as many radio systems as possible, which are needed by our modern societies, without interferences between them.

The management of the radio "natural resource", which is usually called "spectrum" or more simply "frequencies", to insure a variety of practical services on the field throughout the world, is the subject of this book. It considers all possible kinds of instruments: technical, administrative, legal, economical, which may be used. However, it will not deal with radio system engineering, i.e. how to optimize the use of a specific radio resource for a given radio system, on a definite area, in conformance with regulations. As an example, the mobile radio systems or satellite system engineering are two specific subjects which might be the matter of dedicated books. A mobile operator should implement its radio stations in such a way to optimize their coverage, satisfy the customer traffic, lower its investment costs and so on. Specific tools are necessary for this.

Only general tools will be considered here which help to optimize and share the whole radio spectrum resource to satisfy the different needs, taking into account the huge variety of users and uses. Spectrum management, as far as we understand it, does limit itself to rules which help this sharing. It is a science for spectrum regulators and administrators rather than a science for operators which will be outlined further.

It could be useful to mention that this word "spectrum" has several different, albeit related, meanings. The one which will be mainly considered here is the global radio resource, available anywhere and anytime and which has to be organized for its best use. However, the same word may mean other things: as an example, a particular radio signal has an intimate structure, described by a frequency "spectrum" which occupies a frequency band. It is not difficult to make the distinction between these different meanings according to the context.

Among the natural forces, the fundamental interactions which are at work in the matter, those which are carried by radio waves are the "lightest". We could say that

their influence stays on the surface of things. The energy quantum w ($w = h.\upsilon$, according to Planck's formula with h being Planck's constant and υ the wave frequency) is too weak to disturb the atoms and affect the electronic cloud structure around the nucleus. Thus, radio waves are non-ionizing, having no influence on neutral atoms, thus being different from other electromagnetic waves with a higher frequency, such as optical waves. This is truly important when considering, for example, the effects of waves on health.

There has been, in the past, a long and hard debate about the intimate nature of light: is it a wave or a stream of particles? Quantum theory has given an answer. Every electromagnetic signal can be simultaneously described as a wave and a stream of particles and can be observed as one or the other according to the experimental context. However, practically, radio signals only appear as waves. Spectrum management can ignore their quantum aspect.

Radio waves interact with electrons, ions or molecules having an electric polarity. In radiocommunications, the interaction of waves with ions or polar molecules is a rather specific phenomenon which is only seen in some circumstances such as reflection on the Earth's ionosphere or transmission through the atmosphere. In such cases, only waves at specific frequencies are generally concerned. On the other hand, the interaction of waves with electrons, particularly electrons which move freely in metallic mediums, is a fundament of radio techniques, typically the basis of antenna properties. The interaction between electric currents and radio waves at the vicinity of an antenna gives shape to the wavefront which is transmitted. It also determines the strength of the electric current which is inducted in an antenna by a particular incident wavefront. Antenna theory is the basis of radiocommunications.

Actually, the very weak interaction between ordinary radio waves and matter helps to consider the radio spectrum as a rather closed domain of physical phenomena which can be managed for itself without too much care for other aspects of science or social life. In normal conditions, radio waves have no biological, chemical or mechanical impact. However, when used at a high power, they produce of course effects such as heating, which are used in microwave ovens, as an example. The recent debates concerning the impact of mobile phones on public health shows that the public deserves true and precise information in order not to react irrationally to the implementation of modern radio networks.

It is a fact that the rapid development of radio networks of all kinds in our society has changed public feelings about radio. Nowadays everybody has a mobile phone and radio stations are everywhere. Such major contemporary events such as man landing on the Moon, or the Gulf War, have clearly been achievements in radio techniques. The "great ears" of the secret services may be seen as a threat to privacy. Our world is becoming a radio world where waves are weaving an ever denser net around the Earth.

Positively, radio is a basic technology for building the so-called "world village". Available anywhere, at any time, capable of building links at very short distances as well as on a cosmic scale, radio is a unique tool to connect men and things without any material medium. It is also a tremendous tool for social progress. New telecommunications services are often the offspring of radio such as broadcasting in the 1920s, TV in the 1950s, satellites in the 1960s, mobile phones in the 1990s, and radiolocation in the 2000s. But new regulations and new market opportunities are also born from radio implementations. The public debate which has taken place during the last 20 years about deregulation of the information society initially focused on traditional telecommunications cable networks and on the historical telephone operator monopoly. However, radio shuffled the cards and introduced a "wireless society" which is now universally adopted and made most of the former considerations on cable network regulations obsolete. When reading again the innumerable books dealing with deregulation, written during the period 1970-1980, it may be regretted that so many pages deal with cables and so few with radio. Experts are often short-sighted. Now, radio is in the foreground and radio spectrum management is a strategic issue, much more so than cable ownership.

Spectrum management can now be seen as a major goal for telecommunications efficiency. It is necessary that this natural and public resource be utilized for the profit of as many users as possible, taking care of the largest variety of needs. Let us understand that the spectrum resource is not capacity limited. The management of frequencies, if always becoming more accurate and clever, creates ever increasing possibilities.

We are going to describe the main tools available for this management. The book is made up of two parts.

Part 1, up to Chapter 9, is more technical. It deals with the management methods based on electromagnetism laws, information theory, geographical constraints. Basic rules and procedures are described which have been progressively elaborated from the beginning of the 20th century to share the spectrum resource. These rules are backed by international legal provisions which form a radio spectrum law. Current uses of radio are considered with their recent evolutions.

Part 2, more prospectively, describes the bodies in charge of this management with their functions and activities, with reference to the main questions they have to answer. New opportunities to improve the management of spectrum are presented.

Of course, this matter is rapidly changing. However, the general movement has now existed for more than a century. It can be judged that spectrum management has steadily progressed at a continuous pace during this time with some important changes at crucial periods. This is a reason to be confident for the necessary evolutions in the future.