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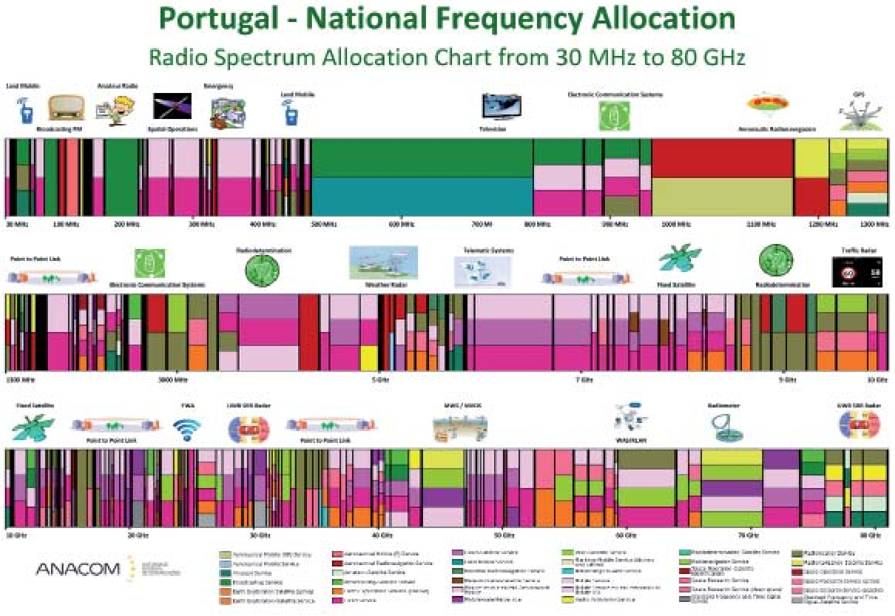

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Contents

Front cover: “The national spectrum allocation in Portugal” (courtesy of ANACOM). See the paper by Ryszard Struzak, Terje Tjelta, and José Borrego, pp. 10-33.

The International Union of Radio Science (URSI) is a foundation Union (1919) of the International Council of Scientific Unions as direct and immediate successor of the Commission Internationale de Télégraphie Sans Fil which dates from 1914.

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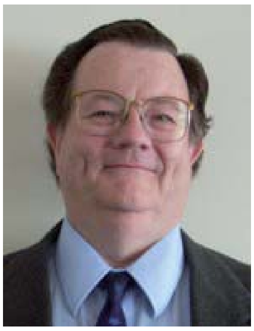

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Our Contributions

The radio-frequency spectrum is a precious, finite natural resource. Its management at both national and international levels is a complex process that has substantially evolved over the years. It is also a process that potentially affects almost all areas of radio science, and from a practical standpoint, almost all radio scientists. The paper by Ryszard Struzak, Terje Tjelta, and José Borrego provides a comprehensive review of this process, its evolution, and its consequences. Furthermore, it is written in a manner that should make it interesting to and accessible by all radio scientists. The article begins by tracing the history of how the spectrum was first exploited and shared, and how interference was first managed. The effects of early monopolies, the first intergovernmental agreements, and the rise of national spectrum management are traced. The evolution of global and regional spectrum management is explained, including the development of current regulatory bodies, and the contributions of URSI. Major trends in spectrum management are then studied, including administrative assignment, spectrum trading, and free access. Some of the consequences of these trends are also examined. Challenges and dilemmas in spectrum management are reviewed, including representation of various groups in society (including developing regions, civil society, and scientific interests); spectrum planning; the effects of monopolies; the marketing of spectrum, and the effects of competition; and trends in spectrum sharing. I think almost all readers of the *Bulletin* will find this paper both interesting and useful.

The efforts of Frank Gronwald in bringing us this paper are gratefully acknowledged.

Özgür Ergül's Solution Box column has two problems in this issue, along with one solution. The first problem, submitted by Bruno Carpentieri, involves electromagnetic scattering from a satellite geometry. The challenge is to reduce the number of iterations required to iteratively solve what turns out to be an ill-conditioned matrix equation, as the problem has been formulated. The second problem, submitted by Manouchehr Takrimi and Vakur Ertürk, involves scattering by a sphere. However, the discretization of the sphere is both dense and extremely nonuniform, leading to significant inefficiencies using conventional solvers. The submitters have provided one possible solution using a broadband multilevel fast multipole algorithm, but they are interested in knowing if there are other solutions. The associated models and data files for both problems are available for downloading.

We have the first of several new, regular columns in this issue. Paul Cannon, URSI President, has provided his first President's Newsletter. He is looking for feedback, so I encourage you to respond to him.

Asta Pellinen-Wannberg has provided her first Women in Radio Science column. She is seeking input and contributions for this column, so you are again urged to respond. She is also introduced in this issue.

Giuseppe Pelosi is starting a Historical Column, and he is introduced in this issue. If you would like to provide a contribution to this column, please contact him.

AP-RASC 2016

The next URSI flagship conference, AP-RASC 2016, will be held August 21-25, 2016, in Seoul, South Korea. The deadline for paper submission is March 15, 2016. The call for papers appears in this issue. There is also a Student Paper Competition, and a Young Scientist Award program. Information on these is available on the conference Web site: www.aprasc2016.org. I urge you to start planning now to submit a paper, and to attend.

Contribute!

The *Radio Science Bulletin* is always looking for papers that will be of interest to the URSI community. If you have such a paper, please consider contributing it to the *Bulletin*. This is the best way to reach the broadest audience of radio scientists.

Ross

President’s Newsletter

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This is the first of an irregular series of variable-length newsletters from the URSI President. As you can see, I am providing myself with plenty of scope to sometimes write very little – and, indeed, sometimes write nothing at all, if there is no news. However, there is no shortage of copy as I write this in September 2015.

As most of you know, I took over as URSI President in August 2014, inheriting a number of initiatives from Phil Wilkinson, and with the intention of introducing a few of my own. Consequently, the last year has been incredibly busy for the Board and Secretariat. We are all of the opinion that we need to modernize and reform URSI – while of course retaining its very good points.

Flagship Meetings

Under the guidance of Phil, URSI adopted a three-year conference cycle of flagship meetings: the Atlantic Radio Science (AT-RASC) meeting in the year after the GASS, the Asia-Pacific Radio Science (AP-RASC) meeting in year two, and then the General Assembly and Scientific Symposium (GASS) in year three. AT-RASC took place in May 2015 (more on that below), AP-RASC (2016) will be held in Seoul, Korea, and the GASS (2017) will be held in Montreal, Canada. As you can imagine, these extra meetings entail an enormous amount of extra work. In order to deal with this, George Uslenghi and Kazuya Kobayashi have kindly agreed to serve as Assistant Secretaries General for AT-RASC (2016) and AP-RASC (2018), respectively. More details of these meetings can be found at the following Web sites:

URSI AP-RASC, August 21-25, 2016, Grand Hilton Seoul Hotel, Seoul, Korea, http://aprasc2016.org.

URSI GASS, August 19-26, 2017, Montreal, Quebec, Canada, http://gass2017.org.

AT-RASC

The first AT-RASC was held in Gran Canaria (Spain), in May 2015. There were over 400 participants and more than 600 papers scheduled over the five-day meeting. Notwithstanding the beach location and glorious weather, the papers were sufficiently good to hold the audiences through to the end! One important novelty was the daily General Lectures, given by international experts. It was most gratifying to see so many people in the auditorium for these. Three of the lectures are available to watch through the URSI Web site. My thanks go especially to Peter van Daele, George Uslenghi, and Kazuya Kobayashi for making this meeting such a success.

The Board and Secretariat took soundings regarding the organization and location of the meeting throughout and after AT-RASC 2015. As a consequence, we have decided to run AT-RASC 2018 in the same location (most likely during the week starting May 28, 2018), so that we can benefit from the organizational experience gained in 2015. Later meetings may move to a different location. Next time, we will be providing greater guidance for those traveling to Gran Canaria from outside of Europe. For those in Europe, it is simple and cheap to travel to the Island, but non-European travel agents were generally not aware of the options.

Early Career Representatives

An important new initiative this triennium was the election of Early Career Representatives (ECRs) from each of the Commissions. I believe that this has been a huge success. Under the guidance of their superb Chair, Stefan Wijnholds, they have participated in the organization of the General Lectures at AT-RASC, provided guidance on the development of the *Radio Science Bulletin*, and advised the Board on how URSI can improve its visibility. The latter will involve the ECRs in the design and testing of new URSI Web pages.

Commission Budgets

You probably know that the Commission Chairs have a budget to support their Commission activities. The introduction of annual flagship meetings with an annual planning cycle has put these budgets under pressure. While we have maintained the Commission budgets at 9000 Euros, we have introduced two innovations to mitigate the impact of these additional meeting commitments. The first is a further discretionary budget of 3000 Euros per Commission, where a good case is made. The second is the ability to roll-over under-spent budgets to the following triennium. You can help these budget pressures still further by organizing your conferences and working groups under the umbrella of our flagship meetings.

Development of the *Radio Science Bulletin* (*RSB*)

My final topic relates to the *RSB*. Ross has led the development of the *RSB* over many years, and it is now a well-respected and valuable publication. The Board decided earlier in the year that it was time to enhance it further by supplementing the tutorial articles with radio-science news articles. Hopefully, you will have already noticed the first steps in this journey. Editing *RSB* every quarter is a mammoth task, and I would publicly like to thank Ross Stone for all of his hard work.

With very kind regards and best wishes,

Prof. Paul Cannon, OBE, FREng

On Radio-Frequency Spectrum Management

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Abstract

This article review lessons learned from the uses of radio-frequency (RF) spectrum at national and international scales. Its main purpose is to stimulate debate on how to allow new wireless systems to operate, and to reduce the chronic apparent shortage of RF spectrum. The article aims at a better understanding of the mechanisms behind spectrum management and their pertinence to the public interest. The main contributions if the article are:

- Considering RF spectrum management as a construct that structures radio services and, at the same time, distributes wealth and power;
- Highlighting major doctrines of RF spectrum management;
- Promoting spectrum management directly by its users;
- Promoting cooperation and transparency.

The several parts of the paper include the evolution of spectrum exploitation, and a foreseeable future by taking a closer look at major dilemmas and challenges. The paper ends with general comments and conclusions.

1. Introduction

"There is no more spectrum available."

This was stated by Herbert Hoover, the US Secretary of Commerce, in 1925. Since then, the statement has been heard each time a new wireless service has been proposed. That shortage of spectrum has been felt as a factor delaying the social and economic development of society. Various proposals have been put forward to solve the problem, but no satisfactory solution has yet been found. The laws of physics impose absolute limits. Progress in science and engineering bring us closer to these limits, while administrative means impose additional restrictions. The latter result from our choices, more or less deliberate. Better policy and organization could augment the outcome drawn from what is physically possible. For example, for all communications between fixed points, cables could be used instead of unguided radio waves, which would leave radio waves for mobile applications. Satellite networks could similarly take over from terrestrial networks. Better propagation and system models could lead to more efficient spectrum use. Alternatively, we could replace inefficient signal-coding and data-compression technologies with better technologies. The Regional Radio Conference (RRC) on terrestrial broadcasting, held in Geneva in 2004/2006, is a good example. The participating countries decided there to move from analog to digital television by June 2015, which freed a significant part of the electromagnetic spectrum for other uses. According to Martin Cooper, a pioneer of mobile radio, large segments of the radio-frequency spectrum are underutilized due to outdated ideas and practices that are still followed [1]. Other professionals have shared his opinion.

Science and engineering make the spectrum potentially usable, but its real use depends on local legal, regulatory, financial, and also perhaps other factors. Diplomats, lawyers, economists, and engineers gather every few years to review and improve the intergovernmental treaties that regulate the uses of radio waves. Traditionally, when doing that they strictly observe the consensus principle. The consensus requirement assures that the majority cannot impose regulations that would harm any vital interests of a single country. As a consequence, with unbalanced representation the conference results might be biased. That could put some spectrum user groups not represented at the conference in an inconvenient situation, which could last for decades. The nearest such event, the World Radio Conference, will be held in Geneva, Switzerland, from November 2 to 27, 2015 [2]. As at such previous conferences, URSI will certainly participate as an observer, i.e., with no voting rights. However, individual URSI scientists can participate and vote if they are members of national delegations.

The target readers of this review are all of those interested in radio and spectrum management mechanisms who do not actively participate in such activities. Because of this, this paper draws heavily from the authors' earlier publications, lectures, and discussions at spectrum-management working groups they chaired in URSI and in other bodies, such as the International Telecommunication Union (ITU). However, the opinions expressed here are the authors' personal opinions.

2. Spectrum Exploitation

This section deals with key ideas and practices inherited from the past. It starts with the genesis of state intervention, national spectrum management, and intergovernmental collaboration. The USA is taken as an example for national management. The mechanism of international regulations in the framework of the International Telecommunication Union is then briefly reviewed. The role of scientific research is outlined, as is the cooperation with URSI and other organizations.

2.1 Unregulated Commons

Radio is associated with the names of James Clerk Maxwell, Heinrich Hertz, and Alexander Popov. None of these marketed his discovery: they were motivated only by scientific curiosity. The first radio company in the world was the Wireless Telegraph & Signal Company, founded by Guglielmo Marconi in Great Britain, in 1897. It started with wireless telegraphs for navies. Since then, military needs have continued to be the major force behind the technological progress of the wireless sector, the extraordinary success of which continues until today. Marconi marked the birth of a new industry that began transforming the Industrial Society into the future Knowledge Society. We all take part in that process, whether we want to or not, having only minuscule influence on it and a very vague idea of where it will ultimately bring us. The way we use the spectrum can accelerate that process, or can slow it down.

Marconi's company offered equipment and services. The spectrum efficiency of his spark-gap transmitters was very low. Their emissions occupied almost the then entire usable radio spectrum over large geographic areas (e.g., some 250 million square kilometers), yet carried only of the order of single bits every few seconds. The Earth's surface could accommodate only a few such transmissions at a time. To avoid interference, the operators invented the rule of "*listen before transmit*," which has been adapted many years later in some local-area wireless computer networking systems, such as Aloha and Wi-Fi. This latter network, which is presently very popular, is based on the Institute of Electrical and Electronics Engineers (IEEE) 802.11 standards. The radio-frequency spectrum was dealt with as a natural "commons" for free use by everybody, just as the air is used for breathing. *Commons* refers to resources that are not privately owned, and are accessible to all members of society. They can include everything from natural resources and common land to computer software. When commonly held property is transformed into private property, this process is known as "*enclosure*" or "*privatization*."

Marconi patented his wireless telegraph to assure him a monopoly, and to block other companies from developing similar devices and services. However, his monopoly did not last long, and new companies appeared in the market. They all chose to compete instead of cooperating, and the competition was fierce. To strengthen his position, Marconi tried various means. He had a good relationship with the ruling class in Italy, as did his spouse in Great Britain. His opponents accused him of bribery of the highest governmental officials to obtain lucrative governmental contracts. The accusations led to political scandal in Great Britain, known widely as the "Marconi scandal," but Marconi did not lose much. It was the first known corruption case in the radio business.

To force people to use his services and devices, Marconi did order his radio operators to ignore messages sent using the competitors' devices, in spite of the fact that in maritime emergencies, the consequences could be tragic. With no regulations, this was quite normal, and in accordance with the concepts of free competition and the Darwinian doctrine of survival of the fittest. One of Marconi's competitors was Karl Ferdinand Braun (who shared the 1909 Nobel Prize in Physics with Marconi). Braun was associated with the German Telefunken Company.

Defending the company's interests, the German government intervened to break down Marconi's monopoly once and forever. The personal experience of a family member of the German Emperor had an effect: his courtesy radio telegram to the US President was rejected by a Marconi operator simply because it was sent from a German-made device. Certainly, there were numerous similar cases, but none directly touched such high personalities. They initiated the international radio regulatory activities that have continued until now. As a consequence of the incident, a preparatory radio conference was called in Berlin in 1903, just six years after Marconi opened his company. The focus was on the maritime services, interconnections, and financial settlements. Interconnectivity does not happen by itself, since it is not in the incumbent's interest to share the income with competitors.

2.2 First Intergovernmental Agreements

The proposed regulations included two important obligations. The first was to receive and process emergency radio messages, no matter what their origin. The second was to continuously watch for distress signals. These proposals turned out to be impossible to adopt at the conference, and the delegations decided to come back to them at the next conference, at the same place, three years later. The Berlin 1906 conference (1) allocated two frequency bands (around 0.5 MHz and 1 MHz) for public correspondence, (2) founded the International Radiotelegraph Union (IRU), and (3) signed the International Radiotelegraph Convention. By setting the rules on how the electromagnetic spectrum was to be used, the signatories de facto declared its collective ownership. However, other independent nations could join, acquiring the same rights. Specific spectrum uses were to be registered, and the IRU Bern Office recorded the ship stations in operation (known as the "Bern List").

However, an inherent conflict appeared at the conference between private interests and public interests. Marconi succeeded in ensuring that the governments of Great Britain and Italy opposed the convention, in order to defend his company's interests. The regulations had to wait six more years, until the following conference in London. The losses due to the delay have never been evaluated. It was the only case of direct governmental protection of a specific company at radio conferences [3] that the authors have found in official documents. If similar cases happened, they were made outside of the conference rooms.

International treaties are part of a worldwide game that governments agree to play. Consensus is an inevitable ingredient, as there are few things able to force a state. Conference negotiations aim at balancing conflicting interests, and large companies have a strong say there. The Berlin controversies had to wait until the 1912 London conference. The famous Titanic disaster was not without effect on the approval, which happened just three months before the conference, and could have been avoided if an agreement had been in place. This luxury ship sank with some 1500 passengers, after colliding with an iceberg during her maiden voyage. Distress signals were immediately sent by radio, but none of the ships that responded were near enough to reach her before she sank. However, a nearby ship that could assist, the Californian, failed because her radio operator switched his radio off after the daylong watch, and the message did not get through [4]. The Titanic disaster did directly or indirectly touch many very wealthy and influential people of the time. They were shocked by the story, and so was the general public. Numerous books and films have kept the memory of that tragedy alive until today. Certainly, the disaster contributed to the approval of the regulations proposed six years earlier.

To improve the coordination of the uses made of radio spectrum, the IRU was transformed into the present International Telecommunication Union (ITU), without major changes in the basic philosophy and regulations earlier agreed to. The ITU is the UN Agency for Information and Communication Technologies (ICT), with a total membership of over 190 Member States, and some 700 private companies from around the world. It consists of three Sectors: Radiocommunication, Standardization, and Development. The Radiocommunication Sector (ITU-R) coordinates radio-communication services, and the international management of the radio-frequency spectrum and satellite orbits. It also develops common technical standards and recommendations, and maintains Radio Regulations and the Master International Frequency Register (MIFR). The Radio Regulations are a binding international treaty, setting out the allocation of frequency bands for different radio services. They also set technical parameters to be observed by radio stations, and procedures for the notification and international coordination of specific frequencies assigned to the stations by Administrations, as well as other procedures and operational provisions. Radio Regulations are set and modified by consensus of all the Member countries at radio conferences; more details are given below.

2.3 National Spectrum Management

National spectrum management and international treaties regulating spectrum exploitation were born at about the same time. Since the very beginning, they have been closely interrelated: modifications of one of them in turn induce a series of consequential changes in the other. However, while the international use of spectrum requires collective consensus of all Member States, every State is fully sovereign for regulating its national uses, as long as it does not touch other country's interests. Consequently, if a station wants its use of radio frequency to be internationally recognized, it must be recorded in the ITU Master International Frequency Register. The notification process includes verification of whether or not the station's parameters agree with the radio regulations and plans in force. ITU only charges for the nominal cost of work. In 1963, the governments extended the concept of spectrum commons to include artificial satellites. Since then, the orbital parameters and frequencies of satellites have been recorded in the Master International Frequency Register.

In practice, the governments translate the Radio Regulations into their national regulations, and assign portions of the spectrum resources among their subjects. Most have introduced the obligatory national spectrum licensing associated with a spectrum-fee system, in spite of the fact that no country pays for the spectrum. Indeed, the fees can be seen as an extra tax imposed on the spectrum users to feed the governmental budget and development plans in sectors that may be far away from telecommunications. Details may differ from country to country. The license offers rights to exploit a specified band of frequencies under specified conditions and for a specified time, which can be – and most often is – extended over the following years. This makes the license quasi-permanent. In some countries, the license is transferable, which makes it not much different from an ownership certificate. The ways in which the licenses have been issued also differ from country to country, and may change with time. By issuing a license, a government can (and often does) control by whom, how, where, and when the spectrum is used, and for what purpose. This is often criticized: we will come back to that in a later section.

Traditionally, the license is awarded on the basis of seniority (the "first come – first served" rule), in comparative hearings, also called "beauty contests" (this could also be done by lottery). The first approach is the simplest to manage, automate, and control. The second approach is based on merit: a jury representing diverse entities considers all the proposals, compares their relative merits, and grants the license to the most-valued proposal. If the process is open to the public with an elected independent jury, the process is known as a "beauty contest." Otherwise, it is often named the "command and control" approach. This is more complex and more time-consuming than the previous procedure, and the "merits" and "values" are often vaguely defined. However, this is the only way to take into account the social consequences of the licensing decision. Distributing the licenses via lottery has not found supporters. Another approach is privatization or auctioning, discussed in a following section.

2.3.1 The FCC Example

This section deals with the US Federal Communications Commission (FCC), for two reasons. First, the FCC is one of the oldest and most-experienced radio regulatory agencies in the world. Second, a number of countries have drawn heavily from its experience, as did international spectrum management. World War I accelerated the development of radio technology, and the global center of the radio industry moved to the USA after the war. New services appeared: the service that developed most dynamically was broadcasting. It has proven its usefulness in commerce (advertising) and in politics. It has become a strong force in modern society, often abused to manipulate public opinion. A growing number of transmitters soon resulted in mutual interference, which lowered both the quality of transmissions and profits. In their rivalry for listeners, the operators increased the signal power radiated, which led to a power race, more interference, and more litigation. The era of spectrum plenty ended. A new era of spectrum scarcity began: it was just at that time that Herbert Hoover declared the lack of spectrum, as quoted in the introduction. All those interested agreed that the free market could not solve the problem, and governmental intervention was necessary. In 1926, a special governmental agency, the Federal Radio Commission (FRC), was created to regulate spectrum uses. The FRC was later transformed into the present Federal Communications Commission (FCC), which exists now. It deals with commercial radio, television, wire, satellite, and cable "as the public interest, convenience, or necessity" require.

There are five independent Commissioners of equal power who direct the FCC, which is a rather unique structure: in other agencies, there is typically only one director. Every candidate is proposed by the US President and confirmed by the Congress; the president also nominates the Chair. None of the Commissioners can have a financial interest in any Commission-related business, but each is required to be thoroughly familiar with the radio sector. Only three of them may be members of the same political party. They have to act in a fully transparent manner. Supposedly, the US legislature set all these precautions to assure that FCC decisions are impartial, fair, and free of political or commercial influences. In spite of this, some FCC decisions have been criticized as being biased. Critical voices were also heard when it was disclosed that the FCC Chair nominated in 2013 had earlier worked as a lobbyist for the cable and wireless industry. The FCC alone employs about 1900 persons, and spends some US$350 million per year. These resources are needed to manage commercial applications of the spectrum. They do not cover the governmental spectrum uses that are managed by the National Telecommunication and Information Agency (NTIA). The FCC homepage also lists the Interdepartmental Radio Advisory Committee, which helps to coordinate all activities related to spectrum use in the country [5].

2.4 Spectrum Management Evolution

2.4.1 Global and Regional Spectrum Management

The two Berlin conferences marked the end of the era of unregulated spectrum commons, and the beginning of spectrum regulation. Garrett Hardin, a prominent American ecologist, showed many years later that any *unregulated* commons is unsustainable by its very nature [6]. His famous phrase, the "tragedy of commons," has often been misused in spectrum-related discussions. The spectrum has become the natural public goods (commons) belonging to the whole of humanity, represented by the sovereign governments: parties to the Convention. This was in accordance with the ideas of Henry George, an influential American economist, writer, and politician. George held that people could own and trade what they create, but things found in nature should belong to all. The States have agreed that they are the sole sovereign entities deciding (together) on how the spectrum is to be used. Each state shall have free access to the spectrum. The spectrum shall not be traded, but its uses shall be regulated.

World War I did freeze international cooperation and accelerated the development of radio technology at the same time. The first radio conference after the war was held in Washington, DC, in 1927, just after the FCC was created in the USA. Many famous scientists participated, including Edward V. Appleton, the future laureate of the 1947 Nobel Prize in Physics. The Washington Conference updated the international spectrum-management system. It reviewed the Radio Regulations, defined a number of new radio services, allocated a specific frequency band to each, and extended the regulated frequency range up to 60 MHz. Similarly, World War II again froze the collaboration, and accelerated the development of radio technology. Just after the war, the Allied countries imposed a new international deal, aimed at "lasting international peace, justice, collaboration, and mutual trust." The United Nations organization was created, and the ITU became straightaway its specialized agency. The 1947 conference held in Atlantic City again extended the amount of regulated spectrum, and introduced new allocations.

Among others milestones, the non-telecommunication use of radio-frequency energy was recognized there. Specific radio bands were reserved for industrial, scientific, medical [ISM], and domestic uses. Since then, the power industry developed enormously. Collecting solar power in outer space and transporting it to the Earth's surface using microwaves was proposed decades ago. Wireless powering reappeared in relation to the powering of drones, electric cars, and the Internet of Things. The present tiny ISM frequency bands may be insufficient for such new applications, and additional bands may be necessary. In addition, ISM bands have now successfully been used for new telecommunication systems, such as Wi-Fi and similar systems. New powering systems operating in these bands create a serious potential threat to them.

Technology development continued: the subsequent conferences adapted the regulations to the changing reality. The 1959 radio conference accepted the idea of "passive services." Until then, a service had to transmit radio waves to be qualified as such: those services that only received signals had been outside the purview of the Radio Regulations. For instance, radio astronomy, remote sensing of the Earth, etc., were excluded. The regulations began to differentiate between the *physical use of spectrum*, when a frequency band and part of space was "filled in" with RF energy, and the *administrative use of spectrum*, when it was reserved for signal reception, or for a future use. The first Conference for Space Communications was held in 1963, just six years after the Soviet Union launched the first artificial satellite around the Earth. This conference extended the ITU-regulated commons over outer space and geostationary satellite orbits. New space services were defined, new spectrum allocations were made, satellite positions were assigned, and Radio Regulations were updated. The Outer Space Treaty entered into force in 1967. It explicitly stated that outer space was "not subject to national appropriation by claim of sovereignty, by means of use or occupation, or by any other means," like the earlier spectrum. In 1992, spectrum allocations for Global Mobile Personal Communications by Satellite (GMPCS) were made. This opened new possibilities, earlier unimagined and not yet explored in full. This also significantly removed the pressure on the terrestrial spectrum, but increased further disproportions existing among the ITU Member States, at the same time. As previously, the electromagnetic spectrum and satellite orbits were collectively managed by all the ITU Member States on behalf of and for the benefit of all the people of the world. Further information can be found in [7] and on the ITU Internet home page.

The radio conferences are practical means for managing the spectrum. They may be worldwide or regional, general or specialized. The general conferences are authorized to deal with virtually all aspects of spectrum use. The specialized conferences deal with particular services and/or particular portions of the spectrum. The regional conferences are held to solve specific spectrum-use problems within particular geographic regions. Some Radiocommunication Conferences are convened to negotiate and agree upon international frequency plans for specific applications, geographical regions, and frequency bands, which are subject to a priori planning. They are organized regularly and when needed. The participants in the conferences are official governmental delegations of the ITU Member Countries, each having one voice. The conferences are also open to intergovernmental organizations and the specialized agencies of the United Nations. Nongovernmental entities authorized by their countries are admitted, too (since 1993).

2.4.2 Worldwide and Regional Radio Conferences

Radio Conferences, worldwide and regional, serve as the foundation of global spectrum management in the framework of the ITU. As they all are similar, we here present only one: the Regional Radio Conference (RRC) Geneva 2004/2006, which opened a new era in global management of spectrum for digital broadcasting. It was called to coordinate the deployment of some 70500 transmitting stations in 118 countries. Two conditions were imposed: (1) no more than 448 MHz of spectrum should be used, and (2) the plan should assure the conflict-free operation of the stations, without causing or suffering unacceptable interference as much as practical. The conference was split into two sessions, the first held in 2004 and the second in 2006. The preparations took six years. At the first session, the participating countries agreed upon the principles, technical characteristics, and working methods. Each country defined then its requirements during the intersession period. The requirements were submitted to the second session for iterative adjustments, if necessary. Over 1000 delegates worked hard for five weeks at formal sessions, working groups, and private meetings. The success was possible thanks to the good will and high competence of the participants, as well as the exemplary cooperation between the ITU Secretariat, the European Broadcasting Union (EBU), and the European Organization for Nuclear Research (CERN). The iterative planning was largely automated, based on the software developed by the European Broadcasting Union. Two computer networks were used. One was the ITU's distributed system of some 100 personal computers. The other was the CERN Grid infrastructure, with a few hundred dedicated computers. The outcome was a new treaty replacing the earlier agreements concerning analogue broadcasting plans that existed since 1961 for Europe, and since 1989 for Africa [8]. Figure 1 is a photo of the plan for digital television in the printed version (over 2000 A4 pages), and in the electronically readable version on CD. With this plan, a significant part of the electromagnetic spectrum was made open for other uses, the well-known "Digital Dividend" [9]. Not all countries participated in the conference. Some questioned the spectrum-planning idea in general: see the discussion below for the reasons.

2.4.3 Radio Regulations Board

Consecutive ITU radio conferences are usually separated by a period of a few years. If an urgent international problem arises in the time between them, it is the Radio Regulations Board (RRB) that decides what to do until the nearest conference. It is the only ITU body authorized to decide which party is right and which party is wrong, in an objective and fully transparent procedure. During the conferences, the board members participate in their advisory capacity. This section describes how the Radio Regulations Board has evolved.

Each Radio Conference makes Radio Regulations more detailed, and more difficult to interpret and to implement. From a few pages in 1906, their volume increased to more than 1000 pages, not counting numerous frequency plans and agreements separately published. Probably the largest changes introduced by a single conference took place at the 1947 Atlantic City conference. To assist the Members in practical implementation of these changes, the conference created the International Frequency Registration Board (IFRB), which years later became the present Radio Regulations Board (RRB). It was modeled after the FCC, discussed in a previous section. The board members are elected by all the Member States at the Plenipotentiary Conference. They have to act independently, and serve as "custodians of an international public trust." They must be "thoroughly qualified by technical training in the field of radio and possessing practical experience in the assignment and utilization of frequencies." Interestingly, such qualifications are only required in regard to the Board members: the other elected ITU officials can be lawyers, managers, etc., with no technical training at all. The board's decisions have been ultimate: only the Member States can change them. In spite of several revisions of the ITU's basic documents, the substance of these provisions has

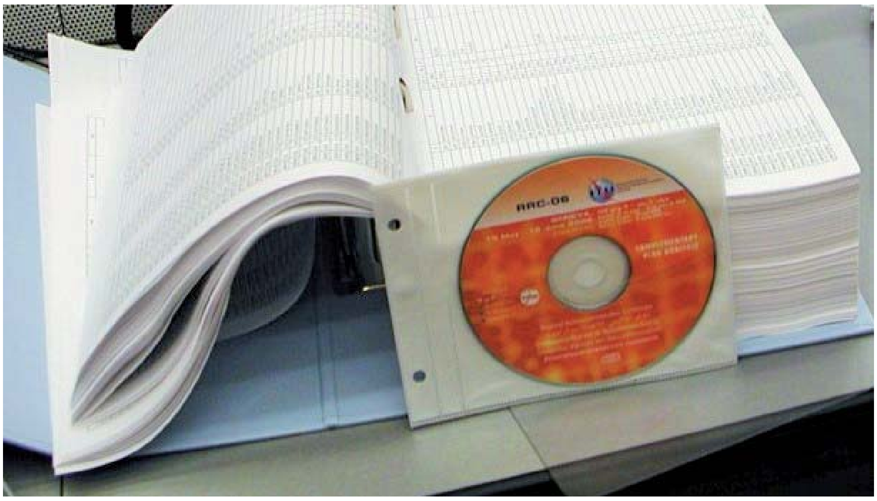

Figure 1. A photo of the Plan TV GE 06, CD and printed versions (courtesy of the National Institute of Telecommunications, Poland).

not been changed until now. Traditionally, the board works in full transparency, with the documentation of each case open to all interested ITU Members. However, recently a party requested that its case be considered behind closed doors, referring to its trade secrets, but the board rejected that request.

The board was envisioned "as something of a cross between the Federal Communication Commission and the International Court of Justice" to solve urgent intergovernmental conflicts that appear during the periods between the conferences [10]. In reality, it never achieved any status comparable to the Court of Justice. The major reason was the failure of Member States to allow the board to perform all of its functions as an intergovernmental arbitrator on the frequency uses: it seemingly was not in the best interest of the largest corporations. The 1965 Montreux Plenipotentiary Conference might even have abolished the board completely, had it not been strongly supported by the developing countries, as Codding noted. These countries considered the board as a neutral body, capable of assisting in protecting their interests in conflicts with foreign companies. The board has survived, but its size and importance was reduced, and the pressure of some countries to get rid of it continued. In 1994, the full-time board was replaced by a part-time board and its Secretariat was merged with the CCIR Secretariat into one Radiocommunication Bureau.

2.4.4 CCIR Supporting Studies

The success of the Geneva 2004/2006 conference was possible thanks to earlier careful studies in the European Broadcasting Union and elsewhere. Indeed, it was realized early that negotiations at the Radio Conferences required a lot of background scientific and engineering knowledge. With this in mind, the 1927 Washington conference created a special organ within the ITU, the International Radio Consultative Committee (CCIR) and its Study Groups. The aim was to facilitate the conferences by separating discussions on the well-defined engineering issues from political and economic negotiations. The Member Countries defined questions to be studied (voluntarily), and the results of these studies were submitted to the conference. They were also independently published in the form of the famous CCIR Green Books, Recommendations, Reports, and Handbooks. The CCIR studies significantly contributed to the diffusion of the progress in radio science and engineering.

The spectrum-scarcity problem had to wait until the CCIR General Assembly New Delhi 1970 created the Study Group on Spectrum Management and Monitoring. The assembly elected the first author (R. S.) as its Vice Chair; he served in that function until he became a CCIR official in 1985. CCIR contributed to the development of spectrum engineering, frequency planning, electromagnetic compatibility, and related disciplines. In 1994, CCIR became a part of the ITU-R Sector and ceased to exist as a separate organ, but the Study Groups and working methods have continued until now. Their publications have enjoyed great popularity, as have computer programs [11, 12]. More recently, in parallel with the Study Groups, the ITU has organized a series of open seminars and conferences devoted to specific problems of current interest, e.g., the Kaleidoscope Events. That collaboration proved to be extremely useful, in spite of some limitations discussed below.

2.4.5 URSI Contributions

The CCIR/ITU Study Groups have drawn heavily from the knowledge voluntarily brought by other organizations and individuals. Richard Kirby, the then CCIR Director, noted [13]:

> Even in the earliest days of radio, some of the best scientific minds were challenged by the problem of sharing the radio frequency spectrum among different users.

The International Union of Radio Science (URSI) was one of the first such organizations. The first URSI General Assembly was held in Brussels in July 1922 [14]. URSI was born under the patronage of the Belgian King Leopold II. As the possessor of the Belgian Congo, he was materially interested in having inexpensive communication means with (and within) his colony. At that time, with no satellites, only terrestrial radio could offer such communications, and URSI greatly contributed to progressing radio science and in removing obstacles in the way to global radio services. The second General Assembly of URSI and the ITU radio conference in Washington in 1927 were jointly organized, and URSI took an active part in the creation of the CCIR. Many URSI scientists were involved, contributing to the development of radio science and its applications, and to strengthening the role of science in intergovernmental agreements. Since then, a number of URSI reports have been approved by CCIR and used by ITU Members without modifications.

The collaboration was most effective when Balthazar Van der Pol, URSI Vice President (1934-1950) and Honorary President (1952-1959), also served as the CCIR Director (1949-1956). The URSI General Assembly in Tel Aviv in 1987, after the CCIR presentation [15], created the Working Group on Spectrum Management in Commission E, with the first author (R.S.) as its first Chair. However, he soon had to withdraw because it "could create potential conflicts" between CCIR and URSI according to ITU legal advisors, as URSI is a non-governmental entity, while CCIR/ITU was an intergovernmental organization. With time, some URSI scientists also lost their initial enthusiasm (except for radio astronomers and remote-sensing specialists), and the group was temporarily inactive. Some wonder if it could be related to changes in the funding mechanism of research projects and in an increased role of big companies, which are more interested in competition and exclusive spectrum use rather than in sharing the spectrum with others. The working group on spectrum was reestablished at the URSI General Assembly in 2005.

2.4.6 Other Contributions

URSI was not alone: numerous scientific and R&D laboratories (governmental and private) from around the world have supported the CCIR/ITU-R Study Groups. Their contributions to spectrum management cannot be overvalued. They are too many to be all listed here. The Institute of Radio Engineers (IRE), established in 1912, is one of the oldest. In 1963, it transformed into the Institute of Electrical and Electronic Engineers (IEEE), the world's largest professional association for the advancement of technology, according to their declaration. Among scientists, it is known not only through its numerous publications and conferences, but also through its Fellow program of professional recognition. The first IEEE Fellow was Jonathan Zenneck, a German physicist famous for his work on radiowave propagation over the Earth's surface in the 1900s. The IRE Professional Group on Communications Systems (PGCS) was organized in 1952. Five years later, the group on Radio Frequency Interference (PGRFI) was created. Later, they became the present IEEE Communication Society (ComSoc) and the IEEE Electromagnetic Compatibility Society (EMC-S), respectively. These are some of the first organizations that called attention to the spectrum-scarcity problems, and have played a major role in shaping spectrum management. Their reports are the definitive works representing the collective wisdom of some of the most distinguished leaders in science and engineering [16-18]. Recent IEEE activities in that area are coordinated by the IEEE Dynamic Spectrum Access Networks (DySpAN) Committee, among others. The spectrum-utilization issues were also debated at IEEE sponsored symposia around the globe, e.g., the International Wroclaw Symposia and EMC Zurich Symposia, organized since 1972, currently, the EMC Europe Symposia.

Lots of improvements in spectrum management came as a result of DARPA, MITRE, and NATO projects [19, 20]. In Europe, studies of the European Broadcasting Union (EBU) have been highly valued and often served as the basis for Radio Conferences: this was the case of the Regional Radio Conference Geneva 2004/2006, mentioned earlier. Many saw the UK's Radiocommunication Agency (now OFCOM), with its cooperating R&D university teams, as one of the world leaders in spectrum management and engineering [21]. More recently, the European Commission (EC), with the European Conference of Postal and Telecommunications Administrations (CEPT) and its European Communications Office (ECO), have been successfully working towards improved spectrum use. They have created various groups and committees (e.g., the Radio Spectrum Policy Group, RSPG, and the Radio Spectrum Committee, RSC), and supported specialized symposia and conferences. These studies are in close association with the ITU studies, and most of their results are freely available via the Internet.

2.4.7 National Spectrum Management

Since the nineties, in addition to traditional administrative spectrum licensing, auctions have become a popular national methodology also believed to create incentives for effective utilization of spectrum, as well as revenue for governments. Figure 2 shows the spectrum price (in Euros per MHz per capita) observed at auctions in various countries in the years 2006 to 2011. The amount paid in the auctions was covered in consumer bills, as no

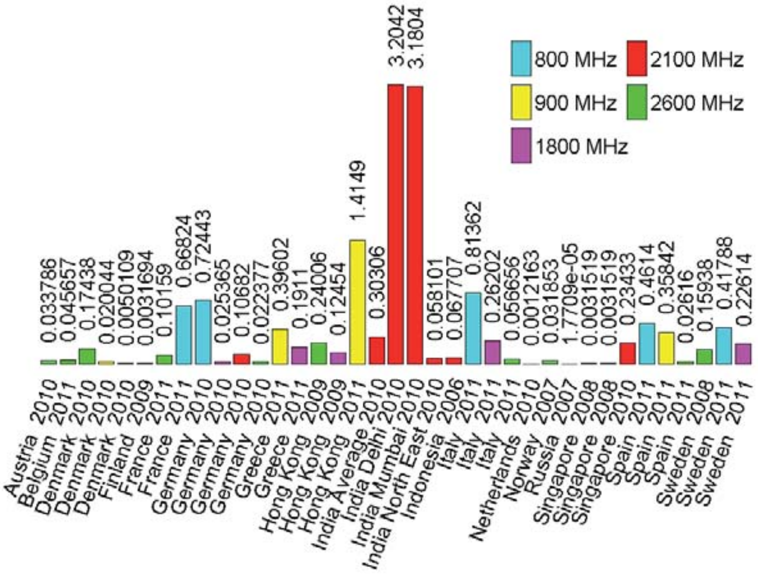

Figure 2. Auction prices given in Euro/MHz/Population, from [22]. (Note: This is for paired spectrum. The Euro/MHz/Population values were based on historical exchange rates when the different auctions were worked out. When calculating Euro/MHz/Population, the sum of the uplink and downlink bandwidth was taken into account. In auctions where paired/unpaired spectrum was sold in bundles, the amount of paired spectrum was used.)

company would operate to lose money. It was the highest in India, some three thousand times higher than in the Netherlands: if related to the average income per capita, the difference would be even greater.

2.5 Regulated RF Spectrum

This section is a short summary of the major practical results of common studies and collaborative negotiations within the ITU framework. Historically, the ITU has divided the world into three regions, as shown in Figure 3, for the purposes of managing the global radio spectrum and in order to avoid harmful interference between systems. Each region has specific allocation plans, by considering regionally harmonized bands, which take into account regional standards and peculiar aspects of the respective markets.

Region 1 comprises Europe, Africa, the Middle East, the former Soviet Union, and Mongolia. Region 2 covers the Americas, Greenland, and some Pacific Islands. Region 3 contains most of non-former-Soviet-Union Asia, and most of Oceania. The ITU Members have been dealing with the regulated frequency bands as often as they found it useful, according to the above three regions.

Radio Conferences change Radio Regulations, often extending the spectrum limits as shown in Figure 4. The 2015 World Radio Conference will discuss possible further extensions.

The total volume of regulated spectrum has been approximately doubling every 30 months or so, as Cooper, quoted earlier, calculated. He added [1]:

> Since 1901,...spectral efficiency in telephone communications has improved by a factor of about one trillion. Since 1948, it has improved a million times over. And when introduced in 1983, cellular communications immediately offered a ten-fold increase in spectrum capacity – by transmitting in 30 MHz of spectrum what would have taken 300 MHz to transmit with the previous generation of technology. Today's cellular systems are better than 100 times more efficient than the mobile telephones of the 1980s.

It should be noted here that radiowave propagation effects make some frequency bands unsuitable for specific applications. The total regulated spectrum is divided into small pieces, each allocated to a specific service or use, such as terrestrial, or space services; fixed, or mobile services; industrial, medical, domestic, and scientific applications, generally the same in all Regions. Some details may, however, differ from country to country and from region to region, which obstructs the free movement of devices (e.g., mobile phones) and international exchange. For example, Figure 5 shows the current national allocations for Portugal.

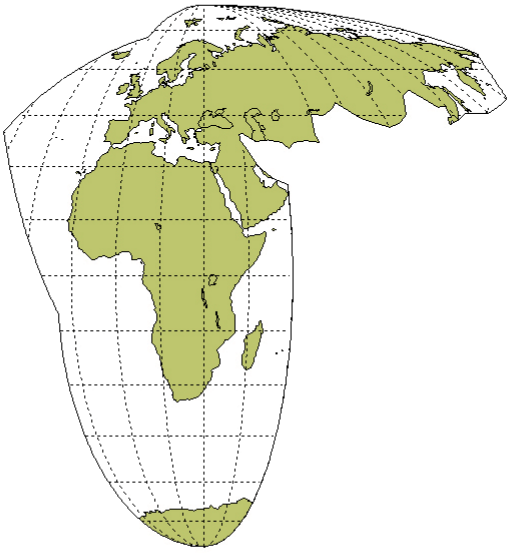

Figure 3a. A map of ITU Region 1.

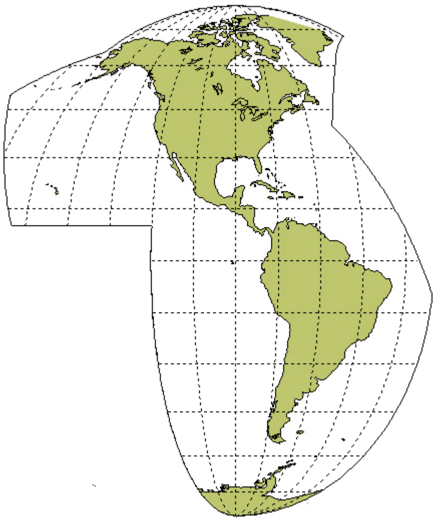

Figure 3b. A map of ITU Region 2.

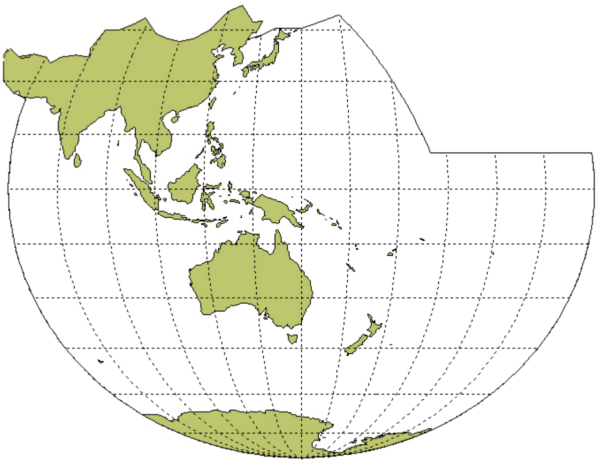

Figure 3c. A map of ITU Region 3.

3. Spectrum-Management Trends

This part focuses on foreseeable perspectives of spectrum management. Radio services [24] have increased in popularity. This has been a steady trend since the radio was first invented. This has also been true of the demand for access to radio frequencies. One traditional way of meeting the demand is to use increasingly higher and not-yet-explored radio frequencies, and to develop more-efficient methods for spectrum utilization. The management of the spectrum of these must also be developed, as described in previous sections. Spectrum management in the future will be a mixture of the current practice of today, with an emphasis on improving efficient spectrum utilization. There are several multidisciplinary factors that play important roles. These comprise the physics of electromagnetic waves and their propagation, technology for spectrum utilization and handling interference, market mechanisms for access to spectrum, and regulatory regimes.

Future spectrum management must take all of these into consideration through a good understanding of physics, technology, and economics in developing the rules for the actors involved. Furthermore, spectrum efficiency must be taken into account, addressing the desired benefit from our collective utilization of the radio spectrum. There is no single metric that can be used in this respect [25]. Technical, economic, and societal judgments therefore apply. In the following, the article is organized in subsections on spectrum management through administrative, trade, and free access to the resources.

3.1 Administrative Assignment

In a way, there must be some administrative rules irrespective of the spectrum-management method used. By assigning exclusive rights to use spectrum at a frequency and in an area, the national spectrum authority gives a user great freedom within the set of constraints that come with the right. No one else can deploy the same spectrum in this area. The rights are often given for many years, to allow sustainable business to be established or continued. Although this describes current spectrum management in many situations, it will most likely continue this way in the foreseeable future for a large part of the spectrum.

Within some services, there is an increasing concern about spectrum scarcity. In particular, mobile data is growing so fast that many operators will be looking for new spectrum resources. Of course, the scarcity also leads to innovation, such that the same amount of spectrum can be used for more traffic and more terminals. Furthermore, many applicants often wish to establish business, and this itself becomes an incentive to make good use of often highly costly access rights. The authorities must look for improved methods of assigning frequency rights. One example is to use graph-theoretic methods in assigning frequency for radio links in popular bands [26], contrasting the usually simplistic methods used today for making assignments. The study indeed indicated a potential for getting noticeably more out of the spectrum, and suggested a closer interdisciplinary collaboration between experts of radiowave propagation and frequency assignments.

Although often all spectrum of interest is already allocated for some service types and even assigned to users, measurements show that only a limited part is utilized at given location and time (see, for example, [27], indicating an overall utilization of 11.2% in Hull, UK, of bands ranging from 180 MHz to 2700 MHz). These types of observations, among other aspects, have motivated the development of cognitive radio equipment that can take advantage of the frequency blocks and time slots when no one else is using them. From the spectrum-management side, this needs development of rules that on the one side motivates equipment vendors to develop suitable technology, and on the other side motivates operators to invest in the technology.

A broad area is dynamic spectrum sharing, as different from traditional long-term spectrum sharing for different services, such a fixed terrestrial and fixed satellite links. There are several methods of shorter-term more-dynamic sharing that have been put forward. At a political level, sharing seems to be pushed believing that this will lead to far better spectrum utilization [28]. It has been suggested that beneficial sharing opportunities be identified in licensed and license-exempt bands, making sufficient license-exempt-band spectrum available for wireless innovation, and defining common paths to sharing based on contractual arrangements.

New spectrum-sharing techniques can be sorted into two groups [29, 30]. One is dynamic spectrum sharing, utilizing parts or "holes" of spectrum with limited spectrum rights. The other is a more-protected form, called authorized shared access, licensed shared access, or priority access. These methods span a gradually decreasing degree of control, from exclusive rights to opportunistic dynamic shared access.

3.2 Spectrum Trading

The economics of spectrum management cover many parts. Some are tightly linked, and are of command and control regimes under an administrative spectrum management regime. At the other end, spectrum access is a free-market item [31]. However, for services such as mobile communications, spectrum is largely treated as property, following on from suggestions by Coase [32]. Spectrum authorities organize auctions for allocation of frequency blocks, rather than other methods such as a contest or lottery.

Spectrum auctions have evolved since they were first used 20 years ago. The goal should be a high degree of spectrum efficiency, and not maximum revenue from the auction, since the first will create greater revenues, in the long run. Cramton suggested a combinatorial clock auction as being much better than a simultaneous ascending auction, and that this will as well enable a technology-neutral approach, if wanted [33].

In free-market-controlled spectrum management, a spectrum-property system must be defined [34], such as the time for utilization, the area where it is valid, and the spectrum identified. These rights must be exchangeable. An example deploying cognitive radio was given for micro-trading of spectrum rights for mobile-service operations in bands on a secondary basis [35], e.g., in broadcast bands utilizing "holes," called "white spaces," opportunistically non-used in the primary-user spectrum.

Game-theoretical approaches have been suggested to effectively take advantage of the shared-spectrum regimes [36]. Intelligence in next-generation networks, with the concept of equilibrium, will enable fair optimum spectrum utilization. These ideas are still in the early phases, and more research is needed.

An idea of a fully free spectrum utilization for any type of network was suggested for the future mobile and wireless system [37]. The marketplace took over and services were delivered by virtual operators. The value chain consisted of the various elements, such as the spectrum, radio access network, value-added services, and so on, with the different actors and not with a single mobile-network operator.

3.3 Free Access

Wireless local area networks (WLANs) in the form of Wi-Fi have become a great success. A significant part of the broadband traffic from a large number of terminals will go over Wi-Fi for at least part of the route. This happens in spite of the fact that radio systems have no guaranties for satisfactory access to the spectrum at 2.4 GHz or 5 GHz. It is therefore not strange that the so-called "commons" spectrum is thought of as a future solution, and more should be allocated for commons. In commons, specific rules apply, and no management is needed. A rule can simply be just to limit the radiated power to a maximum value. However, as such, it is not really free use, as someone has to set the rules and control the regime [38].

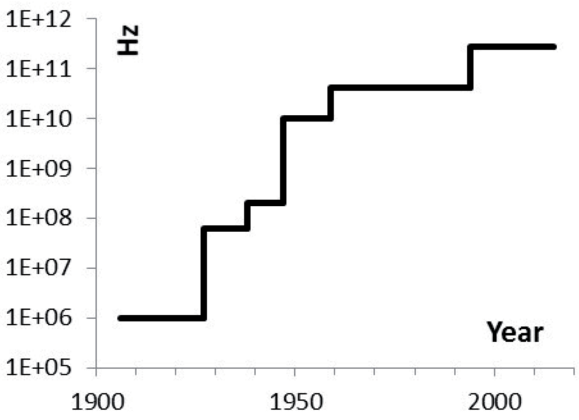

Figure 4. The maximum frequency allocated in the Radio Regulations by Radio Conferences in the years from 1906 to 2015. (Note: The complete lists of the ITU conferences can be found in [23].)

A radical suggestion has been proposed to allow anyone to transit anywhere and anytime, as long as the transmission does not cause interference that cannot be dealt with by the other user [39]. The proposal is to create something called "supercommons," where technology manages both wanted and unwanted signals, without other management.

4. Challenges and Dilemmas

The ITU's spectrum management, based on intergovernmental negotiations at radio conferences, has matured since the first meetings in Berlin. Previous sections outlined the way it has evolved and may further evolve. During the century, this has assured the phenomenal progress in all the fields that depend on applications of information and communication technologies, and specifically wireless. The history of radio has proven the ITU radio conferences to be practical: no other field of human activity has noted a comparable rate of progress. The ITU has made it possible to seamlessly communicate around the globe, and to assure the benefits of scale. The mechanism is not ideal, but it has been the only one possible: the only mechanism all the ITU Member Countries could accept. Nevertheless, this mechanism has been criticized by the private sector and by civil society activists, by developed countries and those developing: they all doubt if that mechanism fairly serves all members of society. To complete this review, this part offers a closer look at some of these critical comments, raised by various parties at various occasions.

For instance, a fundamental issue is the difference in the national and international spectrum treatments. Internationally, spectrum is offered for use for free, with no quotas or licenses, and with only basic operational restrictions imposed on its use globally and regionally. However, nationally it offered as a sellable, rentable, or licensable commodity (except for tiny ISM bands that are license-exempted). The idea of spectrum sharing contradicts the concept of exclusive spectrum use. License exempting negates the licensing. Free competition rules out regulations. Dynamic spectrum management goes against spectrum plans, which in turn excludes ad-hoc spectrum allocations. The idea of transparency negates the trade-secret principle.

All of these ideas seem to follow the Cartesian approach, in which a complex problem is broken down into

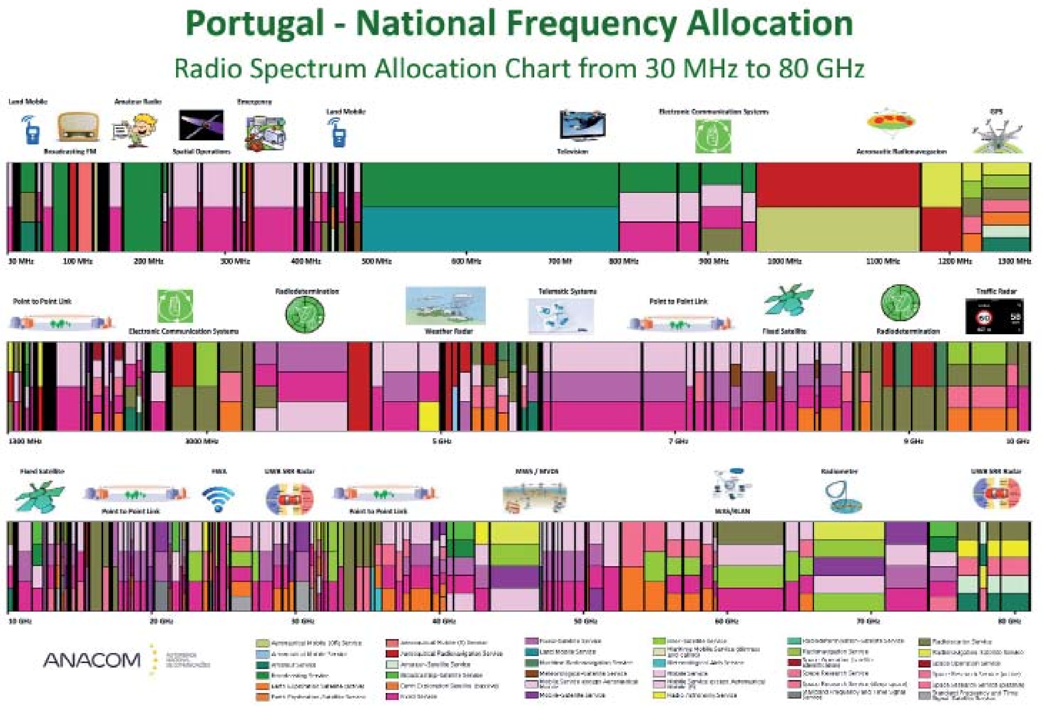

Figure 5. The national spectrum allocation in Portugal (courtesy of ANACOM).

smaller and simpler bits, each for a specific partial problem separately analyzed. Spectrum scarcity is a complex issue. It cannot be fully understood in terms of its individual component parts, disregarding complex interactions among them and with the rest of the surrounding world. Spectrum scarcity involves a combination of engineering, economic, political, and social issues that cannot be separately solved [40]. A holistic approach is needed, treating the problem as a whole within its full context. There is a striking similarity between the radio-frequency spectrum and environmental problems. The concept of a *supernetwork* may be helpful here. Anna Nagurney [41] defined it as a network that is above and beyond classic networks (informational, financial, social, etc.), including complex interactions among them, both visible and hidden. She classified supernetworks as "*system-optimized*" or "*user-optimized*." Equally well, they could be termed "*investor-profit-optimized*" and "*customer-benefit-optimized*."

4.1 Representation

Some private sector representatives note that problems considered at the ITU radio conferences are in reality those of competing companies. Direct negotiations between those interested, without involvement of third parties, would be cheaper, easier, and quicker, and the results would be better for all, they say: governmental interventions distort the competition. On the other hand, some civil society activists accuse governments of representing only the interests of the largest companies. They say such companies have quite different interests from small companies and individuals, which are the weaker parts of society in each country. Similarly, some delegates from developing countries believe their negotiation positions are weaker, and their interests are not taken into account as they should be. At intergovernmental forums, large enterprises lobby national delegations to adopt their views as the country's position. Small companies and citizens usually lack resources to do so. Often, they are unable to even properly formulate, justify, and convey their views, or to predict all the consequences of the proposals just negotiated. This section sums these up.

4.1.1 Developing Regions

The ITU Member States differ in population, wealth, knowledge, and in many other aspects. Similar disparities among regions and social groups exist in each country. They have different potentials, needs, and lobbying powers [42]. Radio-spectrum negotiations imply a lot of difficult work to be done before and during the negotiations. Documents for consideration may include hundreds and thousands of statements, proposals, and counter-proposals, each being a complex mixture of technical and legal issues. Some of them may require an immediate reaction during the meeting, as even a small oversight may have consequences difficult to correct later. Multiple committees and ad-hoc groups at the conference, often working in parallel, create serious problems for small delegations unable to participate in more than one group at a time. The following excerpt from the Bogota Declaration describes problems seen by some delegates [43]:

> The Treaty...cannot be considered as a final answer to the problem of the exploration and use of outer space, even less when the international community is questioning all the terms of international law which were elaborated

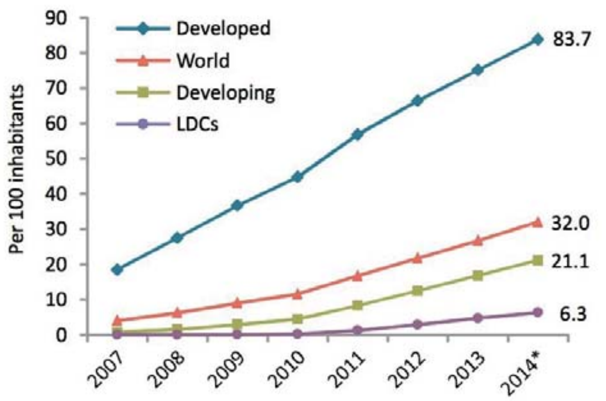

Figure 6. The active mobile broadband subscriptions by level of development, 2007 to 2014 (* denotes estimate; [47]).

when the developing countries could not count on adequate scientific advice and were thus not able to observe and evaluate the omissions, contradictions and consequences of the proposals which were prepared with great ability by the industrialized powers for their own benefit.

The declaration, published by a group of a few equatorial states that felt they were being misled, voiced the opinion of a larger group of countries that were only partially familiar with the newest achievements of science and technology, and felt to be outside of the closed "club of rich." The consensus idea is great under the assumption of a common interest, common understanding, and good will of all the negotiators. Study Groups, mentioned earlier, aim at reaching that, but unfortunately, not all Members can participate in their studies, for various reasons. With this in mind, conference preparatory meetings were long ago proposed [44, 45], where the future delegates could be familiarized well in advance with problems to be negotiated. That makes the preparations for Radio Conferences almost a continuing occupation, which not all companies or even countries can easily bear. Proposals to facilitate this by wider automation of the ITU [46], which would close it to medium access control (MAC) known from computer technology, are not very popular; automates are still too simplistic now. They cannot completely substitute for humans at the negotiations; moreover, they could make some informal deals and secret agreements difficult, if not impossible.

Wireless technologies eliminate the need for expensive cable networks, and their wide use would reduce the disparity among countries and improve connection with social groups in poor, underdeveloped, or remote regions. Unfortunately, the scarcity of free spectrum is a serious obstacle. The world is now in the midst of a major debate about the public-policy goals. The issue has been discussed at the United Nations, the World Summit on Information Society, the UNESCO-ITU Broadband Commission for Digital Development, and at other forums. They have all set up universal broadband connectivity as an essential element of sustainable development. A series of steps have already been made in order to make these more popular. However, in spite of the progress made, the *digital divide* has not disappeared. Figure 6 shows that it increased from about some 20 percentage points in 2007 up to 70 percentage points in 2014, and that the trend continues.

Generally, the growth of telecommunication services can be described by logistic functions, which indicate that in some cases the divide cannot be reduced, or could be chaotic [48, 49]. The diverging lines of Figure 6 send a strong message: the goal to eliminate the digital divide is physically unrealizable, or our approach to it is inefficient, and needs a substantial review.

4.1.2 Civil Society

Ideally, a government operates diligently, and represents the interests of all citizens in a just way. Unfortunately, this is not always the case: not every government is seen by all the citizens as trustworthy. To force honesty, civil-society activists demand more transparency. They demand the right to see the documents and negotiations to be sure that there is no difference between what the government publicly declares and what it does behind closed doors, hoping this will limit corruption. In some countries, this has appeared to be impossible, and they do not consent to allowing civil society observers at ITU negotiations. However, recently, under public pressure, the ITU has decided to provide free online access to ITU-R recommendations, and some other documents, to the general public. Providing such access to all input and output documents of all ITU conferences (postulated since long ago, among others by the first author when he served at the ITU headquarters) was questioned. The argument is that it would cause potential harm to private or public interests, which could outweigh the benefits of accessibility.

Civil society activists also want to bring to the process a variety of views and expertise that relate to ITU activities, such as expansion, development, and adoption of information and communication technologies, sustainable development, access to knowledge, consumer rights, social justice, and human rights. More and more often, one hears from critics that profit-oriented needs dominate those non-profit needs such as health care, education, science, etc., not mentioning the communication costs for ordinary citizens.

4.1.3 Science Interests

Observational radio astronomy explores extremely weak electromagnetic radiations coming from the universe. Space research, remote Earth exploration, and some other sciences do similar exploration. Manmade radiations, no matter whether intentional or spurious, can falsify these observations, or make them useless. Unfortunately, the intensity of manmade radiations increases from year to year. The 1992 UNESCO conference [50] appealed to all intergovernmental organizations to amplify efforts toward protecting the future of such research. One of the ways to do so is to improve the transparency of governmental decisions at all levels, including voting at radio conferences. We mentioned earlier the votes of two delegations at the first Berlin conference, which delayed the solution of communications at high seas until the Titanic disaster. This was the only case the authors found noted in conference documents since the time of Marconi. If there were other such cases, they were outside of the conferences. Unfortunately, bribery has been in the limelight from time to time, and according to Brian Robinson, Chair of the Scientific Committee on Frequency Allocations for Radio Astronomy and Space Science, known by its short designation as IUCAF, the following note was included in his report [51]:

> IUCAF members had to evolve from being starry-eyed astronomers as they encountered a world of politics, lobbying, entertainment, threats, espionage, and bribery. On one occasion, an offer (in Geneva) of two million dollars in cash "to shut up" proved no match for dedication to the joys and excitement of twentieth century astrophysics.

The note mirrors relations existing within some countries, rather than characterizing the ITU radio conferences.

4.2 Spectrum Planning

Plans introduce predictability valued by many: the participants in the TV planning conference in Geneva 2004/2006 considered their plan a great success. Planning is also the only way to reserve a portion of the resource when it cannot be shared after a faster competitor takes it. A position in the geostationary satellite orbit is a good example here, as the total number of such positions is physically limited. However, spectrum planning has been criticized, and this section explains why.

A frequency plan is understood as a table, or generally, a function that assigns appropriate static characteristics to each of the radio stations at hand. Examples are the operating frequency; power radiated; antenna location, height, and radiation pattern; polarization; service area; etc. In frequency plans, specific frequency bands are reserved a priori for particular applications, well in advance of their real use. Individual regions may have various allotment plans for specific services (e.g., broadcasting), within their respective areas.

The plans make a one-time distribution of the spectrum resource on the basis of the expected or declared needs of all interested parties. Critics of the planning approach indicate that it is inflexible and freezes technological progress. Indeed, the progress is very fast, and implementation of the plan may last several years. Technology known at the time of creation of the plan may be obsolete at the time of its implementation. Another difficulty is the impossibility of predicting future requirements with a needed degree of accuracy, and plans based on unrealistic data have no value. Next, radio spectrum is available at no cost at international planning conferences, and there is no mechanism to limit the requirements, except for a general appeal for minimizing its use. There are no accepted or objective criteria for evaluating each country's stated needs, and there are no quotas on the amount of spectrum assigned to each country. In fact, the individual country itself may have no idea of its needs over the time period for which the plan is to be constructed. It is thus not surprising that each country has an incentive to overstate its requirements, rather than underestimate. Under these circumstances, it is easy to make a case that the plans are not only difficult to construct, but when constructed, will lead to a waste of spectrum and orbit, as noted by Glen O. Robinson of the Virginia School of Law, a former FCC Commissioner [18].

4.2.1 Emergency Communications

The 1912 London Conference resolved the problem of emergency communication at high seas, but left open other problems for more than eighty years. In 1995, Hans Zimmermann of the UN Office for the Coordination of Humanitarian Affairs (OCHA) described the issue as follows [52]:

> If anywhere on the ocean a vessel with a crew of one is in distress, all related communications have absolute priority and are free of charge....The necessity for absolute priority of distress signals has been recognized worldwide since the 14 of April 1912, when the "Titanic" hit an iceberg. However when, after earthquake, some 10000 persons are trapped under the debris of buildings and houses, any customs official can prevent the arriving rescue teams from outside the affected country from entering this country with walkie-talkies. And another official might easily prevent the teams from using their communications equipment, unless they first obtain a license from a national telecommunication authority whose building may just have collapsed in the earthquake. Also, if a team is, by chance, nevertheless able to use its satellite terminal, they are three months later presented with telephone bills for tens of thousands of dollars. Such is the sad experience of those who provide international humanitarian assistance in the age of information super highways.

The problem was known for long and its solution was known too. What was missing has been the willingness to make practical steps, or there were insurmountable differences in the hierarchies of values, or in conflicting interests of large corporations. Many tragic disasters had to happen until, under the pressure of the general public, the governments agreed to remove interstate obstacles to quick deployment of communication means during emergencies. The 1986 Chernobyl Nuclear Power Plant disaster was an example. A long time passed until the Convention on the Provision of Telecommunication Resources for Disaster Mitigation and Relief Operations was signed in Tampere, in 1998 [53]. Although the convention has removed major legal obstacles, physical and organizational barriers have remained. Emergency communications are still far away from what are needed and what are technically possible, as indicated in the 2000 OCHA evaluation report [54]. To discharge the OCHA duties, the report proposed a global emergency communication infrastructure accessible to all, from any place at any time. The proposed infrastructure would be based on a constellation of low-orbiting satellites, continuously accessible, like the GPS. In spite of the fifteen years that have passed since its publication, no public discussion about its possible implementation even started.

4.3 Monopoly

Monopoly means a lack of economic competition to produce the good or service, a lack of viable substitute goods, and a high profit. In most countries, monopoly is against the law, except for the state monopoly. However, in many countries, a *legal monopoly* is approved by the state if it is justified by the need to provide an incentive to invest in a risky venture, or for other reasons, e.g., to enrich an interest group. Intellectual property rights (IPR), such as copyrights, trademarks, patents, industrial design rights, and trade secrets, are examples of such government-granted monopolies. This section sums up some comments on the topic.

4.3.1 AT&T Example

While the breaking of Marconi's monopoly took a decade or so, AT&T's monopoly (and that of its subsidiaries, the Bell System) operated in the USA for more than a century: from 1875 until 1984. There were six thousand independent (wired) telephone companies in the US serving three million subscribers. However, subscribers to different companies could not call each other because the competing companies refused connections. The AT&T monopoly solved the problem. AT&T was granted the status of a "regulated natural monopoly," obliged to provide *universal, end-to-end integrated, efficient, and inexpensive telecommunication services*. The doctrine of natural monopoly says that regulation is the most appropriate substitute for the competitive marketplace *provided it is independent, intelligent, considerate, thorough, and just*. Due to economies of scale, grouping of like activities in a single company in many cases could assure better and more efficient service to the public than a number of separate mutually competing companies could offer.

AT&T used its unique position and wealth to create the Bell Laboratories in 1925, which became one of the best and largest telecommunication research laboratories in the world. They developed radio astronomy, the transistor, the laser, the charge-coupled device (CCD), the *UNIX* operating system, the *C*, *S*, and *C++* programming languages, information theory, and many other things. Seven Nobel Prizes were awarded for work completed at Bell Laboratories. Being a regulated monopoly, Bell Labs were largely insulated from market pressures. That allowed them to develop a culture that venerated quality and excellence within a noncompetitive framework of innovation and practicability. In 1984, AT&T ended operation as a monopolist, and most of the former Bell Labs have been scaled down, or shut down entirely. The divestiture was not welcomed by everybody, as one can read in the history of AT&T [55]:

> ...the global telecommunications industry entered an era of unprecedented chaos and instability – marked by oversupply, fraud, a complicated regulatory environment and nonstop pricing pressures. Combined, these forces led to an industry meltdown in which numerous bankruptcies, defaults and business failures occurred; investors lost billions and countless workers in the communications sector lost their jobs.

Other critics pointed out fragmentation and repetition of efforts, and a lot of energy and resources lost in mutual fights. Another comment underlined that after the divestiture, no company could create and maintain a research laboratory of comparable scale and quality. The reason was high costs and risk of research confronted with smaller income (due to a divided market) and an uncertain future (due to competition). Some one hundred years after breaking Marconi's monopoly, the OECD stated [56]:

> Limited spectrum and increasing demand for data services mean that mobile networks will strive to offload traffic to fixed networks....The challenge for regulator is that, regardless of the technology used, many parts of the OECD look likely to face monopolies or duopolies for fixed networks. Wireless can provide competition, but spectrum availability will always limit that are not a constraint for fibre.

4.3.2 Intellectual Property Rights

Intellectual property rights (IPR) have two sides. One side is the interest of the owner of the rights. On the other side are the interests of the rest. This helps in protecting a monopoly from competition, with society often paying for it. Consider smartphones, for example. The last few years noted over 140 patent disputes on these alone, with the litigation costs running up to US$3 million per suit. Just two companies, Apple and Samsung, have disputed over US$2 billion in patent-related damage compensations [57-59]. Armstrong and his colleagues estimated patent royalties on a hypothetical US$400 smartphone to be in excess of US$120, which almost equals the cost of the device's components. The costs of the disputes may reduce the profitability and incentives to invest and compete. Most patent disputes are sterile, and not in the best interest of society. They absorb time and money that could instead be better used improving the products or lowering their price. Intellectual property rights play an important societal role that largely exceeds the commercial interests of a single company. With the present practices, "only lawyers win in patent wars," as Popelka briefly put it [60].

4.3.3 Spectrum Privatization

Guaranteed exclusivity in the use of a band of spectrum is a form of monopoly. It can be granted through privatization or licensing. The former offers the owner maximum freedom in the use of spectrum. From the access viewpoint, the licensed exclusivity does not differ much from spectrum ownership. The influence of large corporations has been growing, and so has been the pressure to privatize the spectrum and free it from any regulations as much as possible. The ultimate goal is to replace the spectrum commons by private spectrum [61], and licensing by free competition, also known as the *survival-of-the-fittest doctrine*. This doctrine says that the strong should see their wealth and power increase, while the weak should see their wealth and power decrease, disappearing at the end. It implies taking out some form of collective ownership and handing over resources to private owners, if possible. David Bollier, a popular promoter of public interests, compared the private appropriation of collectively owned resources to the movement to enclose common lands in England. The process started there in the XVIth century, and now most of the previously common land belongs to individuals that in total account for less than 0.1% of the population [62-64]. Its more recent variant is known as *free-market environmentalism*.

More and more countries grant exclusive licenses to the highest bidders, and open the secondary spectrum markets. Seeking the maximum possible return on the investment dollar is a strong motivating force, but it threatens other important values. Not everybody accepts that a rush for profit should be the only, or the most important, driving force in life. Many prophets and philosophers have long since indicated the negative effects of this. Recently, even major economists noticed this problem [65]. If not restricted by rules of tradition, religion, law, ethics, rational moderation, or by other factors, excessive greed may easily destroy the social order, and lead to crime and wars.

4.3.4 Spectrum Ownership Doctrine

Except for radio waves of natural origin, radio frequencies are inherent characteristics of radio devices: the latter cannot exist or operate without the former. The ownership of a device logically extends over the RF waves radiated or received by it. The spectrum-ownership concept interrupts that connection. Named *flexible spectrum use* by Robert Matheson [66], the concept also ignores electromagnetic interactions and the inherent dynamics of the radio-signal environment. The doctrine is based on two simple rules. One assures the owner's rights: "Transmit within signal power restrictions inside your licensed electro-space region," while the other protects the neighbor's rights: "Keep your signals below 'X' outside that region." This exploits an apparent analogy between land ownership and spectrum ownership over the specific service region. When you own a walled garden, you can arrange the garden at will as long as you remain within the walls. However, with spectrum it is not as simple as it might look at first glance, because it is impossible to determine the "walls" of spectrum property with any precision.

One has to realize that the unguided wave-propagation laws do not allow for any abrupt change of signal power. Simple *borderlines* between the inside and outside at the edge of the service region are physically unrealizable in free space: a finite-sized *buffer region* separates neighboring service regions. That buffer region must be sterile. None of the neighbors can extend his/her radio services there, unless special precautions are applied; careful coordination of geographic distance, signal-power density, frequency, time, or coding might be necessary. Second, the flexible-spectrum-use doctrine is static, and neglects the impact of a changing environment, which can change [67-68] without the owner's consent or even knowledge.

Without firmly freezing the future signal environment, e.g., through strict spectrum planning, such uncertainties reduce the secondary spectrum marked to nil. That fact calls into question the very concept of private spectrum and its flexible use for active services, not mentioning the more difficult case of the property of frequencies used for passive services. Laws of physics firmly say that in a dense signal environment, no freedom exists in the use of spectrum. While the idea of privately owned spectrum makes sense in the case of isolated radio systems, it is physically unrealizable where the spectrum is congested. With proper spectrum management, the probability of such interactions is analyzed before issuing the license, and is kept at an acceptable level.

4.4 Spectrum Market

The spectrum market is not a new idea. The thought of selling spectrum rights was put forward for the first time at the 1906 Berlin conference. The Russian delegation suggested a kind of transit fees for radio waves propagating over the country's territory. Some fifty years later, in 1959 Ronald Coase of the FCC suggested property rights and spectrum market as a more efficient method of allocating the spectrum to users. (He was the laureate of the 1991 Nobel Prize in Economic Sciences, for his work on transaction costs and property rights). Then Equatorial countries, in their *Bogota Declaration*, mentioned earlier, claimed that the satellites located above their territories should pay a kind of *parking fee*. In 1995, Richard Butler, then the ITU Secretary General, put forward that positions of orbiting satellites be traded, and the income be used to finance the activities of the ITU. He did that when some ITU Member States failed to pay their contributions: with no cash, he would have been forced to close operations and fire the staff. The Member States rather preferred to pay the contributions than to rent orbital positions or shut down the ITU. None of the privatization ideas have been accepted until now at the international forum. The majority of ITU Member States firmly supported the commons character of the radio spectrum and satellite orbits.

Spectrum auctioning has been practiced in a number of countries. For governments, it has become attractive because it solves the access rights to spectrum in cases where too many are interested, and also provides money inflow to the budget. However, the FCC Commissioners, like many other experts, long opposed the idea of a spectrum market, so it had to wait some thirty years for its first implementation. Interestingly, it did happen in New Zealand and not in the USA, as one could expect. New Zealand introduced spectrum auctions for tradable leases up to 20 years in 1989. However, many are against spectrum auctions. Earl Holliman, the US Army Spectrum Manager, wrote:

> We hear a lot about auctions. The auction approach does not stimulate technology towards more efficient frequency uses. It lets a successful bidder only get richer and pushes the smaller operator back.

For companies, auctions involve large uncertainties and high risks: the expected and needed profits for planned operations might never come true. For customers, they may mean an increase in the price of services. Huge amounts have been paid for frequency bands that were never used [69, 70]. Some auctions are seemingly used to block competitors rather than to put the spectrum into use. Auctions have been claimed to be corruption-immune, but several scandals have shown the opposite. The 2010 spectrum scam in India, quoted earlier, was an example.

Some economists do not believe in the efficiency of the free market. For instance, Joseph Stiglitz, the laureate of the 2001 Nobel Prize in Economic Sciences, says it is only under exceptional circumstances the markets can be efficient. He wrote [71]:

> For more than 20 years, economists were enthralled by so-called ‘rational expectations’ models which assumed that all participants have the same (if not perfect) information and act perfectly rationally, that markets are perfectly efficient, that unemployment never exists...and where there is never any credit rationing. That such models prevailed, especially in America’s graduate schools, despite evidence to the contrary, bears testimony to a triumph of ideology over science. Unfortunately, students of these graduate programmes now act as policymakers in many countries, and are trying to implement programmes based on the ideas that have come to be called market fundamentalism.

Numerous other authors are of similar opinions, such as, e.g., Eli M. Noam, Samuel A. Simon, Joseph H. Weber, and Yohai Benkler. Most surprisingly, George Soros, a famous billionaire, joined other critics, writing [72]:

> Although I have made a fortune in the financial markets, I now fear that the untrammeled intensification of laissez-faire capitalism and the spread of market values into all areas of life is endangering our open and democratic society .

The UN has called a special summit to consider, among other problems, the “Fundamental Defects of the Free Market System” [73]. The 2011 Washington Declaration on intellectual property and the public interest clearly stated [74]:

> Markets alone cannot be relied upon to achieve a just allocation of information goods – that is, one that promotes the full range of human values at stake in intellectual property systems. This is clear, for example, from recent experiences in the areas of public health and education, where intellectual property has complicated progress toward meeting these basic public needs.

This would indicate that practices protecting intellectual property rights should be seen from a wider socio-economic viewpoint, taking into account society as a whole: not only those who benefit now, but also those who pay or loose in a longer perspective.

Many worry that privatization, if widely introduced, would be incapable of assuring balanced sustainable socio-economic development; that government and corporate surveillance would increase without limits; that the free flow of content we are now proud of would stop; and that intellectual property rights would extend into the interminable past. The uncertainty results from our dilemmas on the hierarchy of values. Erich Fromm, a German philosopher, put it briefly: “to have, or to be?” – a basic question to which everybody has their own answer. Spectrum trading also offers opportunities to the benefit of both operators and the society served, when spectrum can be more effectively utilized in an area or a market.

4.4.1 Competition

In the opinion of many experts, the progress in mobile and broadband communications, and generally in the radio applications we enjoy today, would not have developed at the pace we have seen if there were no competition. It may not be so easy to prove generally, but for many, the cost of communication services has not increased in the latest decades. Rather, the opposite has occurred relative to daily spending for living, and such services have become much more affordable [75]. Furthermore, information and communication technology services have become much more important, highly beneficial, and even absolute necessary for a well-functioning society.

However, other cases show that competition may not serve society well, as illustrated by the following example. When serving in the ITU headquarters, the first author organized the CCIR library of spectrum-management software freely offered by ITU Members. The software could be copied and used at no cost by all those interested. This was functioning well, but a problem appeared when the program for practical planning of low-power (local) TV stations was offered [76]. It was then one of few programs using digital terrain models and inexpensive personal computers. It generated great interest among small and medium enterprises, in both developed and developing countries. Its user interface was in Polish, and it was proposed to translate it into English and other ITU official languages, which would make it more useful in many countries. However, a few delegates representing private business were against this, arguing that "it would kill our business." As no required consensus was reached, the proposal was not approved. In addition, as a consequence, there is no such free software provided by ITU today.

With the consensus rule, a single company can easily block other enterprises, but opposite cases also happened. For instance, one can learn from the FCC home page that Edwin Armstrong, an American inventor, proposed his frequency-modulation system in 1935. However, companies in the United States, afraid that it would reduce their profits, blocked it for some twenty-five years, until the 1960s. Similarly, for more than a decade, civilian applications of spread-spectrum technology were blocked. More recently, the promising low-Earth orbit (LEO) [77] and high-altitude platform (HAP) [78] technologies were blocked. The majority blamed the general crisis for that, but some suspected the competing companies of significantly contributing to that. More recently, the FCC stated that it had to protect consumers from mobile-broadband providers' commercial practices masquerading as "reasonable network management." Working hand in hand with citizens, the FCC is setting "strong rules that protect consumers from past and future tactics that threaten the Open Internet" and promote "more broadband, better broadband, and open broadband networks." The providers hold all the tools necessary to deceive consumers, degrade content, or disfavor the content that they don't like. Some companies make practical use of these tools, keeping third-party applications within a carrier-controlled "walled garden," as in the early days of electrical communications. That practice ended when the Internet protocol (IP) created the opportunity to leap the wall, but the FCC has continued to hear concerns about other broadband-provider practices involving blocking or degrading third-party applications.

4.5 Spectrum Sharing

Privatization pressure provoked countermovement and the revival of interest in spectrum commons and cooperatives. One of the most respected researchers in that area was Elinor Ostrom, a US economist and the only woman who won the Nobel Prize in Economic Sciences (in 2009), for "her analysis of economic governance, especially the commons." Her studies have indicated that the commons are sustainable if they are well managed, best done by their owners, themselves. Interestingly, that principle has intuitively been practiced on the global scale by ITU Members since 1906, well before Ostrom's studies. More recently, the principle was extended over the users of Wi-Fi and similar technologies, which became the most popular use of spectrum commons. For instance, in 2013, more Internet traffic was carried over Wi-Fi than via any other path, resulting in some US$222 billion in value added to the US economy alone [79]. That evidences the practicality of spectrum sharing and the numerous benefits in comparison with the exclusive (private or licensed) spectrum, including lower access cost. Note that there has always been a part of the wealth kept in common, examples being public roads and parks. Since the very beginning, spectrum access has been free for each and any government: what many civil society activists expect is an extension of that practice over individual spectrum users, without any governmental brokerage.

The US President's Council of Advisors on Science and Technology (PCAST) suggested a three-tier "dynamic sharing" Spectrum Access System (SAS), making spectrum sharing the norm. Under the Spectrum Access System, Federal primary systems would receive the highest priority and protection from harmful interference. Secondary licensees would register deployments and receive some quality-of-service protections, possibly in exchange for fees. General Authorized-Access users would be allowed opportunistic access to unoccupied spectrum (when no Primary or Secondary Access users were using a given frequency band in a specific geographical area or time period) [80]. The National Telecommunication and Information Agency has already identified a total of 960 MHz of federal spectrum as candidates for sharing using that approach. The European Commission is considering similar sharing possibilities, based on contracts between the users. This is seen as a natural extension of the previous spectrum policies: licensed access allowing operators to offer a predicted quality of service, and license-exempt access fostering widespread contributions to innovation and fast-paced investment in emerging technologies [81]. However, incumbent commercial or government users may be reluctant to give up their exclusive rights to individual spectrum bands, concerned about already made or planned long-term investments in communication networks, including access to spectrum. And yet, technology is being developed and deployed to allow for such sharing by new entrants without risking interference to the incumbents' systems. A number of countries have pursued regulations or trials that enable license-exempt, Wi-Fi-like devices to access vacant spectrum in the television broadcast bands ("white spaces"). These are expected to improve Internet access, facilitate the delivery of government services, establish communication channels in the wake of earthquakes, typhoons, etc.

4.6 Other Issues

Since the very beginning, scientists have worked on issues that have extended our knowledge about the universe, and made our lives easier, safer, and richer. There is a wealth of literature on the benefits radio waves have brought to humanity. However, that progress has also brought negative effects. The perception of electromagnetic waves has been changing. From an abstract concept, it morphed to a tradable commodity, and from a scientific curiosity, to an apparatus of indoctrination, a weapon in physical conflicts, and a tool for criminals. In addition to the unknown long-term biological side effects of man-generated electromagnetic waves, there are also other sources of worry. Like health, they only indirectly relate to spectrum use. Discussing them in detail clearly exceeds the scope of this article, so we only mention some here, which we believe are needed to better understand the role and complexity of spectrum management.

4.6.1 Orbital Debris

Since 1957, after the launch of the first Earth-orbiting artificial satellite, the near-Earth environment has served as a gigantic rubbish collector. Orbital debris (also called space debris) is a collection of man-made objects launched into space and left there with no purpose after their mission ended. They are dead satellites and their fragments, upper stages of rockets and their fragments, and other abandoned objects. The total number of these objects is counted in the millions of pieces. It increases with every new launch of a space object and with each new satellite explosion, and with accidental fragmentation or due to anti-satellite tests in outer space. These objects are all orbiting with hyper velocities of a few to dozens of kilometers per second, and can damage operating satellites and space vehicles. For comparison, the velocity of a bullet fired from the famous AK 101 Kalashnikov rifle is less that one kilometer per second. The threat of impact damage is a growing concern. Medium-size objects (0.1 cm to 10 cm in diameter) are the greatest challenge, because they are not easily tracked, and have a kinetic energy high enough to cause catastrophic damage. For instance, a particle with a mass of 10 g moving 10 km/s has a kinetic energy comparable to a one-ton car running on a highway at a speed of 100 km/h. Penetration of even a small particle through a critical component, such as a flight computer or propellant tank, can result in loss of a spacecraft. If a 10 cm object of 1 kg mass collided with a typical spacecraft bus, over one million fragments of 1 mm in size and larger could be created, according to NASA. Such a collision would result in the formation of a debris cloud, which poses a magnified impact risk to any other spacecraft in the orbital vicinity. Mutual collisions can further multiply the numbers. Encounters with clouds of smaller particles can also be devastating for future missions. For instance, the solar panels of the Hubble Space Telescope (launched in 1990 and remaining in operation) have been replaced several times because of damage caused by tiny objects. Such objects may also efficiently block scientific observations of some regions in the sky.

A few countries do radar, optical, and infrared surveillance of space for security reasons. The smallest traceable objects are about 10 cm in diameter at low altitudes, and about 1 m in diameter at geostationary orbit. Some space debris could escape towards other celestial bodies, burn in the atmosphere, or fall on the Earth. However, to do so their velocity must change. What slows them and forces them to fall down is air drag, but this decreases with altitude. At high altitudes, it is negligible, which implies a long time for orbiting in space. Table 1 lists the expected orbital lifetimes for selected circular orbits.

At geostationary (GSO) altitude, no effective natural removal mechanism exists, except for solar-radiation pressure. From a practical standpoint, objects located in geostationary orbit would indefinitely remain in that vicinity, if not moved at the end of a mission. Orbital debris is a good illustration of the CC-PP (communize costs – privatize profits) behavior of satellite companies first described by Hardin, mentioned earlier. Some of the objects launched are send back to the Earth, especially after the invention of re-useable space vehicles, but the creation rate of debris has outpaced the removal rate. Maintaining the current design and operational practices could ultimately render some regions in space useless, and even dangerous.

4.6.2 Issues to Watch

The future of radio applications may not be as wonderful as it could be, and as most people would like it to be. Technological progress is often driven by military programs that aim at improving ways enemies are destroyed, or allies are protected. However, many byproducts of these programs find later civilian applications, making our life easier, healthier, and pleasanter. Unfortunately, a military

Table 1. The lifetimes of circular orbits [82].

Orbital Altitude (km)	Lifetime
200	1-4 days
600	25-30 years
1000	2000 years
2000	20 000 years
36 000 (GSO)	Indefinite

invention might also become accessible to criminals, or a government might use it against their own citizens: the latter practice ends often in a government overthrow or revolution.

4.6.2.1 Propaganda

Radio as a wartime propaganda tool become popular during World War II (it later was supplemented by television). Wireless can bring all the persuasive power to millions of people at relatively low cost, ignoring national borders and front lines. However, its power was demonstrated earlier, in 1938, in the USA, after the airing of *The War of the Worlds*, an innocent episode of a radio drama series. Orson Wells presented it so realistically that the radio transmission was taken as real news, and caused mass panic, difficult to manage. Since then, radio and television have become major advertising means. However, they also serve as efficient *propaganda* and *brainwashing* tools in political/ideological campaigns. More recently, mobile phones, SMS (short messaging service) and online social-networking services such as *Twitter* and *Facebook* have similarly affected the social lives and activities of people, starting from the election campaigns in the USA to social protests such as Occupy Wall Street or the Arab Spring of 2010. The unprecedented ease and scale of wirelessly manipulating public opinion worries many. The Arab Spring protests transformed into revolutions that overthrew a few governments. It explains why so many other governments want to control the access to radio waves and to the information they carry.

4.6.2.2 Espionage, Cyber Attacks, and Jamming

The fear of war, criminal acts, or losing power pushes governments not only to license access to spectrum, but to also develop intelligence, eavesdropping, and surveillance, which is relatively easy in the case of wireless communications. However, these may also be used against the citizens' right to privacy. Some years ago, the European Parliament initiated an investigation into the ECHELON system [83], created to monitor the military and diplomatic communications of the Soviet Union and its allies during the Cold War. With time, it had evolved, allegedly becoming a global system for the interception of any communications over the globe, including private and commercial communications. Another worrying issue is massive surveying of people. According to the press, there is one surveillance camera for every eleven people in Great Britain. An even more worrying issue is the use of radio waves for criminal attacks and secret wars in cyberspace [84]. Real data from that area are rarely published, but the scale of the issue can be judged from the expenses incurred. According to the press, the defense cyberspace budget for 2015 includes US$5 billion in the USA alone; other countries may spend proportionally.

Jamming was widely used during World War II and the Cold War. Later, unintended interference was often noted. For instance, deliberate jamming of telecommunications satellites was observed and increased between 2009 and 2012. In several circumstances, France raised this issue to the Radio Regulations Board. Several European countries also submitted a proposal to WRC-12 on this issue, which led to an evolution of the Radio Regulations that gave more weight to the issue of deliberate interference.

4.6.3 Power from Space

New, cheap, and environmentally friendly energy sources are now sought in several countries. The world's population is expected to reach 10 billion people by the year 2050, and the present energy sources will be insufficient to satisfy their needs, according to current projections. Among various ideas, the space solar power (SSP) concept has been studied. In 2007, URSI published a comprehensive report on the topic [85]. Among additional possible solar-power satellite (SPS) applications, the report listed sending energy from spacecraft to spacecraft, bringing energy to remote areas on the globe that are difficult to otherwise access, or providing energy to the dark side of the moon. The report stressed that URSI did not unanimously advocate solar-power satellites. Within URSI, there are both advocates of solar-power satellites, and voices of concern and severe reservation.

The solar-power satellite studies started in the USA, during the oil crisis of the seventies, aimed at limiting the dependence of the national economy on foreign oil. In 1974, a patent was granted for a solar power satellite to collect power from the sun in space, and then transmit it down using a microwave beam to the Earth for use. One of the more recent solar-power satellite systems considered huge ($\sim 10\ \text{km}^2$) arrays of photovoltaic cells placed in an Earth orbit, or on the moon to convert the sunlight into electricity. Such arrays would be unaffected by cloud cover, atmospheric dust, or by the Earth's twelve-hour day-night cycle. To reduce the necessary area of costly solar arrays, sunlight could be additionally concentrated using giant mirrors. The incident solar radiation would be converted into electricity using the photovoltaic process. Another part that would manifest itself as heat could also be converted into electricity using thermoelectric devices. These would serve as thermal pumps, removing heat from the photovoltaic panels and lowering their temperature.

The electricity would then be converted to microwaves, and beamed by a composite space antenna ($\sim 6\ \text{km}^2$) towards a huge Earth antenna ($\sim 12\ \text{km}^2$). The space antenna would assure a pointing accuracy of about 0.0005°, which would mean about a $\sim 300\ \text{m}$ pointing error on the Earth's surface. The terrestrial antenna would contain a large number of receiving antennas combined with rectifiers and filters (called a rectenna), which would convert the microwave power into electrical current, injected into the power network. To limit the health danger, the receiving antenna would be located in the desert, or in mountains far away from densely populated areas. The size of the microwave beam could be large enough to keep the power density within safe limits.

A space solar-power system using today's technology could generate energy at a higher cost than the current market price. One estimate was that it would take 15 to 25 years of further research to overcome that difference. In 2001, Japan announced that they plan to launch a giant solar-power station by 2040. Preparatory studies are also being undertaken in the European Union and in the United States. There are many questions to be solved. For instance, the URSI report quoted earlier lists the following:

> What is the impact of SPS electromagnetic emissions – both intended and unwanted (harmonics of the microwave frequency, unexpected and harmful radiation resulting from malfunctions) at microwave frequencies and other related frequencies – on telecommunications, remote sensing, navigation satellite systems, and radio-astronomical observations? What actions can be taken to suppress this unwanted emission? Constraints imposed by the Radio Regulations of the International Telecommunication Union must be taken into account.

However, more important questions remain to be solved before solar-power satellites could operate, e.g., health and environmental problems not yet solved. Others have indicated that it is potentially a double application technology: a solar-power satellite station could easily be converted into a dangerous weapon. Space weapons using solar energy are not a new idea. In World War II, some German scientists were speculating on the use of gigantic mirrors that could concentrate solar energy to set fire to an enemy's cities, manufacturing, crop fields, etc., during wartime. High-power microwave beams could cause similar damage. Between the wars, the solar-power satellite mirrors could be used to control local weather conditions over a selected region. The size, complexity, environmental hazards, and cost of a space solar power undertaking are daunting challenges.

5. Concluding Remarks

This paper has reviewed basic issues of radio-frequency spectrum use. It has shown how deeply our current concepts are rooted in the past, and how often they are dictated by the short-term benefits of the few. It has summarized arguments and lessons learned since the invention of radio, which could be usable in current debates on how to reduce the chronic apparent shortage of RF spectrum. It has highlighted major doctrines focusing on a better understanding of how the spectrum-management mechanisms are associated with the public interest and distribution of information, knowledge, wealth, and power. It pointed up similarities between spectrum conservation and environmental protection. The paper is intended to promote cooperation, transparency, and direct involvement of spectrum users into its management process. It focused on issues that could be improved through good will, negotiations, and consensus without in principle requiring extra resources.

The fundamental question of whether it is better to privatize the spectrum or to keep it as a regulated commons, to sell it, or to distribute it freely, will probably be open for decades. Many have hoped for a long time that science and engineering will solve the spectrum-scarcity problem. Science and engineering are universal – independent of nationality, ideological convictions, or political orientation – which makes joint efforts much easier than in any other field. However, history shows the opposite: spectrum scarcity increases with the progress made in science and engineering. Many have anticipated such an approach to spectrum management could be as useful as it has been found to be in the military. However, negotiations and lobbying will probably continue as the basis for spectrum management for a long time. Human motivations and ways of thinking have not changed much since the invention of radio, and most probably will not change in the foreseeable future, shaping spectrum use. The reason is that society is not uniform. It is composed of groups, each having different world views, interests, needs, and powers. What is best for one group is not necessarily good for the others. The dominant group usually tries to use all possible means and ways to keep the benefits it acquired as long as possible.

The ITU negotiation system has evolved during 150 years and each radio conference makes it better, but it is still not ideal: some of its weaknesses were indicated in the above sections. Notwithstanding this, the history of radio has evidenced that in spite of the threat of supporting some particular interests [22], it has been serving humanity well, not to mention that it has been the only acceptable mechanism. That is an optimistic view. An even more optimistic remark is that the ITU system is not static: it is a dynamic and self-healing system (even if it now recommends static spectrum allocations). The more people understand better spectrum-management mechanisms, the more chances the system will be improved at a future conference. Various forums exist within and outside of the ITU to discuss and understand better problems accompanying the uses of the radio spectrum, not only the positive uses but also the negative uses; not only seen from a narrow engineering or economic viewpoint, but also from a wider perspective. These forums try to call attention to the need for limiting the negative effects before they develop in full. Should the voice of radio scientists be heard there? ITU has not yet definitely solved the spectrum-scarcity problem, just as the whole of humanity has not solved problems of hunger, health, and many others. According to Hardin, quoted earlier, the scarcity problem cannot be ultimately solved only by technical means, without involving the system of human values and ideas. Mahatma Gandhi, the famous Indian leader, put it briefly as follows:

> There is enough on the Earth to meet everybody's need but not sufficient to meet anybody's greed.

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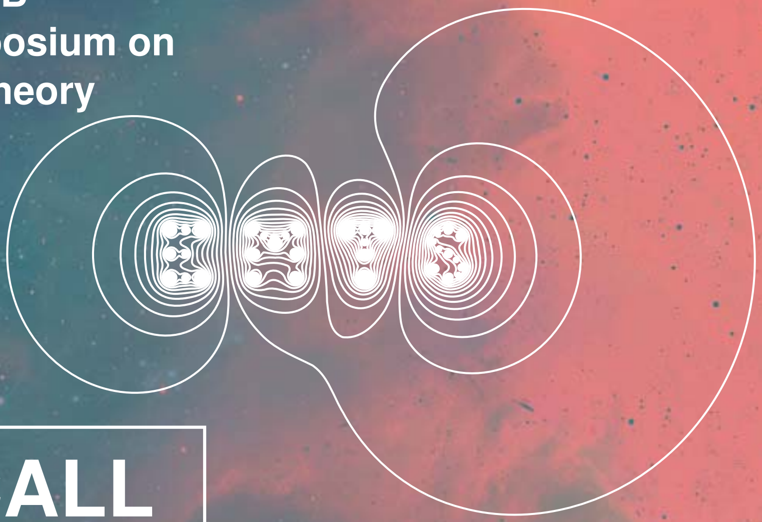
URSI Commission B International Symposium on Electromagnetic Theory (EMTS 2016)

Espoo, Finland
August 14–18, 2016



FIRST CALL

The International Symposium on Electromagnetic Theory (EMTS 2016) is held 14–18 August 2016 in Espoo, Finland. It is organized by the Commission B (Fields and Waves) of the International Union of Radio Science (URSI) and Aalto University. EMTS 2016 is the 22nd event in the triennial series of international EMT symposia which has a long history since 1953. Its scope covers all areas of electromagnetic theory and its applications, and it is the major scientific event of the Commission B, along with the URSI General Assembly and Scientific Symposium.

The venue is the main building of Aalto University in the Otaniemi Campus, 9 km west of Helsinki center and 27 km from the Helsinki airport. The area is well connected with public transportation.

The conference offers plenary talks by distinguished speakers, regular oral and poster sessions, and a one-day school for young scientists (August 14) focusing on a given topic in electromagnetics. A number of Young Scientist Awards will be offered covering the registration fee and accommodation during the conference. In addition, business meetings, receptions, and conference banquet will be organized.

EMTS 2016 focuses on electromagnetic fields and their applications. Contributions on any aspect of the scope of Commission B are invited. The submission (2–4 pages in IEEE two column format) will be reviewed by the Commission B Technical Advisory Board.

Paper submission and registration opens
15 Jan 2016

Submission deadline
15 Feb 2016

Notification of acceptance
before 30 Apr 2016

Early bird and author registration
ends 31 May 2016

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A! Aalto University

In Memoriam: Abdul Kalam

Many of us were shocked and stunned when we heard the news of the sudden demise of our beloved former President of India, Dr. A. P. J. Abdul Kalam. That was on the evening of July 27, 2015. Dr. Kalam was 84 years old. One of us (PK) was very closely associated with him for more than 50 years, from the very early stages of India's space program, conceived by Prof. Vikram Sarabhai, himself a space scientist of repute.

Figure 1. Dr. A. P. J. Abdul Kalam, then President of India, at the opening of the 2005 URSI General Assembly in New Delhi, India.

In 1962, the Indian National Committee for Space Research was formed. The government undertook the program of launching sounding rockets from a place near Thiruvananthapuram, in the extreme south of India, to study the effects of the equatorial electrojet formed in the ionosphere. This place was selected as it was close to the geomagnetic equator. Three persons from the Physical Research Laboratory (PRL) – one of whom was the first author – were selected to undergo training at the Goddard Space Flight Center, NASA, USA. Some more people later joined the team, all working in the area of electronics, starting from January 1963. A. P. J. Abdul Kalam joined this team, as well. Dr. Kalam was the only aeronautical engineer in the team, and had earlier worked with the Defense Research and Development Organization (DRDO) in Hyderabad, on hovercraft technology.

Prof. E. V. Chitnis from PRL came for a visit to NASA. He brought along a large-scale map of the Thumba area, from where rockets were supposed to be launched. These maps helped our team in developing the plans for the Thumba Equatorial Rocket-Launching Station. When these maps were studied and simple plans were drawn up, it became clear that the government's acquisition of such a large tract of land, of about 500 acres, could not be solely for the launching of the four rockets that NASA was planning to give to India. At that time, the team had no full awareness of the plans of the government of India, or the ideas of Dr. Homi Bhabha and Dr. Vikram Sarabhai, two of the most acclaimed scientists of modern India. They ushered the atomic-energy and space ages into the country, regarding the future of the space program in India.

However, the Indian team was fired up with ideas regarding the development of our own rockets. The team started dreaming about developing laboratory spaces where development work could be carried out. It was clear that not only rockets made outside of India were going to be launched, but also rockets made within India would be launched. Facilities for the development of Indian rockets had to be made. Based on that, the laying of roads and civil construction work was started in June 1963, at Thumba (on the outskirts of Thiruvanathapuram). Nearby, on the Veli hill, the Space Science and Technology Centre was established. This was renamed the Vikram Sarabhai Space Centre.

In those days, there were many questions asked by NASA colleagues about why the Department of Atomic Energy was involved in the space effort. The explanation given by the team that the Tata Institute of Fundamental Research and the Physical Research Laboratory, which were in the forefront of research in cosmic rays and the upper atmosphere, were part of the Department of Atomic Energy, convinced them that the work was a national effort.

Subsequently, when the team returned to India, Dr. Kalam went directly to TERLS. The first Nike Apache rocket, carrying the sodium-vapor payload developed by CNES, France, was successfully launched on November 21, 1963. It gave tremendous experience to everyone involved. The work on the development of solid propellants and the mechanical hardware was uppermost in everybody's mind. By early 1964, the first computer, MINSK II, was established, and Dr. Kalam was the first major user of that machine for his "Wind Weighting Programme," for targeting the launch azimuth and elevation angles of the Indian rocket launches.

As early as 1964, Dr. Kalam took great interest in lightweight high-strength composite materials for the rocket payloads. Not only were the mechanical properties of the fiberglass materials used in the payloads and support structures being discussed in the team, but the insulating and RF properties of the fiberglass were also being discussed. This resulted in the development of RF-transparent antenna windows for the rocket nosecones. In addition, it was known to the team that the same material could be used as a non-magnetic material for rocket payloads carrying a proton-precession magnetometer. Later, Dr. Kalam was able to establish the reinforced plastic fabrication facilities at Thiruvananthapuram. These facilities delivered the required

Figure 2. (l-r) Prof. Kristian Schlegel, then President of URSI; Dr. A. P. J. Abdul Kalam, then President of India; and Dr. A. P. Mitra, Honorary President of URSI, at the 2005 URSI General Assembly in New Delhi, India

materials and finished products for the Indian rockets and satellites. The motor casings for the fourth stage of the SLV 3 vehicle, the nozzle inserts and the carbon-fiber-reinforced plastic antenna for the APPLE satellite, were delivered during the time when Dr. Kalam was at ISRO as the Project Director. He also developed the GFRP antenna for ground use. He contributed greatly to the development of the PSLV configuration, which even now is the workhorse for the ISRO's launch-vehicle program. It should be remembered that this vehicle was used for launching the Chandrayaan I and the Mars Orbiter missions. Even later, when he was at DRDO, he had taken the initiative for developing a lightweight adjustable graphite-fiber calipers to be used by children affected with polio.

Dr. Kalam took a keen interest in the development of stage-separation systems, heat-shield separation systems, and the necessary explosives. The basic knowledge developed from that time is applicable even today. He was also responsible for developing partnerships with a large number of small- and medium-scale industries for the delivery of the required subsystems for the launch-vehicle program.

After working for two decades in ISRO, Dr. Kalam took the responsibility for developing the guided missile system at the DRDO, where he had started his career. This led to the development of the AGNI and PRITHVI missiles. All the required critical technologies were indigenously developed. During this time, Dr. Kalam also became involved with the Indian nuclear program, leading to the successful Pokhran nuclear tests, performed by the Department of Atomic Energy.

Dr. Kalam then served as the Principal Advisor to the government of India during 1999 to 2001. After 2001, he was involved in educational activities. In particular, he wrote a book, *Wings of Fire*, for students and lay people. This showed his simplicity, humanism, dynamism, and vision. He was hence greatly admired in India. In July 2002, Dr. Kalam was elected the President of India for a five-year period. During his tenure, he was a great favorite among young Indians all over the country, who became "Kalam fans," and raised him to an iconic status.

Dr. Kalam's presidency had an important consequence for URSI. The Indian URSI committee had been trying to get URSI to hold its General Assembly in India for a long time. Finally, at the URSI 2002 General Assembly in Maastricht, The Netherlands, India was voted to be the next venue for the 2005 URSI General Assembly. Dr. A. P. Mitra, who was then the past President of URSI, took up the challenge, along with scientists of repute such as Prof. Govind Swarup. One of the authors (SA) was the President of the Indian National Committee of URSI starting from 2004. It was decided in the Local Organizing Committee meeting to invite Dr. Abdul Kalam to inaugurate the conference (Figure 1). SA had the privilege of meeting him, and also of writing some parts of his inaugural speech! What was more thrilling was that Dr. Kalam insisted on giving an evening lecture on his vision for India's connectivity. This had to have been unprecedented in the history of URSI: that a sitting President of a country delivered a scientific/technical lecture at an URSI General Assembly! He kept the audience enthralled with his vision of India for 2020, and won the admiration of all the scientists and engineers who were participating in the 2005 URSI General Assembly (Figure 2). In our considered opinion, this was perhaps the best URSI General Assembly held in the past 30 years, due to the presidential inauguration and evening lecture.

Dr. Kalam came from a very modest background, his father being a boatman. By the strength of his conviction, character, and hard work, he rose to be a Bharat Ratna ("Jewel of India"). He was a very warm human being. There are countless heart-warming stories of his simplicity, generosity, and great vision for making his country of birth shine. He was fiercely loyal to India, and will be long remembered as the best President India has had since its independence.

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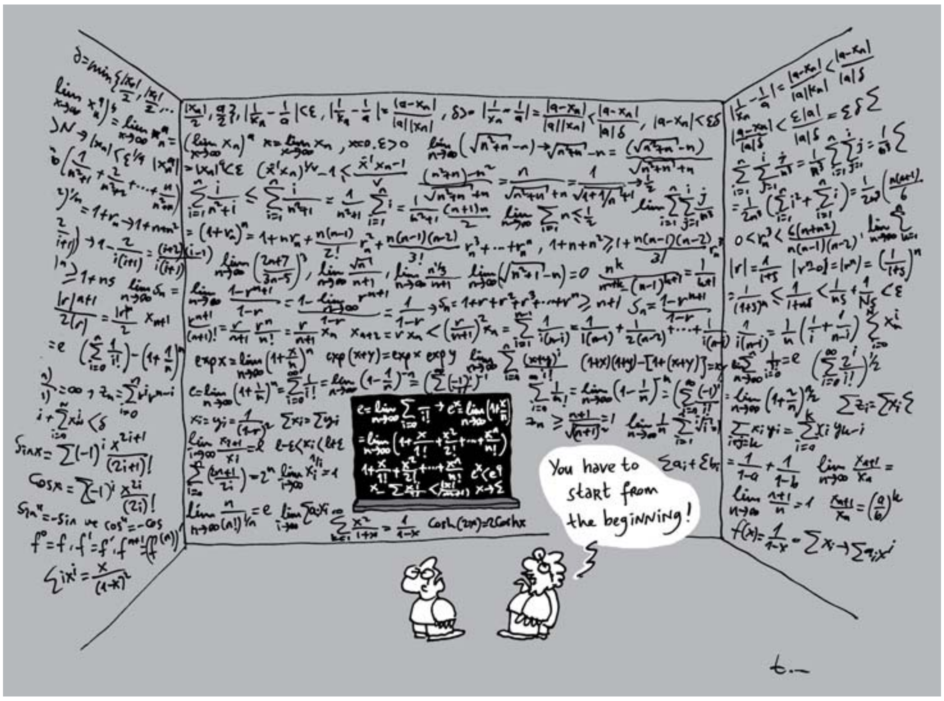

Solution Box

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SOLBOX-02

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SOLBOX-03

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1. Introduction

In this issue, we have two new problems, SOLBOX-02 and SOLBOX-03, as well as a solution of SOLBOX-03 by its submitters.

SOLBOX-02, which was submitted by Bruno Carpentieri, involves a satellite geometry that is modeled with perfectly conducting surfaces. The scattering problem is formulated with the electric-field integral equation (EFIE), leading to an ill-conditioned matrix equation that is difficult to iteratively solve, despite its small size. The aim and the challenge for this problem is to reduce the number of iterations. The associated matrix is available for downloading by interested readers.

SOLBOX-03, which is submitted by Manouchehr Takrimi and Vakur B. Ertürk, involves just a small sphere. However, the sphere is densely discretized, and the discretization is extremely nonuniform, so that conventional solvers become inefficient. The solution provided by the submitters was achieved by using a broadband multilevel fast multipole algorithm (MLFMA), incorporating incomplete tree structures. The model of the sphere can be downloaded by interested readers who would like to test their solvers.

With the submission of these new problems, we now have a total of three problems that can be solved with alternative implementations. We are looking forward to receiving submissions of new problems, as well as alternative solutions to these interesting three problems. Please remember that the aim of this column is to seek the most optimum solutions to electromagnetic problems, allowing us to share our knowledge and know-how. All electromagnetic code developers and users are invited to provide submissions.

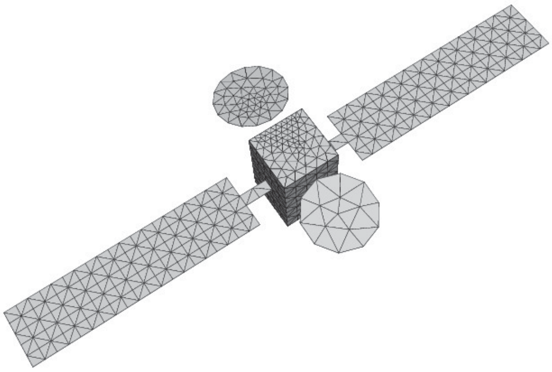

Figure 1a. The satellite problem for SOLBOX-02.

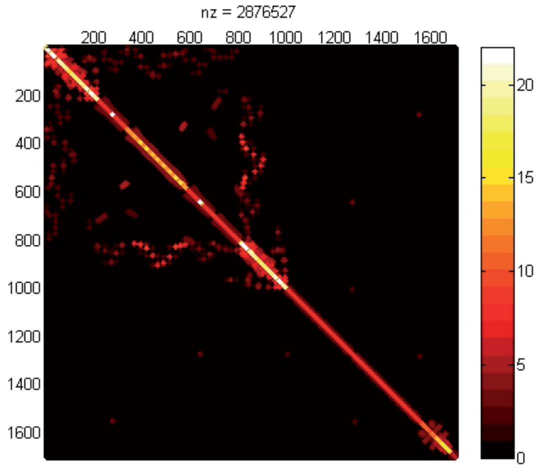

Figure 1b. An illustration of the related matrix for the problem in Figure 1a.

2. Problems

2.1 Problem SOLBOX-02 (by B. Carpentieri)

This problem concerns the design of fast iterative methods for solving dense linear systems arising from the boundary-element discretization of electromagnetic scattering problems expressed in an integral formulation. We concentrate our attention on the electric-field integral-equation formulation for perfectly conducting objects. The geometry is a satellite, depicted in Figure 1a, which is illuminated by an incident plane wave at 222 MHz. We consider the Galerkin discretization of the electric-field integral equation using the Rao-Wilton-Glisson basis functions for the surface-current expansion, which gives rise to a dense, complex, symmetric (but non-Hermitian) linear system. In Figure 1b, the pattern of the large entries of the matrix is plotted. Despite the small size (only 1699 unknowns), the problem is representative of the general trend for this class of problems. As a reference, in *MATLAB* (*version R2013a*), the un-restarted GMRES method required 389 iterations with no preconditioning, and 309 iterations with diagonal preconditioning, to solve the pertinent linear system. The computational cost increased further when GMRES was restarted: Using a restart value equal to 50, convergence was achieved after 40 outer and 36 inner GMRES iterations with no preconditioning, and 32 outer and 25 inner iterations with diagonal preconditioning. The particular aim is to find better preconditioners to accelerate Krylov-subspace methods for this problem class. The matrix data for the satellite problem are available for downloading in *MATLAB* at

https://www.dropbox.com/s/z9zlkz5letirsry/satellite.mat?dl=0.

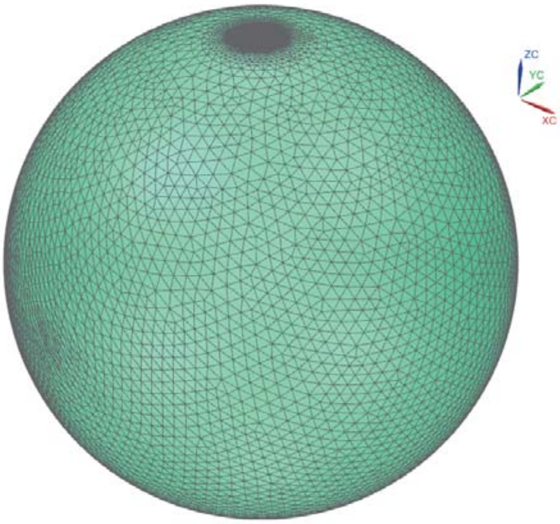

Figure 2. An isometric view of the sphere model possessing a dense discretization around the north pole with a multi-scale factor of 110 (SOLBOX-03).

2.2 Problem SOLBOX-03 (by M. Takrimi and V. B. Ertürk)

Figure 2 illustrates a perfectly electrically conducting sphere of radius 5 cm ($\lambda/20$) at 300 MHz with a highly nonuniform triangulation. The edge size for the triangles varied from 0.034 mm ($\lambda/30000$) at the north pole up to 3.8 mm ($\lambda/263$) at the south pole, resulting a nonuniform mesh that had a multi-scale factor of 110. The multi-scale factor is defined as the ratio of the largest edge length to the smallest edge length over the entire meshed surface. The total number of triangles was 120,992. A `.unv` model file of the sphere generated by the Siemens *NX* (*version 8.5*) program is available at

https://www.dropbox.com/s/m9bntgze75mqqtt/Sphere_R%3Dp05m_multiscale%3D110_Un%3D181K_unv.rar?dl=0

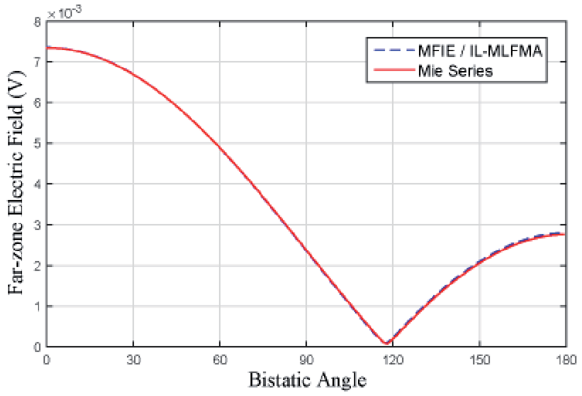

Figure 3. The solution of the problem SOLBOX-03 using a broadband implementation of MLFMA, compared to the Mie-series results.

The sphere was illuminated by a unit plane wave, polarized in the *x* direction, and propagating in the *z* direction. It was desired to find the far-zone electric field (the electric field times the distance from the object, when the distance approached infinity) scattered from the sphere.

3. Solution to Problem SOLBOX-03

3.1 Solution Summary

Solver Type (e.g., noncommercial, commercial): Noncommercial research-based code developed at Bilkent University, Ankara, Turkey, and CEMMETU, Ankara, Turkey.

Solution core algorithm or method:
Frequency-domain incomplete-leaf MLFMA (IL-MLFMA) [1]

Programming language or environment (if applicable): *MATLAB* + *MEX*

Computer properties and resources used:
Single core of 3 GHz Intel Xeon X5472, *Windows 7* (64-bit), 32 GB ECC RAM

Total time required to produce the results shown (categories: < 1 sec, < 10 sec, < 1 min, < 10 min, < 1 hour, < 10 hours, < 1 day, < 10 days, > 10 days): < 10 hours

3.2 Short Description of the Numerical Solution

Problem SOLBOX-03 was solved using the incomplete-leaf version [1] of the scaled MLFMA [2, 3] in the frequency domain. The solver was based on a nonuniform clustering, where only the overcrowded boxes were divided into smaller boxes for a given basis-function population threshold (100, for this solution). The problem was formulated with the magnetic-field integral equation (MFIE) [4], which is suitable for low-frequency perfectly conducting objects. The magnetic-field integral equation was discretized with the Rao-Wilton-Glisson functions [5] over multi-scale triangles. The model file that was provided with the problem definition was used, leading to a total of 181,488 unknowns. Both near-field and far-field interactions were computed using second-order Gaussian quadrature rules. Two digits of accuracy and 4×4-point interpolations were also considered for the MLFMA computations. The number of iterations to reach a residual error of 0.001 was 66, using GMRES without preconditioning. The field intensities and the Mie-series solution were calculated in the far-zone at 360 points.

3.3 Results

Figure 3 depicts the far-zone electric field (V) as a function of the bistatic angle, along with the Mie-series solution for the problem SOLBOX-03. The data samples were plotted using the plot command of *MATLAB*. There was fairly good agreement between the simulated results and the analytic Mie-series solution. The small discrepancy originated from the approximate method (diagonalization of the Green's function) in the low-frequency regime, due to the use of the scaled MLFMA [2].

4. References

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2016, 33rd National Radio Science Conference (NRSC)

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The National Radio Science Committee of the Academy of Scientific Research and Technology (ASRT) along with AASTMT are holding the 33rd National Radio Science Conference at the AASTMT South Valley campus in Aswan during the period 22-25 February 2016. The conference program will consist of invited sessions on selected topics and contributed sessions. The submitted papers must describe original work and cover the activities of the URSI commissions A-K, namely:

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I - Radio astronomy
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Review papers describing new trends and state of the art of some of the URSI activities are welcome. Accepted papers will be published in the conference proceedings conditional upon presentation of the paper and in-advance registration by at least one of the authors. Presented papers will be included in IEEE Xplore. A special student session will host a limited number of posters presenting B.Sc. graduation projects or Masters' work, with free registration. Best papers and best student papers will be selected by the organizing committee for awards.

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Prospective authors of papers describing original work are invited to get the standard format and to submit papers electronically through the conference website. The maximum number of pages is 8 per paper.

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Paper submission deadline: **September 14th, 2015**
Notification of acceptance: **December 2nd, 2015**
Camera-ready manuscript: **January 4th, 2016**

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Historical Column

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With the *Radio Science Bulletin* Editor, W. Ross Stone, we thought about adding some sort of periodic Historical Column to the *Bulletin*. This seemed appropriate, given the general interest in the history of science in general, and in radio waves in particular, that has arisen in the community. The idea is once a year or so to collect some papers dedicated to the history of a given topic, possibly focusing on its different aspects. These collections will take the form of "special sections" of the *Bulletin*, a sort of "monograph" with an in-depth focus on given aspects.

Contributions to the special section will be both by invitation and open contribution. They should of course comply with the *Bulletin*'s author guidelines, available at http://www.ursi.org/en/files/ informationforauthors.pdf.

The topic of the first special section will be the history of radar. The tentative schedule is for the September 2016 issue of the *Bulletin*, and hence perspective authors should submit their manuscripts by June 1, 2016, so as to allow for a round of review and revision. A second special section may be on radio astronomy, but for this, please stay tuned for the next announcement.

Those wishing to contribute individual historical articles to appear in the column in between the special sections are strongly encouraged to contact the Associate Editor.

Introducing Giuseppe Pelosi, Associate Editor for the Historical Column

Giuseppe Pelosi was born in Pisa, Italy, in 1952. He received the Laurea (Doctor) degree in Physics (*summa cum laude*) from the University of Florence in 1976. He is currently with the Department of Information Engineering of the same university, where he is Full Professor of Electromagnetic Fields. He was a Visiting Scientist at McGill University, Montreal, Quebec, Canada, from 1993 to 1995, and a professor at the University of Nice-Sophie Antipolis, France, in 2001. His research activities are mainly focused on numerical techniques for applied electromagnetics (antennas, circuits, microwave and millimeter-wave devices, and scattering problems).

Giuseppe was coauthor of several scientific publications on the aforementioned topics, appearing in international referred journals and national and international conferences. He was guest Editor of several special issues of international journals: *IEEE Antennas and Propagation Magazine*, 2013 (with J. L. Volakis and Y. Ramhat-Samii); *IEEE Transactions on Antennas and Propagation*, 2001 (with V. Grikunov and J. L. Volakis); *International Journal of Numerical Modelling: Electronic Networks, Devices and Fields*, 2000 (with P. Guillon and T. Itoh); *Electromagnetics*, 1998 (with J. L. Volakis); *Annales des Telecommunications* (with J. M. Bernard and P. Y. Ufimtsev), 1995; *COMPEL*, 1994 (with P. P. Silvester); *COMPEL*, 2002; *Alta Frequenza-Rivista di Elettronica*, 1992 (with P. P. Silvester).

Giuseppe was also coauthor of three books: *Finite Elements for Wave Electromagnetics* (with P. P. Silvester, IEEE Press, 1994); *Finite Element Software for Microwave Engineering* (with T. Itoh and P. P. Silvester, Wiley, 1996); and *Quick Finite Elements for Electromagnetic Fields* (with R. Coccioli and S. Selleri, Artech House, 1998 and 2009). With P. P. Silvester, he was the promoter of the International Workshop on Finite Elements for Microwave Engineering. This workshop is held every two years, and is the meeting point for finite-element researchers from all over the world. The next workshop, number 13, will be held in 2016 in Florence, Italy.

Giuseppe is also active in the study of the history of the telecommunications engineering field. He has been the Associate Editor for the Historical Corner of the *IEEE Antennas and Propagation Magazine* since 2006. Among his latest publications in this field is the book *A Wireless World. One Hundred Years Since the Nobel Prize to Guglielmo Marconi* (Series Contribution to the History of the Royal Swedish Academy of Sciences, 2012).

Giuseppe was elected a Fellow of the IEEE "for contributions to computational electromagnetics." He was a member of the Board of Directors of the Applied Computational Electromagnetics Society (ACES) (1999-2001), of the Board of Directors of the IEEE Central and South Italy Section (1992-1995 and 1995-1998), and Chair of the IEEE Magnetics Chapter of the same Section (1996-1999).

Women in Radio Science

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In 1984, Florence, Italy, I attended my first URSI General Assembly. I had recently changed over from particle physics for a PhD with the brand new EISCAT radar in northern Scandinavia. At the get-together event, I felt totally lost. The other participants looked like my father's generation, serious Humphrey Bogart-type gentlemen from the black-and-white movie era. There was no resemblance to the junior scientists of both sexes bathing in the conference-venue fountains, or even to the colorful middle-aged senior scientists at particle-physics meetings. I soon understood that many topics at URSI represented the mature technological revolution that had already accelerated in the late 1800s. A more serious generation and selection of people represented radio science, while particle physics was still in its thriving youth, collecting Nobel prizes and attracting many young people.

I was happy to be born in a place and time in which education was made possible, in principle, to everyone, by a beneficial student-loan system. To become a scientist as a woman was no longer so stigmatized as it had been for Marie Curie. Today, there are a few more women at meetings than there were at the Solvay Conferences in Brussels in the 1910s.

After 30 years in radio science, I have somehow been included in some committees at URSI. I am astonished that the gender balance in the upper echelons is still strongly reminiscent of the situation in Florence in 1984, or Solvay in 1911. There is so much talent, experience, and creativity that could contribute to the organization. I am not claiming that the men do not do their work: some of them really bear a large burden, as we could testify at the URSI AT-RASC meeting on Gran Canaria in May. However, from the statistical point of view, there could be almost twice as many people to share the heaviest burden if the gender balance was better.

In space physics and engineering programs in Sweden, there are quite consistently some 30% female students. Today, everybody can follow space exploration with excitement, and observe how our territory expands beyond the solar system. Besides the reality, there is a lot of fiction, and already school girls can identify themselves with female leaders and heroes in space, figures such as Captain Kathryn Janeway on the USS Starship *Voyager* some decades ago, and Dr. Amelia Brand in *Interstellar*, recently. Such small things actually matter.

It is still more important that we have good examples in real life. When young female scientists can see and communicate with older women in science, they do not feel as lost as I felt in Florence in 1984. The most ambitious women can even think about trying to reach the highest positions. I have also been astonished that within organizations such as URSI, it does seem to be a rule that one should find a female delegate for every committee, or explain in written form why none were found. The same is true with the people invited to give the General Lectures. In Sweden, we have to do this continuously for every academic committee, and it is much easier to invite the woman than to have to explain why one was not found.

URSI is a fantastic organization, with its over 40 Member countries covering all the continents. At the URSI meetings, a colorful mixture of people meet and learn to know each other. Even though we scientists are sometimes childishly protective of our own topics, we are seldom intolerant against people from other backgrounds. That can be witnessed at university campuses all over the world.

There have been successful efforts to rejuvenate the URSI attendees through such initiatives as the Student Paper Competitions and Young Scientists Awards. At the URSI AT-RASC, about 20% of the Young Scientist Awardees were young women from different parts of the world. For URSI, it is a challenge to see these young women as a gift, and as potential members of the future committees. They probably worked hard to get the ticket to Gran Canaria, and have a lot to offer to the society, if they are just encouraged to do so.

This column will be a forum for discussion on how we can strengthen young female scientists' confidence to take part in, and eventually lead, some sectors of the technical development in the world. My plan is to profile female scientists in different phases of their careers, to tell about the successes but also about the specific difficulties they experienced as women on their way. I have already received hints on some women to profile, but would be happy if you could submit suggestions and ideas on how to continue the Women in Radio Science column.

I am looking forward to your contributions.

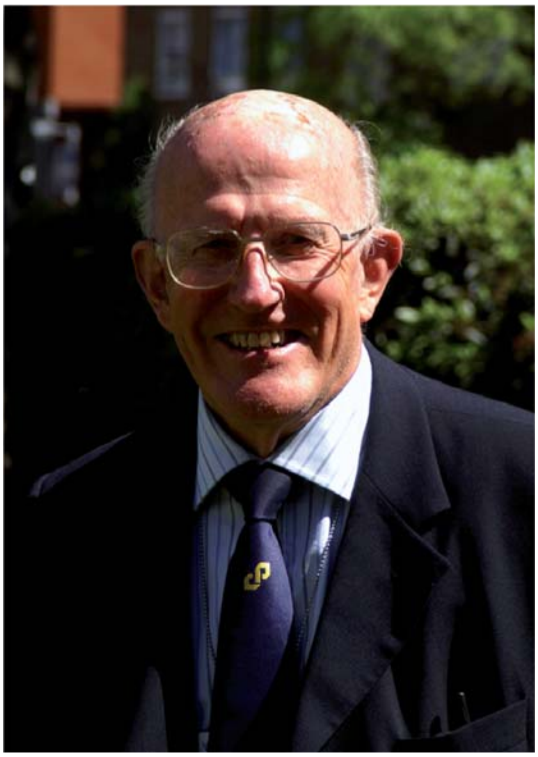
Introducing Asta Pellinen-Wannberg, Associate Editor for Women in Radio Science Column

Asta Pellinen-Wannberg is a Professor of Physics at Umeå University, Sweden. She was born in Helsinki, Finland. She received her BSc in Mathematics, and her MSc in Physics and Teacher Education at the University of Helsinki, Finland. She received her PhD in Space Physics at Umeå University, Sweden. She was an Assistant in the Department of High Energy Physics at the University of Helsinki starting in 1979. She was employed as an engineer and scientist by the Swedish Institute of Space Physics in Kiruna beginning in 1982. She became a Senior Lecturer and Professor at Umeå University in 1996.

Asta's research interests include auroral physics, meteor physics, and space environmental issues. She has about 50 publications. She observed meteor-head echoes with the EISCAT radars in 1990. She was initiative coordinator of the SpaceMaster – Joint European Master in Space Science and Technology in the European Union Erasmus Mundus Programme. She was the main organizer of the Meteoroids 2001 conference, and of the 12th EISCAT International Workshop 2005 in Kiruna. She was the Swedish delegate to the EISCAT Council for 2002-2008. She is the President of the Swedish URSI Committee and a member of the URSI Council for 2015-2017.

Peter Clarricoats Receives Sir Frank Whittle Medal

Prof. Peter Clarricoats CBE FREng FRS has received one of the UK Royal Academy of Engineering's highest accolades, the Sir Frank Whittle Medal, for his influential achievements spanning more than half a century. Academy President Prof. Dame Ann Dowling DBE FREng FRS presented the award to Prof. Clarricoats, Emeritus Research Professor at Queen Mary University of London, at the Academy's annual general meeting in London on Monday, September 21.



Over the last 50 years, Prof. Clarricoats' successes ranged from pioneering research with Nobel laureate Sir Charles Kao KBE FREng FRS on optical-fibre technology, to influential work on the design and development of high-performance microwave antennas for space-borne satellite communications. Prof. Clarricoats' immense contributions have made him one of the best-known microwave engineers of his generation.

Prof. Clarricoats was the first person in the UK to explore the behavior of ferrites at microwave frequencies. His book, *Microwave Ferrites* (1960), became an essential text for those developing microwave radar and communications systems. Working at the University of Leeds from 1963, he was the first to use computers to design microwave waveguide junctions, a function that exists in many software packages to this day. He also established *Electronic Letters*, an internationally successful journal.

At Queen Mary University of London, Prof. Clarricoats developed a theory that confirmed the correct choice of physical attributes in optical fibres, essential for long-distance communication links. He then turned his attention to microwave antennas for communication and radar systems. Most ground-station reflectors, radio-astronomy reflectors, and satellite antennas now use corrugated horns of the type first investigated by Prof. Clarricoats in the 1970s and 1980s. Since his partial retirement, Prof. Clarricoats has remained as an emeritus professor and continued his industrial and senior government appointments with organizations including the British Ministry of Defence and the European Space Agency.

Academy Past President Sir David Davies CBE FREng FLSW FRS, who supported Prof. Clarricoats' nomination, said, "I have known Peter since the 1960s and have always been an admirer of his work. His long and substantial list of major contributions to the field of microwaves and antennas, extending well beyond his retirement, speaks for itself. I am delighted that he is to receive the 2015 Sir Frank Whittle Medal."

Prof. Clarricoats said:

> Since I joined the academic world from industry in 1959, I have been able to start research groups at Queens University Belfast, the University of Leeds, and finally at Queen Mary University of London, where I have spent the last 47 years. In all three, I was greatly helped by outstanding colleagues, and from the outset was fortunate to have support from industry, government, and the European Space Agency. We had great success in solving many of the problems they posed, often with innovative ideas. My message to academics is to get involved with industry.

Prof. Clarricoats was active in URSI throughout his career. He served as Vice-President and Treasurer of URSI from 1993 to 1999.

[Material for the above item was taken from a press release from the Royal Academy of Engineering.]

Congratulations to President of URSI Russian National Committee on 80th Birthday

Prof. Yu. V. Gulyaev, the President of the URSI Russian National Committee, turned 80 years old on the September 18, 2015.

Prof. Gulyaev, an academician of the Russian Academy of Sciences, is an outstanding, well-known scientist in radio science, electronics, and informatics. He was one of the founders of such new scientific and technical fields as acoustoelectronics, acoustooptics, and spin-wave electronics. He predicted the existence of a new fundamental type of surface acoustic waves in piezoelectric materials, known as the Bleustein-Gulyaev waves. These and other results from Prof. Gulyaev and the investigations of his scientific school are used in new technologies of information processing and telecommunications. Together with his associates, Prof. Gulyaev carried out precise measurements and dynamic mapping of the physical fields and radiation of the human body for the purpose of early medical diagnostics.

The main scientific results obtained by Prof. Gulyaev have been published in more than 600 scientific articles, 11 monographs, and 80 patents.

Prof. Gulyaev is an excellent organizer and leader. For a long time (1988-2014), he was a Director of the Kotelnikov Institute of Radioengineering and Electronics of the Russian Academy of Sciences (IRE RAS). He is now a Scientific Supervisor of the IRE RAS. He has been a member of the Presidium of the Russian Academy of Sciences since 1992.

Prof. Gulyaev has always been passionately involved in not only his own research, but also in supporting and nurturing young colleagues. He does his best to train them to be broadly competent in radiophysics. Many of these colleagues have become famous scientists themselves, and regard him as their great teacher.

Prof. Gulyaev is the President of the URSI Russian National Committee. He is also the President of the Russian A. S. Popov Scientific and Technical Society of Radioengineering, Electronics and Telecommunications, a Life Fellow of the IEEE, and a Past President of the International Union of Scientific and Technical Societies and Unions of CIS countries. The fruitful scientific, pedagogical, research, organizational, and public activities of Prof. Gulyaev have been recognized by many national and international prizes. These include the Hewlett-Packard Europhysics Prize of the European Physical Society, for his work in the field of radio engineering and electronics; the Popov Gold medal of RAS; and the IEEE Rayleigh Prize.

Prof. Gulyaev's selfless work and boundless devotion to science have earned him the love and respect of all his coworkers and friends.

Dear Yuriy Vasil'evich:

With all our heart, we wish you much health, courage, energy!

Stay always full of young creative spirit and many creative ideas!

We are sure you will do a lot more for our beloved science!

Happy birthday to you!

All of your colleagues and friends.

Submitted by G. Chukhray
Secretary of URSI Russian National Committee
E-mail: australia2@yandex.ru

Call for Papers

URSI 2016 URSI Asia-Pacific Radio Science Conference AP-RASC 2016

August 21-25, 2016 / Grand Hilton Seoul Hotel, Korea

The Asia-Pacific Radio Science Conference (AP-RASC) is a triennial conference for the exchange of information on the research and development in the field of radio science. It is one of URSI flagship conferences with URSI GASS and URSI AT-RASC. The objective of the AP-RASC is to review current research trends, present new discoveries, and make plans for future research & special projects in all areas of radio science, especially where international cooperation is desirable.

This AP-RASC, 2016 URSI Asia-Pacific Radio Science Conference (URSI AP-RASC 2016)will be held at Grand Hilton Hotel Seoul, Korea on August 21-25, 2016. We will have an open scientific program composed of submitted papers within the domains covered by all 10 commissions of URSI.

Topical Areas

- Commission A: Electromagnetic Metrology, Electromagnetic Measurements and Standard
- Commission B: Fields and Waves
- Commission C: Radio-communication Systems and Signal Processing
- Commission D: Electronics and Photonics
- Commission E: Electromagnetic Noise and Interference
- Commission F: Wave Propagation and Remote Sensing
- Commission G: Ionospheric Radio and Propagation
- Commission H: Waves in Plasmas
- Commission J: Radio Astronomy
- Commission K: Electromagnetics in Biology and Medicine

Young Scientist Programs

The following two programs are planned for young scientists.

- Student Paper Competition (SPC)
- Young Scientist Award (YSA)

Paper Submission Deadline : *March 15, 2016*

All authors are requested to submit their abstract via on-line. Please prepare the abstract both PDF and MS Word format for the submission. The detailed information on abstract submission will be posted at the URSI AP-RASC 2016 website (www.aprasc2016.org).

Important Dates

- **Paper Submission**
  March 15, 2016
- **YSA/SPC Paper Submission**
  March 31, 2016
- **Acceptance Notification**
  April 30, 2016
- **Author Registration**
  June 15, 2016
- **Early Registration**
  July 15, 2016

Organized by

KIEES U.R.S.I.

Co-organized by

RRA NATIONAL RADIO RESEARCH AGENCY

ETRI Electronics and Telecommunications Research Institute

KASI Korea Astronomy and Space Science Institute

www.aprasc2016.org

[Editor's note: the following lists are provided as updates to the lists that appeared in the December 2014 issue of the *Radio Science Bulletin*, No. 351. WRS]

Representatives of Scientific Organizations

COSPAR (Committee on Space Research):
Prof. I. Stanislawska (Poland)

IAU (International Astronomical Union):
Dr. R. Schilizzi (UK)

ICG (International Committee on Global Navigation Satellite Systems):
Prof. P. Doherty (USA)

ICSU (International Council of Scientific Unions):
Prof. P. Cannon (UK)
Dr. P. Wilkinson (Australia)

ICSU World Data System:
Dr. D. Bilitza (USA)

ISES (International Space Environment Service):
Dr. M. Terkildsen (Australia)

ISPRS (International Society for Photogrammetry & Remote Sensing):
Prof. T. J. Tanzi

IUCAF (Scientific Committee on Frequency Allocations for Radio Astronomy and Space Science):
Dr. H.S. Liszt (Chair, USA)
Prof. S. Ananthakrishnan (India, Comm J)
Dr. W.A. Baan (ex officio)
Prof. I. Häggström (USA, Comm G)
Prof. S. C. Reising (USA, Comm F)
Dr. A. T. Tzioumis (Australia, Comm J)
Dr. W. Van Driel (France, Comm J)

IUGG/IAGA (International Union of Geodesy and Geophysics/International Association of Geomagnetism and Aeronomy):
Prof. F. Lefeuvre (France)

SCAR (Scientific Committee on Antarctic Research):
Dr. G. de Franceschi (Italy)

SCOR (Scientific Committee on Oceanic Research):
Dr. R. Lang (USA)

SCOSTEP (Scientific Committee on Solar-Terrestrial Physics):
Prof. C. Rodger (New Zealand)

WHO EMF (World Health Organization – Electromagnetic Field Programme):
Prof. B. Veyret (France)

Working Groups 2014-2017

D.1 RFID Technologies and Privacy of Data
Chair: Dr. S. Tedjini (France)
Vice-Chair: Dr. G. Marrocco (Italy)

E.1 Terrestrial and Planetary Electromagnetic Noise Environment
Co-Chairs: Y. Hobara (Japan), K. Hattori (Japan), A.P. Nickolaenko (Ukraine), C. Price (Israel)

E.2 Intentional Electromagnetic Interference
Co-Chairs: M. Bäckström (Sweden) and W. Radasky (USA)

E.3 High Power Electromagnetics
Co-Chairs: R. L. Gardner (USA) and F. Sabath (Germany)

E.4 Lightning Discharges and Related Phenomena
Co-Chairs: S. Yoshida (Japan) and Dr. V. Rakov (USA)

E.5 Interaction with and Protection of Complex Electronic Systems
Co-Chairs: J-P. Parmentier (France), F. Gronwald (Germany), and H. Reader (South Africa)

E.6 Spectrum Management
Chair: J. P. Borrego (Portugal)

E.7 Geo-Electromagnetic Disturbances and Their Effects on Technological Systems
Chair: A. Viljanen (Finland)

E.8 Electromagnetic Compatibility in Wired and Wireless Systems
Co-Chairs: F. Rachidi (Switzerland) and A. Zeddam (France)

E9. Stochastic Techniques in EMC
Co-Chairs: L. Arnaut (UK), S. Pignari (Italy), and R. Serra (Netherlands)

F.1 Education and Training in Remote Sensing and Related Aspects of Propagation/Next-Generation Radar Remote Sensing
Chair: M. Chandra (Germany)
Co-Chairs: J. Isnard (France), W. Keydel (Germany), E. Schweicher (Belgium)

G.1 Ionosonde Network Advisory Group (INAG)
Chair: I. Galkin (USA)
Vice-Chairs: J. B. Habarulema (South Africa), Dr. B. Ning (China CIE)
INAG Bulletin Editor: P. Wilkinson (Australia)

G.2 Studies of the Ionosphere Using Beacon Satellites
Chair: P. Doherty (USA)
Honorary Chair: R. Leitinger (Austria)

G.3 Incoherent Scatter
Chair: M. McCready (USA)
Vice-Chair: I. McCrea (UK)

K.1 Stochastic Modeling for Exposure Assessment
Co-Chairs: Dr. J. Wiart (France) and Dr. T. Wu (China CIE)

Joint Working Groups

EFGHJ. RFI Mitigation and Characterization
Chair for Commission E: F. Gronwald (Germany)
Chairs for Commission F: A. K. Mishra (South Africa), D. Le Vine (USA)
Chair for Commission G: T. Bullett (USA)
Chair for Commission H: H. Rothkaehl (Poland)
Chairs for Commission J: R. Bradley (USA),W. Baan (Netherlands)

EGH. Seismo Electromagnetics (Lithosphere-Atmosphere-Ionosphere Coupling)
Chair for Commission E: Y. Hobara (Japan)
Chair for Commission G: S. Pulinets (Russia)
Chair for Commission H: H. Rothkaehl (Poland)

EHG. Solar Power Satellites
Chair: H. Matsumoto (Japan)
Co-Chair for Commission E: J. Gavan (Israel)
Co-Chair for Commission H: K. Hashimoto (Japan)
Co-Chair for Commission G: K. Schlegel (Germany)

FG. Atmospheric Remote Sensing Using Satellite Navigation Systems
Co-Chairs for Commission F: N. Floury (Netherlands)
Chair for Commission G: C. Mitchell (UK)

GF. Middle Atmosphere
Chair for Commission F: Dr. F. Marzano (Italy)
Co-Chairs for Commission G: J. L. Chau (Peru), E. Kudeki (USA)

GH. Active Experiments in Plasmas
Chair for Commission G: T. Pedersen (USA)
Chair for Commission H: M. Kosch (South Africa)

HJ. Computer Simulations in Space Plasmas
Co-Chairs for Commission H: Y. Omura (Japan) and B. Lembege (France)
Chair for Commission J: K. Shibata (Japan)

Inter-Commission Data Committee
Chair: S. Wijnholds (the Netherlands)

Inter-Union Working Groups

URSI/IAGA VLF/ELF Remote Sensing of the Ionosphere and Magnetosphere (VERSIM)
Chair for URSI (Commissions E, G, H): M. Clilverd (UK)
IAGA Chair: J. Bortnik (USA)

URSI/COSPAR on International Reference Ionosphere (IRI)
Chair: D. Altadill (Spain)
Vice-Chair for URSI: V. Truhlik (Czech Republic) Vice-Chair for COSPAR: S. Watanabe (Japan) Secretary: D. Bilitza (USA)

URSI/IUCAF Inter-Commission Working Group on Radio Science Services
Chair for IUCAF: Dr. W. Van Driel (France)(ex officio)

URSI/IAU Inter-Union Working Group on the History of Radio Astronomy
Chairs: R. Schilizzi (UK), R. Wielebinski (Germany)

URSI Conference Calendar

September 2015

URSI-JRSM 2015
Tokyo, Japan, 3-4 September 2015
Contact: Prof. Kazuya Kobayashi, Department of Electrical, Electronic and Communication Engineering, Chuo University, 1-13-27 Kasuga, Bunkyo-ku, Tokyo 112-8551, Japan, Fax: +81-3-3817-1847, E-mail:kazuya@tamacc.chuo-u.ac.jp, http://www.ursi.jp/jrsm2015/

Metamaterials 2015
Oxford, United Kingdom, 7-10 September 2015
Contact: Prof. Richard W. Ziolkowski, Litton Industries John M. Leonis Distinguished Professor, Electrical and Computer Engineering Professor, College of Optical Sciences, University of Arizona, Tucson, AZ 85721, E-mail: ziolkowski@ece.arizona.edu, http://congress2015.metamorphose-vi.org

IEEE Radio and Antenna Days of the Indian Ocean 2015
Mauritius, 21 - 24 September 2015
Contact: RADIO 2015 Conference Secretariat, Radio Society (reg. no. 13488), Gobinsing Road, Union Park, Mauritius, Email: radio2015@radiosociety.org
http://www.radiosociety.org/radio2015

November 2015

IRI Workshop
Bangkok, Thailand, 2-13 November 2015
Contact: Secretariat IRI workshop 2015, Faculty of Engineering, King Mongkut's Institute of Technology Ladkrabang, Chalongkrung Rd. Ladkrabang, Bangkok 10520, Thailand, Fax : +662 3298325, E-Mail : IRISecretary@kmitl.ac.th
http://www.iri2015.kmitl.ac.th/

COSPAR 2015 - 2nd Symposium of the Committee on Space Research (COSPAR): Water and Life in the Universe
Foz do Iguacu, Brazil, 9-13 November 2015
Contact: COSPAR Secretariat, 2 place Maurice Quentin, 75039 Paris Cedex 01, France
Tel: +33 1 44 76 75 10, Fax: +33 1 44 76 74 37, E-mail: cospar@cosparhq.cnes.fr, http://cosparbrazil2015.org/

URSI-RCRS 2015 - 2nd URSI Regional Conference on Radio Science
New Delhi, India, 16-19 November 2015
Contact: Dr. Paulraj R., Convener, URSIRCRS2015, School of Environmental Sciences, Jawaharlal Nehru University, New Mehrauli Road, New Delhi, 110 067, India, Tel: + 91 11 2670 4162, Email: rcrsdelhi@gmail.com, http://www.ursi.org/img/website24x24.jpg

December 2015

ICMARS 2015
11th International Conference on Microwaves Antenna Propagation & Remote Sensing
Jodhpur, Rajasthan, India, 15-17 December 2015
Contact: Contact: Prof. O.P.N. Calla, ICRS, Plot No 1, Rano ji Ka Bagh, Khokhariya Bera, Nayapura, Mandore, Jodhpur 342304 Rajasthan, India, Fax +91 291-257 1390
http://www.icmars.org

April 2016

EuCAP 2016 - European Conference on Antennas and Propagation 2016
Davos, Switzerland, 10 - 15 April 2016
Contact: Prof. Juan R. Mosig, LEMA – EPFL, École Polytechnique Fédérale de Lausanne, Lausanne, Switzerland, E-mail juan.mosig@epfl.ch

June 2016

EUSAR 2016 - European Conference on Synthetic Aperture Radar 2016
Hamburg, Germany, 6-9 June 2016
Contact: EUSAR 2016 Conference Office c/o VDE, Ms. Hatice Altintas, Stresemannallee 15, D-60596 Frankfurt, Germany
Fax: +49 69 96 31 52 13, E-Mail: Hatice.altintas@vde.com
http://www.eusar.de

July 2016

COSPAR 2016 - 41st Scientific Assembly of the Committee on Space Research (COSPAR) and Associated Events
Istanbul, Turkey, 30 July – 7 August 2016
Contact: COSPAR Secretariat, 2 place Maurice Quentin, 75039 Paris Cedex 01, France, Tel: +33 1 44 76 75 10, Fax: +33 1 44 76 74 37, E-mail: cospar@cosparhq.cnes.fr
https://www.cospar-assembly.org/

August 2016

EMTS 2016 - 2016 URSI Commission B International Symposium on Electromagnetic Theory
Espoo, Finland, 14-18 August 2016
Contact: Prof. Ari Sihvola, Aalto University, School of Electrical Engineering, Department of Radio Science and Engineering, Box 13000, FI-00076 AALTO, Finland, E-mail: ari.sihvola@aalto.fi

HF13 - Nordic HF Conference with Longwave Symposium LW 13
Faro, Sweden (north of Gotland in the Baltic Sea), 15-17 August 2016
Contact: Carl-Henrik Walde, Tornvägen 7, SE-183 52 Taby, Sweden, tel +46 8 7566160 (manual fax switch, E-mail info@walde.se, http://www.ursi.org/img/website24x24.jpg

AP-RASC 2016 - 2016 URSI Asia-Pacific Radio Science Conference
Seoul, Korea, 21 - 25 August 2016
Contact: URSI AP-RASC 2016 Secretariat, Genicom Co Ltd, 2F 927 Tamnip-dong, Yuseong-gu, Daejeon, Korea 305-510, Fax.: +82-42-472-7459, E-mail: secretariat@aprasc2016.org, http://www.ursi.org/img/website24x24.jpg

October 2016

ISAP 2016 - 2016 International Symposium on Antennas and Propagation
Okinawa, Japan, 24-28 October 2016
Contact: Prof. Toru Uno, Tokyo Univ. of Agriculture & Technology, Dept of Electrical and Electronic Engineering, 2-24-16 Nakamachi, Koganei 184-8588, Japan, Fax +81 42-388 7146, E-mail: uno@cc.tuat.ac.jp, http://isap2016.org/

August 2017

URSI GASS 2017 - XXXIInd URSI General Assembly and Scientific Symposium
Montreal, Canada, 19-26 August 2017
Contact: URSI Secretariat, c/o INTEC, Sint-Pietersnieuwstraat 41, 9000 Gent, Belgium, E-mail info@ursi.org

May 2019

EMTS 2019 - 2019 URSI Commission B International Symposium on Electromagnetic Theory
San Diego, CA, USA, 27-31 May 2019
Contact: Prof. Sembiam R. Rengarajan, California State University, Northridge, CA, USA, Fax +1 818 677 7062, E-mail: srengarajan@csun.edu

URSI cannot be held responsible for any errors contained in this list of meetings

Information for Authors

Content

The *Radio Science Bulletin* is published four times per year by the Radio Science Press on behalf of URSI, the International Union of Radio Science. The content of the *Bulletin* falls into three categories: peer-reviewed scientific papers, correspondence items (short technical notes, letters to the editor, reports on meetings, and reviews), and general and administrative information issued by the URSI Secretariat. Scientific papers may be invited (such as papers in the *Reviews of Radio Science* series, from the Commissions of URSI) or contributed. Papers may include original contributions, but should preferably also be of a sufficiently tutorial or review nature to be of interest to a wide range of radio scientists. The *Radio Science Bulletin* is indexed and abstracted by INSPEC.

Scientific papers are subjected to peer review. The content should be original and should not duplicate information or material that has been previously published (if use is made of previously published material, this must be identified to the Editor at the time of submission). Submission of a manuscript constitutes an implicit statement by the author(s) that it has not been submitted, accepted for publication, published, or copyrighted elsewhere, unless stated differently by the author(s) at time of submission. Accepted material will not be returned unless requested by the author(s) at time of submission.

Submissions

Material submitted for publication in the scientific section of the *Bulletin* should be addressed to the Editor, whereas administrative material is handled directly with the Secretariat. Submission in electronic format according to the instructions below is preferred. There are typically no page charges for contributions following the guidelines. No free reprints are provided.

Style and Format

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