Radio Frequencies: Policy and Management

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***Abstract*—The electromagnetic spectrum is a valued shared resource. Its scientific use allows us to learn about our universe, measure and monitor our planet, and communicate scientific data. The use of the spectrum is managed by national, regional, and global regulatory frameworks. There are increasing demands for new or extended allocations because of vast technological advances in the past few years. Understanding spectrum management is important in the successful planning and execution of missions and instruments, as well as in determining the potential source of radio frequency interference in existing data and instruments, and in working to ameliorate its impact. This paper provides a summary of this framework for radio scientists and engineers.**

***Index Terms*—Radio astronomy, radio frequency interference, radio science, spectrum management.**

I. Introduction

THE electromagnetic spectrum is a vital resource shared by many communities. In the regulatory world, use of the spectrum for a specified purpose by a community is defined by the International Telecommunications Union (ITU) as a service, of which there are 41 [1], [2]. It is with regard to these services that the overall use of spectrum is debated and allocated. The scientific services (listed in Table I) represent an important class of use of the spectrum but must compete in the regulatory world and the commercial marketplace to obtain and retain useful access to specific bands within the spectrum. Though many technical tools are being developed to mitigate the impact of to radio frequency interference (RFI), it remains important to work within the regulatory environment to maximize opportunities for important scientific discoveries.

As radio waves do not respect geopolitical boundaries, the management of the spectrum must consider international and national concerns. This management process involves many agencies around the globe, and the ITU, an international treaty organization. As scientists and members of society, we also rely on the other services and use equipment that may potentially interfere with our own signals and with those of other scientific users of the spectrum. The shared use of the spectrum carries a shared responsibility among all of the users to maximize the use of this important and limited resource effectively for everyones benefit.

This paper summarizes the regulatory and policy environment that controls passive scientific use of the electromagnetic spectrum and points to other reference material. Understanding this structure may help researchers both to improve system design for the present and future RFI environment, and to

TABLE I
SCIENCE SERVICES OF THE RADIOCOMMUNICATIONS SECTOR OF THE ITU-R

Service	Abbreviation	Description
Earth Exploration-Satellite Service	EESS	Both active and passive remote sensing from orbit; and the data up- & downlinks ITU-R RR 1.51
Radionavigation Satellite Service	RNSS	Accurate position and timing data ITU-R RR 1.54, Article 26
Meteorological Aids Service	MetAids	Radio communication for meteorology *e.g.* weather balloons ITU-R RR 1.50
Meteorological Satellite Service	MetSat	Earth exploration satellite service for meteorological applications; Weather satellites data communications ITU-R RR 1.52
Radio Astronomy Service	RAS	Passive ground-based observations for the reception of radio waves of cosmic origin ITU-R RR 1.58, Article 29
Space Research Service	SRS	Both active and passive science satellite telemetry and data up- & downlinks, space-based radio astronomy and other services ITU-R RR 1.55

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Fig. 1. Approximate global regions for international frequency allocations as specified by the radiocommunications sector of the ITU-R.

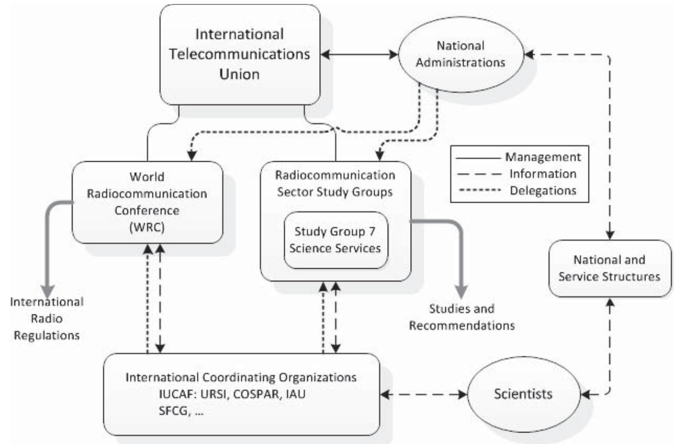

Fig. 2. Diagram showing the structure of the international frequency allocation process with respect to the requirements and protection of scientific services.

identify current sources of RFI by understanding how services use the spectrum. It is meant as a brief introduction for the working scientist. The international structure is discussed, with specific examples from the U.S.

II. Overview

At the international level, the treaty organization that deals with radio waves is the Radiocommunication Sector of the ITU (ITU-R) [3]. The ITU is a specialized agency of the United Nations and the ITU-R is one of its three sectors, the others being Telecommunication, Standardization, and Development. For purposes of international frequency allocations, ITU-R divides the world into three regions, as shown in Fig. 1.

The ITU considers issues of frequency allocations via a very formal and lengthy process, with any binding outcomes negotiated as part of the World Radiocommunication Conferences (WRCs) held every three to five years. Much of the work of the ITU occurs within study groups that generate informative reports that provide input to the WRCs. The process starts with specific questions or agenda items, which are investigated via study groups, which then generate recommendations and reports. The results may then be introduced into regulations adopted by the adhering administrations around the globe.

Although the international process discussed above addresses only those issues that do or could cross international borders, many countries and/or regions attempt to maintain domestic regulations and structures roughly consistent with the ITU-R radio regulations and their appropriate region. One reason is that countries would prefer not to have separate regulations for border and interior regions.

Regions typically then organize themselves into regional international groups to coordinate and communicate among countries that have some common interests (such as lying within the potential footprint of space-borne transmitters). Member states within a region may, and often do, have bilateral or multilateral agreements for spectrum issues that may be binding or collaborative in nature.

In most cases, countries then have national agencies to set and enforce rules and regulations, which typically have the force of law within each country. It is important to bear in mind that the national administrations have the sovereign right to administer spectrum use within their borders as they see fit as long as the national implementation does not violate the ITU-R radio regulations. It is primarily these national rules that govern issues of direct concern to radio scientists, but this is for all potentially impacted nations. The United States has two agencies responsible for regulating the use of spectrum within the U.S. and its territories: the Federal Communications Commission (FCC) for nonfederal-government use and the National Telecommunications and Information Administration (NTIA) for federal use. Some countries manage the radio frequency spectrum within a larger agency that may also oversee postal and telecommunication services, or transportation and commerce.

The spectrum rules and regulations allocate specific ranges of frequency to one or more services, on an exclusive or shared basis. Most allocations are shared between multiple services and even exclusive allocations are then shared among the community that operates within that service. For shared allocations, there are one or more primary services and there may also be one or more secondary services. Secondary services are not permitted to cause interference to a primary service and may not claim protection from harmful interference by a primary service.

Allocations typically also have other restrictions or sometimes multiple uses. Some allocations are labeled space-to-earth, meaning the use is restricted to transmission in that direction. Additionally, the allocations have many associated footnotes, which may originate from a national agency or from discussions within the ITU. The footnotes typically spell out peculiarities or special conditions on an allocation, or may be informational or encourage adoption of, say, a particular recommendation. One example is ITU-R RR 5.149, which urges administrations to take all practicable steps to protect the radio astronomy service from harmful interference.

III. International Organizations

As mentioned above, the international aspect of radio frequency assignment coordination is conducted under the ITU, which is an international treaty organization adhered to by nearly all of the nations around the globe. Representation to the ITU (via participation in the WRC) is therefore via appointed representatives from the signing administrations. Fig. 2 shows a flowchart of the international process in the context of the science services. The resultant ITU-R radio regulations codifies the definitive international agreement and may be found online [4]. The ITU also publishes handbooks for various services including one for radio astronomy [5] and one for the Earth Exploration-Satellite Service (EESS) [6].

In addition to the regulatory work, there is a great deal of technical and policy expertise and consultative infrastructure around the ITU-R, primarily centered on the Study Groups. The Study Groups are broken down into Working Parties and ad-hoc Task Groups, where the adopted questions and assigned WRC agenda items are studied and considered. Study Group 7 addresses issues for the scientific services, which are listed in Table I. Working party 7C (WP7C) is concerned with remote sensing and WP7D is concerned with radio astronomy. WP7A deals with time and frequency standards and WP7B deals with space radiocommunication.

Other international groups have a role in the process. The International Council of Scientific Unions operates under the United Nations Educational, Scientific and Cultural Organization and provides additional input from the science community through the Scientific Committee on Frequency Allocations for Radio Astronomy and Space Science (known by its historic acronym IUCAF) [7]. Three international scientific unions sponsor IUCAF: the International Union of Radio Science (URSI), the International Astronomical Union (IAU), and the Committee on Space Research.

The European Conference of Postal and Telecommunications Administrations (CEPT) [8] is a coordinating and communication organization that brings together regulators and policy makers among its 48 European member states. The CEPT Electronics Communications Committee attempts to harmonize the use of radio spectrum across Europe. The CEPT European Communications Office Frequency Information System is an important tool for searching through European spectrum allocations and information [9]. Within the CEPT, the Working Group on Frequency Management meets regularly with the participation of all CEPT member states for the discussion of issues related to spectrum use in Europe.

The Committee on Radio Astronomy Frequencies (CRAF) is an expert committee of the European Science Foundation and helps address concerns and issues of the European community of radio astronomers in a subset of Region 1 [10]. CRAF also maintains helpful handbooks on frequency management and radio astronomy [11], [12].

The Radio Astronomy Frequency Committee in the Asia-Pacific (RAFCAP) acts as the scientific expert committee on frequency issues for Asia-Pacific radio astronomy and related sciences in a subset of Region 3 [13].

The Inter-American Telecommunications Commission [14] is a regional organization that coordinates telecommunication, information and communication technology among the members of the Organization of American States. Other regional groups include the African Telecommunications Union [15], the Asia-Pacific Telecommunity [16], the Arab Spectrum Management Group [17], and the Caribbean Telecommunications Union [18].

The IEEE is an international organization for the advancement of technical innovation whose members often invent and develop devices that could potentially cause interference and suffer interference from others. The IEEE Geoscience and Remote Sensing Society (GRSS) brings together many scientists and engineers engaged in Earth remote sensing. The GRSS Technical Committee on Frequency Allocations in Remote Sensing (FARS) is chartered to provide technical assessments, guidance and recommendations regarding matters of frequency sharing and interference between remote sensing and other uses of the radio wave spectrum [19].

The Space Frequency Coordination Group (SFCG) is an informal international group incorporating the worlds space agencies to discuss issues related to the use of spectrum for space-related activities. The SFCG produces and adopts resolutions and recommendations regarding technical and administrative issues for the effective use of the global space systems spectrum [20].

IV. National Organizations

As mentioned above, the U.S. spectrum is regulated by the FCC [21] for nonfederal use and by the NTIA [22] for federal use. National structures vary across the globe. Additionally, the internal structures to provide input both to national regulations and to the WRCs vary across the globe and across services.

Within the United States, the NTIA seeks advice from the Interdepartmental Radio Advisory Committee (IRAC) in coordinating the needs among the federal users of spectrum [23]. The U.S. National Science Foundation (NSF) [24], the National Aeronautics and Space Administration (NASA) [25], the National Oceanic and Atmospheric Administration [26], the military branches and the Department of Commerce all have spectrum managers to facilitate and coordinate spectrum use with other agencies and with the commercial world via the FCC.

The U.S. National Academy of Sciences hosts the Committee on Radio Frequencies (CORF) [27] to examine spectrum issues that may be of interest to scientific users of the spectrum and to conduct studies on how it may effectively be used. CORF has published a handbook [28] and has recently conducted a study of the scientific use of the spectrum with an eye toward the future [29]. CORF participates in the regulatory process by submitting comments on FCC notices and educates researchers about spectrum issues.

In Europe, in addition to the CEPT, individual countries have national regulators. For example, in the United Kingdom, the Office of Communications is the consolidated independent regulator for the spectrum, and in the Netherlands the Independent Post and Telecommunications Authority serves that role. Table II provides a listing of a few selected national spectrum regulators. A search on telecommunications regulators will provide more information online.

V. Allocation Summary

As mentioned earlier, spectrum is allocated by service and region and by function or other feature. Recall that Table I summarizes the science services and Fig. 1 shows the Regions. Service allocations are either exclusive or shared as Primary or Secondary users. If regulators consider that the possibility of interference is below the protection criteria, there may be multiple primary users in a given allocation. In addition, many allocations have an associated footnote which may detail additional constraints on an allocation, or point out some other recommended practice. The footnotes are part of the Regulations. Note that the allocations do change and that many associated issues accompany an allocation on top of simply noting the service and frequency. The relevant radio regulations should be consulted when planning any mission or instrument. Table III provides a list of selected online allocation tables.

The Radio Astronomy Service (RAS) was recognized as a service at the 1959 World Administrative Radio Conference. Allocations at intervals of about 1 octave with bandwidths of about 1% were recommended, along with extra protection of the 1420 MHz hydrogen line. At the time, molecular spectral lines from rotational and hyperfine radio transitions were still unknown, with the 18-cm hyperfine lines of OH only found in 1963. The recommendations were largely adopted, as well as

TABLE II
LIST OF SOME NATIONAL SPECTRUM REGULATORY AGENCIES AND THEIR WEB ADDRESSES

Country	Regulator Name	URL
Argentina	Secretaria de Comunicaciones	http://www.secom.gov.ar/
Australia	Australian Communications and Media Authority (ACMA)	http://www.acma.gov.au/
Austria	Austrian Regulatory Authority for Broadcasting and Telecommunications (RTR)	http://www.rtr.at/
Brazil	Agencia Nacional de Telecomunicacoes (ANATEL)	http://www.anatel.gov.br/
Canada	Canadian Radio Television and Telecommunications Commission	http://www.crtc.gc.ca/
Caribbean	Eastern Caribbean Telecommunications Authority (ECTEL)	http://www.ectel.int/
Chile	Subsecretaria de Telecomunicaciones (SUBTEL)	http://www.subtel.cl/
Finland	Ministry of Transport and Communications	http://www.mintc.fi/
France	Autorité de Régulation des Communications Électroniques et des Postes (ARCEP)	http://www.arcep.fr/
Germany	The Federal Network Agency	http://www.bundesnetzagentur.de/
Greece	National Telecommunications and Post Commission (EETT)	http://www.eett.gr/
Hong Kong	Office of the Communications Authority (OFTA)	http://www.ofta.gov.hk/
Iceland	Ministry of Interior	http://eng.innanrikisraduneyti.is/
India	Telecom Regulatory Authority of India (TRAI)	http://www.trai.gov.in/
Ireland	Office of the Director of Telecommunications Regulation (ODTR)	http://www.odtr.ie/
Italy	Italian Communications Authority	http://www.agcom.it/
Japan	Ministry of Internal Affairs and Communications	http://www.soumu.go.jp/
Jordan	Telecommunication Regulatory Commission	http://www.trc.gov.jo/
Lithuania	Lithuanian Communications Regulatory Authority (CRA)	http://www.radio.lt/
Macau	Office for the Development of Telecommunications and Information Technology	http://www.gdtti.gov.mo/
Malaysia	Malaysian Communications and Multimedia Commission (MCMC)	http://www.skmm.gov.my/
Malta	Malta Communications Authority	http://www.mca.org.mt/
Mexico	Comisión Federal de Telecomunicaciones (COFETEL)	http://www.cft.gob.mx/
Netherlands	Independent Post and Telecommunications Authority (OPTA)	http://www.opta.nl/
New Zealand	Commerce Commission of New Zealand	http://www.comcom.govt.nz
Nigeria	Nigerian Communications Commission	http://www2.ncc.gov.ng/
Norway	Norwegian Post and Telecommunication Authority	http://www.npt.no/
Pakistan	Pakistan Telecommunication Authority	http://www.pta.gov.pk/
Philippines	National Telecommunications Commission (NTC)	http://www.ntc.gov.ph/
Portugal	Autoridade Nacional de Comunicações (ANACOM)	http://www.anacom.pt/
Russia	Ministry for Communications and Informatization of the Russian Federation	http://minsvyaz.ru/
Saudi Arabia	Communications & Information Technology Commission (CITC)	http://www.citc.gov.sa/
Singapore	Infocomm Development Authority of Singapore (IDA)	http://www.ida.gov.sg/
South Africa	The Independent Communications Authority of South Africa (ICASA)	http://www.icasa.org.za/
Spain	Comision del Mercado de las Telecomunicaciones (CMT)	http://www.cmt.es/
Sweden	The National Post and Telecom Agency (PTS)	http://www.pts.se/
Taiwan	National Communications Commission	http://www.ncc.gov.tw/
Turkey	Telekomunikasyon Kurumu	http://www.tk.gov.tr/
United Kingdom	UK Office of Communications (OFCOM)	http://www.ofcom.org.uk/
United States	Federal Communications Commission National Telecommunications and Information Administration	http://www.fcc.gov/ http://www.ntia.doc.gov/

a few allocations for other important molecules. Modifications have been made in subsequent WRCs. Fig. 3 provides a summary of RAS allocations. Again, it is important to note that this figure is not the full story and that the Regulations contain much more detail in the effort to effectively and collaboratively share this immensely important resource.

The Earth Exploration-Satellite Service (EESS) was recognized at WARC-71, noting that other associated scientific services also exist, e.g., the meteorological services. Frequencies are allocated for specific atmospheric and geophysical features, and for transmission of data back to the Earth. Fig. 4 provides a summary of EESS allocations.

The CORF, CRAF, and ITU handbooks mentioned earlier have a good deal of useful information regarding the allocations, and the various applicable rules and recommendations. Appendix F of the CORF handbook [28] lists the ITU recommendations that pertain to radio astronomy and remote sensing.

VI. TECHNICAL ISSUES

Spectrum allocations and regulations have an impact in instrument design and planning. These relate to in-band emission, out-of-band emission, sidelobe levels, propagation direction, and so on. Proper design of both the transmitter and receiver can help mitigate deleterious impacts of RFI. The goal is an effective collaboration among all of the users coexisting in time, frequency and location. Section VI of the ITU-R RR [4] defines some of the technical terms as they are used in a regulatory environment.

TABLE III
LIST OF SELECTED ONLINE FREQUENCY ALLOCATION TABLES AND TOOLS

Org	URL	Description
ITU-R	http://www.itu.int/pub/R-REG-RR/	ITU-R Radio Regulations
FCC	http://www.fcc.gov/oet/spectrum/table/fcctable.pdf	US FCC allocations
NTIA	http://www.ntia.doc/gov/page/2011/manual-regulations-and-procedures-federal-radio-frequency-management-redbook/	US Federal allocations and rules – "Redbook"
	http://www.ntia.doc.gov/files/ntia/publications/spectrum_wall_chart_aug2011.pdf	US allocation poster
EFIS	http://www.efis.dk/views2/search-allocations.jsp/	EFIS allocation search
Spectrum Wiki	http://www.unwantedemissions.com	US wiki community search and information site
ACMA	http://www.acma.gov.au/webwr/radcomm/frequency_planning/spectrum_plan/aust_rf_spectrum_plan.zip	Australian allocations
	http://www.acma.gov.au/webwr/radcomm/frequency_planning/spectrum_plan/aust_rf_spectrum_allocations_chart.pdf	Australian allocation poster

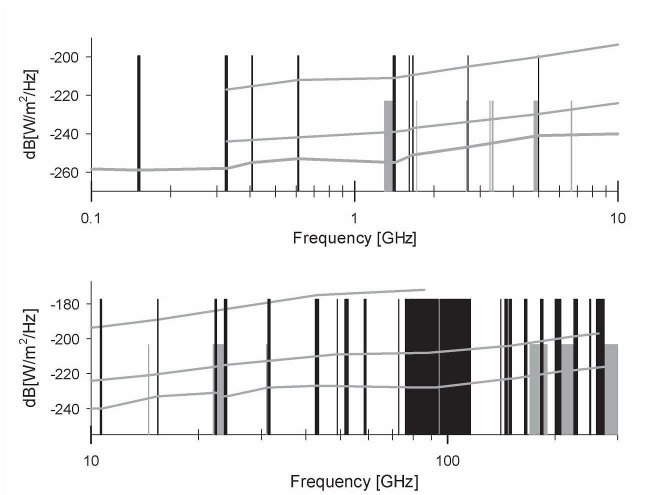

Fig. 3. RAS allocations showing a superset of the ITU, regional and US allocations. Primary allocations are the taller black blocks, whereas secondary allocations are the shorter gray blocks. The top panel shows the allocations up to 11 GHz and the bottom panel shows 11–240 GHz. The gray lines in both show the Recommendation ITU-R R.769 levels for: (lower line) continuum, (middle line) spectral line, and (top line) long baseline interferometry.

For sensitive scientific observations, there are essentially three regimes of interference.

1) Very high levels that drive electronics into saturation. These can render the entire receiver useless for the duration of those signals. If these occur in a protected band, the offender, if identified, should be contacted and advised to find an ITU-recommended means of mitigation or to cease transmission. If the issue persists, one should contact the appropriate regulator. If they are not in a protected band, one may approach the transmitter controller to help on a voluntary basis; the receiver, however, has no right to protection and must work around the issue as best as possible, for example by using a notch filter or by changing bands.
2) High identifiable levels that may be excised or mitigated. The same band-protection issues apply, but it may be possible to share the band effectively with only minor impact by employing fairly simple and effective techniques of frequency and/or time excision, if the interferer does not occupy a large fraction of the frequency band or integration time.
3) Low levels of interference that are only seen in long integrations or as a general increase in the noise level. These are the most pernicious, as they can be difficult to identify and deal with. When it can be tracked down, this interference is often found to be the result of out-of-band interference from other services or of other pieces of equipment that may incidentally radiate. Intermittent and moving interference sources in this regime are particularly difficult to deal with.

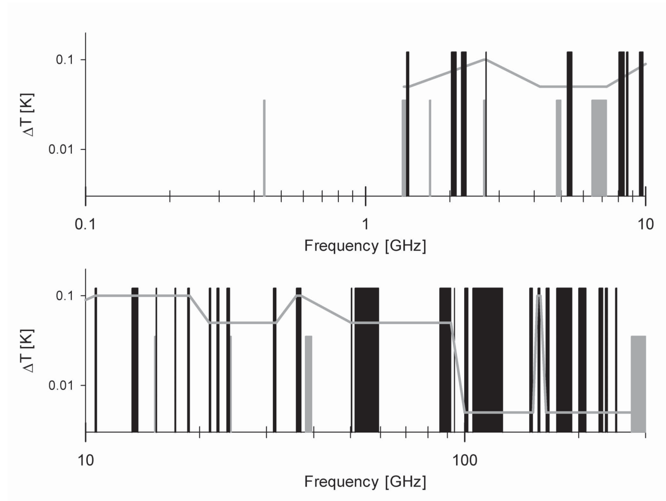

Fig. 4. EESS (active and passive) allocations showing a superset of the ITU, regional and US allocations but excluding communication allocations. Primary allocations are the taller black blocks, whereas secondary allocations are the shorter gray blocks. The top shows the allocations up to 11 GHz and the bottom panel shows 11–240 GHz. The gray lines in both show the Recommendation ITU-R RS-2018-2 sensitivity levels.

The above regimes relate to in-band emission as well as excessive out-of-band or spurious emission from other bands that either may be insufficiently filtered at the band edges or have high levels of power in intermodulation products that fall into an allocated band.

The different services may have different considerations and approaches based on the observing mode and location. For example, radio telescopes all point away from the Earth, hence space-based transmitters have the greatest potential for causing strong interference as they can fall within the near-in sidelobes of the radio telescope. However, a fixed (and typically remote) location of a radio observatory makes it easier to protect from terrestrial emissions based on location; this is a key aspect for protection of radio astronomy observations. On the other hand, the EESS looks down on the Earth and is constantly scanning different locations, thus these techniques are not appropriate, and spectral allocations are more important.

A. Radio Astronomy Service

For radio astronomy, levels of harmful interference are provided in recommendation ITU-R RA.769. In terms of protection thresholds, one must be working in an appropriately allocated band although some footnotes for other bands encourage all practicable efforts to adhere to this recommendation. The recommendation is specified as both a power flux density at the telescope site, as well as spectral power flux density. It is specified in terms of both a single-dish receiver and a long baseline interferometer, which provides an additional level of coping with interference.

Three principles are used in deriving the recommendation.

1) The maximum level of interference that can be tolerated is that which increases the overall output power of the receiver by 10% of the root mean square (rms) noise level averaged over 2000 s.
2) Interference levels are assumed to come in from the sidelobe of an antenna, as there is not much that can be done if one points a large antenna directly at the source of interference. Generally, a sidelobe level of 0 dBi is assumed, as discussed in the ITU handbook. A standard reception pattern of a large antenna is given in recommendations ITU-R SA.509, S.580, and S.1428.
3) As mentioned above, the averaging time used in the calculations is 2000 s as a representative value.

The resulting sensitivity thresholds are shown in Fig. 3, superimposed on the allocation summary. The expectation is not zero, but that the harmful interference from a system or satellite network should impact less than 2% of the aggregate data, and from all systems less than 5% of the aggregate data (ITU-R RA.1513).

In the ITU-R radio regulations, Chapter VI contains much practical information on transmission rules. For example, Article 22 therein discusses the characteristics of downlinks that may impact radio astronomy.

As mentioned earlier, radio observatories are typically located in remote areas, to ease the impact of interference. Telescopes operating at lower frequencies (below about 15 GHz) are typically in valleys, which provide additional interference shielding. Telescopes operating at higher frequencies are located higher on mountaintops to get above as much of the atmosphere (particularly water vapor) as possible. Analogously to national parks, some countries designated certain regions as radio quiet zones (RQZs) to facilitate this science. RQZs have an additional level of regulatory protection to protect the spectrum.

In the United States, the National Radio Quiet Zone (NRQZ) was established by the FCC in 1958 to protect the National Radio Astronomy Observatory (NRAO) located at Green Bank, WV, as well as the U.S. Navy Information Operations Command located at Sugar Grove, WV [30]. The NRQZ encompasses approximately 34 000 km^2 of land in Virginia and West Virginia and is bounded by latitudes 37° 30′ 0.4″ N and 39° 15′ 0.4″ N and by longitudes 78° 29′ 59.0″ W and 80° 29′ 59.2″ W. All new or modified fixed licenses transmitters inside the NRQZ require coordination against set thresholds.

The U.S. supports another RQZ in Colorado, the Table Mountain field site and RQZ [31], which is a site that can be used for testing of sensors or other radio studies.

In preparation for a new large international radio telescope called the Square Kilometer Array (SKA), both Australia and South Africa have protected remote areas. In Australia, the Midwest RQZ [32], [33] was established in 2005 to protect a large area in Western Australia. In South Africa, the Astronomy Geographic Advantage Act was passed in 2007, to protect a large area of the Northern Cape [34].

Some observatories in Europe have some level of local protection, which is discussed at the CRAF web-site. In addition, Chile has an RQZ around the Atacama large millimeter/submillimeter array.

B. Earth Exploration-Satellite Service

For EESS, levels of sensitivity are provided in recommendation ITU-R RS.2017. These are specified in terms of rms radiometric temperatures (ΔT_e). The interference levels shown are determined such that unwanted interference levels are below 20% of $k_B \Delta T_e B$, where k_B is Boltzmanns constant and B is the reference bandwidth.

The ITU also recommends that the availability of EESS passive sensor data should exceed 99%, with typically a threshold of 99.99%. The ITU-R RS and SA recommendations have a number of documents for sharing of satellite-based systems. These may be found under www.itu.int/pub/R-REC.

C. Intentional, Unintentional, and Incidental Radiation

The preceding discussion has dealt with potential interference from licensed transmitters that is, devices whose licensed intent is to radiate power. However, all electronic devices radiate electromagnetic waves of some power and frequency some worse than others. Issues related to this unlicensed intentional, unintentional, and incidental radiation are addressed in spectrum management and regulation as well. In the United States, the Code of Federal Regulations Title 47 (FCC) Part 15 is the document that contains such regulatory information the so-called Part 15 devices [35].

RFI from Part 15 devices can impact both the scientific instrument itself (for example, auxiliary equipment in a packaged sensor) and the operation of an observatory. The effect is more important at lower frequency observatories, but even millimeter-wave observatories can be impacted via an intermediate frequency. Most electronics require additional screening to coexist at a radio observatory.

All equipment in and around a scientific receiver should be tested to determine its suitability for that location. There are many stories of seemingly innocuous pieces of equipment tucked away in locations around the observatory being the source of frustrating and harmful interference until located and powered down or shielded.

The broad area coverage of satellite-based sensors makes them vulnerable to inference from fixed or moving interference sources of all types. The RFI from these devices can significantly hinder the collection of critical environmental measurements at or near the interference source and, thereby adversely impact weather services. The density of the unlicensed active devices is a particular concern because the sensor will integrate the interference of all the systems in view at a given time. Out-of-band emissions from other services or illegal transmitters are frequent sources of interference for EESS.

VII. Conclusion

Although scientists who use the electromagnetic spectrum need not be experts in spectrum management, it is important that they understand the general environment in which their use of the spectrum resides. Typically, use is governed by the laws of the country of residence, which are generally aligned with the ITU-R Radio Regulations in terms of allocations. Understanding spectrum use more broadly can help in designing instruments that work effectively in the actual radio frequency environment as well as identifying sources of interference. EESS, with its downward-looking satellites that see the entire globe, are more exposed to this international milieu of spectrum use.

The allocations that are currently in place have been set over time via a complex series of meetings and processes. Although these allocated bands are used heavily, modern instruments typically work over broader frequency ranges in order to achieve their scientific goals. Radio astronomy has generally located its observatories in remote locations in order to continue its sensitive measurements. Proper system design for out-of-band rejection and controlling system intermodulation is important, so understanding the frequency structure in which a sensor will operate is critical.

As a common resource to us all, the electromagnetic spectrums shared use carries with it a shared responsibility among its large community of users in order to avoid a tragedy of the commons [36]. The recent study about the future scientific use of the spectrum [29], surveys the landscape and options for this purpose. This report recognizes the need for a win-win scenario of collaboration and regulation and that all users must share in this responsibility.

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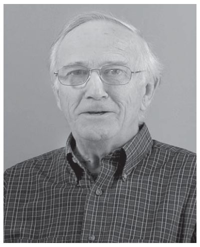

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