The Future of Regulations for Radio Astronomy

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For approximately 50 years, the period that goes from K.G. Jansky's discovery of cosmic radio waves in 1932, to the launch of the first of non-geostationary satellite systems in the early 1980s, the protection of radio astronomy installations from man-made interference was relatively simple. The problem could be characterized as follows: given a large antenna (a radio telescope during this time period was most likely a single dish) at a known location, how could it best be protected from interference from one or more transmitter(s) that are a) either fixed at known location(s) or, b) moving relatively slowly; and that are radiating either co-frequency or in a neighboring band. The first line of defense, of course, has been to situate the observatory as far as possible from sources of man-made radio noise.

Over these years radio astronomy became integrated into the elaborate international and national regulatory structures conceived for the protection of all radio equipment. Radio astronomy was recognized as a "radio service" and the band 1400-1427 MHz was allocated to passive research at the 1959 World Radio Conference in Geneva. A number of relatively narrow bands have been allocated to radio astronomy at dm-, cm- and mm- wavelengths at successive World Radio Conferences held by the International Telecommunication Union (ITU). Much of the spectrum between 70 and 275 GHz was reallocated to radio astronomy at the World Radiocommunication Conference of 2000 (WRC-2000), most of it shared with active radio services. As long as they observed in bands allocated to radio astronomy, radio telescopes were protected by national and international regulations from transmissions by other licensed services. The Radio Regulations (RR), an international treaty that regulates the uses of the radio spectrum beyond national frontiers, provides for the registration of radio telescopes, so that interference in radio astronomy bands could be minimized at these sites. A series of non-mandatory ITU Recommendations that provide information about the level of protection needed at radio astronomy sites, which are the frequency bands of most importance to radio astronomers, and other matters of interest were adopted over the years. In addition, because of the remoteness of most observatories, observing outside radio astronomy bands was possible most of the time, even in the bands for which no regulatory protection was available. If all else failed bad data could be thrown out, provided it comprised only a small fraction of the observations.

For radio astronomers, the advent of non-geostationary (NGSO) satellite systems, (e.g. GLONASS, GPS or Iridium) that begun to be deployed in the early 1980's, dealt a blow to this regulatory protection scheme. NGSO systems provide coverage everywhere on Earth, at all times, and for the first time since the beginnings of radio astronomy denied access to some bands completely. NGSO satellites orbit at heights of a few hundred to ten thousand km above the Earth, move fast in and out of the sidelobes of the telescope and many have multiple beams. The astronomers' problem was made worse because the unwanted emissions of some systems made highly sensitive observations difficult and in some cases impossible even when those observations were being made at frequencies far from the band intentionally occupied by the satellite transmission, and even in radio astronomy bands. While radio telescopes continued to be remotely located to avoid man-made interference as much as possible, remote location did no longer afford protection from NGSO systems. Throwing out the occasional bad data point was no longer an option either, as NGSO satellites interfered with observations all the time. To defend their access to the spectrum radio astronomers attempted to obtain more stringent regulations during much of the 80's and 90's. In particular, they tried to

- Drive new allocations to satellite downlinks as far away as possible from radio astronomy bands. This effort, made more difficult by the numerous bands of interest to astronomers, met with some limited successes, but failed to be adopted by Administrations as a guiding principle for new allocations.
- Place mandatory regulatory limits on unwanted emissions from satellite borne transmitters. Four specialized ITU Task Groups (TG 1/3, 1/5, 1/7 and 1/9) have been convened since the mid-90s to deal with this issue. These task groups placed a huge burden of manpower and cost on the radio astronomy

community and, fair to say, on the other communities that participated in them as well. Some general rules were adopted for space stations and spurious emissions were restricted, but the outcome is far from what is needed for effective protection of radio astronomy.

Progress was made in the following areas:

- Mandatory out-of -band emission limits have been adopted for the protection of some radio astronomy bands from the unwanted emissions of satellite systems that operate nearby in the spectrum. These emission limits are contained in footnotes to the international Table of Allocations (Art. 5 of the RR)
- World Radiocommunication Conference 2003 (WRC-03) adopted a Resolution [Res**. 739 (WRC-03)**], containing guidance to Administrations on how to resolve problems between the radio astronomy and satellite services. This Resolution also contains threshold levels that can be used to trigger consultations between Administrations.
- A Recommendation (**Rec. RA.1513**) quantified the percentage of acceptable data loss to radio astronomy due to interference from other services
- Recommendations were developed to calculate threshold levels of interference by NGSO systems, through the adoption of a new methodology.

The existing regulatory structures have become further strained from a radio astronomy point of view in the last decade. The science increasingly requires access to all, or most of the spectrum, because interest in researching the early Universe and therefore highly red-shifted spectral lines increased enormously in recent years. Radio astronomy allocations are narrow, and cover only a limited range of Doppler shifts at cm- and dm-wavelengths. In some cases, particularly when lines were discovered in the last 25 years, there is no radio astronomy allocation to cover it at all. Table 1, that shows an extract from Rec. ITU-R RA.314 on Radio Frequency Lines of Greatest Importance to Radio Astronomy illustrates the point. Notes in the last column indicate those cases when the width of the band allocated to radio astronomy is less than the minimum recommended, that in any event extends in red-shift only out to the Virgo cluster (Note 3), or when the line is not even mentioned in the RR, i.e. there is no allocation to cover it (Note 6).

Table 1
From: Radio Frequency Lines of Greatest Importance to Radio Astronomy
Recommendation ITU-R RA.314

Substance	Rest frequency	Suggested minimum band	Notes (1)
Deuterium (DI)	**327.384 MHz**	**327.0- 327.70 MHz**	
Hydrogen (HI)	**1 420.406 MHz**	**1 370.0-1 427.00 MHz**	**(2)(3)**
Hydroxyl radical (OH)	**1 612.231 MHz**	**1 606.8-1 613.80 MHz**	**(4)**
Hydroxyl radical (OH)	**1 665.402 MHz**	**1 659.8-1 667.10 MHz**	**(4)**
Hydroxyl radical (OH)	**1 667.359 MHz**	**1 661.8-1 669.00 MHz**	**(4)**
Hydroxyl radical (OH)	**1 720.530 MHz**	**1 714.8-1 722.20 MHz**	**(3), (4)**
Methyladyne (CH)	**3 263.794 MHz**	**3 252.9-3 267.10 MHz**	**(3), (4)**
Methyladyne (CH)	**3 335.481 MHz**	**3 324.4-3 338.80 MHz**	**(3), (4)**
Methyladyne (CH)	**3 349.193 MHz**	**3 338.0-3 352.50 MHz**	**(3), (4)**
Formaldehyde (H_2CO)	**4 829.660 MHz**	**4 813.6-4 834.50 MHz**	**(3), (4)**
Methanol (CH_3OH)	**6 668.518 MHz**	**6 661.8-6 675.20 MHz**	**(3)**
Helium ($^3He^+$)	**8 665.650 MHz**	**8 657.0-8 674.30 MHz**	**(3), (6)**
Methanol (CH_3OH)	**12.178 GHz**	**12.17 - 12.19 GHz**	**(3), (6)**
Formaldehyde (H_2CO)	**14.488 GHz**	**14.44 - 14.50 GHz**	**(3), (4)**

In response to the requirements of the science, many radio telescopes in operation have been outfitted with extremely broadband receivers, without regard to frequency allocations. This tendency is even more conspicuous for the next generation of radio telescopes that are under construction or are being planned, e.g. ALMA or the SKA. Interferometers are, however, much less susceptible to interference than single dish telescopes.

On the side of the active services, transmitters have become also less and less confined to specific frequency bands, and low power devices that require no license to operate have become ubiquitous. The last decade has seen the introduction of ultra-wide band devices, software defined and cognitive radio. The general tendency is well described in the program advertising the First IEEE International Symposium on New Frontiers in Dynamic Spectrum Access Networks, to be held in November at Baltimore, in the USA:

> “Current radio technology trends promise to enable "Dynamic Spectrum Access" (DSA) networks, using wide-band spectrum sensing, real-time spectrum allocation and acquisition, and infrastructureless mesh networks. Not only do these trends challenge the existing technologies, they challenge the traditional "command and control" methods of allocating and licensing spectrum by government fiat…Today we are moving away from command and control approaches to spectrum management toward market-based methods and expanded unlicensed use. Tomorrow technology trends are forcing an inflection point in policy, leading to the adaptation of rules and practices radically different from today’s regulations”

It appears therefore timely for the radio astronomy community to initiate a debate about the appropriateness of changes to the current regulatory structure. For example, should radio astronomers continue to maintain that all relatively narrow bands allocated to radio astronomy below about 70 GHz are needed and useful? Should the Rec. 769 levels continue to be used as the cornerstone for the protection of the next generation of instruments? Should the radio astronomy community attempt to trade protection in many bands at all radio astronomy sites them for a high level of protection across <u>most</u> of the spectrum at a few places worldwide? How should the radio astronomy community attempt to influence the evolution of the regulatory structure? For example, should instrument specific levels that take into account the geographical outlay and frequency coverage of an instrument be calculated on a case-by-case basis? How can radio telescopes develop/take advantage of appropriate mitigation techniques and what are the limitations of those techniques? How can dynamic, cognitive methods be taken advantage of to benefit passive users of the spectrum, and how can such techniques be reflected in the regulations?

While these questions need to be considered and eventually settled, it should be emphasized that the current regulatory structure has served radio astronomy well for many years, and there should be no rush to change it. Changes, if any, should be adopted only after a thorough discussion of the issues and possible options, and only after a consensus has been achieved by the international radio astronomy community.