Frequency Management for Remote Sensing

David Kunkee
Chair, Frequency Allocations in Remote Sensing (FARS) Technical Committee
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As many of you are aware there are currently three major Earth science missions under development that will be designed to make passive measurements in the L-band region which, in general, is heavily utilized by active radio services. The band 1400 – 1427 MHz is of course protected from all radio emissions and is reserved for passive radio services only. However, this does not prevent out-of-band, spurious, and harmonic emissions originating from properly-operating transmitters from occurring in the "protected" band. Sensitive radiometers with limited out-of-band rejection may also respond to strong signals in adjacent bands. Recently, aircraft experiments and RFI mitigation studies have shown that many signals can be detected within 1400 – 1427 MHz and that operation outside this band segment is much worse. Indeed, discussions about RFI are now common in conference sessions related to microwave remote sensing.

Given the scientific need and significant investment in spaceborne microwave remote sensing at the lower frequencies (<15 GHz), it is critical that remote sensing scientists and engineers understand the RF environment in this spectral region. And then accordingly, the importance of the political and technical aspects of frequency management that are our best chance of ensuring continued availability of useable spectrum for remote sensing and Earth science measurements. This article will provide a short introduction to the frequency management process as it relates to remote sensing. Links to selected websites are provided for additional information at the end.

For the purpose of frequency management, radio transmitters are separated in to well-defined radio services such as Fixed Service (FS) for transmitters operating from fixed terrestrial locations, Mobile Service (MS) for transmitters operating mobile, Radiolocation for radars etc. Remote sensing of the Earth performed from space is also defined to be a radio service: the Earth Exploration Satellite Service (EESS). There are both active and passive subcategories to the EESS. Each radio service is allocated specific frequencies where they can operate. Any particular band segment can be allocated to many radio services so a hierarchy is set up to define which services can and can not interfere with each other when they must share a band segment. This achieved by defining three types of allocations: primary, secondary and footnote. Stated simply, services that have a secondary allocation or footnote, must not interfere with services that have a primary

allocation within that segment and must accept any interference that may occur from the primary service. Services assigned a footnote within a band typically enjoy little benefit. Two services may also be authorized co-primary. In this case, the two services must work out any interference issues among themselves. Other examples are services allocated primary or secondary on a "non-interfering basis", or limitations placed on effective isotropic radiated power (EIRP) of transmitters operating within a band segment. For a chart that shows the U.S. frequency allocations, see the following URL: http://www.ntia.doc.gov/osmhome/allochrt.html

World-wide radio regulations are administered by the International Telecommunication Union (ITU) headquartered in Geneva, Switzerland. In order to perform their administration, the ITU divides the world into three regions as shown in Figure 1. Europe and Africa are within Region 1, North and South America are within Region 2 and India, Japan, Australia and Southeast Asia comprise Region 3. The ITU sponsors the World Radiocommunication Conference (WRC), held every three years in recent times, in order to determine radio regulations by international agreement.

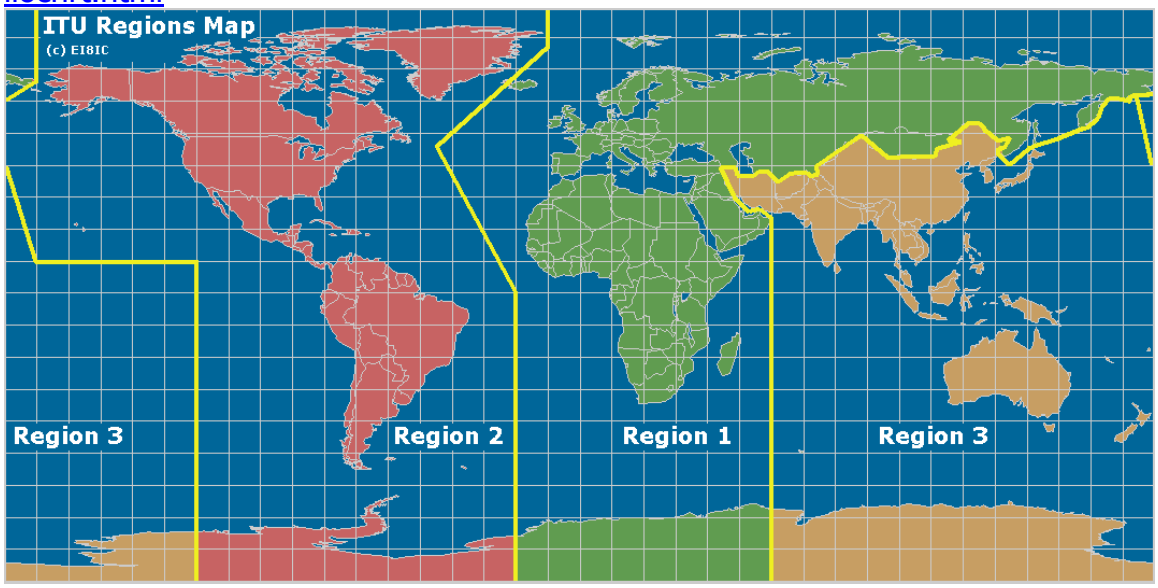

Figure 1. International Telecommunications Union (ITU) Regions

With the establishment of internationally-agreed allocations, local and national governments provide the authority for radio services to operate within each segment consistent the agreements. Within the U.S., authority to operate commercial (non-Government) radio services is granted by the Federal Communications Commission (FCC). Radio services operated by the Government are administered by the National Telecommunication and Information Administration (NTIA).

Radio receivers are registered and transmitters must be licensed.
There are three types of services within EESS: 1) EESS-passive operation includes observation of upwelling emissions from the earth and its atmosphere, 2) active remote sensing (EESS-active), where the Earth and its atmosphere are probed by transmitting radio signals and observing the return, and 3) communication with the satellites carrying EESS sensors for the purposes of commanding and to downlink observed data - these transmitters are also considered to operate within the EESS.

Passive microwave remote sensing of the atmosphere takes advantage of absorption in the Earth's atmosphere to probe temperature and moisture profiles and to derive a variety of additional products from those measurements.

Table 1. Frequencies for passive remote sensing of the atmosphere

Frequency	**Constituent**	**Data Product**
22.235 GHz	Water	Total Atmospheric Water
50 – 60 GHz	Oxygen	Atm. Vertical Temperature Profile
183.31 GHz	Water	Atm. Vertical Moisture Profile

Characteristics of the Earth's surface are observed using window frequencies of the atmosphere. Multiple bands are generally required to resolve parameters such as sea surface temperature, sea surface winds, soil moisture, rain, snow /ice cover, etc. However, the atmospheric window frequencies are located in regions of the spectrum most utilized by communication systems and may experience interference, particularly below ~15 GHz, where terrestrial and Earth-to-Space communication services are prevalent. Table 2 shows some frequency bands commonly used by EESS-passive systems for Earth surface observation:

Table 2. Frequencies commonly used for passive remote sensing of the Earth's surface

Frequency	**~Zenith Opacity (clear)**	**Parameters**
6.9 GHz	0.03 dB	Sea Surface Temperature/Soil Moisture
10.6 GHz	0.06 dB	SST, Rain
18.6 GHz	0.3 dB	Surface Obs, Rain
36.5 GHz	0.6 dB	Surface Obs, Rain
89.0 GHz	>1.0 dB	Atmosphere, Clouds, Imaging, Rain

Active sounding (EESS-active) is utilized for ocean altimetry, precipitation retrieval, and sea surface winds (scatterometry). Typical frequencies of operation are shown in Table 3 and some common data downlink frequencies are shown in Table 4.

Table 3. Frequencies commonly used for active microwave remote sensing:

Frequency	Parameters	Reference:
13.8 GHz	Rain/ Altimetry/ Sea Winds	TRMM
35.5 GHz	Rain/Altimetry	DPR/GPM
94.1 GHz	Clouds	CloudSat

Table 4. A partial list of frequencies used for data downlinks and relay from EESS satellites.

Frequency	Description	Bands
8.025, 8.175, 8.400	OES Downlinks	X-band downlinks
13.75 GHz	TDRSS relay	Ku-band
25.5 – 27.00 GHz	Wideband downlink	Ka-band downlinks

Compatibility between radio services that must share spectrum is considered in detail at the national and international level within the frequency management process. Before a service can be assigned a new allocation in a new band it must show that it is compatible with existing services in that band. Each service defines what "acceptable" interference is to them. The maximum acceptable interference level for the EESS depends on the characteristics of the interference and are stated as: 1) data loss < 5% of the time for randomly occurring interference – RFI which is not always in the same place and time, 2) data loss < 1% of the time for interference occurring in the same location, and 3) in special circumstances where the interference may have dire effects (e.g. tied directly to critical operational weather forecasting or function), interference must be < 0.01%.

At the international level, study groups are formed within the ITU to address frequency management issues of related radio services. The Science Services are addressed by Study Group 7 (SG7). Within SG7, there are several working parties that concentrate on problems related to specific services. Remote sensing and EESS are served by Working Party 7C (WP7C). Within the U.S. regulatory structure, the Department of State chairs the U.S. National Committee which organizes a parallel structure of study groups and working parties. Accordingly, U.S. WP7C addresses detailed frequency management issues for EESS. The U.S. WP7C consists of individuals that are fluent in the scientific applications as well as the basic frequency management structure. Upon completion of its studies on a

specific issue, U.S. WP7C may provide a report on their findings and recommendations. Some reports from WP7C as well as other studies on interference levels and compatibility between radio services can be found on the FARS website for reference: http://www.ewh.ieee.org/soc/grss/fars/index.html.

Recommendations from the ITU provide a basis for much of the work performed in WP7C. For instance, ITU Recommendations ITU-R SA.1028 and SA.1029 describe the performance basis and interference criteria for satellite passive remote sensing on a band-by-band basis. The ITU recommendations for active remote sensing are contained within ITU-R SA.577 and SA.1166. Overall, there are many ITU recommendations addressing interference levels, performance, and operating characteristics of the various radio services. The recommendations are updated periodically and available from the ITU for a nominal fee: http://www.itu.int/publications/online/index.html

The World Radio Conference (WRC) is the meeting the ITU uses to determine the radio regulations. Before an item can be placed on the agenda at a WRC meeting, it must be put on a future WRC agenda at an earlier WRC. During the time between meetings (3 – 6 years) each agenda item is studied to determine the impact of the proposed change and the study results returned to a WRC meeting for action. Figure 2 illustrates the process involved for changing a frequency allocation. In this example the change originates with NASA shown in the lower left.

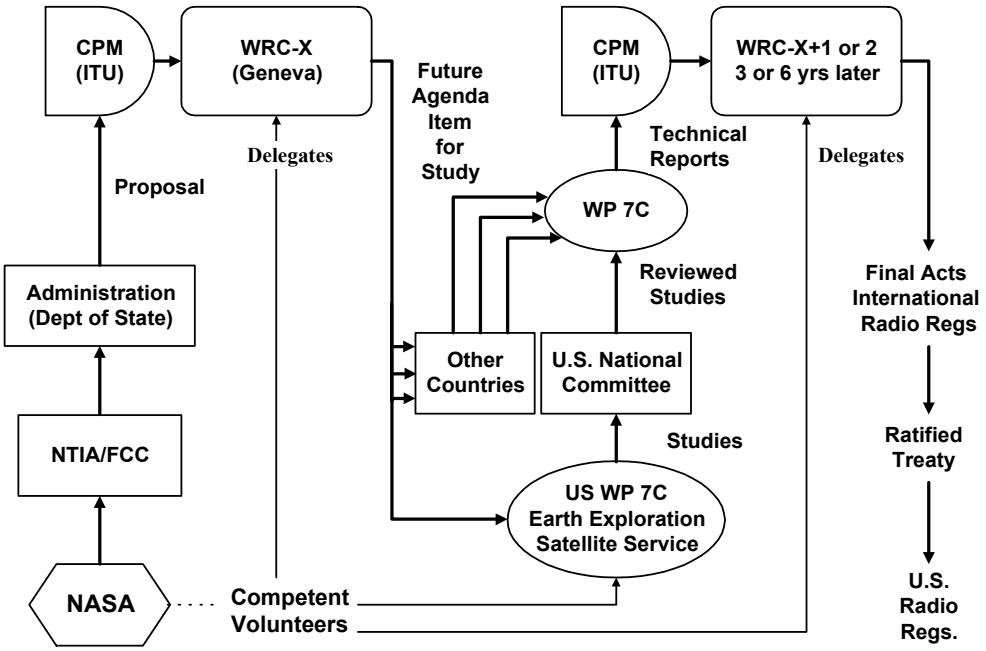

Figure 2. Process for changes to a frequency allocation. (Courtesy C. Wende)

The timeline for changes to frequency allocation are dictated in part by the periodicity of the meetings required to reach agreement between all of the concerned parties. Table 5 below, shows the occurrence of the major meetings that appear in Figure 2.

Table 5. Periodicity of major meetings involved in the international frequency management process.

Meeting	**How Often**	**Length**
WRC	Every ~3 years	1 month
Conference Prep Meeting (CPM)	2 every ~3 years	??
ITU WP7C	2 per year	7 – 10 days
USA WP7C	4 – 6 weeks	1 or 2 days
SFCG	1 per year	2 weeks
NASA – ESA	1 per year	USA/EU

For a summary of results from past WRCs and notes on planning for future WRCs, please see the following URL:
http://www.itu.int/ITU-R/conferences/wrc/index.asp

Frequency management is a complicated mix of consensus building, technical detail, and political process. Involvement in this process is necessary to ensure our scientific and operational measurements do not become permanently contaminated by other radio services. Secondly, awareness and working knowledge of other radio services and their potential to impact EESS observations is necessary for instrument designers and can aid consensus building within the EESS community on frequency management issues. Concern about RFI is highest within regions of the spectrum that are highly utilized such as frequencies below ~15 GHz where contamination of EESS observations may routinely occur.

For more information regarding the frequency management process:

NASA Spectrum Management Office:
http://spectrum.nasa.gov/
http://spectrum.nasa.gov/references/rf_policies/index.aspx

Department of Commerce Office of Radio Frequency Management
http://www.orfm.noaa.gov/#About%20Us1

NTIA:
http://www.ntia.doc.gov/ntiahome/aboutntia/aboutntia.htm

ITU Radiocommunications Sector:
http://www.itu.int/ITU-R/

FCC:
http://www.fcc.gov/aboutus.html

IEEE-GRS Frequency Allocations in Remote Sensing (FARS):
http://www.ewh.ieee.org/soc/grss/fars/index.html