Principles of Spectrum Management

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Abstract

This paper describes the basic principles of the main work related to frequency spectrum management consisting of spectrum engineering, spectrum planning, spectrum authorization, and spectrum monitoring.

1. Spectrum Management Definition

Spectrum management is the part of telecommunications policy and regulation that the spectrum is allocated for particular uses, is supposed to be equipped with the specific technical and service rules, to ensure the performance of industry and of institutions devoted to ensuring public safety, security and national defense. In detail, spectrum management consists of:

- a. Spectrum engineering
- b. Spectrum planning
- c. Spectrum authorization
- d. Spectrum monitoring.

2. Principles of Spectrum Engineering

Spectrum engineering work has been done for hundreds of years by experts in colleges and industries, and by The International Telecommunication Union set out in Radio Regulation documents that are periodically updated, and the latest edition currently in effect is the 2016 edition.

In the document Radio regulation division of the region in the world into three regions, wherein each region has been assigned different frequency allocation. Figure 1 presents the division of the world into 3 regions of Radio Regulation.

Figure 1. For the allocation of frequencies the world has been divided into three Regions

In each region a different frequency allocation is applied, in which the steps taken by The International Telecommunication Union when compiling the frequency allocation table are as follows:

- 1) Assign the Services which are the use of the frequency spectrum.
- 2) Grouping the spectrum into 9 frequency bands.
- 3) Divide each frequency band into several sub-bands.
- 4) Allocate each sub-band to use one or more services.

2.1. Radio Communication Service

Radio Communication service is a service involving the transmission, emission and/or reception of radio waves for specific telecommunication purposes, in the Radio regulation, unless otherwise stated, any radio communication service relates to terrestrial. Radio communication services that are assigned the frequency allocation by The International Telecommunication Union are as follows:

- 1) Fixed service: A radio communication service between specified fixed points.
- 2) Fixed-satellite service: A radio communication service between earth stations at given positions, when one or more satellites are used; the given position may be a specified fixed point or any fixed point within specified areas; in some cases this service includes satellite-to-satellite links, which may also be operated in the inter-satellite service; the fixed-satellite service may also include feeder links for other space radio communication services.
- 3) Inter-satellite service: A radio communication service providing links between artificial satellites.
- 4) Space operation service: A radio communication service concerned exclusively with the operation of spacecraft, in particular space tracking, space telemetry and space tele-

command. These functions will normally be provided within the service in which the space station is operating.

- 5) Mobile service: A radio communication service between mobile and land stations, or between mobile stations (CV).
- 6) Mobile-satellite service: A radio communication service: – between mobile earth stations and one or more space stations, or between space stations used by this service; or – between mobile earth stations by means of one or more space stations. This service may also include feeder links necessary for its operation.
- 7) Land mobile service: A mobile service between base stations and land mobile stations, or between land mobile stations.
- 8) Land mobile-satellite service: A mobile-satellite service in which mobile earth stations are located on land.
- 9) Maritime mobile service: A mobile service between coast stations and ship stations, or between ship stations, or between associated on-board communication stations; survival craft stations and emergency position-indicating radio beacon stations may also participate in this service.
- 10) Maritime mobile-satellite service: A mobile-satellite service in which mobile earth stations are located on board ships; survival craft stations and emergency position-indicating radio beacon stations may also participate in this service.
- 11) Port operations service: A maritime mobile service in or near a port, between coast stations and ship stations, or between ship stations, in which messages are restricted to those relating to the operational handling, the movement and the safety of ships and, in emergency, to the safety of persons. Messages which are of a public correspondence nature shall be excluded from this service.
- 12) Ship movement service: A safety service in the maritime mobile service other than a port operations service, between coast stations and ship stations, or between ship stations, in which messages are restricted to those relating to the movement of ships. Messages which are of a public correspondence nature shall be excluded from this service.
- 13) Aeronautical mobile service: A mobile service between aeronautical stations and aircraft stations, or between aircraft stations, in which survival craft stations may participate; emergency position-indicating radio beacon stations may also participate in this service on designated distress and emergency frequencies.
- 14) Aeronautical mobile (R)* service: An aeronautical mobile service reserved for communications relating to safety and regularity of flight, primarily along national or international civil air routes.
- 15) Aeronautical mobile (OR)** service: An aeronautical mobile service intended for communications, including those relating to flight coordination, primarily outside national or international civil air routes.
- 16) Aeronautical mobile-satellite service: A mobile-satellite service in which mobile earth stations are located on board aircraft; survival craft stations and emergency position-indicating radio beacon stations may also participate in this service.
- 17) Aeronautical mobile-satellite (R)* service: An aeronautical mobile-satellite service reserved for communications relating to safety and regularity of flights, primarily along national or international civil air routes.
- 18) Aeronautical mobile-satellite (OR)** service: An aeronautical mobile-satellite service intended for communications, including those relating to flight coordination, primarily outside national and international civil air routes.

- 19) Broadcasting service: A radio communication service in which the transmissions are intended for direct reception by the general public. This service may include sound transmissions, television transmissions or other types of transmission (CS).
- 20) Broadcasting-satellite service: A radio communication service in which signals transmitted or retransmitted by space stations are intended for direct reception by the general public. In the broadcasting-satellite service, the term “direct reception” shall encompass both individual reception and community reception.
- 21) Radio determination service: A radio communication service for the purpose of radio determination.
- 22) Radio determination-satellite service: A radio communication service for the purpose of radio determination involving the use of one or more space stations. This service may also include feeder links necessary for its own operation.
- 23) Radio navigation service: A radio determination service for the purpose of radio navigation.
- 24) Radio navigation-satellite service: A radio determination-satellite service used for the purpose of radio navigation. This service may also include feeder links necessary for its operation.
- 25) Maritime radio navigation service: A radio navigation service intended for the benefit and for the safe operation of ships.
- 26) Maritime radio navigation-satellite service: A radio navigation-satellite service in which earth stations are located on board ships.
- 27) Aeronautical radio navigation service: A radio navigation service intended for the benefit and for the safe operation of aircraft.
- 28) Aeronautical radio navigation-satellite service: A radio navigation-satellite service in which earth stations are located on board aircraft.
- 29) Radiolocation service: A radio determination service for the purpose of radiolocation.
- 30) Radiolocation-satellite service: A radio determination-satellite service used for the purpose of radiolocation. This service may also include the feeder links necessary for its operation.
- 31) Meteorological aids service: A radio communication service used for meteorological, including hydrological, observations and exploration.
- 32) Earth exploration-satellite service: A radio communication service between earth stations and one or more space stations, which may include links between space stations, in which: – information relating to the characteristics of the Earth and its natural phenomena, including data relating to the state of the environment, is obtained from active sensors or passive sensors on Earth satellites; – similar information is collected from airborne or Earth-based platforms; – such information may be distributed to earth stations within the system concerned; – platform interrogation may be included. This service may also include feeder links necessary for its operation.
- 33) Meteorological-satellite service: An earth exploration-satellite service for meteorological purposes.
- 34) Standard frequency and time signal service: A radio communication service for scientific, technical and other purposes, providing the transmission of specified frequencies, time signals, or both, of stated high precision, intended for general reception.
- 35) Standard frequency and time signal-satellite service: A radio communication service using space stations on earth satellites for the same purposes as those of the standard frequency and time signal service. This service may also include feeder links necessary for its operation.

- 36) Space research service: A radio communication service in which spacecraft or other objects in space are used for scientific or technological research purposes.
- 37) Amateur service: A radio communication service for the purpose of self-training, intercommunication and technical investigations carried out by amateurs, that is, by duly authorized persons interested in radio technique solely with a personal aim and without pecuniary interest.
- 38) Amateur-satellite service: A radio communication service using space stations on earth satellites for the same purposes as those of the amateur service.
- 39) Radio astronomy service: A service involving the use of radio astronomy.
- 40) Safety service: Any radio communication service used permanently or temporarily for the safeguarding of human life and property.
- 41) Special service: A radio communication service, not otherwise defined in this Section, carried on exclusively for specific needs of general utility, and not open to public

2.2. Frequency bands

The initial grouping of the frequency spectrum is in the form of frequency-bands, in which the radio frequency spectrum is grouped into 9 bands, as shown in FIG. 2.

Band number	Symbols	Frequency range (lower limit exclusive, upper limit inclusive)	Corresponding metric subdivision
4	VLF	3 to 30 kHz	Myriametric waves
5	LF	30 to 300 kHz	Kilometric waves
6	MF	300 to 3 000 kHz	Hectometric waves
7	HF	3 to 30 MHz	Decametric waves
8	VHF	30 to 300 MHz	Metric waves
9	UHF	300 to 3 000 MHz	Decimetric waves
10	SHF	3 to 30 GHz	Centimetric waves
11	EHF	30 to 300 GHz	Millimetric waves
12		300 to 3 000 GHz	Decimillimetric waves

NOTE 1: "Band N" (N = band number) extends from 0.3×10^N Hz to 3×10^N Hz.

NOTE 2: Prefix: k = kilo (10^3), M = mega (10^6), G = giga (10^9).

Figure 2. Frequency Bands

2.3. Sub-Bands and Table of Frequency Allocation

Frequency sub-bands is a term I'm promoting, and not an official term from The International Telecommunication Union. My reason for using the term is because the non-telecommunication engineers' reader will be confused, why on one page of the Radio Regulation document, there is a radio spectrum grouping into nine bands, but when looking at the frequency allocation table, as if there is no correlation.

Consider the figures 3, 4, and 5 shows the frequency allocations for the three lowest spectrum of radio communications, wherein the lowest grouping is the 8.3 kHz - 110 kHz band that penetrates the boundaries of two bands, which VLF band (3 - 30 kHz) and LF (30 kHz - 300 kHz), then in the third lowest grouping there is a 255 kHz - 400 kHz band that penetrates the boundaries of two bands which LF band (30 - 300 kHz) and MF (300 kHz - 3 MHz).

8.3-110 kHz		
Allocation to services		
Region 1	Region 2	Region 3
Below 8.3	(Not allocated) 5.53 5.54	
8.3-9	METEOROLOGICAL AIDS 5.54A 5.54B 5.54C	
9-11.3	METEOROLOGICAL AIDS 5.54A RADIONAVIGATION	
11.3-14	RADIONAVIGATION	
14-19.95	FIXED MARITIME MOBILE 5.57 5.55 5.56	
19.95-20.05	STANDARD FREQUENCY AND TIME SIGNAL (20 kHz)	
20.05-70	FIXED MARITIME MOBILE 5.57 5.56 5.58	
70-72 RADIONAVIGATION 5.60	70-90 FIXED MARITIME MOBILE 5.57 MARITIME RADIO- NAVIGATION 5.60 Radiolocation	70-72 RADIONAVIGATION 5.60 Fixed Maritime mobile 5.57 5.59
72-84 FIXED MARITIME MOBILE 5.57 RADIONAVIGATION 5.60 5.56		72-84 FIXED MARITIME MOBILE 5.57 RADIONAVIGATION 5.60
84-86 RADIONAVIGATION 5.60		84-86 RADIONAVIGATION 5.60 Fixed Maritime mobile 5.57 5.59
86-90 FIXED MARITIME MOBILE 5.57 RADIONAVIGATION 5.56	5.61	86-90 FIXED MARITIME MOBILE 5.57 RADIONAVIGATION 5.60
90-110	RADIONAVIGATION 5.62 Fixed 5.64	

Figure 3. Frequency Allocation of the Lowest Band

110-255 kHz		
Allocation to services		
Region 1	Region 2	Region 3
110-112 FIXED MARITIME MOBILE RADIONAVIGATION 5.64	110-130 FIXED MARITIME MOBILE MARITIME RADIO- NAVIGATION 5.60 Radiolocation	110-112 FIXED MARITIME MOBILE RADIONAVIGATION 5.60 5.64
112-115 RADIONAVIGATION 5.60		112-117.6 RADIONAVIGATION 5.60 Fixed Maritime mobile 5.64 5.65
115-117.6 RADIONAVIGATION 5.60 Fixed Maritime mobile 5.64 5.66		117.6-126 FIXED MARITIME MOBILE RADIONAVIGATION 5.60 5.64
126-129 RADIONAVIGATION 5.60		126-129 RADIONAVIGATION 5.60 Fixed Maritime mobile 5.64 5.65
129-130 FIXED MARITIME MOBILE RADIONAVIGATION 5.60 5.64	5.61 5.64	129-130 FIXED MARITIME MOBILE RADIONAVIGATION 5.60 5.64
130-135.7 FIXED MARITIME MOBILE 5.64 5.67	130-135.7 FIXED MARITIME MOBILE 5.64	130-135.7 FIXED MARITIME MOBILE RADIONAVIGATION 5.64
135.7-137.8 FIXED MARITIME MOBILE Amateur 5.67A 5.64 5.67 5.67B	135.7-137.8 FIXED MARITIME MOBILE Amateur 5.67A 5.64	135.7-137.8 FIXED MARITIME MOBILE RADIONAVIGATION Amateur 5.67A 5.64 5.67B
137.8-148.5 FIXED MARITIME MOBILE 5.64 5.67	137.8-160 FIXED MARITIME MOBILE 5.64	137.8-160 FIXED MARITIME MOBILE RADIONAVIGATION 5.64
148.5-255 BROADCASTING	160-190 FIXED	160-190 FIXED Aeronautical radionavigation
5.68 5.69 5.70	190-200 AERONAUTICAL RADIONAVIGATION	

Figure 4. Frequency Allocation of the Second Lowest Band

200-415 kHz		
Allocation to services		
Region 1	Region 2	Region 3
255-283.5 BROADCASTING AERONAUTICAL RADIONAVIGATION 5.70 5.71	200-275 AERONAUTICAL RADIONAVIGATION Aeronautical mobile	200-285 AERONAUTICAL RADIONAVIGATION Aeronautical mobile
283.5-315 AERONAUTICAL RADIONAVIGATION MARITIME RADIONAVIGATION (radiobeacons) 5.73 5.74	275-285 AERONAUTICAL RADIONAVIGATION Aeronautical mobile Maritime radionavigation (radiobeacons)	
	285-315 AERONAUTICAL RADIONAVIGATION MARITIME RADIONAVIGATION (radiobeacons) 5.73	
315-325 AERONAUTICAL RADIONAVIGATION Maritime radionavigation (radiobeacons) 5.73 5.75	315-325 MARITIME RADIONAVIGATION (radiobeacons) 5.73 Aeronautical radionavigation	315-325 AERONAUTICAL RADIONAVIGATION MARITIME RADIONAVIGATION (radiobeacons) 5.73
325-405 AERONAUTICAL RADIONAVIGATION	325-335 AERONAUTICAL RADIONAVIGATION Aeronautical mobile Maritime radionavigation (radiobeacons)	325-405 AERONAUTICAL RADIONAVIGATION Aeronautical mobile
	335-405 AERONAUTICAL RADIONAVIGATION Aeronautical mobile	
405-415 RADIONAVIGATION 5.76	405-415 RADIONAVIGATION 5.76 Aeronautical mobile	

Figure 5. Frequency Allocation of the Lowest Band

2.4. Principles of Spectrum Planning, Authorization, and Monitoring

Spectrum Manager's work and authorization work that is the authority of each country must be integrated, where both parties must understand the aspects that must be met by each side. Thus Spectrum manager should not only understand the technical and technological aspects of the spectrum planning, but also understand the economic and legal aspects that result from a determination of frequency allocation.

Spectrum managers should also understand that although The International Telecommunication Union provides several alternative frequency bands for each service, as stated in Radio Regulation documents, in most services there is an international agreement of associations that are stakeholder spectrum frequencies. Then, in the frequency band to be chosen, if there is no agreement from the international association, and the selection of a frequency band will also affect the industry that makes the equipment and users who will use radio communications.

The regulator or government must have monitoring systems and equipment used to monitor the practice of an individual or company of a frequency license holder.

Some important things for Assignment and use of frequencies quoted from Radio Regulation 2016 edition issued by The International Telecommunication Union:

- Member States shall endeavor to limit the number of frequencies and the spectrum used to the minimum essential to provide in a satisfactory manner the necessary services. To that end they shall endeavor to apply the latest technical advances as soon as possible (CS 195).

- b) Member States undertake that in assigning frequencies to stations which are capable of causing harmful interference to the services rendered by the stations of another country, such assignments are to be made in accordance with the Table of Frequency Allocations and other provisions of these Regulations.
- c) Any new assignment or any change of frequency or other basic characteristic of an existing assignment (see Appendix 4) shall be made in such a way as to avoid causing harmful interference to services rendered by stations using frequencies assigned in accordance with the Table of Frequency Allocations in chapter 4 of Radio Regulation and the other provisions of these Regulations, the characteristics of which assignments are recorded in the Master International Frequency Register.
- d) Administrations of the Member States shall not assign to a station any frequency in derogation of either the Table of Frequency Allocations in chapter 4 of Radio Regulation or the other provisions of these Regulations, except on the express condition that such a station, when using such a frequency assignment, shall not cause harmful interference to, and shall not claim protection from harmful interference caused by, a station operating in accordance with the provisions of the Constitution, the Convention and these Regulations.
- e) The frequency assigned to a station of a given service shall be separated from the limits of the band allocated to this service in such a way that, taking account of the frequency band assigned to a station, no harmful interference is caused to services to which frequency bands immediately adjoining are allocated.
- f) For the purpose of resolving cases of harmful interference, the radio astronomy service shall be treated as a radio communication service. However, protection from services in other bands shall be afforded the radio astronomy service only to the extent that such services are afforded protection from each other.
- g) For the purpose of resolving cases of harmful interference, the space research (passive) service and the earth exploration-satellite (passive) service shall be afforded protection from different services in other bands only to the extent that these different services are protected from each other.
- h) Where, in adjacent Regions or sub-Regions, a band of frequencies is allocated to different services of the same category (see Sections I and II of Article 5), the basic principle is the equality of right to operate. Accordingly, the stations of each service in one Region or sub-Region must operate so as not to cause harmful interference to any service of the same or higher category in the other Regions or sub-Regions. (WRC-03)
- i) No provision of these Regulations prevents the use by a station in distress, or by a station providing assistance to it, of any means of radio communication at its disposal to attract attention, make known the condition and location of the station in distress, and obtain or provide assistance.
- j) Member States recognize that the safety aspects of radio navigation and other safety services require special measures to ensure their freedom from harmful interference; it is necessary therefore to take this factor into account in the assignment and use of frequencies.
- k) Member States recognize that among frequencies which have long-distance propagation characteristics, those in the bands between 5 MHz and 30 MHz are particularly useful for long-distance communications; they agree to make every possible effort to reserve these bands for such communications. Whenever frequencies in these bands are used for short- or medium distance communications, the minimum power necessary shall be employed.
- l) To reduce requirements for frequencies in the bands between 5 MHz and 30 MHz and thus to prevent harmful interference to long-distance radio communications,

administrations are encouraged to use, whenever practicable, any other possible means of communication.

- m) When special circumstances make it indispensable to do so, an administration may, as an exception to the normal methods of working authorized by these Regulations, have recourse to the special methods of working enumerated below, on the sole condition that the characteristics of the stations still conform to those inserted in the Master International Frequency Register:
 - a. A station in the fixed service or an earth station in the fixed-satellite service may, under the conditions defined in Nos. 5.28 to 5.31, transmit to mobile stations on its normal frequencies;
 - b. A land station may communicate, under the conditions defined in Nos. 5.28 to 5.31, with fixed stations in the fixed service or earth stations in the fixed-satellite service or other land stations of the same category. 4.15A (SUP - WRC-12)
- n) However, in circumstances involving the safety of life, or the safety of a ship or aircraft, a land station may communicate with fixed stations or land stations of another category.
- o) Any administration may assign a frequency in a band allocated to the fixed service or allocated to the fixed-satellite service to a station authorized to transmit, unilaterally, from one specified fixed point to one or more specified fixed points provided that such transmissions are not intended to be received directly by the general public.
- p) Any mobile station using an emission which satisfies the frequency tolerance applicable to the coast station with which it is communicating may transmit on the same frequency as the coast station on condition that the latter requests such transmission and that no harmful interference is caused to other stations.
- q) In certain cases provided for in Articles 31 and 51, aircraft stations are authorized to use frequencies in the bands allocated to the maritime mobile service for the purpose of communicating with stations of that service (see No. 51.73). (WRC-07)
- r) Aircraft earth stations are authorized to use frequencies in the bands allocated to the maritime mobile-satellite service for the purpose of communicating, via the stations of that service, with the public telegraph and telephone networks.
- s) In exceptional cases, land mobile earth stations in the land mobile-satellite service may communicate with stations in the maritime mobile-satellite and aeronautical mobile-satellite services. Such operations shall comply with the relevant provisions of the Radio Regulations relating to those services and shall be subject to agreement among administrations concerned, taking due account of No. 4.10.
- t) Any emission capable of causing harmful interference to distress, alarm, urgency or safety communications on the international distress and emergency frequencies established for these purposes by these Regulations is prohibited. Supplementary distress frequencies available on less than a worldwide basis should be afforded adequate protection.
- u) Transmissions to or from high altitude platform stations shall be limited to bands specifically identified in Article 5. (WRC-12)
- v) Space research systems intended to operate in deep space may also use the space research service (deep space) allocations, with the same status as those allocations, when the spacecraft is near the Earth, such as during launch, early orbit, , flying by the Earth and returning to the Earth. (WRC-15)

3. Economic Factor of Spectrum Used For Mobile Communication

The economic factor of using the spectrum for mobile communication can be calculated using empirical formulas developed by radio telecommunication experts, although the level of

certainty of calculation will not reach 100%, calculations should still be made, especially when the government will hold frequency spectrum auctions. For use on 5G mobile communications, it should start from now on the preparation to take into account the needs of traffic that will be soaring, because currently developing Machine to Machine communication, almost certainly the frequency used in frequency bands 9 it is almost certain the frequency used in the frequency band 9 (0.3 MHz - 3 MHz), such as which is used on 3G and 4G systems will not suffice, so it should switch in the frequency band 10 (3 MHz - 30 MHz).

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