
# RADIO SPECTRUM MANAGEMENT

## POLICIES, REGULATIONS AND TECHNIQUES

HAIM MAZAR (MADJAR)

WILEY

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*To my mother Suzanne (Sévilia) Madjar and to my wife Nitza (Ben-Shemesh) Mazar*

# Contents

# About the Author

Dr. Haim Mazar (Madjar) has more than 45 years of experience in wireless communications (including broadcasting, mobile, fixed, radiolocation, satellite and public services) and RF spectrum management. In addition to contributing to ITU-D and ITU-T Study Groups, Haim has contributed to all ITU-R Study Groups (and their associated Working Parties), in total, more than 180 technical contributions. Elected by 88 countries at the ITU Radio Assembly 2015, he serves as Vice Chair of ITU-R Study Group 5 (Terrestrial Services). Dr. Mazar is a consultant for national administrations and industries around the world on spectrum management, the ruling of Short Range Devices and RF Human Hazards. He holds a BSc EE, from the Technion Israel Institute of Technology in 1971; an MBA from Bar Ilan University in 1988; and a PhD from Middlesex University, London, UK, in 2008, focusing on regulatory frameworks for wireless communications. He is currently a radio communications lecturer and since January 2016, a guest professor at Xihua University, Chengdu, China.

# Foreword

Mr. Mazar has been involved extensively in ITU activities since 1991 and is well known and appreciated within the wireless regulatory community. This book is intended to provide engineers, lawyers and economists involved in wireless communications a valuable source of information and inspiration for professional activities in this field.

I am sure that all professionals involved in regulatory and standardization activities relating to wireless communications will appreciate this book.

François Rancy
*Director, Radiocommunication*
*Bureau International Telecommunication Union*

# Preface

An understanding of the policies, regulations, standards and techniques of radio spectrum management is useful to those who manage and administrate it, to operators, to equipment providers and to the users of wireless communication (i.e., all of us). For many years the author has been deeply involved in ruling the RF spectrum at the national, regional and global levels. The book is based on the professional experience of the author, his academic courses, presentations and tutorials in five continents. The book reflects this legacy and will be of use to engineers, lawyers and economists, who serve the global industry of the wireless world; in it they may find solutions to the problems they frequently encounter.

The book provides the background and an overall view, evaluating the regulatory framework for wireless communications of most administrations. The European idea to transfer national regulatory power to an intergovernmental authority may be repeated in other continents, to assist many developed and developing countries. Rather than creating new regulations and standards, administrations worldwide may follow the European, North American or Asian rules.

The regulation of the RF spectrum is concerned with the following features: regulating uncertain risks, harmful interference, the security of life services, and placing on the market new wireless technologies. Unwanted emissions and human hazards are problems that require world-views and values to guide their regulation.

The nine chapters of the book explore the administrative, engineering, legal and economic aspects of wireless communications; then the main international and regional organizations influencing the regulation and standardization of the RF spectrum are detailed. The national regulations and standards of China, France, the UK and the USA serve as case studies. Other topics discussed are the proliferation of cellular base stations, the public dislike of large antenna structures, and the growing concern about electromagnetic pollution. These topics oblige regulators to be involved, therefore, human exposure to RF is emphasized.

Chapter 1 explores wireless communications, by giving a short historical overview, depicting the basic communication channels and detailing the RF bands. Chapter 2 examines the main regulated radio services. The broadcasting delivery and technical parameters of analog and digital sound (radio) and video (television) are detailed; the analog radio FM and digital DVB-T are emphasized. Due to its importance and the continuous need for additional RF to provide capacity and coverage, a section focuses on the cellular service. Fixed point-to-point and point-to-multipoint are radiocommunication services between specified fixed stations; therefore, the fixed service can be provided by alternative cable or satellite systems. However, line-of-sight and non-line-of-sight links provide quick cost-effective broadband solutions. Satellites are used for commerce, government purposes, science, research and astronomy; therefore, satellite orbits, plus services and equipment are specified.

As regulators and the public are very concerned about Short Range Devices (SRDs), Chapter 3 provides their technical and operating parameters; SRDs are not considered a "radiocommunication service"; thus they operate normally on this basis: unlicensed, unprotected and with non-interference with other radio equipment. The roaming of SRDs obliges regional and global harmonization. The global success of Wi-Fi can be compared to the triumph of GSM. Wi-Fi, RFID and the citizens' band 26.96–27.28 MHz serve as case studies.

Chapter 4 describes policies, the legal and economic frameworks to manage the RF spectrum; the central planning (*ex-ante* and *a-priori*) approach is compared and contrasted with the market-based (*ex-post* and *a-posteriori*) style. The main objectives of spectrum control are listed. The two different legal traditions (civil law and common law) characterize the legislative environment; the importance of the radiocommunications law to the legal framework is specified; the property rights of the license holders are discussed; international, regional and national legislation is reviewed. The economic aspects of the RF are also analyzed; the benefits of wireless communications to economic welfare and to increase productivity are indicated; countries include the RF spectrum as a non-produced asset in their national cost accounting. License fees are evaluated by secondary trading, auctions and lotteries; the annual fees are quantified; international, regional and national frequency allocation tables are explained; redeployment and refarming are economic tools to optimize RF use.

Chapter 5 studies end-to-end wireless communication; power and unwanted emissions of transmitters are examined for RF sharing. Since receivers can be interfered with, their selectivity, noise and sensitivity are assessed. As there is no RF signal without antennas, a section details their fundamental parameters (aperture, beamwidth and gain; polarization, bandwidth, insertion loss and impedance). Because the attenuation of the RF signal is fundamental to the RF environment, free-space propagation loss and Maxwell's equations are presented, Fresnel zones are proved, near-field and far-field are compared. The frequency dependency when penetrating walls and bypassing obstacles explains why traditional cellular systems operate below 6 GHz. Non-linear and linear RF interference and spectrum sharing are calculated, and mitigation techniques are proposed to decrease interference.

Chapter 6 explores the international spectrum management and standardization by cataloging the relevant players and detailing how rules and standards are developed and implemented. The three ITU sectors of Development ITU-D BDT, Telecommunications ITU-T TSB and Radio ITU-R BR are surveyed. Readers may learn about bilateral and multilateral agreements between administrations, cross-border coordination and mitigation techniques to avoid interference.

Chapter 7, on regional RF spectrum management, details the exceptional European model, as a result of which the EU countries relinquish some of their sovereignty. European regulation, the main players, intergovernmental and international regulatory relationships, the legislation on the spectrum, computerized tools and harmonized activities are described. The main regional American players are OAS, CITEL and CAN. Regulation and standardization in the two major camps (Europe and North America) are compared and summarized. Regulation is explored in Asia, the (ex-Russian) Regional Commonwealth in the field of communications (RCC), the Arab countries and Africa (African Telecommunications Union, the West African states, the East African community and the South African region).

Chapter 8 details the national spectrum management: roles, objectives, basic functions, guidelines and practices to optimally manage the RF spectrum. Administrative trends in spectrum management, smarter technologies and wireless innovation modernize the ruling. The chapter discusses how China, France, the UK and the USA manage their spectrum.

Chapter 9 presents RF health risks as a social story; the electromagnetic hypersensitivity and electrophobia are explained; international, regional and national thresholds are compared; power density and field-strength are simulated and measured to define safety distances around base stations. The impact of RF hazards limits on mobile network planning is quantified; policies and mitigation techniques to reduce human exposure are proposed.

# Acknowledgments

As this book extends over a wide area of subjects and many regulatory bodies I wish to acknowledge the contribution of a large number of colleagues who reviewed the text and suggested valuable editions. In view of the diversified nature of the material on the one hand and the focused nature of most contributors, I believe that the best way to recognize the assistance by these contributors is by way of the following table.

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| 2. Aldo Scotti | 9 | IT |
| 3. Alex Orange | 7 | NZ |
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(Continued)

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(Continued)

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Last but not least are the members of my family who were patient with me during the long period that this book was written, a period over which the book took up most of my attention.

# Acronyms and Abbreviations

| | |
|---|---|
| 1G | First Generation |
| 2G | Second Generation |
| 3G | Third Generation |
| 3GPP | Third Generation Partnership Project |
| 3GPP2 | Third Generation Partnership Project 2 |
| 4G | Fourth Generation |
| ABU | Asia-Pacific Broadcasting Union |
| AF | Annual Fee |
| AHCIET | *Asociación Iberoamericana de Centros de Investigación y Empresas de Telecomunicaciones* (Ibero-American Association of Telecommunications Research and Enterprises) |
| AICTO | Arab Information and Communication Technology Organization |
| AM | Amplitude Modulation |
| ANFR | *Agence Nationale des Fréquences* (France) |
| ANSI | American National Standards Institute (USA) |
| APT | Asia-Pacific Telecommunity |
| ARCEP | *Autorité de Régulation des Communications Electroniques et des Postes* (France) |
| ARCTEL-CPLP | *Associação de Reguladores de Comunicações e Telecomunicações da Comunidade dos Países de Língua Portuguesa* (Association of Communications and Telecommunications Regulators of the Community of Portuguese-Speaking Countries) |
| AREGNET | Arab Regulators Network |
| ARIB | Association of Radio Industries and Businesses (Japan) |
| ARRL | American Radio Relay League Incorporated |
| ASETA | Association of Andean Community Telecommunications Enterprises |
| ASK | Amplitude Shift Keying |
| ASMG | Arab States Spectrum Management Group |
| AT-DMB | Advanced Terrestrial Digital Multimedia Broadcasting (South Korea) |
| ATIS | Alliance for Telecommunications Industry Solutions |
| ATSC | Advanced Television Systems Committee (USA and Canada) |
| ATU | African Telecommunications Union |
| AWG | APT Wireless Group |
| BASK | Binary Amplitude Shift Keying |
| BBC | British Broadcasting Corporation (UK) |
| BDT | Telecommunications Development Bureau (ITU) |
| BER | Bit Error Rate |
| BEREC | Body of European Regulators for Electronic Communications |
| BFSK | Binary Frequency Shift Keying |

| | |
|---|---|
| BIPM | *Bureau International des Poids et Mesures* |
| BIS | Business, Innovation and Skills (UK Department) |
| Bps | Bits Per Second, also termed bit/s |
| BPSK | Binary Phase Shift Keying |
| BR | Bureau Radio (ITU) |
| BSS | Broadcasting-Satellite Service |
| BW | Band Width |
| BWA | Broad Wireless Access |
| C/A | Coarse/Acquisition (civilian code of GPS ) |
| CA | Channel Arrangement |
| CAATEL | *Comité Andino de Autoridades de Telecomunicaciones* (Andean Committee of Telecommunications) |
| CAN | *Comunidad Andina de Naciones* |
| CANTO | Caribbean Association of National Telecommunication Organizations |
| CAPTEF | *Conférence des Administrations des Postes et Télécommunications des pays d'Expression Française* |
| CATV | Cable TV |
| CCA | Combinatorial Clock Auction |
| CCSA | China Communications Standards Association |
| CDMA | Code Division Multiple Access |
| CEN | European Committee for Standardization |
| CENELEC | European Committee for Electrotechnical Standardization |
| CEPT | European Conference of Postal and Telecoms Administrations |
| CFR | Code of Federal Regulations (USA) |
| C/I | Carrier to Interference |
| CISPR | International Special Committee on Radio Interference |
| CITEL | *Comisión Interamericana de Telecomunicaciones* (Inter-American Commission of Telecommunications) |
| CJK | China, Japan and South Korea |
| C/N | Carrier to Noise (interchangeable with S/N) |
| CNR | Carrier to Noise Ratio (interchangeable with SNR) |
| COPANT | Pan American Standards Commission |
| COSPAS-SARSAT | International Satellite System for Search and Rescue |
| CPCE | *Code des postes et des communications électroniques* (France) |
| CPG | Conference Preparatory Group (CEPT) |
| CRAF | Committee on Radio Astronomy Frequencies (Europe) |
| CRASA | Communication Regulators' Association of Southern Africa |
| CRS | Cognitive Radio System |
| CS | Constitution and Convention (ITU) |
| CSA | *Conseil Supérieur de l'Audiovisuel* (France) |
| CTO | Commonwealth Telecoms Organisation |
| CTU | Caribbean Telecommunications Union |
| DAA | Detect And Avoid |
| DAB | Digital Audio Broadcasting |
| DAS | Dynamic Access to Spectrum |
| dB | deciBel |
| dBd | dB relative to half Dipole antenna |
| dBi | dB relative to Isotropic antenna |
| dBm | dB relative to 1 mW |

| | |
|---|---|
| DBS | Direct Broadcast Satellite |
| dBW | dB relative to 1 W |
| DCMS | Department for Culture, Media and Sport (UK) |
| DD | Digital-Dividend |
| DFS | Dynamic Frequency Selection |
| DGPS | Differential Global Positioning System |
| DL | Down Link (downlink) |
| DMB-T/H | Digital Media TV Broadcasting-Terrestrial/Handheld) (South Korea); see also T-DMB and AT-DMB |
| DRM | *Digital Radio Mondiale* |
| DSB | Digital Sound Broadcasting |
| DTH | Direct To Home |
| DTMB | Digital Terrestrial Multimedia Broadcast (China) |
| DTT | Digital Terrestrial Television |
| DTTB | Digital Terrestrial TV Broadcasting |
| DVB-H | Digital Video Broadcasting – Handheld |
| DVB-T | Digital Video Broadcasting – Terrestrial |
| EAC | East African Community |
| EACO | East African Communications Organization |
| EASA | European Aviation Safety Agency |
| EBU | European Broadcasting Union |
| EC | European Commission |
| ECC | Electronic Communications Committee (Europe) |
| $E_c/I_0$ | Energy of Carrier over Interference reference |
| ECO | European Communications Office |
| ECOWAS | Economic Community of West African States |
| ECTEL | Eastern Caribbean Telecommunications Authority |
| EDGE | Enhanced Data rates for Global Evolution |
| EEA | European Economic Area |
| EFTA | European Free Trade Association |
| EHF | Extremely High Frequency (30–300 GHz) |
| EHS | Electromagnetic HyperSensitivity |
| E.I.R.P. | Equivalent Isotropically Radiated Power |
| EMF | Electro Magnetic Fields |
| EN | European Standard |
| EPRA | European Platform of Regulatory Authorities |
| ERC | European Radiocommunications Committee |
| E.R.P. | Effective Radiated Power |
| ESA | European Space Agency |
| ETSI | European Telecommunications Standards Institute |
| EU | European Union and European Commission |
| FAA | Federal Aviation Administration (USA) |
| FCC | Federal Communications Commission (USA) |
| FDD | Frequency Division Duplexing |
| FDMA | Frequency Division Multiple Access |
| FHSS | Frequency Hopping Spread Spectrum |
| FM | Frequency Modulation |
| FRATEL | *réseau FRAncophone des régulateurs des TÉLécommunications* (France) (Francophone Telecoms Regulatory Network) |

| | |
|---|---|
| FS | Fixed Service |
| FSK | Frequency Shift Keying |
| FSS | Fixed Satellite Service |
| FWS | Fixed Wireless Systems |
| GDP | Gross Domestic Product |
| GE-89 | Regional Agreement for the African TV Broadcasting Area (Geneva 1989) |
| GE-2006 | Regional Radio Conference 2006; also called RRC-06 Agreement |
| GEO | GEostationary Orbit (equivalent to GSO) |
| GLONASS | *Глобальные Навигационные Спутниковые Системы* (Russian GPS) *ГЛОНАСС*, *Global'naya Navigatsionnaya Sputnikovaya Sistema* (GNSS) |
| GMDSS | Global Maritime Distress and Safety System |
| GPS | Global Positioning System |
| GS1 | Global Standards One |
| GSM | *Groupe Spéciale Mobile* (Global System for Mobile communications) |
| GSMA | GSM Association |
| GSO | Geostationary Satellite Orbit (equivalent to GEO) |
| G/T | Gain to noise Temperature |
| HCM | Harmonized Calculation Method (Europe) |
| HDTV | High Definition TV |
| HEO | High Earth Orbit, Highly Elliptical Orbit or Highly Eccentric Orbit (low under 1,000 km, high up to 40,000 km) |
| HF | High Frequency (3–30 MHz) |
| HFCC | High Frequency Co-ordination Conference |
| HRP | Hypothetical Reference Path |
| HRX | Hypothetical Reference Connection |
| Hz | Hertz (the base unit of frequency) |
| IAF | International Astronautical Federation |
| IARC | International Agency for Research on Cancer |
| IARU | International Amateur Radio Union |
| IATA | International Air Transport Association |
| IAU | International Astronomical Union |
| IBB | Integrated Broadcast-Broadband |
| IBOC | In Band On Channel |
| ICAO | International Civil Aviation Organization |
| ICNIRP | International Commission on Non-Ionizing Radiation Protection |
| ICT | Information and Communication Technologies |
| IEC | International Electrotechnical Commission |
| IEEE–SA | Institute of Electrical and Electronics Engineers – Standards Association |
| IIRSA | South American Regional Infrastructure Integration |
| IMO | International Maritime Organization |
| IMP | Inter Modulation Products |
| IMSO | International Mobile Satellite Organization |
| IMT | International Mobile Telecommunications |
| I/N | Interference to Noise |
| IP | Internet Protocol |
| IP3 | 3rd order Intercept Point |
| IRG | Independent Regulators Group (pan-European body) |
| ISDB-T | Integrated Services Digital Broadcasting Terrestrial |
| ISM | Industrial, Scientific and Medical |

| | |
|---|---|
| ISO | International Organization for Standardization |
| ITSO | International Telecommunications Satellite Organization |
| ITU | International Telecommunication Union |
| ITU-D | ITU – Development Sector |
| ITU-R | ITU – Radiocommunications Sector |
| ITU-T | ITU – Telecommunications Sector |
| LBT | Listen Before Talk |
| LEO | Low-altitude Earth Orbit (about 1,000 km above sea level) |
| LF | Low Frequency |
| LoS | Line-of-Sight |
| LSA | Licensed Shared Access |
| LTE | Long-Term Evolution |
| MEO | Medium-altitude Earth orbit (about 10,000 km above sea level) |
| MERCOSUR | *Mercado Común del Sur* (Common South American Market) |
| MF | Medium Frequency |
| MFN | Multi Frequency Network |
| MIFR | Master International Frequency Register |
| MIIT | Ministry of Industry and Information Technology (China) |
| MIMO | Multiple Input and Multiple Output |
| MMN | Man-Made Noise |
| MOD | Ministry of Defence (UK) |
| MoU | Memorandum of Understanding |
| MPE | Maximum Permissible Exposure |
| MPEG | Moving Picture Experts Group |
| MSS | Mobile Satellite Service |
| NABA | North American Broadcasters Association |
| NAFTA | North American Free Trade Agreement |
| NATO | North Atlantic Treaty Organization |
| NF | Noise Figure |
| NGSO | Non Geo-Stationary Orbit (also termed non-GSO or non-GEO) |
| NIR | Non Ionizing Radiation |
| NLoS | Non-Line-of-Sight |
| NOI | Notice of Inquiry (USA FCC) |
| NRA | National Regulatory Authority |
| NSM | National Spectrum Management |
| NTIA | National Telecommunications and Information Administration (USA) |
| NTSC | National Television System Committee (originated by USA, 1954) |
| OAS | Organization of American States |
| OECD | Organisation for Economic Co-operation and Development |
| OET | Office of Engineering and Technology (USA FCC) |
| Ofcom | Office of Communications (UK) |
| OFDMA | Orthogonal Frequency Division Multiple Access |
| PAL | Phase Alternation by Line (originated by Germany and UK, 1967) |
| PED | Personal Electronic Device |
| PIM | Passive Inter Modulation |
| P-MP | Point-to-Multi-Point |
| P-P | Point-to-Point |
| PR | Protection Ratio |
| PRN | Pseudo Random Numbers (used in GPS) |

| | |
|---|---|
| PSK | Phase Shift Keying |
| PSTN | Public Switched Telephone Network |
| PTC | Pacific Telecommunications Council |
| PV | Present Value |
| QAM | Quadrature Amplitude |
| QED | *quod erat demonstrandum* (Latin: which was to be demonstrated) |
| QoS | Quality of Service |
| QPSK | Quadrature Phase Shift Keying |
| R&O | Report and Order (USA) |
| R&TTE | Radio equipment and Telecommunications Terminal Equipment Directive 1999/5/EC |
| RAN | Radio Access Network |
| RBDS | Radio Broadcast Data System |
| RCF | Regional Commonwealth in the Field of Communication (former USSR) |
| RDS | Radio Data System |
| RED | Radio Equipment Directive (2014/53/EU) |
| REGULATEL | *Foro latinoamericano de entes REGULAdores de TELecomunicaciones* (Latin American Forum of Telecom Regulators) |
| RF | Radio Frequency |
| RFID | Radio Frequency IDentification |
| RLAN | Radio Local Area Network |
| RMS | Root Mean Square |
| RNSS | Radio Navigation Satellite Service |
| RR | Radio Regulations of ITU |
| RSC | Radio Spectrum Committee (EC body) |
| RSCP | Received Signal Code Power |
| RSPG | Radio Spectrum Policy Group (EU) |
| RSRP | Reference Signal Received Power |
| RSRQ | Reference Signal Received Quality |
| RSSI | Received Signal Strength Indicator |
| SADC | Southern African Development Community |
| SAR | Specific Absorption Rate |
| SAT HB | Satellite Communications Handbook |
| SC | Safety Code (Health Canada) |
| SCDMA | Synchronous Code-Division Multiple Access |
| SC-FDMA | Single Carrier Frequency Division Multiple Access |
| SCG | Spectrum Coordination Group (Asia-Pacific) |
| SDO | Standard Development Organization |
| SDR | Software Defined Radios |
| SECAM | *SÉquentiel Couleur Avec Mémoire* (originated by France, 1967) (Sequential Color with Memory) |
| SFN | Single Frequency Network |
| SINR | Signal to Interference plus Noise Ratio (interchangeable with SNIR) |
| S/N | Signal to Noise (interchangeable with C/N) |
| SNIR | Signal to Noise plus Interference Ratio (interchangeable with SINR) |
| SNR | Signal to Noise Ratio (interchangeable with CNR) |
| SRD | Short Range Device |
| ST-61 | Regional Agreement for the European Broadcasting Area (Stockholm 1961) |
| STM | Synchronous Transport Module level (such as STM-1 and STM-4) |

| | |
|---|---|
| T-DAB | Terrestrial Digital Audio Broadcasting |
| TDD | Time Division Duplexing |
| TDMA | Time Division Multiple Access |
| T-DMB | Terrestrial Digital Multimedia Broadcasting (South Korea); same as DMB-T |
| TD-SCDMA | Time Division Synchronous Code Division Multiple Access (China) |
| TIA | Telecommunications Industry Association (USA) |
| TPC | Transmitter Power Control |
| TSB | Telecommunication Standardization Bureau (ITU) |
| TTA | Telecommunications Technology Association (South Korea) |
| TTC | Telecommunications Technology Committee (Japan) |
| TVRO | TeleVision Receive-Only |
| UE | User Equipment |
| UHF | Ultra High Frequency (300–3,000 MHz) |
| UK | United Kingdom |
| UKSSC | UK Spectrum Strategy Committee |
| UL | Up Link (uplink) |
| UMTS | Universal Mobile Telecommunication System |
| UNASUR | *Unión de NAciones SURamericanas* (Union of South American Nations) |
| UNESCAP | United Nations Economic and Social Commission for Asia and the Pacific |
| U-NII | Unlicensed-National Information Infrastructure (USA FCC) |
| US | United States |
| UTRA | UMTS Terrestrial Radio Access |
| UTRAN | UMTS Terrestrial Radio Access Network |
| UWB | Ultra Wide Band |
| VHF | Very High Frequency (30–300 MHz) |
| VSAT | Very Small Aperture Terminal |
| VSB | Vestigial Side Band |
| VSWR | Voltage Standing Wave Ratio |
| WARC | World Administrative Radio Conference (ITU) |
| WAS | Wireless Access Systems |
| WATRA | West Africa Telecommunications Regulators Assembly |
| W-CDMA | Wideband-Code Division Multiple Access |
| WHO | World Health Organization |
| Wi-Fi | Wireless Fidelity (IEEE) |
| WiMAX | Worldwide Interoperability for Microwave Access |
| WLAN | Wireless Local Area Network |
| WRC | World Radio Conference (ITU) |
| WSD | White-Space Devices |
| WTA | Wireless Telegraphy Act |
| WTO | World Trade Organization |

# 1

# The Radio Frequency Spectrum and Wireless Communications

## 1.1 Historical Overview

Between 1864 and 1873, James Clerk Maxwell (1831–1894), a Scottish theoretical physicist, demonstrated that four relatively simple equations could fully describe electric and magnetic fields and their interaction. He described how charges and currents can produce an electromagnetic radio wave. In 1887, in the research laboratory of a young German physicist, Heinrich Hertz, the first radio transmitter began working briefly over a range of just a few meters. Alexander Popov (1859–1906) demonstrated his instrument for the detection and recording of electrical oscillations on May 7, 1895. In the spring of the same year, Guglielmo Marconi (1874–1937) took his wireless experiments outdoors and soon discovered that an intervening hill was no barrier to the reception of electromagnetic waves. According to the ITU Statistics (ITU 2015), in December 2014, there are more than 7 Billion mobile-cellular telephone subscriptions in the 228 ITU Member States; this is equivalent to 100% of the world's population.

The Radio Frequency (RF) spectrum is a natural resource; however, it is commonly agreed that wireless telecommunications need regulation at national, regional and global levels. The first sentence of the International Telecommunication Union (ITU) Constitution (ITU 2011) fully recognizes "the sovereign right of each State to regulate its telecommunication." The sovereign right of states to act independently within their territory is enshrined in general international law. RF is a national limited resource, much like water, land, gas, and minerals. Like these, it is scarce; however, the RF is renewable and not nearing exhaustion. It requires optimal use; if we do not use the RF spectrum in real time, this is an economic waste of a national resource. The RF is an ethereal medium, carrying wireless e-communications: a networked service of general economic interest (similar to transport, gas, and electricity). RF regulation is nationally important in theory, policy, and practice. Technological advances, innovation, penetration of new technologies, economic and military power are all directly connected to wireless regulation. The radio frequencies serve as a lever to raise the economic and social conditions of society.

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The RF ether is not related to any cultural factor *per se*: history, tradition, language, religion, or legal origin. RF is perceived as a technical rather than a cultural factor, in contrast to currency, legislation, taxes or left-hand driving issues. In RF allocation, the common denominator among countries may be the dominant factor. For this reason the RF standards can be harmonized more easily (unlike, e.g., foreign affairs), and the national RF allocation chart can be copied without alteration, from country to country (if these countries are located in the same ITU region). Lessons, ideas, and technologies cross the ocean easily, as RF is the same worldwide, it exists everywhere, it serves all nations, and it deserves to be used rationally, for worthwhile applications, such as saving lives, emergencies, navigation, smart sustainable cities, multicultural broadcasting, health, education, agriculture, science, research, meteorology, astronomy, the environment, urban and rural planning, and basic human welfare.

The RF spectrum is located in the public domain of a nation, so the State authority must manage it efficiently, for the greatest benefit of the entire population. RF spectrum management takes place within a regulatory framework comprised of engineering, and the main departments in the government regulating the economy and legislation. Authorized spectrum users enjoy the benefits of the RF license and its associated obligations to access the spectrum.

## 1.2 A General Communication Channel

The definition of telecommunication given in the ITU Constitution is: "any transmission, emission or reception of signs, signals, writings, images and sounds or intelligence of any nature by wire, radio, optical or other electromagnetic systems." Figure 1.1 schematically depicts a general communication channel (Shannon, 1949, p. 2). There are two kinds of media: wired (the transmitter is linked to the receiver via a cable) or wireless (the transmitter is linked to the receiver via electromagnetic waves). This book discusses the wireless medium. Most vital industry and military sectors are based on access to radio frequencies: mobile communications, audio and television broadcasting, satellites, radiolocation, transportation, and the Internet of Things (IoT).

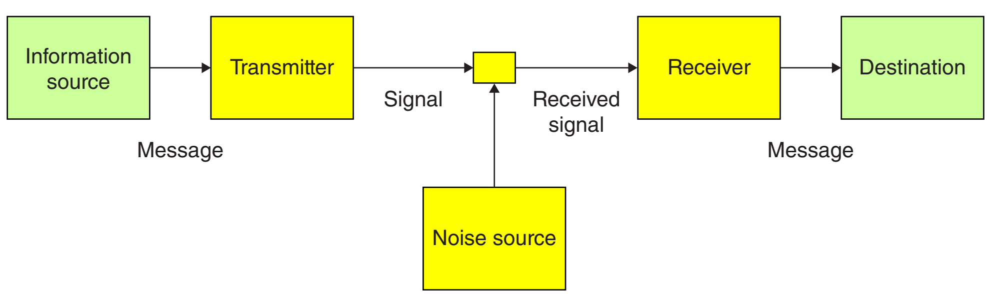


**Figure 1.1** Shannon's schematic diagram of a general communication

## 1.3 Radio Frequency Bands

Based on ITU Radio Regulations (ITU 2012), No. 2.1 (Article 2, provision 1), Table 1.1 specifies the symbols of the radio frequency bands.

**Table 1.1** RF spectrum frequency bands

| Band number | Symbols | Frequency range | Metric subdivision |
|---|---|---|---|
| 4 | VLF | 3–30 kHz | Myriametric waves |
| 5 | LF | 30–300 kHz | Kilometric waves |
| 6 | MF | 300–3,000 kHz | Hectometric waves |
| 7 | HF | 3–30 MHz | Decametric waves |
| 8 | VHF | 30–300 MHz | Metric waves |
| 9 | UHF | 300–3,000 MHz | Decimetric waves |
| 10 | SHF | 3–30 GHz | Centimetric waves |
| 11 | EHF | 30–300 GHz | Millimetric waves |
| 12 | | 300–3,000 GHz | Decimillimetric waves |

## 1.4 Scarcity of the RF Spectrum

Provision 0.3, in the principles of the ITU Radio Regulations, states: "[R]adio frequencies and the geostationary satellite orbit are limited natural resources and … they must be used rationally, efficiently and economically." The institutional, legal and economic challenges are mainly due to the scarcity of radio resources. Figure 1.2 depicts how the RF enters a higher RF, due to the scarcity of radio resources and the need for higher bandwidths. The relatively lower frequencies, such as the VHF and UHF bands, are the scarcest, due to their quality, with extended range and reliable wireless communications, without line-of-sight between the transmitter and the receiver. Scarcity is the direct result of the spread of cellular equipment and the growing demand for wireless data; the RF is the narrow bottleneck that prevents higher capacities.

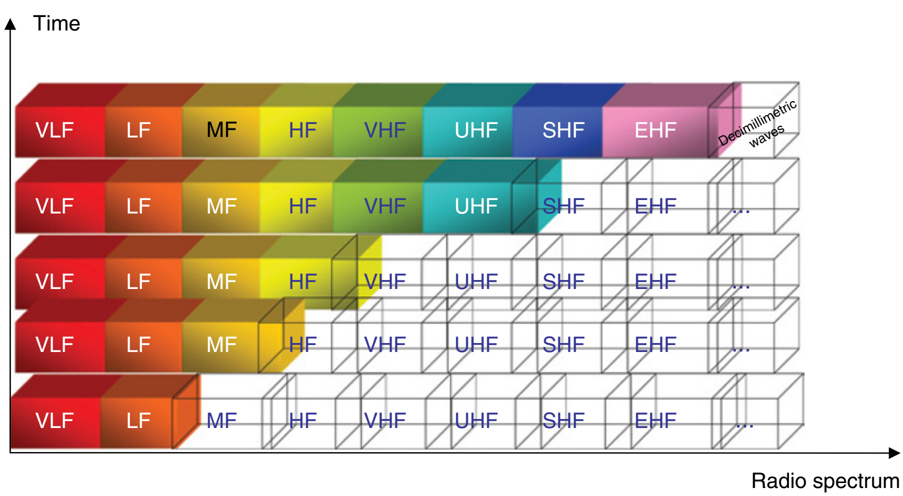


**Figure 1.2** Scarcity of RF increases in time. Source: ITU-D Resolution 9 report ITU-D 2014 Market mechanisms used for frequency assignment; Resolution 9: participation of countries, particularly developing countries, in spectrum management. Reproduced with permission

As the RF spectrum is limited, the regulators and all the wireless players will have to accommodate more services in less spectrum, within budgetary limits. The challenges in frequency management are no longer simply technical and administrative, but also economic and financial.

Market strategies are steadily imposing themselves on all the players in the radio communications sector, especially regulators and operators. The World Trade Organization's (WTO) Telecommunications Services Reference Paper of April 24, 1996 (paragraph 6) promotes new methods to allocate and use scarce resources:

> Any procedures for the allocation and use of scarce resources, including frequencies, numbers and rights of way, will be carried out in an objective, timely, transparent and non-discriminatory manner. The current state of allocated frequency bands will be made publicly available, but detailed identification of frequencies allocated for specific government uses is not required.

Around the world, the most restricted licensed RFs are the FM radio 88–108 MHz, the cellular frequency bands, and the satellite Ku Band 12–18 GHz. However, despite RF scarcity, it is important to note that at any place in the world, most of the available frequencies are unused, see Chapter 8.

## References

Note: * the author contributed to this reference.

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Shannon, C.E. (1949) A mathematical theory of communication. *Bell System Technical Journal* **27**, 379–423.

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# 2

# The Main Regulated Radio Services

## 2.1 General

The International Telecommunication Union Radio Regulations (ITU RR) Article, 1 provision 19, defines radiocommunication service thus: "A service involving the transmission, emission and/or reception of radio waves for specific telecommunication purposes." In the RR, unless otherwise stated, any radiocommunication service relates to terrestrial radiocommunication. This chapter is extensively based on the provisions of ITU-R; the international regulatory body developing these free web deliveries: Radio Regulations, Recommendations and Reports. Details of engineering material such as transmitters, receivers, antennas, propagation, link budget, interference, diversity and mitigation techniques are provided in Chapter 5. The ITU Radio Regulations Volume 1 states that the RR allocate the Radio Frequency (RF) to services and administrations, that is, governments, assign the RF to stations. The main services specified in the RR Section III: Radio services in this order are:

- *Terrestrial Services*: broadcasting; fixed; mobile (land, maritime and aeronautical); radio determination; radio navigation (maritime and aeronautical); radio location; meteorological aids; standard frequency and time signal; radio astronomy; amateur; safety; special.
- *Space Services*: fixed-satellite; inter-satellite; space operation; mobile-satellite; maritime mobile-satellite; aeronautical mobile; aeronautical mobile-satellite; broadcasting-satellite; radio determination-satellite; radio navigation-satellite; maritime radio navigation-satellite; aeronautical radio navigation-satellite; radio location-satellite; earth exploration-satellite; meteorological-satellite; standard frequency and time signal-satellite; space research; amateur-satellite.

This chapter discusses only the services that most concern regulators around the world: broadcasting video (television) and sound (radio), mobile (mainly cellular), fixed point-to point and point-to-multipoint, satellite communications. These radio services are also the main contributors to the fees; see Chapter 4.

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To save space, important services, such as radio location, radio amateur,[1] science (earth, space/passive and active), radio astronomy, safety, distress and emergency services, are not detailed. Short Range Devices (SRDs) are described in Chapter 3. This chapter highlights regulatory and standardization issues; therefore, many ITU publications are given in the references.

## 2.2 Terrestrial Broadcasting Delivery: Sound (Radio) and Video (Television)

### *2.2.1 Definitions and Introduction*

Following the ITU Constitution 1.38, the definition of broadcasting service is*:* "A *radiocommunication 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."

The broadcasting service consists of sound, video and data broadcasting. Broadcasting serves an important social function, and consequently many countries have established public service broadcasters as a matter of public policy. The British Broadcasting Corporation (BBC), for example, was established by Royal Charter in the United Kingdom. Based on that Charter, the BBC has six public broadcasting purposes:

- sustaining citizenship and civil society;
- promoting education and learning;
- stimulating creativity and cultural excellence;
- representing the nation, regions and communities;
- bringing the nation to the world and the world to the nation;
- helping to deliver to the public the benefit of emerging communications technologies and services, and taking a leading role in the switchover to digital broadcasting.

According to the ITU Radio Regulations, the bands allocated to the broadcasting service start at 47 MHz (Band I) and 174 MHz (Band III), respectively. Terrestrial broadcasting of FM audio and TV is located at VHF (30–300 MHz) and UHF (300–3,000 MHz). The original broadcasting band designations I, III, IV and V derive from the Regional Agreement for the European Broadcasting Area concerning the use of Frequencies by the Broadcasting Service in the VHF and UHF Bands (Stockholm1961) and the African VHF/UHF Broadcasting Conference (Geneva 1963). The frequency ranges at that time were Band I: 41–68 MHz, Band III: 162–230 MHz, Band IV: 470–582 MHz and Band V: 582–960 MHz.

In Tables 2.1 and 2.2, the numbers after the channel number indicate the starting RF of the channel, for example, channel 21 starts at 470 MHz; the number of the channel in bold indicates the last channel in the row. Table 2.1 details the broadcasting designation bands mainly in ITU Region 1[2]; these channels are used in Western Europe, Africa, and many Asian countries.

Table 2.2 details the broadcasting designations used mainly in ITU Region 2; the channels are used in North America, most of Latin America, South Korea, Taiwan and the Philippines. It is important to note that the TV channel separation is 6 MHz, not as in Table 2.1.

At 698–890 MHz, in the Americas, in ITU Region 2, the mobile service is co-primary with broadcasting. Taking into account cognitive radio systems (CRSs) and White Spaces, the coexistence

[1] Amateur radio is a valuable volunteer emergency communications service and public resource.

[2] The ITU RF allocations are different in the three Regions (see Figure 6.1): Europe, Africa, the Middle East, west of the Persian Gulf, including Iraq, the former Soviet Union and Mongolia (Region 1); the Americas (Region 2); and the rest of Asia (Region 3).

**Table 2.1** Designation of VHF/UHF broadcasting bands, mainly in the ITU Region 1

| Band | RF (MHz) | TV channels' number, starting at (MHz) | TV channel separation |
|---|---|---|---|
| Band I | 47–68 | **2**:47 (MHz), 3:54; **4**:61 (MHz) | |
| Band II | 87.5–108* | FM channels; 100 kHz channel separation | 7 MHz |
| Band III | 174–230 | **5**:174, 6:181; 7:188; 8:195; 9:202; 10:209; 11:216; **12**:223 (MHz) | |
| Band IV | 470–582** | **21**:470; 22:478; 23:486; 24:494; 25:502; 26:510; 27:518; 28:526; 29:534: 30:542; 31:550; 32:558; 33:566; **34**:574 (MHz) | 8 MHz |
| Band V | 582–862*** | **35**:582; 36:590; 37:598; 38:606; 39:614; 40:622; 41:630; 42:638; 43:646; 44:654; 45:662; 46:670; 47:678; 48:686; 49:694; 50:702; 51:710; 52:718; 53:726; 54:734; 55:742; 56:750; 57:758; 58:766; 59:774; 60:782; 61:790; 62:798; 63:806; 64:814; 65:822; 66:830; 67:838; 68:846; **69**:854 (MHz) | |

Notes:
* 87.5–108 MHz: FM radio broadcasting is known as Band II internationally.
** The UK defines Band IV as 470–614 MHz, and Band V as 614–854 MHz.
*** Including land mobiles except aeronautical, as first digital-dividend at 790–862 MHz and as second digital-dividend at 694–790 MHz.

**Table 2.2** Designation of VHF/UHF broadcasting bands, mainly in the ITU Region 2

| Band | RF (MHz) | TV channels, number starting at (MHz) |
|---|---|---|
| Band I (VHF low) | 54–88 | **2**:54; 3:60; 4:66; 5*:76; **6****:82 (MHz) |
| Band II (international) | 87.5–108 | FM channels; 200 kHz channel separation |
| Band III (VHF high) | 174–216 | **7**:174; 8:180; 9:186; 10:192;11:198; 12:204; **13**:210 (MHz) |
| UHF bands | 470–698 | **14**:470; 15:476; 16:482; 17:488; 18:494; 19:500; 20:506; 21:512; 22:518; 23:524; 24: 530; 25:536; 26:542; 27:548; 28:554; 29:560; 30:566; 31:572; 32:578; 33:584; 34: 590; 35:596; 36:602; 37:608; 38:614; 39: 620; 40:626; 41:632; 42:638; 43:644; 44:650; 45:656; 46:662; 47:668; 48:674; 49:680; 50:686; **51**:692 (MHz) |

Notes:
* Channel 5 starts at 76 MHz and not 72 MHz.
** Channel 6: 82–88 MHz; analog TVs' audio operates at 87.75 MHz, and can be received as a normal 88.1–107.9 MHz FM radio.

of mobile and broadcasting services is difficult; therefore, TV channels 52–83, starting at 698–884 MHz, are used for Low Power TV and TV translator; see the Federal Code of Regulation (CFR) 47, Part 2 and Part 74, subpart G. Furthermore, channel 51 is adjacent to the cellular A-Block of the 700 MHz band; therefore, the United States and Canada restrict broadcasting on that channel; see Federal Communications Commission (FCC) Public Notice DA-11-1428A1 and Industry Canada Advisory Letter – Moratorium on the Use of Television Channel 51.

Section 2.2 on broadcasting is divided into sound (audio) and video (TV) broadcasting; the text starts with analog and continues with digital. The RF L band 1,452–1,492 MHz is the worldwide allocation to broadcasting; Europe uses it for T-DAB, see ERC Report 25 and ETSI EN 302 077. North America uses this band for Mobile Aeronautical telemetry; see CFR 47, Part 2.

### 2.2.2 *Broadcasting Video and Audio Delivery*

Video and audio broadcasting are received off-air from terrestrial or satellite transmitters, delivered by cables such as fiber optics and coaxials, and distributed via IP-based delivery platforms. The video return-channel on cable TV, the Internet protocol television (IPTV) and direct broadcast satellite (DBS)[3] enable interactive services, such as on-demand multimedia. Similar to the audio signal, there is a growing tendency to deliver video content to any device, anywhere; a digital TV signal can be transmitted from the broadcasting tower, overlaid on cellular long-term evolution (LTE) infrastructure (through which the signaling is provided), to deliver video content directly to mobile devices such as tablets and smartphones, without the need for dedicated built-in receivers. Figure 2.1 depicts the video and audio broadcasting networks. Table 2.3[4] details the specific properties of different radio communication delivery methods.

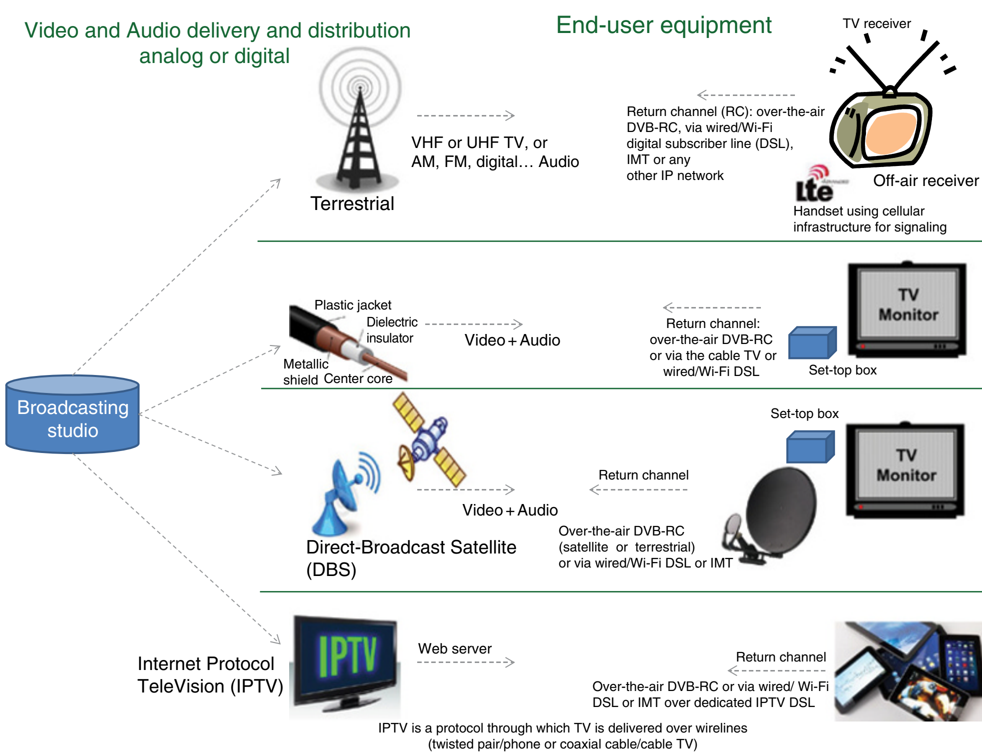


**Figure 2.1** Broadcasting delivery and distribution. (See insert for color representation of the figure.)

Integrated Broadcast-Broadband (IBB) systems integrate traditional broadcasting (terrestrial, satellite, cable) and broadcasting in mobile networks as well as other types of broadcasting, taking into account the peculiarities of countries and regions. Figure 2.2[5] depicts the media and

[3] There should be a solid state power amplifier (SSPA) of 1–6 W connected to the feed. The return-channel bit rate at DBS is usually low. The return-channel can be external to the satellite, such as an Internet connection.
[4] With many updates, Table 2.3 uses data from Report ITU-R BT.2302 Table 1.
[5] See also Recommendation ITU-R BT.2037 and Report ITU BT.2267.

**Table 2.3** Properties of different broadcasting radio communication deliveries

| Technology | Advantages | Disadvantages |
|---|---|---|
| Wire communication | All types of content and information services; the highest data transmission rate; hundreds of channels; robustness against RF interference; data security; bidirectional data transmission; no RF human hazards | Very expensive to build and operate the communication links due to specific rural conditions; high requirements to routing nodes and upper-level communication channels; impossible to serve mobile subscribers |
| Mobile communication | All types of content and information services; possible to serve mobile subscribers; portable receiver equipment; very suitable for on-demand content delivery; built-in bidirectional data transmission | Great demand for radio spectrum, limited radio link bandwidth, degraded communication when user peak load; immune to RF interference; expensive to build and operate the infrastructure; increases human exposure to RF |
| Satellite communication and broadcasting | Very efficient delivery of the same content to the whole country, to large regions, covers up to 40% of the world; "clean radiation" with minimal RF human hazards | Small bandwidth per subscriber when delivering individual content; low efficiency of local content transmission; shortage of and high cost of satellite channels; expensive bi-directional subscriber equipment and complex installation of broadcast subscriber equipment; immune to RF interference |
| Terrestrial broadcasting | Low cost of transmission network infrastructure, low cost of receiving devices, very efficient delivery of the same content to medium and small territories | Small bandwidth per subscriber when delivering individual content, limited number of available radio channels, one-direction transmission (downlink); difficult to install stations; no direct return channel*;RF human hazards in the vicinity of transmitters |

Note:
* DVB-RCT (Digital Video Broadcasting – Return Channel Terrestrial) does not yet provide direct interactive terrestrial TV; the return channel for (voting, quizzes, etc.) operates via the Internet.

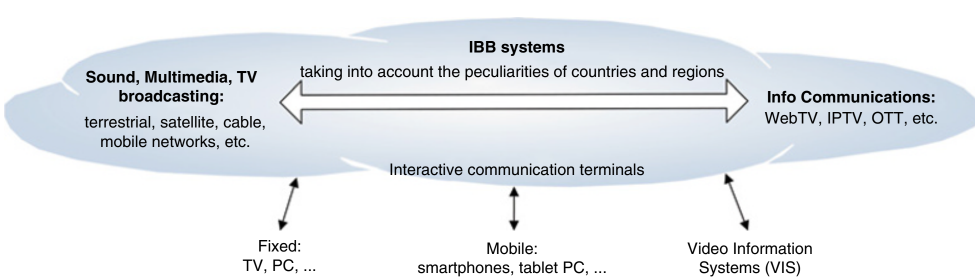


**Figure 2.2** Terrestrial, satellite, cable and broadcasting in mobile networks. Source: ITU Figure 1 in Report ITU-R BT.2295. Reproduced with permission
Note: OTT, over-the-top technology.

the means for transmission and reception of information and interactive services of sound, multimedia and television broadcasting.

For terrestrial, satellite and IPTV broadcasting delivery, the reception mode affects the adopted standard and transmitted power; the reception is either fixed or mobile. The reception modes are portable outdoor, portable indoor and mobile. The technical parameters to be evaluated are: field-strength usually expressed in dB(μV/m) and for digital broadcasting bit error rate (BER) for different code rates after different decoding stages. Fixed TV is usually received in horizontal polarization and sound is received in vertical polarization, as cars tend to use a vertical whip vertically polarized.

### *2.2.3 Terrestrial Sound (Audio)*

Extensive sound broadcasting services, both public and private, exist throughout the world, and have provided sound programs for listeners for more than 90 years (the BBC has been in operation since 1922). Terrestrial delivery offers mobile reception, particularly in cars, that is both cost-effective and reliable for the content providers. Propagation features below 30 MHz are ideal for wide area or directive long distance coverage, free from the constraints of other methods. Although audio modulation (AM) radio in the low frequency (LF), medium frequency (MF) and high frequency (HF) bands has provided penetration and extended coverage for regional, national and international sound broadcasting since the 1930s, it has suffered a decline in recent years, due to high electricity costs and poor audio quality, relative to frequency modulation (FM) radio and digital audio broadcasting (DAB). Unlike TV, sound broadcasting has always used similar modulation techniques throughout the world, such as AM or FM and similar, if not identical, frequency bands, also enabling radio mass production and leading to a receiver that could be used worldwide, for the benefit of the listener. However, the channel separations vary in the different ITU Regions: for AM Medium Waves 10 kHz in ITU Region 2, but 9 kHz in Regions 1 and 3.

Long waves (LF) operate from 153 to 279 kHz, with 9 kHz channel spacing generally used. LF radio is used for radio broadcasting only in ITU Region 1 (Europe, Africa, and northern and central Asia) and is not allocated elsewhere; the ITU Radio Regulations allocation is 148.5–255 kHz. Medium waves (MF) operate from 531 to 1,611 kHz in ITU Regions 1 and 3, with 9 kHz spacing, and 540 to 1610 kHz in ITU Region 2 (the Americas), with 10 kHz spacing. ITU Region 2 also authorizes the extended AM broadcast band, between 1,610 and 1,710 kHz. The ITU Radio Regulations allocations are 526.5–1,606.5 kHz in ITU Regions 1 and 3 and 525–1,705 kHz in Region 2. MF carry the "AM radio" that most people listen to. Short waves (HF) operate from approximately 2.3 to 26.1 MHz, divided into 14 broadcast bands.

#### **2.2.3.1 Analog Sound**

FM radio was first used in monaural form in 1940; in 1960, FM stereo was introduced. The most prevalent wireless terrestrial sound in the world today is still the frequency modulation (FM) radio, operating worldwide at 87.5–108 MHz. The excessive use of this VHF/FM frequency band causes congestion in most countries, increases the level of interference and limits the number of programs which can be transmitted. Actually, the FM success has delayed the introduction of digital audio broadcasting.

The RF FM signal consists of a carrier frequency modulated by the sound signal to be transmitted, after pre-emphasis.[6] In West European countries and the United States, the maximum deviation is ±75 kHz; in the former USSR and in some other European countries, it is ±50 kHz; see Recommendation ITU-R BS.450. Emissions exceeding the maximum deviation may interfere with adjacent channels. In frequency planning, channels are assigned in such a way that the carrier frequencies, which define the nominal placement of the RF channels within the band, for both monophonic and stereophonic transmissions, are integral multiples of 200 kHz in America,[7] of 100 kHz in Europe and of 50 kHz in Italy.

The RF bandwidth explains the FM channel separation: 50–200 kHz. The bandwidth of the carrier signal, which is frequency modulated by a continuous signal, is approximated by Carson's bandwidth rule[8]:

$$bw = 2\left(\Delta f + f_m\right)$$

where $bw$ is the total significant (98%) bandwidth, $\Delta f$ is the peak frequency deviation FM signal from the center frequency, and $f_m$ is the highest modulating signal frequency. Defining the ratio $\Delta f/f_m$ as the modulation index $\beta$, $\Delta f = \beta f_m$ and $bw = 2(\beta f_m + f_m) = 2(1+\beta)f_m$.

The human ears are sensitive to audio signals 20–15,000 Hz; for $\beta = 5$ and maximal modulating frequency of 15 kHz, the modulated (peak deviation) monaural signal swings to 5 × 15 kHz = 75 kHz above and below the RF carrier. Therefore, the American maximum deviation $\Delta f$ = 75 kHz and $f_m$ =15 kHz, $bw = 2(\Delta f + f_m) = 2(75+15)$kHz = 180kHz; it is close to the common 200 kHz channel bandwidth.

In stereo FM audio radio, there are three standard modulating signals (see Figure 2.3): a 19 kHz pilot carrier to enable FM stereo receivers to detect and decode the stereo left (L) and right (R) channels; L + R in the range 50–15,000 Hz, similar L – R in the range 23–53 kHz (a double-sideband suppressed carrier (DSBSC) AM centered at 2×19 kHz). The modulating (multiplexing) signal includes a 57 (3×19) kHz subcarrier that carries the radio data system (RDS)[9] and radio broadcast data system (RBDS)[10] signals. The stereo baseband signal is backwards compatible with FM monophonic receivers. A monophonic receiver simply demodulates the L + R signal and delivers it to the listener. Figure 2.3[11] depicts the FM stereo baseband signal, which is modulated on the FM carrier (88–108 MHz).

As the peak stereo modulating has circa 53 kHz information (RDS/RDBS is neglected due to the low modulation), using Carson's rule $bw = 2(1 + \beta)f_m = 2(1 + \beta)53$ kHz = $(1 + \beta)106$ kHz. In order to keep the total $bw$ around 200 kHz, $\beta$ is approximately 1. Depending on power, peak deviation and $\beta$, adjacent (in location and frequency) FM stations need RF separation up to 400 kHz; this request is difficult to implement, due to the scarcity of FM radio frequencies.

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[6] FM radio is inherently a noisy medium; the noise has triangular distribution: louder at higher frequencies. To overcome it, FM broadcast uses pre-emphasis and de-emphasis. The pre-emphasis characteristic of the emitted sound signal is equivalent to the admittance-frequency curve of a parallel resistance-capacitance circuit having a time constant of 50 µs in Europe and Australia or 75 µs in the USA. At the receiver site, after the discriminator block, a low-pass de-emphasis filter attenuates at the same amount the higher frequencies noise of the message (the base band).

[7] So, some American FM radio receivers, with odd center frequency channel-spaced every 200 kHz, cannot operate in Europe.

[8] FCC Memorandum Opinion and Order DA 12-1507 is an example of using Carson's (1922) rule.

[9] RDS has been the standard in Europe and Latin America since the early 1990s. RDS is a communications protocol for embedding small amounts of digital services in conventional FM radio broadcasts. The 57 kHz subcarrier carries several types of low-bandwidth text information transmitted, including time, alternative frequency, station identification and program information.

[10] RBDS is the official name used for the US version of RDS; the two standards are only slightly different.

[11] Figure 2.3 uses data also from Liang, Tan and Kelly, *Introduction to FM-Stereo-RDS Modulation* and Frequency Modulation Tutorial (Der).

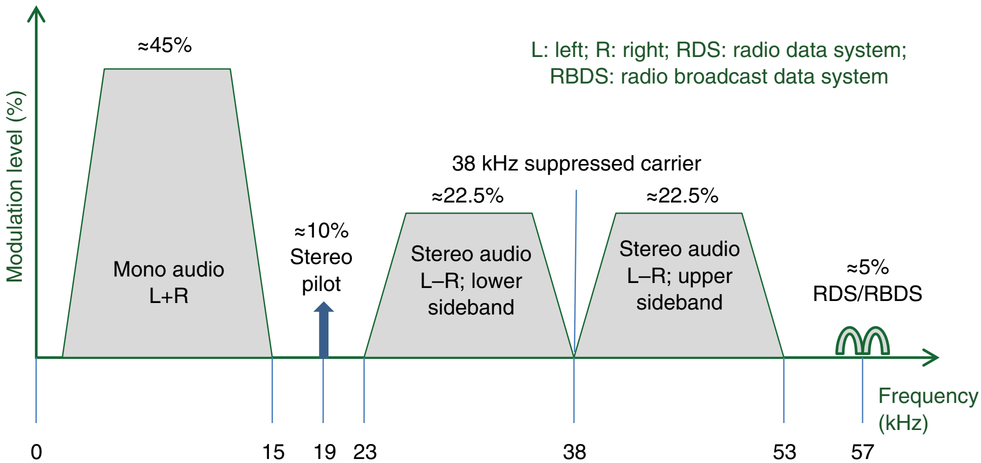


**Figure 2.3** FM stereo composite baseband signal, before modulating the FM carrier

The signal-to-noise ratio (*snr*) for mono signals equals $3 \times \beta^2 (\beta + 1)$. This *snr* equation illustrates the trade-off that exists between message signal quality (*snr*) and FM transmission bandwidth: to get higher coverage, increase the transmitted power or increase $\beta$ (but the *bw* increases). If the *snr* at the input of the FM discriminator is less than a threshold, clicks and crackling are generated, this is the threshold effect or capture effect. The FM threshold is the minimum *snr* yielding FM improvements.

Stereo FM signals are more susceptible to noise and multipath distortion than are mono FM signals. With a weak signal, FM on mono output sounds better. The narrower bandwidth of the monophonic receiver is the reason: reducing the filtering rejects the stereo L – R lower and upper sidebands; see Figure 2.3. Hence, the monaural baseband bandwidth is 15 kHz, compared to a stereo signal requiring a bandwidth of 53 kHz; at least the noise level *kt(bw)f* of monaural is lower due to *bw*, see Section 5.4.1. For the same RF level, the *snr* is greater for monaural as compared to stereo; therefore, the required field-strength for satisfactory service is higher for stereo (see Table 2.4), and the stereo pilot lamp lights up only for strong FM signals.

Recommendation ITU-R BS.412 details the planning standards for terrestrial FM radio sound broadcasting at VHF. Measured at 10 m above ground level, a satisfactory service requires a median field-strength not lower than those given in Table 2.4. Due to interference, the field-strength values that can be protected are generally higher than those of Table 2.4; Table 2.4 adapts BS.412 Table 1, with clarifications.

**Table 2.4** Median field-strength for satisfactory service

| Areas | FM audio (88–108 MHz) | |
|---|---|---|
| | Mono dB (μV/m) | Stereo dB (μV/m) |
| Rural | 48 | 54 |
| Urban | 60 | 66 |
| Large cities | 70 | 74 |

Source: Recommendation ITU-R BS.412. Reproduced with permission

Figure 2.4 depicts the protection ratios for FM radio reception. The RF protection ratios are required to give satisfactory monophonic reception, in systems using a maximum frequency deviation of ±50 kHz, for tropospheric interference; see curve M2 in Figure 2.4. For steady interference (terrestrial non tropospheric), it is preferable to provide a higher degree of protection, shown by the curve M1 in Figure 2.4. The corresponding values for stereophonic systems using a maximum frequency deviation of ±50 kHz are those given by the curves S2 and S1 in Figure 2.4. For the maximum frequency deviation of ±75 kHz, similar numbers are found in BS.412 Fig. 1. Interesting note: due to intermodulation, the 50 kHz adjacent stereo channel interferes more than the co-channel.[12] For carrier frequency differences greater than 400 kHz, the protection ratio values should be substantially lower than –20 dB.

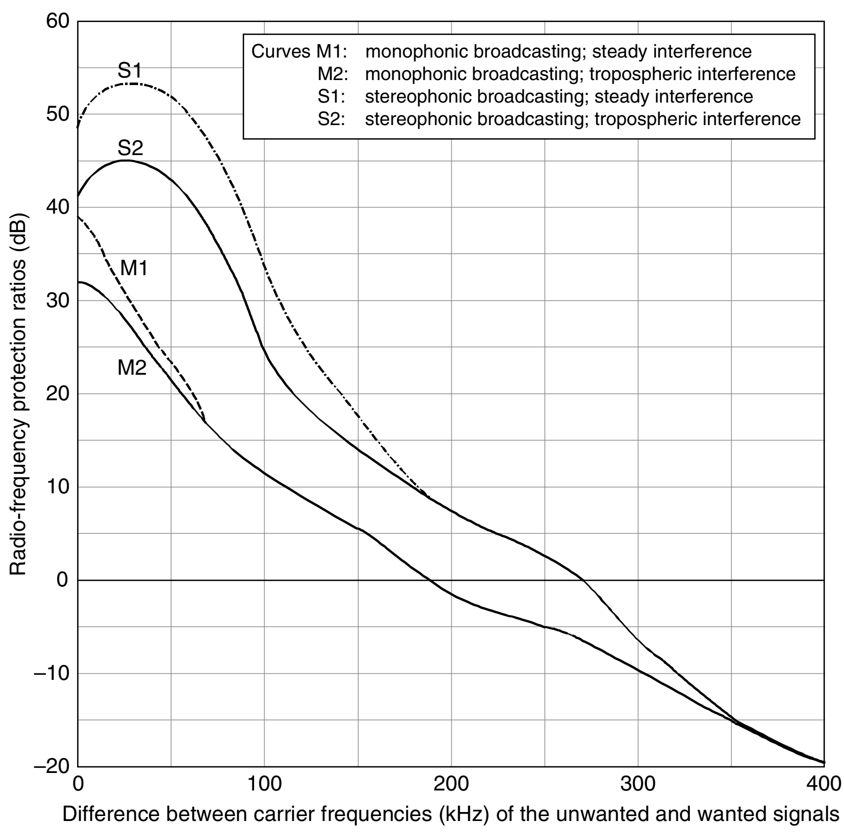


**Figure 2.4** Protection ratios to protect FM monophonic and stereophonic reception. Source: Recommendation ITU-R BS.412 Fig. 2. Reproduced with permission

[12]As the stereo signal is modulated on the 38.0kHz suppressed carrier, the interference is most sensitive on that "out of band frequency."

#### 2.2.3.2 Digital Broadcasting Sound

These are the digital terrestrial broadcasting systems (TV and sound): ATSC, DAB, DRM (MW+ HF), DTMB, DVB-T, DVB-H, DVB-SH, DVB-T2, IBOC (HD radio FM), ISDB-T (ISDB-$T_{SB}$ for Sound Broadcasting), T-DMB and AT-DMB.

The introduction of new forms of digital information and entertainment, including satellite radio and Internet streaming of radio programming, presents challenges for analog radio. Analog radio may need to transit to digital broadcasting in order to add new programming and the new features necessary to make radio competitive with new forms of digital entertainment and information. Source and channel coding, digital modulation and advanced signal processing enable digital sound broadcasting (DSB) systems. Like digital TV, DSB offers a better spectrum and power efficiency as well as better performance in multipath environments than analog systems. DSB provides high-quality stereophonic sound of two or more channels to vehicular, portable and fixed receivers. DSB allows a trade-off among quality (data services and bit rates), coverage (derived from emission power), and the number of sound programs available. A common receiver may provide local, sub-national and national terrestrial VHF/UHF network services. DSB advances value-added services with different data capacities. Table 2.5 specifies the field-strength thresholds at an antenna height of 10 m, for RF band III, in Region 1. Table 2.5 adapts BS.1660 Table 1, with clarifications.

**Table 2.5** Minimum median equivalent field-strength (dB(μV/m)) for digital sound

| Frequency band (MHz) | 174–230 |
|---|---|
| Minimum equivalent field-strength (dB(μV/m)) | 35 |
| Location percentage correction factor (50% to 99%) (dB) | 13 |
| Antenna height gain correction (dB) | 10 |
| Minimum median equivalent field-strength for planning (dB(μV/m)) | 58 |

Source: BS.1660 Table 1. Reproduced with permission

The field-strength 58 dB(μV/m) is similar to the FM values 54 (rural) and 66 (urban) dB(μV/m) in Table 2.4. These are the main standards of digital broadcasting sound on *digital radio mondiale* (DRM); In Band On Channel (IBOC); Integrated Services Digital Broadcasting Terrestrial ISDB-$T_{SB}$ and Terrestrial Digital Audio Broadcasting (T-DAB). Recommendation ITU-R BS.1114 details the systems for terrestrial digital sound broadcasting to vehicular, portable and fixed receivers in the frequency range 30–3,000 MHz. Various digital systems have been developed for terrestrial sound broadcasting; see Report ITU-R BT.2140. Report ITU-R BS.2214 specifies the planning parameters for terrestrial digital sound broadcasting systems in the VHF bands.

### 2.2.4 *Terrestrial Video (Television)*

Video broadcasting is a point-to-multipoint TV transmission for public reception, typically from a fixed emitter to fixed and portable receivers. In 2014, TV viewing in the major EU markets (Germany, France, Italy, Spain and the UK) over different delivery platforms, on large TV screens, is around 4 h/day per person, reaching 87% of the population every day; TV delivery via

Wi-Fi at home or in a public place and including the mobile network is increasing: distributed as 80% home Wi-Fi, 10% outside home Wi-Fi, 10% mobile; see EC Report 2014. There are four main types of video broadcasting receivers:

1. fixed digital TV and set-top box for fixed reception, using either roof-top antennas or fixed indoor antennas;
2. portable TV or radio sets;
3. car-installed terminals and mobile hand-held terminals, possibly integrating with cellular functions;
4. mobile/portable broadband wireless systems.

Although most home audio systems incorporate a radio receiver, much of the daily listening is on portable, car-installed or mobile hand-held receivers. In contrast, most TV viewing is on fixed receivers, which means that distribution by cable, satellite, and internet (via cable or Wi-Fi) is also widespread. The proportions of off-air, cable and satellite viewing vary greatly between countries. Cable and satellite TV distribution until now has offered a wider range of program content than off-air reception. The balance of advantages could change now as the transition to digital TV progresses. The more extensive digital television broadcasting platforms offer more than 100 mixes of high-definition TV, standard-definition TV and radio channels with either free-to-air or with conditional access distribution.

In many countries, hand-held portable TV receivers have become popular. South Korea has provided nationwide Terrestrial Digital Multimedia Broadcasting (T-DMB) since March 2007, and in Japan, the One-Seg service for handheld receivers using the central segment of the ISDB-T signal started in April 2006; see Report ITU-R BT.2140. Technically, the cellular infrastructure can transmit video streaming to the user terminal, but this concept is far from the original cellular concept of making the best use of a spectrum, with relatively short duration voice and data transmissions, while moving from place to place. With surveys showing that typically more than 70% of broadband and multimedia access through cellular networks is static and within buildings, it is necessary to consider the consequences of cellular downlinks being occupied for extended periods on a multiple one-to-one basis. Moreover, such usage also tends to be highly asymmetrical. The demand on the downlink spectrum then becomes enormous though, while, at the same time, much of the uplink spectrum is underused. If the bulk of future spectrum demand in cellular networks comes from mostly static video streaming, then more attention to the network architecture is needed in order to ensure that cellular networks do not become an inefficient form of broadcasting, which would tend to be the case with frequency division duplexing (FDD). However, there have been successful trials using LTE Broadcast/Multicast: multiple users receiving the same content simultaneously. LTE mobile networks are no longer a purely one-to-one medium; they have the capacity to send content to many users simultaneously; LTE networks distribute live and other digital media, offering service differentiation among mobile network operators.

Figure 2.5 depicts the measurement of digital TV adjacent to analog TV[13]; M1 is the analog Video, M4-analog synch, M3-analog sound and M2-digital OFDM.

[13] Measured on 19 September 2006 by the author.