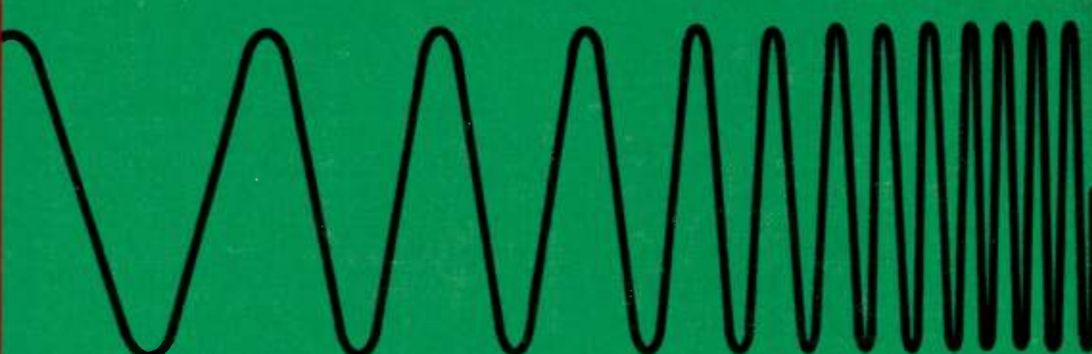
Radio Spectrum HANDBOOK

BY JAMES M. MOORE



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Preface

There is no question that the use of radio waves by man has changed our lives profoundly. We are all aware of "radio" as an aural broadcasting medium, and, whether we realize it or not, television, too, is a form of radio broadcasting. We may be less aware of the many other forms of radiocommunication, but these also have their impact on the way we live.

Unfortunately, the person who wants to know why broadcast stations are assigned as they are or what is happening outside the confines of his radio or television dial has been confronted by an "information gap." He may have found brief snatches of information about one radio service or another in books or electronics magazines, but if he wanted more information, it was buried in engineering texts or government documents. There has been no one source of this information for all frequencies, written expressly for the layman. The purpose of this book is to fill this gap.

In compiling a work of this type, two factors immediately become apparent: (1) It is impossible to discuss a technical subject adequately without using some technical terms, and (2) there is an unbelievably large mass of material that must be sorted, rearranged, and simplified. The first problem was solved by including Chapters 2 and 3, which contain the technical information the nontechnical reader needs for an understanding of the remainder of the book. These chapters were prepared especially for the person who has little or no background in electronics, but they were not "written down" to the reader.

In meeting the second problem, an effort has been made to include coverage of all significant uses of radio, but with emphasis on those that are likely to be of greatest interest to the most readers. It is not possible in a book of this size to give a complete assignment breakdown for each frequency band, but a summary sufficient to show the nature of the use of each band has been included. Basically, the book covers frequency usage in the United States, but, particularly for those frequencies on which long-distance transmission is likely to occur, foreign usage is covered as well. At the beginning of each frequency-allocation chapter, a table provides an overall summary of the uses of all frequencies included in the chapter. Following this, the individual radio services covered by the table are discussed. Thus, the information is organized both by frequency and by usage.

Of necessity, a great deal of the information in this book is based on government publications, particularly the Rules and Regulations of the Federal Communications Commission. In compiling and editing this material, it has been our intention to report rather than to interpret. For this reason, several definitions have been quoted directly rather than paraphrased.

For most people, learning about radiocommunications kindles an interest in listening to them. Therefore, information on typical receivers available for the various frequency bands has been included. To help illustrate the kinds of signals to be expected, and as a matter of general interest, several items of transmitting equipment have been described as well. The author expresses his appreciation to the receiver and transmitter manufacturers who provided specifications and photographs of their equipment.

Radio Spectrum Handbook has been written to increase your knowledge of a fascinating and important subject, and to enhance your pleasure in radio listening. To the extent that we have succeeded in these objectives, our efforts in preparing this volume will have been rewarded. Good listening!

JAMES M. MOORE

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CHAPTER 1

Allocation of the Radio Spectrum

It has been only about 100 years since James Clerk Maxwell derived mathematical equations describing radio waves, and even less time since Heinrich Hertz succeeded in transmitting and receiving such waves in his laboratory (1888). It was not until the 20th century (1901) that Guglielmo Marconi first spanned the Atlantic Ocean with the wireless telegraph. It was also in the early years of this century that such pioneers as Fessenden, de Forest, Alexanderson, and many others laid the technical foundation for the vast radiocommunications system we take for granted today. Broadcasting has been with us only a half century, and many applications of radio technology, such as space communications, are developments chiefly of the last decade.

It is difficult to imagine a modern society without radio.* From the earliest days of "wireless," radio has played a vital role in safety at sea. Today it serves myriad purposes in marine and aeronautical navigation, communication, and safety. The importance of radiocommunications and telemetry in the exploration of space is well known. In more down-to-earth usage, radio waves touch our daily lives in such diverse fields as mass communications, medicine, microwave cooking, law enforcement, and many others. Thus we see that radio, with its many uses, has played a large part in the development of our 20th-century civilization.

*The word "radio" is used in this book to refer to all communication by means of radio waves, including television.

WHAT IS THE SPECTRUM?

One of the most remarkable things about radio is that it can be used for so many different things at the same time, even in the same place. As an example, there could be three radios and a TV set in the same house, all receiving different programs at the same time. There might be from two to twenty standard broadcast (a-m) stations in a given city, all operating simultaneously without interfering with each other. And at the same time, police, fire, and taxicab radios and many other transmitters are very likely in operation.

All of this diverse, simultaneous operation is possible because radio waves have a property known as *wavelength*. It is possible to generate waves in a great variety of lengths and to separate the signals that waves of different lengths produce in receiving circuits. The entire range of wavelengths radio energy can have is called the *radio spectrum*. In this book, we will be talking about waves of lengths ranging from more than nine miles to less than one-half inch.

In Chapter 2, it will be shown that for each wavelength there is a corresponding *frequency* of alternating antenna current, and it is usually more convenient to think in terms of frequency than of wavelength. The range of wavelengths mentioned above corresponds to frequencies between about 20 kilohertz (kHz), or kilocycles per second, and 30,000,000 kHz.

REGULATIONS AND ALLOCATIONS

A study of the uses of the radio spectrum is basically a study of the way in which parts of the spectrum are allocated, or limited to use for specified purposes. Thus broadcast stations operate in certain parts of the spectrum, police stations operate in other parts, aircraft-navigation systems operate in still other parts, etc.

Why Allocations?

Although many stations on different frequencies can operate in the same geographical area at the same time, only *one* station at a time can operate without interference on any *one* frequency in a given area. Also, each signal actually occupies a group of adjacent frequencies rather than a single frequency. Finally, practical receivers are somewhat limited in their ability to separate signals that are close in frequency. The result is that, at the present state of development of radio technology, there is a practical limit to the number of stations that can operate without creating an intolerable interference condition.

Since the possible number of stations is not limitless, some entity must regulate the use of the spectrum. This entity must define acceptable interference levels, set transmission standards (for example, frames per second and lines per frame for television), decide who may operate stations, etc. Because of the distances reached by some radio signals, this regulation must be national and even international in scope. So it is that the regulatory entity for radiocommunications is an agency of national government.

Regulatory Agencies and Agreements

National governments enact and enforce radio laws and regulations. Generally, this regulation is performed within a framework of international agreements, both regional and world-wide in scope. A listing of only those treaties affecting the United States would require several pages of fine print, but the agreement of world-wide importance is the International Telecommunication Convention (Montreux, 1965).

International Telecommunication Union (ITU) — The International Telecommunication Convention is the governing document of the International Telecommunication Union (ITU); more than 130 countries, including the United States, are members of this specialized agency of the United Nations.

The ITU (then the International Telegraph Union) was formed in 1865 by some 20 European states in order to facilitate telegraphic communication across international borders. Telephone and radio communication were added to the organization's activities in 1885 and 1906, respectively, and the first ITU frequency allocations were made in 1927. In 1932, the name International Telecommunication Union was adopted to reflect the expanded responsibilities of the organization. In 1947, the ITU became a specialized agency of the United Nations, and its headquarters were moved from Berne to Geneva, Switzerland, in 1948.

The Plenipotentiary Conference is the governing body of the ITU. It is composed of delegations from the member nations and meets approximately every five years. Among other things, it makes revisions to the Convention. At this writing, the most recent Plenipotentiary Conference was in Montreux, Switzerland, in 1965.

Among the purposes of the ITU is the furtherance of effective and efficient use of all forms of telecommunication. Consequently, two of its functions are the allocation of radio frequencies and the registration of frequency assignments, for the purpose of eliminating harmful interference between stations in different countries. This function is performed by the International Frequency Registration Board (IFRB), one of the permanent organs of the ITU.

Federal Communications Commission (FCC)—In the United States, the basic document controlling telecommunications is the Communications Act of 1934 (as subsequently amended). This act applies to the 50 states, Guam, Puerto Rico, and the Virgin Islands. (It does not apply to the Canal Zone.) The Communications Act established an independent governmental agency, the Federal Communications Commission (FCC), which is responsible for regulation of interstate and foreign wire and radio communication. The commission, therefore, has responsibility for administration within the United States of international telecommunication agreements to which this country is a party.

Among its duties, the FCC allocates frequency bands for the various radio services, determines frequencies to be used by individual stations, licenses and regulates stations and operators, and regulates common carriers involved in interstate and foreign communication. However, radio operations of the Federal Government are not regulated by this agency.

Operation of the FCC is conducted in accordance with the Communications Act, the Administrative Procedure Act, and other applicable acts of Congress. It is directed by seven commissioners, who are appointed by the President. These appointments must be approved by the Senate, and not more than four of the commissioners may be members of the same political party. Commissioners' appointments are for a term of seven years, except for appointments made to fill an unexpired term. The President designates one of the commissioners chairman, and during his term of appointment the chairman serves in that capacity at the pleasure of the President.

Certain commission responsibilities are delegated to boards and committees of commissioners, individual commissioners, and staff units. The staff is organized as follows:

Bureaus: Broadcast, Common Carrier, Field Engineering, and Safety and Special Radio Services
CATV Task Force
Staff Offices: Executive Director, General Counsel, Chief Engineer, Opinions and Review, Secretary, Information, Hearing Examiners, and Review Board

The commission has about 1500 regular employees. About one-fourth of these are involved in field-engineering activities.

Frequency Allocations

Allocation of radio frequencies consists of dividing the spectrum into a number of segments, or frequency bands. Each band is then reserved for a specific use or uses. These band assignments are arbitrary to a certain extent, but they are influenced by the behavior of radio waves at different frequencies. For example, in some frequency bands, signals can be transmitted for great distances; hence these frequencies are allocated for long-distance communication, international broadcasting, etc. The transmission, or propagation, of radio waves for the various frequency bands will be covered in Chapter 2.

The ITU allocation plan divides the world into three geographical regions (Fig. 1-1). Insofar as is practical, the FCC frequency allocations conform to those for Region 2.

For convenience, frequencies in the spectrum often are classified as shown in Table 1-1. We will examine the propagation characteristics and uses of

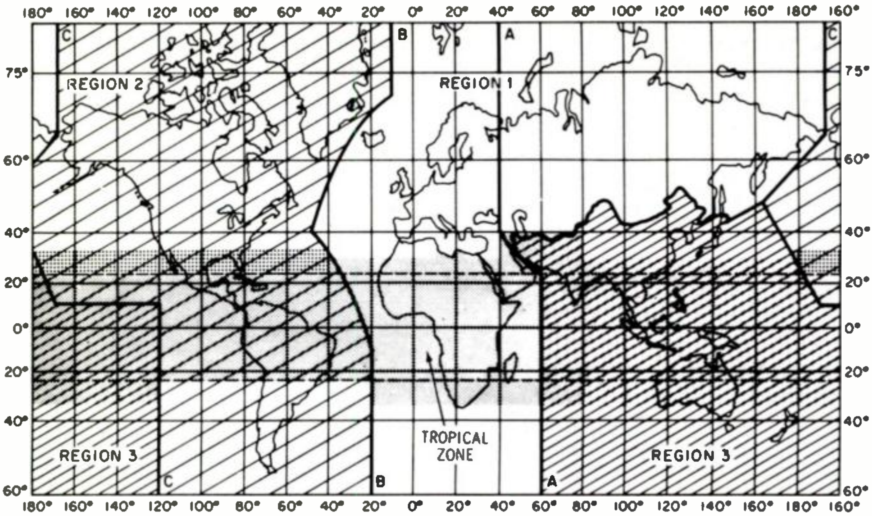


Fig. 1-1. Map showing ITU Regions.

each frequency range in detail in subsequent chapters.

Call Signs

As an aid to enforcement of radio laws and regulations, most transmitting stations in the world are required to identify themselves at intervals when they are in operation. In most cases, each station is assigned a *call sign*, a combination of letters or letters and numbers that serves to identify the station. By international agreement, the first characters of the call sign indicate the country in which the station is authorized to operate. These national prefixes are listed in Table 1-2.

Within a country, the form of the call sign may be used to indicate the type of station identified. In the United States, the system shown in Table 1-3 is used. In addition to the call signs shown in the table, call-sign groups are assigned to the military services as follows: AAA through AEZ and ALA through ALZ, Department of the Army; AFA through AKZ, Department of the Air Force; and NAA through NZZ, jointly to the Department of the Navy and the U.S. Coast Guard.

For some kinds of stations, other forms of identification may be used in lieu of call signs. A few examples, taken from Section 2.303 of the FCC Rules and Regulations, are given in Table 1-4. Other examples are broadcast organizations in other countries that use their names or slogans as identification.

Table 1-1. Classification of Radio Frequencies

Designation	Abbreviation	Frequency Range*
Very Low Frequency	vlf	3 to 30 kHz
Low Frequency	lf	30 to 300 kHz
Medium Frequency	mf	300 to 3000 kHz
High Frequency	hf	3 to 30 MHz
Very High Frequency	vhf	30 to 300 MHz
Ultrahigh Frequency	uhf	300 to 3000 MHz
Superhigh Frequency	shf	3 to 30 GHz
Extremely High Frequency	ehf	30 to 300 GHz

*Abbreviations for the units of frequency are explained in Table 2-1, Chapter 2.

Table 1-2. International Call-Sign Prefixes

First Three Characters in Call Sign	Country in Which Station Is Authorized
AAA-ALZ	United States
AMA-AOZ	Spain
APA-ASZ	Pakistan
ATA-AWZ	India
AXA-AXZ	Australia
AYA-AZZ	Argentina
BAA-BZZ	China
CAA-CEZ	Chile
CFA-CKZ	Canada
CLA-CMZ	Cuba
CNA-CNZ	Morocco
COA-COZ	Cuba
CPA-CPZ	Bolivia
CQA-CRZ	Portuguese Territories
CSA-CUZ	Portugal
CVA-CXZ	Uruguay
CYA-CZZ	Canada
DAA-DTZ	Germany
DUA-DZZ	Philippines
EAA-EHZ	Spain
EIA-EJZ	Ireland
EKA-EKZ	Soviet Union
ELA-ELZ	Liberia
EMA-EOZ	Soviet Union
EPA-EQZ	Iran
ERA-ERZ	Soviet Union
ESA-ESZ	Estonia
ETA-ETZ	Ethiopia
EUA-EWZ	Soviet Bielorussia
EXA-EZZ	Soviet Union
FAA-FZZ	France and Territories
GAA-GZZ	Great Britian
HAA-HAZ	Hungary
HBA-HBZ	Switzerland
HCA-HDZ	Ecuador
HEA-HEZ	Switzerland
HFA-HFZ	Poland
HGA-HGZ	Hungary
HHA-HHZ	Haiti
HIA-HIZ	Dominican Republic
HJA-HKZ	Colombia
HLA-HMZ	Korea
HNA-HNZ	Iraq
HOA-HPZ	Panama
HQA-HRZ	Honduras
HSA-HSZ	Thailand
HTA-HTZ	Nicaragua
HUA-HUZ	El Salvador
HVA-HVZ	Vatican City

Table 1-2. International Call-Sign Prefixes (Cont'd.)

First Three Characters in Call Sign	Country in Which Station Is Authorized
HWA-HYZ	France and Territories
HZA-HZZ	Saudi Arabia
IAA-IZZ	Italy and Territories
JAA-JSZ	Japan
JTA-JVZ	Mongolia
JWA-JXZ	Norway
JYA-JYZ	Jordan
JZA JZZ	Irian
KAA-KZZ	United States
LAA-LNZ	Norway
LOA-LWZ	Argentina
LXA-LXZ	Luxembourg
LYA-LYZ	Lithuania
LZA-LZZ	Bulgaria
MAA-MZZ	Great Britain
NAA-NZZ	United States
OAA-OCZ	Peru
ODA-ODZ	Lebanon
OEA-OEZ	Austria
OFA-OJZ	Finland
OKA-OMZ	Czechoslovakia
ONA-OTZ	Belgium
OUA-OZZ	Denmark
PAA-PIZ	Netherlands
PJA-PJZ	Netherlands Antilles
PKA-POZ	Indonesia
PPA-PYZ	Brazil
PZA-PZZ	Surinam
QAA-QZZ	(Letters in this group used as service abbreviations. Not used as call signs.)
RAA-RZZ	Soviet Union
SAA-SMZ	Sweden
SNA-SRZ	Poland
SSA-SSM	United Arab Republic
SSN-STZ	Sudan
SUA-SUZ	United Arab Republic
SVA-SZZ	Greece
TAA-TCZ	Turkey
TDA-TDZ	Guatemala
TEA-TEZ	Costa Rica
TFA-TFZ	Iceland
TGA-TGZ	Guatemala
THA-THZ	France and Territories
TIA-TIZ	Costa Rica
TJA-TJZ	Cameroon
TKA-TKZ	France and Territories
TLA-TLZ	Central African Republic

Table 1-2. International Call-Sign Prefixes (Cont'd.)

First Three Characters in Call Sign	Country in Which Station Is Authorized
TMA-TMZ	France and Territories
TNA-TNZ	Congo (Brazzaville)
TOA-TQZ	France and Territories
TRA-TRZ	Gabon
TSA-TSZ	Tunisia
TTA-TTZ	Chad
TUA-TUZ	Ivory Coast
TVA-TXZ	France and Territories
TYA-TYZ	Dahomey
TZA-TZZ	Mali
UAA-UQZ	Soviet Union
URA-UTZ	Soviet Ukraine
UUA-UZZ	Soviet Union
VAA-VGZ	Canada
VHA-VNZ	Australia
VOA-VOZ	Canada
VPA-VSZ	British Territories
VTA-VWZ	India
VXA-VYZ	Canada
VZA-VZZ	Australia
WAA-WZZ	United States
XAA-XIZ	Mexico
XJA-XOZ	Canada
XPA-XPZ	Denmark
XQA-XRZ	Chile
XSA-XSZ	China
XTA-XTZ	Upper Volta
XUA-XUZ	Cambodia
XVA-XVZ	Vietnam
XWA-XWZ	Laos
XXA-XXZ	Portuguese Territories
XYA-XZZ	Burma
YAA-YAZ	Afghanistan
YBA-YHZ	Indonesia
YIA-YIZ	Iraq
YJA-YJZ	New Hebrides
YKA-YKZ	Syria
YLA-YLZ	Latvia
YMA-YMZ	Turkey
YNA-YNZ	Nicaragua
YOA-YRZ	Romania
YSA-YSZ	El Salvador
YTA-YUZ	Yugoslavia
YVA-YYZ	Venezuela
YZA-YZZ	Yugoslavia
ZAA-ZAZ	Albania
ZBA-ZJZ	British Territories
ZKA-ZMZ	New Zealand
ZNA-ZOZ	British Territories
ZPA-ZPZ	Paraguay
ZQA-ZQZ	British Territories

Table 1-2. International Call-Sign Prefixes (Cont'd.)

First Three Characters in Call Sign	Country in Which Station Is Authorized
ZRA-ZUZ	South Africa
ZVA-ZZZ	Brazil
2AA-2ZZ	Great Britain
3AA-3AZ	Monaco
3BA-3FZ	Canada
3GA-3GZ	Chile
3HA-3UZ	China
3VA-3VZ	Tunisia
3WA-3WZ	Vietnam
3XA-3XZ	Guinea
3YA-3YZ	Norway
3ZA-3ZZ	Poland
4AA-4CZ	Mexico
4DA-4IZ	Philippines
4JA-4LZ	Soviet Union
4MA-4MZ	Venezuela
4NA-4OZ	Yugoslavia
4PA-4SZ	Ceylon
4TA-4TZ	Peru
4UA-4UZ	United Nations
4VA-4VZ	Haiti
4WA-4WZ	Yemen
4XA-4XZ	Israel
4YA-4YZ	International Civil Aviation Organization
4ZA-4ZZ	Israel
5AA-5AZ	Libya
5BA-5BZ	Cyprus
5CA-5GZ	Morocco
5HA-5IZ	Tanzania
5JA-5KZ	Colombia
5LA-5MZ	Liberia
5NA-5OZ	Nigeria
5PA-5QZ	Denmark
5RA-5SZ	Malagasy
5TA-5TZ	Mauretania
5UA-5UZ	Niger
5VA-5VZ	Togo
5WA-5WZ	Western Samoa
5XA-5XZ	Uganda
5YA-5ZZ	Kenya
6AA-6BZ	United Arab Republic
6CA-6CZ	Syria
6DA-6JZ	Mexico
6KA-6NZ	Korea
6OA-6OZ	Somali
6PA-6SZ	Pakistan
6TA-6UZ	Sudan
6VA-6WZ	Senegal
6XA-6XZ	Malagasy
6YA-6YZ	Jamaica
6ZA-6ZZ	Liberia

Table 1-2. International Call-Sign Prefixes (Cont'd.)

First Three Characters in Call Sign	Country in Which Station Is Authorized
7AA-7IZ	Indonesia
7JA-7NZ	Japan
7OA-7PZ	(Not Allocated)
7QA-7QZ	Malawi
7RA-7RZ	Algeria
7SA-7SZ	Sweden
7TA-7YZ	Algeria
7ZA-7ZZ	Saudi Arabia
8AA-8IZ	Indonesia
8JA-8NZ	Japan
8OA-8RZ	(Not Allocated)
8SA-8SZ	Sweden
8TA-8YZ	India
8ZA-8ZZ	Saudi Arabia
9AA-9AZ	San Marino
9BA-9DZ	Iran
9EA-9FZ	Ethiopia
9GA-9GZ	Ghana
9HA-9HZ	Malta
9IA-9JZ	Zambia
9KA-9KZ	Kuwait
9LA-9LZ	Sierra Leone
9MA-9MZ	Malaysia
9NA-9NZ	Nepal
9OA-9TZ	Congo (Leopoldville)
9UA-9UZ	Burundi
9VA-9WZ	Malaysia
9XA-9XZ	Rwanda
9YA-9ZZ	Trinidad and Tobago

Laws Regarding Reception of Signals

Although laws and regulations usually are thought of in connection with transmitting stations, there also are legal restrictions that bear directly or indirectly on the *reception* of signals.

The Communications Act of 1934 contains a section (Sec. 605) that deals specifically with preserving privacy of communication. In general, it prohibits divulging the contents of any message (transmitted by wire or radio) to anyone but the intended recipient, his agent, or others legally entitled to the information. (Communications broadcast to the general public and messages relating to ships in distress are exempted.)

Other Federal regulations, contained in Part 15 of the FCC Rules and Regulations, place limits on the level of radiation of radio waves from receiving equipment. Some receiving circuits by their nature generate radio waves in order to operate (e.g., the local oscillator in a superheterodyne radio or TV receiver—see Chapter 2). Other circuits generate radio waves as an undesirable by-product of their intended operation (e.g., the horizontal-sweep section of a TV receiver). If these wave emissions are not limited in amplitude, they can (and sometimes do) cause unnecessary interference to reception of desired signals by other receivers in the vicinity. Part 15 establishes radiation limits for receivers operated in the 30-890 MHz range, and manufacturers must provide certification that their receivers meet these requirements. Radiation limits

Table 1-3. Make-Up of Call Signs in the U.S.[1]

Class of Station	Make-Up of Call Sign			Call-Sign Groups (Inclusive)
	Letters +	Digits +	Letters	
Coast (Classes I and II) Except Coast Telephone in Alaska	3			KAA-KZZ WAA-WZZ[2]
Coast (Class III) and Maritime Radiodetermination	3	3		KAA200-KZZ999 WAA200-WZZ999
Coast Telephone (Alaska)	3	2		KAA20-KZZ99 WAA20-WZZ99
Fixed	3	2		KAA20-KZZ99 WAA20-WZZ99
Ship Telephone	2 3	4 4		WA2000-WZ9999 Descending From WZZ9999
Aeronautical	3	1		KAA2-KZZ9 WAA2-WZZ9
Land Mobile (Base)	3	3		KAA200-KZZ999 WAA200-WZZ999
Land Mobile (Mobile Telephone)	2	4		KA2000-KZ9999 WA2000-WZ9999
Broadcasting (Standard)	4			KAAA-KZZZ WAAA-WZZZ[2]
Broadcasting (FM)	4 6			KAAA-KZZZ WAAA-WZZZ[2] KAAA-FM–KZZZ-FM WAAA-FM–WZZZ-FM
Broadcasting (TV)	4 6			KAAA-KZZZ WAAA-WZZZ[2] KAAA-TV–KZZZ-TV WAAA-TV–WZZZ-TV
TV Broadcast Translator	1	Output Channel Number	2	K02AA-K83ZZ W02AA-W83ZZ
Experimental	2	1	3[3]	KA2XAA-KZ9XZZ WA2XAA-WZ9XZZ
Amateur	1 1 2 2	1 1 1 1	2[4] 3[4] 2[4] 3[4]	K1AA-K0ZZ W1AA-W0ZZ K1AAA-K0ZZZ W1AAA-W0ZZZ KA1AA-KZ0ZZ WA1AA-WZ0ZZ KA1AAA-KZ0ZZZ WA1AAA-WZ0ZZZ
Standard Frequency				WWV, WWVB-WWVI, WWVL, WWVS

Table 1-3. Make-Up of Call Signs in the U.S.[1] (Cont'd.)

Class of Station	Make-Up of Call Sign			Call-Sign Groups (Inclusive)
	Letters +	Digits +	Letters	
Space Station	2	2		KA20-KZ99 WA20-WZ99
Citizens Radio	3	4		KAA0001-KZZ9999
Citizens Radio (Trust Territories)	1	4		K0001-K9999

[1]For classes of stations not listed here, see Section 2.302 of the FCC Rules and Regulations.
[2]But see listing for "Standard Frequency."
[3]Letter "X" always follows digit.
[4]Letter "X" never follows digit.

also are specified for community antenna television, or cable television, (CATV) systems. (The same Part 15 requires that television receivers—with some exceptions, including those manufactured before May 1, 1964—be capable of receiving all 82 channels.)

Many fm stations transmit background music by a multiplex system. These programs are used by business places which rent or lease special receiving equipment for the purpose. For a long time, reception of such signals by individuals, if not done for gain or profit, was tolerated. Recently, however, the Department of Jusice has held in effect that *any* unauthorized reception of these programs is unlawful, and at FCC request at least one major mail-order electronics firm has agreed to stop selling such equipment to the general public.

A complete listing of all laws regarding radio reception is beyond the scope of this book. For example, many state and local governments prohibit unauthorized use of police-band receivers in automobiles. Also, for obvious safety reasons, operation of TV sets in automobiles is banned or restricted in many localities. When doubt arises, information regarding such laws often can be

Table 1-4. Identification Other Than Call Signs

Class of Station	Method of Identification
Aircraft (U.S. Registry) Telephone	Registration number preceded by the type of aircraft, or the radiotelephony designator of the aircraft operating agency followed by the flight identification number.
Aircraft (Foreign Registry) Telephone	Foreign registry identification consisting of five characters. This may be preceded by the radiotelephony designator of the aircraft operating agency, or it may be preceded by the type of the aircraft.
Aeronautical	Name of the city, area, or airdrome served, together with such additional identification as may be required.
Land Mobile: Public Safety, Forestry Conservation, High Maintenance, Local Government, Shipyard, Land Transportation, and Aviation Services	Name of station licensee (in abbreviated form if practicable); or location of station; or name of city, area, or facility served. Individual stations may be identified by additional digits following the more general identification.
Land Mobile: Broadcasting (Remote Pickup)	Identification of associated broadcasting station.

obtained from the nearest FCC field office, local libraries, or law-enforcement agencies, as appropriate.

WHAT CAN BE RECEIVED

The number of uses for radio is limited mainly by man's imagination and ingenuity. Consequently, a host of different kinds of transmissions occupies the radio spectrum.

Who Operates Stations

Throughout the world, governments and their agencies operate stations for various purposes: communications (military and nonmilitary), navigation systems, and in many countries, broadcasting. Commercial communications and broadcast stations may be operated by either government agencies or private enterprises. To varying degrees, individuals may be authorized to operate stations, as a hobby or for other specified purposes.

Types of Stations

The most familiar type of station is probably the broadcast station. Those stations broadcasting to the general public may transmit programs for domestic or foreign reception. They may employ amplitude modulation (a-m) or frequency modulation (fm) for sound transmission and a-m for television (TV) picture transmission. (The different kinds of modulation will be explained in Chapter 2.)

A-m stations in the domestic service operate on medium frequencies and (outside the Western Hemisphere) on low frequencies. In addition, domestic hf broadcast stations are operated in some countries to reach remote areas or for better signal-to-noise characteristics. However, hf (short-wave) stations are more widely used for international broadcasting.

Fm and television broadcast stations operate on very high or (for television) ultrahigh frequencies. These frequency bands can best accommodate the relatively wide-band transmissions of TV and fm stations.

In addition to the stations broadcasting programs to the general public, other stations broadcast primarily for special-interest groups. Such broadcasts include aeronautical weather transmissions, standard-frequency transmissions, and educational broadcasts in the Instructional Television Fixed Service (ITFS). These special-interest transmissions are generally outside the regular broadcast bands.

Broadcasting, however, accounts for only a small part of the total spectrum usage. A great number of stations are involved in transmitting messages between specific locations—point-to-point communications. Some of the general categories of communications are listed below; these will be mentioned only briefly here and covered in more detail in later chapters.

Amateur: Stations are operated by their licensees solely with a personal aim; no material compensation is received for use of the station.

Citizens Band: Stations are licensed to individuals or businesses for private communications or remote-control activity (within certain limitations specified for this service).

Commercial: Stations may be operated for hire (common carrier) or by business organizations for their own communications.

Government and Public Safety: Stations may be operated for communications by police and fire departments and other agencies of government.

Aeronautical and Maritime: Stations are operated for communication with ships or aircraft.

Space Communications: Transmissions include communications relay, and communication with manned space vehicles.

Military: Transmissions range from battlefield two-way radio to entertainment broadcasts for remote bases.

In addition to messages as such, other information is transmitted from point to point or obtained by radio. Applications include radar, navigation systems, remote control, telemetry, and radio astronomy.

CHAPTER 2

The Nature of Radio Waves

Any study of the uses of the radio spectrum involves considerations of how radio waves are produced, the ways in which they travel from the transmitter to the receiver, and the ways in which they are modified to convey intelligence. This chapter presents the basic concepts necessary for an understanding of the remainder of the book.

HOW RADIO WAVES ARE PRODUCED AND RECEIVED

Electrical current through a wire or other conductor usually is defined as a flow of *electrons,* which are extremely small parts of atoms. If the electron flow is in one direction only, the current is called *direct current.* If the current periodically reverses its direction, it is called *alternating current.* Fig. 2-1 shows a graph, or *waveform,* of current amplitude, or strength, as the current changes with time. Each time the current goes through its complete series of amplitude values, it is said to have completed one *cycle.* The graph in Fig. 2-1 shows that, during the time interval illustrated, the current has gone through two cycles.

The number of cycles that occur during a specified interval of time is called the *frequency* of the alternating current. The specified time interval is almost always one second, and for many years the basic unit of frequency was called the *cycle per second.* It was common to shorten this term to "cycle," with "per second" being understood. This terminology, while commonly understood, was not precise, and to eliminate possible confusion, the scientific community decided to establish a one-word term defined to mean "cycle per second." The word chosen was *hertz* (abbreviated Hz), in honor of Heinrich Hertz, who first generated and received radio waves. Since the frequencies involved in radio work are quite high, the terms kilohertz (1000 hertz), megahertz (1,000,000 hertz, and gigahertz 1,000,000,000 hertz) are commonly used. The latter terms are abbreviated kHz, MHz, and GHz, respectively. (Notice that the plural of hertz also is written "hertz.") Although these new terms are becoming widely used, the older terms still may be encountered, particularly in older writings. Table 2-1 relates the old and the new terms for convenience.

When alternating current passes through an antenna conductor, electromagnetic energy spreads out from the wire at (very nearly) the speed of light. The region in which this energy exerts an influence is called an electromagnetic *field.* The intensity of the energy leaving the antenna at any instant de-

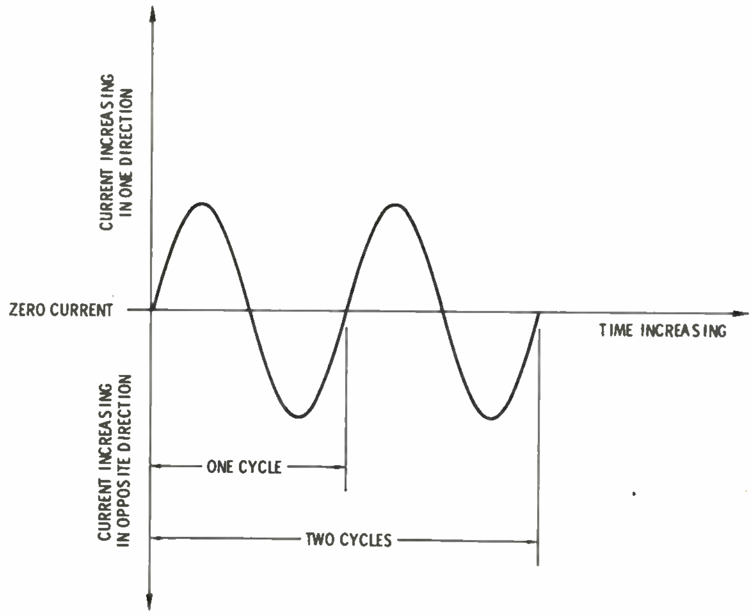


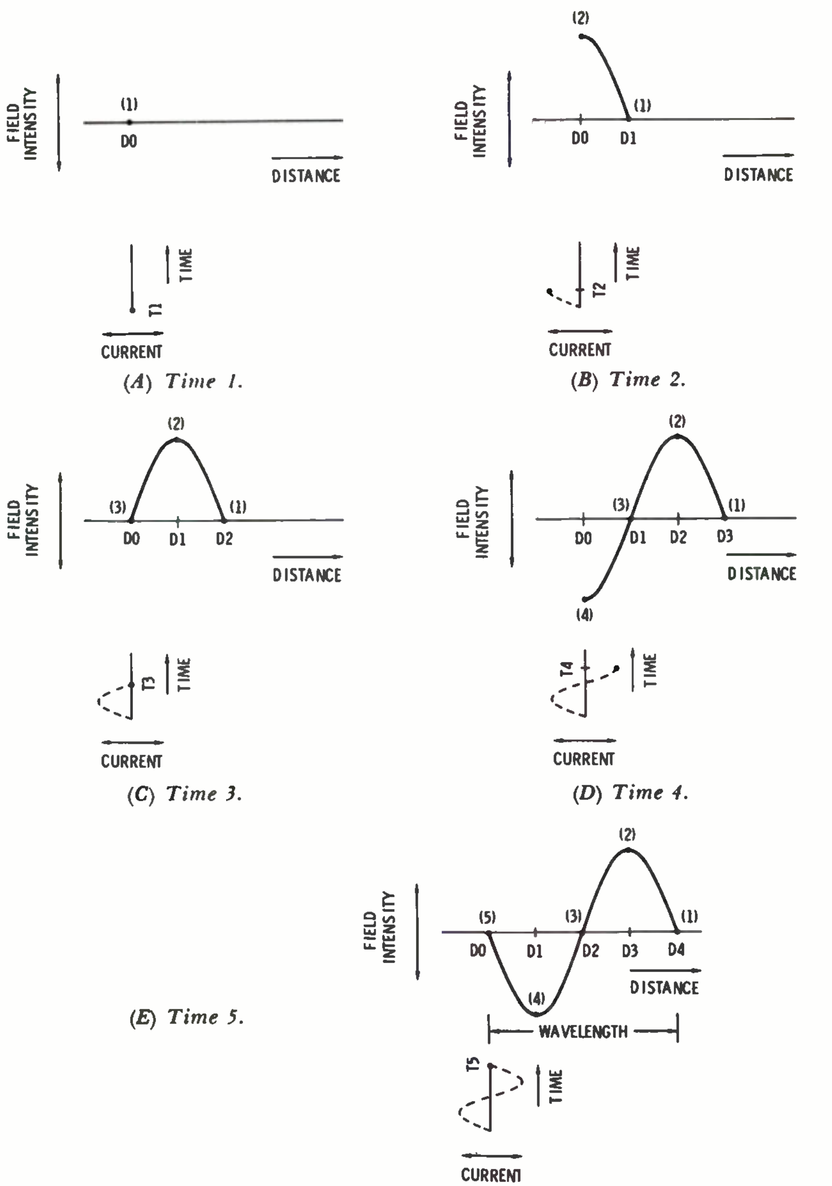
Fig. 2-1. Waveform of alternating current.

pends on the strength of the current at that instant, and therefore the field is of a pulsating nature. The pulsating amplitude and rapid expansion of the field combine to produce electromagnetic waves. The result is analogous to the rings that spread out from the point of impact when a pebble is dropped into a pond.

Fig. 2-2 is a simplified representation of the way radio waves are formed. A graph of current intensity versus *time* is drawn on each vertical axis, and a graph of field intensity versus *distance* is drawn on each horizontal axis. The antenna is at point D0 on the distance axis. Fig. 2-2A represents the intensity of energy (1) leaving the antenna at time T1. At time T2 (Fig. 2-2B), this energy has moved distance D1 from the antenna; the energy leaving the antenna at time T2 has an intensity represented by (2). At time T3 (Fig. 2-2C), the energy labelled (1) has moved distance D2, and the energy labelled (2) has moved distance D1. Figs. 2-2D and 2-2E show similar representations for later times; in Fig. 2-2E,

Table 2-1. Frequency Terminology

Old Term	Abbreviation	New Term	Abbreviation	Definition
Cycles per Second	cps or c/s	Hertz	Hz	....
Kilocycles per Second	kc or kc/s	Kilohertz	kHz	1000 Hz
Megacycles per Second	Mc or Mc/s	Megahertz	MHz	1,000,000 Hz
Gigacycles (Kilomega-cycles) per second	Gc or Gc/s (kMc or kMc/s)	Gigahertz	GHz	1,000,000,000 Hz



(*A*) *Time 1.* (*B*) *Time 2.* (*C*) *Time 3.* (*D*) *Time 4.* (*E*) *Time 5.*

Fig. 2-2. Representation of wave formation.

one cycle of antenna current has been completed. The curve (5) (4) (3) (2) (1) represents the electromagnetic wave generated by one cycle of the antenna current. Distance D4 is the wavelength.

The speed with which the wave moves does not change appreciably, but the frequency of the antenna current can have almost any desired value. In Fig. 2-2, if it takes one-millionth of a second for the wave to travel distance D4, there is one cycle of antenna current in one-millionth of one second, and there are one million cycles in one second. The frequency is therefore 1 megahertz (1000 kilohertz). If the frequency is doubled, the energy *still* travels distance D4 in one-millionth of a second, but there are now *two* waves in this distance; the wavelength is *half* as great. Simply stated, wavelength is inversely proportional to frequency. It can be seen, then, that wavelength depends on two factors, frequency and the speed at which the field expands. These factors are related by the formula

$$\lambda = \frac{300{,}000}{f}, \text{ or } f = \frac{300{,}000}{\lambda}.$$

where,

λ is the wavelength in meters, and
f is the frequency in kilohertz.

For wavelength in feet, the formula is

$$\lambda = \frac{984{,}000}{f}, \text{ or } f = \frac{984{,}000}{\lambda}$$

where,

λ is the wavelength in feet, and
f is the frequency in kilohertz.

The foregoing discussion has dealt with how an alternating current in a transmitting antenna causes radio waves to be emitted. The reciprocal action also occurs. Note that Fig. 2-2 shows graphs of field intensity versus distance at five different instants. To an observer at any point on the distance axis (for example, point D1), the passing wave appears as a field with a pulsating amplitude. A receiving antenna at this point would have an alternating voltage induced in it by the pulsating field. This induced voltage results in an alternating current in the receiver circuits. Assuming the transmitting and receiving stations are not moving with respect to each other, the received voltage (and the current it produces) has the same frequency as the current in the transmitting antenna. (A few of the significant characteristics of receiving antennas will be shown in Chapter 3.)

Radio waves are the medium of message transmission between the sending and receiving antennas; in the electronic circuits of the transmitter and receiver, however, alternating electrical currents are involved. Thus it is convenient in most cases to talk about frequency instead of wavelength. (An exception occurs in the case of antennas, where certain critical dimensions are computed in terms of wavelength.)

FACTORS THAT AFFECT TRANSMISSION RANGE

A number of factors affect the maximum distance at which waves transmitted from a given station can be converted into useful signals. The strength of the pulsating field at the receiving antenna, the efficiency of this antenna, and the sensitivity of the receiver are important. So is the amount of interference, both from other stations and from electrical noise, or "static." Usually the receiver and antenna can be selected by the listener for best results consistent with economic or other factors. Field strength and interference levels, however, usually are the result of outside forces. These include transmitting power, the mechanisms of wave propagation, and the sources of interference.

Transmitting Power

Obviously, a greater current in the transmitting antenna will result in a stronger field around the receiving antenna, other factors being equal. An increase in transmitting-antenna current may be achieved by increasing the transmitter power.

The effect of an increase in transmitter power often can be obtained by using a transmitting antenna that concentrates a larger than normal part of the radiated energy toward the receiving antenna. Such concentration is achieved at the expense of reduced radiation in other directions. This method of increasing apparent power leads to use of the term *effective radiated power.* For instance, an fm broadcast station might use a 1000-watt transmitter, but its antenna might be designed to concentrate the energy toward the horizon so that the effect of a 3000-watt transmitter is obtained. The station is said to have an effective radiated power of 3000 watts, even though its transmitter output is only 1000 watts.

Wave Propagation

It has been pointed out already that radio waves behave differently at different frequencies, and this fact accounts partly for the allocation of the frequency bands for various uses. Radio waves are transmitted, or *propagated,* by rather complex mechanisms, not all of which are fully understood. So far as radio reception is concerned, however, it is the results of the transmission mechanisms that are of interest, and these results will be discussed in the next several paragraphs.

Types of Waves—Radio waves may travel from the transmitting antenna to the receiving antenna by three kinds of paths: along the surface of the earth, directly through the air and/or through space, or by reflection from the upper atmosphere. According to which of these paths is traveled, waves may be classified as *ground waves, space waves,* or *sky waves,* respectively. The type of path involved in a given transmission depends on the wavelength and therefore on the frequency.

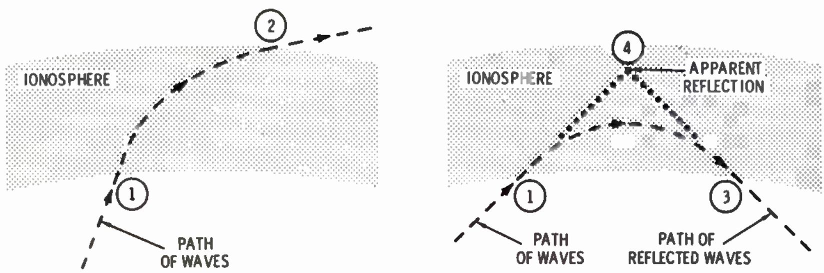
The Ionosphere—A part of the atmosphere of great importance in radio-wave propagation is the *ionosphere.* Under the influence of the sun, primarily through ultraviolet radiation, this region of the upper atmosphere (from about 50 to 200 miles in altitude) is *ionized* into a great, although variable, number of free electrons and electrically charged gas molecules (ions). It is the electrons that are important in the mechanics of wave propagation.

The intensity of ionization in the ionosphere is not uniform; instead it is more intense at some altitudes than at others. Because of this variation, the ionosphere is usually described as consisting of *layers.* The height, thickness, and intensity of these layers are variable, depending on such factors as time of day, time of year, and time during the 11-year sunspot cycle. (For example, at night the lowest layer disappears and the two highest layers merge.) Also, disturbances on the sun cause temporary changes in the ionosphere which can disrupt communications.

The importance of the ionosphere lies in its ability to reflect radio waves under certain conditions. Whether a given wave is absorbed by, reflected from, or transmitted through the ionosphere depends on the wavelength, the angle at which the wave strikes the ionosphere, and the makeup of the ionosphere at the time in question. For the purposes of this book, we will consider only the results of the action of the entire ionosphere, without going into the contributions of each layer.

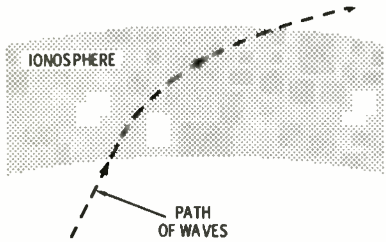
The action of the ionosphere on waves is shown in simple form by Fig. 2-3. (The dash lines represent the paths followed by the waves.) In Fig. 2-3A, the waves enter the ionosphere at point 1. The path is bent as the waves travel through the ionized medium, but they travel all the way through and emerge at point 2.

In Fig. 2-3B, the waves strike the ionosphere at an angle that is less steep.

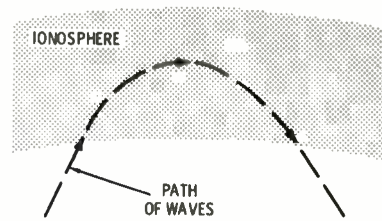


(*A*) *No reflection.* (*B*) *Reflection.*

Fig. 2-3. Ionospheric reflection of radio waves.



(*A*) *High frequency.*



(*B*) *Low frequency.*

Fig. 2-4. Effect of frequency on reflection.

Now the bending of the path is enough to cause the waves to emerge at point 3 and return toward the earth. Although the waves have been bent, or *refracted,* the effect is the same as if they had been *reflected* from point 4. The amount of maximum possible bending increases as the frequency decreases (Fig. 2-4), but absorption of energy from the wave also increases as the frequency decreases.

The part played by the ionosphere in propagation in each part of the spectrum will be discussed in later chapters. It should be kept in mind that the division points between the various frequency ranges are somewhat arbitrary and are used mainly for convenience. There are no abrupt changes in propagation characteristics as these "dividing lines" are crossed. Instead, there is a gradual change in characteristics as the frequency is increased or decreased.

Noise and Interference

For satisfactory reception, the absolute strength of the signal is not so important as the *relative* strength of the desired signal compared to any undesired signals that may be present. These unwanted signals may be electrical disturbances caused by lightning, electrical machinery, etc., called *noise,* or they may originate from other stations, in which case they are called *interference.* In areas of high electrical noise or severe interference, a strong signal is needed for intelligibility. In areas of low noise and interference, a rather weak signal may give entirely satisfactory results.

Generally speaking, atmospheric noise (static) is the result of thunderstorm activity. It is propagated by the same mechanisms as any other signal. It tends to be most troublesome at low and medium frequencies, although it is present to some extent even at vhf. It is particularly noticeable in the tropics and, during the summer months, in the temperate zones.

Man-made electrical noise is produced by all kinds of electrical and electronic equipment. As a result, such noise is most prevalent in and near concentrations of population. Often it is carried into a receiver by the power line. Common sources of this noise are the brushes of motors and generators, automobile ignition systems, and neon and fluorescent lights.

A third form of noise is that inherent in the receiver itself. Some circuits and components introduce less noise than others, and this factor is of importance in the design of equipment for the reception of weak signals.

TYPES OF MODULATION

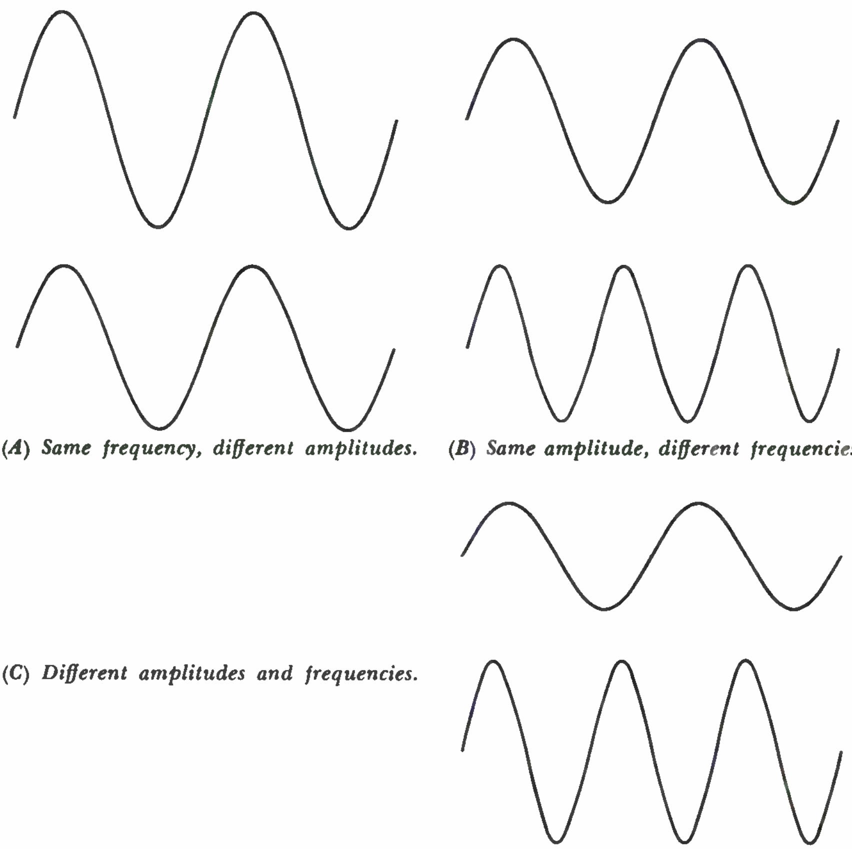
In tuning through the spectrum, the listener may encounter a host of different types of modulation, such as amplitude modulation, phase modulation, frequency modulation, pulse modulation, etc. Since the equipment and techniques needed to receive a signal depend on the modulation method in use, a basic understanding of radio modulation is desirable.

What Is Modulation?

Modulation is a process in which some characteristic of a continuous stream of uniform radio waves is varied, or modified, to represent the desired intelligence (sound, picture, teleprinter pulses, etc.). At this point, it might be asked, "Why do we have to modulate at all? Why not just feed the audio or video signal directly into an antenna?" Unfortunately, this simple approach can not be used. For one reason, at the lower audio frequencies, the antenna would have to be several hundred miles long. It is more practical to use the same wire to make a telephone line for closed-circuit communication. But even more important, there would be no way to tune, or separate desired and undesired signals; there would be only one channel for communication. The solution to these problems is to superimpose the desired signal onto a *carrier* current of higher frequency; this process, as mentioned previously, is called *modulation*. The modulated carrier may be applied to an antenna to generate radio waves, and these waves will induce a modulated voltage or current in the receiving antenna and circuits.

Amplitude, Frequency, and Phase Modulation

A radio wave has three basic properties that can be varied in the modulation process: amplitude, frequency, and phase. The meaning of the terms amplitude and frequency should be clear from previous discussion: Fig. 2-5A shows two waves of the same frequency but different amplitudes; Fig. 2-5B shows two waves of the same amplitude but different frequencies; and Fig. 2-



(*A*) *Same frequency, different amplitudes.*

(*B*) *Same amplitude, different frequencies.*

(*C*) *Different amplitudes and frequencies.*

Fig. 2-5. Frequency and amplitude comparisons.

5C shows two waves that have different amplitudes and frequencies.

Fig. 2-6 illustrates the meaning of *phase*. This property is a measure of the time difference between corresponding parts of waves of the same frequency. Notice that at any given instant, waves A and B are at corresponding points in their cycles: at T0 both are at zero, at T1 both are at their positive peaks, etc. In other words, waves A and B are in step, or *in phase*, with each other. Obviously, then, wave C is out of step, or *out of phase* with waves A and B; there is a *phase difference* between wave C and wave A or B. For convenience, the three waves in Fig. 2-6 are shown with the same amplitude. They could just as easily have different amplitudes. For example, waves A and B could have different amplitudes but would still be in phase, so long as their positive peaks, zero values, etc., occur in step.

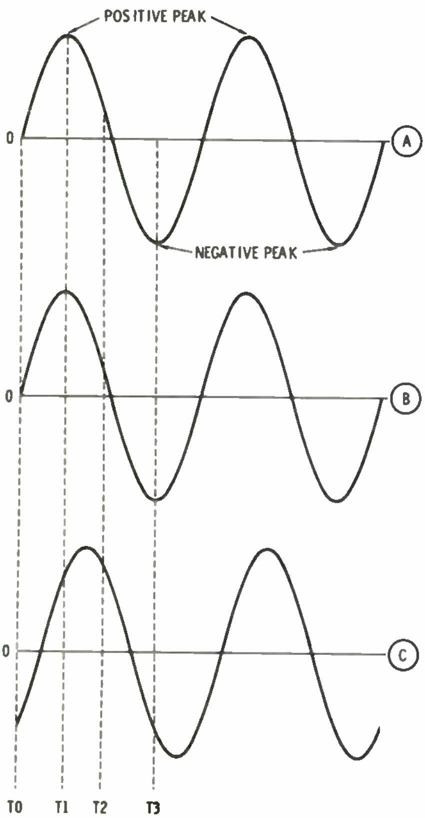


Fig. 2-6. Waveforms in and out of phase.

Any of the three properties—amplitude, frequency, or phase—may be varied in the modulation process. In Fig. 2-7, waveform A represents an audio signal, and waveform B represents an unmodulated carrier. Waveform C shows the result of amplitude modulation: The amplitude of waveform B has been made to vary in accordance with the amplitude of waveform A. If a line (the dash line in Fig. 2-7) is drawn to connect the peaks of waveform C, this *envelope* is a replica of waveform A.

Waveform D in Fig. 2-7 represents frequency modulation of waveform B by waveform A. The *frequency* of waveform D is proportional to the *amplitude* of waveform A. (The frequency change of D has been exaggerated in the drawing to make it readily apparent.)

Fig. 2-8 illustrates phase modulation. The solid line (A) is the unmodulated wave, and the dash line (B) is the modulated wave. During the time interval from T0 to T1, waveform B has had its phase changed by an amount p. Notice that waveform B has completed its cycle in less time than T1; phase modulation has been accompanied by frequency modulation. (But notice also that the frequency is changed only while the phase is *changing;* a constant phase difference would not result in a frequency difference—see Fig. 2-6). By proper choice of modulator circuits in the transmitter, phase modulation can be made equivalent to frequency modulation.

Modulation Percentage

The amplitude of the modulating signal relative to the carrier signal determines the intensity of amplitude modulation. Fig. 2-9 shows amplitude-modulated carriers for three different levels of modulating signals; the carrier level is the same for all three waveforms. Fig. 2-9A shows a low degree of modulation. Fig. 2-9B shows the maximum degree of modulation that is

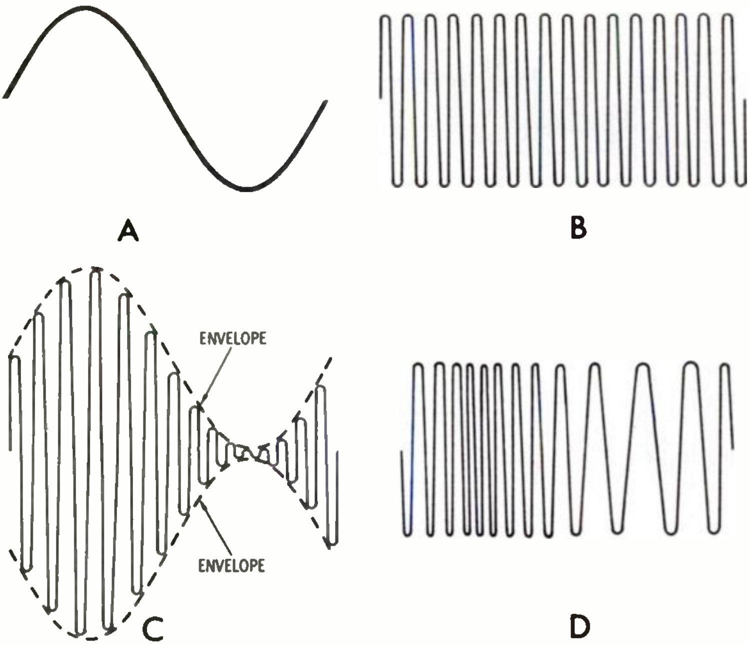


Fig. 2-7. Amplitude and frequency modulation.

possible before distortion begins; the carrier is reduced just to zero at the negative peak of the modulating signal. Fig. 2-9C shows a condition known as *overmodulation*, which causes interference to stations operating on adjacent frequencies. The degree of modulation can be expressed as a percentage, with no modulation corresponding to zero percent and the condition in Fig. 2-9B corresponding to 100 percent. Modulation in excess of 100 percent on negative peaks usually is prohibited.

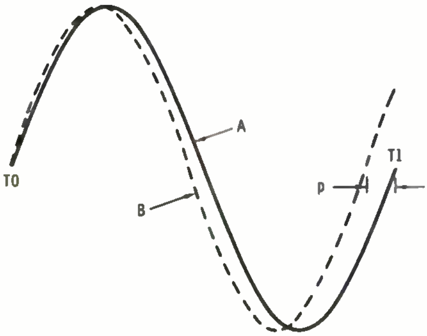
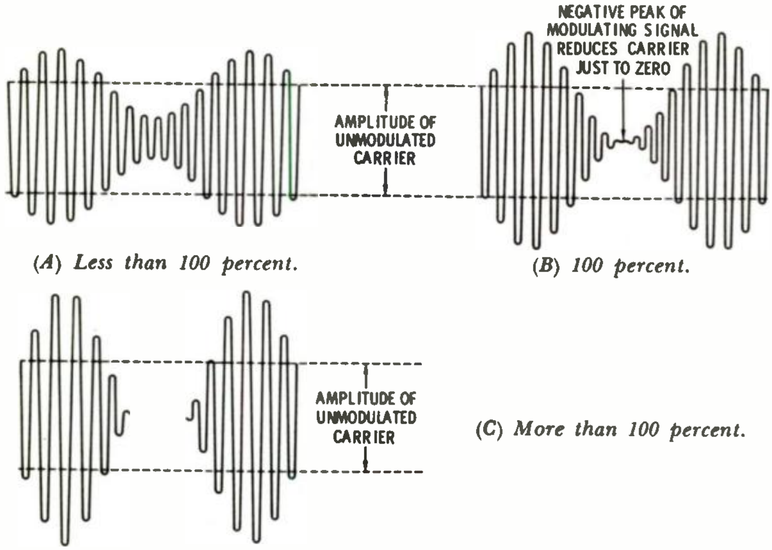


Fig. 2-8. Phase modulation.

Although an effect such as that in Fig. 2-9C does not occur in frequency modulation, distortion results if the frequency swing exceeds the bandwidth of the fm receiver. For this reason, some selected amount of frequency deviation is defined as 100-percent modulation for fm systems. For example, a swing of ±75 kHz is defined as 100-percent modulation for fm broadcast stations in the United States; for most vhf communications systems, ±5 kHz is defined as 100-percent modulation.

Sidebands

When a detailed mathematical analysis of a modulated waveform is made, an important fact emerges: The modulated signal contains not only the carrier frequency, but also other frequencies, both higher and lower than the carrier frequency. Since there are usually several of these additional frequencies, which occupy bands of frequencies above and below the carrier frequency, they are referred to as *sidebands*.

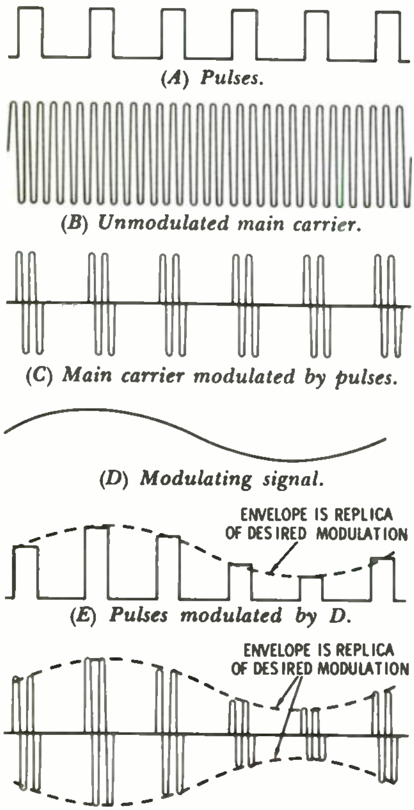


(*A*) *Less than 100 percent.*

(*B*) *100 percent.*

(*C*) *More than 100 percent.*

Fig. 2-9. Modulation percentage.



(*A*) *Pulses.*

(*B*) *Unmodulated main carrier.*

(*C*) *Main carrier modulated by pulses.*

(*D*) *Modulating signal.*

(*E*) *Pulses modulated by D.*

(*F*) *Main carrier modulated by E.*

Fig. 2-10. Pulse modulation.

In amplitude modulation, the sidebands extend above and below the carrier frequency by an amount equal to the highest modulating frequency present. (Speech, music, etc., are made up of a mixture of several frequencies present simultaneously.) In frequency modulation, the relationships are more complex, but a useful approximation is to assume that each sideband has a width equal to the maximum frequency swing plus the highest modulating frequency.

The practical significance of the presence of sidebands is that (1) each station occupies a band of frequencies rather than a single frequency, and (2) the receiver must be capable of passing this band of frequencies if accurate signal reproduction is desired. In the case of amplitude modulation, it has been found that only one of the two sidebands, together with the carrier, is sufficient for signal reproduction at the receiver. An important saving in spectrum space therefore is made possible by transmitting only one sideband. Practical transmitting circuits have been developed to accomplish this end, and single-sideband (ssb) transmissions are common in point-to-point communications. Here, the usual practice is to

Table 2-2. Modulation Symbols

Type of Transmission	Symbol
Amplitude Modulation	
Unmodulated Carrier	A0
Telegraphy Without Audio Tone[1]	A1
Telegraphy by On-Off Keying of Modulating Audio Tone or of Tone-Modulated Carrier[2]	A2
Telephony	
Double Sideband	A3
Single Sideband, Reduced Carrier	A3A
Single Sideband, Suppressed Carrier	A3J
Two Independent Sidebands	A3B
Facsimile	
Main Carrier Modulated Directly or by Frequency-Modulated Subcarrier	A4
Single Sideband, Reduced Carrier	A4A
Television (Vestigial Sideband[3])	A5C
Multichannel Voice-Frequency Telegraphy (Single Sideband, Reduced Carrier)	A7A
Other Cases (Two Independent Sidebands)	A9B
Frequency (or Phase) Modulation	
Telegraphy (Frequency-Shift Keying—One of Two Frequencies Transmitted at Any One Time)	F1
Telegraphy by Keying of Modulating Tone or of Carrier Frequency Modulated by Tone	F2
Telephony	F3
Facsimile (Direct Modulation of Carrier)	F4
Television	F5
Four-Frequency Diplex Telegraphy	F6
Other	F9
Pulse Modulation	
Pulsed Carrier With No Modulation Intended to Carry Information	P0
Telegraphy by Keying of Pulsed Carrier Without Modulating Audio Frequencies	P1D
Telegraphy by Keying of Modulating Tone or of Modulated Pulsed Carrier	
Amplitude Modulation of Pulses	P2D
Width Modulation of Pulses	P2E
Phase Modulation of Pulses	P2F
Telephony	
Amplitude Modulation of Pulses	P3D
Width Modulation of Pulses	P3E
Phase Modulation of Pulses	P3F
Code Modulation of Pulses (After Sampling and Quantization)	P3G
Other	P9

[1]Also called continuous-wave (cw) transmission.
[2]Also called interrupted-continuous-wave (icw) transmission.
[3]Part of one sideband suppressed.

remove, or suppress, one sideband and the carrier prior to transmission. For intelligible reception, it is necessary to add, or reinsert, a carrier in the receiver. (Since no carrier is transmitted, no carrier power rating for the transmitter can be given. Instead, reference is made to the power corresponding to the maximum point of the envelope, or *peak envelope power*.)

Pulse Modulation

Another type of modulation is used in some special applications. In this method, the carrier is modulated by a series of pulses (Figs. 2-10A, 2-10B, and 2-10C), and the desired modulation is applied to the pulses (Figs. 2-10D, 2-10E, and 2-10F). The process is called *pulse modulation,* and it is usually classed as a separate type of modulation even though the pulses themselves are applied to the carrier by one of the basic modulation processes. Modulation of the pulses (as distinguished from modulation of the main carrier) may consist of changes in any of several properties of the pulses: amplitude, width (duration), phase (position relative to some reference), etc.

Multiplex

A technique used in telemetry, stereo fm, color television, etc., is called *multiplex* transmission. In this case, one carrier is modulated with a signal to be transmitted. This modulated carrier in turn modulates a second carrier. The second carrier is called the *main carrier,* and the first is called a *subcarrier.* More than one subcarrier may be impressed upon the same main carrier, and the subcarriers may be transmitted in addition to the regular modulation of the main carrier.

Classification of Techniques

Many variations of the basic modulation processes are possible. For convenience, symbols may be assigned to these variations, as shown in Table 2-2, which is adapted from Section 2.201 of the FCC Rules and Regulations.

CHAPTER 3

Receiving Equipment

The function of a receiver is to convert the radio-frequency signals supplied to it by the receiving antenna into an output of a desired form. This output may be directly in the form of sound or a picture, or it may be a voltage or current for application to some other device—a typewriter, an amplifier, a control mechanism, etc.

RECEIVER CHARACTERISTICS

Receiver designs are as diverse as the applications of radio, but there are a few characteristics that are of interest in all of them. Some of the most often encountered characteristics are selectivity, sensitivity, noise, and spurious responses.

Selectivity

The first thing a receiver must do is to separate the desired signal from other signals. To do this, it must differentiate between signals of different frequency. (Differentiation between directions of arrival is accomplished by the antenna.) It has been mentioned already that a modulated signal contains a group, or band, of frequencies, and that a receiver must accept all of these frequencies in order to reproduce accurately the information the signal contains. Ideally, it should not accept any other frequencies; this response is illustrated by curve A in Fig. 3-1. An actual receiver response curve might look more like curve B in Fig. 3-1; although the receiver does respond to frequencies outside the desired band, it favors the desired frequencies. Curve C indicates response outside the intended band almost as great as that inside the band (normally an undesirable situation).

The ability of a receiver to separate desired and undesired frequencies is called *selectivity*. A sharply selective receiver can distinguish between signals that are close in frequency, but usually at a sacrifice in fidelity. Often a compromise is accepted; in communications applications, some fidelity can be sacrificed in favor of rejection of interference. (It should be noted that even a receiver with good selectivity cannot completely reject a very strong signal that is near in frequency to a very weak signal.)

Sensitivity

The measure of the ability of a receiver to respond to signals to which it is tuned is called *sensitivity*. A sensitive receiver produces a usable output from a relatively weak input signal. A receiver with poor sensitivity requires a relatively strong input signal to produce a usable output.

Noise

All receivers produce a certain amount of electrical *noise* in their circuits. This noise, particularly that originating in the receiver stages nearest the antenna, places a limit on how weak a signal can be received. Thus, low internal noise is a desirable receiver characteristic.

Spurious Responses

Receiver circuits can produce *spurious,* or unwanted, signals. In a good receiver, these signals are held to a low level. One type of such undesired signals is called *cross modulation.* Some receiver circuits, in the presence of signals much stronger than they are designed to handle, change their operating characteristics in such a way that they mix two or more signals; the mixture may then appear at a number of places on the dial, even though the receiver is not "tuned" to any of the stations involved. Sometimes cross modulation occurs in places external to the receiver, and the cross-modulation products are radiated to the receiver just as any other signal would be. In such cases, the undesired signal generation must be eliminated, since there is no way for the receiver to reject the unwanted signals.

Another common type of spurious signal is called an *image.* The meaning of this term will be discussed later in this chapter in connection with superheterodyne receivers.

TYPES OF RECEIVERS

In Chapter 2, it was shown that the carrier waves generated by a transmitter are modulated to carry intelligence. The receiver must then *demodulate* the received signal in order to recover the intelligence. The section, or stage, of the receiver that performs this function is called a *demodulator,* or, more often, a *detector.* The design of the detector depends on the type of modulation to be received and on the purpose (and cost) of the receiver.

Simple Receivers

The simplest receiver consists simply of a diode detector. The "crystal set" of early radio days is an example of

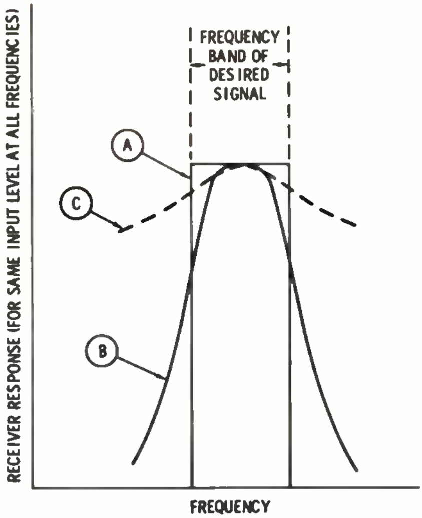


Fig. 3-1. Selectivity curves.

this type of receiver. Its chief advantage is its simplicity; its disadvantages are extremely poor sensitivity and selectivity.

When a tube (other than a diode) or a transistor is used in the detector, an improvement in selectivity and sensitivity can be obtained by introducing *regeneration* into the circuit. Regeneration means taking part of the output signal from the stage and using it to aid, or boost, the input signal. If the regeneration is increased beyond a critical point, however, the detector breaks into oscillation; that is, it begins to generate a carrier signal of its own. This local signal and the received carrier differ slightly in frequency, and they combine in the detector to form an audio-frequency "beat," which is heard in the output as a tone, whistle, or squeal. This beat interferes with normal a-m reception, but it makes cw (code) transmissions audible, and it is helpful in locating weak a-m signals.

A variation of the regenerative detector is the *superregenerative* detector. This detector is designed so that it goes into and out of oscillation many times each second. Thus it takes advantage of the high sensitivity available at the threshold of oscillation. The superregenerative detector can be tuned to a point on the slope of its response curve (selectivity curve) and used as an fm detector.

Ordinarily, the detector alone does not provide sufficient output to operate a speaker, so a receiver consisting of only a detector is used with earphones. Sometimes one or more stages of audio amplification may be added so that speaker listening is possible.

For most applications, the receivers described in the foregoing paragraphs do not provide all the features or the quality of performance needed. These simple receivers find their chief use as educational construction projects.

The TRF Receiver

A substantial improvement in sensitivity and selectivity can be obtained by placing one or more tuned radio-frequency amplifier stages ahead of the detector (i.e., between the antenna and detector). In the early days of radio, tuned-radio-frequency, or TRF, receivers were common. However, each rf stage of such a receiver must be provided with variable tuning, and this requirement is awkward to meet, especially from a mechanical standpoint, when several stages are involved. Consequently, the TRF receiver is seldom used today, except in special applications such as fixed-tuned receivers.

The Superheterodyne Receiver

Most receivers today are of the *superheterodyne* type. A well-designed receiver of this type provides excellent selectivity and sensitivity. However, certain spurious responses peculiar to the superheterodyne must be minimized in the design.

The superheterodyne principle can be illustrated with the aid of Fig. 3-2, which is a block diagram of a radio receiver. The same principles apply to receivers for TV, radar, etc.

The speaker is the output *transducer;* that is, it converts electrical impulses into some other form, in this case sound. The detector performs the demodulation function, and the audio amplifier builds up the output of the detector to the level, or strength, required to drive the speaker.

The detector receives its input from the *intermediate-frequency* (*i-f*) amplifier. This amplifier is tuned to the same frequency, called the intermediate frequency, regardless of what frequency is being received. The frequency-converter stage converts the desired station frequency to the intermediate frequency, and the preselector section rejects antenna signals at frequencies other than the desired one.

The converter performs two functions, generation of a radio-frequency signal by a *local oscillator,* and combination of this signal with the incoming (station) signal in a *mixer.* In the mixer, several new frequencies are produced (a phenomenon called *heterodyning*), including the sum and difference of the local-oscillator and incoming frequencies. Usually, the difference frequency is selected (by a tuned circuit) for use as the i-f.

In the example of Fig. 3-2, the desired signal is at 1000 kHz. To receive this signal, the local oscillator is adjusted (with a "tuning" control on the receiver front panel) to operate at 1455 kHz; the difference frequency, 455 kHz, is the i-f, to which the i-f amplifier is tuned. Note that if a signal of 1910 kHz were present at the mixer, it, too, would yield a 455-kHz difference frequency when the oscillator is set at

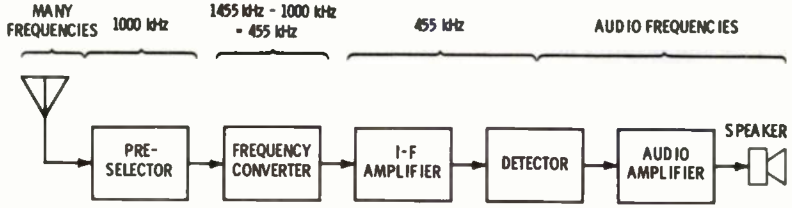


Fig. 3-2. Block diagram of superheterodyne receiver.

1455 kHz. The unwanted signal at 1910 kHz is called the *image*. The preselector serves to admit only the desired signal and to suppress the image. (Of course, to receive a different desired frequency, the oscillator frequency of Fig. 3-2 would have to be changed, and the image would be at a new frequency.)

A related problem exists because practical oscillators generate not only the intended frequency but also multiples, or *harmonics*, of that frequency. It is possible for these harmonics to combine with strong signals far outside the desired band to produce an unwanted signal at the i-f.

In inexpensive receivers, the preselector usually consists of a tuned circuit at the mixer input. When a greater degree of image rejection is needed, one or more tuned rf amplifiers may be added ahead of the mixer, or the designer may elect to use a *double-conversion* circuit. In this type of receiver, the incoming signal is first converted to a high i-f; this places the image frequency far from the desired frequency and makes it easier to reject. The first i-f is then converted to a second, lower i-f. Occasionally, *triple conversion* may be employed.

The advantage of the superheterodyne receiver is that the low-frequency, fixed-tuned i-f amplifier can be designed and adjusted for high amplification and the desired selectivity characteristic. Variable tuning is confined to the converter and preselector sections, and problems of *tracking* (making the variable tuned circuits follow each other accurately) are thereby reduced (although not eliminated).

Communications Receivers

A *communications receiver* (almost always a superheterodyne) includes functions and features not found in the usual broadcast-band receiver. It generally has several switch-selected tuning ranges, or frequency bands. A "bandspread," or oscillator fine-tuning, control is provided to make accurate tuning easier. An "antenna trimmer" allows precise adjustment of the preselector to compensate for slight errors in tracking between the variable tuned circuits. Variable or switched selectivity may be set to provide only the bandwidth needed for a given signal, thus minimizing interference from signals on adjacent frequencies. When needed, a signal from a *beat-frequency oscillator* (BFO) may be injected into the i-f amplifier to render cw (code) signals audible or to reinsert the carrier for single-sideband reception. There may be a separate rf gain control, an S-meter to indicate relative signal strength, a noise-limiter switch, an automatic-gain-control (agc) on-off switch, an earphone jack, and other features.

In a highly sensitive vhf or uhf receiver, the inherent noise in the receiver is amplified in the presence of a signal and is heard as a "rushing" or hissing sound. This noise can be quite annoying, particularly at high listening levels, so many receivers incorporate a circuit that silences the audio output when no signal is being received. This function of the receiver is called *squelch*. Usually a control is provided for determining the signal strength required before the squelch circuit turns on the audio output.

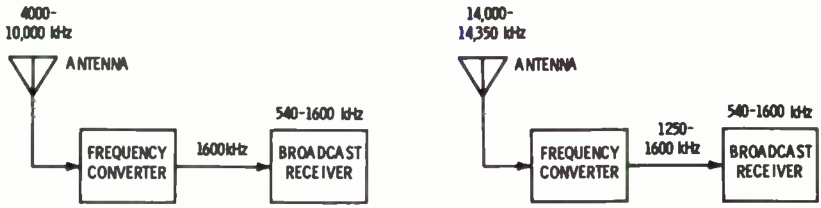
Numerous examples of receivers for all bands will be shown in subsequent chapters.

RECEIVER ACCESSORIES

Often, it is possible to extend the usefulness of a receiver by the use of accessory devices. Accessories are available to extend the frequency coverage of the basic receiver, to add the capability of receiving additional types of signals, to permit accurate calibration of the tuning dial, etc.

Frequency Converters

The tuning range of a receiver can be extended by the addition of a frequency converter, as in Fig. 3-3. The converter operates on the heterodyne principle and converts, or translates, signals from the antenna to frequencies



(*A*) *Tunable converter.* (*B*) *Fixed-tuned converter.*

Fig. 3-3. Use of external frequency converter.

within the receiver tuning range. The external converter performs the same function as the internal preselector and converter sections of Fig. 3-2, and the receiver of Fig. 3-3 becomes equivalent to the remaining sections of Fig. 3-2. If the receiver is a superheterodyne, the converter-receiver combination becomes a double superheterodyne.

In the example of Fig. 3-3A, the receiver is tuned to a fixed frequency (1600 kHz), and the converter is tuned to the desired incoming frequency (some frequency between 4000 and 10,000 kHz). Whatever input frequency is selected, the converter changes it to one output frequency (1600 kHz in Fig. 3-3A). In the example of Fig. 3-3B, the converter translates a band of input frequencies to a band of output frequencies. In this case, tuning is accomplished in the receiver, and the receiver must have sufficient tuning range to cover the spread of frequencies desired.

In general, with the arrangement of Fig. 3-3 advantage can be taken of such receiver characteristics as selectivity, gain, BFO, etc. However, the converter can contribute the same kinds of spurious responses that any other frequency converter can.

Other Converters and Adapters

In addition to frequency conversion at the receiver input, it is possible to use an adapter to add desired functions at the receiver output. The adapter takes the output from the receiver demodulator and converts it into some output form the receiver itself is not capable of producing. An example is a multiplex stereo adapter for a monophonic fm receiver.

Sometimes, converters combine several functions. For example, one type of converter receives fm signals in the 88-108 MHz range and converts them to a-m signals at some frequency in the 540-1600 kHz range. When such a converter is used with an a-m automobile radio, it permits use of the existing antenna and the audio amplifier and speaker of the a-m radio, without the need for internal modifications.

Q Multiplier

An accessory sometimes used with inexpensive communications receivers is the *Q multiplier*. This device, connected to the i-f amplifier, is used to improve the selectivity of the receiver. The unit in Fig. 3-4 is designed for use with receiver i-f's in the 450-500 kHz range; a tuning control may be set to the exact frequency required. The *Q* multiplier may be used to sharpen (peak) the normal receiver selectivity, or to reject (null) an unwanted signal. The model shown uses one dual-purpose tube and a solid-state power rectifier. It operates from 105-125 or 210-250 volts, 50-60 Hz. It measures 2⁹⁄₁₆" × 9¹⁄₃₂" × 3⅝" and weighs 2½ pounds.

Frequency Calibrator

When accurate frequency indication by a receiver dial is desired, a frequency calibrator may be used. The heart of this device is a crystal-controlled oscillator, which possesses excellent frequency stability. The oscillator is adjusted to a known frequency, and then

Courtesy Heath Company

Fig. 3-4. *Heathkit* Model GD-125 *Q* multiplier.

harmonics of this frequency provide reference signals at precise frequency intervals. These signals may be used to check the calibration of the receiver tuning dial.

The crystal calibrator in Fig. 3-5 uses a transistor oscillator circuit powered by a 9-volt battery. The oscillator operates at 100 kHz and produces signals at 100-kHz intervals up to 54 MHz or higher. It measures 4½″ ×2½″ × 2⅝″ and weighs 9 ounces.

Other Accessories

The devices mentioned in this section serve as examples of the kinds of receiver accessories that are used. Other auxiliary equipment, such as teleprinter adapters, rf preamplifiers (signal boosters), facsimile printers, etc., may be employed as the occasion demands.

Courtesy Heath Company

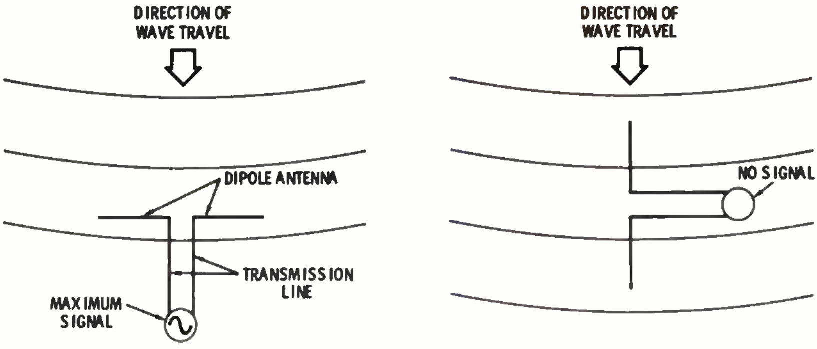
Fig. 3-5. *Heathkit* Model HD-20 crystal calibrator.

CHARACTERISTICS OF THE RECEIVING ANTENNA

Antennas have certain properties that can be put to good, practical use. Although these paragraphs are primarily directed at the subject of receiving antennas, transmitting antennas have corresponding properties.

Directivity

One of the simplest practical antennas is the *dipole*. As Fig. 3-6 shows, this antenna consists of two sections, with a two-conductor transmission line connected at the center. Maximum signal voltage is produced in this antenna when it is placed broadside to the passing wave, as in Fig. 3-6A. When the antenna is in line with the direction of wave travel (Fig. 3-6B), the signal voltage is zero. In other words, waves arriving broadside to the antenna produce a signal, and waves arriving from the ends of the antenna do not. Waves arriving from other directions produce intermediate signal values (assuming the wave amplitude



(*A*) *Perpendicular to wave travel.* (*B*) *Parallel to wave travel.*

Fig. 3-6. Effect of antenna orientation.

is the same for each direction), as shown by the graph in Fig. 3-7A. This property of the antenna to favor waves from certain directions is called *directivity*. Actually, Fig. 3-7A shows the antenna directivity in only one plane; the complete directivity graph would be a three-dimensional figure, something like Fig. 3-7B.

Gain

Fig. 3-6 shows an antenna consisting of one dipole; this is a *single-element* antenna. By using two or more elements, antenna designers can obtain a great variety of antenna directivity graphs, or *patterns*. Fig. 3-8 shows one possible pattern (dash line), drawn to the same scale as the simple dipole pattern (solid line). Note that the maximum signal voltage with the multiple-element antenna (points B and E) is greater than the maximum voltage from the single dipole (points G and H). The multiple-element antenna (often called an *array*) is said to possess *gain* with respect to the dipole. Note also that the voltage between points A and F and points C

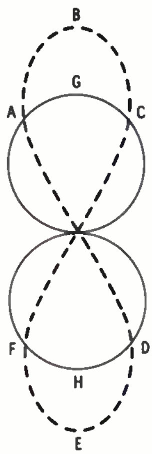
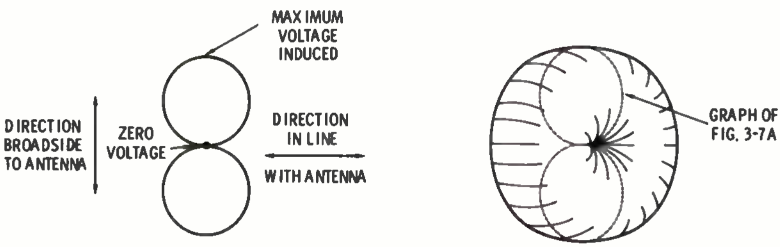


Fig. 3-8. Antenna gain.



(*A*) *In one plane.* (*B*) *In three dimensions.*

Fig. 3-7. Antenna patterns.

and D is less for the array than for the dipole. The higher voltage for waves arriving from one direction has been achieved at the expense of reduced voltage for waves arriving from other directions. Stated another way, an increase in gain has been accompanied by an increase in directivity, or vice versa. (This same principle was mentioned briefly in connection with the discussion of effective radiated power in Chapter 2).

Polarization

A fundamental attribute of an electromagnetic wave is its *polarization*. This property is determined by the direction of the electric component of the electromagnetic field; for practical purposes, it is sufficient to say that a vertically oriented antenna produces vertically polarized waves, and a horizontally oriented antenna produces horizontally polarized waves.

CHAPTER 4

Low and Very Low Frequencies

Although the low and very low frequencies were the first to be put to practical use, they are probably the least well known frequency range. Nevertheless, there is considerable activity on these bands. In fact, engineers are working as diligently to extend the lower limit of the radio spectrum as they are to extend the upper limit. Although frequencies below 10 kHz are not allocated at present, frequencies as low as 7 *hertz* are being investigated.

At very low frequencies (below 30 kHz), long-distance communications (particularly naval communications), radionavigation, and standard-frequency transmissions predominate. Services operating in the low-frequency range (30-300 kHz) include marine, aeronautical, radionavigation, standard frequency, and (in some parts of the world) broadcasting services.

TRANSMISSION CHARACTERISTICS

It has been pointed out that each frequency range has its own transmission characteristics which influence the uses to which it is put. The frequency ranges considered in this chapter are characterized by long-distance and comparatively stable transmission.

Propagation at Very Low Frequencies

At very low frequencies (below 30 kHz—see Table 1-1), the distance between the earth and the ionosphere is only a few times the wavelength. At these frequencies, it is believed that the ionosphere and the surface of the earth form a giant "wave guide," through which the vlf waves are propagated.

Vlf signals can be transmitted for distances up to several thousand miles. At distances up to several hundred miles, signal variation is small. At greater distances, there is an increase in received signal strength at night, and the difference is more pronounced as the frequency increases. There are also variations over the year and the 11-year sunspot cycle, but there is an absence of the short-term variations known as *fading*. A characteristic of these waves that is put to good use in submarine communications is their deep penetration into the earth.

Propagation at Low Frequencies

In the low-frequency range (30-300 kHz), propagation is mainly by means of the ground wave, because, in terms of wavelength, physically practical transmitting antennas are short and close to the earth. As the frequency increases, signal losses increase and transmission range decreases. Signal losses also depend on the nature of the soil and the roughness of the terrain over which the waves pass. At night, skywave reflection from the ionosphere gives increased transmission range.

Limitations on VLF Transmissions

Although the propagation characteristics at the lower end of the spectrum make these frequencies attractive, there are other factors which balance these advantages. First of all, the efficiency of a transmitting antenna depends on the size of the antenna relative to a wavelength. At vlf, antenna dimensions become enormous, and even an inefficient antenna represents a difficult engineering problem and a tremendous capital investment.

Another problem is the bandwidth of the transmitted signal. It was shown earlier that modulation of a carrier is accompanied by the generation of sidebands. When the width of the sidebands is not small compared to the carrier frequency, the signal is a *wideband* signal. At vlf, the carrier frequency is so low that even low-quality speech modulation results in such a wide-band signal that, if transmitted, only a few of these signals would occupy the entire vlf band. Furthermore, the practical bandwidth is limited by the characteristics of the transmitting system, particularly the antenna. Consequently, modulation in this band normally is limited to cw (code).

A further problem at vlf is the presence of atmospheric electrical noise. It is the nature of such noise that its intensity increases as the frequency decreases, and therefore strong signals (high transmitter power) are required in this band to overcome the noise. Powers on the order of a million watts are in use at some stations.

ALLOCATIONS

The FCC allocations for frequencies below approximately 300 kHz are shown in Table 4-1. In this table, a primary service, as the term implies, is dominant within the frequency range listed. Stations in a secondary service use the frequencies on condition that they do not interfere with the primary service, and they are not protected from interference caused by the primary service. (Note that the same service might be a primary service in one frequency band and a secondary service in some other band.)

Radio Services

Radio operations are classified into services according to the nature and purpose of the transmission. The names of the services shown in Table 4-1 and other allocations lists in this book are those used by the FCC. For our purposes, these services may be defined briefly as follows. (For exact FCC definitions, see Part 2, Section 2.1, FCC Rules and Regulations.)

Aeronautical Fixed Service: A fixed service intended for the transmission of information related to air navigation, preparation for flight, and safety of flight.

Aeronautical Mobile Service: A mobile service between land and airborne stations, or between airborne stations, in which stations aboard survival craft may participate also.

Aeronautical Multicom Service: A mobile service not open to public correspondence, used for communications essential to the conduct of activities being performed by or directed from private aircraft.

Aeronautical Radionavigation Service: A radionavigation service intended for the benefit of aircraft.

Amateur Service: A service of self-training, intercommunication, and technical investigation carried on by authorized persons interested in radio technique solely with a personal aim and without pecuniary interest.

Aviation Services: The Aeronautical Fixed Service, Aeronautical Mobile Service, Aeronautical Radionavigation Service, and, secondarily, the handling

Table 4-1. FCC Frequency Allocations (VLF and LF)

Frequencies (kHz)	Service	Class of Station
Below 10	(Not Allocated)	
10-14	Radionavigation	Radionavigation Land Radionavigation Mobile
14-19.95	Fixed	Fixed
19.95-20.05	Standard Frequency	Standard Frequency
20.05-59	Fixed	Fixed
59-61	Standard Frequency	Standard Frequency
61-70	Fixed	Fixed
70-90	Fixed Radiolocation*	Fixed Radiolocation Land Radiolocation Mobile
90-110	Radionavigation	Radionavigation Land Radionavigation Mobile
110-130	Fixed Maritime Mobile Radiolocation*	Coast Fixed Radiolocation Land Radiolocation Mobile Ship
130-160	Fixed Maritime Mobile	Coast Fixed Ship
160-200	Fixed	Fixed
200-285	Aeronautical Radio-navigation Aeronautical Mobile*	Aeronautical Aircraft Radionavigation Land
285-325	Maritime Radio-navigation	Radionavigation Land

*Secondary service; others are primary.

of public correspondence to and from aircraft.

Broadcasting Service: A radiocommunication service in which transmissions (sound, television, etc.) are intended for direct reception by the general public.

Citizens Radio Service: A radiocommunication service of mobile and non-mobile stations intended for personal or business communication, radio signalling, remote control of objects or devices, and other purposes not specifically prohibited.

Communication-Satellite Service: A service involving the use of satellites in the exchange of communications.

Community Antenna Relay Service: A fixed service for the transmission of broadcast-station signals to a terminal point from which the signals are distributed to the public by cable.

Disaster Communications Service: A service of stationary and mobile stations used to provide essential communications during a disaster or other incident because of which normal facilities have been lost, or because of which there is a temporary need for facilities in addition to those normally available.

Domestic Fixed Public Service: A fixed service, the stations of which are open to public correspondence, between sending and receiving points all within (1) Alaska, (2) Hawaii, (3) the 48 adjacent states, or (4) a single U.S. possession. (Generally, above 72 MHz communications between the 48 states and Canada or Mexico, or between Alaska and Canada, are considered to be in this service.)

Domestic Public Radiocommunication Services: Land mobile and domestic fixed public services the stations of which are open to public correspondence (see next subsection).

Fixed Public Control Service: A fixed service for transmitting intelligence between stations in the public radiocommunication services and the associated message centers or control points.

Fixed Service: A service of radiocommunication between specified fixed points.

Industrial Radio Services: Services essential to, operated by, and for the sole use of, enterprises which for purposes of safety or other necessity require radiocommunication.

International Fixed Public Radio Service: A fixed service, the stations of which are open to public correspondence. In general, it includes those stations not listed under the Domestic Fixed Public Radio Service.

Land Mobile Service: A mobile service between base stations and land mobile stations, or between land mobile stations. A land mobile station is a mobile station capable of surface movement within a country or continent.

Land Transportation Radio Service: A private service of radiocommunication essential to, and operated for the use of those engaged in, certain land transportation activities.

Maritime Mobile Service: A mobile service between coast and ship stations, or between ship stations. Survival-craft stations may participate also.

Maritime Radionavigation Service: A radionavigation service for the benefit of ships.

Meteorological Aids Service: A service used for purposes of meteorological, including hydrological, observations and exploration.

Meteorological-Satellite Service: A space service in which results of meteorological observations, made by instruments on earth satellites, are transmitted from the satellites to earth stations.

Mobile Service: A service of radiocommunication between mobile and land stations, or between mobile stations. (A land station is one not intended to be used while in motion.)

Public Safety Radio Service: A service of radiocommunication essential either to the discharge of non-Federal governmental functions or the alleviation of an emergency endangering life or property.

Radio Astronomy Service: A service involving the use of radio astronomy (astronomy based on the reception of radio waves of cosmic origin).

Radiodetermination Service: A service involving the determination of position, or obtaining information related to position, by means of the propagation properties of radio waves.

Radiolocation Service: A service involving use of radiodetermination for purposes other than radionavigation.

Radionavigation-Satellite Service: A service using space stations on earth satellites for the purpose of radionavigation. (In certain cases, supplementary information necessary for the operation of the radionavigation system may be transmitted or retransmitted also.)

Radionavigation Service: A radiodetermination service used for purposes of navigation, including obstruction warning.

Safety Service: A service used permanently or temporarily for the safeguarding of human life and property.

Space Research Service: A space service in which spacecraft or other objects in space are used for scientific or technological research purposes.

Space Service: A service between earth stations and space stations, between space stations, or between earth stations by way of retransmission or reflection from objects in space.

Standard Frequency Service: A service providing transmission of specified frequencies of stated high precision, for general reception.

Terrestrial Service: Any radio service, other than a space service or the Radio Astronomy Service.

Definitions of Other Terms

In addition to the names of the various services, several other specialized terms will be encountered in connection with the frequency-allocation tables in this and following chapters. Some of these terms are defined in the following paragraphs. In addition to the terms as shown here, various combinations of the listed terms may be used. (As in the preceding section, the definitions given are adequate for the purposes of this book; for exact FCC definitions, refer to Section 2.1 of the FCC Rules and Regulations.)

Airdrome Control Station: A station used for communications between an airport control tower and aircraft.

Base Station: A land station used for communications with land mobile stations.

Coast Station: A land station in the Maritime Mobile Service. Class-I coast stations provide long-distance communication to ships at sea. Class-II coast stations provide regional service. A public coast station is open to public correspondence; a limited coast station is not open to public correspondence.

Fixed Station: A station in the fixed service.

Mobile Station: A station used while in motion or while stopped at unspecified points.

Operational Station: A station, not open to public correspondence, operated for its own use by an organization that operates its own radiocommunication facilities in the Public Safety, Industrial, Land Transportation, Marine, or Aviation Services.

Public Correspondence: Any telecommunication which an office or station, because of being at the disposal of the public, must accept for transmission.

Telecommunication: The transferring of sound, images, or other intelligence by radio, wire, optical, or other electromagnetic means.

Specific FCC Frequency Allocations

Frequencies (in kilohertz) allocated for use by coast radiotelegraph stations in the general areas indicated are:

North Atlantic Coast	*South Atlantic Coast*
	137.70
112.85	
124.05	*Central Pacific Coast*
130.35	126.15
132.10	147.85
134.55	
137.00	*Gulf of Mexico Coast & Puerto Rico*
146.80	153.0
147.50	

The international calling frequency in this band is 143 kHz. Frequencies for ship radiotelegraph stations are 152, 153, 154, 155, 156, 157, and 158 kHz.

In Alaska, radiotelegraph stations in the Public Fixed Service share the frequency 149.6 kHz with stations in the Alaska Communication System (ACS), which is operated by the U.S. Army Signal Corps.

Frequencies in the 200-285 kHz band may be assigned to airdrome control stations; usually, operation on these frequencies is supplemental to operation of a station in the vhf band. Frequencies in the 90-110 kHz and 200-415 kHz bands are available for assignment to land stations used in aeronautical radionavigation. (The 200-415 kHz band is for radio beacons.) For a special aeronautical radionavigation system in the New York City area, the following frequencies (in kHz) are allocated:

70.8375	85.005	113.340	127.5075
84.945	85.065	116.1735	

Also, frequencies available to ship telephone and telegraph stations are available to aircraft stations under certain conditions and for certain purposes.

Land and mobile stations in the Industrial Radiolocation Service may be assigned to frequencies in the 70-90 and 110-130 kHz bands. This service is secondary to other services in these bands.

Bands in the vlf and lf range available to the International Fixed Public Service are as follows. All frequencies are in kilohertz. (Other services also may be assigned some of the frequencies in these bands.)

14-19.5	61-90
20.05-59	110-200

In addition to licensed stations, unlicensed low-power communication devices may be operated in the 10-490 kHz band. The FCC Rules and Regulations place definite limits on the strength of the signals such devices may radiate. Also, the devices must be certified as meeting these requirements. (For full details, see Volume II, Part 15, of the FCC Rules and Regulations.)

Allocations Elsewhere in the World

The allocations shown in Table 4-1 are those adopted by the Federal Communications Commission. In general, the uses shown conform to the ITU allocations, either world-wide or for Region 2. One significant difference is the band 150-285 kHz; in Region 1, this band is allocated for broadcasting. (See Fig. 1-1, Chapter 1 for a map of the ITU regions.) Broadcast stations in some countries also operate on frequencies ranging from 285 kHz to the beginning of the medium-frequency broadcast band.

SOME VLF TRANSMISSIONS

It would be difficult to select a "typical" vlf station, since each of these installations to a great extent represents a unique engineering problem. An interesting facility, however, is WWVL, one of the standard time and frequency stations of the National Bureau of Standards (NBS). This station radiates a 2000-watt signal on a frequency of 20 kHz from a transmitter site near Ft. Collins, Colorado. The frequency of WWVL is kept accurate by comparison to the output of the atomic standard maintained by the NBS at its laboratories in Boulder, Colorado. (Frequently, the transmissions alternate between 20.0 kHz and 19.9 or 20.5 kHz; the frequency changes each 10 seconds. These changes are the only means of station identification broadcast by WWVL.)

Several vlf stations are listed in Table 4-2; these stations also serve as standard frequency and time sources. For long-distance communication, the U.S. Navy maintains vlf stations such as NAA, NSS, and NPG/NLK. The latter station has its antenna suspended

Table 4-2. Some VLF Stations

Call Sign	Location	Frequency (kHz)	Transmitter Power (kW)[1]	Radiated Power (kW)[1]
GBR	Rugby, United Kingdom	16	300	40
NAA	Cutler, Maine	17.8	2000	1000
NBA	Balboa, Canal Zone	24	300	30
NPG/NLK	Jim Creek, Washington	18.6	1200	250
NPM	Lualualei, Hawaii	26.1	1000	100
NSS	Annapolis, Maryland	21.4	1000	100

[1]Power is listed in kilowatts (kW), where 1 kW = 1000 watts.

Table 4-3. Low-Frequency Broadcast Stations

Frequency (kHz)	Call Sign	Location	Power (kW)[1]
151	——	Cologne, W. Germany	50
182	——	Reykjavik, Iceland	100
191	SBG	Motala, Sweden	600
200	——	Droitwich, United Kingdom	400
218	——	Monte Carlo, Monaco	1200
233	——	Junglinster, Luxembourg	1100

[1]Power is listed in kilowatts (kW), where 1 kW = 1000 watts.

across a valley in the mountains of Washington state.

The vlf frequencies from about 10 to 14 kHz contain the transmissions of the Omega navigation system. A proposed eight stations will cover the earth with specially coded signals. Special receivers compare the phase of signals from different transmitter locations, and from this information accurate determinations of position can be made.

SOME LF TRANSMISSIONS

Another part of the NBS Ft. Collins installation is station WWVB, which radiates 10,000 watts at 60 kHz. This station continuously broadcasts a special pulsed timing code. The code (together with a 45° phase advance at 10 minutes past the hour and a 45° phase retardation at 15 minutes past the hour) also serves to identify the station. Like WWVL, WWVB has the atomic standard at Boulder as its ultimate reference for time and frequency.

Table 4-3 lists a few of the broadcast stations (none in the United States) that operate in the lf band. Notice that many of these stations do not have call signs.

A number of low-frequency radio beacons throughout the country are operated as aids to aeronautical navigation. As an added service, weather information is broadcast over many of these transmitters. Table 4-4 is a list of some of the stations from which these transmissions are made. In general, the stations listed have a power of 400 watts and broadcast continuous transcribed weather information. (These stations are not assigned call signs that conform to Table 1-2.)

The loran-C navigation system operates at 100 kHz. (Loran is an acronym derived from the phrase *LO*ng *RA*nge *N*avigation.) Pulses are transmitted from a "master" station and repeated by a "slave" station a known distance away. At a receiver on board an aircraft, the arrival times of the pulses from the two sources are compared, and comparisons for two or more station pairs are used to compute the position of the aircraft.

VLF RECEPTION

The transmissions in the vlf range are for highly specialized purposes, such as military communications, precision navigation, and precise standards of frequency (and therefore time). Consequently, commercially made receivers for this band are of professional or laboratory quality, and they are priced accordingly. Since these transmissions have little entertainment value, consumer-type vlf receivers are not manufactured. The hobbyist must rely on surplus or home-made equipment for low-cost receivers for this band (and for the lower portions of the lf band as well.) From time to time, plans for such receivers are published in electronics hobby magazines.

LF RECEPTION

For frequencies up to about 150 kHz, the comments in the preceding

Table 4-4. Low-Frequency Weather Broadcasts

Location	Frequency (kHz)	Identifying Letters
Albuquerque, N.M.	230	ABQ
Atlanta, Ga.	266	ATL
Birmingham, Ala.	224	BH
Burlington, Vt.	323	BTV
Chicago, Ill.	350	MDW
Cleveland, O.	344	CLE
Detroit, Mich.	388	DT
Ft. Worth, Tex.	365	FT
Jackson, Miss.	260	HKS
Jacksonville, Fla.	344	JAX
Las Vegas, Nev.	206	LAS
Los Angeles, Cal.	332	LAX
Minneapolis, Minn.	266	MS
Newark, N.J.	379	EWR
Oklahoma City, Okla.	350	OKC
Phoenix, Ariz.	326	PHX
Portland, Ore.	332	PDX
Seattle, Wash.	362	SEA
Spartanburg, S.C.	248	SPA
Washington, D.C.	332	DC

paragraph apply. However, a number of manufacturers market receivers that tune above this frequency (some tune slightly below it as well). Two representative examples follow; notice that each includes lf coverage as one of several switch-selected tuning ranges, or bands.

Although the receiver in Fig. 4-1 is basically a short-wave listener's receiver, it includes the 180-420 kHz band. The other bands covered by this receiver are 550-1550 kHz, 2-5 MHz, 5-12.5 MHz, and 12.5-30 MHz. The intermediate frequency is 1682 kHz. The circuit contains six tubes and eight diodes, and it requires 45 watts from a 50- or 60-Hz source. (It may be wired to operate from either a 120- or 240-volt source.) Controls include:

Courtesy Heath Company

Fig. 4-1. *Heathkit* Model GR-54 receiver.

bandspread, af gain (volume) and on-off, rf gain, antenna trim, a-m/upper-sideband/lower-sideband switch, band (frequency-range) switch, main tuning, bandspread (fine tuning), automatic-volume-control (avc) switch, automatic-noise-limiter (anl) switch, receive/standby switch, and a meter adjustment (on rear panel). Provision is included for earphones or an external speaker. A built-in meter indicates relative signal strength. An external antenna is used (an internal rod antenna also is included for the 550-1550 kHz band). The receiver is supplied in kit form for construction by the purchaser.

Fig. 4-2 shows a solid-state (tubeless) portable receiver that tunes the 88-108 MHz fm broadcast band and the following a-m bands: 150-400 kHz, 540-1600 kHz, 1.7-4 MHz, 4.7-10 MHz, 11.6-12.1 MHz (25-meter band), 15.0-15.7 MHz (19-meter band), 17.4-18.2 MHz (16-meter band), and 21.1-22.2 MHz (13-meter band). Two antennas are built in: a bar antenna for the 150-400 kHz and 540-1600 kHz bands, and a telescoping rod antenna for the other bands. A jack for an external antenna is provided. Controls include band selector, tuning, tone-control switch, volume/on-off, and afc switch. Other features include automatic frequency control (afc) for fm, automatic

Courtesy JVC America, Inc.

Fig. 4-2. Nivico Model 8500 receiver.

gain control (agc), two earphone jacks, a tuner output jack (to feed an external amplifier), a tuning indicator, and a dial check light for tuning in the dark. The unit may be powered from six D-size flashlight cells, or from a 120-volt, 60-Hz ac source. The receiver measures 9" × 14⅛" × 5¼", and it weighs 10½ pounds, including the flashlight cells.

CHAPTER 5

Medium Frequencies

Those frequencies between 300 and 3000 kHz are called medium frequencies. This range includes broadcast bands, maritime and aeronautical frequencies, and an amateur band.

PROPAGATION AT MEDIUM FREQUENCIES

During the day, the ionosphere absorbs medium-frequency sky waves, and transmission is mainly by means of the ground wave. Attenuation, or weakening, of the waves increases as the frequency increases. Poorly conducting soil attentuates the waves more than highly conducting soil does; rough terrain reduces them more than smooth terrain does. Other factors being equal, the greatest range is obtainable over sea water; the range over rocky, mountainous terrain is greatly reduced. Horizontally polarized waves are attenuated much more than vertically polarized waves are; hence, the use of vertical polarization is universal at medium frequencies.

At night, reflection of the sky wave from the ionosphere takes place, and nighttime reception over distances of hundreds (sometimes thousands) of miles is not unusual. During the hours that the medium-frequency skywave is returned to earth, three types of station "service areas" exist. (These areas are defined mainly for broadcast stations, but the principles are the same regardless of the purpose of the transmission.) Close to the station, only the ground wave is present, because the nature of most medium-wave antennas is such that radiation at high angles is small, and practically no sky wave is returned to the earth (Fig. 5-1). This area is called the *primary service area.* At lower angles, a strong sky wave is reflected and returns to the earth in an area where the ground wave also is strong. The two waves interfere with each other. Because the ionosphere is constantly changing, the nature of the interference also changes constantly—there are severe fading and varying degrees of audio distortion. This area is the *intermittent service area.* For still lower angles, the sky wave returns in an area where the ground wave is very weak or absent. This is the *secondary service area.* In this area, too, some fading and distortion are experienced because of the changeable nature of the ionosphere.

MEDIUM-FREQUENCY ALLOCATIONS

Almost every type of radio service is allocated frequencies in some part of the medium-frequency range: amateur, broadcast, maritime, aviation, police, etc. The FCC allocations for the frequencies between 300 and 3000 kHz

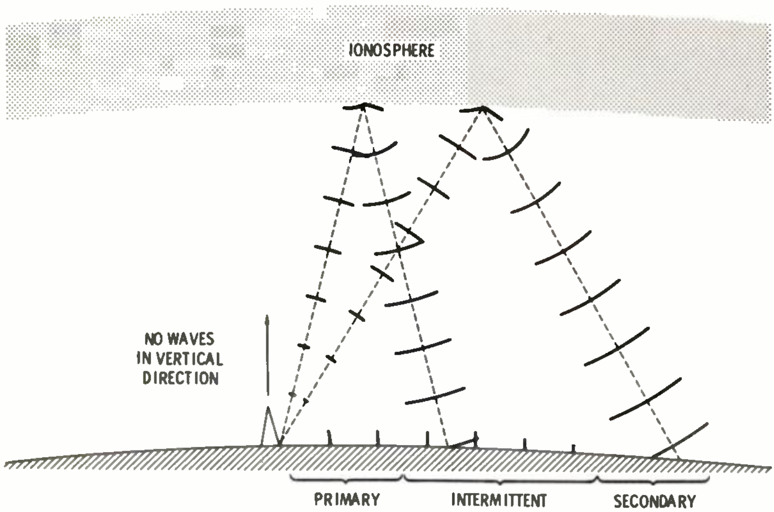


Fig. 5-1. Medium-frequency service areas.

are summarized in Table 5-1. The terms used in this table were defined in Chapter 4 in connection with Table 4-1. The allocations for individual services are examined in greater detail in the following sections.

MEDIUM-FREQUENCY BROADCASTING

The band 535-1605 kHz is known as the *standard broadcast band.* The use of these frequencies in the United States has developed under a rather complicated system of allocations. Although recent allocations proposals, if adopted, will limit drastically future growth of the use of this band in the U.S., the system under which the more than 4000 existing stations were assigned is of interest. (It should be noted that a number of applications filed before the "freeze" still may be approved.)

Classes of Channels and Stations

The band is divided into 106 *channels,* each of which is 10-kHz wide. Each channel is designated by its center frequency; thus, for example, the channel designated 540 kHz extends from 535 to 545 kHz. For allocation purposes, the channels are divided into three classes: clear, regional, and local.

Clear Channels—A *clear* channel is intended for the use of one or more high-power stations, which cover large areas by means of the sky wave (in addition to their ground-wave coverage). The dominant stations on the clear channels are designated Class-I stations. On some clear channels, secondary stations, designated Class-II stations, are permitted to operate. Class-II stations are required to protect Class-I stations and other Class-II stations from interference; a Class-I station is required to protect only other Class-I stations.

On certain clear channels, one Class-I station (called a Class I-A station) is given exclusive use of the channel in the 48 adjacent states (Table 5-2). These stations operate with a power of 50,000 watts. (Daytime and limited-time stations in the 48 states were authorized on some of these channels prior to adoption of the present rules. These stations have been permitted to continue in operation.)

On each of 12 other clear channels, there are one Class-I station and one full-time Class-II station (called a Class II-A station) in the 48 adjacent states (Table 5-3). On these channels, the Class-I stations operate with 50,000 watts. The Class II-A stations must operate with a minimum power of 10,-

Table 5-1. FCC Frequency Allocations (MF)

Frequency (kHz)	Service	Class of Station
285-325	Maritime Radionavigation	Radionavigation Land
325-405	Aeronautical Radionavigation	Aeronautical
	Aeronautical Mobile*	Aircraft
		Radionavigation Land
405-415	Maritime Radionavigation	Aeronautical
	(Radio Directionfinding)	Aircraft
	Aeronautical Radionavigation*	Radionavigation Land
	Aeronautical Mobile*	Radionavigation Mobile
415-490	Maritime Mobile	Coast
		Ship
490-510	Mobile	Coast
		Mobile
510-535	(Not available to non-Government stations [except 512 kHz])	
535-1605	Broadcasting	Standard Broadcast
1605-1715	Aeronautical Radionavigation	Base
	Fixed	Mobile
	Land Mobile	Fixed
	Maritime Mobile	Land Mobile
	Radiolocation	Radionavigation Land
1715-1750	Fixed	Base
	Land Mobile	Mobile
	Maritime Mobile	Fixed
	Radiolocation	Land Mobile
		Ship
1750-1800	Fixed	Fixed
	Mobile	Land
	Radiolocation	Mobile
1800-2000	Radionavigation	Amateur
	Amateur*	Loran
2000-2107	Maritime Mobile	Coast (2000-2068.5, 2078.5-2089.5, 2092.5-2107 kHz)
		Ship (2000-2035, 2065-2107 kHz)
2107-2170	Fixed	Base
	Land Mobile	Coast
	Maritime Mobile	Fixed
		Land Mobile
		Ship
2170-2194	Mobile	Aircraft
		Coast
		Ship
		Survival Craft
2194-2495	Fixed	Base
	Land Mobile	Coast
	Maritime Mobile	Fixed
		Land Mobile
		Ship
2495-2505	Standard Frequency	Standard Frequency
	Radio Astronomy*	Radio Astronomy
2505-2850	Fixed	Base
	Land Mobile	Coast
	Maritime Mobile	Fixed
		Land Mobile
		Ship
2850-3155	Aeronautical Mobile	Aeronautical
		Aircraft

*Secondary service; others are primary services.

Table 5-2. Nonduplicated Clear Channels

Channel (kHz)	Station	City of License
640	KFI	Los Angeles, Cal.
650	WSM	Nashville, Tenn.
660	WNBC	New York, N.Y.
700	WLW	Cincinnati, O.
750	WSB	Atlanta, Ga.
770[1]	WABC	New York, N.Y.
820	WBAP	Fort Worth, Tex.
830	WCCO	Minneapolis, Minn.
840	WHAS	Louisville, Ky.
870	WWL	New Orleans, La.
1040	WHO	Des Moines, Ia.
1160	KSL	Salt Lake City, Utah
1200	WOAI	San Antonio, Tex.

1. Use of this frequency is the subject of litigation. At present, KOB, Albuquerque, N.M. also operates on the channel with 50,000 watts, unlimited time.

000 watts at night (some have a night power of 50,000 watts). They operate with 10,000 or 50,000 watts daytime power. In addition to the Class II-A stations listed in Table 5-3, there is a full-time 5000-watt Class-II assignment on 760 kHz (KFMB) San Diego, California; WJR, Detroit is the Class-I station on this channel.

Certain clear channels are reserved for Class-I stations in neighboring countries (Table 5-4). Except for certain specific assignments, no U.S. station may operate at night on a Mexican clear channel. In addition, the power of U.S. daytime-only stations on the Mexican clear channels is limited to 5000 watts (1000 wats near the border). U.S. stations operating at night on the Canadian clear channels must be at least 650 miles from the border. U.S. stations on these channels may have powers of 250 to 50,000 watts. There are strict limits to the signal strength a station on a Mexican or Canadian clear channel may deliver to the border of the other country involved. (On U.S. clear channels, protection from foreign stations is provided under terms of the North American Regional Broadcasting Agreement and the U.S.-Mexican agreement.) All U.S. stations on the Canadian and Mexican clear channels are Class-II stations.

On the remaining clear channels, there may be one or more Class-I stations (in this case, called Class I-B sta-

Table 5-3. Channels for Class II-A Stations

Channel (kHz)	Class I Station	Class II-A Station
670	WMAQ, Chicago, Ill.	KBOI, Boise, Id.
720	WGN, Chicago, Ill.	—, Las Vegas, Nev.*
780	WBBM, Chicago, Ill.	KCRL, Reno, Nev.
880	WCBS, New York, N.Y.	KRVN, Lexington, Nebr.
1020	KDKA, Pittsburgh, Pa.	KSWS, Roswell, N.M.
1030	WBZ, Boston, Mass.	KTWO, Casper, Wyo.
1100	WKYC, Cleveland, O.	KREX, Grand Junction, Colo.
1120	KMOX, St. Louis, Mo.	KPNW, Eugene, Ore.
1180	WHAM, Rochester, N.Y.	KOFI, Kalispel, Mont.
1210	WCAU, Philadelphia, Pa.	KGYN, Guymon, Okla.

*Under construction; call letters to be assigned.

tions) and a number of Class-II stations. These frequencies are 680, 710, 810, 850, 940, 1000, 1060, 1070, 1080, 1090, 1110, 1130, 1140, 1170, 1190, 1500, 1510, 1520, 1530, 1540, 1550, and 1560 kHz. (U.S. stations on 1540 kHz must give protection to a Class-I allocation in the Bahamas.) Class-II stations on these frequencies are further classified as Class II-B (unlimited time) or Class II-D (daytime only). On these channels, Class-I stations may operate with powers of 10,000 to 50,000 watts, and Class-II stations may operate with powers of 250 to 50,000 watts.

Table 5-4. Clear Channels for Neighboring Countries

Channel (kHz)	Country
540	Canada & Mexico
690	Canada
730	Mexico
740	Canada
800	Mexico
860	Canada
900	Mexico
990	Canada
1010	Canada
1050	Mexico
1220	Mexico
1570	Mexico
1580	Canada

Regional Channels—A *regional* channel is used by several stations of moderate power. These stations, designated Class-III stations, give ground-wave service to their city of license and surrounding rural areas. Class III-B stations have a minimum power of 500 watts and a maximum power of 1000 watts (night) or 5000 watts (day). Class III-A stations have powers of 1000 to 5000 watts and are afforded a greater degree of nighttime interference protection than are Class III-B stations. The regional channels (in kilohertz) are:

550	610	930	1250	1310	1380	1460
560	620	950	1260	1320	1390	1470
570	630	960	1270	1330	1410	1480
580	790	970	1280	1350	1420	1590
590	910	980	1290	1360	1430	1600
600	920	1150	1300	1370	1440	

Local Channels—*Local* channels are used by Class-IV stations, which operate with low power and serve their city of license and immediately surrounding area. These stations operate with 250 watts at night and 250, 500, or 1000 watts during the day (250 watts maximum day or night near the Mexican border). In earlier years, these stations were permitted a minimum of 100 watts, which a few still use. Also, a few Class-IV stations operate on regional channels; the rules no longer provide for this type of operation, but existing stations have been permitted to continue in operation. The local channels are 1230, 1240, 1340, 1400, 1450, and 1490 kHz.

Hours of Operation

Standard broadcast stations are required to operate for at least two-thirds of their authorized hours between 6 a.m. and 6 p.m., and (except for daytime-only stations) for at least two-thirds of their authorized hours between 6 p.m. and midnight. (Sundays are excepted.)

Maximum operating hours are specified in the license of a standard broadcast station. The major reason for this is the fact that propagation characteristics at medium frequencies differ greatly between day and night. Operating hours are specified according to the following categories.

Unlimited Time—When a station is authorized for unlimited-time operation, no maximum limit is placed on the hours the station may operate.

Limited Time—A Class-II station licensed for limited-time operation may operate during daytime hours (see below). In addition, it may operate during nighttime hours when the dominant station is not operating, and, if it is located east of the dominant station, it may operate until sunset at the location of the dominant station. New limited-time authorizations have been banned since 1959.

Daytime—A daytime station is permitted to operate between average monthly sunrise and average monthly sunset at the transmitter location. (Under certain conditions, sign-on for some daytime stations may be as early as 6 a.m. during those months when the average time of sunrise is after 6 a.m.) The average times of sunset and sunrise are determined by the actual sunset and sunrise times on the fifteenth day of the month, rounded to the nearest quarter hour.

Sharing Time—Sometimes, two or more stations agree to divide the total available time on a channel among them.

Specified Hours—In some cases, a license specifies the exact operating hours for a station. This term is applied in cases of specified hours other than daytime, limited-time, or sharing-time authorizations. The most usual instance is a local-channel station which, for economic or other reasons, does not wish to operate during all of the nighttime hours required by an unlimited-time authorization.

Methods of Minimizing Interference

Several methods are available for minimizing interference between standard broadcast stations, and all are used in various combinations. All involve minimizing the signal that one station places in the service area of another station.

Separation—The simplest methods of reducing interference are frequency and distance separation. That is, insofar as possible, stations in the same general area are assigned different frequencies (at least 40 kHz apart in the same city), and stations on the same frequency are separated by a distance sufficient to avoid mutual interference. The required distance of separation sometimes is reduced by limiting the power of one or more of the stations involved; the local channels are an example of this expedient.

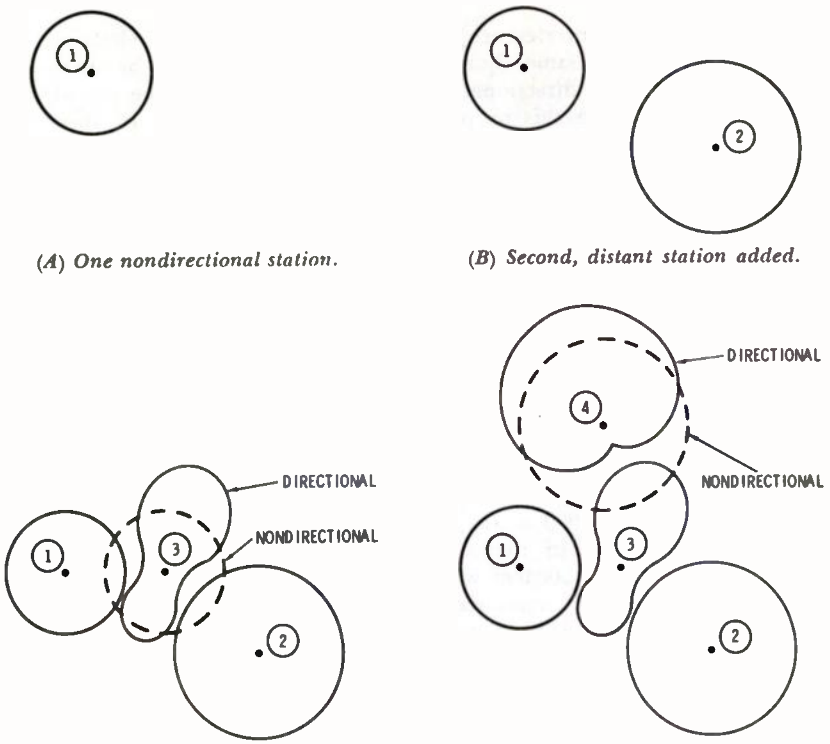
Directional Antennas—As use of the standard broadcast band grew, wide separations alone became inadequate for accommodating the increasing number of stations, and use of the directional transmitting antenna became popular. Today directional antennas with from two to as many as twelve elements (towers) are employed.

Fig. 5-2 shows how directional antennas might be used to make possible the construction of stations where nondirectional antennas would cause interference to other facilities using the same frequency. (Fig. 5-2 is a hypothetical, simplified situation, not an actual case.) Assume that station 1 began operating on the frequency many years ago (Fig. 5-2A). At a later time, station 2 went on the air (Fig. 5-2B). The stations are far enough apart that both can operate nondirectionally; that is, each uses a single-tower antenna. Still later, station 3 was built (Fig. 5-2C). If it operated nondirectionally (dash line), it would interfere with both existing stations. However, when a directional antenna is used at station 3, there is no interference problem. Similarly, still newer station 4 (Fig. 5-2D) must use a directional antenna to protect station 3 from interference. Notice that existing stations are not required to change their antenna patterns for the benefit of new stations.

In Fig. 5-2, it was assumed that all four stations operate on the same channel. Directional antennas sometimes are needed to prevent interference between stations on adjacent channels, that is, channels separated by 10, 20, or 30 kHz.

Occasionally, directional antennas are used for purposes other than interference reduction. For example, Fig. 5-3 shows how such an antenna might be used by a station near the coast to concentrate its signals over the land, and hence not waste its power over an unpopulated area (the ocean).

Different Facilities for Day and Night—Medium-frequency waves can



(*A*) *One nondirectional station.* (*B*) *Second, distant station added.*

(*C*) *Third station added.* (*D*) *Fourth station added.*

Fig. 5-2. Use of directional antennas to reduce station interference.

travel great distances at night because of ionospheric reflection. For this reason, the interference problem is much more troublesome at night than during the day. Several restrictions on station operation have been adopted to reduce this problem. Among them are the following:

1. Many stations are permitted to operate during daytime hours only. (A few stations are licensed for limited-time operation, as mentioned earlier.)
2. Some stations operate with reduced power at night.
3. Many stations operate with a directional antenna at night. Some stations operating directionally during the day use a different directional pattern at night.
4. Many stations use a combination of reduced power and a directional antenna at night.

The propagation characteristics do not change abruptly at sunrise or sunset. The FCC rules recognize transition periods extending for two hours after sunrise and two hours before sunset. During these "critical hours," Class-II stations are required to take measures

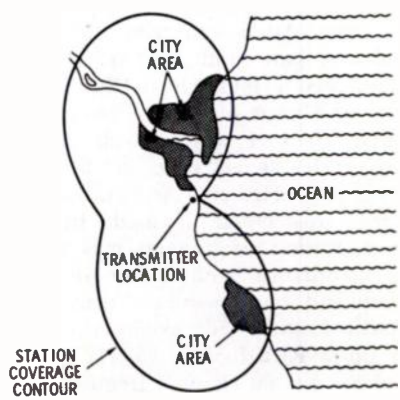


Fig. 5-3. Use of directional antenna to concentrate signal.

to avoid sky-wave interference to Class-I stations on the same channel. Power reduction and/or directional antennas are employed for this purpose. (Facilities authorized before this rule took effect were not required to be changed.)

Broadcasting in Other Countries

The preceding description of radio allocations was limited to broadcasting in the United States as regulated by the Federal Communications Commission. There are some differences, of course, in other countries. One has to do with station power. In the United States and Canada, standard broadcast stations operate with powers from 250 (sometimes 100) to 50,000 watts. In some countries, powers in excess of 50,000 watts—sometimes 500,000 watts or more—may be used. Occasionally, powers of less than 100 watts may be encountered. In the U.S., stations are licensed with powers of 100, 250, 500, 1000, 5000, 10,000, 25,000, or 50,000 watts. Other power levels may be authorized in other countries. For instance, stations in Mexico have such powers as 150 watts, 350 watts, 400 watts, and others, in addition to the standard powers.

In North America, a channel width of 10 kHz is used, with channel frequencies in multiples of 10 (540 kHz, 550 kHz, 560 kHz, etc.). This plan is followed also in most of South America, in Australia and New Zealand, and in some Asian countries (including India, Japan, and China). Another plan, used extensively in Europe, Africa, and parts of Asia, is based on a 9-kHz channel width. Such channel frequencies as 548 kHz, 557 kHz, 566 kHz, 575 kHz, etc., are encountered where this system is used. In some areas, station assignments may not be in accordance with either of these plans and may be unique with a particular country. For example, stations in Costa Rica have a 25-kHz spacing and operate on channel frequencies of 550 kHz, 575 kHz, 600 kHz, etc., through 1600 kHz.

In the tropics, the electrical noise level in the standard broadcast band is quite high due to the prevalence of thunderstorm activity. In these areas, use is made of the *tropical broadcast bands*. One of these bands extends from 2300 to 2495 kHz (2300 to 2498 kHz in ITU Region 1). Areas which have stations in this band include Brazil, China, Equador, Grenada, Guatemala, Haiti, Indonesia, Israel, Mexico, New Guinea, Rhodesia, South Africa, South Korea, Venezuela, and Zambia. In general, channel frequencies are multiples of ten (2330 kHz, 2340 kHz, etc.), but there are several exceptions. Most of the stations operate with power of 1000 watts or less.

Other Broadcast Activities

Frequently, broadcast stations have a need to relay program material from remote locations to the studio or transmitter site. Telephone lines may be used for this purpose, but a number of broadcasters use radio relays known as *remote-pickup* (rpu) stations. In the United States, rpu frequencies in the mf range are 1606, 1622, and 1646 kHz. Normally, type A3 emission (a-m) is authorized on these frequencies.

The frequency 2500 kHz is used for standard frequency and time broadcasts. Because this usage is so closely related to similar operations on high frequencies, broadcasts on 2500 kHz will be covered in Chapter 6.

AMATEUR RADIO

Amateur radio stations share use of the 1800-2000 kHz band with the loran-A navigation system; the loran operation has priority of use of the band. (For an explanation of loran, see Chapter 4.) In this band, amateur stations may use only type A1 or A3 emissions. In many areas, the power is limited to much less than the 1000 watts permitted on most amateur frequencies. Also, amateur operation is prohibited for some combinations of location and frequency in this band.

(For more information about amateur radio, see Chapters 6, 7, and 8.)

MARITIME STATIONS

Stations in the maritime services are allocated frequencies near both extremes of the medium-frequency range. Near the lower extreme, the frequency 410 kHz is for use in radiodetermination and related communications. The calling and distress frequency for radiotelegraphy is 500 kHz; 512 kHz is a calling frequency for use when 500 kHz is occupied with distress messages.

Radiotelegraph Frequencies

Frequencies (in kilohertz) below the broadcast band for use by coast radiotelegraph stations are:

North Atlantic
418
436
442
460
472
476
482

Central Atlantic
428

South Atlantic
434
464
472
488

North Pacific
482
488

Great Lakes
482

Central Pacific
426
436
460
476

South Pacific
418
464
482

Gulf of Mexico
416
420
434
438
478
484

Hawaii
484

Puerto Rico
486

Frequencies (in kilohertz) below the broadcast band available to ship radiotelegraph stations are:

425	468
444*	480
454	

*For communication with U.S. Government stations only (except for distress communication).

Frequencies (in kilohertz) above the broadcast band for coast radiotelegraph stations are:

North Atlantic
2036
2040.5
2046.5
2051
2054
2060

Central Atlantic
2063

South Atlantic
2039
2043.5
2051
2057

North Pacific
2058.5
2063

Central Pacific
2037.5
2045
2061.5

South Pacific
2049.5
2055.5

Gulf of Mexico
2042
2048
2049.5
2052.5
2055.5
2063

Hawaii
2052.5

Puerto Rico
2052.5

Ship radiotelegraph calling frequencies (in kilohertz) above the broadcast band are:

2089.75	2091
2090	2091.25
2090.25	2091.5
2090.5	2091.75
2090.75	2092
	2092.25

The frequencies 2071 and 2076 kHz are available for transmission of wide-band telegraphy, facsimile, and special transmission systems.

Radiotelephone Frequencies

In the maritime bands above the broadcast band, the frequency 2182 kHz is the international radiotelephone distress and general calling frequency. Intership safety frequencies are 2638 kHz (all areas), 2003 kHz (Great Lakes), 2142 kHz (southern Pacific coast), 2830 kHz (Gulf of Mexico), and 2738 kHz (all areas except Gulf of Mexico). These frequencies also may be used for operational communications on a non-

Table 5-5. Coast-Station Frequencies

Coast Station Transmitting Frequency (kHz)	Coast Station General Location	Coast Station Receiving Frequency (kHz)
2506	San Francisco	2406
2530	Hawaii	2134
2590	New York	2198

interference basis. Frequencies for safety, business, and operational communication with limited coast stations are 2738, 2830, and 2214 kHz.

The frequencies in Table 5-5 are available to Class-I (long-range) coast stations for use when the coast station and ship station transmit alternately on different frequencies. Similar allocations in the 2-kHz region are made to Class-II (regional) public coast stations and to ship radiotelephone stations carrying public correspondence. Specific frequencies to be used depend on the location of the coast station with which the ship communicates. These allocations are summarized in Table 5-6; for full details, including frequencies for other locations and limitations on the use of individual frequencies, see Section 83.354 of the FCC Rules and Regulations (Part 83, Volume IV). The frequencies 2400, 2738, 2782, and 2784 kHz are available for

Table 5-6. Maritime Radiotelephone Frequencies

Location of Coast Station	Coast Station Transmitting Frequency (kHz)	Mobile Station Transmitting Frequency (kHz)
Boston, Mass.	2450	2366
	2566	2390
	2506	2406
New York, N.Y.	2522	2126
	2558	2166
	2590	2198
	2482	2382
Baltimore, Md.	2558	2166
Miami, Fla.	2490	2031.5
	2514	2118
	2550	2158
	2442	2406
New Orleans, La.	2598	2206
	2558	2166
	2482	2382
Great Lakes	2514	2118
	2550	2158
Los Angeles-San Diego, Cal.	2566	2009
	2466	2382
	2598	2206
	2522	2126
Seattle, Wash.	2522	2126
	2482	2430
Hilo, Hawaii	2582	2198
St. Thomas I., V.I.	2506	2009

use when the ship station and Class-II coast station transmit alternately on the same frequency. See the FCC Rules and Regulations (Section 83.354) for details of use.

Carrier frequencies between 2000 and 2450 kHz which are available to ship public radiotelephone stations for transmitting public correspondence to coast stations are available also to marine fixed stations for the same purpose. In addition, the frequencies used by ship radiotelephone stations in transmitting to a coast station may be assigned to a marine receiver-test station associated with the coast station.

It should be noted that a great many users of the mf maritime band (e.g., pleasure-boat operators) will be required to shift to vhf fm by 1977. Those users who remain in the band (those who need the long-range characteristics of the band) will be required to change from conventional a-m to single-sideband operation.

Direction Finding

The assigned frequency for direction finding is 410 kHz. In the event of distress, 500 kHz and 2182 kHz may be used for direction finding in connection with search and rescue operations.

Power Limitations

For those frequencies in this chapter below the broadcast band, the maximum transmitter power for coast radiotelegraph stations is 40,000 watts. For coast radiotelegraph stations operating between 2035 and 2065 kHz, the maximum power is 6600 watts. For coast radiotelephone stations on most frequencies in the 2000-4000 kHz band, the maximum transmitter power is 1500 watts during the day and 700 watts at night.

The maximum power for ship radiotelegraph stations is 8000 watts for passenger ships of 5000 or more gross tons, and 2000 watts for all other vessels. For ship radiotelephone stations the minimum power is 15 watts. In general, the maximum power is 150 watts for all communications on the Great Lakes and the Mississippi River system, and ship-to-ship communications elsewhere. For ship-to-shore communications in areas other than the Great Lakes and the Mississippi River system, the usual maximum is 1000 watts for passenger ships of 5000 or more gross tons, and 400 watts for other vessels.

FREQUENCY ASSIGNMENTS IN ALASKA

Special rules apply to fixed public stations and maritime stations in Alaska (Part 85, Volume IV, FCC Rules and Regulations). In Alaska as elsewhere, distress frequencies are 500 kHz (radiotelegraphy) and 2182 kHz (radiotelephony). Other allocations are summarized in the following paragraphs.

Frequencies for Fixed Public Stations

The following frequencies (in kilohertz) are available to fixed public stations for telegraphy and/or telephony:

1646	2006	2506
1652	2422	2512
1660	2430	2538
1708	2450	2566
1712	2482	2616

Each frequency above is available only in a specific zone or zones and some are subject to other special restrictions. The frequency 2118 kHz is available in all zones.

Frequencies are assigned for use by fixed public stations in communicating with specific stations of the Alaska Communication System (ACS). The frequencies and the corresponding ACS stations are 1666 kHz (Ketchikan and King Salmon), 2256 kHz (Anchorage and Ketchikan), 2466 kHz (Wrangell, King Salmon, Kotzebue), 2474 kHz (Sitka, Kodiak, Nome, Barrow), 2632 kHz (Cordova, Fairbanks, Bethel, and Unalaska), 2694 kHz (Juneau, Cold Bay), and 2776 kHz (Ketchikan). These frequencies are for telegraphy and/or telephony (except 1666 kHz is for telegraphy only).

Maritime Frequencies

Frequencies for ship radiotelegraph stations include 500 kHz (calling and distress); 425, 448, 454, 468, and 480 kHz (working); 410 kHz (direction finding and related communications); and 444 kHz (communication with U.S. Government stations). The frequency 2091 kHz is the international calling frequency for ship radiotelegraph stations assigned to the 2065-2107 kHz band. It is also used to establish contact with coast radiotelegraph stations operating in the 2035-2065 kHz band or with ship or coast radiotelegraph stations in the 1605-2035 kHz and 2107-3400 kHz bands. Working frequencies for ship radiotelegraph stations are assigned in the 2065-2107 kHz band (and in hf bands). Frequencies for public coast radiotelegraph stations are 416, 438, and 2052.5 kHz.

For stations using radiotelephony, 2638 and 2738 kHz are available for intership communications in all zones. The frequencies 1622 and 2382 kHz are available for telegraph and/or telephone communication between public coast stations and public ship stations (any type of vessel). For telegraphy or telephony between vessels of less than 500 gross tons, 1622 kHz may be used. For similar communication between vessels of over 500 gross tons, 2382 kHz may be used.

For public telephone service between ship stations and ACS coast stations, ship-station frequencies of 2134 and 2240 kHz are used. The coast stations use 2312 and 2400 kHz.

Frequencies (in kilohertz) for public coast and ship radiotelephone and radiotelegraph stations are:

1646	2422	2506
1652	2430	2512
1708	2450	2538
1712	2482	2566
2118		

Each frequency is for use in a specified zone or zones, and some frequencies are subject to other limitations.

FREQUENCIES FOR AVIATION

Medium frequencies available to aircraft stations include 410 kHz (international direction-finding frequency for use outside the continental United States), 457 kHz (working frequency for aircraft on oversea flights), and 500 kHz (international calling and distress frequency for ships and aircraft over the seas). Also, for specified purposes, ship calling and working frequencies may be assigned to aircraft.

Frequencies (in kilohertz) for aeronautical enroute stations serving routes in the indicated areas are:

2861—Alaska, U.S. possessions in West Indies
2868—Far East, North Atlantic
2875—Alaska
2889—Western South America
2896—Central West Pacific
2910—Eastern South America, Europe, North Pacific
2924—Alaska
2931—North Atlantic
2945—North Atlantic, South Pacific
2952—Caribbean
2966—Caribbean, Eastern Africa
2987—U.S.-Alaska via Canada, North Atlantic, Far East, Southeast Asia

Two frequencies in the mf range are available to flight-test stations for communication with aircraft beyond vhf range. These frequencies are 2868 and 2994 kHz. Single-sideband emission is required.

For airdrome control stations, frequencies in the band 325-405 kHz are available. Usually, operation on these frequencies is supplementary to vhf operations.

Frequencies in the bands 200-415 kHz and 1800-2000 kHz are available for assignment to radionavigation land stations. (The 200-415 kHz band is for radio beacons.)

The frequencies 2371 kHz and 2374 kHz are available to Civil Air Patrol stations. Operation on either frequency may be with 1600 watts maximum power and single-sideband emission. In addition, type A1, A2, or A3 emission may be used on 2374 kHz with 400 watts maximum power.

Aeronautical fixed stations are operated in association with aeronautical enroute stations. They are used for point-to-point communications related to "safety, regularity, and economy of flight." Such stations may be assigned frequencies in the bands 1605-1750 kHz, 2107-2170 kHz, 2194-2495 kHz, and 2505-2850 kHz.

INDUSTRIAL RADIO SERVICES

Most of the frequencies allocated to the Industrial Radio Services lie above the mf region, so these services will be discussed in more detail in later chapters. (In particular, see Chapter 6 for definitions of these services.) However, a few frequencies above the standard broadcast band are available for assignment to the services indicated below:

1614—Petroleum
1628—Petroleum, Motion Picture
1652—Petroleum, Motion Picture
1676—Petroleum, Forest Products
1700—Petroleum, Forest Products
2292—Power, Petroleum, Motion Picture, Special Industrial
2398—Power, Petroleum, Forest Products, Motion Picture, Special Industrial

These frequencies (all in kHz) are available for base and mobile stations. In general, the power input on these frequencies does not exceed 2000 watts, and the emission is type A3 with a maximum bandwidth of 8 kHz. The listed frequencies are not always available; in such cases, a substitute frequency may be assigned in the bands 1605-1750, 2107-2170, 2194-2495, 2505-2850, 3155-3400, or 4438-4650 kHz.

Land and mobile stations in the Industrial Radiolocation Service may be assigned frequencies in the 1605-1800 kHz band. Power input is limited to 500 watts, and bandwidth is limited to 2 kHz.

PUBLIC SAFETY SERVICES

Some stations in the Police, Fire, Forestry Conservation, Special Emergency, and State Guard Radio Services are assigned frequencies in the mf range. A summary of the allocations for these services is contained in Table 5-7. Some of the restrictions or special uses applicable to specific frequencies are enumerated in the Notes column of the table. For a more detailed discussion of these services, see Chapter 7; additional information also is contained in Chapters 6 and 8.

In addition to the allocations indicated in Table 5-7, ship-station frequencies in the band 2000-3000 kHz used for telephone communication with public coast stations may be assigned to fixed stations in the Special Emergency Radio Service. These assignments are made for emergency communications between isolated locations and public coast stations.

State Guard licensees may be granted a second frequency in the 2505-3500 kHz band, if the frequency is available and if a need for it can be shown.

In general, stations in these services use type A3 emission on medium frequencies; maximum bandwidth is 8 kHz. Maximum power input is 2000 watts, except as noted.

OTHER ALLOCATIONS

The Disaster Communications Service is a service of stationary and mobile stations used to provide essential communications during a disaster or other incident because of which normal facilities have been lost, or because of which there is a temporary need for facilities beyond those normally available.

Frequencies (in kilohertz) for radiotelegraph operation in this service are:

1750.5	1754.5
1751.5	1755.5
1752.5	1756.5
1753.5	1757.5

Table 5-7. Frequencies for Public Safety Services

Frequency (kHz)	Service	Type of Station	Notes
1610-1730	Police	Base, Mobile	1,2,3,4
1630	Fire	Base, Mobile	
2212	Forestry-Conservation	Base, Mobile	5
2226	Forestry-Conservation	Base, Mobile	5
2236	Forestry-Conservation	Base, Mobile	5
2244	Forestry-Conservation	Base, Mobile	5
2326	Police	Base, Mobile	2,5
2366	Police	Base, Mobile	2,5
2382	Police	Base, Mobile	2
2390	Police	Base, Mobile	2,5
2406-2430	Police	Base, Mobile	1,2
2442-2490	Police	Base, Mobile	2,6
2726	State Guard, Special Emergency	Base, Mobile	
2804-2812	Police	Zone, Interzone	7,8

1. Frequencies are assigned to police stations at 8-kHz intervals in the indicated band; the first and last carrier frequencies are shown.
2. Assigned according to a geographical assignment plan.
3. Some base stations serving state police mobile stations may use power input up to 10,000 watts.
4. Some frequencies available on condition that harmful interference is not caused to Canadian stations.
5. Available on condition that harmful interference is not caused to Canadian stations.
6. On 2490 kHz, some base stations serving state police mobile stations may use power input up to 10,000 watts.
7. Frequencies are assigned to police stations at 4-kHz intervals in the indicated band; the first and last carrier frequencies are shown.
8. Type A1 emission only; maximum power input 1000 watts.

Radiotelephone (type A3 emission) frequencies (in kilohertz) are:

1768.5	1789.5
1775.5	1796.5
1782.5	

The frequency 1761.5 kHz is designated the scene-of-disaster channel. Type A1, A2, or A3 emission is authorized on this frequency. Normally, the power input is limited to 500 watts for these stations, except on the scene-of-disaster frequency when life or property is in danger.

Frequency bands in which stations in the International Fixed Public service may be assigned include the following (all frequencies in kilohertz):

1605-1750
2107-2170
2194-2495
2505-2850

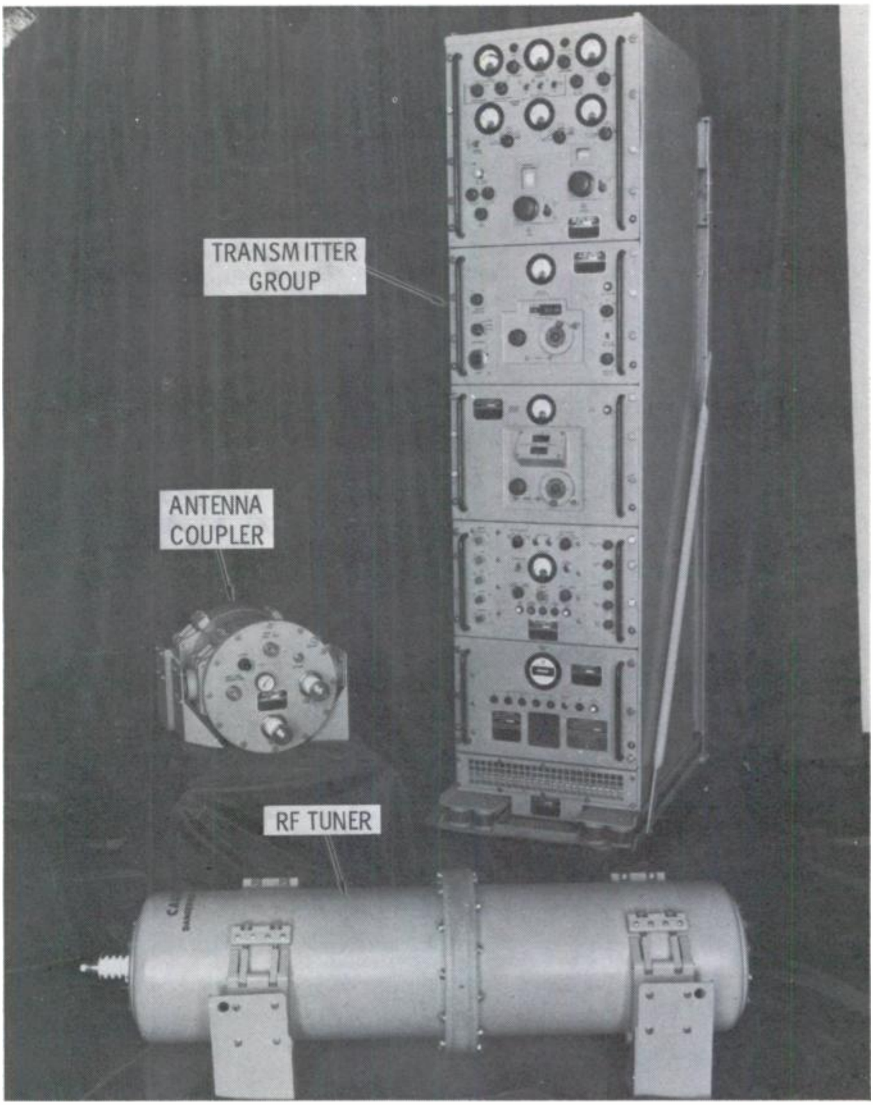
Low-power communication devices may be operated on any frequency in the 510-1600 kHz band, subject to certain limits on radiation.

MF TRANSMITTING EQUIPMENT

Aside from the pure interest value, an examination of transmitting equipment for a frequency band can give an insight into the kinds of signals being transmitted in that band. With this objective in mind, we will examine a few examples of communications equipment for the mf band.

Fig. 5-4 shows a radio transmitting set for use aboard U.S. Navy surface vessels. It provides a peak power output of 500 watts and has continuous tuning through the range 300-1500 kHz. Types of emission include cw (manual and machine keying), tone-modulated cw, teleprinter (using frequency-shift keying), and voice (amplitude modulated).

In the cw mode, the equipment is capable of a rate of 600 words per minute when machine keyed, or 30 words per minute when hand keyed. Slow-speed tone-modulated cw (with a 1000-Hz tone) also is possible. In teleprinter use, the speed capability is 60



Courtesy American Electronic Laboratories, Inc.

Fig. 5-4. *AEL* radio transmitting set AN/WRT-1A.

words per minute; frequency-shift keying is used, with the frequency-shift deviation adjustable up to 500 Hz in either direction from the carrier frequency.

Shown in Fig. 5-5 is a marine radiotelephone. This unit normally operates in the 2000-4500 kHz range, but with modifications it can be used over a range of 1605-6525 kHz. It operates from a 13.6-volt dc power source (or other sources through the use of adapters) and delivers an rf output of 51 watts, amplitude modulated. Incorporated in the same unit is a 25-watt "loud hailer," which also includes a listening device and functions as a foghorn/deck call. The equipment measures 4" × 12" × 14" and weighs 11 pounds.

A 1000-watt a-m broadcast transmitter is illustrated in Fig. 5-6. This transmitter has provision for power reduction to 250 watts (a version with reduction to 500 watts is available also). This feature would be used at a station that must operate with reduced night power; a Class-IV station operating with 1000 watts daytime and 250 watts nighttime is an example. The transmitter has a master start-stop switch, and safety interlocks prevent the application of power to the various circuits in a wrong sequence. Metering of all important circuits is provided, and the transmitter may be remotely controlled. The transmitter automatically restores itself to operation after a momentary fault, and it may be reset manually or by remote control after longer outages.

This transmitter, which uses five receiving-type tubes and four power tubes, is available factory wired or in kit form. It is powered from a 208-240 volt, 50- or 60-Hz source; source-power requirements are 2900 watts with no modulation, 3300 watts with average modulation, and 3900 watts with 100-percent modulation. The unit measures 75" × 34" × 25.5" and weighs 850 pounds. It may be operated at altitudes up to 8000 feet and in ambient temperatures up to 113°F.

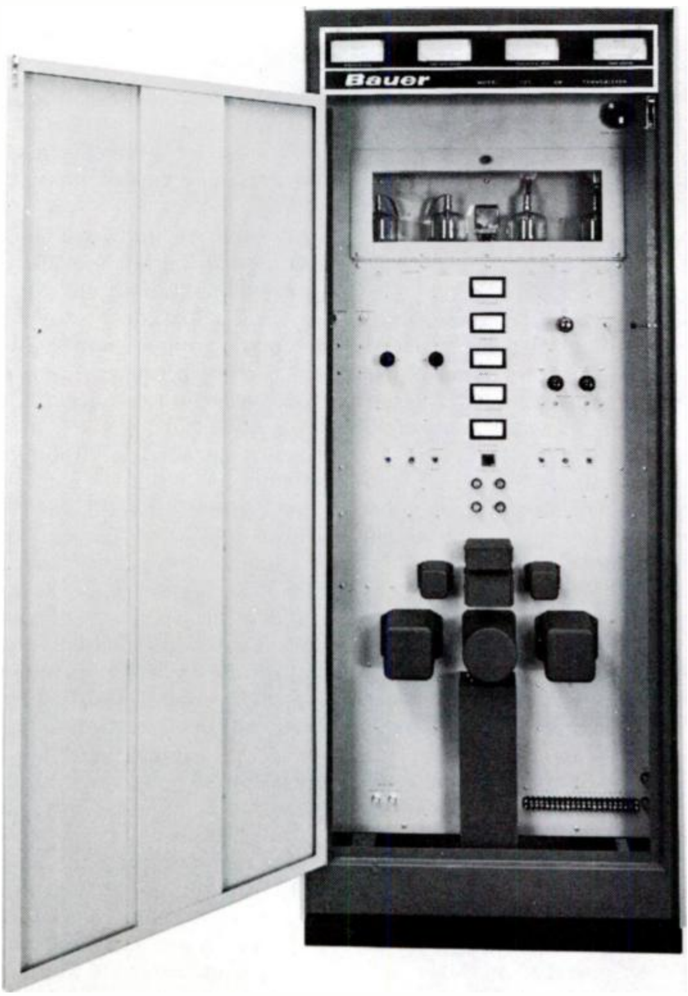
A transmitter for a maximum-power (in the U.S.) standard-broadcast station is shown in Fig. 5-7. This transmitter has a rated output of 50,000 watts, but there is provision for power reduction to 25,000 or 10,000 watts. The circuit includes 11 tubes, including a large rf output tube and a pair of large modulator tubes. For the three large power tubes, this transmitter employs "vapor-phase" cooling rather than liquid or forced-air cooling. In this system, water is piped to a jacket around the tube, and heat from the tube causes the water to boil. As the water boils, it changes from the liquid state, or phase, to the vapor phase (steam), and in doing so it absorbs a great deal of heat from the tube. The heat is then carried away in the steam. An external heat exchanger condenses the steam back to water, and the heat is released to the surroundings. The water then is returned to the tubes and repeats the cycle.

The power supplies and low-level rf stages in this transmitter are solid-state (that is, they contain no tubes); there

Courtesy Raytheon Company

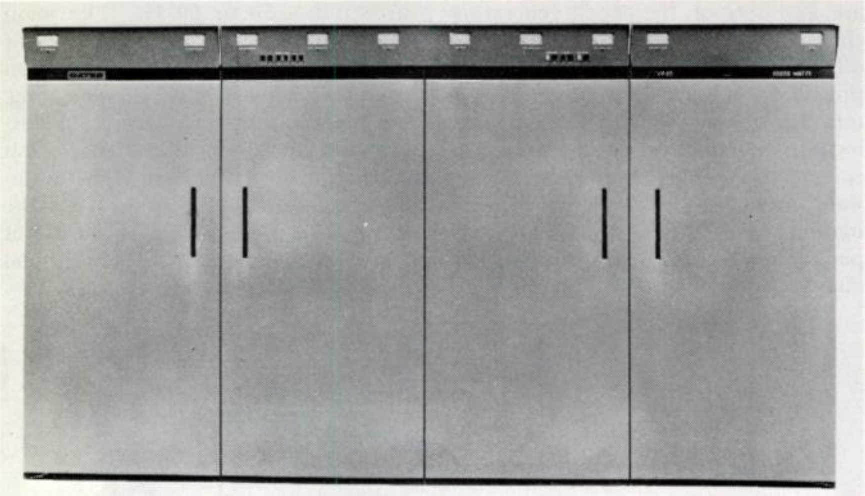
Fig. 5-5. Raytheon Model 2X2 marine radiotelephone.

are two sets of frequency generating circuits, one "on the air" and the other on standby. Automatic overload protection is provided. Fourteen meters, ten on the front of the unit, are included for monitoring important circuits. Power consumption at 50,000-watt output is 85,000 watts for no modulation and 125,000 watts for 100-percent modulation. The required primary power source is 380 or 460 volts, three phase, 50 or 60 Hz. The main transmitter is 78″ × 144″ × 48″ (height × width × depth), but, as is common for transmitters of high power rating, the large transformers are located externally. Also, the heat exchanger adds 48″ to the overall height. The transmitter weighs 12,000 pounds. It may be operated at altitudes up to 6000 feet (it may be modified for higher altitudes on special order).



Courtesy Granger Associates, Bauer Broadcast Products

Fig. 5-6. Bauer Model 707 standard-broadcast transmitter.



Courtesy Gates Radio Company

Fig. 5-7. *Gates* Model VP-50 50,000-watt standard-broadcast transmitter.

MEDIUM-FREQUENCY RECEIVERS

Medium-frequency receivers available to the public fall into two general classes: (1) broadcast receivers that cover only the standard broadcast band or the standard and fm broadcast bands, and (2) general-coverage receivers that include mf bands in addition to some combination of other bands in the lf, hf, or vhf ranges. The first class includes the "shirt-pocket" a-m portable, the elaborate a-m/stereo-fm high-fidelity receiver, and everything in between. Because receivers of this type are so well known and so widely used, they will not be discussed here. A few examples of receivers of the second class are included in this chapter, and additional examples will be found in other chapters according to the other frequency bands they include.

The receiver in Fig. 5-8 covers five bands in the lf, mf, and hf ranges: 150-400 kHz, 550-1600 kHz, 1.6-4.8 MHz, 4.8-14.5 MHz, and 10.5-30 MHz. Circuits are provided for reception of a-m, cw, and ssb transmissions. The design includes the use of field-effect transistors in the rf section (to improve sensitivity and reduce cross modulation) and mechanical filters in the i-f section to provide selectivity. Features include an illuminated dial, a noise limiter, automatic volume control, illuminated signal-strength meter, and operation from power sources of either 117 volts ac or 12 volts dc (negative ground). An external speaker (or headphones) and antenna are required.

A portable multiband receiver is shown in Fig. 5-9. Eleven bands cover lf, standard-broadcast, hf, and fm-broadcast frequencies. The circuit includes a mechanical filter, automatic noise limiter, automatic frequency control on the fm band (to minimize tuning drift), and a beat-frequency oscillator with pitch control. Other features include a tuning meter, push-button operation of power and band selector, a built-in ac power supply, phono and recorder input jacks, a stereo input and a stereo output, and an earphone jack. In addition to the built-in antennas, there are provisions for external a-m and fm antennas and an external ground connection. A world time map and time-conversion tables are included.

Fig. 5-10 shows a marine receiver that includes a direction-finding capa-

Courtesy Allied Radio Shack

Fig. 5-8. *Allied* Model A-2515 five-band receiver.

Courtesy Matsushita Electric Corporation of America

Fig. 5-9. *Panasonic* Model RF-5000A portable multiband receiver.

Courtesy Heath Company

Fig. 5-10. *Heathkit* Model MR-18 receiver with direction finder.

bility. Bands covered are 180-420 kHz, 540-1610 kHz, 1.6-4.05 MHz, and 3.95-11.5 MHz. The circuit is all solid-state (no tubes). Field-effect transistors are used in the mixer, oscillator, and cw/ssb detector stages. Fixed-aligned ceramic filters determine the i-f selectivity. Other features are a built-in sense antenna (the purpose of this antenna will be explained in a following paragraph); reception of a-m, cw, and ssb signals; and a switchable automatic noise limiter. The rechargeable nickel-cadmium battery has an approximate life of 10 hours at full charge; built-in circuits charge this battery from either a 120-volt ac source or a 12-volt ship battery. A spring-return dial-light switch limits battery drain.

The principles of direction finding applicable to this and similar receivers may be summarized briefly as follows. A loop antenna (Fig. 5-11A) has a directional characteristic similar to that shown in Fig. 5-11B. The significance of the reception pattern of Fig. 5-11B is that waves arriving from a direction perpendicular to the plane of the loop produce very little signal (the parts of the pattern labelled "null"). Maximum signal is developed when the plane of the loop is aligned with the direction from which the signals arrive. (Do not confuse the action of the loop with that of the simple dipole discussed in Chapter 3; they are two different antennas.)

Now refer to Fig. 5-12. Assume the antenna has been rotated until a null indication is obtained. (The null is used rather than the maximum because the null is much more narrow and therefore gives a more accurate determination of direction.) The operator now knows that the station being received lies in either direction A or

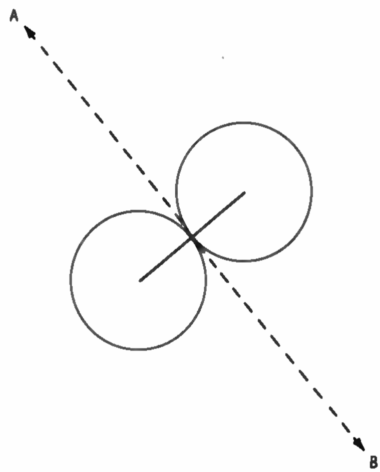
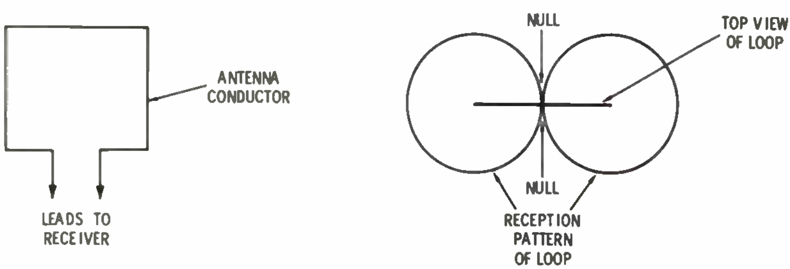


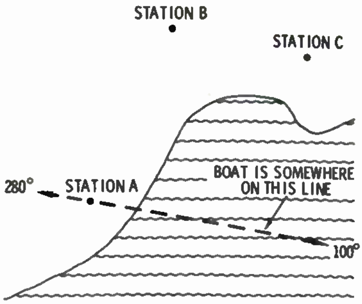
Fig. 5-12. Directions of minimum pickup by loop antenna.



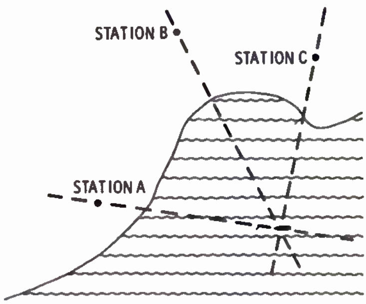
(*A*) *Simplified construction.*

(*B*) *Reception pattern.*

Fig. 5-11. Operation of loop antenna.



(*A*) *One bearing.*



(*B*) *Three bearings.*

Fig. 5-13. Determination of position with radio direction finder.

direction B. The directions of two or more stations are determined in this way, and if the station locations are known, the position of the boat can be found by triangulation (Fig. 5-13). For example, suppose the loop shows that station A is at a direction of either 100° or 280° (just south of east or just north of west). Both the boat and the station are thus known to be on one line that runs in these directions, so a 100°-280° line is drawn through the location of station A on a map (Fig. 5-13A). By a similar process, a line is drawn through the location of each of the other stations (Fig. 5-13B). The position of the boat is the point at which the lines intersect.

Sometimes it is desirable to know which of the two possible directions indicated by the loop is the correct one. In such cases, a signal from a nondirectional *sense* antenna is combined in a certain way with the signal from the loop. The combination of the two antennas has one direction of maximum response instead of two. The loop pattern is used to find two possible, accurately determined directions. The sense antenna is switched into the circuit so that the combined pattern may be used to determine which of the two possible directions is the correct one.

The sense antenna usually is a vertical whip. In the receiver of Fig. 5-10, the loop is in the form of a coil of wire wound on a ferrite core; however, it has the directional properties of a loop.

Fig. 5-14 shows a general-purpose communications receiver designed for amateur, short-wave-listener, marine, and other uses. Solid-state circuitry is employed, including field-effect transistors in the signal path. The receiver covers 150-500 kHz and any 23 ranges (each 500 kHz wide) from 500 kHz to 30 MHz (ten ranges are furnished, and the others are supplied at extra cost). The tuning dial is readable in 1-kHz increments. Bandwidths of 0.4, 2.4, and 4.8 kHz are provided for reception of cw, ssb, and a-m, respectively. Power sources may be 115 volts ac, 220 volts ac, or 12 volts dc. The receiver measures 10¾" × 5½" × 12¼" and weighs 14 pounds.

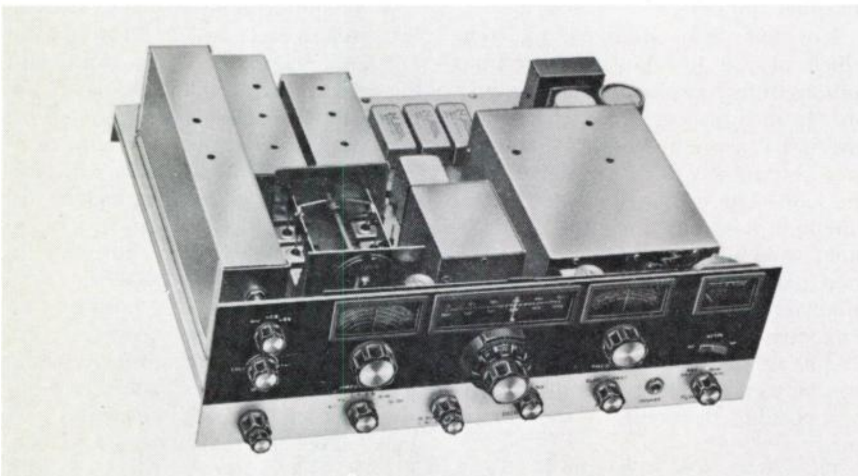
A communications receiver intended for professional use is illustrated in Fig. 5-15. The receiver is shown with the case removed so that some of the interior construction can be seen. This solid-state receiver covers frequencies from 500 kHz to 30 MHz with frequency indication in 1-kHz increments. Frequency stability (tuning drift) is no more than 100 Hz from turn-on, including the effects of a 20-percent variation of line voltage. A built-in calibrator provides reference signals every 50 kHz. A crystal lattice filter provides 2.1-kHz selectivity for ssb reception; filters for cw (0.5-kHz selectivity) and a-m (5-kHz selectivity) are available. The receiver can be used for reception of a-m, cw, ssb (upper sideband [usb] or lower sideband [lsb]), and radio teleprinter. A dual-conversion superheterodyne circuit is employed, and a noise blanker and selectable (fast or

Courtesy R. L. Drake Company

Fig. 5-14. Drake Model SPR-4 general-purpose receiver.

slow) automatic gain control (agc) are provided.

Front-panel controls include an a-m–usb–lsb selector; BFO-frequency control; three tuning controls; meter function switch; gain controls (af and rf); band switch; blanker control; rf-attenuator control (used to reduce overloading caused by strong signals); selectivity control; agc fast-slow switch; and an off-standby-operate-calibrate switch. A headphone jack also is located on the front panel. The receiver may be powered from 115 or 230 volts ac (50 or 60 Hz) or from 18 volts dc. It measures 6″ × 17″ × 14″ in its cabinet or 8¾″ × 19″ × 14″ for rack mounting. It weighs 25 pounds.



Courtesy Galaxy Electronics

Fig. 5-15. Galaxy Model R-530 communications receiver.

CHAPTER 6

High Frequencies

In the early days of radio, it was believed that range of transmission was directly related to wavelength. "Short waves" (corresponding to frequencies above roughly 1500 kHz) were assumed to be of no value. As the use of radio grew, amateur operators were restricted to this "worthless" region of the spectrum. As the amateurs experimented with higher and higher frequencies, however, it was found that, far from being useless, the frequencies up to about 30 MHz possess highly useful long-distance propagation, or transmission, characteristics.

The frequencies between 3 and 30 MHz (3000 kHz and 30,000 kHz) are classified as *high frequencies.* Within this range are aeronautical, maritime, communications, broadcast, amateur, Citizens radio, and other bands.

HIGH-FREQUENCY PROPAGATION

At high frequencies, the strength of the ground wave decreases rapidly with distance, and most useful communication is by means of the sky wave. The ionosphere therefore is of great importance in high-frequency communication over long distances.

Ionospheric Reflections

In connection with Fig. 2-3, it was shown how radio waves are "reflected" by the ionosphere. It was shown by Fig. 2-4 that the amount of bending of the wave path decreases as the frequency increases. Fig. 6-1 shows three paths for waves of the same frequency emitted from point A. Waves leaving at angle a are reflected by the ionosphere and return to point B on the earth. Waves leaving at higher angle b are reflected and return to nearer point C. However, an angle (such as c) is eventually reached for which the wave path cannot be bent sharply enough to return to earth. Hence, in Fig. 6-1 no signal is returned to point D or other points nearer to the transmitter. The area between the useful ground wave and the nearest point at which a useful sky wave reaches the earth is called the *skip zone;* the sky waves "skip" over it. A skip zone exists at those frequencies at which long-distance sky-wave communication is carried on; at lower frequencies, the sky wave and ground wave may overlap, as described in Chapter 5.

Frequency Limitations

In Fig. 6-1, increasing the frequency would cause the waves to skip over point C, since there would be less bending of the path through the ionosphere. Thus for hf communication between two specified points, there is a *maximum usable frequency* (muf), above which communication cannot be carried on.

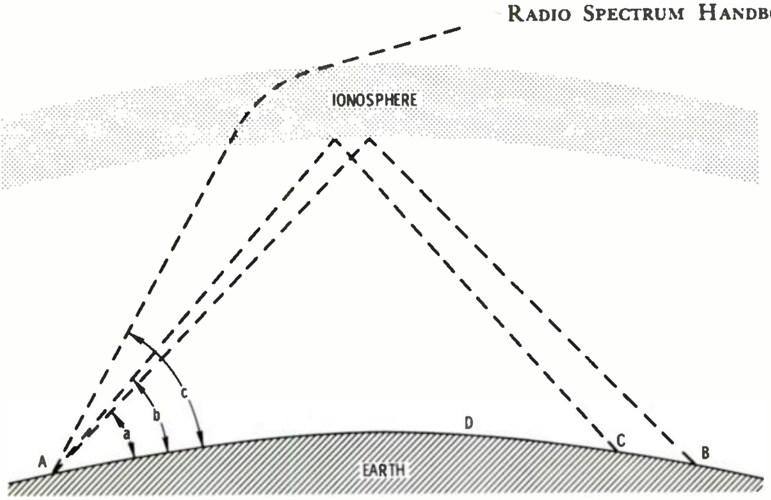


Fig. 6-1. Skip zone.

Ionospheric absorption increases as frequency decreases, so in effect there are an upper limit and a lower limit to the frequencies that may be used efficiently for communication: The upper limit is the muf (actually a somewhat lower frequency to allow for variation), and the lower limit is the frequency at which absorption losses become intolerable.

The maximum usable frequency, and consequently the best frequency for transmission, depends on conditions in the ionosphere at a given time. In general, the numerical value of the muf behaves as follows: The muf is higher in the daytime (at the point of reflection) than at night. The daytime value is greater in the winter than in the summer, but the nighttime muf is higher in the summer than in the winter. The muf is higher at the peak of the 11-year sunspot cycle than it is at the minimum point in the cycle.

Multihop and Multipath Transmission

In Fig. 6-1, the waves experience only one reflection in traveling from transmitter to receiver. The waves are said to have made one "hop." It is entirely possible for a wave to be reflected from the earth, back to the ionosphere, and back to the earth again, as shown by path ABCDE in Fig. 6-2. More than two hops are possible.

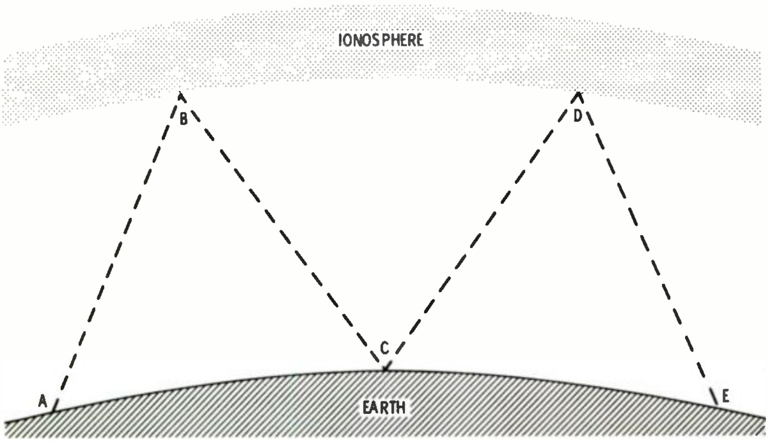


Fig. 6-2. Multihop path.

It is possible for waves from the same transmitter to follow more than one path to a receiving point, because of reflections from more than one layer of the ionosphere, reflections between layers and then to the earth, propagation by paths with different numbers of hops, etc. The results of such *multipath* transmission are fading and distortion of the received signal.

HIGH-FREQUENCY ALLOCATIONS

The FCC Rules and Regulations allocate the hf frequency bands as shown in Table 6-1. The terms used in the table were defined in Chapter 4 in connection with Table 4-1. The frequencies for which the listed service is "Government" are allocated for use by the Federal government and are not assigned by the FCC.

HIGH-FREQUENCY BROADCASTING

Several bands of frequencies in the hf region are allocated for broadcasting. Depending on circumstances, stations may be used for domestic or international broadcasting.

U.S. International Broadcasting

The FCC Rules and Regulations define an international broadcasting station as, "a broadcasting station employing frequencies allocated to the broadcasting service between 5950 and 26,100 kHz, whose transmissions are intended to be received directly by the general public in foreign countries." Two kinds of operation of international broadcasting stations are defined. *Contract operation* is operation under contract with a U.S. government agency; the agency controls program content, target areas to which the transmissions are directed, and the time of broadcast. *Private operation* is any operation other than contract operation or actual operation of stations by the Federal government.

Frequency Assignments — In connection with frequency assignments for international broadcasting stations, the term *frequency-hour* is encountered. This term simply means the use of one frequency for one hour. Frequency usage depends on the season of the year. For this purpose, four seasons are defined: vernal equinox season, February 1-April 31; summer season, May 1-July 31; autumnal equinox season, August 1-October 31; and winter season, November 1-January 31.

The FCC rules bearing on frequency usage by international broadcasting stations may be summarized briefly as follows. Frequencies are assigned to authorized stations for use in broadcasting to specified target areas during specified hours. Desired frequencies may be requested, and such requests are honored when possible consistent with interference and propagation conditions and other requirements. The assignment of frequency-hours for each season is a separate case and is not renewable; new assignments must be obtained for the next season. Frequency assignments are not exclusive; that is, a frequency authorized to one station also is available for assignment to other stations.

Only one frequency is permitted to be used at one time under the same authorization and call-letter assignment. Also, only one frequency may be used at any one time for any one program transmission, unless the program is intended for more than one target area, all of which cannot be served on a single frequency.

The total maximum number of frequency-hours per day authorized for all private operation in each frequency band is specified for each season. This total depends partly on the number of frequency-hours scheduled for use by both government and contract operations; in general, when more government and contract operations are scheduled, fewer frequency-hours are available for private operations. If more than the maximum available frequency-hours are requested, the

Table 6-1. FCC Frequency Allocations (HF)

Frequency (MHz)	Nature of Services	Class of Station
2.850- 3.155	Aeronautical Mobile	Aeronautical
		Aircraft
3.155- 3.240	Fixed	Base
	Land Mobile	Coast
	Maritime Mobile	Fixed
		Land Mobile
		Ship
3.240- 3.400	Fixed	Base
	Land Mobile	Coast
	Maritime Mobile	Fixed
	Mobile	Land
		Land Mobile
		Mobile
		Ship
3.400- 3.500	Aeronautical Mobile	Aeronautical
		Aircraft
3.500- 4.000	Amateur	Amateur
4.000- 4.063	Fixed	Fixed
4.063- 4.438	Maritime Mobile	(See Table 6-9.)
4.438- 4.650	Fixed	Base
	Mobile	Fixed
		Mobile
4.650- 4.750	Aeronautical Mobile	Aeronautical
		Aircraft
4.750- 4.995	Fixed	Fixed
4.995- 5.005	Standard Frequency	Standard Frequency
	Radio Astronomy*	Radio Astronomy
5.005- 5.450	Fixed	Fixed
5.450- 5.730	Aeronautical Mobile	Aeronautical
		Aircraft
5.730- 5.950	Fixed	Fixed
5.950- 6.200	Broadcasting	International Broadcasting
6.200- 6.525	Maritime Mobile	(See Table 6-9.)
6.525- 6.765	Aeronautical Mobile	Aeronautical
		Aircraft
6.765- 7.000	Fixed	Fixed
7.000- 7.300	Amateur	Amateur
7.300- 8.195	Fixed	Fixed
8.195- 8.815	Maritime Mobile	(See Table 6-9.)
8.815- 9.040	Aeronautical Mobile	Aeronautical
		Aircraft
9.040- 9.500	Fixed	Fixed
9.500- 9.775	Broadcasting	International Broadcasting
9.775- 9.995	Fixed	Fixed
9.995-10.005	Standard Frequency	Standard Frequency
	Radio Astronomy*	Radio Astronomy
10.005-10.100	Aeronautical Mobile	Aeronautical
		Aircraft
10.100-11.175	Fixed	Fixed
11.175-11.400	Aeronautical Mobile	Aeronautical
		Aircraft
11.400-11.700	Fixed	Fixed
11.700-11.975	Broadcasting	International Broadcasting
11.975-12.330	Fixed	Fixed
12.330-13.200	Maritime Mobile	(See Table 6-9.)
13.200-13.360	Aeronautical Mobile	Aeronautical
		Aircraft

Frequency (MHz)	Nature of Services	Class of Station
13.360-14.000	Fixed	Fixed
14.000-14.350	Amateur	Amateur
14.350-14.990	Fixed	Fixed
14.990-15.010	Standard Frequency Radio Astronomy*	Standard Frequency Radio Astronomy
15.010-15.100	Aeronautical Mobile	Aeronautical Aircraft
15.100-15.450	Broadcasting	International Broadcasting
15.450-16.460	Fixed	Fixed
16.460-17.360	Maritime Mobile	(See Table 6-9.)
17.360-17.700	Fixed	Fixed
17.700-17.900	Broadcasting	International Broadcasting
17.900-18.030	Aeronautical Mobile	Aeronautical Aircraft
18.030-19.990	Fixed	Fixed
19.990-20.000	Standard Frequency Radio Astronomy*	Standard Frequency Radio Astronomy
20.000-20.010	Standard Frequency Space Research*	Standard Frequency Earth Space
20.010-21.000	Fixed	Fixed
21.000-21.450	Amateur	Amateur
21.450-21.750	Broadcasting	International Broadcasting
21.750-21.850	Fixed	Fixed
21.850-22.000	Aeronautical Fixed Aeronautical Mobile	Aeronautical Aeronautical Fixed Aircraft
22.000-22.720	Maritime Mobile	(See Table 6-9.)
22.720-23.200	Fixed	Fixed
23.200-23.350	Aeronautical Fixed Aeronautical Mobile	Aeronautical Aeronautical Fixed Aircraft
23.350-24.990	Fixed	Fixed
24.990-25.010	Standard Frequency Radio Astronomy*	Standard Frequency Radio Astronomy
25.010-25.330	Land Mobile	Base Land Mobile
25.330-25.600	(Government)	
25.600-26.100	Broadcasting	International Broadcasting
26.100-26.480	Land Mobile	Base Land Mobile
26.480-26.950	(Government)	
26.950-26.960	Fixed	Fixed
26.960-27.230	Citizens	Fixed Land Mobile
27.230-27.280	Fixed Mobile	Fixed Land Mobile
27.280-27.540	Land Mobile	Base Land Mobile
27.540-28.000	(Government)	
28.000-29.700	Amateur	Amateur
29.700-29.800	Land Mobile	Base Land Mobile
29.800-29.890	Fixed	Fixed
29.890-29.910	(Government)	
29.910-30.000	Fixed	Fixed

*Secondary service; others are primary services.

rules provide for apportionment of the available frequency-hours among the applicants.

Technical Requirements—Technical requirements for U.S. international broadcast stations include a power of at least 50,000 watts and an antenna power gain of at least 10 in the direction of the target area to be served. Stations must provide specified minimum field intensities to intended target areas. Protection from interference must be afforded to cochannel and adjacent-channel signals within areas being served by other stations having priority of assignment.

Private Stations—At present, only three private organizations are engaged in international broadcasting in the United States. These are Radio New York Worldwide (WNYW—formerly WRUL), the Far East Broadcasting Co., Inc., Whittier, Calif. (KGEI), and World International Broadcasters, Inc., Red Lion, Pa. (WINB).

Broadcasting Outside the U.S.

The tropical broadcast bands were discussed in Chapter 5. In the hf portion of the spectrum, the frequencies from 3.200 to 3.400 MHz and 4.750 to 5.060 MHz (excluding 4.995 to 5.005 MHz) are used for this purpose. These bands sometimes are referred to as the 90- and 60-meter bands, respectively, according to the wavelength that corresponds to the approximate center frequency of the band. Stations operate in these bands in many countries of Asia, Africa, and South America, and on tropical islands. In general, the uniform 10-kHz channel spacing used in the North American standard broadcast band is not found in these bands.

Other frequencies allocated on a world-wide basis for broadcasting are as follows: 5.950-6.525 MHz (49-meter band), 9.550-9.775 MHz (31-meter band), 11.70-11.975 MHz (25-meter band), 15.1-15.45 MHz (19-meter band), 17.7-17.9 MHz (16-meter band), 21.45-21.75 MHz (13-meter band), and 25.6-26.1 MHz (11-meter band). In Region 1, the band 3.95-4.0 MHz is allocated for broadcasting, and in Region 3 the band 3.9-4.0 MHz is allocated to this service. The frequencies from 7.1 to 7.3 MHz are a broadcast band in Regions 1 and 3. In addition, many stations may be found on frequencies not included in any of these bands.

In general, channel center frequencies of foreign stations fall on multiples of 5 and 10 kHz, (5965 kHz, 5970 kHz, etc.), but many also fall at intermediate values, such as 6169 kHz, 6172 kHz, 9623 kHz, 11,827 kHz, etc. The powers of these stations range from a few hundred watts to a few thousand watts.

U.S. Broadcast-Auxiliary Frequencies

The use of remote-pickup (rpu) stations was described in Chapter 5. Frequencies (in megahertz) in the hf range available for rpu applications are:

25.87	26.11	26.25	26.39
25.91	26.13	26.27	26.41
25.95	26.15	26.29	26.43
25.99	26.17	26.31	26.45
26.03	26.19	26.33	26.47
26.07	26.21	26.35	
26.09	26.23	26.37	

Emissions on these frequencies may be either A3 or F3.

Low-power broadcast auxiliary "stations" (cue transmitters, wireless microphones, etc.) may be licensed in the band from 26.10 to 26.48 MHz. Carrier frequencies are not specified, but emissions must be confined within the band. Power output is limited to 1 watt.

STANDARD FREQUENCY AND TIME TRANSMISSIONS

In many technical and scientific activities, there is a need for a precise time reference, to correlate events or for other purposes. Such references are broadcast by a number of stations around the world.

NBS High-Frequency Services

The National Bureau of Standards (NBS) has made standard-frequency

Table 6-2. WWV and WWVH Frequencies

Frequency (MHz)	WWV Power (Watts)	WWVH Power (Watts)
2.5	2500	1000
5	10,000	2000
10	10,000	2000
15	10,000	2000
20	2500	—
25	2500	—

broadcasts from station WWV since 1923; since 1966, WWV has been located at Fort Collins, Colorado. In 1948, WWVH, Maui, Hawaii, was put on the air to provide additional coverage for the service. (Transmissions from WWVL [vlf] and WWVB [lf] were covered in Chapter 4. The 2.5-MHz transmissions of WWV and WWVH, although mf signals under the frequency classification used in this book, are covered in this chapter for convenience.) The transmitted signals consist of carriers of precise frequency, which are modulated with standard audio frequencies, time signals, and other information.

Carrier Frequencies—Table 6-2 shows the carrier frequencies and corresponding powers used by WWV and WWHV. All antennas of WWV are nondirectional. The WWVH antennas for 5, 10, and 15 MHz are directional with greatest radiation toward the west. Both stations use conventional (double-sideband) amplitude modulation. The carrier frequencies are maintained by methods that make use of the atomic frequency standard maintained by the NBS at Boulder, Colorado. The WWV and WWVH frequencies are held stable to better than ±2 parts in 100,000,000,000; however, variations in the medium of propagation often result in somewhat less accuracy of the frequencies as received.

Audio Tones—Stations WWV and WWVH operate 24 hours a day and follow the schedule shown in Fig. 6-3. Standard audio frequencies (tones) of 600 Hz and 440 Hz are transmitted during alternate 5-minute intervals, beginning with 600 Hz on the hour. The tones last for 2 minutes (except 3 minutes on the hour) on WWV and for 3 minutes on WWVH, and the start of each tone marks the beginning of the 5-minute interval. (The 440-Hz tone is the standard musical pitch in the United States and many other countries.) The accuracy of the audio frequencies as transmitted is the same as that of the rf carrier. (However, note that the tones used for Morse-code transmissions on these stations are not standard frequencies.)

Time Information—Seconds pulses are transmitted by both stations. These pulses are synchronized with the carrier frequencies; for example, on the 5-MHz carrier, a pulse begins coincident with each 5,000,000th cycle of the carrier. Each pulse is 5 milliseconds (0.005 second) in duration and consists of five cycles of a 1000-Hz tone on WWV or six cycles of a 1200-Hz tone on WWVH. The 600-Hz or 440-Hz tone is interrupted 40 milliseconds for each seconds pulse, and the pulse starts 10 milliseconds after the start of the interruption. The 59th pulse of each minute is omitted, and the start of the next minute is marked by the transmission of two pulses 0.1 second apart (the beginning of the first pulse of this pair marks the actual beginning of the minute). The beginning and ending of the 600-Hz and 440-Hz tones mark the 2-, 3-, and 5-minute intervals; the stopping and starting of the tones are synchronized with the seconds pulses.

Time announcements are made every five minuts by voice and by International Morse code. Greenwich Mean Time (GMT), sometimes called Universal Time (UT), is announced according to the 24-hour system. That is, midnight at longitude zero (Greenwich, England) is 0000, 1 a.m. is 0100, 2:30 p.m. is 1430, etc. At WWV, the announcement (code followed by voice) is made during the last half of the last minute of each 5-minute interval (see Fig. 6-3). A typical announcement is, "National Bureau of Standards, WWV, Fort Collins, Colorado. Next tone begins at nine hours, twenty-five minutes, Greenwich Mean Time." At WWVH, the announcement is made during the *first* half of the last minute of the 5-minute interval (Fig. 6-3). However, the tone referred to starts at the same time from both stations, although there may be an apparent difference because of propagation differences. (As a matter of interest, the voice announcements are recorded, not made by a "live" announcer.)

Fig. 6-3 shows that a WWV time code is transmitted for 1-minute periods ten times each hour. The code, called the NASA 36-Bit Time Code, is produced at a rate of 100 pulses per second; the pulses are actually short "bursts" of a 1000-Hz tone. The code contains information that identifies (in GMT) the second, minute, hour, and day of the year. It is synchronous with the frequency and time signals.

Frequency Offset—All carrier and modulation frequencies of WWV and WWVH are offset from standard frequency by a small amount to reduce the difference between the broadcast time and astronomical time (called "UT2"). The amount of the offset is known, and it is changed no more often than once a year. A reminder of the existence of this offset is broadcast

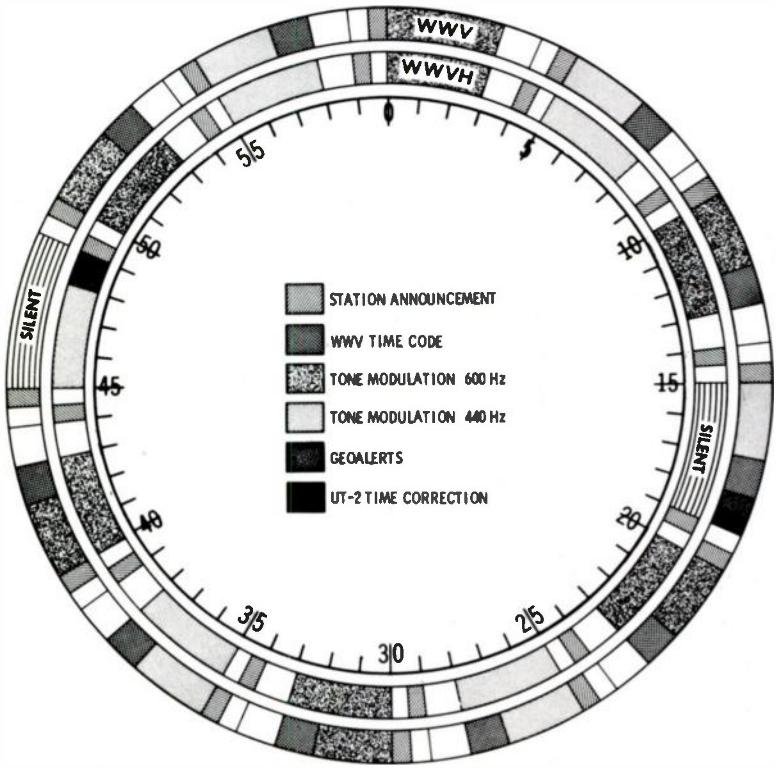


Fig. 6-3. Schedule of WWV and WWVH services.

Table 6-3. Number Code for Propagation Forecasts

Disturbed Grades (W)	Unsettled Grade (U)	Normal Grades (N)
1. Useless	5. Fair	6. Fair to Good
2. Very Poor		7. Good
3. Poor		8. Very Good
4. Poor to Fair		9. Excellent

in code immediately following the voice announcement during the 59th minute of the hour. In 1969, for example, the reminder was M300, meaning minus 300 parts in 10^{10}. (10^{10} = 10,000,000,000.)

Time Adjustments—Besides the frequency offset, 100-millisecond adjustments in the *time signals* are made as needed (but always at the first of a month) to bring these signals into close agreement with UT2. For users who need even closer agreement of the time signals with UT2, correction factors are broadcast (in code) during the 19th minute of the hour on WWV and the 49th minute of the hour on WWVH. (These times are indicated by the letter "U" in Fig. 6-3.) The correction statement consists of the letters "UT2" followed by "AD" (for "add") or "SU" (for "subtract") and three digits representing the correction in milliseconds. The amount of correction is based on information supplied by the U.S. Naval Observatory.

Forecasts—During the last half of each fifth minute, WWV broadcasts a propagation forecast for North-Atlantic paths. The announcement (in International Morse code) consists of a letter representing conditions at the time of the forecast, and a number representing expected conditions during the six hours following issuance of the forecast. (Forecasts are issued[1] at 0500, 1100 [1200 from November 1 to April 30], 1700, and 2300 UT.) The letters used are N (normal), U (unsettled), and W (disturbed). The numbers are listed in Table 6-3. For example, if conditions are normal at the time of the forecast, but are expected to deteriorate to poor to fair during the next six hours, the broadcast forecast would be N4. (In addition to the propagation forecasts, letter symbols indicating the current geophysical alert are transmitted at the times marked "G" in Fig. 6-3.)

Other Stations

In addition to the NBS broadcasts, standard frequency and time signals are broadcast from stations in a number of foreign countries. One such station is CHU, operated by the Dominion Observatory, Ottawa, Canada. CHU operates continuously on frequencies of 3.33 MHz (300 watts), 7.335 MHz (3000 watts), and 14.670 MHz (5000 watts). Second markers consist of 200 cycles, minute markers of 500 cycles, and hour markers of 1000 cycles of a 1000-Hz tone. The beginning of the marker pulse indicates the exact time.

Station announcements are made in code and by voice. The code announcement is made on the hour. A voice announcement is given each minute. A time code similar to that transmitted by WWV is broadcast ten times per hour.

Table 6-4 lists other standards stations that operate in the hf range. (As stated before, although 2.5 MHz is a medium frequency according to the classification used in this book, it has been included with the hf standard frequencies for convenience.)

[1]The propagation forecasts are prepared by the ESSA Telecommunication Service Center, ESSA Research Laboratories, Institute for Telecommunication Sciences, Boulder, Colorado.

Table 6-4. Foreign Standard-Frequency Stations

Location	Call Sign	Carrier Frequency (MHz)	Power (Watts)	Modulation Frequency (Hz)*
Buenos Aires, Argentina	LOL	5	2000	440, 1000, S
		10	2000	440, 1000, S
		15	2000	440, 1000, S
Lyndhurst, Victoria, Australia	VNG	5.425	500	1000, S
		7.515	500-10,000	1000, S
		12.005	10,000	1000, S
Prague, Czechoslovakia	OMA	2.5	1000	1000, S
Rugby, England	MSF	2.5	500	S
		5	500	S
		10	500	S
New Delhi, India	ATA	10	2000	1000, S
Tokyo, Japan	JJY	2.5	2000	1000, S
		5	2000	
		10	2000	
		15	2000	
Olifantsfontein, South Africa	ZUO	5	4000	S
		10**	250	S
Neuchatel, Switzerland	HBN	5	500	S
Moscow, U.S.S.R.	RWM/RES	5	20,000	1000, S
		10	20,000	1000, S
		15	20,000	1000, S

* The symbol S in this column indicates seconds markers.
**Transmitter at Johannesburg.

AMATEUR RADIO

One of the oldest applications of radio is its use by amateur operators. The FCC Rules and Regulations define an amateur operator as "a person interested in radio technique solely with a personal aim and without pecuniary interest. . . ." The amateur service, in addition to its value as a hobby, provides a training ground for radio operators, functions as an emergency communication service, contributes to the advancement of radio technology, and enhances international good will.

Frequencies

Table 6-5 lists the frequencies in the hf range allocated for use by amateurs in the United States. The table also shows the types of emission permitted in each band; the emission designators as applied to amateur radio are defined in Table 6-6. (For a more complete list, see Table 2-2, Chapter 2.)

Technical Requirements

On the bands listed in Table 6-5, amateur stations are permitted a maximum supply-power input of 1000 watts to the amplifier stage that feeds the antenna. The actual radio-frequency power output is less than 1000 watts because the amplifier is less than 100-percent efficient in converting dc supply power into rf power.

On frequencies below 29 MHz, the bandwidth of an F3 emission (frequency or phase modulation) must not exceed the bandwidth of an A3 emission having the same audio characteristics. This is narrow-band fm, or nbfm. The bandwidth of an A5 or F5 transmission must not exceed the bandwidth of an A3 single-sideband transmission. Simultaneous use of A3 and A5 emissions on the same carrier frequency is permitted, provided the total bandwidth does not exceed that of an A3 double-sideband emission. Any car-

Table 6-5. Amateur High-Frequency Band Allocations

Frequencies	Emissions
80-Meter Band (kHz)	
3500-4000	A1
3500-3800	F1
3800-3900	A5, F5
3800-4000*	A3, F3
40-Meter Band (kHz)	
7000-7300	A1
7000-7200	F1
7200-7250	A5, F5
7200-7300	A3, F3
20-Meter Band (MHz)	
14.0-14.35	A1
14.0-14.2	F1
14.2-14.275	A5, F5
14.2-14.35	A3, F3
15-Meter Band (MHz)	
21.0 -21.45	A1
21.0 -21.25	F1
21.25-21.35	A5, F5
21.25-21.45	A3, F3
10-Meter Band (MHz)	
28.0-29.7	A1
28.5-29.7	A3, A5, F3, F5
29.0-29.7	F1

*3900-4000 not available in Baker, Canton, Enderbury, Guam, Howland, Jarvis, Palmyra, American Samoa, and Wake Islands.

rier frequency within a band may be used, provided that all sidebands fall within the limits of the band.

Radio teleprinter transmissions (RTTY) must be made at 60 words per minute (± 5 words per minute). When frequency-shift keying (F1) is used, the frequency shift must be less than 900 Hz. When audio frequency-shift keying (A2 or F2) is used, the audio frequency must not exceed 3000 Hz, and the change of the audio frequency with keying must be less than 900 Hz.

Operating Limitations

Amateur operators may not receive any material compensation for the use of their stations. They may not use their stations for broadcasting, they may not transmit music, and they may not use "codes and ciphers" to render messages unintelligible. However, generally recognized abbreviations may be used to facilitate operation, and International Morse code and teleprinter code are permitted.

Operator Licensing

Amateur licenses are issued in several classes, under what is known as an

Table 6-6. Types of Emissions for Amateur Stations

Symbol	Transmission
	Amplitude Modulation
A0	No Modulation*
A1	Telegraphy (On-Off Keying)
A2	Telegraphy by On-Off Keying of Modulating Tone or Tones, or by On-Off Keying of Carrier Modulated by Tone or Tones
A3	Telephony (Including Single and Double Sideband With Full, Reduced, or Suppressed Carrier)
A4	Facsimile
A5	Television
	Frequency or Phase Modulation
F1	Telegraphy by Frequency-Shift Keying Without Modulating Tone
F2	Telegraphy by On-Off Keying of Modulating Tone, or by On-Off Keying of Carrier Modulated by Tone
F3	Telephony
F4	Facsimile
F5	Television
P	*Pulse Modulation*

*Also can be designated F0.

incentive system. Each higher class of license entitles the holder to increased privileges. The *novice class* license is designed to give the beginner on-the-air experience; it is a two-year, nonrenewable license. Novice operators may operate, with telegraphy only and a maximum input power of 75 watts, in the bands 3700-3750 kHz, 7150-7200 kHz, and 21.10-21.25 MHz, (also 145-147 MHz in the vhf range). *Technician class* operators are restricted to certain frequencies in the vhf range (see Chapter 7), but they have all authorized amateur privileges on those frequencies. *General class* and *conditional class* licenses permit all authorized privileges except the use of those frequencies reserved for higher license classes. *Advanced class* and *amateur extra class* licenses have all authorized amateur privileges plus exclusive use of the frequencies in Table 6-7.

Amateur licenses are obtained on the basis of increasingly difficult examinations, and, in the case of the amateur extra class license, prior experience as a licensed amateur. Except as noted for the novice class, the license term is five years and, subject to certain requirements, the licenses are renewable.

Table 6-7. Reserved Amateur Frequencies

Frequency Band	Amateur Extra*	Advanced*
(kHz)		
3500-3525	X	
3800-3825	X	
3825-3900	X	X
7000-7025	X	
7200-7250	X	X
(MHz)		
14.0 -14.025	X	
14.2 -14.275	X	X
21.0 -21.025	X	
21.250-21.275	X	
21.275-21.350	X	X
50.0 -50.1	X	X

*"X" indicates frequencies available to holders of license of this class.

World-Wide Allocations

World-wide allocations of frequencies for amateur use include the bands 7.0-7.1 MHz, 14.0-14.35 MHz, 21.0-21.45 MHz, and 28.0-29.7 MHz. In addition, the frequencies 3.5-4.0 MHz and 7.1-7.3 MHz are amateur bands in Region 2.

CITIZENS RADIO SERVICE

One of the most popular segments of the radio spectrum is the hf band allocated to the Citizens Radio Service. This service is popularly known as "CB radio," from the initials of the term "Citizens band." The FCC defines the Citizens Radio Service as "a radiocommunications service of fixed, land, and mobile stations intended for short-distance personal or business radiocommunications, radio signaling, and control of remote objects or devices by radio; all to the extent that these uses are not specifically prohibited. . . ." Among some 18 uses that are specifically prohibited are:

1. Engaging in radiocommunications as a hobby or diversion, i.e., operating the station as an activity in and of itself.
2. In connection with any illegal activity.
3. For transmitting obscene, indecent, or profane words or meaning.
4. To carry communications for hire (whether payment is direct or indirect).
5. To communicate with other than Citizens radio stations.
6. For communication not directed to specific stations or persons (with some exceptions, including emergencies and obtaining assistance or information while travelling).
7. For attempting to communicate over a distance of more than 150 miles (applies to Class-D stations).

When a listener or CB operator scans the Citizens band for the first time, he will observe that actual operation on the band has little resemblance to that prescribed by the FCC Rules and Regulations for this service. The tremendous number of stations using the Citizens band has rendered effective enforcement of the rules difficult. Unfortunately, many individuals take advantage of this situation and operate their stations with excessive power and/or in direct violation of other rules, to the detriment of legitimate operators.

Rules Governing Class-C and Class-D Stations

Two classes of Citizens radio stations are authorized to operate in the hf range. Class-C stations may employ only amplitude tone modulation or on-off keying of an unmodulated carrier for control of remote objects or devices, or for remote actuation of devices used solely to attract attention. These stations are not protected from interference caused by industrial, scientific, or medical devices operating in the 26.96-27.28 MHz band, or caused by other Citizens radio stations. Frequencies for Class-C stations are listed in Table 6-8.

Class-D stations employ amplitude voice modulation, including single sideband and/or reduced or suppressed carrier. Tone signals are permitted only when needed to operate circuits which establish and/or maintain communication. These stations are not protected from interference caused by industrial, medical, or scientific equipment, or by other Citizens radio stations. Frequencies which Class-D stations are authorized to use are indicated in Table 6-8.

The maximum permitted power *input* is 5 watts for Class-C and -D stations (30 watts for Class-C stations on 27.255 MHz). The maximum permitted rf power *output* is 4 watts (24 watts for Class-C stations on 27.255 MHz).

Low-Power Devices

In addition to licensed Citizens radio stations, low-power communication devices (unlicensed) may be operated on any frequency between 26.97 and 27.27 MHz. Low power in this case means 100 milliwatts or less input to the final stage. Each device must bear a manufacturer's certificate to show that it meets all technical requirements for this type of operation.

Table 6-8. Citizens Radio Frequencies

Channel Number (Class D)	Carrier Frequency (MHz)	Class of Station
1	26.965	D
2	26.975	D
3	26.985	D
	26.995	C
4	27.005	D
5	27.015	D
6	27.025	D
7	27.035	D
	27.045	C
8	27.055	D
9	27.065	D*
10	27.075	D*
11	27.085	D*
	27.095	C
12	27.105	D*
13	27.115	D*
14	27.125	D*
15	27.135	D
	27.145	C
16	27.155	D
17	27.165	D
18	27.175	D
19	27.185	D
	27.195	C
20	27.205	D
21	27.215	D
22	27.225	D
23	27.255**	C, D*

*Only these channels may be used for communication between units of different stations; all Class-D channels may be used for communication between units of the same station.

**This channel is shared with other services.

MARITIME STATIONS

The Maritime Mobile Service is a service between coast stations and ship stations, or between ship stations. Frequencies allocated to the Maritime Mobile Service are listed in Table 6-9. Within these bands, frequencies are assigned to stations on the basis of type and purpose of station, geographic location, operating-range requirements, interference considerations, etc. Full

Table 6-9. Maritime Mobile Allocations (HF)

Types of Stations	Frequency Band (MHz)
Ship (Telephony)	4.063 - 4.1395 6.200 - 6.2104 8.195 - 8.2812 12.330 -12.421 16.460 -16.565 22.000 -22.0945
Ship, Coast (Telephony, Simplex)	4.1395 - 4.1425 6.2104 - 6.2165 8.2812 - 8.288 12.421 -12.4315 16.565 -16.576 22.0945 -22.112
Ship (Wideband Telegraphy, Facsimile, Special Transmission Systems)	4.1425 - 4.1625 6.2165 - 6.2445 8.288 - 8.328 12.4315 -12.4795 16.576 -16.6365 22.112 -22.1605
Ship, Buoy, Interrogating Coast (Oceanographic Data Transmission)	4.1625 - 4.166 6.2445 - 6.248 8.328 - 8.3315 12.4795 -12.483 16.6365 -16.640 22.1605 -22.164
Ship (Narrow-Band Direct-Printing Telegraph and Data-Transmission Systems)	4.166 - 4.17225 6.248 - 6.25825 8.3315 - 8.34175 12.483 -12.50325 16.640 -16.6605 22.164 -22.1845
Ship (High Traffic, Telegraphy)	4.17225- 4.178 6.25825- 6.267 8.34175- 8.356 12.50325-12.534 16.6605 -16.712 22.1845 -22.2225
Ship (Calling, Telegraphy)	4.178 - 4.187 6.267 - 6.2805 8.356 - 8.374 12.534 -12.561 16.712 -16.748 22.2225 -22.2675
Ship (Low Traffic, Telegraphy)	4.187 - 4.231 6.2805 - 6.3455 8.374 - 8.4595 12.561 -12.689 16.748 -16.9175 22.2675 -22.374

Table 6-9. Maritime Mobile Allocations (HF) (Cont'd.)

Types of Stations	Frequency Band (MHz)
Coast (Wide-Band and Manual Telegraphy, Facsimile, Special and Data Transmission Systems, and Direct-Printing Telegraph Systems)	4.231 - 4.361 6.3455 - 6.514 8.4595 - 8.7285 12.689 -13.1075 16.9175 -17.255 22.374 -22.6245
Coast (Telephony)	4.361 - 4.438 6.514 - 6.525 8.7285 - 8.815 13.1075 -13.200 17.255 -17.360 22.6245 -22.720

details of these assignment rules are too lengthy and complex for inclusion here. Additional information concerning frequencies used by the maritime services may be found in Parts 81, 83, and 85 (Volume IV) of the FCC Rules and Regulations.

Generally, in these bands radiotelegraphy is by means of A1 emission, and radiotelephony is by means of single-sideband emission. (Some conventional a-m may be encountered until the transition to ssb is completed.) In general, transmitter powers for coast stations are limited to the maximum values shown in Table 6-10 for radiotelegraphy and Table 6-11 for radiotelephony. In Table 6-11, the power shown for ssb emissions is peak envelope power. Classes of stations not shown in Table 6-11 are limited to powers of 1000 watts or less.

Maximum power for shipboard radiotelegraph stations is 2000 or 8000 watts, depending on the size of the vessel. In general, the minimum power for shipboard radiotelephone stations is 15 watts, and the maximum power ranges from 150 to 3000 watts, depending on location, size of vessel, etc.

Table 6-10. Radiotelegraph Power Limits (Coast Stations)

Frequency Band (MHz)	Maximum Transmitter Power (Watts)
4.000- 7.000	10,000
8.000- 9.000	20,000
12.000-27.500	30,000

FREQUENCIES FOR AVIATION

Frequency allocations for aeronautical purposes are shown in Table 6-1. Some examples of uses of frequencies by the aviation services are given in the following paragraphs.

The frequency 3023.5 kHz is a calling and working frequency for private aircraft; in addition, this frequency is available to air-carrier aircraft when vhf service is not available. The frequency 3281 kHz is available to lighter-than-air craft and stations serving these craft; this frequency also is available for ground and aircraft flight-test stations. The frequency 8364 kHz is available for use in survival craft for search and rescue communication with stations in the Maritime Mobile Service. In addition, miscellaneous maritime frequencies may be assigned to aircraft stations under some conditions.

Frequencies in the following list are available for assignment to aeronautical enroute stations in Alaska. Those frequencies identified by an asterisk are for use only in serving scheduled air carriers along specified routes. (An

Table 6-11. Radiotelephone Power Limits (Coast Stations)

Frequency Band (MHz)	Class of Station[1]	Type of Emission	Maximum Power (Watts)
2.000- 4.000	Any	a-m	1500 (day) 700 (night)
		ssb	1000
4.000-18.000	Class I	a-m	70,000
18.000-27.500	Class I	a-m	27,000
4.000-27.500	Class I	ssb	50,000
	Class II	ssb	1000
	Class II	a-m	1500

[1]Class-I and Class-II stations provide long-distance and regional communication, respectively.

aeronautical enroute station communicates primarily with aircraft stations, that is, with stations on board aircraft.) The frequencies in the list are given in megahertz.

3.411	6.568*
3.446*	6.617*
3.481*	10.041*
4.668	10.057*
4.696 (Day only)	11.295*
5.547*	11.319*
5.631* (Shared with FAA)	

In the continental United States (except Alaska), the frequency 4.654 MHz is available, under certain conditions, for emergency and backup service to aircraft operating in support of offshore drilling operations. Under certain conditions, this frequency may be assigned to aeronautical fixed stations in Alaska.

For enroute stations in U.S. possessions in the West Indies, the frequencies 5.461 MHz, 6619.5 MHz (prior to September 17, 1970), 6.575 MHz (after September 17, 1970), and 8.924 MHz (after September 17, 1970) are available.

A number of frequencies in the hf range are available for assignment to international aeronautical en route stations. Some of these frequencies, for the route areas indicated, are listed in Table 6-12.

Frequencies (in megahertz) available to the Civil Air Patrol are shown in the following list:

4.4645	4.5995
4.4675	4.6025
4.5045	4.627
4.5075	4.630
4.582	26.62
4.585	

Some of these frequencies are limited to use in specified states. Emissions may be A1, A2, A3, F1, or single sideband, depending on the specific frequency. Maximum power limits of 5, 250, 400,

Table 6-12. International Enroute Frequencies (kHz)

U.S.-Alaska (via Canada)	North Atlantic
5454	5610
8868	5624
8917	5638
8924	5673
11,359	8854
11,383	8889
13,280	8910
	8945
	13,288
Caribbean	13,328
5484	13,352
5568	17,965
6540	
6561	
6568	**North Pacific**
8840	
8959	5589
10,017	8938
11,343	13,264
11,367	17,909
13,320	
17,925	

and 1600 watts are specified, depending on the frequency.

Aeronautical fixed stations may be assigned frequencies in the following bands:

Kilohertz

3155-3400	5730-5950
4000-4063	6765-7000
4438-4650	7300-8195
4750-4995	9040-9500
5005-5450	9775-9995

Megahertz

10.1-11.175	18.03-19.99
11.4-11.7	20.01-21.0
11.975-12.33	21.75-22.0
13.36-14.0	22.72-24.99
14.35-14.99	29.8-29.89
15.45-16.46	29.91-30.0
17.36-17.7	

INDUSTRIAL RADIO SERVICES

The Industrial Radio Services are for the use of commercial enterprises for communications necessary to carry on their activities. The services in this category are the following:

Power Radio Service: This service is to provide communication for organizations engaged in producing or distributing electrical power, gas, water, or steam.

Petroleum Radio Service: This service is for organizations engaged in prospecting for, producing, or transporting (by pipeline) petroleum or petroleum products.

Forest Products Radio Service: This service is for organizations engaged in logging, tree farming, and certain related activities, such as hauling, manufacture of lumber products, or manufacture of pulp and paper products.

Motion Picture Radio Service: Organizations engaged in producing or filming motion pictures may operate stations in this service.

Relay Press Radio Service: Stations in this service may be authorized to organizations engaged in the publication of a daily newspaper or engaged in the operation of an established press association.

Special Industrial Radio Service: Organizations eligible to have stations in this service include those engaged in farming, ranching, and related activities; heavy construction; mining; and certain other activities related to industrial operations or public health.

Business Radio Service: This service is available for use by any organization engaged in a commercial activity; by educational or philanthropic institutions; by clergymen or ecclesiastical institutions; and by hospitals, clinics, and medical associations.

Industrial Radiolocation Service: Use of this service is available to any organization engaged in commercial, industrial, scientific, or educational activity. It is also available to corporations or associations organized for the purpose of furnishing a radiolocation service.

Manufacturers Radio Service: Organizations eligible for assignments in this service are those engaged entirely in the transformation of raw materials or parts into finished products.

Telephone Maintenance Radio Service: This service is for organizations engaged in rendering wire or wire and radio communication available to the public for hire.

In general, stations in these services are restricted to A3 or F3 emission for radiotelephony, although other classes of emission may be authorized in special cases. Tone signals for the purpose of establishing and maintaining communication are permitted. When a-m is used, the modulation percentage must not exceed 100 percent on negative peaks, but normally it must be greater than 70 percent (on peaks). Transmitters, except mobile units with power input of 3 watts or less, must be equipped with devices to limit the maximum modulation percentage and the audio bandwidth.

The rules provide that the transmitting power in these services must be no more than the minimum required for the intended communication. For fre-

Table 6-13. Frequencies (MHz) for Industrial Radio Services (HF)

Power	Petroleum	Forest Products	Motion Picture	Relay Press	Special Industrial	Business	Industrial Radioloc.	Manu-facturers	Telephone Maintenance
							3.230 through 3.400		
4.6375	4.6375		4.6375		4.6375				
	25.02								
	25.04								
	25.06								
	25.08								
	25.10								
	25.12								
	25.14								
	25.16								
	25.18								
	25.20								
	25.22								
	25.24								
	25.26								
	25.28								
	25.30								
	25.32								

27.235	27.235	27.235	27.235	27.235	27.235	27.235		27.235	27.235
27.245	27.245	27.245	27.245	27.245	27.245	27.245		27.245	27.245
27.255	27.255	27.255	27.255	27.255	27.255	27.255		27.255	27.255
27.265	27.265	27.265	27.265	27.265	27.265	27.265		27.265	27.265
27.275	27.275	27.275	27.275	27.275	27.275	27.275		27.275	27.275
					27.29				
					27.31				
					27.33				
					27.35				
					27.37				
						27.39			
						27.41			
						27.43			
						27.45			
						27.47			
						27.49			
						27.51			
						27.53			
		29.71							
		29.73							
		29.75							
		29.77							
		29.79							

quencies above 25 MHz, power in excess of 500 watts is not authorized in these services; on lower frequencies, power up to 2000 watts may be authorized. On several specific frequencies, lower power limits are established.

Frequencies in the hf range available to the Industrial Radio Services are summarized in Table 6-13. Several of the frequencies for these services are in the area of transition from the hf to the vhf region of the spectrum. The applicable frequencies between 3 and 30 MHz are listed in Table 6-13. Other frequencies, above 30 MHz, will be listed in subsequent chapters.

LAND TRANSPORTATION SERVICES

The Land Transportation Services include the Motor Carrier Radio Service, the Railroad Radio Service, the Taxicab Radio Service, and the Automobile Emergency Radio Service (for organizations that provide emergency road service for disabled vehicles). The frequencies available to these services in the 3-30 MHz range are:

27.235 MHz
27.245 MHz
27.255 MHz
27.265 MHz
27.275 MHz

The power input to the transmitter final stage is limited to 30 watts maximum; other technical requirements are essentially as described for the Industrial Radio Services.

SERVICES FOR PUBLIC CORRESPONDENCE

Stations which are open to public correspondence operate in the Domestic Public Radio Services and the International Fixed Public Radiocommunications Services. Public correspondence is defined as "any telecommunication which the offices and stations, by reason of their being at the disposal of the public, must accept."

The Domestic Public Radio Services are the Domestic Public Land Mobile Radio Service, the Rural Radio Service, the Point-to-Point Microwave Radio Service, and the Local Television Transmission Service. One frequency in the range covered by this chapter is available to the last two of these services: Microwave auxiliary stations may use the frequency 27.255 MHz on a shared basis with other services and with a maximum power output of 50 watts. Microwave auxiliary stations are used for communications related to surveying microwave paths, aligning microwave antennas, etc.

In Alaska, frequencies are assigned to public fixed stations on a zone basis. Frequencies in the hf region available in all zones include 3.201 MHz, 5.1675 MHz (6 a.m. to 9 p.m. local time), and 8.070 MHz (limited to 6 a.m. to 6 p.m. in most zones). These frequencies are for telegraphy and/or telephony. In addition, the frequency 3.261 MHz is available in some zones, also for telegraphy and/or telephony.

The following frequencies are for use in communicating with fixed stations of the Alaska Communication System (ACS): 3.357, 3.365, 5.1375, and 5.2075 MHz. These frequencies are for use with telegraphy and/or telephony; each frequency is specified for use in communicating with certain ACS stations, and some may be used only during specified hours.

Stations in the International Fixed Public services are assigned frequencies in the following bands:

Kilohertz	*Megahertz*
3155-3400	13.36-14.00
4000-4063	14.35-14.99
4438-4650	15.45-16.46
4750-4995	17.36-17.70
5005-5450	18.03-19.99
5730-5950	20.01-21.00
6765-7000	21.75-21.85
7300-8195	22.72-23.20
9040-9500	23.35-24.99
9775-9995	26.95-26.96
10,100-11,175	29.80-29.89
11,400-11,700	29.91-30.00
11,975-12,330	

Types of emission may include A0, A1, A2, A4, F1, F2, F4, single sideband, independent sideband, and, under certain circumstances, conventional a-m.

PUBLIC SAFETY SERVICES

In the Police Radio Service, zone and interzone stations may be assigned to the frequencies listed below.

5.135 MHz
5.140 MHz
5.195 MHz
*7.480 MHz
*7.805 MHz
*7.935 MHz

On these frequencies, only type A1 emission is authorized (except as noted below), and power input to the final rf stage of the transmitter must not exceed 1000 watts. The frequency 5.195 MHz is primarily a calling frequency. The frequencies 5.135 and 7.480 MHz may be assigned to fixed police stations in Alaska for point-to-point radiotelephone (A3 emission) communications; final-stage input is limited to 1000 watts. The frequencies identified by an asterisk may be used only between two hours after local sunrise and two hours before local sunset.

The frequency 3.201 MHz is available in the Special Emergency Radio Service. This service will be described in the next chapter, since most of its available frequencies are in the vhf range.

In addition to the frequencies mentioned above, 27.235, 27.245, 27.255, 27.265, and 27.275 MHz are shared with other services. Stations using these frequencies in the Public Safety Services are limited to a power input of 30 watts.

In general, stations in these services are restricted to A3 emission on frequencies below 30 MHz (A1 emission for zone and interzone stations).

OTHER SERVICES

Experimental stations are authorized from time to time to carry out various programs of research or development. Stations engaged only in scientific or technical experiments not related to any specific service may be assigned to any frequency allocated to the fixed, land mobile, or broadcasting services. Stations engaged solely in conducting ionospheric soundings by sweeping a band of frequencies may be authorized to use any frequency band not allocated to radio astronomy.

Developmental stations are used in the development and testing of equipment, or in obtaining engineering data, for a specific service. These stations usually are assigned to frequencies appropriate to the service for which the investigation is being made.

The band from 27.23 to 27.28 MHz is available for authorizations to students (in the seventh grade or higher); such authorizations are made for the purpose of presenting experiments or demonstrations for school or school-approved projects. These authorizations are of a temporary nature. Normally, the power input to the transmitter final stage is limited to 5 watts.

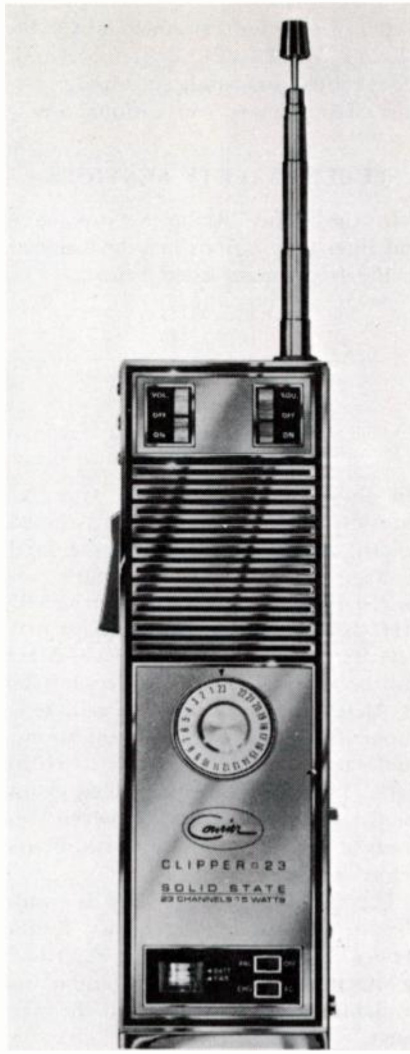
Certain types of equipment used for industrial, scientific, and medical (ISM) purposes depend on the generation of rf energy for their operation. Although ISM equipment is not intended to be used for communication, much of it does radiate energy that could cause interference. Recognizing this fact, the FCC has allocated certain frequencies for operation of ISM equipment. On these frequencies, other services are not protected from interference caused by ISM operations. The ISM frequencies in the hf range are 13.560 MHz and 27.120 MHz. A tolerance (difference above or below the specified frequency) of 6.78 kHz for 13.560 MHz and 160 kHz for 27.120 MHz is allowed.

In 1963, the ITU held a Space Radiocommunication Conference to allocate frequency bands for space communication. One of the recommendations of the conference was that the frequency 20.007 MHz be designated for use in connection with search and rescue operations.

HF TRANSMITTING EQUIPMENT

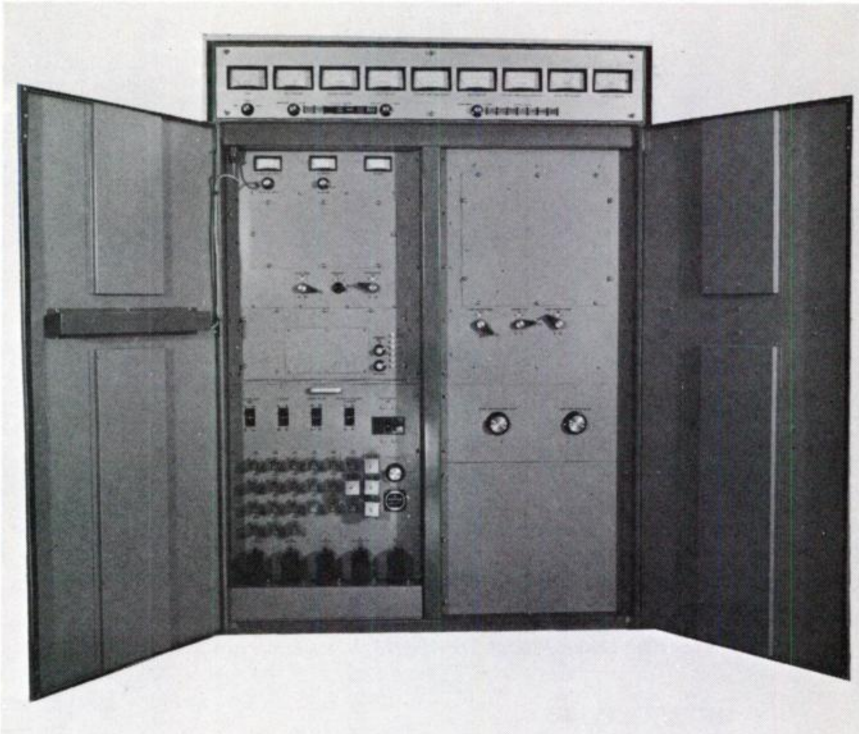
Fig. 6-4 shows an all-solid-state, hand-held transmitter-receiver combination, or transceiver, for use in the Citizens Radio Service. The transmitter section is capable of operation on any of the 23 class-D Citizens channels; a channel selector is set to the desired channel number. The transmitter power input is 5 watts. A dual-purpose meter indicates rf output and provides a battery check. The receiver is a dual-conversion superheterodyne with a ceramic filter for enhanced selectivity; audio output power is 0.5 watt. The transceiver measures 3⅜" × 11⅛" × 2½" and weighs 4¾ pounds. An ac-operated power supply, available as an accessory, permits use of the transceiver as a base station, or it may be used to recharge nickel-cadmium batteries when these are used to power the unit. An adapter cord is available to permit operation from a cigarette-lighter receptacle. A 57-inch telescoping antenna is built in, and there is provision for connecting an external antenna.

Hand-held transceivers with power inputs ranging from 100 milliwatts to 5 watts are made by several manufacturers of CB equipment.



Courtesy Courier Communications
Fig. 6-4. Courier Clipper 23 transceiver.

In some transmitting installations, use is made of an *exciter*. This device generates the desired signal, but at a low power level. An external amplifier then is used to attain the desired output power, but otherwise does not modify the signal. One such amplifier, shown in Fig. 6-5, delivers an output of 10,000-20,000 watts cw, or 40,000-60,000 watts peak envelope power. The amplifier may be adjusted to any frequency between 3 and 30 MHz. Possible types of emissions (determined by the external exciter) include cw, a-m, single sideband, frequency-shift keying, pulse-code modulation, and others. Driving power required from the exciter is 100 milliwatts. Both tubes and solid-state devices are used in this equipment; the high-power final-amplifier tube is vapor cooled. In the event of trouble in the final stage, provision is made for connecting the next-to-last stage to the antenna for reduced-power emergency operation. Other features include provision for remote control from a distant point, illuminated meters across the top of the cabinet and on the front access door, safety door interlocks to protect the operator, a system of automatic devices to protect the equipment in case of a malfunction, and a system of indicator lights to



Courtesy American Electronic Laboratories, Inc.

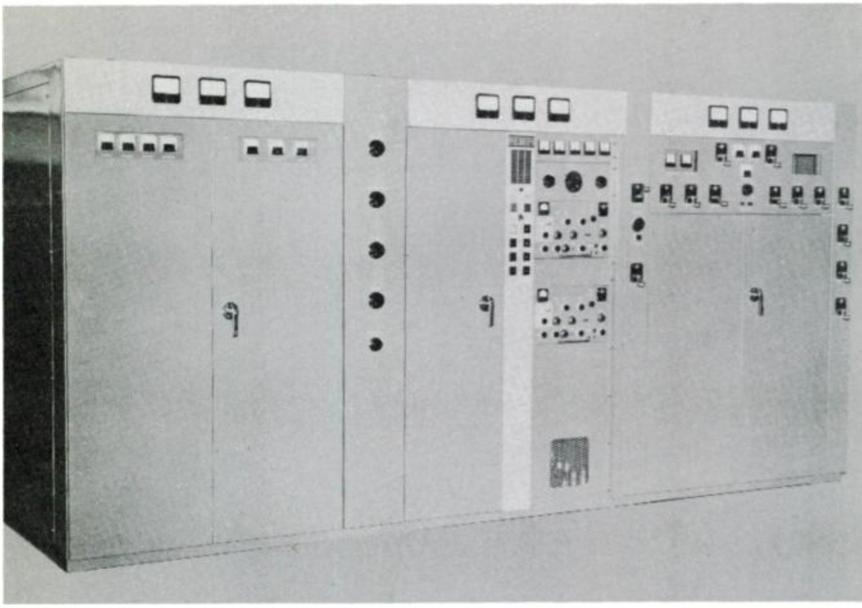
Fig. 6-5. *AEL* Model LA-40KA hf linear amplifier.

show the location of the malfunction. The amplifier requires a three-phase power source of 208-230 volts, 50-60 Hz; power consumption is 53,000 watts for a 10,000-watt carrier output at 100-percent modulation. The equipment is rated for operation over a temperature range of 0-50°C at 95-percent relative humidity, up to an altitude of 5000 feet. It measures 76″ × 48″ × 50″ (H × W × D), not including the heat exchanger for the vapor-cooling system; it weighs 2100 pounds, including the heat exchanger.

Fig. 6-6 shows a high-frequency broadcast transmitter with a rated carrier power output of 100,000 watts. This transmitter is available with modulator stages for a-m, or without modulators for cw (code) transmission. Amplifier tuning is continuous from 3 to 26.1 MHz. The exciter has provision for selection of ten fixed frequencies; it also has an input for an external variable-frequency oscillator and for frequency-shift-keying operation. A change of carrier frequency requires 3 minutes or less for retuning of the transmitter.

Twenty tubes are used in this transmitter; the largest, of which there are four, weigh 65 pounds each. Voltages as high as 15,000 volts are produced in the transmitter for use with these tubes. Thirty meters are provided to indicate the important voltages and currents in the equipment. The transmitter is forced-air cooled by a blower driven by a 20-hp motor.

The cabinets are provided with doors and removable panels for easy access during maintenance. The main part of the transmitter measures 6½′ × 14′ × 5′, but, as is standard for high-power transmitters, several of the largest components (such as large transformers and the blower) are located externally. The shipping weight of this transmitter is 29,000 pounds.



Courtesy Gates Radio Company

Fig. 6-6. *Gates* Model HF-100 hf broadcast transmitter.

HF RECEIVERS

Fig. 6-7 shows a low-priced kit-type receiver for short-wave listening (it also includes lf and mf coverage). The receiver consists basically of a regenerative detector followed by an audio amplifier. Four frequency bands are switch selectable: 140-560 kHz, 560-1730 kHz, 1.73-5.5 MHz, and 5.5-18 MHz. These frequencies include the 160-, 80-, 40-, and 20-meter amateur bands; broadcast bands; marine and aircraft bands; etc. Provisions are made for connecting either a long or short antenna, depending on signal strengths and frequencies; there is also a ground terminal. A jack permits use of the 1-watt audio amplifier with headphones instead of the built-in speaker. Controls include main tuning, fine tuning, band selector, regeneration, and volume/on-off. The circuit uses three tubes and requires 30 watts of power from a 117-volt, 50-60 Hz source. A power transformer is included to eliminate the shock hazard frequently associated with ac-dc circuits. The receiver measures 7″ × 10″ × 7″ and weighs 9¾ pounds.

Fig. 6-8 shows another kit-type receiver, this one using a superheterodyne circuit. Bands covered are: 200-400 kHz, 550-1800 kHz, 1.8-4.8 MHz, 4.8-12 MHz, and 12-30 MHz. Controls include power on/off, automatic volume control on/off, automatic noise limiter on/off, main tuning, band spread (fine tuning), band selector, volume, antenna trimmer, and sensitivity. The antenna-trimmer control makes it possible to compensate manually for slight tracking errors in the variable tuned circuits and thus to provide best response to each received frequency. An illuminated signal-strength meter aids in accurate tuning. The sensitivity control determines the amount of amplification in the i-f amplifier. When this control is advanced far enough, the i-f stage breaks into self-oscillation and also functions as a beat-frequency oscillator (BFO) for reception of cw or ssb signals. A built-in antenna is provided for the 550-1800 kHz band; external antennas are required for the other bands. A front-panel jack permits substitution of headphones for the built-in speaker. A code-

Courtesy Heath Company

Fig. 6-7. *Heathkit* Model GR-81 short-wave-listener's radio.

key jack is provided for code practice. The receiver operates from a 110-130 volt, 60-Hz source. Its size is 5½″ × 12¼″ × 8″.

The receiver shown in Fig. 6-9 tunes four bands: 535-1600 kHz, 1.55-4.5 MHz, 4.5-13 MHz, and 13-30 MHz. Features include electrical band spread; reception of a-m, cw, or ssb; fast and slow automatic volume control (avc); variable-pitch BFO; an rf amplifier stage; automatic noise limiter (anl); and

Courtesy Allied Radio Shack

Fig. 6-8. *Knight-Kit Star Roamer* multiband receiver.

Courtesy Allied Radio Shack

Fig. 6-9. *Realistic* Model DX-150 four-band receiver.

an illuminated signal-strength meter. There is a built-in speaker, and a front-panel jack is provided for headphones or an optional external speaker. There are eleven front-panel controls: main tuning, band spread, BFO pitch, volume/on-off, band selector, antenna trimmer, rf gain, anl switch, a-m/cw/ssb switch, afc fast/slow switch, and a receive/standby switch (silences headphones or speaker while receiver remains on). The receiver is entirely solid-state and can be operated from 117 volts ac or a 12-volt dc, negative-ground source, such as an automobile electrical system or eight size-D cells.

Courtesy Aerotron, Inc.

Fig. 6-10. Ameco Model PT preamplifier.

Courtesy R. L. Drake Company

Fig. 6-11. Drake Model R-4B hf receiver.

This receiver measures 9¼" × 14¼" × 6½"; it weighs 14 pounds. Optional accessories include a 12-volt battery pack (containing eight D cells, battery holders, cables, etc.), a matching speaker, and 8-ohm headphones.

The device illustrated in Fig. 6-10 is a preamplifier used to improve the sensitivity of the receiver portion of an amateur transceiver. It tunes the range from the 160-meter amateur band (1.8-2.0 MHz) through the 6-meter amateur band (50-54 MHz). Essentially, the unit consists of a sensitive rf amplifier with a wide-range gain control to adjust the gain to suit the requirements of a particular situation (i.e., strength of desired signal, presence of strong adjacent-channel signals, etc.). Relays, operated by control circuits in the transceiver, bypass the preamplifier during periods of transmission. The preamplifier has two outputs, one for the transceiver and one for a second receiver (if used). Switched ac outlets on the rear of the unit are provided for the transceiver, second receiver, etc.; an unswitched outlet is available for a clock.

The receiver illustrated in Fig. 6-11 covers all of the 80-, 40-, 20-, and 15-

Courtesy Galaxy Electronics

Fig. 6-12. Two Galaxy Model FFR-230 fixed-frequency receivers.

meter amateur bands, and the 28.5-29.0 MHz portion of the 10-meter band, with 1-kHz dial divisions. Through the use of accessory frequency-control crystals, any ten 500-kHz ranges between 1.5 and 30 MHz may be covered (the manufacturer does not recommend 5-6 MHz). A frequency calibrator is built in. Four bandwidths are switch-selectable: 0.4, 1.2, 2.4, and 4.8 kHz. Reception of a-m, cw, and ssb (either upper or lower sideband) is provided, and a noise blanker is included to operate in all these modes. A crystal lattice filter is used to give improved cross-modulation and overload characteristics. The receiver, which contains both tubes and transistors, is 5½" × 10¾" × 12¼" and has a weight of 16 pounds.

A fixed-frequency receiver for military and commercial applications is illustrated in Fig. 6-12 (two receivers are shown side by side in a single mounting in this photograph). The receiver can be used in the frequency range from 2 to 30 MHz; crystal control of frequency is employed. Received signals may be a-m, cw, ssb (upper or or lower sideband), or teleprinter (RTTY); outputs are provided for operating the appropriate auxiliary equipment. A multiple filter is incorporated to permit changing the bandwidth to suit the signal being received. A built-in meter can be used (by switch selection) for either rf or af indication. This solid-state receiver measures 5.93" × 8.375" × 14.875"; thus two units fit in a single 19"-wide rack space. Each unit weighs 13 pounds and operates from 115/230 volts, 50-60 Hz, or 14-18 volts dc. Metal parts are chromate treated to minimize damage to the equipment that could be caused by corrosion or fungus.

CHAPTER 7

Very High Frequencies

As we progress toward still higher frequencies in the radio spectrum, we find that the behavior of the waves begins to change significantly. The change becomes "official" at 30 MHz, and frequencies from that point to 300 MHz are called *very high frequencies.* Of course, the transition does not occur abruptly at 30 MHz, but as the frequency decreases from this point, hf characteristics become more pronounced, and as the frequency increases, vhf characteristics become more pronounced.

VHF PROPAGATION

In the lower vhf region (below roughly 50 to 100 MHz), there may be some reflection from the ionosphere. There is occasional strong reflection from ionized patches in the E layer of the ionosphere; such reflection is called *sporadic E* reflection. Also, some communication has been carried out on an intermittent basis by reflection from ionized trails formed in the ionosphere by meteors.

The most effective mode of vhf transmission is by the space wave over a *line-of-sight* path (Fig. 7-1). It can be seen that the height of the antennas is an important factor in establishing the maximum distance between transmitter and receiver. If the distance becomes too great for the heights involved, the curvature of the earth interrupts the signal path. Actually the "radio horizon" is somewhat more distant than the optical horizon because of refraction of radio waves by the lower atmosphere, or troposphere.

Tropospheric refraction sometimes causes vhf signals to be received over unusually great distances. The refractive effect of the air can increase under certain weather conditions and "reflect" vhf signals that normally would escape from the earth. Sometimes a "boundary area" may occur that, together with the surface of the earth, forms a "duct" through which the vhf signals may be transmitted for long distances over a multihop path. Distances of 1000 miles or more are possible. (Note that the atmospheric properties discussed in this paragraph are meteorological rather than a result of ionization of the air.)

A propagation mechanism that has attained considerable importance is *tropospheric scattering*. By this means, weak but useful signals may be transmitted to points even hundreds of miles beyond the horizon. It is believed that the troposphere contains numerous discontinuities, or small volumes of air that differ slightly from the surrounding air mass (Fig. 7-2). The waves are scattered, or reflected, from these areas to the receiving location.

Waves may travel from transmitter to receiver over more than one path. In fact, as Fig. 7-3 shows, the "space

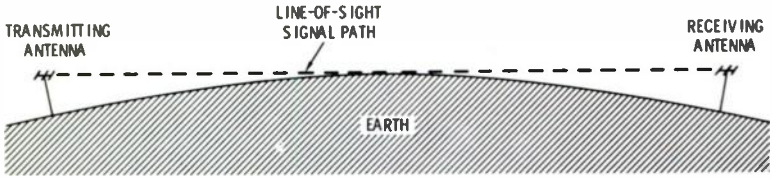


Fig. 7-1. Line-of-sight transmission.

wave" in reality consists of two components, a direct wave and a ground-reflected wave. Because the two waves travel over paths of slightly different length (and because the reflected wave is inverted in the reflection process), the two waves arriving at the receiving antenna are not in phase. Because of this action, the strength of the received signal depends on the physical relationship of the two antennas and the earth. In the usual listening situation, the practical result is simply that the received signal is not as strong as it would be if only the direct wave were involved.

In addition to the type of reflection shown in Fig. 7-3, there may be reflections from mountains, buildings, or other objects. In these cases, the path-length difference may be great enough to cause multiple images (ghosts) in TV reception, deterioration of stereo fm reception, etc. When reflections occur from moving objects, particularly aircraft, the difference in path length changes continuously, and rapid fading, or *flutter,* of the received signal results. This is because when the path-length difference is a multiple of a wavelength the reflected signal reinforces the normal signal. When the path-length difference is an odd multiple of a *half* wavelength, the reflected signal tends to cancel the normal, nonreflected signal.

VHF ALLOCATIONS

Although atmospheric conditions occasionally cause long-distance transmission at vhf, the normal transmission

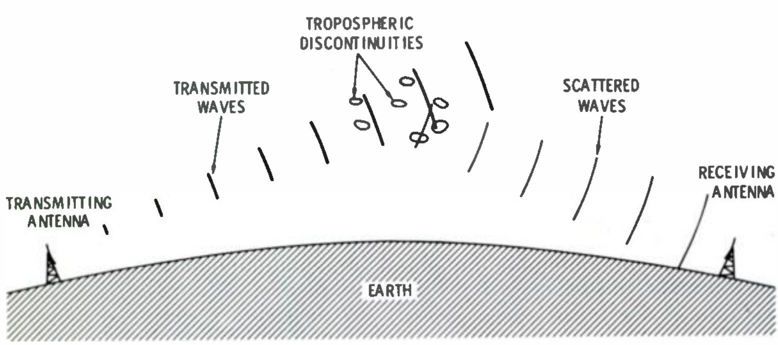


Fig. 7-2. Tropospheric scattering of radio waves.

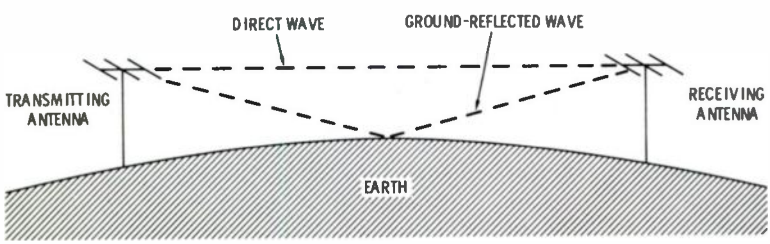


Fig. 7-3. Paths of direct and ground-reflected waves.

range at these frequencies is limited to approximately line-of-sight distances. Therefore, these frequencies are allocated to services for which long-distance communication is either unnecessary or undesirable.

Another factor influences the use of this portion of the spectrum: Notice that the range from 30 to 300 MHz is a band 270 MHz wide. Contrast this with the 30 MHz occupied by the vlf, lf, mf, and hf ranges combined. It can be seen that such services as television, which requires a channel width of 6 MHz (U.S. standard), must be confined to the vhf portion of the spectrum, or higher. For similar reasons, a greater number of narrow channels can be accommodated in this region than at lower frequencies.

Allocation of the vhf part of the spectrum in the United States is shown in Table 7-1. In general, this plan is in conformity with the ITU allocations for Region 2. In the table, the term "Government" means the United States

Table 7-1. VHF Allocations

Frequency (MHz)	Service	Class of Station
30-30.56	(Government)	
30.56-32	Land Mobile	Base
		Land Mobile
32-33	(Government)	
33-34	Land Mobile	Base
		Land Mobile
34-35	(Government)	
35-36	Land Mobile	Base
		Land Mobile
36-37	(Government)	
37-38	Land Mobile	Base
		Land Mobile
38-39	(Government)	
39-40	Land Mobile	Base
		Land Mobile
40-42	(Government)	
42-46.6	Land Mobile	Base
		Land Mobile
46.6-47	(Government)	
47-49.6	Land Mobile	Base
		Land Mobile
49.6-50	(Government)	
50-54	Amateur	Amateur
54-72	Broadcasting	Television (channels 2-4)
72-73	Fixed	Operational Fixed
73-74.6	Radio Astronomy	Radio Astronomy
74.6-75.4	Aeronautical Radionavigation	Aeronautical Radionavigation
75.4-76	Fixed	Operational Fixed
76-88	Broadcasting	Television (channels 5 and 6)
88-108	Broadcasting	FM Broadcasting
108-117.975	Aeronautical Radionavigation	Radionavigation Land
117.975-136	Aeronautical Mobile	Aeronautical
		Aircraft
136-137	Space Research	Space
137-138	Meteorological Satellite	Space
	Space (Telemetering & Tracking)	
138-144	(Government)	
144-148	Amateur	Amateur

Table 7-1. VHF Allocations (Cont'd.)

Frequency (MHz)	Service	Class of Station
148-149.9	(Government)	
149.9-150.05	Radionavigation-Satellite	Space
150.05-150.8	(Government)	
150.8-156.25	Land Mobile	Base Land Mobile
156.25-157.0375	Maritime Mobile	Coast Ship
157.0375-157.1875	(Government)	
157.1875-157.45	Maritime Mobile	Ship
157.45-161.575	Land Mobile	Base Land Mobile
161.575-161.625	Maritime Mobile	Coast
161.625-161.775	Land Mobile	Base Land Mobile
161.775-162.0125	Maritime Mobile	Coast
162.0125-173.2	(Government)	
173.2-173.4	Fixed Land Mobile	Base Fixed Land Mobile
173.4-174.0	(Government)	
174-216	Broadcasting	Television (channels 7-13)
216-220	(Government)	
220-225	(Government) Amateur*	
225-328.6	(Government)	

*Secondary service; others are primary.

Federal Government. (The various services were defined in Chapter 4 in connection with Table 4-1.)

VHF BROADCASTING IN THE UNITED STATES

Four bands of frequencies in this range are available for use by two kinds of broadcast stations: radio and television. These bands are 88-108 MHz for radio; and 54-72, 76-88, and 174-216 MHz for television.

FM Radio Stations

The electrical disturbances commonly known as *static* are basically an amplitude-modulated radiation, and practical receivers cannot distinguish them from a desired a-m signal. If, however, the desired signal is frequency modulated, a significant reduction in relative static level can be achieved. To provide a high-fidelity, "static-free" broadcast service, the FCC authorized fm broadcasting on a regular basis some 30 years ago.

An fm broadcast signal occupies a much wider band of frequencies than does an a-m broadcast signal, so fm broadcasting is allocated a group of frequencies in the vhf range, where the required channel width can be accommodated. Unlike the case in the standard a-m broadcast band, there is no great day-night difference in transmission distance at the frequencies in the fm band. Consequently, regular reception, even of high-power stations, is limited to distances on the order of 100 miles or less. (Intermittent reception at greater distances is common, although largely unpredictable, depending on atmospheric conditions.) This limited transmission distance at first may seem to be a disadvantage, but it greatly eases the interference problem and thereby leads to a distinct advantage:

All fm stations are licensed for unlimited maximum operating time; furthermore, they use the same power day or night.

Frequencies Available — For fm broadcasting stations, full (100-percent) modulation is defined as a swing of 75 kHz in each direction from the carrier (center) frequency. In addition, a 25-kHz "guard band" is provided at each edge of the channel, so the total channel width is $25 + 75 + 75 + 25 = 200$ kHz. There are 100 channels in the fm broadcast band; the carrier frequencies of these channels are 88.1, 88.3, 88.5, etc., through 107.9 MHz. For reference, the FCC has numbered these channels 201, 202, 203, etc., through 300. However, this numbering system is not widely used by the public, and manufacturers calibrate receiver dials in megahertz (MHz) rather than channel numbers.

The portion of the fm band from 92 to 108 MHz is allocated for commercial broadcasting. (In Alaska, the frequencies between 88 and 100 MHz are not available for fm broadcasting. In Hawaii, the band between 98 and 108 MHz is not available for broadcast use.) Commercial stations are assigned frequencies within this band according to the FCC Table of Assignments. This table is a list of cities in the United States and the frequency (or frequencies) available for assignment in each listed city. Stations are assigned only in listed communities (or neighboring communities in some cases) and only to frequencies listed for those communities. However, the table is amended from time to time to add new allocations. The technical standards on which the assignment table is based are summarized in the paragraphs that follow.

Allocation Standards—For the purposes of fm allocation, the United States is divided into three ones. Zone I includes the states of Illinois, Indiana, Ohio, West Virginia, Pennsylvania, Maryland, Delaware, New Jersey, Connecticut, Rhode Island, Massachusetts, and parts of Wisconsin, Michigan, Virginia, New York, Vermont, New Hampshire, and Maine, as shown approximately in Fig. 7-4. Zone I-A includes Puerto Rico, the Virgin Islands, and the portion of California south of the 40th parallel. Zone II includes Alaska,

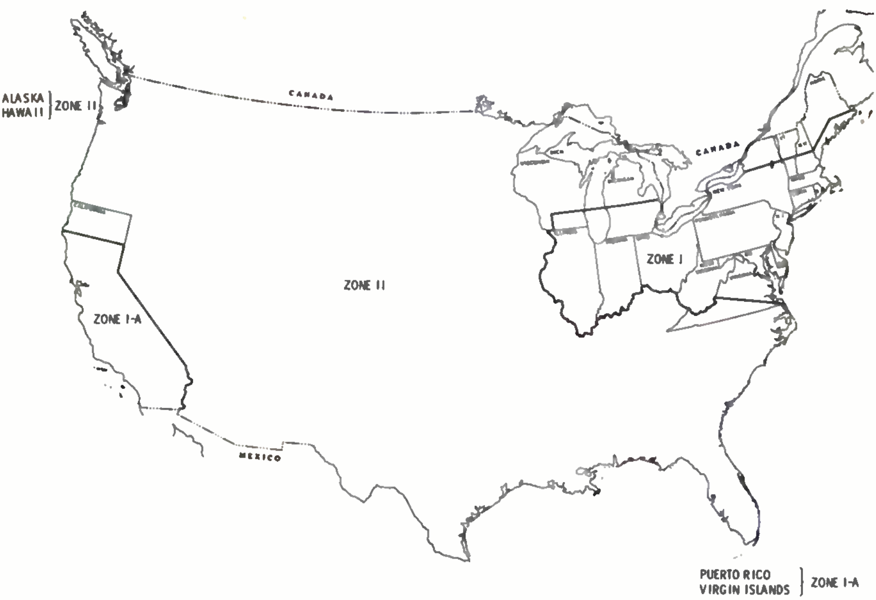


Fig. 7-4. Allocation zones for fm broadcast stations.

Hawaii, and the remainder of the United States not in Zones I and I-A.

There are three classes of fm stations, with the power and antenna-height limitations shown in Table 7-2. Class-A stations are assigned in all zones; the frequencies available to Class-A stations are listed at the bottom of Table 7-2. Class-B stations are assigned in Zones I and I-A, and Class-C stations are assigned in Zone II. The frequencies not listed as Class-A channels in Table 7-2 are for assignment of Class-B or -C stations, depending on the zone.

The coverage of an fm station depends on both its power and the height of its antenna above average terrain. No minimum antenna height is specified, but Table 7-2 shows a maximum antenna height for each class of station. A station may use the maximum power for its class so long as its antenna height does not exceed the limit shown. If the antenna is higher than the indicated limit, the station must use reduced power so that its coverage does not exceed that obtained with maximum power at maximum height. For example, maximum coverage for a Class-B station is the equivalent of 50,000 watts at 500 feet. Suppose, however, that a station has an antenna 1000 feet above average terrain. Then, according to FCC engineering charts, the maximum power for this station is about 9000 watts. In cases of extremely high antennas, stations may be limited to powers less than the minimum shown in Table 7-2. For instance, a Class-C station on a mountain top might have an antenna height above average terrain of 4000 feet; its maximum (and minimum) permitted power would be about 9200 watts.

Frequencies are assigned to communities with sufficient distance separation to permit full-coverage operation by all stations. The mileages specified for the various classes of stations are shown in Table 7-3. Note that minimum separations are established for stations on the same frequency and on frequencies 200, 400, and 600 kHz apart; stations 800 kHz or more apart may be assigned to the same community. The separations shown also apply between commercial stations on 92.1, 92.3, and 92.5 MHz and noncommercial educational stations on 91.5, 91.7, and 91.9 MHz. The separations shown between Class-B and -C stations apply across zone boundaries. A Class-D station is a 10-watt noncommercial educational fm station.

The standard intermediate frequency for fm receivers is 10.7 MHz. If two stations in the same area had frequencies about 10.7 MHz apart, their signals could combine in the receiver to cause serious interference. To avoid this problem, the minimum spacings shown below are required for stations on frequencies 10.6 or 10.8 MHz apart.

Classes of Stations	*Spacing (Miles)*
A-A	5
B-A	10
B-B	15
C-A	20
C-B	25
C-C	30

It should be pointed out that the present fm allocation rules were adopted after several hundred stations were already on the air in accordance with earlier standards. Most of these stations were allowed to continue operating without changing their facilities to comply with the new rules. In fact, special rules were adopted to permit many of these existing stations to improve their facilities even though the new allocation standards would have barred the improvements. The result is that a number of station assignments do not conform to the power and mileage requirements described above. All new stations, however, are required to comply with the present standards.

Antenna Height Above Average Terrain—The antenna heights discussed in this section are height above average terrain. Essentially, this is the height of the center of the antenna above the average level of the terrain lying between 2 and 10 miles from the antenna

Table 7-2. Classes of FM Stations

Class of Station	Power (Watts)[1]		Maximum Antenna Ht (Feet)[3]
	Min[2]	Max[3]	
A[4]	100	3000	300
B	5000	50,000	500
C	25,000	100,000	2000

[1]Effective radiated power.
[2]Power must be sufficient to cover city of license and not less than value shown.
[3]Maximum combination of power and antenna height (see text).
[4]Frequencies (megahertz) available to Class-A stations are:

92.1	95.9	100.1	103.9
92.7	96.7	100.9	104.9
93.5	97.7	101.7	105.5
94.3	98.3	102.3	106.3
95.3	99.3	103.1	107.1

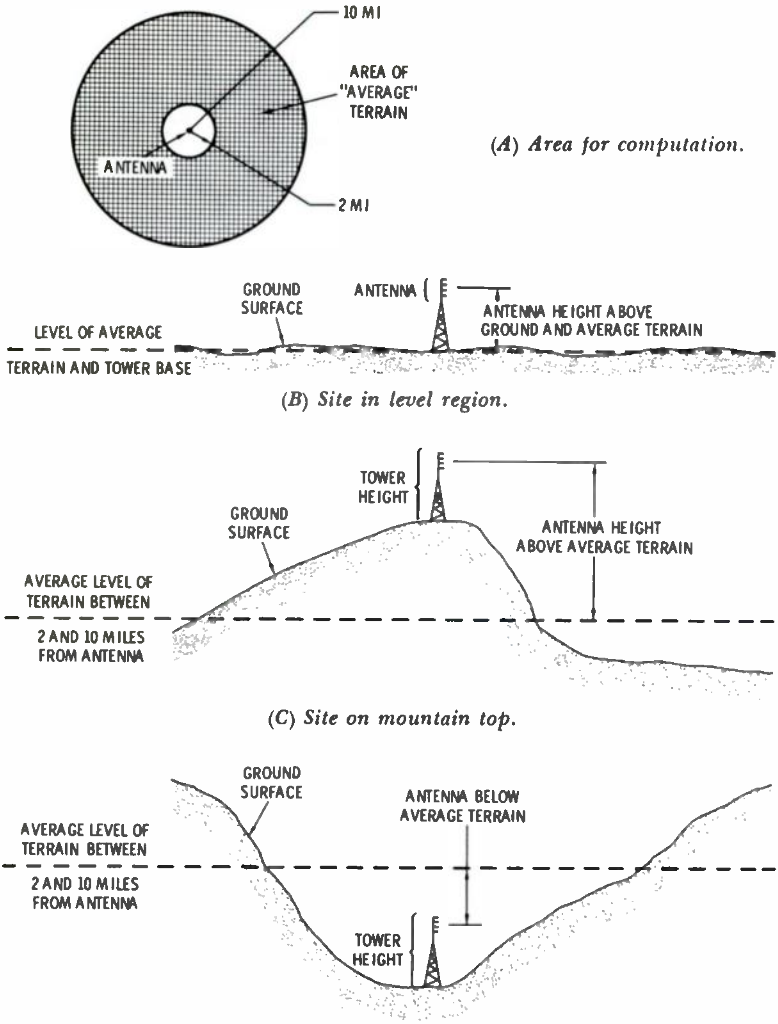
Other frequencies are for Class-B or -C stations.

location (the shaded area in Fig. 7-5A). Fig. 7-5B shows a cross section of relatively level terrain; in this example, the antenna height above average terrain is about equal to the height of the center of the antenna above ground. Fig. 7-5C shows how a mountain location can be used to achieve great height with a short tower. Fig. 7-5D shows how a station in a valley (or on a plain near a mountain range) can have an antenna below average terrain (negative antenna height).

Polarization—At vhf, it is important that the receiving antenna have the same polarization as the transmitting antenna. Therefore, a standard transmitting-antenna polarization—horizontal—is specified. Although horizontal polarization is required, a combination

Table 7-3. Separations for FM Stations

Same Channel				
	A	B	C	D
A	65 mi	—	—	—
B	—	150 mi	170 mi	—
C	—	170 mi	180 mi	—
D	—	—	—	—
Channels 200 kHz Apart				
	A	B	C	D
A	40 mi	65 mi	105 mi	30 mi
B	65 mi	105 mi	135 mi	—
C	105 mi	135 mi	150 mi	—
D	30 mi	—	—	—
Channels 400 kHz Apart				
	A	B	C	D
A	15 mi	40 mi	65 mi	15 mi
B	40 mi	40 mi	65 mi	40 mi
C	65 mi	65 mi	65 mi	65 mi
D	15 mi	40 mi	65 mi	—
Channels 600 kHz Apart				
	A	B	C	D
A	15 mi	40 mi	65 mi	15 mi
B	40 mi	40 mi	65 mi	40 mi
C	65 mi	65 mi	65 mi	65 mi
D	15 mi	40 mi	65 mi	—



(*A*) *Area for computation.*

(*B*) *Site in level region.*

(*C*) *Site on mountain top.*

(*D*) *Site located in valley.*

Fig. 7-5. Antenna height above average terrain.

of horizontal and vertical polarization is permitted. Since automobile and portable fm radios using vertical whip antennas are increasing in popularity, many fm stations have installed dual-polarized antennas. The effective radiated power for vertical polarization may not exceed that authorized to the station for horizontal polarization.

Multiplexing—In Chapter 2, a technique called multiplexing was described. Fm stations use two types of multiplexing to add additional, simultaneous program, channels. One of these is used to add a second audio channel for stereophonic broadcasting to the public. The other is used to add a private channel or channels for transmission of background music or other material to subscribers, or for signals related to station operation (cueing, remote meter readings, program relays to other stations, etc.).

In fm stereophonic broadcasting, two channels, left (L) and right (R), are transmitted. The two channels are mixed and transmitted together on the main channel so that listeners with monophonic receivers may hear the entire program. The *difference* between the L and R signals is transmitted over a subchannel. When this difference signal is recovered by a stereo receiver, by proper mixing of the sum and difference signals the original L and R signals can be recreated.

The subcarrier frequency for the stereophonic difference signal is 38 kHz. The difference subchannel consists of amplitude modulation with the 38-kHz carrier suppressed. (The subchannel is then applied to the *main* carrier by frequency modulation.) In recovering the difference signal in the receiver, it is necessary to reinsert the 38-kHz carrier, and this reinserted carrier must be synchronized with the original 38-kHz carrier at the transmitter. To achieve this synchronization, the receiver makes use of a 19-kHz *pilot subcarrier* broadcast by the station as part of the complete stereo transmission. The pilot subcarrier has exactly one-half the frequency of the subcarrier, so frequency-doubling circuits can be used in the receiver to obtain the required 38 kHz.

Background-music and other private-channel operations are carried on by many fm stations under a Subsidiary Communications Authorization (SCA). These special signals are transmitted on subchannels in the range 20 to 75 kHz (53 to 75 kHz when the station also broadcasts stereo); the SCA subcarrier is frequency modulated. It is possible for an fm station to transmit a stereo broadcast and an SCA program at the same time. (Remember that *any* unauthorized reception of SCA signals is now considered illegal.)

Minimum Schedule—It was mentioned previously that fm stations are licensed with no maximum limit to the hours they may operate. However, commercial stations must maintain a minimum schedule of 36 hours weekly, with a minimum of 5 hours between 6 a.m. and midnight each day (except Sunday). Additionally, fm stations in cities of over 100,000 population must be programmed separately from commonly owned a-m stations in the same area for at least 50 percent of the weekly fm schedule.

Noncommercial Educational Stations—Noncommercial educational stations are licensed only to nonprofit educational organizations for the purpose of advancing an educational program. The portion of the fm band from 88 to 92 MHz is reserved for assignment to these stations, with the following exceptions: The frequencies between 88 and 92 MHz are not available for broadcasting in Alaska; there, noncommercial stations are assigned frequencies between 100 and 108 MHz. Also, in special cases some noncommercial stations in other states are assigned commercial channels. In New York City, the channel centered on 89.1 MHz is reserved for use by the United Nations with the equivalent of 20,000 watts at an antenna height of 500 feet.

There are four classes of noncommercial educational stations. A Class-A station has a power no greater than 3000 watts, or coverage no greater than that obtained with a power of 3000 watts and an antenna height of 300 feet. Stations with greater power or coverage are classified as Class-B stations in Zones I and I-A, and as Class-C stations in Zone II. A Class-D station has a transmitter output of 10 watts or less. Class-A and Class-D stations may be authorized in all zones. All classes of stations may be assigned to any frequency in the reserved portion of the band.

No minimum power or antenna height is specified for stations operating on these frequencies. The maximum-power limitations for Class-B and Class-C commercial stations apply to Class-B and -C educational stations operating on 91.5, 91.7, and 91.9 MHz. The requirements of Table 7-3 also apply to these frequencies.

Noncommercial educational stations are not required to maintain a minimum operating schedule. They may be authorized to transmit stereophonic programs and to conduct other multiplex operations under an SCA.

Table 7-4. VHF Television Channels (United States)

Channel Number	Frequency Limits (MHz)	Picture Carrier (MHz)	Sound Carrier (MHz)
2	54-60	55.25	59.75
3	60-66	61.25	65.75
4	66-72	67.25	71.75
5	76-82	77.25	81.75
6	82-88	83.25	87.75
7	174-180	175.25	179.75
8	180-186	181.25	185.75
9	186-192	187.25	191.75
10	192-198	193.25	197.75
11	198-204	199.25	203.75
12	204-210	205.25	209.75
13	210-216	211.25	215.75

Television Stations

A television signal must convey a great amount of information: the brightness of each of millions of picture elements, the accompanying sound, synchronization information, and, often, color information as well. A considerable band of frequencies is required to accomplish this transmission—in the United States a television channel is 6 MHz wide. Obviously, any significant number of TV channels could be accommodated only in the vhf (or uhf) region of the spectrum.

Television Channels—Initially, 13 television channels were allocated in the vhf region. Channel 1 (44-50 MHz) was withdrawn from this service many years ago; the remaining 12 vhf channels are listed in Table 7-4. (Another 70 channels, in the uhf region, are listed in Chapter 8.) To reduce interference, some stations are required to operate with carrier frequencies offset 10 kHz from the values listed; the offset is above the listed frequencies for some stations and below them for others.

The complete television channel is a miniature "spectrum" itself. Fig. 7-6 shows the organization within a channel. The picture carier is 1.25-MHz above the lower frequency limit of the channel. This carrier is amplitude modulated by the video (picture) signal. The shaded area represents the sidebands generated by modulation of the video carrier. Notice that part of the lower sideband is suppressed in order to conserve as much spectrum space as possible. (It is not technically practical to remove all of the sideband.) This technique is known as *vestigial sideband* transmission.

Color information, when present, is transmitted as sidebands of a pair of

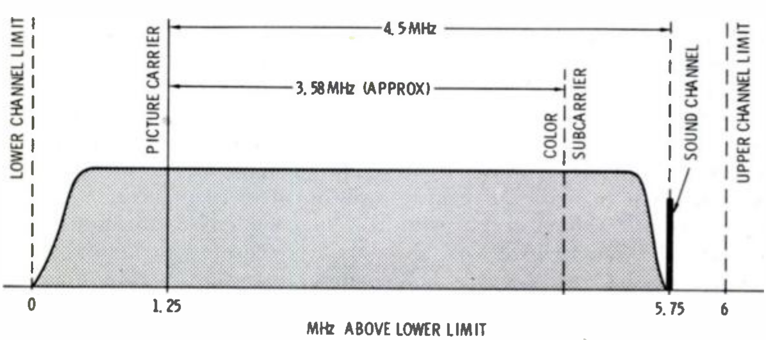


Fig. 7-6. Signal distribution in television channel.

3.579545-MHz subcarriers that are one quarter wave out of phase. The subcarriers themselves are suppressed. A detailed description of color transmission is beyond the scope of this book.

The carrier frequency for the sound channel is 4.5-MHz above the picture carrier. Frequency modulation is used for the sound transmission. A swing of 25 kHz each way from the carrier frequency is defined as 100 percent modulation (compared to 75 kHz for 100 percent modulation of an fm radio station). A guard band above the sound channel completes the 6-MHz interval.

The Video Signal—The video signal is produced by electronically *scanning* the image formed in the pickup tube (camera tube) by the camera lens. An electron beam sweeps across the picture from left to right and from top to bottom. The entire picture is scanned with 525 horizontal lines, and all 525 lines, which form a *frame*, are scanned 30 times per second. As the beam sweeps across the picture, it generates a signal that fluctuates in accordance with the brightness of the various areas of the picture.

In the receiver, these brightness fluctuations are reproduced by an electron beam that sweeps across the face of the picture tube. It is necessary that the two beams be directed at corresponding points in the picture at all times; the circuits that control the motion of the two beams must be *synchronized*. For this purpose, synchronizing pulses are generated at the TV station and transmitted along with the picture information. Together, the picture signal and the synchronizing pulses form the composite video signal which is used to modulate the video carrier.

It is standard to use negative modulation of the video carrier; that is, dark picture areas cause greater signal amplitude than bright areas cause. Maximum signal amplitude is caused by the synchronizing pulses, and *peak visual effective radiated power* from the station occurs during these pulses.

Assignment Table—As with fm, television station assignments are made in accordance with a table of assignments, which lists specific channels for use in specific communities or, under certain conditions, nearby communities. Also, the table specifies which channels are available for commercial use and which are reserved for noncommercial educational stations. Although assignments are made only in accordance with the table, the table can be amended, and is from time to time. The technical standards on which the table (including any amendments) is based are summarized in the following paragraphs.

Allocation Standards—Three zones are defined as shown approximately in Fig. 7-7. Zone I is the same region as Zone I for fm stations. Zone III includes Florida and parts of Texas, Louisiana, Mississippi, Alabama, and Georgia. Zone II consists of the remainder of the fifty states not in the other zones, and Puerto Rico and the Virgin Islands.

Television stations are not divided into classes as fm stations are, but different minimum separations for stations on the same channel are specified for the different zones: Zone I, 170 miles; Zone II, 190 miles; Zone III, 220 miles. Across zone boundaries, the distance for the zone requiring the smaller separation is used. The minimum separation between stations on adjacent channels is 60 miles for all zones; this requirement does not apply for channels 4 and 5 or 6 and 7, because there is a frequency separation between these channel pairs—see Table 7-4. No minimum spacing is established for stations on alternate channels (eg. 2 and 4, 7 and 9, 8 and 10, etc.).

All of the mileage requirements allow for maximum facilities for all stations. These maximums are shown in Table 7-5. As was the case for fm stations, maximum power may be used up to the height indicated. For greater heights, the maximum permitted power is less by an amount depending on the height. The minimum power for television stations is the amount required to cover the principal city, but not less than 100 watts in any horizontal

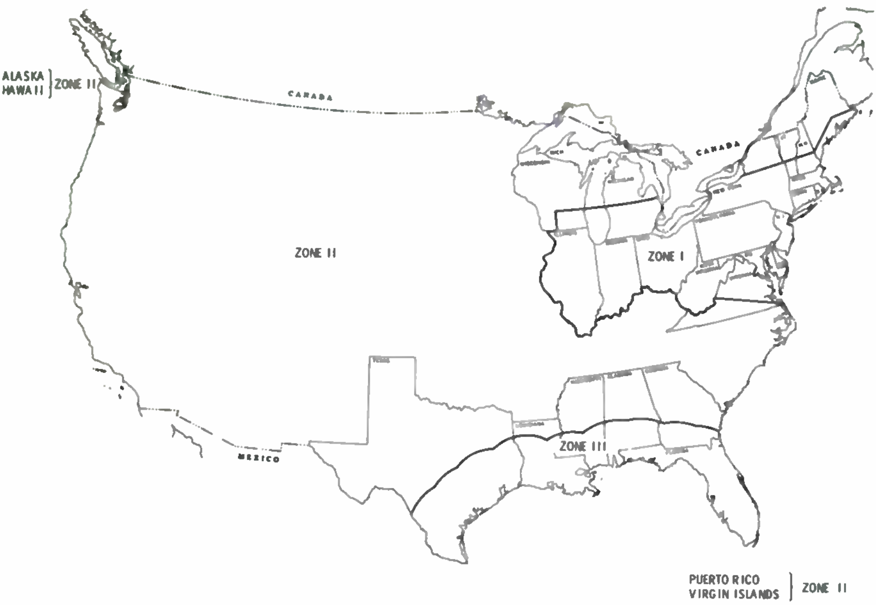


Fig. 7-7. Allocation zones for TV broadcast stations.

direction; no minimum antenna height is specified.

The heights referred to above are antenna height above average terrain, and the powers are peak visual effective radiated power. The sound-channel effective radiated power may be between 10 and 20 percent of the peak visual effective radiated power. Horizontal polarization is required.

Minimum Schedule—All television broadcast stations are licensed for unlimited-time operation, except in rare cases where stations share time on a channel. The required minimum schedule for a commercial station depends on how long the station has been on the air—see Table 7-6. There is no required minimum schedule for noncommercial educational stations.

Subscription Television—Rules have been adopted to govern over-the-air broadcasting of subscription television programs. These are programs that are "scrambled" before transmission so that they can be received, for a fee, only by persons who have the necessary decod-

Table 7-6. Minimum Schedule for Commercial TV Stations

Months on the Air	Min Days Per Week[1]	Min Hours Per Week
0-18	5	12
18-24	5	16
24-30	5	20
30-36	5	24
36 or more	7	28

[1]A minimum of 2 hours per day is required for the number of days per week indicated.

Table 7-5. Maximum Facilities for Television

Channel	Zone	Maximum Power (Watts)	Maximum Height (Feet)
2-6	I	100,000	1000
7-13	I	316,000	1000
2-6	II or III	100,000	2000
7-13	II or III	316,000	2000

ing device. Only one station in a given community may be authorized to broadcast subscription television, and then only if the community receives strong signals from at least four other commercial TV stations that do not broadcast subscription programs. No particular scrambling system is specified, but the system used in each case must be FCC approved. Besides the technical requirements, several restrictions are imposed on the kinds of programs that may be broadcast over subscription television. In addition to the subscription programs, the station must broadcast nonsubscription programs for the applicable minimum period shown in Table 7-6.

VHF BROADCASTING IN OTHER COUNTRIES

The ITU allocations for fm broadcasting are 87.5-100 MHz in Region 1 West, 66-73 MHz in Region 1 East, 88-108 MHz in Region 2, and 87-108 MHz in Region 3. Within these bands (and in some cases outside them), fm stations operate in many countries of the world. Carrier frequencies do not always coincide with those used in the United States and Canada. In addition to the familiar 88.1 MHz, 88.3 MHz, etc., such frequencies as 88.2 MHz, 88.25 MHz, 94.0 MHz, or 94.742 MHz

Table 7-7. VHF TV Channels (Australia)

Channel	Visual MHz	Aural MHz
0	46.25	51.75
1	57.25	62.75
2	64.25	69.75
3	86.25	91.75
4	95.25	100.75
5	102.25	107.75
5A	138.25	143.75
6	175.25	180.75
7	182.25	187.25
8	189.25	194.75
9	196.25	201.75
10	209.25	214.75
11	216.25	221.75

Table 7-8. VHF TV Channels (Europe)

Channel	Visual MHz	Aural MHz
Band I		
2	48.25	53.75
2A	49.75	55.25
3	55.25	60.75
4	62.25	67.75
Band II		
5	175.25	180.75
6	182.25	187.75
7	189.25	194.75
8	196.25	201.75
9	203.25	208.75
10	210.25	215.75
11	217.25	222.75
12	224.25	229.75

Table 7-9. VHF TV Channels (France)

Channel	Visual MHz	Aural MHz
Band I		
2	52.40	41.25
4	65.55	54.40
Band III		
5	164.00	175.15
6	173.40	162.25
7	177.15	188.30
8A	185.25	174.10
8	186.55	175.40
9	190.30	201.45
10	199.70	188.55
11	203.45	214.60
12	212.85	201.70

Table 7-10. VHF TV Channels (Ireland)

Channel	Visual MHz	Aural MHz
Band I		
A	45.75	51.75
B	53.75	59.75
C	61.75	67.75
Band III		
D	175.25	181.25
E	183.25	189.25
F	191.25	197.25
G	199.25	205.25
H	207.25	213.25
J	215.25	221.25

Table 7-11. VHF TV Channels (Italy)

Channel	Visual MHz	Aural MHz
Band I		
A	53.75	59.25
B	62.25	67.75
C	82.25	87.75
Band III		
D	175.25	180.75
E	183.75	189.25
F	192.25	197.75
G	201.25	206.75
H	210.25	215.75
H1	217.25	222.75

Table 7-12. VHF TV Channels (Japan)

Channel	Visual MHz	Aural MHz
1	91.25	95.75
2	97.25	101.75
3	103.25	107.75
4	171.25	175.75
5	177.25	181.75
6	183.25	187.75
7	189.25	193.75
8	193.25	197.75
9	199.25	203.75
10	205.25	209.75
11	211.25	215.75
12	217.25	221.75

Table 7-13. VHF TV Channels (Malaysia)

Channel	Visual MHz	Aural MHz
2	48.25	53.75
3	55.25	60.75
4	62.25	67.75
5	175.25	180.75
6	182.25	187.25
7	189.25	194.75
8	196.25	201.75
9	203.25	208.75
10	210.25	215.75

Table 7-14. VHF TV Channels (Morocco)

Channel	Visual MHz	Aural MHz
4	163.25	168.75
5	171.25	176.75
6	179.25	184.75
7	187.25	192.75
8	195.25	200.75
9	203.25	208.75
10	211.25	216.75

Table 7-15. VHF TV Channels (New Zealand)

Channel	Visual MHz	Aural MHz
1	45.25	50.75
2	55.25	60.75
3	62.25	67.75
4	175.25	180.75
5	182.25	187.75
6	189.25	194.75
7	196.25	201.75
8	203.25	208.75
9	210.25	215.75

Table 7-16. VHF TV Channels (United Kingdom)

Channel	Visual MHz	Aural MHz
Band I		
1	45.0	41.5
2	51.75	48.25
3	56.75	53.25
4	61.75	58.25
5	66.75	63.25
Band III		
6	179.75	176.25
7	184.75	181.25
8	189.75	186.25
9	194.75	191.25
10	199.75	196.25
11	204.75	201.25
12	209.75	206.25
13	214.75	211.25
14	219.75	216.25

Table 7-17. VHF TV Channels (Soviet Bloc and Communist China)

Channel	Visual MHz	Aural MHz
Band I		
1	49.75	56.25
	57.75*	64.25*
2	59.25	65.75
Out of Band		
3	77.25	83.75
4	85.25	91.75
5	93.25	99.75
Band III		
6	175.25	181.75
7	183.25	189.75
8	191.25	197.75
9	199.25	205.75
10	207.25	213.75
11	215.25	221.75
12	223.25	229.75

*Communist China only.

may be encountered, depending on the country involved. Effective radiated powers of less than 100 watts are common, although some stations operate in the 100,000-watt or higher range.

Vhf television frequency bands are 41-68 and 174-216 MHz in Region 1 West; 41-66 and 174-216 MHz in Region 1 East; 54-72, 76-88, and 174-216 MHz in Region 2; and 44-50, 54-68, and 170-216 MHz in Region 3. In the European area, the fm and TV frequencies between 41 and 68 MHz are referred to as Band I, between 87.5 and 100 MHz as Band II, and between 162 and 230 MHz as Band III.

Tables 7-7 through 7-17 list the carrier frequencies for vhf TV channels used in other parts of the world. (U.S. channels are listed in Table 7-4.) Table 7-18 gives the technical features of the several TV systems used in the world; the U.S. system is designated as system M in this tabulation. Table 7-19 indicates the television channel frequencies and technical standards for a number of countries.

BROADCAST-RELATED SERVICES

In addition to regular fm and TV broadcasting stations, other activities closely related to these stations are carried on in the vhf region. Some of these activities involve transmission directly to the public; others involve program relay or related operations.

Remote-Pickup Stations

The FCC allocates the following frequencies for assignment to remote-pickup broadcasting stations. (Those above 161 MHz are not available in

Table 7-18. Television Systems

Identifying Letter	Lines Per Frame	Frames Per Sec	Channel Width (MHz)	Visual-Aural Carrier Separation (MHz)	Visual Modulation[1]	Aural Modulation
A	405	25	5	3.5	Pos	AM
B	625	25	7	5.5	Neg	FM
C	625	25	7	5.5	Pos	AM
D	625	25	8	6.5	Neg	FM
E	819	25	14	11.15	Pos	AM
F	819	25	7	5.5	Pos	AM
G	625	25	8	5.5	Neg	FM
H	625	25	8	5.5	Neg	FM
I	625	25	8	6.0	Neg	FM
K	625	25	8	6.5	Neg	FM
L	625	25	8	6.5	Pos	FM
M	525	30	6	4.5	Neg	FM
N	625	25	6	4.5	Neg	FM

[1] A-m with polarity shown.

Table 7-19. Television Standards

Country	System[1]	Channels[2]	Country	System[1]	Channels[2]
Argentina	N	7-4	Italy	B	7-11
Australia	B	7-7	Japan	M	7-12
Austria	B	7-8	Kenya	B	7-8
Belgium	C	7-8	Luxembourg	F	7-8
Brazil	M	7-4	Malaysia	B	7-13
Canada	M	7-4	Mexico	M	7-4
Chile	N	7-4	Monaco	E	7-9
China (Communist)	D	7-17	Morocco	B	7-14
China (Taiwan)	M	7-4	Netherlands	B	7-8
Colombia	M	7-4	New Zealand	B	7-15
Costa Rica	M	7-4	Nicaragua	M	7-4
Cuba	M	7-4	Norway	B	7-8
Denmark	B	7-8	Panama	M	7-4
Dominican Republic	M	7-4	Paraguay	M	7-4
Ecuador	M	7-4	Peru	M	7-4
El Salvador	M	7-4	Philippines	M	7-4
France	E	7-9	Portugal	B	7-8
Germany (East and West)	B	7-8	Rhodesia	B	7-8
Guatemala	M	7-4	Saudi Arabia	M	7-4
Haiti	M	7-4	Spain	B	7-8
Honduras	M	7-4	Sweden	B	7-8
India	B	7-8	Switzerland	B	7-8
Indonesia	B	7-8	United Arab Republic	B	7-8
Iran	M	7-4	United Kingdom	A	7-16
Iraq	B	7-8	Uruguay	N	7-4
Ireland	A, I	7-16, 7-10	USSR	D	7-17
Israel	B	7-8	Venezuela	N	7-4
			Yugoslavia	B	7-8

[1]See Table 7-18 for meaning of symbols in this column.
[2]Numbers in this column refer to tables in which channels are listed; e.g., channels used in Argentina are listed in Table 7-4.

Puerto Rico and the Virgin Islands.) All frequencies shown are in megahertz.

152.87	153.17	161.64
152.93	153.23	161.67
152.99	153.29	161.70
153.05	153.35	161.73
153.11		161.76

In Puerto Rico and the Virgin Islands, the following frequencies (in megahertz) are available, but are shared with the Land Transportation Radio Service:

160.89	161.07	161.25
160.95	161.13	161.31
161.01	161.19	151.37

In some parts of the continental United States, the frequencies 166.25 MHz and 170.15 MHz are available for assignment to remote-pickup stations.

Either amplitude or frequency modulation may be used by remote-pickup stations operating on the frequencies in the foregoing lists. When fm is used, the maximum permitted bandwidth is 60 kHz (except 30 kHz for 161.64-161.76 kHz).

Television Translator Stations

There are many areas, particularly in sparsely populated sections of the country, where reception of signals from television broadcasting stations is difficult or impossible. In such cases, television translators may be installed to give service to a community. The translator station is built in a location (such as on a mountain top) where reception of signals from the desired TV broadcasting station is possible. The translator equipment then changes the frequency of the signals and rebroadcasts them, on another channel, to the local community. The output of the translator may be on any vhf channel (except 5 or 6 in Alaska and Hawaii) so long as it causes no interference to direct reception of broadcasting stations on the same or adjacent channels.

The maximum peak visual power of the translator is 1 watt for locations east of the Mississippi River, and 10 watts for locations west of the Mississippi River. These limits are for power output from the final amplifier in the translator; there is no limit on the effective radiated power that may be obtained through the use of a high-gain antenna. In the special case of a translator operating on a channel assignment listed in the TV allocation table, the translator must operate with a peak power output of 100 watts (with certain exceptions for translators authorized before this rule was put in effect).

Translators are required to identify themselves in International Morse Code at least once each 30 minutes during operation, unless the station whose programs are being rebroadcast displays the translator identification at certain prescribed times. The code signal (generated by an automatic device) may be transmitted by frequency-shift keying (carrier shift of 5 to 25 kHz) or by amplitude tone modulation of the aural fm carrier (30 percent minimum amplitude modulation).

AMATEUR RADIO

In the United States, three bands of frequencies in the vhf range are allocated for use by amateur operators. The overall bands are 50-54 MHz, 144-148 MHz, and 220-225 MHz. The authorized emissions and other limitations for these bands are shown in Table 7-20.

The band 50-50.1 MHz is reserved for use by holders of amateur extra- and advanced-class licenses only. Only the frequencies between 50.1 and 54 MHz, between 145 and 147 MHz, and above 220 MHz are available to holders of the technician-class license. In addition to the hf bands noted in Chapter 6, novice-class amateurs are authorized to operate in the 145-147 MHz band with telegraphy only. Novices may use a transmitter power input no greater than 75 watts, and their transmitters must have crystal frequency control.

Between 50.1 and 52.5 MHz, the bandwidth of an F3 emission must not exceed that of an A3 emission for the same audio characteristics. On the frequencies listed in Table 7-20, single-sideband or double-sideband A5 emission may be used, and the bandwidth must not be greater than that of an A3 single-sideband or double-sideband signal, respectively. The bandwidth of an F5 emission must not exceed that of an A3 single-sideband emission. Simultaneous use of A3 and A5 emission on the same carrier frequency is permitted if the total bandwidth does not exceed that of a double-sideband A3 emission. Except as noted above for novice stations, the maximum power input in these bands is 1000 watts.

World-wide vhf amateur-band allocations include 50-54 MHz in Regions 2 and 3, 144-146 MHz in Region 1, 144-148 MHz in Regions 2 and 3, and 220-225 MHz in Region 2. Additional information about amateur radio may be found in Chapters 5, 6, and 8.

CITIZENS RADIO SERVICE

In the Citizens Radio Service, the following frequencies (in megahertz) are available only for Class-C stations used for radio remote control of model aircraft:

72.08	72.96
72.24	75.64
72.40	

Operation on these frequencies must not cause interference to industrial users of the same or adjacent frequencies, or to reception of television channels 4 and 5. Citizens-band operation is given no protection from interference caused by other services using these fre-

Table 7-20. VHF Amateur Allocations

Frequencies (MHz)	Emissions[1]
50.0-54.0	A1
50.1-54.0	A2, A3, A4, A5, F1, F2, F3, F5
51.0-54.0	A0
144-148	A1
144-147.9	A0, A2, A3, A4, A5, F0, F1, F2, F3, F5
220-225[2,3]	A0, A1, A2, A3, A4, A5, F0, F1, F2, F3, F4, F5

[1]For explanation of emission symbols, refer to Table 6-6, Chapter 6.
[2]Amateur stations must not interfere with Government radiolocation service.
[3]Not available during certain hours in parts of Texas and New Mexico, except for authorized civil defense use.

quencies. Maximum power input is 1 watt (maximum output 0.75 watt).

For additional information about the Citizens Radio Service, see Chapters 6 and 8.

MARITIME STATIONS

Table 7-1 shows bands of frequencies in the general range 156-162 MHz allocated to the Maritime Mobile Service. Frequencies in these bands are further allocated for use by ship and/or coast stations.

Coast and Ship Stations

Table 7-21 shows frequencies available for assignment to public coast stations, that is, coast stations open to public correspondence. The frequencies listed in Table 7-22 are available for assignment to limited coast stations for communication with ship stations. A limited coast station is defined as "a coast station, not open to public correspondence, which serves the operational and business needs of ships."

Table 7-23 lists frequencies (indicated by an X) available for assignment to ship stations using radiotelephony. For all frequencies in this table, the maximum bandwidth is 20 kHz.

Other Stations

The frequency 156.8 MHz is the international safety and calling frequency for the Maritime Mobile Radiotelephone Service in the band 156-174 MHz. On this frequency, the preferred type of emission is F3. In addition, the frequency 121.5 MHz (type A2 emission only) is available for radio-beacon use on certain survival craft.

Marine receiver-test transmitters are used to provide a signal for use in testing the receiving equipment at an associated public coast station. The frequencies assigned to these test transmitters are those which public ship stations may use to transmit to the coast station (see Table 7-23).

Under certain conditions, the frequencies 156.35, 156.45, and 156.55 MHz may be used for communication between a limited coast station and shipyard mobile stations. Certain operational fixed stations associated with the

Table 7-21. Frequencies for Public Coast Stations

Frequency (MHz)	Conditions of Use
156.750	1, 3
156.800	1, 2
161.800	1, 4
161.825	1, 4
161.850	1, 4
161.875	1, 4
161.900	1
161.925	1
161.950	1
161.975	1
162.000	1

Notes:
1. Frequency deviation ±5 kHz (frequency modulation).
2. National distress, safety, and calling frequency.
3. For use in transmitting environmental information (weather, sea conditions, time signals, etc.) to ships.
4. Not available in Puerto Rico and Virgin Islands.

Maritime Mobile Service may be assigned frequencies in the 72-76 MHz range. These stations include marine control stations (used to control the operation or emission of a coast station), marine repeater stations, and marine relay stations.

Table 7-22 Frequencies for Limited Coast Stations

Frequency (MHz)	Conditions
Distress, Safety, Calling	
156.800	1
Port Operations	
156.275	1, 2
156.325	1, 2
156.600	1
156.675	1
156.700	1
156.725	1
161.600	1, 3, 4
Navigational	
156.650	1, 5
Environmental	
156.750	1, 6
State Control	
156.850	1
Commercial	
156.350	1
156.450	1
156.500	1
156.550	1
156.900	1
156.950	1
156.975	1
157.025	1
Noncommercial	
156.425	1, 7
156.450	1
156.475	1, 8
156.575	1, 8
156.925	1, 8

Notes:
1. Maximum deviation ±5 kHz (frequency modulation).
2. Not available prior to January 1, 1971.
3. Not available in Puerto Rico and Virgin Islands.
4. Ship frequency is 157.00 MHz.
5. In Great Lakes area only, available for commercial communications.
6. For broadcast of environmental information (weather, sea conditions, time signals, etc.) to ships. No corresponding ship frequency allocated.
7. Primarily available to fulfill needs of smaller boats.
8. Available to ship stations and associated coast stations at marinas, yacht clubs, etc.

Technical Requirements

Frequency modulation (F3) is specified for stations on maritime frequencies in the 156-174 MHz range. Operational fixed stations in the 72-76 MHz band may use A1, A2, A3, F1, F2, or F3 emissions. Bandwidth limits are:

Emission	*Bandwidth (kHz)*
A1	0.3
A2	2.8
A3	8.0
F1	0.5
F3	20*

*40 kHz in certain cases.

Maximum transmitter output power for coast stations on the frequencies covered in this section is 50 watts; the maximum for marine utility stations is 10 watts. (A marine utility coast station is a portable limited coast station.) The power limit for marine receiver-test stations with F3 emission is normally 50 watts.

For ship stations operating in the 156-162 MHz band with F3 emission, the maximum transmitter carrier power output is 25 watts. (The maximum carrier power for marine-utility ship stations is 10 watts.) There must be provision for readily reducing the output to 1 watt or less.

In Alaska, the maximum power limits for the frequencies 156.25-161.25 MHz are: ship, 100 watts; limited coast, 100 watts; public coast, 250 watts. For public coast stations in the 161.775-162.025 MHz band, the limit is 1000 watts.

FREQUENCIES FOR AVIATION

Above the fm broadcast band is a band of frequencies allocated for aviation use. Frequencies assignable to ground and airborne stations are listed in the following paragraphs.

Airborne Stations

118.00-135.95 MHz: Within this range, over 200 frequencies are available for air-traffic-control operations.

Table 7-23. Ship-Station Frequencies

Frequency (MHz)	Inter-ship	Ship to Coast	Port Operations	Commercial	Noncommercial	Public Correspondence	Special Uses or Restrictions
156.275	X	X	X	—	—	—	1
156.300	X	—	—	—	—	—	2
156.325	X	X	X	—	—	—	1
156.350	X	X	—	X	—	—	
156.375	X	—	—	X	—	—	
156.400	X	—	—	X	—	—	
156.425	X	X	—	—	X	—	3
156.450	X	X	—	X	X	—	
156.475	—	X	—	—	X	—	4
156.500	X	X	—	X	—	—	
156.525	X	—	—	—	X	—	5
156.550	X	X	—	X	—	—	
156.575	—	X	—	—	X	—	4
156.600	X	X	X	—	—	—	
156.625	X	—	—	—	X	—	5
156.650	X	X	—	—	—	—	6, 7
156.675	X	X	X	—	—	—	
156.700	X	X	X	—	—	—	8
156.725	X	X	X	—	—	—	
156.750	—	—	—	—	—	—	9
156.800	X	X	—	—	—	—	10
156.850	—	X	—	—	—	—	11, 12
156.875	X	—	—	X	—	—	
156.900	X	X	—	X	—	—	
156.925	—	X	—	—	X	—	4
156.950	X	X	—	X	—	—	
156.975	X	X	—	X	—	—	
157.000	X	X	X	—	—	—	13
157.025	X	X	—	X	—	—	
157.200	—	X	—	—	—	X	14
157.225	—	X	—	—	—	X	14
157.250	—	X	—	—	—	X	14
157.275	—	X	—	—	—	X	14
157.300	—	X	—	—	—	X	14
157.325	—	X	—	—	—	X	14
157.350	—	X	—	—	—	X	14
157.375	—	X	—	—	—	X	14
157.400	—	X	—	—	—	X	14
157.425	X	—	—	X	—	—	15

Notes:
1. Not available until after January 1, 1971.
2. Intership Safety.
3. Available to fulfill needs of smaller boats; may not be used in lieu of frequencies allotted for distress, safety, and calling; intership safety; navigational; port operations; or public correspondence.
4. Available to ship stations and associated marinas, yacht clubs, etc.
5. Available for noncommercial intership communications during localized fleet operations, maneuvers during a cruise, and rendezvous.
6. Navigational.
7. Commercial communication (Great Lakes area only).
8. Not available in Puerto Rico and Virgin Islands.
9. Available only to coast stations for broadcasting environmental information (weather, sea conditions, time signals, etc.) to ships.
10. Distress, safety, and calling.
11. State Control.
12. Available for assignment to stations aboard vessels for State Control communications.
13. Ship frequency is 157.00 MHz; coast frequency is 161.600 MHz.
14. These frequencies are paired with Public Coast Station frequencies 161.800 through 162.00 MHz (Table 7-21), respectively.
15. Available for assignment on vessels engaged in commercial fishing, in addition to commercial frequencies. Also available for use between these vessels and associated aircraft while engaged in commercial fishing activities.

These frequencies are spaced 50 kHz apart between 118.00 and 121.40 MHz, 123.60 and 128.80 MHz (except 126.10-126.30 and 126.70 MHz), and 132.05 and 135.95 MHz. Also, the frequencies 121.65, 121.70, 121.75, 121.80 and 121.85 MHz, primarily airport utility frequencies, are available on a secondary basis for air-traffic-control use. The frequency 133.20 MHz is available to aircraft for obtaining weather information from U.S. Air Force radar facilities.

121.5 MHz: This a universal channel for use by aircraft in distress or an emergency situation.

122.9 and 123.1 MHz: These frequencies are for air-air and air-ground search-and-rescue communications.

243 MHz: Emergency and distress frequency for survival-craft stations.

The frequencies listed above are available to private aircraft stations and air-carrier aircraft stations. Additional frequencies are available for use in these classes of aircraft as follows:

Air-carrier aircraft: 122.1 MHz, in Alaska for air traffic control under certain conditions; 122.0 MHz, for communication with Flight Service stations for obtaining weather information; 122.8 MHz, for communications related to safety of flight near landing areas not served by airdrome control or FAA flight service stations. Under certain conditions, frequencies allocated to aeronautical enroute stations may be used also.

Private aircraft: 122.00-122.75 MHz (in 50 kHz increments), for air traffic control operations; 122.80, 122.85, 122.95, and 123.05 MHz, for certain communications with aeronautical advisory stations or between aircraft in flight; 122.9 MHz (A3 emission), communication with aeronautical multicom stations or Government stations, and between aircraft stations for communications related to safety, agricultural, ranching, and conservation activities, forest-fire fighting, aerial application, aerial advertising, or parachute jumping; 123.0 MHz (A3 emission), communications with aeronautical advisory stations. Under certain conditions, the frequencies for aeronautical enroute stations may be used in private aircraft as well.

For the handling of public correspondence, the frequencies available to ship stations also are available to aeronautical public service aircraft stations, with certain restrictions.

Stations on the Ground

Stations on the ground in the aviation services include aeronautical advisory, aeronautical multicom, aeronautical enroute, aeronautical metropolitan, airdrome control, aeronautical utility, search and rescue, flight-test, and instructional stations. Frequencies for these stations are summarized in the following paragraphs.

Aeronautical Advisory Stations—An aeronautical advisory station is defined as "an aeronautical station used for advisory and civil defense communications primarily with private aircraft stations." The FCC Rules and Regulations provide that aeronautical advisory stations at landing areas open to the public must provide service on a required frequency as follows: At landing areas (not heliports) when there is no control tower or FAA flight service station, 122.8 MHz; at such areas when there is a control tower or FAA station, 123.0 MHz; at heliports, 123.05 MHz. Stations required to operate on 123.05 MHz also may be assigned 122.8 MHz for communication with fixed-wing aircraft; those required to operate on 122.8 or 123.0 MHz also may be assigned 123.05 for communication with helicopters. Stations at nonpublic landing areas may be assigned the foregoing frequencies, or, alternatively, 122.85 or 122.95 MHz.

Aeronautical Multicom Stations—An aeronautical multicom station is a station, not open to public correspondence, "used to provide communications essential to conduct of activities being performed by or directed from private aircraft." These stations may be assigned the frequency 122.9 MHz (A3 emission), or, in certain circumstances, 121.5 MHz. Normal uses for these stations, as stated in the FCC Rules and Regulations, are ". . . of a temporary, seasonal, or emergency nature which depend upon an aircraft in flight for the successful or safe conduct of the activity." Permitted communications include, ". . . directing of ground activities from the air, the directing of aerial activities from the ground, and air-to-air communications . . ." not otherwise provided for in the FCC Rules and Regulations. In addition, an aeronautical multicom station may be used as a temporary substitute for an aeronautical advisory station under certain specified conditions.

Aeronautical Enroute Stations—Aeronautical enroute stations communicate with aircraft stations. The frequencies available for assignment to these stations are as follows: In the continental United States (excluding Alaska), there are 64 frequencies between 128.85 and 132.00 MHz; these 64 frequencies are spaced 50 kHz apart. Stations serving international operations also may use these frequencies.

For service to scheduled air carriers, these frequencies (in megahertz) are available in Alaska:

129.1	130.1
129.3	130.3
129.5	130.5
129.7	130.7
129.9	130.9

In Hawaii, these frequencies (in megahertz) are available for service on domestic routes:

129.1	129.9
129.3	130.1
129.5	130.3
129.7	

Assignable frequencies (in megahertz) for service on domestic routes in U.S. possession in the West Indies are:

129.1	129.5
129.3	129.7

In some cases, other unlisted frequencies may be assigned to aeronautical enroute stations if they conform to international allocations.

Aeronautical Metropolitan Stations—The frequencies available for aeronautical enroute stations are available also for aeronautical metropolitan stations. An aeronautical metropolitan station is a station "used for communication with aircraft, including helicopters, operating between a main air terminal of a metropolitan area and subordinate landing areas."

Airdrome Control Stations—An airdrome control station provides communication between an airport control tower and aircraft. The air-traffic-control frequencies listed at the beginning of the airborne-station section (with the addition of 126.70 MHz) are available for assignment to these stations. Normally, airdrome control stations are required to provide service on the universal emergency and distress frequency, 121.5 MHz.

Aeronautical Utility Stations—Aeronautical utility stations are used in ground traffic control at an airport. They may communicate with control towers, ground vehicles, and aircraft on the ground. Available frequencies (in megahertz) are:

121.60	121.80
121.65	121.85
121.70	121.90
121.75	

Search and Rescue—Two frequencies are available for assignment to aeronautical search and rescue stations. The frequency 123.1 MHz is for actual missions, and the frequency 122.9 MHz is for training and practice missions.

Flight Test and Instructional Stations

Ground and aircraft flight-test stations may be assigned to these frequencies (in megahertz):

121.95	123.4
123.2	123.5
123.3	

In addition, these frequencies (in megahertz) are assignable to aircraft manufacturers for flight-test stations:

123.15	123.45
123.25	123.55
123.35	

On the condition that interference is not caused to flight-test communications, the frequencies 123.3 and 123.5 MHz may be assigned to ground and aircraft instructional stations.

Fixed Stations

Operational fixed stations in the aviation services provide link or control circuits, or are used for other aeronautical operations. These stations share the band from 72 to 76 MHz with operational fixed stations in other services. Sixty-eight frequencies are available from 72.02 to 72.98 and 75.42 to 75.98 MHz. Generally, the spacing between adjacent frequencies is 20 kHz; in some cases it is 40 kHz. No harmful interference may be caused to television reception on channels 4 and 5. (Some stations previously authorized to operate in the band 73-74.6 MHz still continue to operate in that band.)

Radionavigation

The following frequencies may be assigned to radionavigation land stations. Individual assignments are coordinated with Government agencies, particularly the Federal Aviation Agency (FAA).

For localizer stations with simultaneous radiotelephone channel, frequencies at 200-kHz intervals from 108.1 to 111.9 MHz are available. (A localizer provides signals for lateral guidance relative to the center line of a runway.)

For aeronautical marker beacons, the frequency 75 MHz is available. (The beacons radiate vertically to provide positional information.)

For radio range stations, the frequencies are 108.2-112.0 MHz (in 200-kHz increments) and the band 112.1-117.9 MHz. (These stations provide signals that establish radial lines for use in navigation.)

The frequencies for radionavigation land stations may be assigned to land stations used in connection with tests of airborne receiving equipment The frequency 108.0 MHz may be assigned for testing of vhf omnirange equipment, and 108.1 MHz may be assigned for testing of vhf localizer equipment. Normally the power used on these two frequencies is 1 watt or less.

Civil Air Patrol

Frequencies for assignment to Civil Air Patrol stations are 143.90 MHz (in the 48 adjacent states) with type A1, A2, and A3 emission and 10 watts maximum power, and 148.15 MHz with type A2 and A3 emission and 50 watts maximum power.

Technical Standards

Authorized bandwidths for stations in the aviation services operating on frequencies listed in this section are 50 kHz for A3 emission and 20 or 40 kHz for F3 emission. The 50-kHz figure for a-m is a temporary standard. Operational fixed stations in the 73.0-74.6 MHz band are subject to the 40-kHz limit for fm; stations in the 72.0-73.0 and 75.4-76.0 MHz bands are subject to the 20-kHz limit. Other bandwidths or emissions may be authorized at times.

In general, stations in these services may use only the minimum power necessary for the required operation. Maximum limits on power output for some classes of stations are:

Aeronautical advisory stations:
10 watts

Aeronautical multicom stations:
10 watts

Aviation instructional stations:
50 watts (ground)
10 watts (airborne)

Airdrome control stations on available frequencies between 118.0 and 135.95 MHz:
50 watts

For operational fixed stations in the 72-76 MHz band, vertical polarization is required.

INDUSTRIAL RADIO SERVICES

A rather complex system of frequency allocations exists for the ten

Industrial Radio Services. (These services are listed and defined in Chapter 6.) Vhf assignments are made in the general frequency ranges of 30-50, 72-76, and 150-174 MHz. Some of the frequencies in these bands are assigned to one service; other frequencies are shared by more than one service. A number of special restrictions as to type of station, use of station, geographic location, etc., apply to various frequencies used by these services.

The frequencies available for assignment to the industrial services are shown, along with a few of the special uses and restrictions, in Table 7-24. Most of the frequency allocations are given in terms of carrier frequencies. In Table 7-24, the first and last carrier frequencies in each group are listed in the first column. In the second column, the usual spacing between frequencies in the group is listed. The service to which the frequency or group of frequencies is allocated is listed in the third column. The fourth column shows the type of station in this service to which the frequencies may be assigned, and the final column indicates some of the restrictions or special uses applicable to the correspoding frequencies. In a few cases, a band of frequencies rather than a carrier frequency is specified; in these cases, the band limits are shown in hyphenated form (e.g., 173.2000-173.2075 MHz). The information in the third, fourth, and fifth columns of the table is typical of the use of the corresponding frequencies; it does not necessarily apply to every fre-

Table 7-24. Industrial-Service Frequencies

Channel Frequencies (MHz)	Channel Interval (MHz)	Service	Type of Station	Notes
30.58 30.72	0.02	Special, Petroleum, Forest Products	Base, Mobile	
30.76 31.04	0.04	Business	Base, Mobile	
31.16 31.96	0.04	Business, Special	Base, Mobile	
33.12 33.40	0.02	Special, Business, Petroleum	Base, Mobile	
35.02 35.18	0.02	Business, Telephone Maintenance	Base, Mobile	
35.70 35.98	0.02	Business, Special	Base, Mobile	
37.44 37.88	0.02	Forest Products, Power	Base, Mobile, Operational Fixed	
40.68	—	Power, Petroleum, Forest Products, Special, Business	Operational Fixed	1, 2
42.96 43.18	0.02	Business, Special, Telephone Maintenance	Base, Mobile	
47.44 47.68	0.04	Special	Base, Mobile	
47.70 49.58	0.02	Power, Forest Products, Petroleum, Special	Base, Mobile	

Table 7-24. Industrial-Service Frequencies (Cont'd.)

Channel Frequencies (MHz)	Channel Interval (MHz)	Service	Type of Station	Notes
72.02 72.98	0.02	Power, Petroleum, Forest Products, Motion Picture, Relay Press, Special, Business, Manufacturers	Operational Fixed, Mobile	
75.42 75.98	0.02	Power, Petroleum, Forest Products, Motion Picture, Relay Press, Special, Business, Manufacturers	Operational Fixed, Mobile	
150.815 151.985	0.03	Business, Special, Telephone Maintenance	Base, Mobile	3
152.300 152.480	0.06	Business, Forest Products, Special	Base, Mobile	
152.87 153.71	0.03	Motion Picture, Special, Manufacturer, Petroleum, Forest Products, Power	Base, Mobile	4
154.46- 154.4675	—	Power	Fixed, Mobile	
154.4675- 154.4750	—	Petroleum, Special	Fixed, Mobile	
154.49	—	Special	Base, Mobile	
154.54 154.60	0.03	Business, Forest Products	Base, Mobile	
154.74	—	Forest Products	Base, Mobile	
157.56 157.74	0.06	Business, Special	Base, Mobile	
158.13 158.46	0.03	Power, Petroleum, Forest Products, Manufacturer, Telephone Maintenance, Special, Business	Base, Mobile	5
169.425 169.525	0.025	Power, Petroleum, Forest Products, Special, Business	Operational Fixed	1
170.225 170.325	0.025	Power, Petroleum, Forest Products, Special, Business	Operational Fixed	1
171.025 171.125	0.025	Power, Petroleum, Forest Products, Special, Business	Operational Fixed	1

Table 7-24. Industrial-Service Frequencies (Cont'd.)

Channel Frequencies (MHz)	Channel Interval (MHz)	Service	Type of Station	Notes
171.825 171.925	0.025	Power, Petroleum, Forest Products, Special, Business	Operational Fixed	1
173.2000- 173.2075 173.2075- 173.2125	—	Power, Petroleum, Forest Products, Special, Business	Fixed, Mobile	
173.225 173.375	0.025	Motion Picture, Power, Petroleum, Forest Products, Relay Press	Base, Mobile	5
173.3875- 173.3925 173.3925- 173.4000	—	Power, Petroleum, Forest Products, Special, Business	Fixed, Mobile	
230	—	Radiolocation	Land or Mobile	
250	—	Radiolocation	Land or Mobile	

Notes:
1. For transmitting hydrological or meteorological data only.
2. Available only in Pennsylvania and West Virginia.
3. Some of these frequencies available only in Puerto Rico and Virgin Islands.
4. In the Power Radio Service, some frequencies not available in Arkansas, Louisiana, Oklahoma, and Texas; in the Petroleum and Forest Products Radio Services, some frequencies available only in these states.
5. In the Power Radio Service, some frequencies not available in Arkansas, Louisiana, Oklahoma, Oregon, Texas, and Washington; in the Petroleum and Forest Products Radio Services, some frequencies available only in these states.

quency in a group, nor does it necessarily include all activities conducted on those frequencies.

In addition to the frequency allocations in Table 7-24, the following frequency bands (in megahertz) may be assigned to stations in the industrial services for narrow-band emissions for developmental purposes:

30.56-30.57
35.00-35.01
35.19-35.20
35.68-35.69
35.99-36.00
37.00-37.01

Some previously authorized stations may operate in the 73.0-74.6 MHz band. However, no new assignments are made to these frequencies.

Stations in these services normally use type A3 or F3 emission for radiotelephony. For purposes other than radiotelephony, A1, A2, F1, or F2 emissions are used. In general, the authorized bandwidths for vhf transmissions are 8 kHz for type A3 emission and 20 kHz for type F3 emission. Licensees are required to use the minimum power necessary to carry out the desired communication. The maximum power input authorized in any case is 500 watts below 100 MHz or 600 watts above 100 MHz. Lower limits are established for certain specific frequencies; limits of less than 1 watt are stipulated in some instances.

LAND TRANSPORTATION SERVICES

The four Land Transportation Services are the Motor Carrier Radio Service, the Railroad Radio Service, the Taxicab Radio Service, and the Automobile Emergency Service (also see

Chapter 6). The vhf allocations for these four radio services are summarized in Table 7-25.

In addition to the frequencies in the table, the following frequencies are available, for developmental use only, to base and mobile stations in any of the Land Transportation Services: 33.00-33.01 MHz, 157.450-157.4625 MHz, and 159.480-159.4875 MHz. Some previously authorized stations may still operate in the 73.0-74.6 MHz band and on 169.575, 170.375, 171.175, and 171.-975 MHz; new authorizations for these frequencies are not made.

In these services, type A3 or F3 emission is used for radiotelephony. For type A3 emission, the maximum bandwidth permitted is 8 kHz. For type F3 emission, the maximum bandwidth normally is 20 kHz. Licensees are required to use only sufficient power to carry on the required communications. The maximum power input authorized in any case is 500 watts below 100 MHz, and 120 watts above 100 MHz.

SERVICES FOR PUBLIC CORRESPONDENCE

The Domestic Public Services include the Domestic Public Land Mobile Radio Service, the Rural Radio Service, and the Point-to-Point Microwave Radio Service. Stations in these services are open to public correspondence; that is, they are available (for hire) to carry communications for other organizations, individuals, etc.

Domestic Public Land Mobile Radio Service

By FCC definition, the Domestic Public Land Mobile Radio Service is "a public communication service for hire between land mobile stations wherever located and their associated base stations . . . within the United States or its possessions, or between land mobile stations in the United States and base stations in Canada."

Ten pairs of frequencies in the vicinity of 35 and 43 MHz are organized as shown in Table 7-27. Each of these frequency pairs is assigned to one of ten zones into which the United States is divided. These frequencies are available for assignment to "stations of communication common carriers which are also in the business of affording public landline message telephone service, for general and dispatch communications." For the same purpose, the frequencies in Table 7-28 are assigned without reference to the zone plan; as the table shows, certain frequencies are assigned to common carriers that also provide landline service, and other frequencies are assigned to those that do not.

Some of the terms used in connection with Tables 7-27 and 7-28 are defined as follows by the FCC:

Dispatch communication: "Two-way voice communication, normally of not more than one minute's duration, between common-carrier base and land mobile stations, or between a common-carrier land mobile station and a landline telephone station not connected to a public message telephone system."

General communication: "Two-way voice communication, through a base station, between a common-carrier land mobile station and a landline telephone station connected to a public message landline telephone system, or between two common-carrier land mobile stations via a base station."

Auxiliary test station: "A fixed station used for test transmissions only . . . for the purpose of determining the performance of fixed receiving equipment which is remotely located from the base station [or control point]. . . ."

Communication common carrier: "Any person [or organization] engaged in rendering communication service for hire to the public."

The following frequencies are assigned to communication common carriers for one-way signaling: 35.22, 35.58, 43.22, and 43.58 MHz. Also, the frequencies 152.84 and 158.10 MHz (for common carriers also providing landline service) and 152.24 and 158.70 MHz (for common carriers not providing landline service) are used for this purpose.

Table 7-25. Frequencies for Land Transportation Services

Channel Frequencies (MHz)	Channel Spacing (MHz)[1]	Service	Type of Station	Notes
30.66 31.14	0.02, 0.04, 0.08	Motor Carrier	Base, Mobile	2, 3
43.70 43.84	0.02	Motor Carrier	Base, Mobile	4
43.86 44.44	0.02	Motor Carrier	Base, Mobile	5, 6
44.46 44.60	0.02	Motor Carrier	Base, Mobile	3
72.02 72.98	0.02, 0.04	Motor Carrier, Railroad	Operational Fixed	2
75.42 75.98	0.02, 0.04	Motor Carrier, Railroad	Operational Fixed	2
150.815 150.875	0.03	Automobile Emergency	Base, Mobile	7, 8
150.905 150.965	0.03	Automobile Emergency	Base, Mobile	7, 9
152.27 157.45	0.03	Taxicab	Base, Mobile	10
157.470 157.500	0.15	Automobile Emergency	Base, Mobile	8
157.53 157.71	0.03	Taxicab	Mobile	10
159.495 160.200	0.15	Motor Carrier	Base, Mobile	11
160.215 161.565	0.15	Railroad	Base, Mobile	12, 13
169.425 169.525	0.25	Railroad	Operational Fixed	14
170.225 170.325	0.25	Railroad	Operational Fixed	14
171.025 171.125	0.25	Railroad	Operational Fixed	14
171.825 171.925	0.25	Railroad	Operational Fixed	14

Notes:
1. Channel spacing refers to separation between channels assigned to services in this table.
2. Frequencies are shared with other services.
3. Assignable to carriers of passengers within a single urban area.
4. Assignable to carriers of passengers between urban areas.
5. Assignable to carriers of property between urban areas.
6. Pairs of frequencies may be assigned for the two-frequency method of operation; see Table 7-26.
7. Not available in Puerto Rico and Virgin Islands.
8. For organizations providing emergency road service to the general public.
9. For associations of owners of private automobiles.
10. Some frequencies available only in metropolitan areas of 50,000 or more population.
11. Assignable to carriers of property.
12. For end-to-end, fixed-point-to-train, or train-to-train communications.
13. In Puerto Rico and Virgin Islands, some frequencies are not available to this service, and others are shared with remote-pickup broadcast stations.
14. For transmission of hydrological and meterological information only, on a noninterference basis with Government stations.

Table 7-26. Frequency Pairs for Two-Frequency Operation*

Base Frequency (MHz)	Mobile Frequency (MHz)
44.36	43.86
44.38	43.88
44.40	43.90
44.42	43.92
44.44	43.94

* See Note 6, Table 7-25.

Table 7-27. Domestic Public Frequencies for Zone Plan

Base Station Frequency (MHz)	Mobile and Auxiliary Test Station Frequency (MHz)
35.26	43.26
35.30	43.30
35.34	43.34
35.38	43.38
35.42	43.42
35.46	43.46
35.50	43.50
35.54	43.54
35.62	43.62
35.66	43.66

Table 7-28. Domestic Public Frequencies for General and Dispatch Communications

Base-Station Frequencies (MHz)	Mobile, Dispatch, and Auxiliary Test Station Frequencies (MHz)
Landline Common Carriers	
152.51	157.77
152.54	157.80
152.57	157.83
152.60	157.86
152.63	157.89
152.66	157.92
152.69	157.95
152.72	157.98
152.75	158.01
152.78	158.04
152.81	158.07
Nonlandline Common Carriers	
152.03	158.49
152.06	158.52
152.09	158.55
152.12	158.58
152.15	158.61
152.18	158.64
152.21	158.67

For control and repeater stations, frequencies in the 72-76 MHz band are shared with other services. Carrier frequencies from 72.02 to 72.98 and 75.42 to 75.98 MHz are specified; the carrier spacing is 0.04 MHz. Some previously authorized stations may still operate in the 73-74.6 MHz band. A control station is a station used to control the emissions or operation of another station; a repeater station automatically retransmits communications received from mobile stations.

Rural Radio Service

Stations in the Rural Radio Service provide public or private-line communications in situations where landline facilities are not practical. The frequencies listed in Table 7-29 are assigned on a secondary basis to stations in the Rural Radio Service (their primary assignment is to the Domestic Public Land Mobile Radio Service).

In the state of Hawaii, frequencies in the 76-108 MHz band are available for assignment to interoffice stations. Carrier frequencies are at intervals of

Table 7-29. Frequencies for Rural Radio Service

Central Office and Interoffice Station Frequencies (MHz)	Rural Subscriber and Interoffice Station Frequencies (MHz)
Landline Common Carriers	
152.51	157.77
152.54	157.80
152.57	157.83
152.60	157.86
152.63	157.89
152.66	157.92
152.69	157.95
152.72	157.98
152.75	158.01
152.78	158.04
152.81	158.07
Nonlandline Common Carriers	
	158.49
	158.52
	158.55
	158.58
	158.61
	158.64
	158.67

0.04 MHz from 76.02 to 87.98 MHz and from 98.02 to 107.98 MHz. In Puerto Rico and the Virgin Islands, the bands 154.05-154.46 MHz and 161.40-161.85 MHz are available to the Rural Radio Service, but are shared with other services. (Spacings between assignments in these frequency bands are not specified.)

Point-to-Point Microwave Service

Although the Point-to-Point Microwave Radio Service operates primarily at frequencies far above the vhf range. frequencies in the 72-76 MHz band are available for use by control stations in this service; these frequencies are shared with other services. Carrier frequencies are assigned in 0.04-MHz steps from 72.02 to 75.98 MHz.

Power and Emission Limitations

Stations in these services are permitted to use only the minimum power necessary to carry on the required communication. In any case, the rated transmitter output power may not exceed 350 watts for frequencies between 30 and 50 MHz, 50 watts for frequencies between 50 and 76 MHz, and 250 watts for vhf frequencies above 76 MHz. In most cases other than base, mobile, and auxiliary test stations in the Domestic Public Land Mobile Radio Service, directional antennas are required.

Stations operating in the 72-76 MHz band, and base, mobile, dispatch, and auxiliary test stations in the Domestic Mobile Radio Service are required to use vertical polarization. Most other stations in the Domestic Public Radio Services are required to use horizontal polarization.

Stations in the Domestic Public Land Mobile Radio Service are limited to an effective radiated power of 500 watts (100 watts for dispatch stations). Base stations in this service with antennas more than 500 feet above average terrain are limited to an effective radiated power less than 500 watts. The amount of power reduction depends on the amount the antenna height exceeds 500 feet. (Remember the distinction between transmitter power and effective radiated power.)

Emissions normally authorized for stations in the Domestic Public Land Mobile service are A3 or F3 for radiotelephony and A1, A2, F1, or F2 for selective signaling. Maximum bandwidths are 1 kHz for A1 emission, 3 kHz for A2 emission, 8 kHz for A3 emission, 3 kHz for F1 emission, 15 kHz for F2 emission, and 20 kHz (40 kHz for frequencies between 50 and 150 MHz) for F3 emission.

Stations in the Rural Radio Service within the continental United States normally may be authorized to use types A1, A2, A3, F1, F2, or F3 emission. In addition, stations in this service outside the continental United States may use type A4 or F4 emission. Maximum bandwidths for the various types of emission are: A1, 1 kHz; A2, 3 kHz; A3, 8 kHz; A4, 12 kHz; F1 and F2, 3 kHz; F3 and F4, 20 kHz (above 150 MHz) or 40 kHz (below 150 MHz).

Stations of the Point-to-Point Microwave Service that operate in the 72-76 MHz band may use "only amplitude-modulated or frequency-modulated emission for radiotelegraphy, radiotelephony, and facsimile." Maximum bandwidths are: A1, 1 kHz; A2, 3 kHz; A3, 8 kHz; F1, 3 kHz; F2, 15 kHz; and F3, 20 kHz (above 150 MHz) or 40 kHz (below 150 kHz).

PUBLIC SAFETY SERVICES

There are six Public Safety Radio Services allocated frequencies in the vhf portion of the spectrum. These are the Local Government Radio Service, the Police Radio Service, the Fire Radio Service, the Highway Maintenance Radio Service, the Forestry-Conservation Radio Service, and the Special Emergency Radio Service.

The names of these services are largely self-explanatory, except perhaps the last named. The Special Emergency Radio Service is defined as a ". . . service of radio communication essential to the alleviation of an emergency endangering life or property." Those eligible for authorizations in this service include ambulance operators and rescue organizations, physicians and veterinarians, disaster relief organizations, persons or organizations operating school buses, and beach patrols. Other uses are for emergency communications from establishments in isolated locations, for standby communication facilities, and for use in expediting repair of public communications facilities. In general, communications in this service are limited to those related to an emergency situation.

Frequencies Allocated

Frequency allocations for the Public Safety Radio Services are summarized in Table 7-30. The first and last carrier frequency in each group are placed together in the first column; the normal separation of carrier frequencies between these limits is shown in the second column. The services which are assigned frequencies in each group are listed in the third column. Some of the frequencies in the group may be shared by more than one of the indicated services; other frequencies in the group

Table 7-30. Public-Safety Frequencies

Channel Frequencies (MHz)	Channel Spacing (MHz)	Service	Type of Station	Notes
30.86 31.98	0.04	Forestry-Conservation	Base, Mobile	1
33.02 33.10	0.02	Highway Maintenance, Special Emergency	Base, Mobile	
33.42 33.98	0.02	Fire	Base, Mobile	2
37.02 37.42	0.02	Police, Local Government	Base, Mobile	
37.90 37.98	0.02	Highway Maintenance, Special Emergency	Base, Mobile	
39.04 39.98	0.02	Police, Local Government	Base, Mobile	3, 4
42.02 42.94	0.02	Police	Base, Mobile	5, 6
44.62 46.58	0.02	Local Government, Fire, Special Emergency, Highway Maintenance, Forestry-Conservation, Police	Base, Mobile	1, 7, 8, 9
47.02 47.40	0.02	Highway Maintenance	Base, Mobile	5
47.42 47.66	0.04	Special Emergency	Base, Mobile	10
72.02 72.98	0.02 & 0.04	Local Government, Police, Fire, Highway Maintenance, Forestry-Conservation, Special Emergency	Operational Fixed	
75.42 75.98	0.02 & 0.04	Local Government, Police, Fire Highway Maintenance, Forestry-Conservation, Special Emergency	Operational Fixed	

Table 7-30. Public-Safety Frequencies (Cont'd.)

Channel Frequencies (MHz)	Channel Spacing (MHz)	Service	Type of Station	Notes
150.995 151.130	0.015	Highway Maintenance	Base, Mobile	11
151.145 151.475	0.015	Forestry-Conservation	Base, Mobile	11
153.755 154.445	0.015	Local Government, Fire	Base, Mobile	12, 13, 14
154.4525- 154.4600	—	Local Government	Fixed	15
154.650 156.240	0.015	Police, Local Government, Special Emergency, Highway Maintenance	Base, Mobile	16
157.050 157.110	0.06	Highway Maintenance	Base, Mobile	17
158.730 159.465	0.015	Police, Local Government, Highway Maintenance, Forestry-Conservation	Base, Mobile	
166.250	—	Fire	Base, Mobile	18
170.150	—	Fire	Base, Mobile	18
170.425	—	Forestry-Conservation	Base, Mobile	19, 20
170.475	—	Forestry-Conservation	Base, Mobile	19, 21
170.575	—	Forestry-Conservation	Base, Mobile	19, 20
171.425	—	Forestry-Conservation	Base, Mobile	19, 21
171.475	—	Forestry-Conservation	Base, Mobile	20, 22
171.575	—	Forestry-Conservation	Base, Mobile	19, 21
172.225	—	Forestry-Conservation	Base, Mobile	19, 20
172.275	—	Forestry-Conservation	Base, Mobile	21, 22
172.375	—	Forestry-Conservation	Base, Mobile	19, 20

Notes:

1. Some frequencies in this group assigned according to geographical assignment plan.
2. On 33.42 MHz, mobile and fixed stations (fire) with 3 watts maximum power.
3. 39.46 MHz is an intersystem police frequency.
4. On 39.06 MHz, 3 watts maximum power.
5. Geographical assignment plan.
6. Frequencies primarily for state police.
7. Some frequencies primarily for state police.
8. 45.88 MHz is an intersystem fire frequency.
9. On 46.30 MHz, mobile and fixed stations (fire) with 3 watts maximum power.
10. 47.42 MHz is for national disaster-relief organizations only.
11. Not available in Puerto Rico and Virgin Islands.
12. Some frequencies not available in Puerto Rico and Virgin Islands.
13. On 153.83 MHz, mobile and fixed stations (fire) with 3 watts maximum power.
14. 154.265 through 154.295 MHz, intersystem fire frequencies.
15. Emergency call boxes, 20 watts maximum.
16. 154.665 through 154.695, 154.905 through 154.935, 155.445 through 155.475, and 155.505 MHz primarily for state police.
17. No new assignments.
18. Only available within 150 miles of New York City.
19. Forest-fire use only.
20. West of Mississippi River only.
21. East of Mississippi River only.
22. Forest-fire and other uses.

may be assigned to only one of the indicated services. The fourth column lists the types of stations that may be authorized within each frequency group; all the indicated types may not be authorized on all frequencies in the group. The fifth column in the table indicates some of the more significant or interesting limitations or special uses applicable to certain of the frequencies.

In addition to the frequency allocations in Table 7-30, the following frequency bands may be assigned for developmental operation:

31.99–32.00 MHz
33.00–33.01 MHz
33.99–34.00 MHz
37.99–38.00 MHz
39.00–39.01 MHz
39.99–40.00 MHz
42.00–42.01 MHz
153.7325–153.7475 MHz
159.4725–159.4800 MHz

Technical Standards

Normally, only A3 or F3 emissions are used in these services. (However, F2 or F9 emission for teleprinters may be used on some frequencies in the Police and Fire Radio Services.) The maximum bandwidths are 8 kHz for type A3 and 20 kHz for type F3 emissions. Stations are limited to the minimum power necessary to accomplish the required communication. Normally, vhf transmitter power input in excess of 500 watts below 100 MHz or 600 watts above 100 MHz is not authorized. However, under certain conditions, state-police base stations may use power inputs up to 10,000 watts. On some frequencies, lower limits are set; for example, see Notes 2, 4, 9, 13, and 15 of Table 7-30. In the 72-76 MHz band, vertical polarization is required.

OTHER SERVICES

Experimental stations engaged only in scientific or technical investigations not related to any specific service may be assigned to any frequency allocated to the fixed, land mobile, or broadcasting services. Developmental stations, which are used for research or testing related to a particular service, usually are assigned frequencies allocated to the service involved.

On frequencies above 70 MHz, low-power communication devices (such as radio controls for door openers) may be operated. (In the 88-108 MHz band, only those low-power devices used for telemetering or wireless-microphone service may be operated.) The rules governing low-power devices limit their range of transmission to extremely short distances and establish other restrictions so that these devices do not interfere with reception of licensed stations.

In a number of major cities along the sea coasts and on the Great Lakes, the U.S. Weather Bureau operates stations which broadcast weather information. These broadcasts are made on the frequency 162.55 MHz; frequency modulation is used.

In the vhf band, the frequency 40.68 MHz ±20 kHz is an ISM frequency. (See Chapter 6 for an explanation of ISM frequencies.)

Certain frequencies in the vhf range are available for use in conjunction with communication satellites. These frequencies and their uses are summarized in Table 7-31.

VHF TRANSMITTING EQUIPMENT

The size and complexity of vhf transmitting equipment covers as wide a range as the number of radio services using these frequencies. As the following paragraphs indicate, units range from desk-top (even pocket-size) models to assemblies occupying several cabinets that are taller than a man.

Communications Equipment

The fm transceiver shown in Fig. 7-8 is available for the 25-54 MHz and 144-174 MHz frequency ranges. It is designed for base-station use in mobile systems operating in the Public Safety, Industrial, Land Transportation, and

Table 7-31 Communication-Satellite Frequencies

Frequency (MHz)	Use of Frequency	Notes
148.25	Space Telecommand	1
154.2	Space Telecommand	1
136-137	Telemetry From Space Stations, Spacecraft Transmissions for Tracking	2
137-138	Telemetry From Space Stations, Spacecraft Transmissions for Tracking	

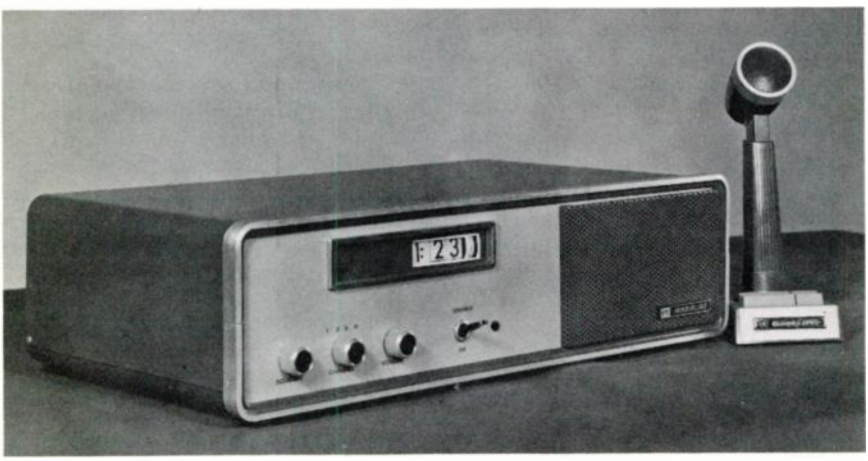
Notes:
1. Maximum occupied bandwidth not to exceed 30 kHz.
2. Basically a space-research band; not intended for operational use after desired orbit is established.

Domestic Public Land Mobile Radio Services. In addition, the 144-174 MHz version may be used in the vhf maritime bands. Rf power output is 40 watts for the 25-54 MHz model and 30 watts for the 144-174 MHz model. Features include automatic tone-coded squelch and provision for optional local and/or remote control and channel monitoring. The transceivers have a one-channel capability as a standard feature, but two channels are optional on the low-band model, and two, three, or four channels are optional on the high-band model. Both models contain 23 transistors, operate from a 110/120-volt, 50- or 60-Hz source, measure 22″ × 14″ × 6″, and weigh 53 pounds.

Fig. 7-9 shows a linear amplifier for the 25-54 MHz band. This unit increases a transceiver rf output (a-m, ssb, or fm) of from 1 to 15 watts to a level of 100 watts (200 watts peak envelope power). (Note that this equipment is intended for use on Business Radio Service frequencies between 25

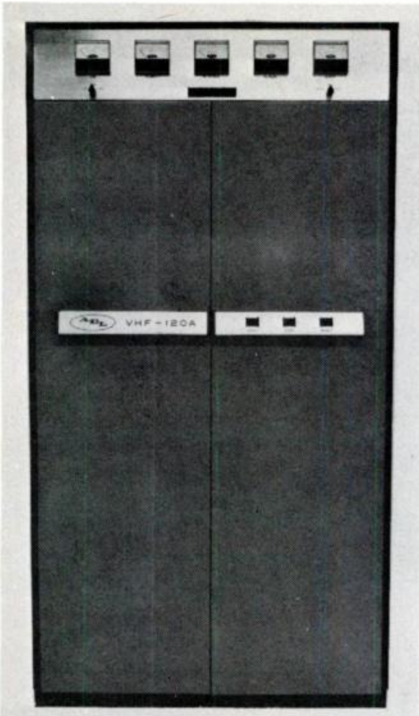
Courtesy Courier Communications

Fig. 7-9. Courier Model BL-100 base linear amplifier.



Courtesy Hammarlund Manufacturing Company, Incorporated

Fig. 7-8. Hammarlund HFM 30/40 communications base station.



Courtesy American Electronic Laboratories, Inc.

Fig. 7-10. *AEL* Model VHF-120A vhf transmitter.

and 54 MHz; it is not authorized for use in the 27-MHz Citizens band.) The amplifier, which is designed for remote operation, is connected between the transceiver and the antenna, and placing the transceiver in the transmit mode automatically activates the amplifier. (The amplifier is bypassed automatically for receiving.) The circuit includes three tubes and seven diodes; a meter is included to facilitate tuning adjustments. This unit requires a 117-volt ac power source. It measures 5″ × 7⅜″ × 7¾″ and weighs 10 pounds. A similar amplifier for mobile installations is available.

The transmitter pictured in Fig. 7-10 is for high-power use in communications, satellite command, and other applications on frequencies from 120 to 155 MHz. Its power-output rating is 2500 watts for cw or a-m operation, and 5000 watts peak for pulse operation. The operating frequency is crystal controlled, and one of four crystals may be switch selected. Provisions are included for operation of the transmitter by remote control. The rf circuits are housed in a 76″ × 40″ × 35″ cabinet; an external 45″ × 62″ × 30″ vault contains af circuits, the large, heavy transformers, and other components. This air-cooled transmitter contains 12 tubes. Interlocks are included to protect the operator from accidental contact with high voltages and to protect the transmitter in case of loss of air cooling. Relays protect the equipment from electrical overload. The transmitter requires a 220-volt, three-phase ac power source. The main cabinet weighs about 1250 pounds, and the vault weighs about 1750 pounds.

An fm marine radiotelephone is shown in Fig. 7-11. This transceiver covers the frequency range from 156.275 to 157.425 MHz. In addition, the receiver section covers 161.600 to 162.55 MHz, permitting reception of U.S. Weather Bureau vhf weather broadcasts on 162.55 MHz. The equipment has a ten-channel capability, including 156.8 MHz, the distress, safety, and calling frequency for this band. A built-in dual-channel monitor permits simultaneous monitoring of this and one other frequency. Maximum transmitter power output is 25 watts, but the output can be reduced to 1 watt or less (as required by FCC rules). The unit uses three tubes in the transmitter section, but the design also makes use of rf field-effect transistors and integrated circuits in the i-f section. The transceiver may be powered from a 12-volt source or, with accessory power supplies, from 24 or 32 volts dc, or 115 or 230 volts ac. The 13-pound unit measures 5″ × 10¾″ × 13⅝″.

A miniature aviation-band transceiver is shown in Fig. 7-12. The receiver covers the 118-127 MHz band; it has an audio output of 1 watt for speaker or 0.2 watt for headphone. The circuit contains 14 transistors and four diodes. The transmitter has crystal positions for ten frequencies be-

Courtesy Raytheon Company

Fig. 7-11. Raytheon Model RAY-42 fm marine radiotelephone.

tween 120 and 124 MHz; its output is ½ watt (a-m) with a 50-percent duty cycle (that is, on for 50 percent of the time and off for 50 percent of the time). The power source may be batteries, or (with an adapter) an aircraft cigarette-lighter receptacle; the dc voltage required is 14 volts. The size of the transceiver is $8\frac{9}{16}'' \times 3\frac{5}{16}'' \times 1\frac{13}{16}''$; its weight is 2 pounds.

Broadcast Transmitters

Many universities, colleges, and high schools operate low-power (Class-D) fm broadcast stations. Fig. 7-13 shows a 10-watt transmitter designed especially for use at such stations. The transmitter is completely self-contained; it is necessary to add only an antenna system and audio equipment. This particular model uses 22 tubes to generate and amplify the fm signal. Front-panel meters show audio level (which indicates degree of modulation), rf output, and plate voltage and plate current of the output amplifier stage. This transmitter is contained in a $26\frac{1}{2}'' \times 28'' \times 14''$ cabinet and weighs 100 pounds when packed for domestic shipment.

Courtesy Regency Electronics, Inc.

Fig. 7-12. Regency Model 601 vhf transceiver.

Two 50-watt versions of the transmitter in Fig. 7-13 are manufactured. One covers the 88-108 MHz band (as does the 10-watt unit). The other covers the 40-220 MHz band. (Below 80 MHz, the maximum frequency swing of this transmitter is ±40 kHz instead of ±75 kHz.) The 40-220 MHz model is designed for use in relaying programs from studios to main transmitter, or between other points. This transmitter finds particular application in foreign countries.

Courtesy Gates Radio Company

Fig. 7-13. Gates Model BFE-10C educational fm broadcast transmitter.

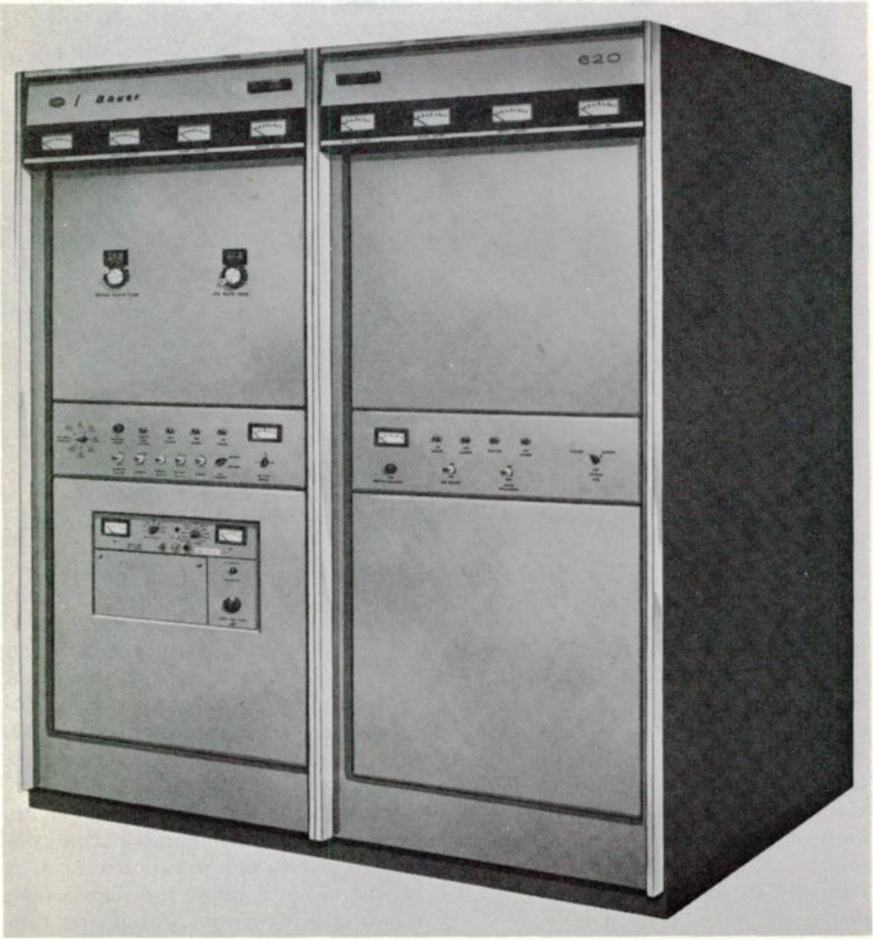
Fig. 7-14 shows an fm transmitter for use by a high-power broadcast station in the 88-108 MHz band. This transmitter uses solid-state circuits to generate the fm signal; three tubes then build the signal up to the 20,000-watt output level. A broadband final amplifier is used to reduce the number of operating adjustments required. A second 20,000-watt amplifier can be added to make a 40,000-watt unit or to provide separate 20,000-watt outputs to horizontally and vertically polarized antennas. The second amplifier is contained in an additional cabinet like the one at the right in Fig. 7-14.

In the transmitter of Fig. 7-14, direct frequency modulation of the main oscillator is used, and an automatic-frequency-control (afc) system is included to mantain the carrier (center, or average) frequency of this oscillator within required limits. The oscillator, modulator, and afc circuits are contained in a unit called the *exciter,* which can be seen through the rectangular opening in the lower front of the left cabinet. Stereo and SCA circuits, when used, also are contained in the exciter.

This transmitter contains automatic overload protection, which restores operation after a momentary overload. A system of tally lights indicates where the overload occured. Automatic controls maintain the operating power output within FCC limits. For 20,000-watt output, the transmitter requires 42,000 watts of power from a 200-250 volt, three-phase, 60-Hz source (50 Hz on special order). The 20,000-watt transmitter weighs 3000 pounds.

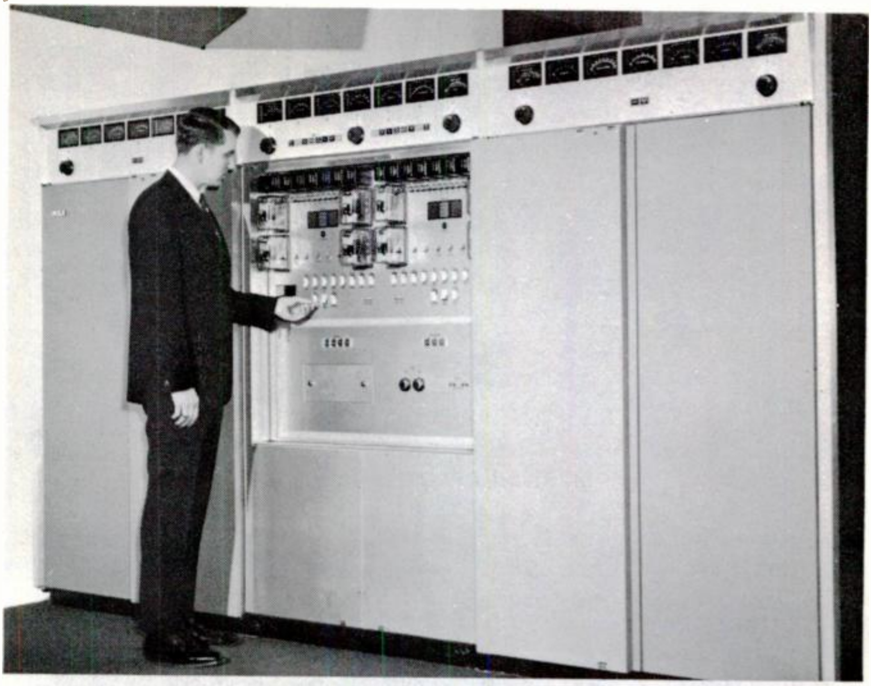
Earlier in this chapter, it was shown that vhf television broadcasting in the United States is assigned to two bands, 54-88 MHz (excluding 72-76 MHz) and 174-216 MHz. These two bands are sufficiently far apart in frequency that manufacturers of broadcast equipment produce two groups of vhf TV transmitters, one for the low band and one for the high band.

Fig. 7-15 shows a low-band transmitter rated for a peak visual power output of 30,000 watts on any channel from 2 through 6 (aural power capability is 7500 watts). This transmitter features complete redundancy of components. That is, the equipment is, in effect, two 15,000-watt transmitters that operate simultaneously with their outputs combined. The advantage of this design is that a failure of one part normally does not disable the entire transmitter, and reduced-power operation can be maintained until repairs are made; thus no air time is lost. Solid-state circuits are used, except for ten tubes in the higher-power amplifier stages. Other design features include the use of modular construction in the



Courtesy Granger Associates, Bauer Broadcast Products

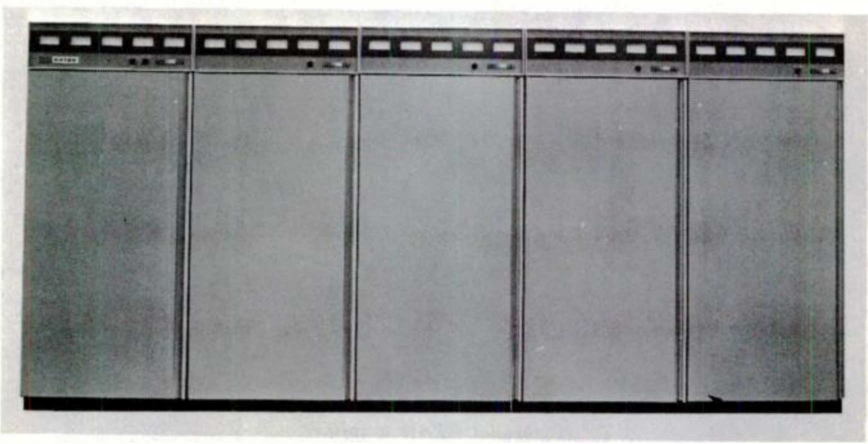
Fig. 7-14. Bauer Model 620 fm broadcast transmitter.



Courtesy RCA

Fig. 7-15. RCA Model TT-30FL vhf television broadcast transmitter.

low-level sections, and motor-driven controls and remote metering of major adjustments. The transmitter operates from a 208-240 volt, three-phase, 50- or 60-Hz power source; power consumption at full output is 50,000 watts for an average picture and 75,000 watts for a black picture. (An additional supply of 100 watts at 115 volts, 50 or 60 Hz is required.) The main transmitter measures 77" × 136" × 30"; two power-supply cabinets measure 77" × 44" × 33" each. Maximum operating altitude is 7500 feet, and the transmitter can be operated in surrounding temperatures from −20° C to 45° C.



Courtesy Gates Radio Company

Fig. 7-16. Gates Model BT-35H vhf television broadcast transmitter.

(*A*) *Model RPL-2T transmitter.*

(*B*) *Model RPL-2R receiver.*

(*C*) *Model RPA-1 amplifier.*

Courtesy Moseley Associates, Inc.

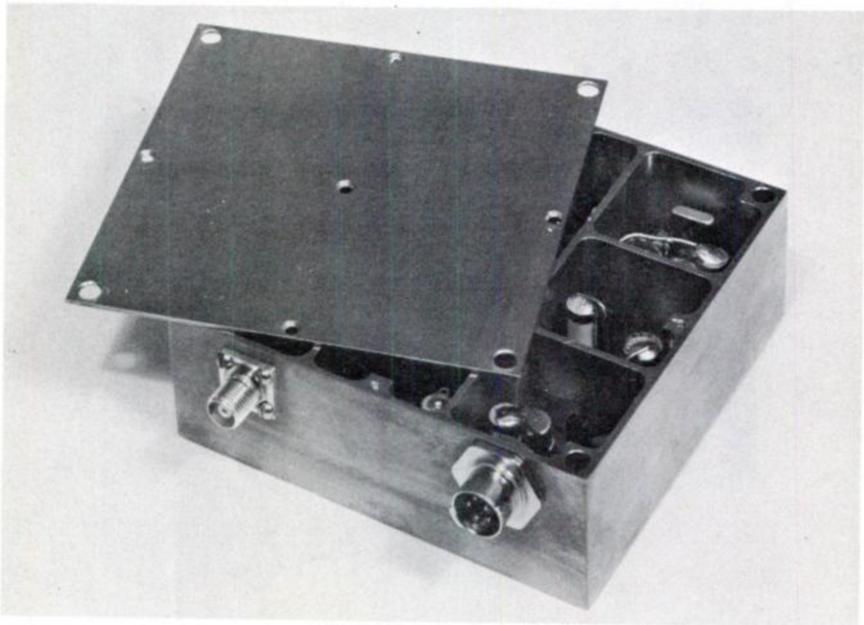
Fig. 7-17. Moseley Associates remote-pickup equipment.

A high-band (channels 7 through 13) vhf TV transmitter is shown in Fig. 7-16. In this transmitter, the complete picture and sound signals (including vestigial-sideband filtering) are generated at a low power level and at a relatively low frequency. Then the signals are mixed with the output of an oscillator and converted to the desired channel frequency. (This process can be looked on as the inverse of the frequency conversion that takes place in a superheterodyne receiver.) Amplifiers then raise the power to the 35,000-watt output level. (This rating is peak visual power; the aural output is 7000 watts.) The exciters are solid-state, and special tubes are used in the power amplifiers. The main part of the transmitter is 72″ × 13′-2″ × 31½″ and weighs 4515 pounds; the external power supply is 34″ × 43″ × 42″ and weighs 1950 pounds.

Fig. 7-17 shows all-solid-state equipment for aural remote-pickup (rpu) applications. The transmitter (Fig. 7-17A) employs direct fm and delivers 30 watts on a frequency in the 148-174 MHz band, or, with the addition of a frequency-tripler unit, 18 watts in the 450-470 MHz band. (See Chapter 8 for frequency allocations above 300 MHz.) The transmitter may be operated from 120- or 240-volt, 50-60 Hz ac or 13.5-volt, negative-ground dc. The ac power source must supply 35 watts on standby and 150 watts during operation; the dc source must supply 0.5 ampere on standby and 6 amperes during operation. The transmitter measures 6¾″ × 16″ × 10¼″ and weighs approximately 26 pounds.

The companion receiver (Fig. 7-17B) for the rpu transmitter is a double-conversion superheterodyne for the 148-174 MHz band and a triple-conversion superheterodyne for the 450-470 MHz band. Field-effect transistors are used in the rf and i-f stages for reduced cross-modulation. An all-solid-state squelch circuit with adjustable threshold is provided. The receiver requires 10 watts from a 120- or 240-volt, 50- or 60-Hz source. It measures 5¼″ × 19″ × 11″.

The audio mixer amplifier and control unit in Fig. 7-17C is for use with



Courtesy American Electronic Laboratories, Inc.

Fig. 7-18. ***AEL*** **telemetry transmitter.**

the rpu transmitter of Fig. 7-17A. This unit may be used to mix as many as three audio signals; the resulting combined signal is applied to the transmitter. Control and metering of the transmitter circuits also can be accomplished through this unit; a single multiconductor cable connects the amplifier/control unit to the transmitter. An audio limiting circuit is included to prevent overmodulation of the transmitter (100 percent modulation corresponds to a 5-kHz frequency swing in the 148-174 MHz band and a 15-kHz swing in the 450-570 MHz band). The amplifier operates from a power source of 120-volt, 50-60 Hz ac, or 11.5-16 volts dc. It is housed in a cabinet that measures 3¾″ × 12″ × 11″.

Equipment for Special Purposes

Fig. 7-18 shows a small pulse transmitter originally developed for telemetry applications in NASA suborbital flights. This solid-state transmitter can be preset to operate on any frequency in the 230-245 MHz band; crystal frequency control is used. The power output during transmission of a pulse is 30 watts. The unit is constructed to withstand the stresses encountered during a rocket launch. It measures 1½″ × 3¾″ × 3¾″.

VHF RECEIVERS

The transistor portable receiver in Fig. 7-19 features a-m and fm broadcast

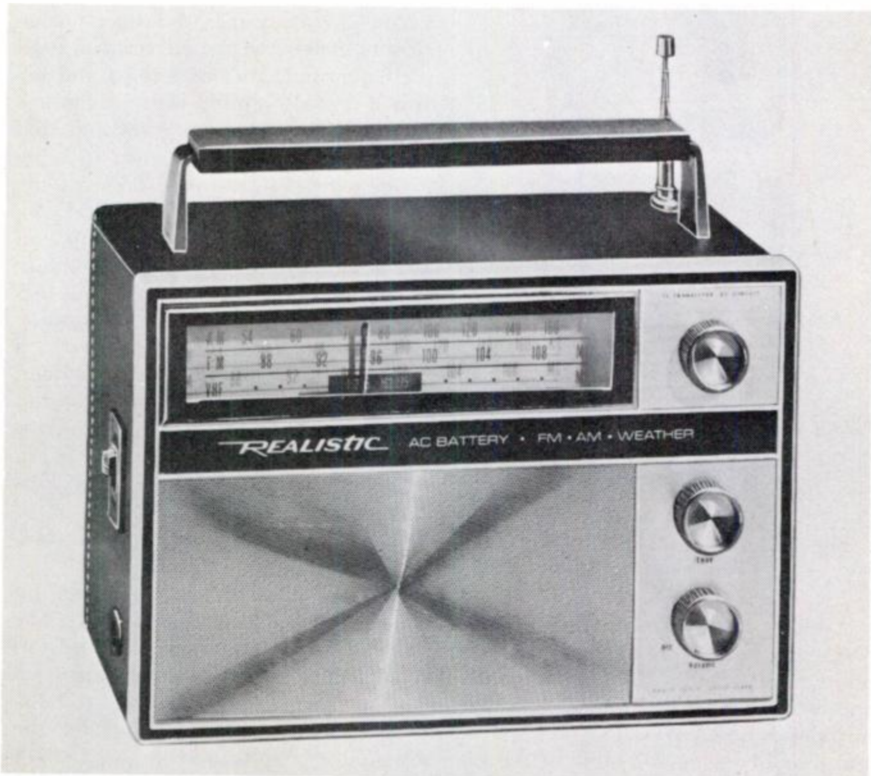
Courtesy JVC America, Inc.

Fig. 7-19. Nivico Model 8510 multiband receiver.

reception, two vhf communications bands, and an mf band including marine frequencies. Frequency coverage is 540-1600 kHz (a-m broadcast), 1.7-4.0 MHz (marine band), 30-50 MHz ("police" band), 88-108 MHz (fm broadcast), and 146-176 MHz ("police" band). Features include automatic frequency control (afc) for fm; a squelch control (operational on all bands, but included particularly for the "police" bands); slide controls instead of knobs for volume, tone, and squelch; push-button band selection; battery-test provision; and a telescoping antenna. Jacks are provided for a tape recorder, an earphone, and an auto antenna. The 1.2-watt audio amplifier drives a 4-inch speaker. The receiver is powered from 120-volt ac or from four size-D cells It measures 8⅞" × 11⅞" × 3⅛" and weighs 5½ pounds.

Fig. 7-20 shows a transistor portable radio that provides reception of a-m and fm broadcasts and U.S. Weather Bureau transmissions on 162.55 MHz (fm). The receiver is powered from four size-D cells or an ac source. It includes a telescoping antenna for vhf, a tone control, and provision for speaker or earphone listening. The size of this receiver is 6¼" × 9½" × 3¼".

A hand-held fm receiver for the 146-175 MHz frequency range appears in Fig. 7-21. The single-conversion superheterodyne circuit contains 11 transistors, two diodes, and one thermistor. A switch permits tuning the receiver or operation on a single crystal-controlled frequency. The unit features 0.1-watt audio output and choice of operation with built-in speaker or earphone (jack provided and earpiece included). A telescoping antenna is built in, and



Courtesy Allied Radio Shack

Fig. 7-20. *Realistic* am/fm/weather receiver.

there is a jack for an external antenna. The receiver operates for about 100 hours from four size-AA (penlight) cells. An ac-operated power supply is available as an accessory. The 8-ounce receiver measures 6″ × 3⅗₂″ × 1⅛″.

Courtesy Aerotron, Inc.

Fig. 7-21. Ameco Model MP-1 vhf fm receiver.

A kit-type fm receiver for the 30-50 MHz and 152-174 MHz bands is pictured in Fig. 7-22. Twenty transistors and ten diodes are used in a circuit that includes a tuned rf stage (preselector) and four i-f stages. Assembly of the kit consists primarily of making connections between preassembled circuit boards; critical circuits are factory adjusted. The receiver includes avc, adjustable squelch, a jack for 8-ohm earphones or an 8-ohm external speaker, and terminals for an external antenna. The dial is illuminated; a logging scale, marked with numbers from 0 to 100, is provided for convenience in noting a dial setting and returning to it. Audio output is 1 watt, and a 4-inch speaker is built in. The receiver operates from 110-120 volt, 50-60 Hz ac; a power transformer is included to reduce the possibility of shock. The receiver is housed in a 5⁷⁄₁₆″ × 11⅞″ × 7¾″ metal case.

Fig. 7-23 shows another kit-type receiver, this one an a-m receiver for aviation frequencies in the 108-136 MHz range. It employs 16 transistors and four diodes in a superheterodyne circuit that includes a tuned rf stage (preselector) and four i-f stages. Assembly involves installing parts on a single circuit board; the tuner (comprising the rf stage, converter, and local oscillator) is factory assembled and adjusted. Vernier tuning with a six-to-one ratio between knob rotation and dial movement is used as an aid in separating signals in crowded areas of the band. Provision is made for crystal control of the local-oscillator frequency on one channel (determined by the choice of crystal). Other features include adjustable squelch, a built-in telescoping antenna, an external-antenna jack, a built-in 3-inch speaker, and a leatherette case with combination tilt-stand and carrying handle. The receiver is powered from six size-C cells or an accessory ac-operated power supply. The receiver measures 7½″ × 8¾″ × 3½″ and weighs 3 pounds (not including C cells).

Fig. 7-24 shows a vhf receiver that includes a tone-alerting capability. The fm receiver circuit is an all-transistor, crystal-controlled, double-conversion superheterodyne. Single-channel and six-channel versions are available for the low (30-50 MHz) and high (152-174 MHz) vhf communications bands. The units may be supplied for use with

Courtesy Allied Radio Shack

Fig. 7-22. *Knight-Kit* Monitor III two-band vhf fm receiver.

single- or two-tone alerting systems. Front-panel controls include channel selector (when applicable), volume control, squelch control, and alarm on/off/reset control. Power-source requirements are 10 watts maximum at 117 volts ac, or 4.5 watts maximum at 12 volts dc. An accessory battery power

Courtesy Heath Company

Fig. 7-23. *Heathkit* Model GR-98 aircraft monitor receiver.

supply is available; this unit automatically switches to battery power if the ac source fails. Unit size is 4¾" × 11" × 7½"; weight is 5½ pounds.

The vhf monitor receiver in Fig. 7-25 is designed primarily for mobile installations, but an external ac-operated power supply is available for base-station operation. This solid-state fm receiver is a double-conversion superheterodyne with crystal frequency control; six channels may be switch selected. Two models are available, one for the 39-46 MHz range and one for the 153-157 MHz range (other ranges between 30 and 50 MHz or 150 and 170 MHz are available on special order). Other features include variable squelch, a built-in 3" × 5" speaker, and a mobile-mounting bracket. The receiver is 2⅛" × 5⁵⁄₁₆" × 7⅞". Power sources may be 12 volts dc (positive or negative ground) or (with external power supply) 117 volts ac.

Shown in Fig. 7-26 is an example of a converter used to shift vhf signals to a lower frequency that can be tuned by an mf or hf receiver. In this case, the incoming vhf signals are converted to 1500 kHz for reception on a standard-

Courtesy Regency Electronics, Inc.

Fig. 7-24. Regency Model TMH-2T/TML-2T tone receiver.

broadcast receiver. This unit connects directly to the antenna input of an automobile receiver; a coupling loop is used with home or portable receivers. The model shown covers 33-48 MHz; other, similar models cover 118-128 and 150-164 MHz. Variable tuning or crystal frequency control may be switch selected, and a squelch control is provided. The converter is powered from a 12-volt dc source. Case size is 2½" × 4½" × 3¼".

Courtesy Herbert Salch and Company, Marketing Division of Tompkins Radio Products

Fig. 7-26. Tompkins *Tunaverter* for low vhf band.

Courtesy Aerotron, Inc.

Fig. 7-25. Ameco Model MRT-6/MRT-7 fm monitor receiver.

CHAPTER 8

Frequencies Above VHF

Above 300 MHz, the spectrum is divided into ultrahigh frequencies (uhf) from 300 to 3000 MHz, superhigh frequencies (shf) from 3 to 30 GHz, and extremely high frequencies (ehf) from 30 to 300 GHz. (The abbreviation GHz stands for "gigahertz"; one gigahertz is 1000 megahertz.) Although the ITU allocations extend only to 40 GHz, the FCC allocations cover the spectrum above this frequency as well.

PROPAGATION AT FREQUENCIES ABOVE VHF

At frequencies above vhf, the wavelength becomes extremely short, and the waves generated at frequencies above roughly 900 MHz often are referred to as *microwaves.* Because of the short wavelengths, reflectors and lenses somewhat like those used to focus or reflect visible light become physically practical, and highly directional antennas (and extremely narrow beamwidths) are common. Line-of-sight transmission is the principal mode of wave propagation, although some use is made of tropospheric scattering techniques. At these frequencies, attenuation caused by rainfall, foliage, etc., can assume serious proportions.

FREQUENCY ALLOCATIONS ABOVE VHF

As was the case for vhf, the uses of the higher frequencies are influenced by two factors: Long-distance transmission is rare, and there is more "spectrum space" to accommodate wide-band services such as television, radar, and multichannel communications systems.

Broadcasting, amateur, radionavigation, communications, and other services operate in the uhf, shf, and ehf portions of the spectrum in accordance with allocations summarized in Table 8-1. Notice that frequencies are listed in terms of megahertz up to 10,000 MHz (10 GHz); above this frequency, the listings are in terms of gigahertz.

Most of the terms in Table 8-1 have been defined in connection with the allocations tables in previous chapters, particularly Table 4-1 in Chapter 4. A few of the terms that have not appeared previously or are of special interest in this chapter are defined as follows:

Community Antenna Relay Station: A station used in the transmission of broadcast-station signals to a terminal point from which the signals are distributed to the public by cable.

Earth Station: A station in the space service located on the surface of the earth, on a ship, or on an aircraft.

International Control Station: A fixed station used to transmit intelligence between a station in the International Fixed Public Radio Service and its associated message centers or control points.

Meteorological Aids Service: A service used in connection with meteoro-

Table 8-1. UHF, SHF, and EHF Allocations

Frequency	Service	Class of Station
(MHz)		
225-328.6	Government	
328.6-335.4**	Aeronautical Radionavigation	Radionavigation Land (Glide Path)
335.4-399.9	Government	
399.9-400.05**	Radionavigation Satellite	Space
400.05-401**	Meteorological Aids	Radiosonde
	Space Research	Space
401-402**	Meteorological Aids	Radiosonde
	Space	Space
402-404**	Meteorological Aids	Radiosonde
404-406**	Meteorological Aids	Radio Astronomy
	Radio Astronomy*	Radiosonde
406-420	Government	
420-450**	Amateur*	Amateur
450-456	Land Mobile	Base
		Land Mobile
456-459	Land Mobile	Mobile
459-465.0125	Land Mobile	Base
		Land Mobile
465.0125-479	Land Mobile	Mobile
470-890***	Broadcasting	Television Broadcast
890-942	Government	
942-952	Fixed	Aural STL
		International Aeronautical Fixed (Outside 48 States)
		International Fixed Public (Outside 48 States)
952-960	Fixed	International Fixed Public (Puerto Rico, Virgin Islands)
		International Control
		Operational Fixed
960-1215**	Aeronautical Radionavigation	
1215-1300**	Amateur*	
1300-1350**	Aeronautical Radionavigation	
1350-1400	Government	
1400-1427**	Radio Astronomy	
1427-1429**	Space	Earth
1429-1435	Government	
1435-1525**	Mobile	Aeronautical Telemetering
1525-1535**	Mobile	Aeronautical Telemetering
	Space	Space
1535-1540**	Space (Telemetering)	Space
1540-1660**	Aeronautical Radionavigation	
1660-1670**	Meteorological Aids	Radiosonde
	Meteorological Satellite	Space
	Radio Astronomy	Radio Astronomy
1670-1690**	Meteorological Aids	Radiosonde
1690-1700**	Meteorological Aids	Radiosonde
	Meteorological Satellite	Space
1700-1710**	Space Research	Space
1710-1850	Government	
1850-1990	Fixed	International Control
		Operational Fixed
1990-2110	Fixed	Television Pickup
	Mobile	Television STL

Table 8-1. UHF, SHF, and EHF Allocations (Cont'd.)

Frequency	Service	Class of Station
(MHz)		
2110-2130	Fixed	Domestic Fixed Public
2130-2150	Fixed	Operational Fixed International Control
2150-2160	Fixed	
2160-2180	Fixed	Domestic Fixed Public
2180-2200	Fixed	Operational Fixed International Control
2200-2290	Government	
2290-2300**	Space Research	Space
2300-2450**	Amateur*	
2450-2500	Fixed Mobile Radiolocation*	
2500-2690	Fixed	International Control Operational Fixed Instructional Television Fixed
2690-2700**	Radio Astronomy	Radio Astronomy
2700-2900	Government	
2900-3100**	Maritime Radionavigation Radiolocation*	
3100-3300	Government	
3300-3500**	Amateur*	
3500-3700	Government	
3700-4200	Communication Satellite Fixed	Common-Carrier Fixed Space
4200-4400**	Aeronautical Radionavigation	Altimeter
4400-4990	Government	
4990-5000**	Radio Astronomy	Radio Astronomy
5000-5250**	Aeronautical Radionavigation	
5250-5350	Government	
5350-5460**	Aeronautical Radionavigation Radiolocation*	
5460-5470**	Radionavigation Radiolocation*	
5470-5600**	Maritime Radionavigation Radiolocation*	
5600-5650**	Maritime Radionavigation Meteorological Aids Radiolocation*	
5650-5925**	Amateur*	
5925-6425	Communication Satellite Fixed	Common-carrier Fixed Fixed Earth
6425--6525	Mobile	Common-Carrier Land Common-Carrier Mobile
6525-6575	Mobile	Operational Land Operational Mobile
6575-6875	Fixed	International Control Operational Fixed
6875-7125	Fixed Mobile	Television Pickup Television STL
7125-7250	Government	
7250-7300	Communication Satellite	Space

Table 8-1. UHF, SHF, and EHF Allocations (Cont'd.)

Frequency	Service	Class of Station
(MHz)		
7300-7750	Communication Satellite	Space
	Meteorological Satellite	
	Fixed (Government)	
	Mobile (Government)	
7750-7900	Government	
7900-7975	Communication Satellite	Earth
	Fixed (Government)	
	Mobile (Government)	
7975-8025	Communication Satellite	Earth
8025-8400	Communication Satellite	Earth
	Fixed (Government)	
	Mobile (Government)	
8400-8500**	Space Research	Space
	Fixed*	Fixed
	Mobile*	Mobile
8500-9000	Government	
9000-9200**	Aeronautical Radionavigation	
	Radiolocation*	
9200-9300	Government	
9300-9500**	Radionavigation	
	Meteorological Aids*	
	Radiolocation*	
9500-10,000	Government	
(GHz)		
10-10.5**	Amateur*	Amateur
	Radiolocation*	Radiolocation Land
		Radiolocation Mobile
10.5-10.55**	Radiolocation	Radiolocation Land
		Radiolocation Mobile
10.55-10.68	Mobile	Operational Land
		Operational Mobile
10.68-10.7**	Radio Astronomy	
10.7-11.7	Fixed	Common-Carrier Fixed
11.7-12.2	Mobile	Common-Carrier Land
		Common-Carrier Mobile (Except Aeronautical)
12.2-12.7	Fixed	International Control
		Operational Fixed
12.7-12.95	Fixed	Community Antenna Relay
	Mobile	Television Intercity Relay
		Television Pickup
		Television STL
12.95-13.2	Fixed	Television Pickup
	Mobile	Television STL
13.2-13.25	Fixed	
	Mobile	
13.25-13.4**	Aeronautical Radionavigation	
13.4-14.0	Government	
14.0-14.3**	Radionavigation	
14.3-14.4**	Radionavigation Satellite	Earth
		Space
14.4-15.25	Government	
15.25-15.35**	Space Research	Space

Table 8-1. UHF, SHF, and EHF Allocations (Cont'd.)

Frequency	Service	Class of Station
(GHz)		
15.35-15.4**	Radio Astronomy	
15.4-15.7**	Aeronautical Radionavigation	
15.7-17.7	Government	
17.7-19.3	Fixed Mobile	
19.3-19.4**	Radio Astronomy	
19.4-19.7	Fixed Mobile	
19.7-21.0	Government	
21.0-22.0	Amateur	
22.0-24.25	Government	
24.25-25.25**	Radionavigation	
25.25-27.525	Government	
27.525-31.3	Fixed Mobile	
31.3-31.5**	Radio Astronomy	
31.5-31.8**	Space Research	
31.8-33.4**	Radionavigation	
33.4-38.6	Government	
38.6-40.0	Fixed Mobile	
40.0-88.0**		Amateur Experimental
88.0-90.0**	Radio Astronomy	
Above 90.0**		Amateur Experimental

*Secondary service; others are primary.
**This band also allocated for Government use.
***The frequencies between 806 and 890 MHz have been reallocated to the land mobile services. These frequencies are available to television translators on a secondary basis only.

logical, including hydrological, observations and exploration.

Radio Astronomy Service: A service involving the use of astronomy based on the reception of radio waves of cosmic origin.

Radiosonde: An automatic radio transmitter which transmits meteorological data; it is usually carried on an aircraft, balloon, kite, or parachute.

Telemetering: The use of telecommunication for the automatic transference of measurement data to a point at a distance from the location of the measuring device.

UHF BROADCASTING

Because television is inherently a wide-band type of emission, only a limited number of TV channels can be accommodated in the vhf portion of the spectrum, particularly since provission must be made for other services. To make additional channels available for television broadcasting, frequencies in the uhf region have been allocated for this purpose. The ITU allocations establish the uhf TV broadcast band as 470-960 MHz in Region 1, 470-890 MHz in Region 2, and 470-585 and 610-960 MHz in Region 3.

UHF Television Broadcasting in the United States

In the United States, 56 television channels, each 6-MHz wide, are established in the 470-806 MHz range. The frequencies between 806 and 890 MHz, formerly designated channels 70 through 83, have been reallocated from television broadcasting to the land mobile services. However, for an indefinite time, television translators will continue to operate in the 806-890 MHz band, although renewals of the licenses of these translators will be on a secondary basis. (That is, television translators must accept interference from land-mobile stations but must not cause interference to such stations.)

Table 8-2 lists the 56 present uhf channels (numbers 14 through 69) and the 14 former channels. Although higher channel frequencies are employed by uhf stations, such signal characteristics as polarity of modulation, channel width, aural-visual carrier spacing, type of sound modulation, synchronizing pulses, etc., are the same for a uhf station as for a vhf station.

Stations are authorized only in the communities (or in some cases nearby communities) and on the channels listed in the FCC table of assignments. Some channels are reserved for noncommercial educational use in specified communities. The table can be amended, and is from time to time. The allocation standards on which uhf assignments are based are summarized as follows.

Table 8-2. United States UHF Television Channels

Channel Number	Channel Limits (MHz)[1]	Channel Number	Channel Limits (MHz)[1]
14	470-476	49	680-686
15	476-482	50	686-692
16	482-488	51	692-698
17	488-494	52	698-704
18	494-500	53	704-710
19	500-506	54	710-716
20	506-512	55	716-722
21	512-518	56	722-728
22	518-524	57	728-734
23	524-530	58	734-740
24	530-536	59	740-746
25	536-542	60	746-752
26	542-548	61	752-758
27	548-554	62	758-764
28	554-560	63	764-770
29	560-566	64	770-776
30	566-572	65	776-782
31	572-578	66	782-788
32	578-584	67	788-794
33	584-590	68	794-800
34	590-596	69	800-806
35	596-602	70	806-812
36	602-608	71	812-818
37	608-614	72	818-824
38	614-620	73	824-830
39	620-626	74	830-836
40	626-632	75	836-842
41	632-638	76	842-848
42	638-644	77	848-854
43	644-650	78	854-860
44	650-656	79	860-866
45	656-662	80	866-872
46	662-668	81	872-878
47	668-674	82	878-884
48	674-680	83	884-890

[1]Visual carrier is 1.25 MHz above lower limit; aural carrier is 0.25 MHz below upper limit.

Allocation Standards—The minimum spacing for stations on the same channel is 155 miles in Zone I, 175 miles in Zone II, and 205 miles in Zone III. (See Fig. 7-7 and related text in Chapter 7 for an explanation of these zones.) Across zone boundaries, the separation required is that of the zone for which the smaller distance is specified. For stations on adjacent channels (e.g., 14 and 15, 15 and 16, etc.) the minimum separation is 55 miles in all zones.

In addition to these basic requirements, minimum separations for certain channel combinations are required to avoid interference generated in the receiver. Such interference may take several forms: Two signals on frequencies separated by an amount equal to the receiver i-f may beat (be mixed) in the receiver to produce an unwanted i-f signal. Two or more strong signals may produce cross modulation. The local oscillator of a receiver tuned to one channel may cause harmful interference on another channel. For certain combinations of channels, the visual or aural carrier of one channel may be at the image frequency corresponding to the other channel. (See Chapter 3 for a definition of the term "image.") To minimize these problems, the minimum-distance requirements in Table 8-3 are imposed. The first column shows the type of interference, and the second column shows the channel separation for which each type of interference exists. The third column shows the minimum distance separation required for stations on channels related as in column 2. For example, suppose station WXX-TV is authorized on channel 46. Another station eight channels removed from channel 46, or on channel 38 or 54, must be located at least 20 miles from WXX-TV. Stations on channels 41 through 44 and 48 through 51 must be 20 miles from WXX-TV; a station on channel 39 or 53 must be 60 miles from WXX-TV, etc.

A uhf station must operate with sufficient power to serve its community of license, but not less than 100 watts in any direction. No minimum antenna height is specified. The maximum power is 5,000,000 watts (1,000,000 watts within 250 miles of the Canadian border). For antenna heights greater than 2000 feet, the maximum power is reduced in accordance with a chart published by the FCC. The powers referred to are peak visual effective radiated power; the aural power must be between 10 and 20 percent of this value. The heights are antenna height above average terrain.

For additional information regarding the operation of television broadcast stations in the United States, see the discussion in Chapter 7.

Translators and Boosters—In addition to "regular" uhf television broadcast stations, translators and on-channel boosters are operated in many areas. Continued translator operation in the 806-890 MHz band will be on a secondary basis, as noted previously. A translator may be asigned to a channel listed in the table of assignments, provided a regular station is not using the channel in the listed community. Translators authorized on this basis must operate with the maximum transmitter output power for uhf translators, 100 watts. There is no limit on the effective radiated power. (The purpose

Table 8-3. Minimum Separations for UHF TV Stations

Type of Interference	Channel Difference	Minimum Separation (Miles)
I-F Beat	8	20
Cross Modulation	2-5	20
Local Oscillator	7	60
Aural Image	14	60
Visual Image	15	75

of television translators was described in Chapter 7.)

Licensees of uhf TV stations may be authorized to operate booster stations, provided the booster does not extend the range of its parent station beyond the range that could be obtained from a station operating with 5,000,000 watts at an antenna height of 2000 feet. The booster station receives signals off the air, amplifies them, and retransmits them on the same channel. The booster is used to fill in low-signal areas in the service of the parent station. The power of the booster is limited to the amount needed to provide service, but in no case more than 5000 watts peak visual effective radiated power. No minimum power is specified.

In addition to the type of booster just described, low-power boosters (5 watts maximum input) may be authorized to rebroadcast signals from uhf translators.

Foreign UHF Television Broadcasting

Uhf TV channels for Europe and Africa are shown in Table 8-4, and those for Japan are shown in Table 8-5. In Japan, technical standards are the same as those in the United States. That is, the picture has 525 lines scanned at a rate of 30 frames per second, the sound channel is fm, etc. For the European and African channels, systems G, H, I, K, and L of Table 7-18 (Chapter 7) apply. Table 8-6 lists the uhf channel plans used in several countries.

Table 8-4. UHF TV Channels (Europe and Africa)

Channel Number	Channel Limits (MHz)	Channel Number	Channel Limits (MHz)
21	470-478	45	662-670
22	478-486	46	670-678
23	486-494	47	678-686
24	494-502	48	686-694
25	502-510	49	694-702
26	510-518	50	702-710
27	518-526	51	710-718
28	526-534	52	718-726
29	534-542	53	726-734
30	542-550	54	734-742
31	550-558	55	742-750
32	558-566	56	750-758
33	566-574	57	758-766
34	574-582	58	766-774
35	582-590	59	774-782
36	590-598	60	782-790
37	598-606	61	790-798
38	606-614	62	798-806
39	614-622	63	806-814
40	622-630	64	814-822
41	630-638	65	822-830
42	638-646	66	830-838
43	646-654	67	838-846
44	654-662	68	846-854

Table 8-5. UHF TV Channels (Japan)

Channel Number	Channel Limits (MHz)
45	662-668
46	668-674
47	674-680
48	680-686
49	686-692
50	692-698
51	698-704
52	704-710
53	710-716
54	716-722
55	722-728
56	728-734
57	734-740
58	740-746
59	746-752
60	752-758
61	758-764
62	764-770

SERVICES RELATED TO BROADCASTING

In addition to the uhf channels allocated for direct TV broadcasting to the public, other uhf and microwave frequencies are used for purposes closely related to broadcasting. These uses include relay of radio or TV programs from remote locations to the main studios or transmitter, transmission of programs from studios to main transmitter (studio-transmitter link, or STL), transmission of programs between stations, and special instructional television broadcasts.

Program Relay and Pickup

Remote-pickup stations may be assigned channel frequencies from 450.05 to 450.95 MHz and 455.05 to 455.95 MHz; the channel spacing is 100 kHz. Emissions may be either A3 or F3. No power limit is specified, but licensees are required to use only enough power to render the desired service.

Low-power broadcast auxiliary stations (wireless microphones, and cue and control-signal transmitters) may be authorized in the 450-451 MHz and 942-952 MHz bands. In addition to wireless-microphone and cuing activities, transmitters in the 942-952 MHz band may be used to transmit synchronizing and control signals to portable TV cameras. The output-power limit in both bands is 1 watt.

Aural-broadcast STL and intercity relay stations may be assigned frequencies in the 942-952 MHz band. This band is divided into 19 channels, each 500 kHz wide. A licensee may be authorized to operate more than one transmitter within a channel to provide more than one audio "circuit." For ex-

Table 8-6. UHF TV Channel Plans

Country	Channel Plan	Table
Austria	Europe/Africa	8-4
Brazil	American	8-2
Canada	American	8-2
Finland	Europe/Africa	8-4
France	Europe/Africa	8-4
Germany (E & W)	Europe/Africa	8-4
Italy	Europe/Africa	8-4
Japan	Japan	8-5
Mexico	American	8-2
Netherlands	Europe/Africa	8-4
Philippines	American	8-2
Spain	Europe/Africa	8-4
Sweden	Europe/Africa	8-4
United Kingdom	Europe/Africa	8-4

ample, two circuits might be desired to relay stereophonic programs. (In addition to the frequencies stated above, some stations previously authorized in the 890-942 MHz band are permitted to continue operating on those frequencies.) No upper power limit is specified, but no more power than is needed to provide satisfactory service may be used. Normally, only frequency modulation is authorized. Directional antennas are required to minimize interference to other operations.

Remote-pickup, STL, and intercity relay stations for television service are assigned frequencies in the bands 1990-2110, 2450-2500, 6875-7125, and 12,700-13,250 MHz. A channel width of 25 MHz is specified, except for frequencies below 2500 MHz, where channel widths of 16, 17, and 18 MHz are specified. Assignments in the bands 17,700-19,300, 19,400-19,700, 27,525-31,300, and 38,-600-40,000 MHz may be made on a case-to-case basis; channel widths in these bands are specified on an individual basis.

The channels listed below are available for assignment to television translator relay stations. These stations are used to relay broadcast-station signals to television translators. (Frequencies are in megahertz.)

2002-2008	2053-2059	2087-2093
2019-2020	2070-2076	2104-2110
2036-2042		

Aural STL, intercity relay, and remote-pickup facilities may be used to transmit the sound portion of a TV program. Also, the sound portion may be transmitted within the television STL, relay, or pickup channel; a separate sound transmitter or multiplex techniques may be used to accomplish this function.

No maximum power is specified for television STL, intercity-relay, and remote-pickup stations. However, no more power than the amount required for satisfactory service may be used. Any suitable type of emission may be authorized, except that television-translator relay stations may use only signals obtained by frequency conversion of a TV broadcast-station signal.

Instructional Television

Stations in the Instructional Television Fixed Service (ITFS) transmit educational material to fixed receiving locations (such as the individual schools in a school system). Thirty-one channels, each 6-MHz wide, are available for this service between 2500 and 2680 MHz; these frequencies are shared with other services.

The technical characteristics of an ITFS television signal are similar in most respects to those of a television broadcast signal. One difference is that vertical or horizontal polarization, or a combination of both, may be used to minimize interference between systems. The use of directional antennas is encouraged for the same reason. The power of each station is limited to the amount needed for satisfactory service; the aural power is between 10 and 70 percent of the peak visual power.

ITFS response stations provide voice communication so that students at the receiving locations may converse with the instructor at the originating point of the instructional television program. All response stations communicating with the same ITFS station use the same frequency, and each ITFS channel has a specific response frequency. The response frequencies are assigned at 125-kHz intervals from 2686.0625 to 2689.9375 MHz. Either a-m or fm may be used. The transmitter output normally is limited to 0.25 watt, but it may be as much as 2 watts in special cases. A directional antenna aimed at the associated ITFS station must be used.

CATV Relay

Basically, a community antenna television (CATV) system receives broadcast television (and sometimes radio) signals off the air, amplifies them, and distributes them by cable to its subscribers. Such systems came into being in areas where direct reception by the public was difficult, and the CATV system provided an antenna system and amplifier capable of delivering a satisfactory signal to the subscribers' receivers. Now the popularity of CATV has spread throughout the country; many systems originate programs in addition to delivering programs received from local, nearby, and distant broadcast stations.

Sometimes it is impractical to use cable in certain parts of a CATV system. For example, it may be necessary to have the receiving point for a distant station many miles from the place in which the CATV system is located. Or, a radio link may be needed for a remote pickup in connection with a program originated by the system. In these cases, microwave stations called *community antenna relay* (CAR) stations are used. The frequencies allocated for use by these stations are in the 12.7-12.95 GHz band; these frequencies are shared with remote-pickup, STL, and intercity relay stations operated in connection with television broadcast stations. CAR stations may be authorized to use fm transmission with a 25-MHz channel width, or vestigial-sideband a-m transmission with a 6-MHz channel width. The peak power output of the transmitter must not exceed 5 watts on any channel.

INDUSTRIAL RADIO SERVICES

Frequencies above 300 MHz allocated to the Industrial Radio Services are summarized in Table 8-7. For some of the frequency bands, the carrier frequencies are specified in the technical portions of the rules governing these services. For these bands, the first and last carrier frequencies are listed, and the normal channel spacing is shown. When channel frequencies are not specified, the band limits are shown (e.g., 1850-1990 MHz, 2130-2150 MHz, etc.). The third column of Table 8-7 lists the services that are allocated frequencies in the band indicated in the left column. When more than one service is listed for a particular band, each service

Table 8-7. Frequencies for Industrial Radio Services

Frequencies (MHz)	Channel Spacing (MHz)	Service	Type of Station	Notes
310		Industrial Radiolocation	Land or Mobile	
406.025 406.175	0.050	Special Industrial, Business, Power, Petroleum, Forest Products	Operational Fixed	1
412.625 412.775	0.050	Special Industrial, Business, Power, Petroleum, Forest Products	Operational Fixed	1
451.025 452.500	0.025	Power, Petroleum, Forest Products, Manufacturers, Telephone Maintenance, Special Industrial	Base, Mobile, Fixed	
452.625 452.900	0.025	Power, Petroleum, Forest Products, Special Industrial, Manufacturers, Telephone Maintenance	Fixed	
452.975 453.000	0.025	Relay Press	Base, Mobile	
453.050 453.975	0.025 0.050	Power, Petroleum, Forest Products, Special Industrial, Manufacturers, Telephone Maintenance	Fixed	
456.025 457.900	0.025	Power, Petroleum, Forest Products, Manufacturers, Telephone Maintenance, Special Industrial, Business	Mobile, Fixed	2

Table 8-7. Frequencies for Industrial Radio Services (Cont'd.)

Frequencies (MHz)	Channel Spacing (MHz)	Service	Type of Station	Notes
457.975 458.000	0.025	Relay Press	Mobile	
458.050 458.975	0.025 0.050	Power, Petroleum, Forest Products, Special Industrial, Manufacturers, Telephone Maintenance	Fixed	
460.025 462.525	0.025	Power, Petroleum, Forest Products, Special Industrial, Manufacturers, Telephone Maintenance, Business	Base, Mobile, Fixed	3
462.750 462.925	0.025	Business	Base	4
463.200 467.525	0.025	Power, Petroleum, Forest Products, Special Industrial, Business, Manufacturers, Telephone Maintenance	Base, Mobile, Fixed	5, 6
467.750 467.925	0.025	Business	Mobile	7
468.200 469.975	0.025	Business	Mobile	
952.1 952.4	0.1	Power, Petroleum, Forest Products, Motion Picture, Relay Press, Special Industrial, Business, Manufacturers, Telephone Maintenance	Operational Fixed	8
952.8 956.3 956.4 959.9	0.1	Power, Petroleum, Forest Products, Motion Picture, Relay Press, Special Industrial, Business, Manufacturers, Telephone Maintenance	Operational Fixed	9, 10, 11
1850-1990	—	Power, Petroleum, Forest Products, Motion Picture, Relay Press, Special Industrial, Manufacturers, Telephone Maintenance	Operational Fixed	
2130-2150	—	Power, Petroleum, Forest Products, Motion Picture, Relay Press, Special Industrial, Manufacturers, Telephone Maintenance	Operational Fixed	
2150-2160	—	Power, Petroleum, Forest Products, Motion Picture, Relay Press, Special Industrial, Manufacturers, Telephone Maintenance, Business	Operational Fixed	12, 13
2180-2200	—	Power, Petroleum, Forest Products, Motion Picture, Relay Press, Special Industrial, Manufacturers, Telephone Maintenance	Operational Fixed	
2450-2500	—	Power, Petroleum, Forest Products, Motion Picture, Relay Press, Special Industrial, Manufacturers, Telephone Maintenance, Industrial Radiolocation	Base, Mobile, Fixed	

Table 8-7. Frequencies for Industrial Radio Services (Cont'd.)

Frequencies (MHz)	Channel Spacing (MHz)	Service	Type of Station	Notes
2500-2690	—	Power, Petroleum, Forest Products, Motion Picture, Relay Press, Special Industrial, Manufacturers, Telephone Maintenance	Operational Fixed	14
2900-3246	—	Industrial Radiolocation		15
3266-3300	—	Industrial Radiolocation		
5350-5650	—	Industrial Radiolocation		16
6525-6575	—	Power, Petroleum, Forest Products, Motion Picture, Relay Press, Special Industrial, Manufacturers, Telephone Maintenance	Base, Mobile	
6575-6875	—	Power, Petroleum, Forest Products, Motion Picture, Relay Press, Special Industrial, Manufacturers, Telephone Maintenance, Business	Operational Fixed	17
9000-9500	—	Industrial Radiolocation		18
10,000-10,550	—	Industrial Radiolocation		19
10,550-10,680	—	Power, Petroleum, Forest Products, Motion Picture, Relay Press, Special Industrial, Business, Manufacturers, Telephone Maintenance	Base, Mobile	
12,200-12,700	—	Power, Petroleum, Forest Products, Motion Picture, Relay Press, Special Industrial, Business, Manufacturers, Telephone Maintenance	Operational Fixed	

Notes:
1. For transmitting hydrological or meteorological data only.
2. On frequencies from 457.525 through 457.600 MHz, maximum power input is 3 watts (Business Radio Service).
3. Frequencies from 460.650 through 460.875 MHz (Business Radio Service) are available for use in connection with servicing and supplying aircraft at airports serving urban areas (20 watts maximum output). Also may be assigned to low-power (3 watts or less) Business Radio stations ". . . in areas removed by 5 miles . . ." from the boundaries of airports serving urban areas; such use is ". . . restricted to the confines of an industrial complex or manufacturing yard area."
4. Available for use in one-way paging.
5. 465.000 MHz available for one-way paging.
6. Frequencies from 465.650 through 465.875 MHz (Business Radio Service) are available for use in connection with servicing and supplying aircraft at airports serving urban areas. Also may be assigned to stations confined to an industrial complex or manufacturing yard area ". . . removed by 5 miles . . ." from the boundaries of airports serving urban areas. Maximum power input is limited to 3 watts for both types of stations.
7. Maximum input power 3 watts.
8. Developmental use only, except radio-alarm use in Business Radio Service.
9. Paired frequencies for duplex (simultaneous two-way) operation; pairs are 952.8 and 956.4 MHz, 952.9 and 956.5 MHz, etc.
10. In Business Radio Service, first and last two pairs are for radio alarm; other pairs are for control repeater.
11. In services except Business Radio, first and last two pairs are for developmental use only.
12. Developmental use only (except Business Radio Service).
13. In Business Radio Service, radio alarm, duplex (simultaneous two-way) only.
14. Television transmission only.
15. In the band 2900-3100 MHz, this service is secondary to the Government Radiolocation Service or other radiolocation or radionavigation services.
16. In the band 5350-5600 MHz, this service is secondary to the Government Radiolocation Service or other radiolocation or radionavigation services.
17. In the Business Radio Service, this band is available only for intercity closed-circuit educational television systems.
18. In the band 9300-9500 MHz, this service is secondary to the Government Radiolocation Service or other radiolocation or radionavigation services.
19. Maximum output 1 watt; pulsed emissions prohibited.

may not necessarily be allocated every frequency in that band. Similarly, not all the types of stations indicated in the fourth column may be authorized on all the frequencies in the indicated band, nor necessarily to all the indicated services.

A great many special uses and limitations exist for the various frequencies covered by Table 8-7. A few of the more interesting of these are indicated in the last column.

In addition to the frequencies in Table 8-7, the following microwave bands (in megahertz) are available in these services, for developmental use only, by base, mobile, or fixed stations:

8400-8500	19,400-19,700
13,200-13,250	27,525-31,000
17,700-19,300	38,600-40,000

Also, previously licensed stations in some of these services may continue to operate in the 890-940 MHz band.

Normally, only type A3 or F3 emission is authorized for radiotelephony. Maximum bandwidths are 8 kHz for type A3 emission, and 20 kHz (below 470 MHz) or 40 kHz (470-950 MHz) for type F3 emission. No more power than is needed for satisfactory service may be used; the maximum power for a given station is specified in its authorization. Technical standards for private microwave systems are summarized in Table 8-8.

LAND TRANSPORTATION RADIO SERVICES

Frequencies between 300 and 952 MHz allocated to the Land Transportation Radio Services are listed in Table 8-9. The first and last carrier frequency in each band are listed together in the first column, and the normal channel spacing (or spacings) within the band is indicated in the second column. Services which may be assigned frequencies in each band are shown in the third column; each service is not necessarily assigned to each frequency in the band. Similarly, where more than one type of station is indicated in the fourth column, each type of station may not be assigned to every frequency in the band. Microwave bands in which frequencies may be assigned to stations in the land transportation services are given in Table 8-10. In addition to the frequencies in the tables, previously authorized stations may continue to use 406.050 MHz (Railroad Radio Service) and frequencies in the 890-940 MHz band (Motor Carrier and Railroad Radio Services).

Table 8-8. Microwave Technical Standards

Frequency Band (MHz)	Maximum Power[1] (Watts)	Maximum Bandwidth	Maximum Beamwidth (Degrees)
952-960	30[2]	100 kHz	20[4]
1850-1990	18	8 MHz	10
2130-2150	15	800 kHz	10
2150-2160	15	10 MHz	360
2180-2200	15	800 kHz	10
2450-2500	12	(Note 3)	(Note 3)
2500-2690	12	4 MHz	10
6525-6575	7	25 MHz	7
6575-6875	7	10 MHz	5
10,550-10,680	5	25 MHz	4
12,200-12,700	5	20 MHz	4
Above 16,000	5	50 MHz	(Note 3)

[1]Maximum rated transmitter output.
[2]100 watts on some frequencies.
[3]Specified in station authorization.
[4]Nondirectional antenna permitted on certain frequencies; other specifications for certain other frequencies.

Table 8-9. Frequencies for Land Transportation Radio Services (UHF)

Frequencies (MHz)	Channel Spacing (MHz)	Service	Type of Station	Notes
406.025 406.175	0.050	Railroad	Operational Fixed	1
412.625 412.775	0.050	Railroad	Operational Fixed	1
451.025 453.975	0.025 0.050	Motor Carrier, Railroad, Taxicab, Automobile Emergency	Base, Mobile, Operational Fixed	2, 3
456.025 457.500	0.025 0.050	Motor Carrier, Railroad, Taxicab	Base, Mobile, Operational Fixed	2
457.625 457.950	0.025	Motor Carrier, Railroad,	Base, Mobile	2, 3
457.975 458.975	0.025 0.050	Motor Carrier, Railroad,	Operational Fixed	2
460.025 460.625	0.025	Motor Carrier, Railroad,	Operational Fixed	2
462.200 462.525	0.025	Motor Carrier, Railroad,	Operational Fixed	2
465.025 465.625	0.025	Motor Carrier, Railroad,	Operational Fixed	2
467.200 467.525	0.025	Motor Carrier, Railroad,	Operational Fixed	2

Notes:
1. For transmission of hydrological or meteorological data only.
2. Where two-frequency system is used, the second frequency is 5 MHz removed from the frequency in this band.
3. The frequencies 452.925, 452.950, 457.925, and 457.950 MHz are available only for use in controlling slave locomotives (type A1, A2, F1, or F2 emission).

In these services, type A3 or F3 emission normally is authorized for radiotelephony. Maximum authorized bandwidths are 8 kHz for type A3 emission and 20 kHz (below 470 MHz) or 40 kHz (470-950 MHz) for type F3 emission. In general, power input no greater than 120 watts (600 watts in special cases) is permitted below 500 MHz. For frequencies from 500 to 952 MHz, the maximum power is as specified in the station authorization. Technical standards for frequencies above 952 MHz are essentially as shown in Table 8-8.

FREQUENCIES FOR AVIATION

Several frequency bands above 300 MHz are available for uses related to aviation. The uses of these bands are summarized as follows:

328.6-335.4 MHz: Glide-path stations are assigned frequencies in this band. (These are land stations.)

420-460 MHz: Radio altimeters may be operated in this band until January 1, 1973.

942-952 MHz: Aeronautical fixed stations may be assigned to frequencies in this band in Alaska, Hawaii, and U.S. Possessions.

952-960 MHz: Operational fixed stations in the Aviation Services may be assigned frequencies in this band. These stations are authorized "for link or control circuits or other aeronautical operations." The assignment of these frequencies is in accordance with Notes 1, 2, 3, and 4 in Table 8-10.

960-1215 MHz: This band is for use of "airborne electronic aids to air navigation and directly associated ground-based facilities."

1300-1350 MHz: This band is for ground-based radars and, in the future, airborne transponders responding to those radars.

1435-1535 MHz: Frequencies between 1435 and 1485 MHz are pri-

Table 8-10. Frequencies for Land Transportation Radio Services (Microwave)

Frequency Band (MHz)	Type of Station	Notes
952.1-952.4	Operational Fixed	1, 2
952.8-956.3 956.4-959.9	Operational Fixed	2, 3, 4
1850-1990	Operational Fixed	
2130-2150	Operational Fixed	
2150-2160	Operational Fixed	1
2180-2200	Operational Fixed	
2450-2500	Base, Mobile, Operational Fixed, Radiolocation	5
2500-2690	Operational Fixed	6
2900-3100	Radiolocation	7, 8
5350-5650	Radiolocation	7, 8
6525-6575	Base, Mobile	
6575-6875	Operational Fixed	
8400-8500	Base, Mobile, Operational Fixed	1
9000-9200	Radiolocation	7, 8
9300-9500	Radiolocation	7, 8, 9
10,000-10,500	Radiolocation	8, 10
10,500-10,550	Radiolocation	5, 11
10,550-10,680	Base, Mobile	
12,200-12,700	Operational Fixed	
13,200-13,250	Base, Mobile, Operational Fixed	1
17,700-19,300	Base, Mobile, Operational Fixed	1
19,400-19,700	Base, Mobile, Operational Fixed	1
27,525-31,300	Base, Mobile, Operational Fixed	1
38,600-40,000	Base, Mobile, Operational Fixed	1

Notes:
1. Developmental use only.
2. Channel spacing 0.1 MHz; first and last channel frequencies are shown.
3. Paired frequencies for duplex operation; first and last frequencies are shown; separation between frequencies in each pair is 3.6 MHz.
4. First two and last two pairs developmental only.
5. 2455 and 10,525 MHz for radiolocation land and mobile speed-measuring devices only.
6. Television transmission only.
7. No speed-measuring devices.
8. Non-Government radiolocation service is secondary to radionavigation, Government radiolocation or other services.
9. Radiolocation coordinated with meteorological aids service.
10. Non-Government radiolocation limited to 1 watt output, no pulse emissions.
11. Type A0 emission, 40 watts maximum output.

marily for use in connection with flight tests of manned craft; frequencies between 1485 and 1535 are primarily for use in connection with flight tests of unmanned craft. A use specifically permitted is telemetry transmission associated with the launch and reentry of "manned or unmanned objects undergoing flight tests."

1535-1660 MHz: This band is for use of "airborne electronic aids to air navigation and any directly associated ground-based facilities."

1850-1990, 2130-2160, 2180-2200, and 2450-2690 MHz: Operational fixed stations in the Aviation Services may be assigned frequencies in these bands. The band 2150-2160 MHz is for developmental use only, and equipment of stations in the 2500-2690 MHz band must meet the technical requirements for the Instructional Fixed Television Service.

2700-2900 MHz: This band is for use by ground radars and, in the future, airborne transponders responding to those radars.

4200-4400 MHz: This band is for use of radio altimeters.

5000-5250 MHz: This band is for use of "airborne electronic aids to air navigation and any directly associated ground-based facilities."

5350-5470 MHz: Airborne radars and associated airborne beacons may be operated in this band.

6525-6575 MHz: Operational land and operational mobile stations may be assigned frequencies in this band.

6575-6875 and 8400-8500 MHz: Operational fixed stations may be assigned frequencies in these bands; the band 8400-8500 MHz is for developmental use only.

8750-8850 MHz: Airborne doppler radars may be operated in this band, subject to interference from stations in the radiolocation service in the 8500-10,000 MHz band.

9000-9200 MHz: This band may be used for ground radars and, in the future, airborne transponders that respond to those radars. (Operation is subject to interference from stations in the radio location service in the 8500-10,000 MHz band.)

9300-9500 MHz: Airborne radars and associated airborne beacons may be operated in this band.

10,550-10,680 MHz: Frequencies in this band are available for assignment to operational mobile stations.

12,200-12,700 and 13,200-13,250 MHz: These bands are available for use by operational fixed stations. The 13,200-13,250 MHz band is for developmental use only.

13,250-13,400 MHz: This band is for use of airborne doppler radar.

14,000-14,400 MHz: This band is available for use in aeronautical radionavigation.

15,400-15,700 MHz: This band is for use of "airborne electronic aids to air navigation and any directly associated ground-based facilities."

17,700-19,300 and 19,400-19,700 MHz: These bands are for operational fixed stations (developmental use only).

24,250-25,250 MHz: This band is available for airborne radionavigational devices and ground-based radionavigation aids operated in cooperation with the airborne devices.

27,525-31,300 MHz: This band is for operational fixed stations (developmental use only).

31,800-33,400 MHz: This band is available for airborne radio-navigation devices and ground-based radionavigation aids operated in cooperation with the airborne devices.

38,600-40,000 MHz: This band is for operational fixed stations (developmental use only).

In addition to the uses listed above, radionavigation land test stations may be authorized for tests of aircraft transmitters or of ground-based receivers operated in conjunction with airborne radionavigation equipment. These stations may be assigned frequencies in the bands normally used by the equipment to be tested.

The technical specifications of Table 8-8 apply in most respects to microwave stations in the aviation services.

PUBLIC SAFETY SERVICES

Frequencies available to the Public Safety Radio Services are shown in Tables 8-11 and 8-12. The applicable services are listed in Table 8-11; the frequencies in Table 8-12 are available to the Local Government, Police, Fire, Highway Maintenance, Forestry Conservation, and Special Emergency services.

In general, A3 or F3 emission is authorized for radiotelephony. (Type F2 or F9 emission is used for teleprinter transmission from base stations in the Police and Fire Radio Services.) The

Table 8-11. Public-Safety Frequencies (UHF)

Frequencies (MHz)	Channel Spacing (MHz)	Service	Type of Station	Notes
451.025 452.500 452.625 452.900 452.975 453.000	0.025		Fixed	1, 2
453.025 453.975	0.025	Local Government, Police, Fire, Highway Maintenance, Forestry Conservation	Base, Mobile	2, 3
456.025 457.500 457.625 457.900 457.975 458.000	0.025		Fixed	1, 2
458.025 458.975	0.025	Local Government, Police, Fire, Highway Maintenance, Forestry Conservation	Mobile	2, 4
460.025 460.500	0.025	Police	Base, Mobile	2
460.525 460.625	0.025	Fire	Base, Mobile	2
462.200 462.525	0.025	—	Fixed	1, 2
465.025 465.500	0.025	Police	Mobile	2
465.525 465.625	0.025	Fire	Mobile	2
467.200 467.525	0.025	—	Fixed	1, 2

Notes:
1. May be assigned to Public Safety Services on a secondary basis to land mobile use in other services; available only at locations 100 miles (75 miles for 30 watts or less input) from center of urbanized areas of population 200,000 or more.
2. For two-frequency systems, separation between frequencies is 5 MHz.
3. In the Local Government Service, the frequencies 453.025, 453.075, 453.125, and 453.175 MHz are reserved for "possible future use for communication related to safety on highways."
4. In the Local Government Service, the frequencies 458.025, 458.075, 458.125, and 458.175 MHz are reserved for "possible future use for communication related to safety on highways."

Table 8-12. Public-Safety Frequencies (Microwave)

Frequency Band (MHz)	Type of Station	Notes
952.1-952.7[1]	Operational Fixed	2
952.8-956.3[1] 956.4-959.9[1]	Operational Fixed	3
1850-1990	Operational Fixed	
2130-2150	Operational Fixed	
2150-2160	Operational Fixed	4
2180-2200	Operational Fixed	
2450-2500	Base, Mobile, Operational Fixed, Radiolocation	
2500-2690	Operational Fixed	5
2900-3100	Radiolocation	6, 7
5350-5650	Radiolocation	6, 7
6525-6575	Base, Mobile	
6575-6875	Operational Fixed	
8400-8500	Base, Mobile, Operational Fixed	4
9000-9200	Radiolocation	6, 7
9300-9500	Radiolocation	6, 7
10,000-10,500	Radiolocation	6, 8
10,500-10,550	Radiolocation	9
10,550-10,680	Base, Mobile	
12,200-12,700	Operational Fixed	
13,200-13,250	Base, Mobile, Operational Fixed	4
17,700-19,300	Base, Mobile, Operational Fixed	4
19,400-19,700	Base, Mobile, Operational Fixed	4
27,525-31,300	Base, Mobile, Operational Fixed	4
38,600-40,000	Base, Mobile, Operational Fixed	4

Notes:
1. First and last channel frequencies, rather than band limits.
2. Channel frequencies are spaced 0.1 MHz; frequencies 952.1 through 952.4 MHz for omnidirectional developmental use only (other than control of traffic signals); 952.5, 952.6, and 952.7 MHz for omnidirectional usage to control traffic signals. Maximum transmitter power output on frequencies covered by this note is 100 watts.
3. Available according to frequency pairing plan. (See Table 8-10, Notes 2, 3, 4.)
4. Developmental use only.
6. Non-Government radiolocation service is secondary to other services, including Government Radiolocation Service. (See Table 8-1.)
7. No speed-measuring devices.
8. Non-Government radiolocation service limited to survey operations, 1-watt maximum power output, no pulsed emissions.
9. Type A0 emission, 40 watts maximum output.

maximum bandwidth for A3 emission is 8 kHz, and the maximum bandwidth for F3 emission is normally 20 kHz in the 450-470 MHz range. No more power than the amount needed to provide satisfactory service may be used. Normally, input power greater than 600 watts is not authorized below 460 MHz. (The maximum power for higher frequencies is as specified in the station authorization.) Microwave technical standards are the same in most respects as those in Table 8-8.

MARITIME FREQUENCIES

Frequencies above vhf for use in the maritime services are summarized as follows:

952-960 MHz: Developmental use for operational fixed stations on land.

1850-1990 MHz: Developmental use for operational fixed stations on land.

2110-2200 MHz: Developmental use for operational fixed stations on land.

2450-2500 MHz: Developmental use for coast, fixed, and ship stations. Shore radiolocation stations. Ship radiolocation stations.

2500-2700 MHz: Developmental use for operational fixed stations on land.

2900-3100 MHz: Shore radiolocation stations. Shore radionavigation stations (including shore radar stations). Ship radiolocation stations.

5350-5460 MHz: Developmental use for ship radiolocation stations and shore radiolocation stations.

5460-5650 MHz: Shore radiolocation stations. Ship radar stations. Ship radiolocation stations.

6425-6575 MHz: Developmental use for coast stations and ship stations.

6575-6875 MHz: Developmental use for operational fixed stations on land.

8400-8500 MHz: Developmental use for coast stations and fixed stations on land.

9000-9200 MHz: Developmental use for shore radiolocation stations and ship radiolocation stations.

9300-9500 MHz: Shore radiolocation stations. Shore radionavigation stations (including shore radar stations). Ship radionavigation (including radar) stations. Ship radiolocation stations.

10,550-10,700 MHz: Developmental use for coast stations and fixed stations.

11,700-12,200 MHz: Developmental use for coast stations and ship stations.

12,200-12,700 MHz: Developmental use for operational fixed stations.

13,200-13,250 MHz: Developmental use for coast stations and fixed stations.

16,000-18,000 MHz and 26,000-30,000 MHz: Developmental use for fixed, coast, and ship stations.

SERVICES FOR PUBLIC CORRESPONDENCE

In the frequency range covered by this chapter, the services that handle public correspondence are assigned frequencies as summarized in Table 8-13. The services covered by this table are the Domestic Public Land Mobile Radio Service, the Rural Radio Service, the Point-to-Point Microwave Radio Service, the Local Television Transmission Service, and the International Fixed Public Radiocommunication Services. Each type of station shown may not necessarily apply to all services indicated for the corresponding band. Some of the restrictions or special uses applicable to certain frequencies are indicated by the notes in the table.

Stations in the Domestic Public services may use only sufficient power to provide the required service. The maximum power outputs authorized are 250 watts between 76 and 500 MHz and 100 watts between 500 and 10,000 MHz (except 5925-6425 MHz). There is no limit above 10,000 MHz. In the band 5925-6425 MHz, the power limit for fixed stations is 20 watts delivered to the antenna, and 316,000 watts effective radiated power. (This limitation is to minimize interference to communication-satellite transmissions.) In general, uhf transmissions below 500 MHz are horizontally polarized, although in some cases combinations of horizontal and vertical polarization may be used. No standard polarization is specified for frequencies above 890 MHz.

In the Domestic Public Land Mobile Service, the maximum effective radiated power is 500 watts (100 watts for dispatch stations). (The limit on transmitter output is stated in the preceding paragraph.) When a base-station transmitting antenna is more than 500 feet above average terrain, the maximum effective radiated power is less than 500 watts by an amount that depends on the height. Normally, type A3 or F3 emission is used for radiotelephony. The maximum bandwidths for frequencies below 500 MHz are 8 kHz for A3 emission, and 20 kHz for F3 emissions. For frequencies above 500 MHz, the bandwidth may be 400 kHz for each derived communication channel (may be restricted to a smaller band-

Table 8-13. Frequencies for Public Correspondence

Frequencies (MHz)[1]	Channel Spacing (MHz)	Service	Type of Station	Notes
454.025 454.350	0.025	Domestic Public Land Mobile, Point-to-Point Microwave	General and Dispatch Communications, Control, Control and Repeater	
454.375 454.650	0.025	Domestic Public Land Mobile, Rural Radio	General and Dispatch Communications, Central Office, Interoffice	
454.700 454.950	0.050	Domestic Public Land Mobile, Rural Radio	General and Dispatch Communications, Central Office, Interoffice	2
459.025 459.350	0.025	Domestic Public Land Mobile, Rural Radio, Point-to-Point Microwave	General and Dispatch Communications, Control, Control and Repeater, Subscriber, Interoffice	
459.375 459.650	0.025	Domestic Public Land Mobile, Rural Radio	General and Dispatch Communications, Subscriber, Interoffice	
459.700 459.950	0.050	Domestic Public Land Mobile, Rural Radio	General and Dispatch Communications, Subscriber, Interoffice	
800-830	—	Point-to-Point Microwave	Fixed	3
890-942	—	Domestic Public Land Mobile, Rural Radio, Point-to-Point Microwave		4
942-952	—	International Fixed Public		5, 6
952-960	—	International Fixed Public		7
2110-2130	—	Domestic Public Land Mobile, Point-to-Point Microwave	Control and Repeater, Fixed	8, 9
2150-2160	—	Point-to-Point Microwave	Fixed	
2160-2180	—	Domestic Public Land Mobile, Point-to-Point Microwave	Control and Repeater, Fixed	8
3700-4200	—	Point-to-Point Microwave, Local Television Transmission	Fixed, Television STL	
5925-6425	—	Point-to-Point Microwave, Local Television Transmission	Fixed, Television STL	
6425-6525	—	Local Television Transmission	Television Pickup, Television Nonbroadcast Pickup	
10,700-11,700	—	Point-to-Point Microwave, Local Television Transmission	Fixed, Television STL	
11,700-12,200	—	Local Television Transmission	Television Pickup, Television Nonbroadcast Pickup	
13,200-13,250	—	Point-to-Point Microwave, Local Television Transmission	Fixed, Television Pickup, Television Nonbroadcast Pickup, Television STL	

Table 8-13. Frequencies for Public Correspondence (Cont'd.)

Frequencies (MHz)[1]	Channel Spacing (MHz)	Service	Type of Station	Notes
17,700-19,300	—	Point-to-Point Microwave, Local Television Transmission	Fixed, Television Pickup, Television Nonbroadcast Pickup, Television STL	
19,400-19,700	—	Point-to-Point Microwave, Local Television Transmission	Fixed, Television Pickup, Television Nonbroadcast Pickup, Television STL	
27,525-31,300	—	Point-to-Point Microwave, Local Television Transmission	Fixed, Television Pickup, Television Nonbroadcast Pickup, Television STL	
38,600-40,000	—	Point-to-Point Microwave, Local Television Transmission	Fixed, Television Pickup, Television Nonbroadcast Pickup, Television STL	

Notes:
1. Frequencies are first and last channel frequencies in band when channel spacing is indicated in second column; frequencies shown with hyphens are band limits.
2. No new assignments pending determination of use by Public Air-Ground Radiotelephone Service.
3. Available only in southeast Alaska; use must not cause interference to broadcasting.
4. Previously authorized stations only.
5. Alaska, Hawaii, and U.S. Possessions only.
6. Assignments in this band available (under specified conditions) to stations in the Point-to-Point Microwave and Rural Radio Services previously authorized in the 890-942 MHz band.
7. Puerto Rico and Virgin Islands only.
8. No television transmission.
9. Frequencies between 2110 and 2120 MHz may be authorized for earth stations for telecommand purposes in connection with deep-space research (Government or non-Government stations).

width when appropriate to the type of operation).

In the Rural Radio Service, A1, A2, A3, F1, F2, and F3 emissions are normally authorized for telephony within the continental United States; multichannel a-m or fm radiotelephony may be authorized in special cases. In addition to the other types of emission, type A4 or F4 may be authorized outside the continental United States. On frequencies below 500 MHz, maximum bandwidths for the various types of emissions are: A1, 1 kHz; A2, 3 kHz; A3, 8 kHz; A4, 12 kHz; F1 and F2, 3 kHz; F3 and F4, 20 kHz.

Table 8-14. Bandwidths for Point-to-Point Microwave Service

Frequency Band (MHz)	Maximum Bandwidth (MHz)
2110-2200	3.5
3700-4200	20
5925-6875	30
10,700-11,700	50
13,200-13,250	25
17,700-19,300	100
19,400-19,700	100
27,525-31,300	200
38,600-40,000	200

In the Point-to-Point Microwave Service, the maximum bandwidths for the different types of modulation on frequencies below 500 MHz are: A1, 1 kHz; A2, 3 kHz; A3, 8 kHz; F1, 3 kHz; F2, 15 kHz; F3, 20 kHz. Maximum bandwidths for microwave frequencies are given in Table 8-14.

In the Local Television Transmission Service, the maximum bandwidths for single-channel operation on frequencies below 500 MHz are 8 kHz for A3 emission and 40 kHz for F3 emission. For microwave frequencies, the bandwidths in Table 8-15 apply.

SATELLITE COMMUNICATIONS

Four frequency bands are available to the Communication-Satellite Service on a shared basis with terrestrial services. These bands are 3700-4200 MHz

Table 8-15. Bandwidths for Local Television Transmission Service

Frequency Band (MHz)	Maximum Bandwidth (MHz)
3700-4200	20
5925-6575	30
10,700-12,200	50
13,200-13,250	25
17,700-19,300	100
19,400-19,700	100
27,525-31,300	200
38,600-40,000	200

and 7250-7750 MHz for satellite-to-earth transmission, and 5925-6425 MHz and 7900-8400 MHz for earth-to-satellite transmission. The first two bands also may be used for transmission of tracking and telemetering signals from a space station operating in the same band. The second two bands also may be used for transmission of telecommand signals from an earth station operating in the same band. (The ultimate allocation of these frequencies between Government and non-Government use has not yet been decided.)

The following frequencies are available for space telecommand use: 450 MHz (maximum bandwidth 0.5 MHz) and the band 1427-1429 MHz. The following frequency bands are available for telemetry from space stations: 400.05-401 MHz (basically for research as opposed to operational use after orbit has been established), 401-402 MHz, and 1525-1540 MHz. For space-station transmissions for tracking purposes, these frequencies are available: 400.05-401 MHz (basically research only) and 1525-1540 MHz.

In general, earth stations operating in the 5925-6425 MHz band are limited to an effective radiated power in any direction in the horizontal plane of 31,600 watts in any 4-kHz band. The corresponding limit for the 7900-8400 MHz band is 316,000 watts (in certain cases, 3,160,000 watts). Normally, the main radiation from an earth-station antenna must be directed at least 3 degrees above horizontal for the 7900-8400 MHz band and 5 degrees above horizontal for the 5925-6425 MHz band.

CITIZENS RADIO SERVICE

Class-A stations in the Citizens Radio Service operate in the 460-470 MHz band with a maximum input power of 60 watts (48 watts output). Base and mobile stations may be assigned these frequencies (in megahertz):

462.550	462.650
462.575	462.675
462.600	462.700
462.625	462.725

Mobile stations may be assigned to these frequencies (in megahertz):

467.550	467.650
467.575	467.675
467.600	467.700
467.625	467.725

The frequencies in the preceding paragraph also are available to fixed stations located more than 100 miles from the center of an urban area of population 200,000 or more. (The minimum distance is 75 miles for transmitter outputs of 15 watts or less.) Fixed stations used to control base stations may be less than 100 miles from the center of the urban area, provided certain other technical requirements are met. (Some previously licensed fixed stations outside the 100-mile limit may operate on frequencies other than those listed.)

Maximum bandwidths for Class-A stations are 8 kHz for type A2 or A3 emission, and 20 kHz for type F2 or F3 emission.

OTHER ALLOCATIONS

The nature of the Amateur Radio Service was discussed in Chapter 6, and amateur frequencies also are listed in Chapters 5 and 7. Amateur frequency bands in the uhf range and above are listed in Table 8-16, together with the

Table 8-16. Amateur Frequencies (UHF and Above)

Frequency Band (MHz)	Authorized Emissions
420-450[1, 2]	A0, A1, A2, A3, A4, A5, F0, F1, F2, F3, F4, F5
1215-1300[1]	A0, A1, A2, A3, A4, A5, F0, F1, F2, F3, F4, F5
2300-2450[1, 3]	A0, A1, A2, A3, A4, A5, F0, F1, F2, F3, F4, F5, P
3300-3500[1]	A0, A1, A2, A3, A4, A5, F0, F1, F2, F3, F4, F5, P
5650-5925[1, 4]	A0, A1, A2, A3, A4, A5, F0, F1, F2, F3, F4, F5, P
10,000-10,500[1]	A0, A1, A2, A3, A4, A5, F0, F1, F2, F3, F4, F5
21,000-22,000	A0, A1, A2, A3, A4, A5, F0, F1, F2, F3, F4, F5, P
Above 40,000	A0, A1, A2, A3, A4, A5, F0, F1, F2, F3, F4, F5, P

[1]Amateur stations must not interfere with Government radiolocation service.
[2]Power input limited to 50 watts in Florida and certain neighboring areas, Arizona, parts of Texas and New Mexico, and parts of the California-Nevada area.
[3]In the band 2400-2450 MHz, no protection is afforded from interference caused by industrial, medical, and scientific devices operating on 2450 MHz.
[4]In the band 5725-5875 MHz, no protection is afforded from interference caused by industrial, medical, and scientific devices operating on 5800 MHz.

types of emission permitted in each band. Except as noted, the maximum permissible power input is 1000 watts. (For an explanation of the emission designations as applied to amateur operations, see Table 6-6, Chapter 6.)

The Experimental Service (Research) involves (1) research in the radio art not related to development of any specific service, or (2) providing essential communications related to research projects. Stations in this service may be assigned frequencies allocated to the fixed, land mobile, or broadcasting services. The Experimental Service (Developmental) involves development of equipment, techniques, or technical information for a specific radio service. Frequencies for these purposes normally are assigned from those allocated to the service involved. Student authorizations may be issued for experimental operations in the bands 460-461 MHz, 462.525-467.475 MHz, and 2450-2500 MHz. Normally, student operations are limited to a power input of no more than 5 watts. (See Chapter 6 for other information about special authorizations made to students.)

Low-power communication devices may be operated on most of the frequencies covered in this chapter, provided certain requirements are met. These requirements include strict limits on the permissible radiated signal (and therefore the operating range) and the duration of transmissions. Full details on the use of these limited-range devices are contained in Part 15 of the FCC Rules and Regulations.

ISM frequencies in the microwave range are listed below. The purpose of ISM frequencies was discussed in Chapter 6.

Frequency (MHz)	*Tolerance (MHz)*
915	±25
2450	±50
5800	±75
22,125	±125

Military operations make use of microwave frequencies. Bands for this purpose include 1710-1850 MHz, 4400-5000 MHz, 7125-8400 MHz, and 14,400-15,250 MHz.

For convenience, frequency bands in the uhf and microwave region are referred to by letter designators. The standard designators are as follows:

Band	*Frequency Range (MHz)*
P	225- 390
L	390- 1550
S	1550- 5200
C	5200- 8500
X	8500-10,900
KU	10,900-17,250
KA	17,250-36,000
Q	36,000-46,000
V	46,000-56,000

EQUIPMENT FOR UHF AND HIGHER FREQUENCIES

In the remainder of this chapter, some examples of equipment for the uhf and shf bands will be described. Most of the equipment for these frequencies is of the type used in professional and commercial applications. This is because of the nature of the services that use these frequencies. Also, in the microwave range the nature of the waves themselves makes practical the use of highly directional antennas to confine the signals to narrow beams. Thus, reception of signals at other than the intended points is unlikely.

UHF Transmitting Equipment

Fig. 8-1 shows an all-solid-state fm two-way radio for the 450-470 MHz band. Design features include an integrated circuit in the receiver section, a crystal-controlled double superheterodyne receiver, a solid-state antenna switch used instead of an electromechanical relay, and electronic regulation of the supply voltage. The speaker and the control head are contained in a single case for mounting at a convenient location. The transmitter, receiver, and power supply are contained in a second case; models are available for front or trunk mounting. The transmitting rf output is 15 watts, and the receiver af output is 5 watts. Options include a tone-coded squelch system (which silences all but the desired messages); operation on one to four channels of transmitter, receiver, or both; telephone-type handset instead of microphone; noise-cancelling microphone; selective calling systems (base station may call specific unit, or mobile unit may call specific station); and a converter for operation from a positive-ground power source. The equipment weighs 28 pounds; the control-head-speaker unit is 3½" × 8³⁄₁₆" × 2⅞", and the transmitter-receiver-power-supply is 4⅞" × 9¼" × 16½".

Fig. 8-2 shows equipment for an aural studio-transmitter-link (STL) system. The STL transmitter in Fig. 8-2A delivers a maximum output of 8 watts on a channel in the 890-960 MHz band. It employs direct frequency modulation, with automatic-frequency-control circuitry to ensure accuracy and stability of the carrier (center) frequency. The receiver (Fig. 8-2B) is a crystal-controlled, double-conversion superheterodyne. A carrier-operated squelch relay cuts off the receiver output in the event of carrier or power-source failure.

For monophonic broadcasts, one STL transmitter and one receiver are used. To relay stereophonic broadcasts with

Courtesy RCA

Fig. 8-1. RCA Super-Fleetfone 500 uhf two-way radio.

(*A*) *Transmitter.*

(*B*) *Receiver.*

Courtesy Moseley Associates, Inc.

Fig. 8-2. Moseley Associates Model PCL-303 aural STL.

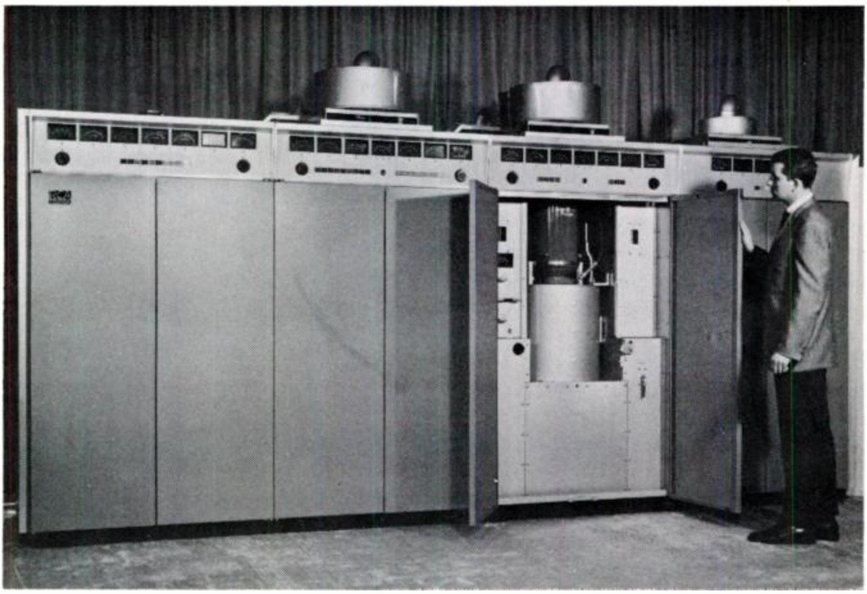
the equipment in Fig. 8-2, two approaches are possible. In one method, two STL transmitters and two receivers are used, one of each for the right channel and one of each for the left channel. In the second method, one transmitter and one receiver are used to relay the composite stereo signal. The composite stereo signal consists of the L + R (main channel) signal, the L − R (stereo subchannel) signal, and the 19-kHz pilot subcarrier. (See Chapter 7 for a description of the stereophonic transmission system used in the United States.) In addition to program audio, a Subsidiary Communications Authorization (SCA) subchannel can be relayed, as can signals for controlling the main broadcast transmitter.

The transmitter measures 5¼″ × 19″ × 16″, and its companion receiver measures 5¼″ × 19″ × 14″. The units may be mounted in a rack (as in Fig. 8-2A) on slides for ready access for maintenance. Multicircuit panel meters are included for making routine circuit tests. Both units operate from a 120- or 240-volt, 50-60 Hz power source. Models that operate in the 300-470 MHz band are available for use in foreign countries. Also, similar equipment is available for data-transmission applications at operational fixed stations in the 952-960 MHz band.

A high-power television broadcast transmitter for uhf channels 14-51 is shown in Fig. 8-3. This transmitter can deliver a peak visual power output of up to 110,000 watts, and when connected to a high-gain antenna it can be used to generate the 5,000,000-watt maximum effective radiated power permitted by the FCC. The cabinet with the doors open contains one of the high-level power amplifiers; the assembly containing the large special tube used in this amplifier can be seen in the center compartment of the cabinet. One of these special tubes (called *klystrons*) is used as the aural output amplifier (output power capability, 24,000 watts). Two klystrons with their outputs combined are used in the visual output amplifier; thus if one fails, the transmitter may continue to operate. (Also, if the aural klystron fails, one of the visual klystrons may be used temporarily in its place.) Other features include eye-level meters, motor drive of all normal operating controls (making remote control possible), and low-level modulation. The transmitter operates from 440-480 volt, three-phase, 60-Hz and 115-volt, 50- to 60-Hz power sources. The equipment measures 77″ × 180″ × 105″. It may be operated in temperatures from 1° C to 45° C at altitudes up to 7500 feet.

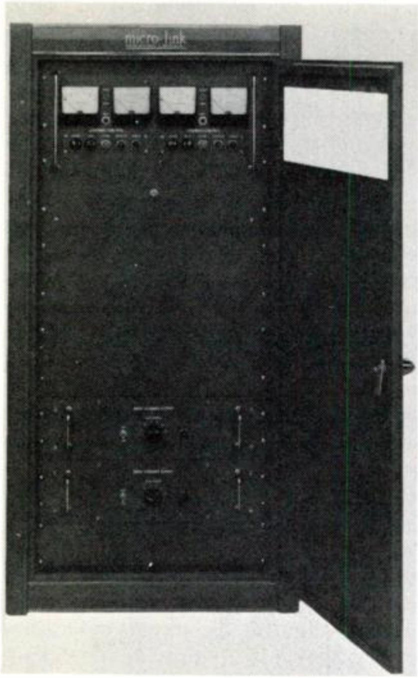
A transmitter for the Instructional Television Fixed Service (ITFS) is shown in Fig. 8-4. In this equipment, the video and audio program signals are applied to solid-state exciters which generate complete television signals on frequencies in the range of channels 7 through 13. These signals then go through up-converters which shift them in frequency to the ITFS band (2500-2690 MHz). Finally, the signals are amplified to an output level of 10 watts on each channel. As many as four channels can be combined in a single waveguide to be carried to the transmitting antenna. The unit in Fig. 8-4 contains the circuits (except exciters) for transmitting two channels; two of these units would be connected to a common waveguide to provide four-channel operation.

An example of an ITFS receiving installation appears in Fig. 8-5. The antenna and its 4-foot reflector "dish"



Courtesy RCA

Fig. 8-3. RCA Model TTU-110A uhf television broadcast transmitter.



Courtesy Micro-Link *Systems—Varian Associates*
Fig. 8-4. *Micro-Link* Model MED-401B transmitter for Instructional Television Fixed Service.

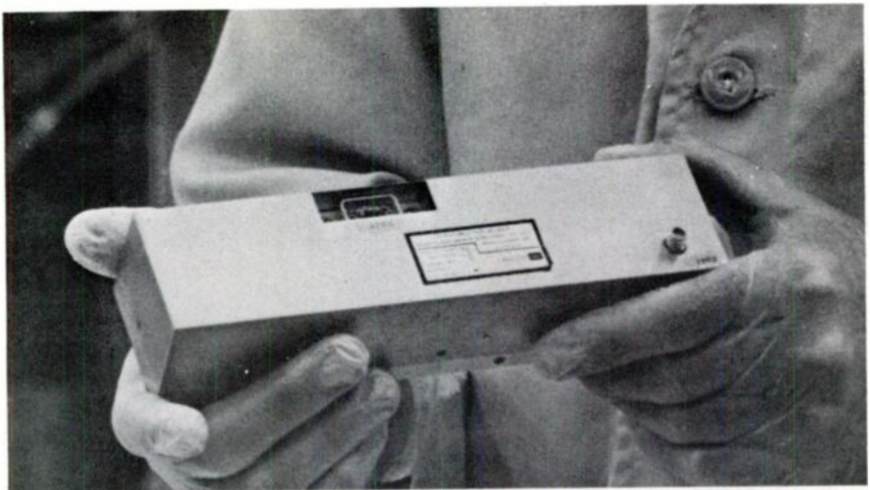
are mounted on an 80-foot tower. Mounted directly behind the antenna is a crystal-controlled down-converter, which receives up to four ITFS channels, converts them to vhf channels, and amplifies the resulting vhf signals. The ITFS programs are then distributed (by cable) to classroom receivers as conventional vhf TV signals. Operating power is delivered to the converter/amplifier through the same coaxial cable that brings the vhf signals from the converter into the building. Placing the converter at the antenna makes it possible to carry the signals down the tower and to the receivers at vhf frequencies rather than the uhf ITFS frequencies. This is desirable because signal losses in the cable are much greater at the higher frequencies.

A data transmitter developed for Project Apollo is shown in Fig. 8-6. This transmitter is used to send to earth data from the Apollo Lunar Surface Experiments Package; it is part of a solid-state system that consists of two identical transmitters (one operational, one backup), and one receiver for reception of commands sent from the Houston Mission Control Center. The command receiver weighs 1½ pounds, and each transmitter weighs one pound. The receiver occupies 64 cubic inches (4″ × 8″ × 2″), and each transmitter occupies 23 cubic inches. The receiving frequency is 2119 MHz, and the carrier frequency of the phase-modulated transmitter is 2280 MHz. The transmitter output of 1 watt is maintained essentially constant over a temperature range of −35°C to +75°C by an automatic-gain-control circuit. In addition to the other data transmitted, the transmitter has provisions for telemetering its own crystal temperature, hot-spot temperature, power-stage current input, and output power. Transmitter power consumption is 7.5 watts from a 29-volt dc source. The receiver requires 0.7 watt at 12 volts and 0.03 watt at −6 volts.

UHF Receiver

A receiver that covers the 450-470 MHz band is shown in Fig. 8-7. This model is intended for base-station (or home) use with a 117-volt ac power source, or mobile use with a 12-volt dc

Courtesy Micro-Link *Systems—Varian Associates*
Fig. 8-5. ITFS receiving installation.



Courtesy Philco-Ford Corporation

Fig. 8-6. Philco-Ford Model T-31 data transmitter for Project Apollo.

power source. In addition to the uhf band, this receiver covers the 30-50 and 152-174 MHz vhf bands. There are two tuning controls, one for the high vhf band, and the other for the low vhf and uhf bands. Features include a front-panel headphone jack, a band switch, a squelch control, and a switch for 5-kHz or 15-kHz selectivity.

SHF Equipment

The nation is covered by a web of invisible microwave beams that carry messages, television programs, and electronically coded data. In general, there are two types of microwave stations: Terminal stations transmit and receive microwave signals, and also are the point of connection between the microwave system and the source or destination of the material being transmitted (such as a TV station, a pipeline pumping station, a telephone exchange, etc.). Repeater stations receive microwave signals, amplify them, and retransmit them. A typical microwave system may have a number of terminal and repeater stations (and stations serving both functions) operating over several paths.

Courtesy Allied Radio Shack

Fig. 8-7. *Realistic* PRO-3 uhf/vhf monitor radio.

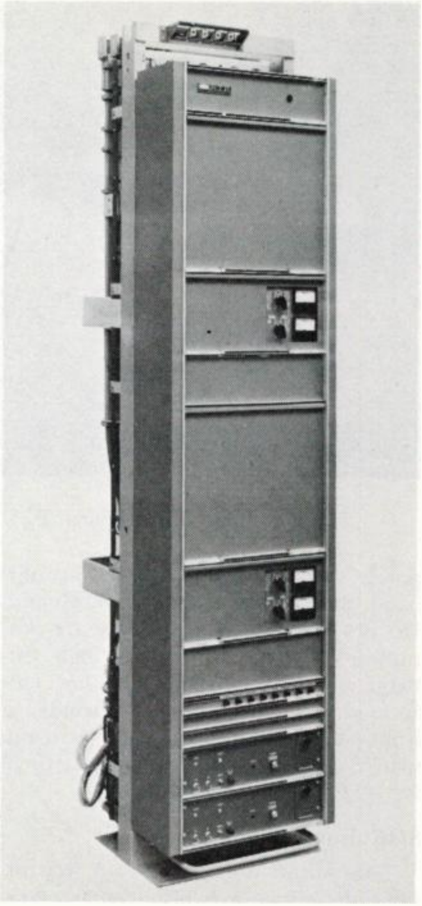
Many different types and arrangements of equipment are used in microwave systems, depending on the purpose and complexity of the system. An example is shown in Fig. 8-8. This equipment is designed to transmit up to 1800 telephone channels (through use of a multiplexing technique), a color television program with up to four program audio channels, or wideband data signals. The rack in Fig. 8-8 contains radio equipment for two microwave channels.

The equipment in Fig. 8-8 employs the heterodyne principle. That is, at repeater stations, the incoming microwave signals are converted to a lower frequency (intermediate frequency, or i-f—in this case 70 MHz) for amplification, and then the i-f is converted back to a microwave frequency for additional amplification and transmission. (At a terminal station, the signals to be transmitted are used to frequency modulate a carrier at the i-f. This i-f signal is then treated as the i-f signal from a receiver would be; that is, it is converted to a microwave frequency for further amplification and transmission to another station.)

The equipment shown here is all solid-state, except for a special power-amplifier tube called a *traveling-wave tube*. Frequency bands covered are 5.9-8.5 GHz and 10.7-13.25 GHz. Power output is 10 watts in the low band and 5 watts in the high band. A rack of equipment such as the one illustrated measures 90⅛″ × 20½″ × 22″ and weighs approximately 500 pounds with equipment for two channels. Some possible station types include two-way, two-channel terminal; one-channel, two-way repeater; or two channel, two-way repeater. (More than one rack is needed for some station types.)

To give some idea of the complexity of microwave equipment, Fig. 8-9 shows a portion of a rack that has been opened for servicing. Most of the equipment shown in this photograph is for one channel.

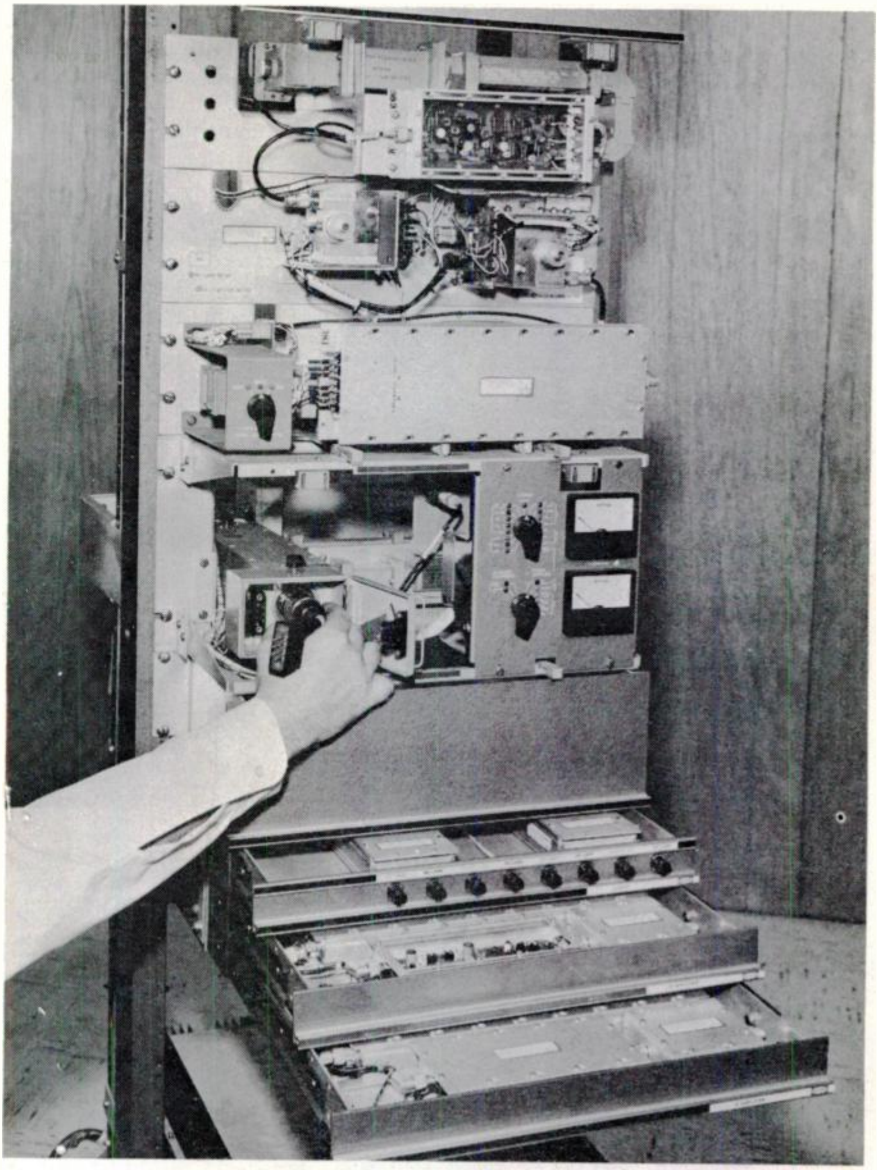
Although the equipment shown here is of the heterodyne type, some systems



Courtesy Raytheon Company
Fig. 8-8. Raytheon KTR-3A microwave relay equipment.

use *remodulating* repeaters. In this type of repeater, the incoming signal is demodulated to recover the information being transmitted. The recovered information is then used to modulate the transmitter for the outgoing signal.

The microwave equipment shown in Fig. 8-10 is intended for relay of television programs in STL, remote-pickup, or intercity-relay applications. The equipment is all-solid-state, is available for the 1990-2110 MHz and 6875-7125 MHz bands, and is designed to handle a color-television picture signal and (as an option) one or two audio subcarriers. The transmitter is frequency modulated and has an output of 2



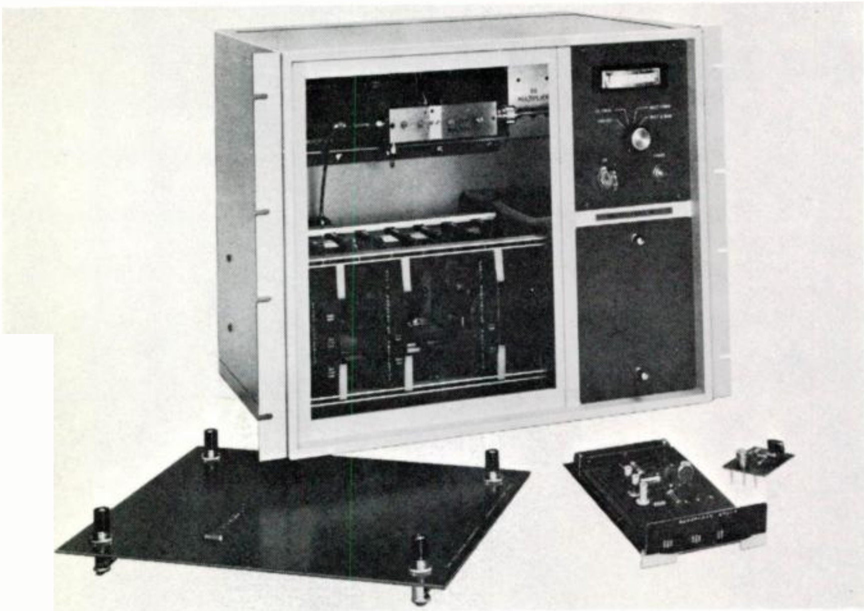
Courtesy Raytheon Company

Fig. 8-9. Raytheon KTR-3A microwave equipment with cabinet panels removed.

watts in the low band or 0.5 watt in the high band. Portable transmitting and/or receiving units consist of the relay-link equipment (in weatherproof case), an antenna with 4-foot dish, and a tripod with pan-and-tilt head to permit aiming the antenna. Rack-mounted versions are available for STL or intercity-relay use.

Other options in addition to audio subchannels include low-noise receiver preamplifiers, traveling-wave-tube output-power boosters (10-watt and 20-watt models), transmitter automatic frequency control (afc is standard on the receivers), and receiver i-f output for heterodyne or other applications. The standard power source is 115 volts, 47-400 Hz ac, but versions for 220 volts, 47-63 Hz ac and 24 or 48 volts dc are available. A receiver or transmitter unit measures 14" × 19" × 12" and weighs 35 pounds.

Fig. 8-11 shows a receiver for such applications as spectrum surveillance, electronic countermeasures, rf-interference studies, field-intensity measurements, and antenna-pattern measure-



(*A*) *Transmitter.*

(*B*) *Receiver.*

Courtesy RHG Electronics Laboratory, Inc.

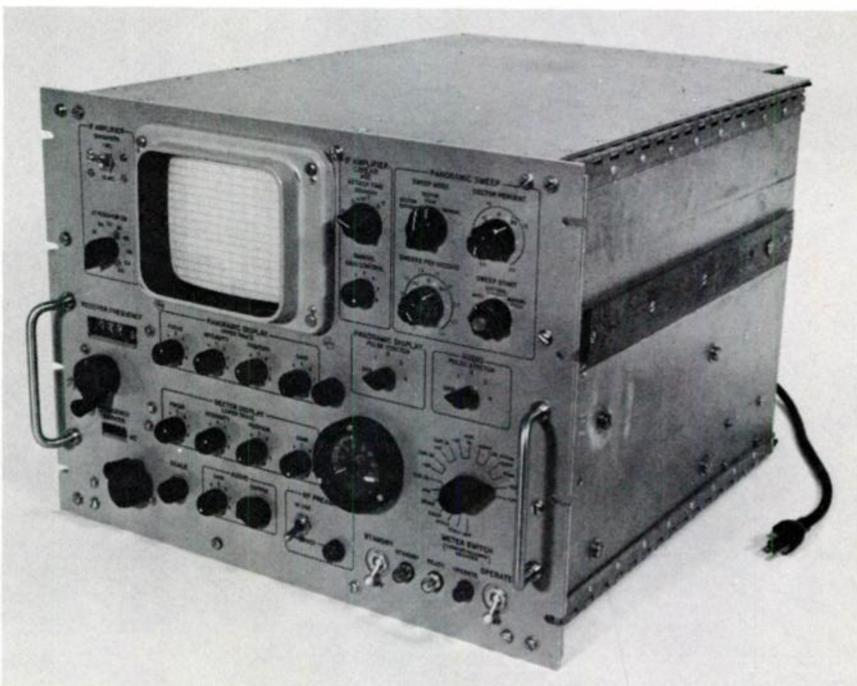
Fig. 8-10. RHG Model MRS-7A microwave equipment.

ments. Five of these receivers, each tuning over a different frequency band, make up a system that covers the range from 500 MHz to 12 GHz. The receiver is a double-conversion superheterodyne. It can be tuned manually, or it can be swept through its frequency band automatically, tuning through the entire band at a rate adjustable from one scan in 33⅓ seconds to 30 scans per second.

The receiver output is displayed on a cathode-ray tube (similar to a TV picture tube) in the following manner: Circuits in the receiver cause the beam of the cathode-ray tube (CRT) to sweep horizontally in step with the variation of the tuning system; thus the horizontal displacement of the spot on the CRT screen at any instant depends on the frequency to which the receiver is tuned at that instant. Other circuits cause the vertical deflection of the spot to depend on the strength of the signal being received at the same instant. As a result of these two actions, the spot on the face of the CRT traces out a graph of signal strength as a function of frequency—a chart of all the receivable signals in the band covered by the receiver. Such a display is known as a *panoramic display*.

The receiver in Fig. 8-11 contains a CRT that has two electron beams, and it provides two simultaneous panoramic displays. One display covers the entire frequency range being swept. The second display covers a segment of the full range that can be varied from 0.5 to 100 percent. The second display makes it possible to examine one signal while still receiving other signals in the band.

Some options available with the receiver are: automatic frequency control, for tracking of signals by the receiver local oscillator; strong-signal–supression circuits; and signal seek-and-lock capability. In the latter operation, the receiver scans through the band until it intercepts a signal. It stops scanning and remains tuned to the



Courtesy American Electronic Laboratories, Inc.

Fig. 8-11. *AEL* Model PAM-2 panoramic and manual receiver.

frequency of the signal for a preset time, and then resumes scanning. Also available is provision for automatically skipping over this frequency on subsequent scans (until the "memory" is reset). An auxiliary detection/analysis unit also is available.

The receiver measures 15" × 17" × 22" and weighs 120 pounds; its associated rf preamplifier measures 4" × 12" × 16" and weighs 30 pounds. The required power source is 115 volts, 50 to 400 Hz.

Communications Satellites

Communications satellites form a new, but increasingly important, link in world-wide communications. The satellites provide transoceanic relays, and their associated ground stations provide the connection between the satellite links and conventional ground communication facilities.

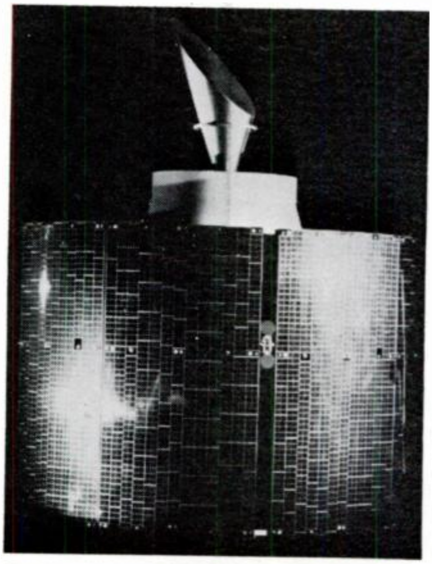
Intercontinental communications satellites are owned by the International Telecommunications Satellite Consortium (Intelsat). Intelsat, which has more than 70 member countries, is managed by the Communications Satellite Corporation (Comsat). Comsat is a corporation created by Congress, but it is financed through the sale of stock rather than by the Government. It is the only U.S. organization permitted to provide commercial communication services by satellite.

Courtesy Communications Satellite Corporation

Fig. 8-12. Antenna dish and pedestal at satellite-communication earth station.

Three Intelsat III satellites are in synchronous orbit; that is, their orbital speed and distance from the earth are such that they appear to be stationary over some point on the surface of the earth. These three satellites, over the Atlantic, Pacific, and Indian Oceans, provide world-wide coverage.

A world-wide network of some 30 earth stations is in operation, with 45 expected to be in service by the end of 1970. In the U.S., there are six earth stations (Fig. 8-12), which are owned jointly by a group of communication common-carrier companies. These stations are at Andover, Maine; Brewster Flat, Washington; Jamesburg, California; Etam, West Virginia; Paumalu, Hawaii; and Cayey, Puerto Rico.



Courtesy Communications Satellite Corporation

Fig. 8-13. An Intelsat III communications satellite.

An example of the earth stations is the Etam facility. It is located in a valley which serves to shield the receiving antenna from interfering signals. The antenna reflector, or "dish," is 97 feet in diameter and weighs 45,000 pounds, yet a complex tracking mechanism keeps it aimed at the satellite with an accuracy within hundredths of a degree.

The Intelsat III satellites (Fig. 8-13) receive signals from an earth transmitting station in the 5.93-6.42 GHz band, amplify them, shift them to the 3.705-4.195 GHz band, and retransmit them to an earth receiving station. There, the signals are boosted by highly sensitive amplifiers, and the message signals are recovered for further transmission over conventional land circuits. The satellite has two repeaters, or transponders, with an effective radiated power of about 160 watts each. The satellites are capable of relaying telephone messages, data, and television signals. They have a capacity of 1200 two-way voice circuits, four color-TV channels, or a mixture of voice and TV channels. Each satellite weighs 268 pounds in orbit and has a designed life of five years.

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