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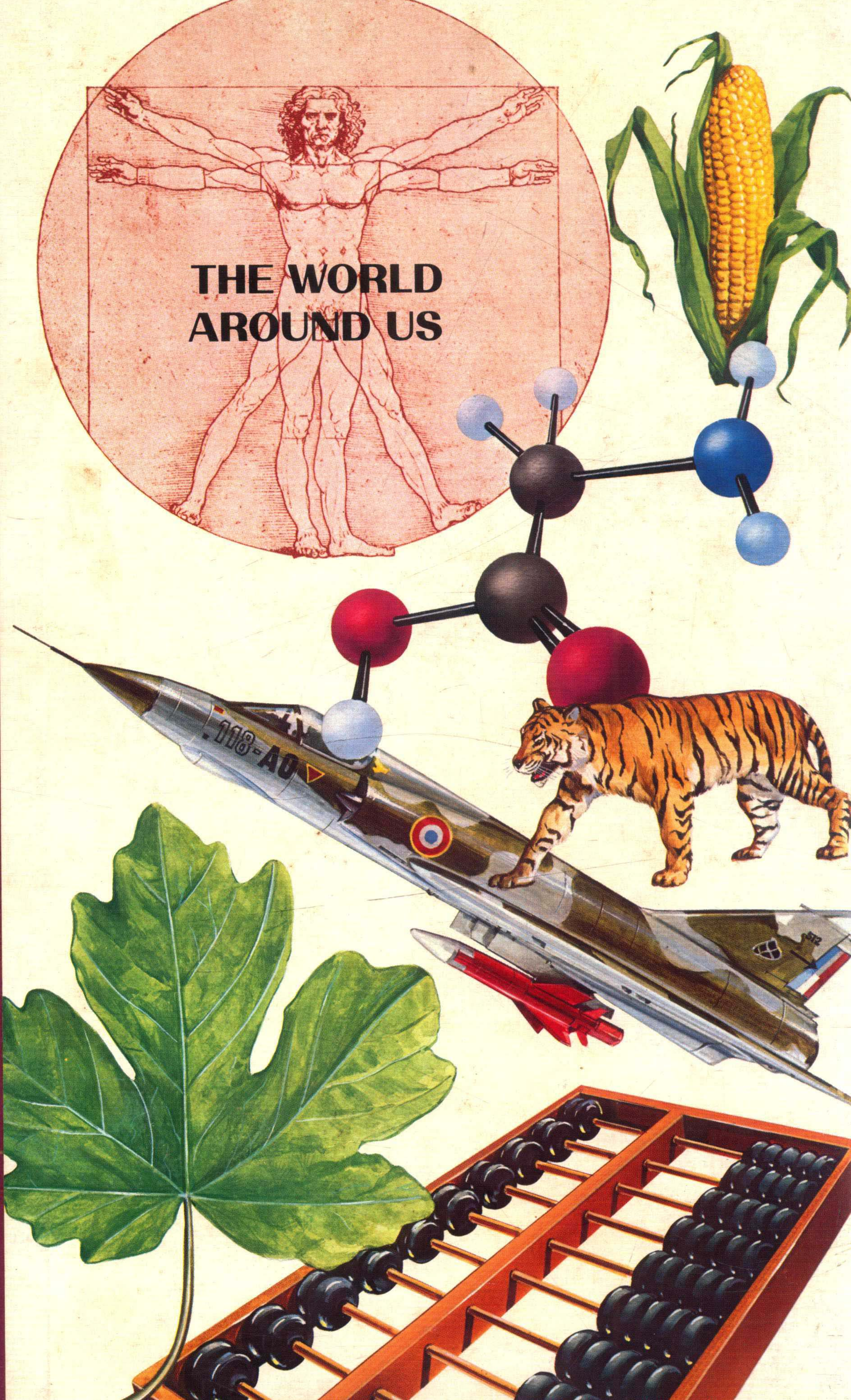
THE WORLD AROUND US



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1768

Encyclopaedia Britannica, Inc.
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PARIS • ROME
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TOKYO • TORONTO

Library of Congress Catalog Card Number: 84-80129

International Standard Book Number: 0-852229-425-5

English language edition by license of Gruppo Editoriale Fabbri

Title page photograph courtesy of Hale Observatories;
California Institute of Technology and
Carnegie Institution of Washington

Printed in U.S.A.

Science and Technology Illustrated

The World Around Us

Science Technology

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Volume 22

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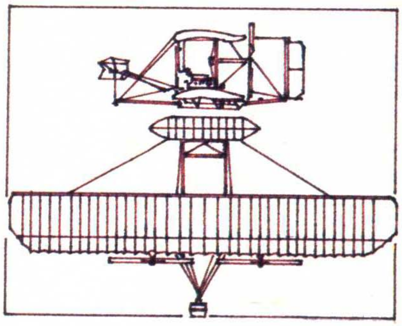

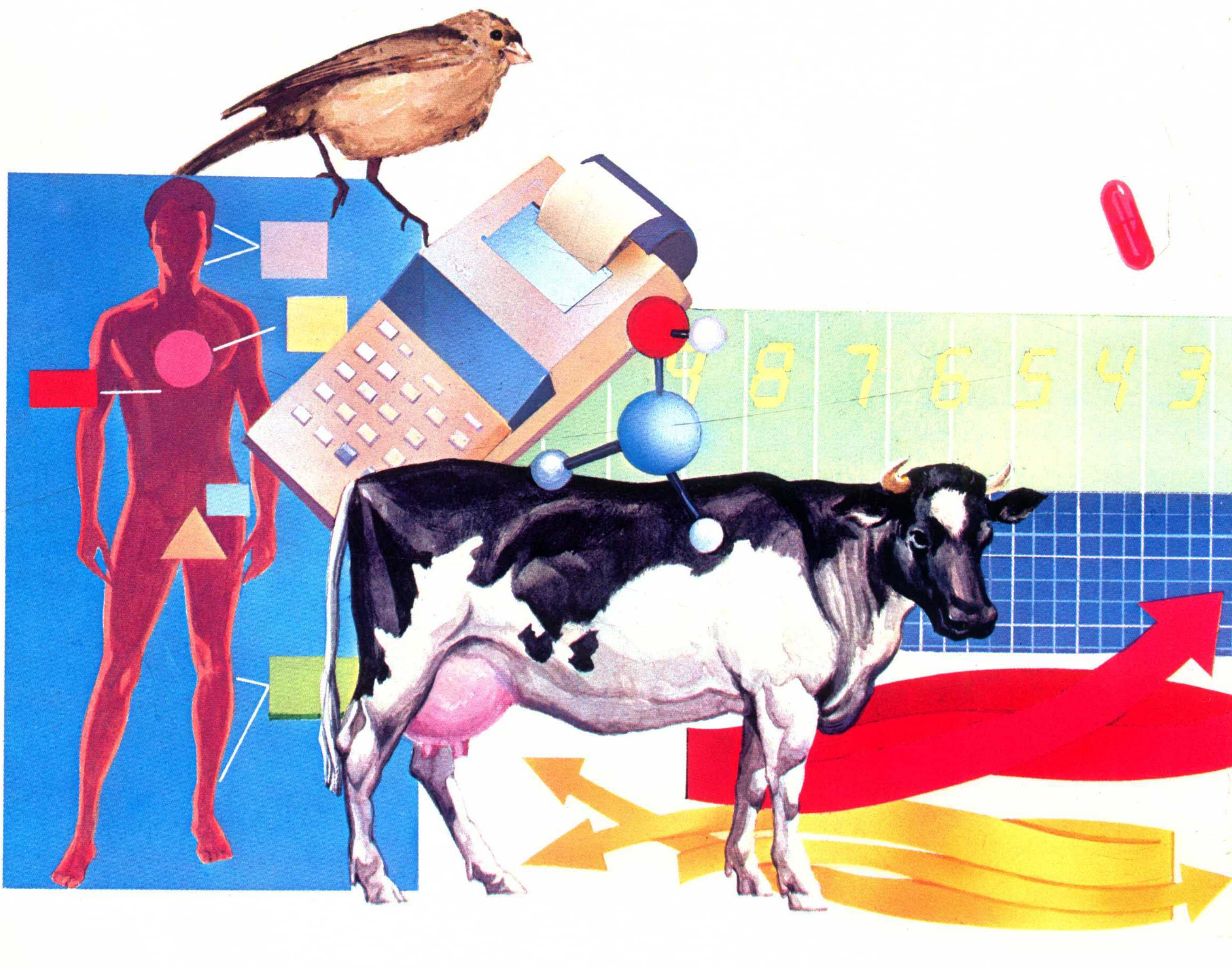

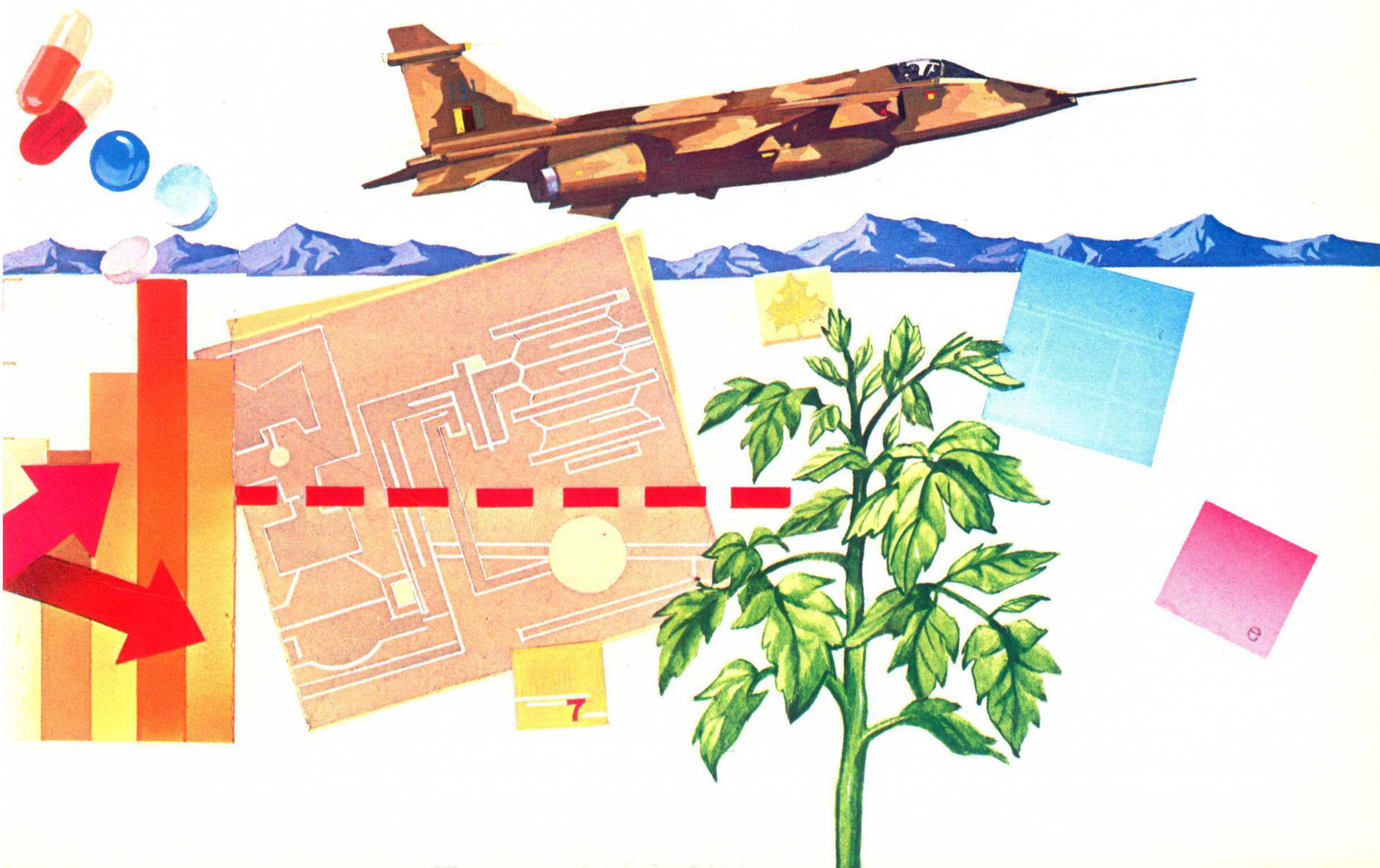

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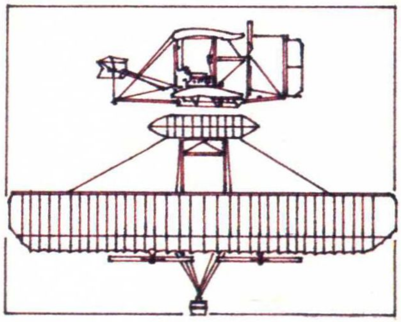


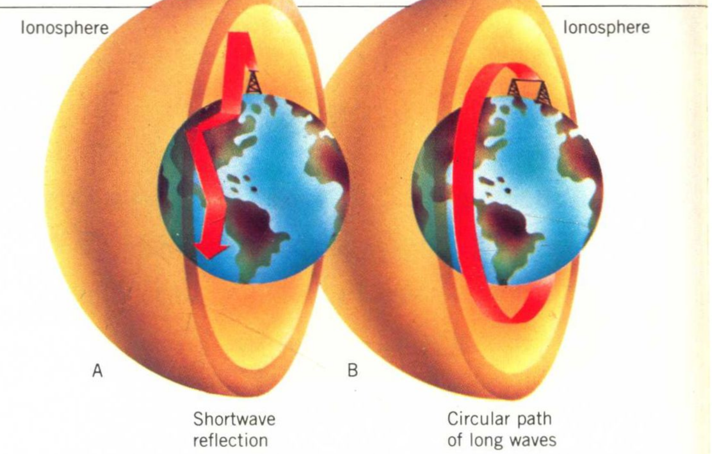
Radio

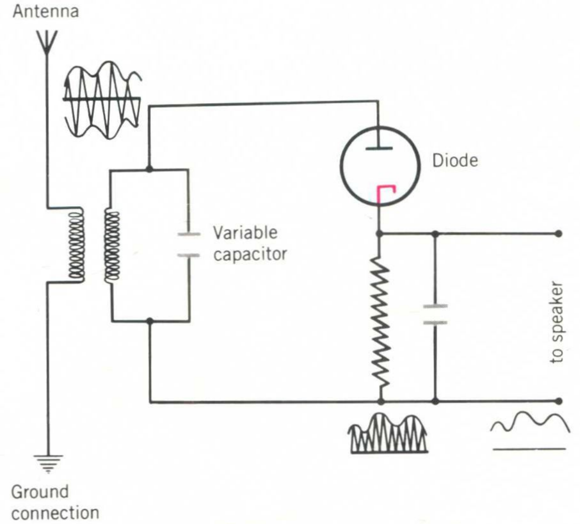
Although television is regarded as the most popular form of electronic communication in the world today, radio remains the most widely used medium of broadcasting. Without radio, many of the services and conveniences we enjoy in our daily lives would no longer be available. Radio plays a major role in public safety, industrial manufacturing and processing, agriculture, transportation, entertainment, national defense, space travel, overseas communication, news reporting, and weather forecasting.

The Italian inventor Guglielmo Marconi is considered to be the father of radio. It was, however, the English scientist James Maxwell who laid the theoretical foundation for the propagation of electronically generated radio waves in 1865, and the German physicist, Heinrich Hertz, who put Maxwell's theories into practice in 1888. When Marconi made his first paid broadcast from the Isle of Wight in 1898, the radio was officially born. Initially used for ship-to-shore communications, radio rapidly expanded to include overseas communications, when the theory that high-frequency radio waves are reflected from the ionosphere to the Earth was proven to be true in 1923.

Even though many new forms and techniques of radio transmission and broadcasting have been developed since the days of the early radio pioneers—including microwave telephone relay links, radio telemetry, and radio control—the basis of radio has remained the same. Radio is, by definition, a tool of communication that uses electromagnetism to transmit information between two points.

Radio signals are transmitted by electromagnetic waves from a transmitting station to a receiving station in a straight line. *Right:* (A) Short wavelengths are reflected by the ionosphere and the Earth's surface. (B) Trajectory of long wavelengths that follow the curvature of the Earth without being reflected.





Left: Schematic diagram of a simple radio diode receiver. The antenna is connected to the transformer's primary coil; the secondary coil is part of an oscillator circuit that has a variable tuning capacitor and receives one frequency. The electromotive force of the radio signal captured by the antenna travels through this oscillator and then passes through a diode, which filters everything but the positive voltage, which represents about half the received signal.

How Radio Works

All radio programs or signals are transmitted within a broad spectrum of waves called the electromagnetic spectrum. This spectrum is responsible for producing a variety of waves, from those that can be detected by the eye as light to those that must be detected by man-made machines, such as X rays. Radio waves are among the many types of electromagnetic waves that travel within the electromagnetic spectrum. Radio waves can be defined by their frequency (in hertz, after Heinrich Hertz, who first produced radio waves electronically), which is the number of times they pass through a complete cycle per second; or by their wavelength, which is determined by the distance (in meters) that is traveled from the crest of one wave to the crest of the next.

Radio frequencies are measured in units called kilohertz (kHz), megahertz (MHz), and gigahertz (1 kilohertz = 1,000 hertz; 1 megahertz = 10^6 hertz; 1 gigahertz = 10^9 hertz). All radio waves fall within a frequency range of 3 kilohertz, or 3,000 cycles per second, to 30 gigahertz. Within this range of frequencies, radio waves are further divided into groups or bands such as very low frequency (VLF 10-30 kHz), low frequency (LF 30-300 kHz), medium frequency (MF 300-3,000 kHz), high frequency (HF 3-30 MHz), and very high frequency (VHF 30-300 MHz).

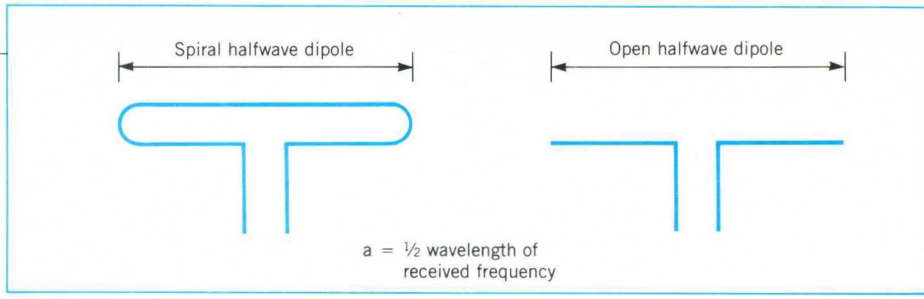
In order to understand how a radio works, it is necessary to follow the path that a radio signal takes to get from one point in space to another. The journey begins when an audible program source, such as a human voice or music, enters a microphone, where it is converted into electrical energy. This electrical audio signal is strengthened by means of amplification, then combined in a process called modulation (see below) with another electrical wave called a carrier wave. This wave, on which the initial audio signal is actually carried, is fed to a transmitter and antenna that throws the modulated carrier wave into the atmosphere, where it is selectively picked up by a receiver. In the receiver, the carrier wave is amplified before being demodulated, when the audio information is separated from it. The audio signal then travels on its own, through an amplifier and into a speaker, where it is reconverted from an electrical signal to a reproduction of the original sound.

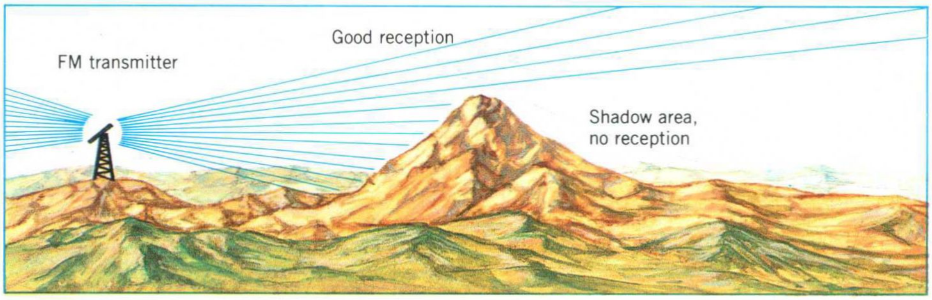
Because all radio waves travel at the speed of light (186,282 miles [299,784 km] per second, which is far greater than the traveling speed of sound), it is possible for radio listeners 3,000 miles (4,800 km) away to hear a live broadcast a fraction of a second sooner than the studio audience hears it.

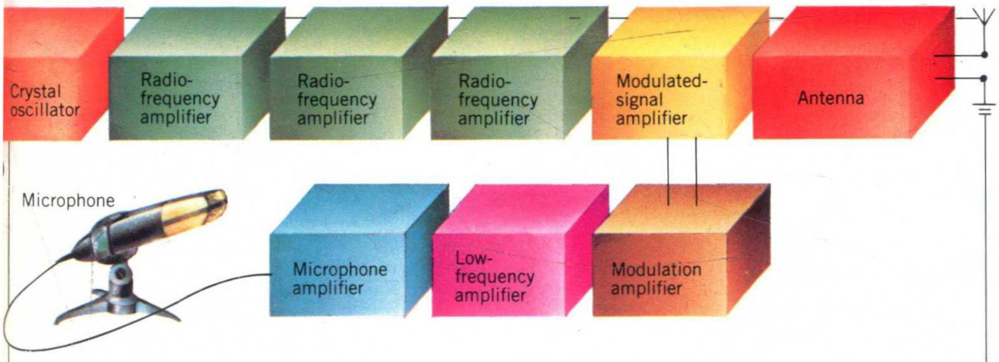
Modulation

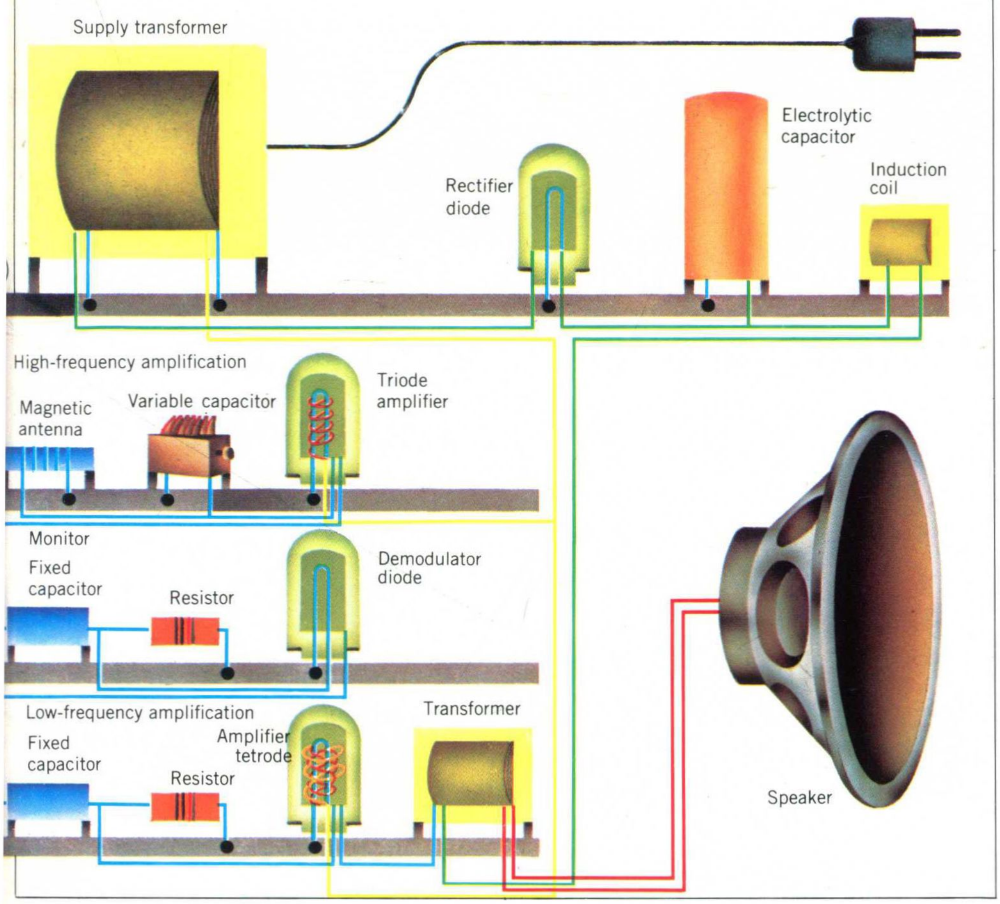
Modulation is the process by which the audio signal is superimposed on the carrier wave; it is the process by which the signal is made to "mount" the carrier wave, as a rider a horse. "To modulate" means to modify some specific quality of a thing—in this case, of the carrier wave. There are two principal modulating techniques. In amplitude modulation (AM), what is modified is the amplitude of a carrier wave on one specific frequency. In

Right: The simplest FM antenna is a half-wave dipole antenna. There are 2 types, spiral and open. A dipole antenna must be mounted in a high place, since obstructions absorb transmissions (see below), and the principal axis must be perpendicular to the director of transmission.









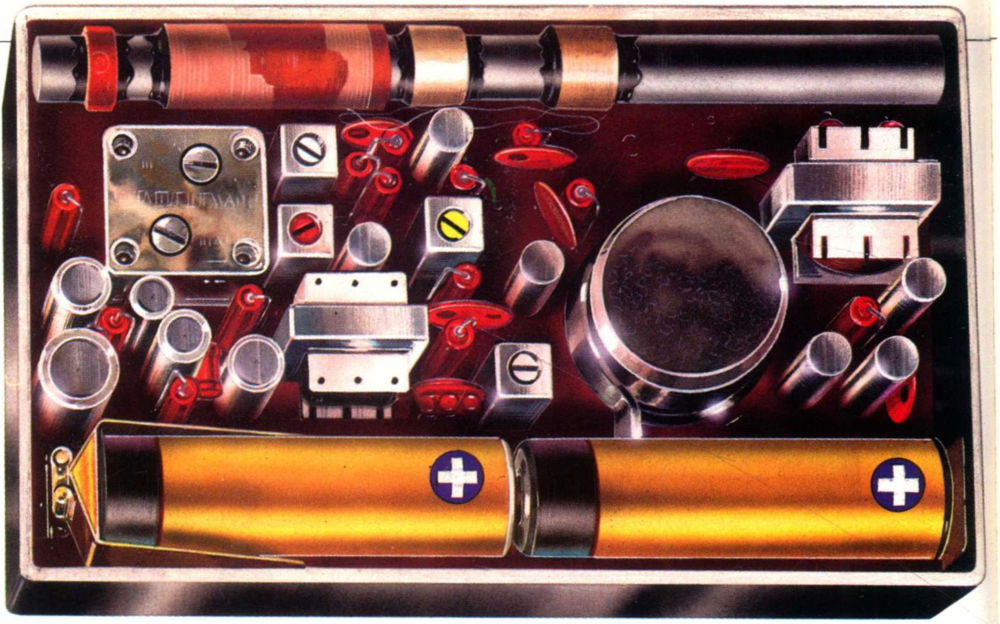
Left: (1) Elements of an amplitude-modulation (AM) transmitter. The carrier wave is superimposed on the transmitted signal at a low frequency and then modulated by an amplifier. (2) AM receiver. The current flow is changed from AC to DC for amplification of the radio signal. The demodulator removes the carrier wave from the audio signal, which is then amplified and passed to the speakers.

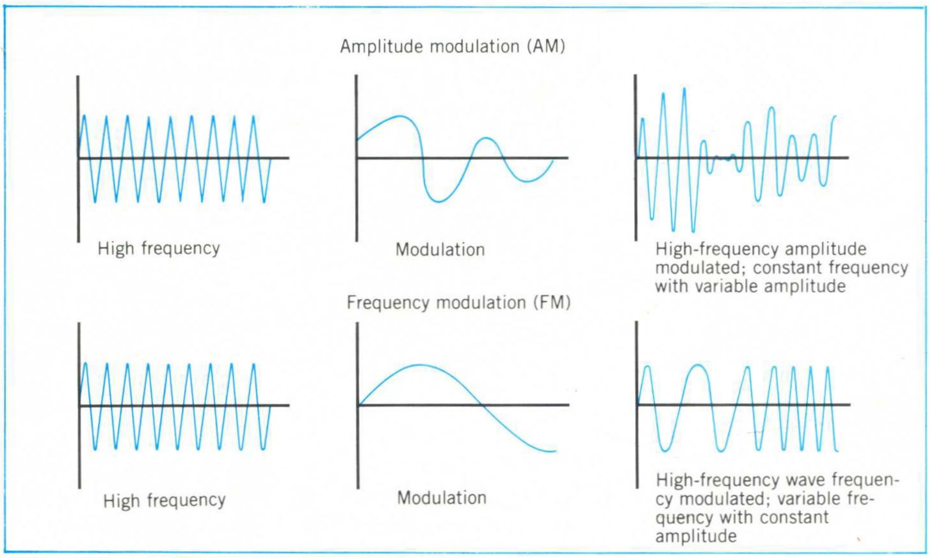
frequency modulation (FM), on the other hand, it is the frequency of the carrier wave that is modified, while its amplitude remains the same. Because the receiver can be tuned to any one carrier wave, it is able to pick up and select the one particular transmission or program carried by that wave at that time. Once the desired transmission has passed through the tuned circuits of the receiver, the carrier wave is no longer needed. It is therefore discarded during demodulation, the process by which the audio signal is made to dismount the carrier wave, as a rider from a horse. The initial audio signal or program then continues the journey on its own through amplification to the speaker.

Radio Transmission: AM, FM, Shortwave

When a program is transmitted through amplitude modulation (AM), the strength (amplitude) of the carrier wave varies according to changes in the initial audio signal, but its frequency remains stable. This stable carrier frequency, which is essential in order to avoid fading and distortion of the signal when it is picked up by the receiver as well as interference with other transmissions, is generated by a device called a crystal oscillator.

Not very different in design from the quartz oscillators that provide stability in quartz clocks, the crystal oscillator in an AM transmitter emits an alternating output voltage called a sine wave. At the required carrier frequency, this carrier wave is amplified by one or more RF (radio-frequency) amplifiers and is then fed to the modulating amplifier. Meanwhile, the audio signal passes from an AF (audio-frequency) amplifier to the modulating amplifier, where the instantaneous strength of the carrier is varied according to the instantaneous magnitude of the audio signal. Because of this process, in which the audio wave is combined with the carrier wave, the AM frequency has a double sideband (DSB), with a width of 5 kilohertz (totaling 10 kilohertz per signal).





Above: Interior of a transistor radio with principal parts indicated: (1) battery, (2) ferrite-core antenna, (3) speaker, (4) transformer, (5) power circuit, (6) oscillator, (7) radio-frequency amplifier, (8) audio-frequency amplifier. These radios can receive both AM and FM signals. In FM, the carrier-wave frequency is modulated; in AM, the carrier-wave amplitude is modulated.

Right: Tuners like these allow 8 AM and 8 FM stations to be preselected.

Two types of radio waves are broadcast by AM transmitters: ground waves, which spread out horizontally from the ground and travel along the Earth's surface, and sky waves, which travel up into the ionosphere where they are reflected back to Earth. This reflecting process, in which the waves are bounced back and forth from the Earth to the ionosphere, allows AM transmissions to travel great distances. AM radio stations with powerful transmitters can reach listeners as far as 1,000 miles (1,600 km) away.

In frequency modulation (FM) transmission, the frequency of the carrier wave varies according to the strength of the audio signal or program. Unlike AM, where the strength of the carrier wave varies, the strength of the carrier wave in FM remains the same, while its frequency varies above and below a central value. Broadcast (as opposed to communications) FM transmissions have a full radio-frequency bandwidth of 200 kilohertz. FM

broadcast waves (88-108 MHz) are shorter than AM broadcast waves (540-1,600 kHz) and do not go as far.

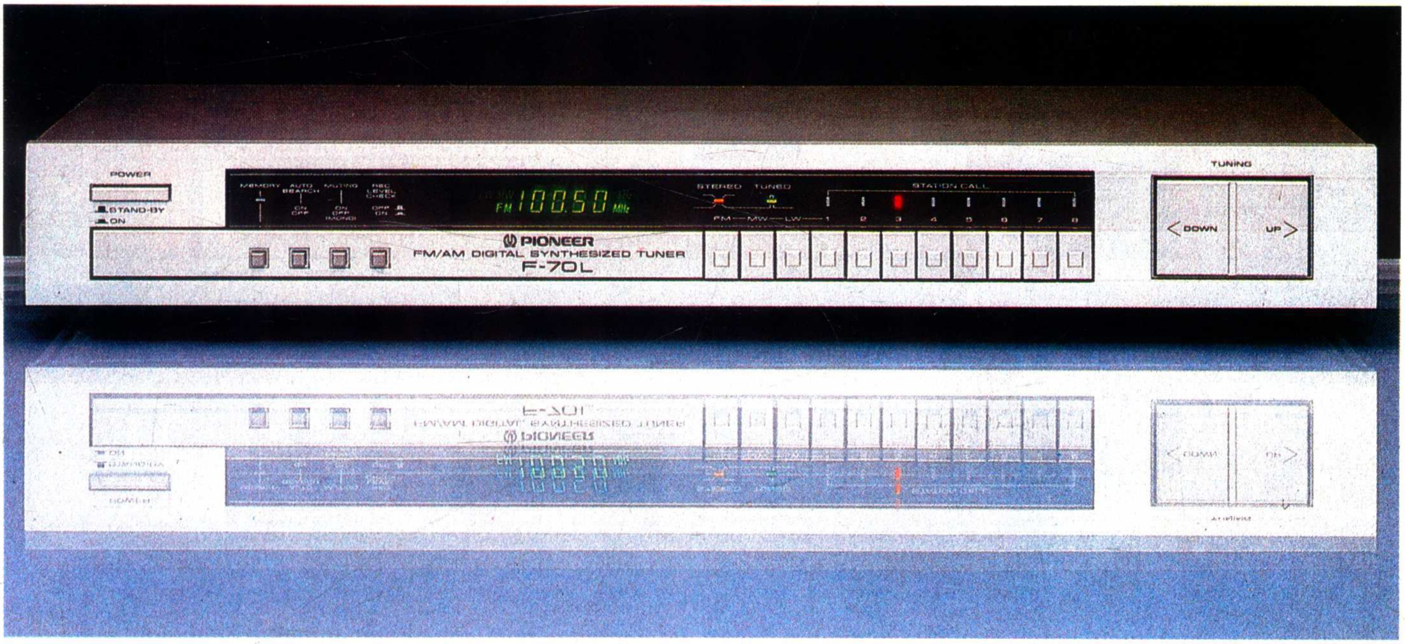
FM stations generally reach audiences from 15 to 65 miles (24-105 km) away. Because the frequency of the carrier wave is modulated, rather than the amplitude, background noise is reduced.

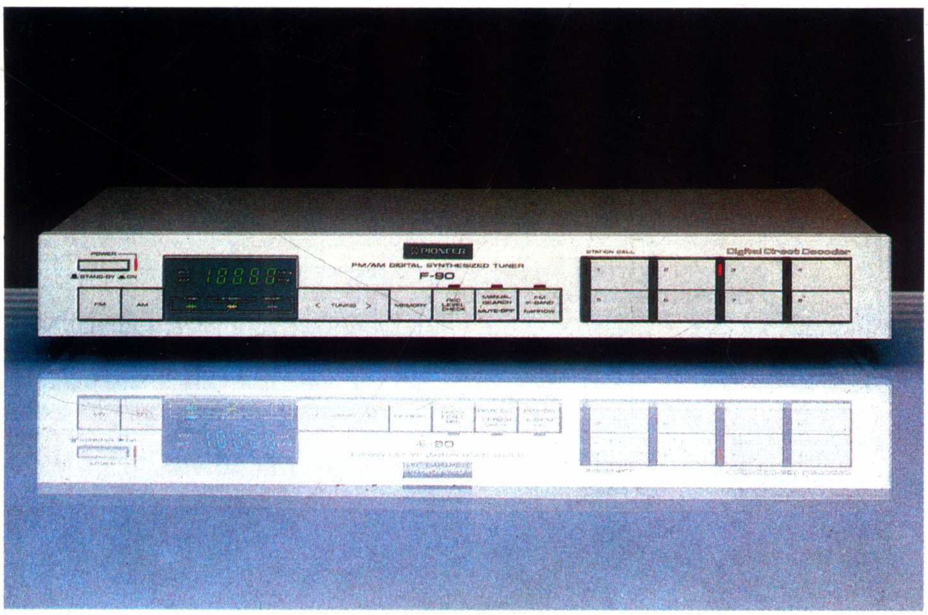
With the discovery shortly before World War I, that radio waves could travel great distances through reflection from layers of ionized air, shortwave radio transmissions began, using high-frequency waves (1.6-30 MHz) that can carry signals for thousands of miles. During World War I, most nations carried out all long-distance communication by shortwave transmission. Because of frequent jamming (when too many signals are transmitted simultaneously within the same frequency range [often done intentionally]), interception (when a message or broadcast is picked up by one or more unauthorized outside receivers), and interference (when electrical currents or radio waves cross into other fields of reception), messages have often been coded and used with highly directional antennae.

Radio Receivers

At present, there are two main types of receivers used in radio communication. The "tuned radio frequency" (TRF) is used for low-frequency and very-low-frequency AM signals. In the TRF receiver, each of the several RF amplifier stages is tuned to the carrier frequency of the desired station. The superheterodyne receiver is the most widely used system in both AM and FM receivers. In the superheterodyne system, the carrier frequency of the incoming signal is changed so that it can be amplified at one specific frequency in the receiver, rather than having to retune all the RF amplifier stages to the carrier frequency of the station to be received, as in a TRF receiver. This conversion takes place when the frequency of the incoming signal and the output frequency of the receiver's tunable oscillator both pass through the converter stage.

The term "intermediate frequency" (IF) refers to the modified form the carrier frequency takes when it has been tuned to the circuitry of the receiver. Once produced, this intermediate frequency is amplified by an RF amplifier tuned to that intermediate frequency and then demodulated. The signal, now separated from the carrier, is amplified by an audio-frequency amplifier and then fed to a speaker. For example, if the station carrier is 1040 kHz, and the oscillator in the receiver is tuned to 585 kHz, the intermediate frequency is 455 kHz—a common IF for AM broadcast receivers.





Because the FM wave carrier is modulated in the transmitter by varying its frequency rather than its amplitude, the FM receiver system needs to create a varying voltage amplitude that corresponds to the varying frequency. This is done in the FM discriminator, where demodulation takes place. In an FM receiver, devices are also used to produce the cleanest, clearest sound, including stages of IF (intermediate frequency) amplification and a "limiter" stage that clips off any amplitude variations and extraneous noises on the IF carrier wave before it enters the discriminator. *See also* ANTENNA.

Radio Astronomy

In 1930, Karl Guthe Jansky, a young engineer in the fledgling science of radio, was assigned by the Bell Telephone Laboratories to study certain kinds of static that were hampering ship-to-shore and transatlantic radio communications. Jansky tinkered until he came up with a strange-looking apparatus made up of many interconnecting radio aerials mounted on a dolly that could be rotated around a central pivot on a set of four wheels taken from a Model T Ford car. Together with such familiar sources of static as lightning from local thunderstorms and a weaker type traceable to distant storms, Jansky also picked up a weak, steady hiss of static that he was at a loss to identify.

At first, Jansky thought the mysterious sound might be coming from the Sun, since it seemed strongest in the solar region of the sky. Then he noticed that the direction of the strongest signal varied regularly from day to day, until, over the course of a year, the source made a complete circle and returned to the solar region again. He puzzled long over his mysterious static, and by 1933 he had concluded that the radio waves were coming from the Milky Way—specifically, from a point near the center of the Galaxy in the constellation Sagittarius.

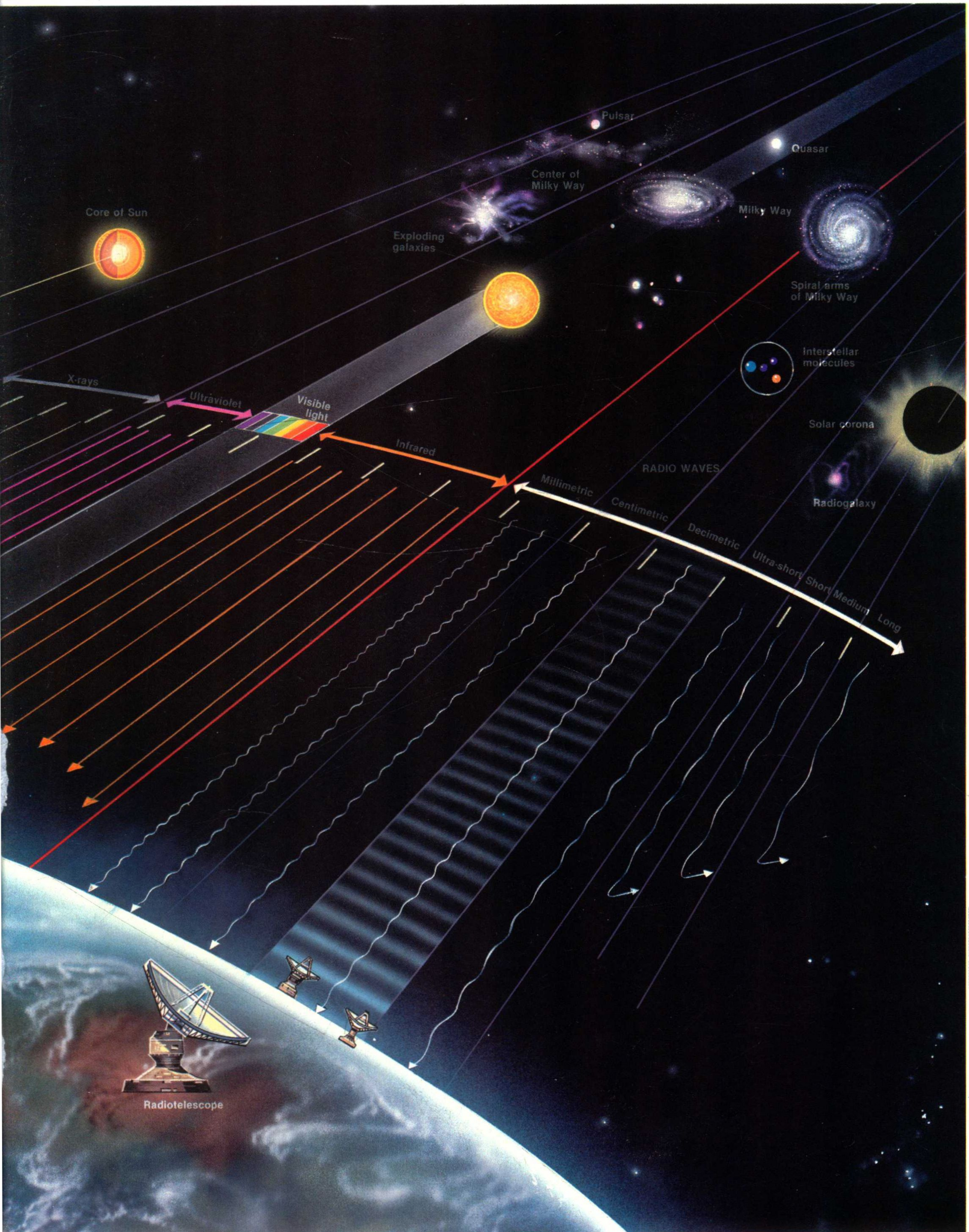
In this way, with the work of one person whose curiosity went well beyond the call of duty, the science of radio astronomy was born.

Jansky's discovery was described in a full-column story in the *New York Times* on May 5, 1933, headlined "New Radio Waves Traced to Center of Milky Way." An enterprising radio producer even broadcast a sample of galactic static as recorded by the Bell Laboratories. One newspaper commentator remrked that it sounded remarkably like the hiss of steam from a household radiator. It is hard to believe today, when radio astronomy is so indispensable a tool for scientists seeking an understanding of the Universe, that in the early 1930s Jansky's discovery received virtually no attention from the scientific community. Jansky himself was assigned to other projects and did no further significant research in the field.

Grote Reber's Telescope

Fortunately, a young radio buff named Grote Reber used $1,300 of his own scanty funds to build the first radio telescope, a parabolic (dish-shaped) antenna, in his own backyard. The reflector surface, designed to pick up and focus radio waves from outer space, was a little over 30 feet (9 m) in diameter and was made of 45 pieces of galvanized sheet iron mounted on 72 wooden rafters cut to give a para-

Diagram illustrates how radio astronomy has contributed to our understanding of the Universe. Each form of electromagnetic radiation, from the ultrashort gamma waves, through X rays, ultraviolet light, visible light, and infrared radiation, to the longest of the radio waves, is associated with a different type of astronomical phenomenon. Only by combining information from all these sources can astronomers gain a complete picture of the galaxy and space beyond. (Length of waves is indicated in centimeters.)



Pulsar
Quasar
Center of Milky Way
Milky Way
Core of Sun
Exploding galaxies
Spiral arms of Milky Way
Interstellar molecules
Solar corona
X-rays
Ultraviolet
Visible light
Infrared
RADIO WAVES
Millimetric
Centimetric
Decimetric
Ultra-short
Short
Medium
Long
Radiogalaxy
Radiotelescope

bolic shape to the finished instrument. During the autumn and winter of 1938-39, he experimented constantly with his new "telescope," until he finally started detecting radio impulses at a wavelength of 1.87 m (6.1 feet).

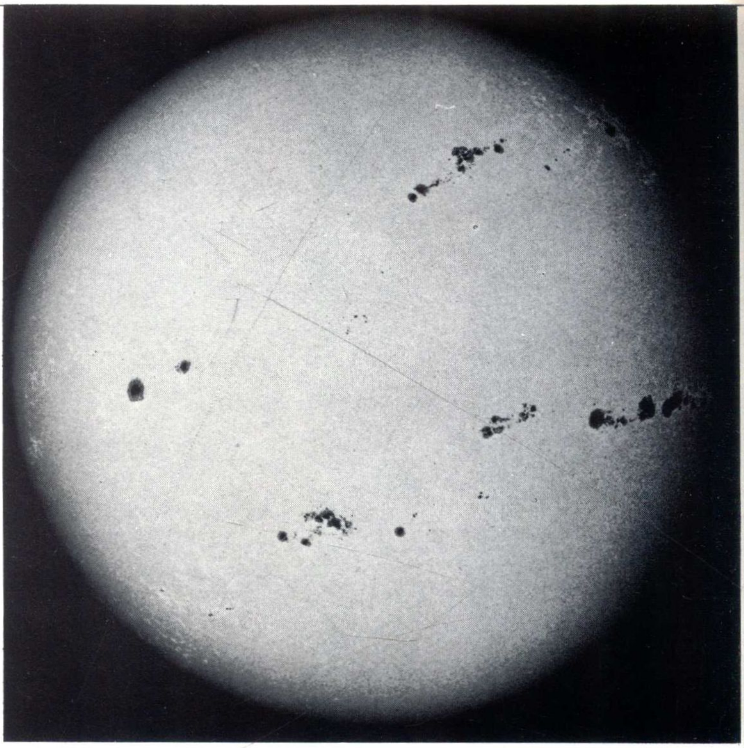
In trying to understand what it is that radio astronomers do, we might recall that traditional astronomers who study the Universe through conventional optical telescopes use only a very small part of the electromagnetic spectrum, the narrow band of waves that are visible to the eye. Other kinds of electromagnetic waves, detectable only by instruments, include cosmic rays, gamma rays, X rays, ultraviolet rays (too short to be detected by the eye), infrared rays (too long for us to see), and, longest of all, radio waves. The wavelengths of all these various forms of electromagnetic radiation—that is, the distance from the crest of one wave to the next—are measured in various units, from angstroms (1×10^{-10} m) for gamma rays, X rays, ultraviolet rays, and visible light, through microns (millionths of a meter) for infrared light, to the familiar millimeters, centimeters, meters, and kilometers for microwaves, short radio waves, broadcast-band radio waves, and long radio waves, which may have wavelengths up to 1,000 kilometers.

Synchrotron Radiation

During World War II, great advances were made in the study of radio theory and practice. Thus, when astronomers after the war got around to developing the field opened up by Jansky and Reber's researches, they found efficient new tools ready, and over the last 3 or 4 decades, radio astronomy has radically changed our understanding of the Universe. Before we take a look at these developments, let us examine what radio astronomers observe with their radio telescopes.

When you listen to the radio or watch television, the program is being transmitted by human manipulation of wave phenomena. Special wavelengths are selected, apparatus is assembled to convert sight and sound into electronic terms, and your receiver reconverts electronic impulses into visual and audible effects that your eyes and ears can detect. The radio waves picked up by radio telescopes are of a special kind known as synchroton radiation, produced whenever (as in the stars and galaxies) there are electrons orbiting in a magnetic field.

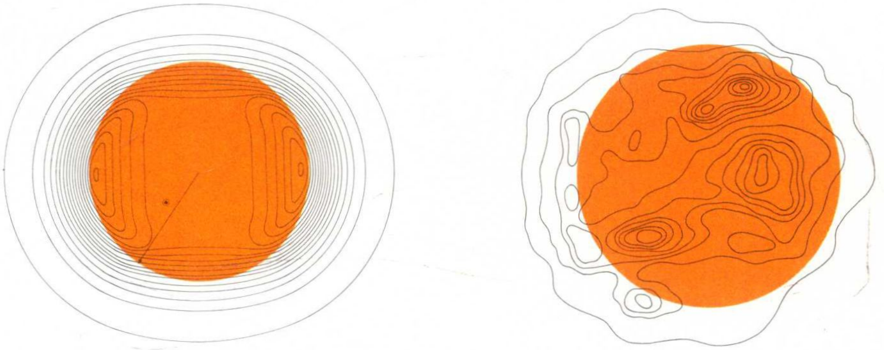
Virtually all heavenly bodies have detectable magnetic fields, ranging from very weak to incredibly intense, which produce radio waves that travel at very close to the speed of light (186,000 miles, or 300,000 km, per second). The radio waves

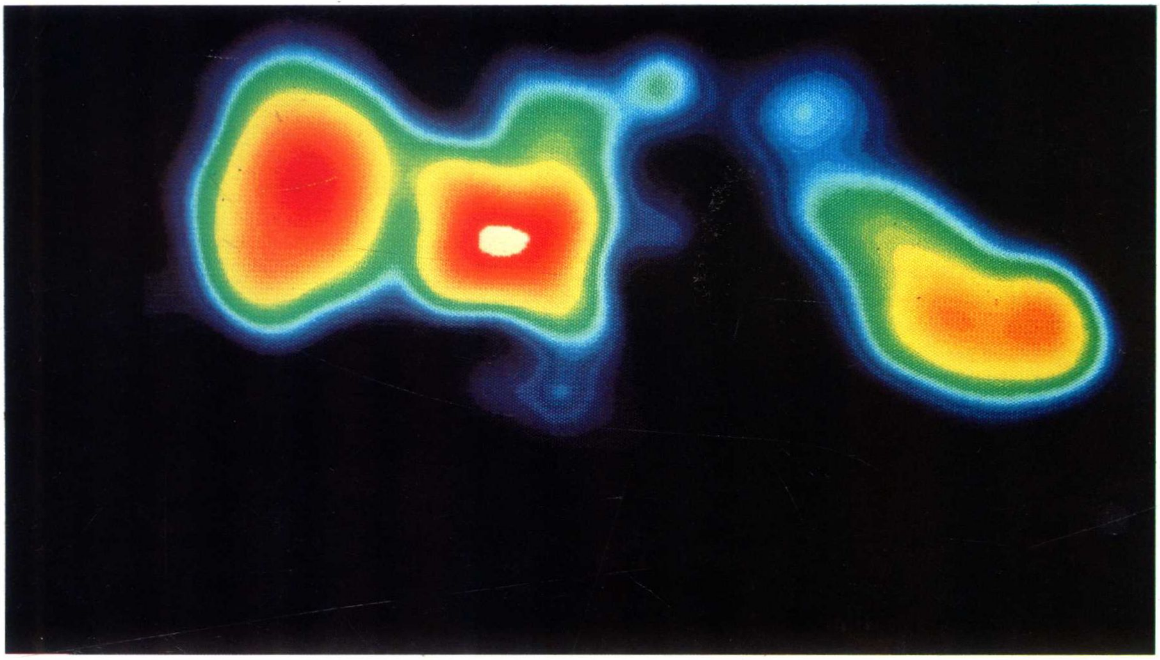


Right: Photograph in visible light of the Sun during a period of solar disturbance. Sunspots are evident.

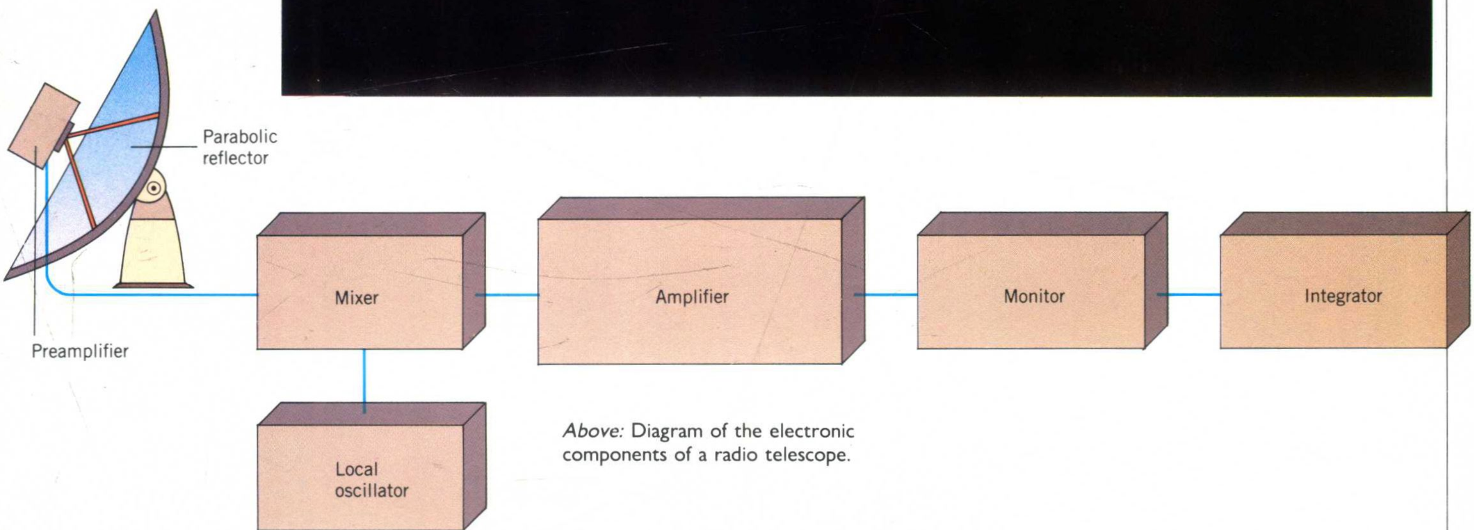
Below: Radio-telescope images of the Sun in a calm state (left) and in a disturbed state (right).

Bottom: Radio-telescope image of a distant galaxy superimposed on an optical photograph of the same galaxy.





Right: Computer-generated false color image of the nucleus of a radio galaxy. Two radio telescopes, mounted 10,000 km apart and synchronized with an atomic clock, were used to produce this high-resolution image.



Above: Diagram of the electronic components of a radio telescope.

emitted fall between the wavelengths of approximately 0.2 inch (0.5 cm) to a maximum of about 100 feet (30 m). Radio astronomers can either simply receive and examine the radio waves or, for certain special purposes, generate radio waves themselves and bounce them off such celestial objects as the Moon or the planets of the Solar System. Knowing how long it takes a wave to reach its target and return, it is easy to calculate the distance to the target by multiplying the time in seconds by the speed of light.

One of the first tasks radio astronomers assumed was to find evidence of meteor showers during daytime hours. Meteors (shooting stars) are a familiar sight to most people, for they are easily visible at night when they burn up in the Earth's atmosphere. Scientists had long assumed that there must be similar meteor activity during the daylight hours, but until the great, fully steerable radio telescope at Jodrell Bank in England became available, it was impossible to find any evidence to support their conjecture. The Jodrell Bank instrument, acting as a radar transmitter, showed that such daytime meteors exist, and the British astronomers found they could also record the growth of the meteor track and calculate the speed of the meteors. The last bit of information was useful in proving that meteors are inhabitants of the Solar System since their maximum observed speeds are well below the escape velocity that would be characteristic of a body capable of leaving the gravitational field of the Sun.

In the period when the Jodrell Bank radio telescope was the biggest in the world, such British scientists as Sir Bernard Lovell, J. S. Hey, and the Nobel laureate Sir Edward V. Appleton were the outstanding leaders in the field. Today, there are radio-astronomy facilities elsewhere in Britain as well as in Australia, Canada, the United States, the Netherlands, Russia, France, Italy, and Japan; their number and distribution are still increasing.

Radio Stars

The first identification of a radio star was made by Hey and a group of colleagues working with a modified radar receiver. Although the term "radio star" is widely used, what Hey discovered is probably not a single star but a sharply limited region of the sky producing intense radiation. Radio stars may be galaxies merging and passing through one another, remnants of supernovas like the Crab Nebula, or even luminous clouds of gas. Hey's source has been named Cygnus A, meaning the first radio source identified in the constellation Cygnus. Gradually, thousands of radio stars have been identified and named, but Cygnus A is still probably the most powerful of all.

Once radio astronomers had informed their colleagues in charge of the great optical telescopes that something strange was happening at a certain location in the sky, it was found out that the powerful source of radio waves is two galaxies in collision—or, rather, *was,* since it has taken both light and radio waves from Cygnus