**Microwave**

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*This article is about the* [*electromagnetic wave*](https://en.wikipedia.org/wiki/Electromagnetic_wave)*. For the cooking appliance, see* [*Microwave oven*](https://en.wikipedia.org/wiki/Microwave_oven)*. For other uses, see* [*Microwaves (disambiguation)*](https://en.wikipedia.org/wiki/Microwaves_%28disambiguation%29)*.*

A telecommunications tower with a variety of dish antennas for [microwave relay](https://en.wikipedia.org/wiki/Microwave_relay) links on [Frazier Peak](https://en.wikipedia.org/wiki/Frazier_Peak), Ventura County, [California](https://en.wikipedia.org/wiki/California).

The atmospheric [attenuation](https://en.wikipedia.org/wiki/Attenuation) of microwaves in dry air with a precipitable water vapor level of 0.001 mm. The downward spikes in the graph correspond to frequencies at which microwaves are absorbed more strongly. Some standardsdesignate the righthand side of the graph as within the range of [infrared](https://en.wikipedia.org/wiki/Infrared).

**Microwaves** are a form of [electromagnetic radiation](https://en.wikipedia.org/wiki/Electromagnetic_radiation) with [wavelengths](https://en.wikipedia.org/wiki/Wavelength) ranging from as long as one meter to as short as one millimeter; with [frequencies](https://en.wikipedia.org/wiki/Frequency) between 300 MHz (100 cm) and 300 GHz (0.1 cm). This broad definition includes both [UHF](https://en.wikipedia.org/wiki/Ultra_high_frequency) and [EHF](https://en.wikipedia.org/wiki/Extremely_high_frequency) ([millimeter waves](https://en.wikipedia.org/wiki/Millimeter_wave)), and various sources use different boundaries. In all cases, microwave includes the entire [SHF](https://en.wikipedia.org/wiki/Super_high_frequency) band (3 to 30 GHz, or 10 to 1 cm) at minimum, with [RF engineering](https://en.wikipedia.org/wiki/RF_engineering) often restricting the range between 1 and 100 GHz (300 and 3 mm).

The [prefix](https://en.wikipedia.org/wiki/Prefix) [*micro-*](https://en.wiktionary.org/wiki/micro-) in *microwave* is not meant to suggest a wavelength in the micrometer range. It indicates that microwaves are "small", compared to waves used in typical [radio broadcasting](https://en.wikipedia.org/wiki/Radio_broadcasting), in that they have shorter wavelengths. The boundaries between [far infrared](https://en.wikipedia.org/wiki/Far_infrared), [terahertz radiation](https://en.wikipedia.org/wiki/Terahertz_radiation), microwaves, and [ultra-high-frequency](https://en.wikipedia.org/wiki/Ultra-high-frequency) [radio](https://en.wikipedia.org/wiki/Radio) [waves](https://en.wikipedia.org/wiki/Wave) are fairly arbitrary and are used variously between different fields of study.

Beginning at about 40 GHz, the atmosphere becomes less transparent to microwaves, due at lower frequencies to [absorption](https://en.wikipedia.org/wiki/Absorption_%28electromagnetic_radiation%29) from water vapor and at higher frequencies from oxygen. A spectral band structure causes absorption peaks at specific frequencies (see graph at right). Above 100 GHz, the absorption of electromagnetic radiation by Earth's atmosphere is so great that it is in effect [opaque](https://en.wikipedia.org/wiki/Opacity_%28optics%29), until the atmosphere becomes transparent again in the so-called [infrared](https://en.wikipedia.org/wiki/Infrared) and [optical window](https://en.wikipedia.org/wiki/Optical_window) frequency ranges.

The term *microwave* also has a more technical meaning in [electromagnetics](https://en.wikipedia.org/wiki/Electromagnetics) and [circuit theory](https://en.wikipedia.org/wiki/Circuit_theory). Apparatus and techniques may be described qualitatively as "microwave" when the frequencies used are high enough that wavelengths of signals are roughly the same as the dimensions of the equipment, so that [lumped-element circuit theory](https://en.wikipedia.org/wiki/Lumped_element_model) is inaccurate. As a consequence, practical microwave technique tends to move away from the discrete [resistors](https://en.wikipedia.org/wiki/Resistor), [capacitors](https://en.wikipedia.org/wiki/Capacitor), and [inductors](https://en.wikipedia.org/wiki/Inductor) used with lower-frequency [radio waves](https://en.wikipedia.org/wiki/Radio_waves). Instead, [distributed circuit elements](https://en.wikipedia.org/wiki/Distributed_element_model) and transmission-line theory are more useful methods for design and analysis. Open-wire and coaxial [transmission lines](https://en.wikipedia.org/wiki/Transmission_line) used at lower frequencies are replaced by [waveguides](https://en.wikipedia.org/wiki/Waveguide) and [strip line](https://en.wikipedia.org/wiki/Stripline), and lumped-element tuned circuits are replaced by cavity [resonators](https://en.wikipedia.org/wiki/Resonator) or resonant lines. In turn, at even higher frequencies, where the wavelength of the electromagnetic waves becomes small in comparison to the size of the structures used to process them, microwave techniques become inadequate, and the methods of [optics](https://en.wikipedia.org/wiki/Optics) are used.

**The electromagnetic spectrum**

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| --- |
| [**Electromagnetic spectrum**](https://en.wikipedia.org/wiki/Electromagnetic_spectrum) |
| **Name** | **Wavelength** | [**Frequency (Hz)**](https://en.wikipedia.org/wiki/Hertz#SI_multiples) | [**Photon**](https://en.wikipedia.org/wiki/Photon)[**energy**](https://en.wikipedia.org/wiki/Energy) **(**[**eV**](https://en.wikipedia.org/wiki/Electronvolt#Properties)**)** | **Range width (**[**Bel**](https://en.wikipedia.org/wiki/Bel)**)** |
| [Gamma ray](https://en.wikipedia.org/wiki/Gamma_ray) | < 0.02 nm | > 15 [E](https://en.wikipedia.org/wiki/Exa-)Hz | > 62.1 [ke](https://en.wikipedia.org/wiki/Kilo-)V | infinite |
| [X-ray](https://en.wikipedia.org/wiki/X-ray) | 0.01 nm – 10 nm | 30 EHz – 30 [P](https://en.wikipedia.org/wiki/Peta-)Hz | 124 keV – 124 eV | 3 |
| [Ultraviolet](https://en.wikipedia.org/wiki/Ultraviolet) | 10 nm – 400 nm | 30 PHz – 750 THz | 124 eV – 3 eV | 1.6 |
| [Visible light](https://en.wikipedia.org/wiki/Visible_light) | 390 nm – 750 nm | 770 THz – 400 THz | 3.2 eV – 1.7 eV | 0.3 |
| [Infrared](https://en.wikipedia.org/wiki/Infrared) | 750 nm – 1 mm | 400 THz – 300 GHz | 1.7 eV – 1.24 [me](https://en.wikipedia.org/wiki/Milli)V | 3.1 |
| **Microwave** | 1 mm – 1 m | 300 GHz – 1 GHz | 1.24 meV – 1.24 [µe](https://en.wikipedia.org/wiki/Micro-)V | 3 |
| [Radio](https://en.wikipedia.org/wiki/Radio_waves) | 1 mm – 100,000 km | [300 GHz](https://en.wikipedia.org/wiki/Extremely_high_frequency) – [3 Hz](https://en.wikipedia.org/wiki/Extremely_low_frequency) | 1.24 meV – 12.4 [fe](https://en.wikipedia.org/wiki/Femto-)V | 8 |

**Microwave Sources**

Cutaway view inside a [cavity magnetron](https://en.wikipedia.org/wiki/Cavity_magnetron) as used in a [microwave oven](https://en.wikipedia.org/wiki/Microwave_oven) *(left)*. Antenna splitter: [microstrip](https://en.wikipedia.org/wiki/Microstrip) techniques become increasingly necessary at higher frequencies *(right)*.

High-power microwave sources use specialized [vacuum tubes](https://en.wikipedia.org/wiki/Vacuum_tube) to generate microwaves. These devices operate on different principles from low-frequency vacuum tubes, using the ballistic motion of electrons in a vacuum under the influence of controlling electric or magnetic fields, and include the [magnetron](https://en.wikipedia.org/wiki/Magnetron) (used in [microwave ovens](https://en.wikipedia.org/wiki/Microwave_oven)), [klystron](https://en.wikipedia.org/wiki/Klystron), [traveling-wave tube](https://en.wikipedia.org/wiki/Traveling-wave_tube) (TWT), and [gyrotron](https://en.wikipedia.org/wiki/Gyrotron). These devices work in the [density](https://en.wikipedia.org/wiki/Density) modulated mode, rather than the [current](https://en.wikipedia.org/wiki/Electric_current) modulated mode. This means that they work on the basis of clumps of electrons flying ballistically through them, rather than using a continuous stream of electrons.

Low-power microwave sources use solid-state devices such as the [field-effect transistor](https://en.wikipedia.org/wiki/Field-effect_transistor) (at least at lower frequencies), [tunnel diodes](https://en.wikipedia.org/wiki/Tunnel_diode), [Gunn diodes](https://en.wikipedia.org/wiki/Gunn_diode), and [IMPATT diodes](https://en.wikipedia.org/wiki/IMPATT_diode). Low-power sources are available as benchtop instruments, rackmount instruments, embeddable modules and in card-level formats. A [maser](https://en.wikipedia.org/wiki/Maser) is a solid state device which amplifies microwaves using similar principles to the [laser](https://en.wikipedia.org/wiki/Laser), which amplifies higher frequency light waves.

All warm objects emit low level microwave [black-body radiation](https://en.wikipedia.org/wiki/Black-body_radiation), depending on their [temperature](https://en.wikipedia.org/wiki/Temperature), so in meteorology and [remote sensing](https://en.wikipedia.org/wiki/Remote_sensing) [microwave radiometers](https://en.wikipedia.org/wiki/Microwave_radiometer) are used to measure the temperature of objects or terrain . The sun and other astronomical radio sources such as [Cassiopeia A](https://en.wikipedia.org/wiki/Cassiopeia_A) emit low level microwave radiation which carries information about their makeup, which is studied by [radio astronomers](https://en.wikipedia.org/wiki/Radio_astronomer) using receivers called [radio telescopes](https://en.wikipedia.org/wiki/Radio_telescope). The [cosmic microwave background radiation](https://en.wikipedia.org/wiki/Cosmic_microwave_background_radiation) (CMBR), for example, is a weak microwave noise filling empty space which is a major source of information on [cosmology](https://en.wikipedia.org/wiki/Physical_cosmology)'s [Big Bang](https://en.wikipedia.org/wiki/Big_Bang) theory of the origin of the [Universe](https://en.wikipedia.org/wiki/Universe).

**Microwave uses**

Microwave technology is extensively used for [point-to-point telecommunications](https://en.wikipedia.org/wiki/Point-to-point_%28telecommunications%29) (i.e. non-broadcast uses). Microwaves are especially suitable for this use since they are more easily focused into narrower beams than radio waves, allowing [frequency reuse](https://en.wikipedia.org/wiki/Frequency_reuse); their comparatively higher frequencies allow broad [bandwidth](https://en.wikipedia.org/wiki/Bandwidth_%28signal_processing%29) and high [data transmission rates](https://en.wikipedia.org/wiki/Data_transmission_rate), and antenna sizes are smaller than at lower frequencies because antenna size is inversely proportional to transmitted frequency. Microwaves are used in spacecraft communication, and much of the world's data, TV, and telephone communications are transmitted long distances by microwaves between ground stations and [communications satellites](https://en.wikipedia.org/wiki/Communications_satellite). Microwaves are also employed in [microwave ovens](https://en.wikipedia.org/wiki/Microwave_oven) and in [radar](https://en.wikipedia.org/wiki/Radar) technology.

**Communication**

Main articles: [Point-to-point (telecommunications)](https://en.wikipedia.org/wiki/Point-to-point_%28telecommunications%29), [Microwave transmission](https://en.wikipedia.org/wiki/Microwave_transmission) and [Satellite communications](https://en.wikipedia.org/wiki/Satellite_communications)

Before the advent of [fiber-optic](https://en.wikipedia.org/wiki/Fiber-optic) transmission, most [long-distance](https://en.wikipedia.org/wiki/Long-distance_call) [telephone calls](https://en.wikipedia.org/wiki/Telephone_call) were carried via networks of [microwave radio relay](https://en.wikipedia.org/wiki/Microwave_radio_relay) links run by carriers such as [AT&T Long Lines](https://en.wikipedia.org/wiki/AT%26T_Long_Lines). Starting in the early 1950s, [frequency division multiplex](https://en.wikipedia.org/wiki/Frequency_division_multiplex) was used to send up to 5,400 telephone channels on each microwave radio channel, with as many as ten radio channels combined into one antenna for the *hop* to the next site, up to 70 km away.

[Wireless LAN](https://en.wikipedia.org/wiki/Wireless_LAN) [protocols](https://en.wikipedia.org/wiki/Protocol_%28computing%29), such as [Bluetooth](https://en.wikipedia.org/wiki/Bluetooth) and the [IEEE](https://en.wikipedia.org/wiki/IEEE) [802.11](https://en.wikipedia.org/wiki/802.11) specifications used for Wi-Fi, also use microwaves in the 2.4 GHz [ISM band](https://en.wikipedia.org/wiki/ISM_band), although [802.11a](https://en.wikipedia.org/wiki/802.11a) uses [ISM band](https://en.wikipedia.org/wiki/ISM_band) and [U-NII](https://en.wikipedia.org/wiki/U-NII) frequencies in the 5 GHz range. Licensed long-range (up to about 25 km) Wireless Internet Access services have been used for almost a decade in many countries in the 3.5–4.0 GHz range. The FCC recentlycarved out spectrum for carriers that wish to offer services in this range in the U.S. — with emphasis on 3.65 GHz. Dozens of service providers across the country are securing or have already received licenses from the FCC to operate in this band. The WIMAX service offerings that can be carried on the 3.65 GHz band will give business customers another option for connectivity.

[Metropolitan area network](https://en.wikipedia.org/wiki/Metropolitan_area_network) (MAN) protocols, such as [WiMAX](https://en.wikipedia.org/wiki/WiMAX) (Worldwide Interoperability for Microwave Access) are based on standards such as [IEEE 802.16](https://en.wikipedia.org/wiki/IEEE_802.16), designed to operate between 2 to 11 GHz. Commercial implementations are in the 2.3 GHz, 2.5 GHz, 3.5 GHz and 5.8 GHz ranges.

[Mobile Broadband](https://en.wikipedia.org/wiki/Mobile_Broadband) Wireless Access (MBWA) protocols based on standards specifications such as [IEEE 802.20](https://en.wikipedia.org/wiki/IEEE_802.20) or ATIS/ANSI [HC-SDMA](https://en.wikipedia.org/wiki/HC-SDMA) (such as [iBurst](https://en.wikipedia.org/wiki/IBurst)) operate between 1.6 and 2.3 GHz to give mobility and in-building penetration characteristics similar to mobile phones but with vastly greater spectral efficiency.

Some [mobile phone](https://en.wikipedia.org/wiki/Mobile_phone) networks, like [GSM](https://en.wikipedia.org/wiki/Global_System_for_Mobile_Communications#Radio_interface), use the low-microwave/high-UHF frequencies around 1.8 and 1.9 GHz in the [Americas](https://en.wikipedia.org/wiki/Americas) and elsewhere, respectively. [DVB-SH](https://en.wikipedia.org/wiki/DVB-SH) and [S-DMB](https://en.wikipedia.org/wiki/S-DMB) use 1.452 to 1.492 GHz, while proprietary/incompatible [satellite radio](https://en.wikipedia.org/wiki/Satellite_radio) in the [U.S.](https://en.wikipedia.org/wiki/U.S.) uses around 2.3 GHz for [DARS](https://en.wikipedia.org/wiki/Digital_Audio_Radio_Service).

Microwave radio is used in [broadcasting](https://en.wikipedia.org/wiki/Broadcasting) and [telecommunication](https://en.wikipedia.org/wiki/Telecommunication) transmissions because, due to their short wavelength, highly [directional antennas](https://en.wikipedia.org/wiki/Directional_antenna) are smaller and therefore more practical than they would be at longer wavelengths (lower frequencies). There is also more [bandwidth](https://en.wikipedia.org/wiki/Bandwidth_%28signal_processing%29) in the microwave spectrum than in the rest of the radio spectrum; the usable bandwidth below 300 MHz is less than 300 MHz while many GHz can be used above 300 MHz. Typically, microwaves are used in [television news](https://en.wikipedia.org/wiki/Television_news) to transmit a signal from a remote location to a television station from a specially equipped van. See [broadcast auxiliary service](https://en.wikipedia.org/wiki/Broadcast_auxiliary_service) (BAS), [remote pickup unit](https://en.wikipedia.org/wiki/Remote_pickup_unit) (RPU), and [studio/transmitter link](https://en.wikipedia.org/wiki/Studio/transmitter_link) (STL).

Most [satellite communications](https://en.wikipedia.org/wiki/Satellite_communications) systems operate in the C, X, Ka, or Ku bands of the microwave spectrum. These frequencies allow large bandwidth while avoiding the crowded UHF frequencies and staying below the atmospheric absorption of EHF frequencies. [Satellite TV](https://en.wikipedia.org/wiki/Satellite_TV) either operates in the C band for the traditional [large dish](https://en.wikipedia.org/wiki/TVRO) [fixed satellite service](https://en.wikipedia.org/wiki/Fixed_satellite_service) or Ku band for [direct-broadcast satellite](https://en.wikipedia.org/wiki/Direct-broadcast_satellite). Military communications run primarily over X or Ku-band links, with Ka band being used for [Milstar](https://en.wikipedia.org/wiki/Milstar).

**Navigation**

*Further information:* [*Satellite navigation*](https://en.wikipedia.org/wiki/Satellite_navigation) *and* [*Navigation*](https://en.wikipedia.org/wiki/Navigation)

[Global Navigation Satellite Systems](https://en.wikipedia.org/wiki/Global_Navigation_Satellite_System) (GNSS) including the Chinese [Beidou](https://en.wikipedia.org/wiki/Beidou_navigation_system), the American [Global Positioning System](https://en.wikipedia.org/wiki/Global_Positioning_System) (GPS) and the Russian [GLONASS](https://en.wikipedia.org/wiki/GLONASS) broadcast navigational signals in various bands between about 1.2 GHz and 1.6 GHz.

**Radar**

An [air traffic control](https://en.wikipedia.org/wiki/Air_traffic_control) radar using pipes as [waveguides](https://en.wikipedia.org/wiki/Waveguide)

Main article: [Radar](https://en.wikipedia.org/wiki/Radar)

[Radar](https://en.wikipedia.org/wiki/Radar) uses microwave radiation to detect the range, speed, and other characteristics of remote objects. Development of radar was accelerated during World War II due to its great military utility. Now radar is widely used for applications such as [air traffic control](https://en.wikipedia.org/wiki/Air_traffic_control), weather forecasting, navigation of ships, and [speed limit enforcement](https://en.wikipedia.org/wiki/Speed_limit_enforcement).

Microwaves cannot be carried with usable efficiency in ordinary [transmission lines](https://en.wikipedia.org/wiki/Transmission_line) but require waveguide, such as a metal pipe.

A [Gunn diode](https://en.wikipedia.org/wiki/Gunn_diode) oscillator and waveguide are used as a motion detector for [automatic door openers](https://en.wikipedia.org/wiki/Swing_door_operator).

The [ALMA](https://en.wikipedia.org/wiki/Atacama_Large_Millimeter_Array) telescope

Improving [CMBR](https://en.wikipedia.org/wiki/Cosmic_microwave_background_radiation)-maps

**Radio astronomy**

Main article: [radio astronomy](https://en.wikipedia.org/wiki/Radio_astronomy)

Most [radio astronomy](https://en.wikipedia.org/wiki/Radio_astronomy) uses microwaves. Usually the naturally-occurring microwave radiation is observed, but active radar experiments have also been done with objects in the solar system, such as determining the distance to the [Moon](https://en.wikipedia.org/wiki/Moon) or mapping the invisible surface of [Venus](https://en.wikipedia.org/wiki/Venus) through cloud cover.

The [Atacama Large Millimeter Array](https://en.wikipedia.org/wiki/Atacama_Large_Millimeter_Array), located at more than 5,000 meters (16,597 ft) altitude in Chile, observes the [universe](https://en.wikipedia.org/wiki/Universe) in the [millimeter and sub-millimeter](https://en.wikipedia.org/wiki/Terahertz_radiation) wavelength ranges. The world's largest ground-based astronomy project to date consists of more than 66 dishes and was built in an international collaboration by Europe, North America, East Asia and Chile.

The [cosmic microwave background radiation](https://en.wikipedia.org/wiki/Cosmic_microwave_background_radiation) (CMBR) has been mapped by a number of instrument at an ever increasing resolution. The CMBR is understood to be a "relic radiation" from the [Big Bang](https://en.wikipedia.org/wiki/Big_Bang). Due to the expansion and thus cooling of the Universe, the originally high-energy radiation has been shifted into the microwave region of the radio spectrum. Sufficiently sensitive [radio telescopes](https://en.wikipedia.org/wiki/Radio_telescope) can detected the CMBR as a faint background glow, almost exactly the same in all directions, that is not associated with any star, galaxy, or other object.

**Heating and power application**

A [microwave oven](https://en.wikipedia.org/wiki/Microwave_oven) passes (non-ionizing) microwave radiation at a frequency near [2.45 GHz (12 cm)](https://en.wikipedia.org/wiki/ISM_band) through food, causing [dielectric heating](https://en.wikipedia.org/wiki/Dielectric_heating) primarily by absorption of the energy in water. Microwave ovens became common kitchen appliances in Western countries in the late 1970s, following the development of less expensive [cavity magnetrons](https://en.wikipedia.org/wiki/Cavity_magnetron). Water in the liquid state possesses many molecular interactions that broaden the absorption peak. In the vapor phase, isolated water molecules absorb at around 22 GHz, almost ten times the frequency of the microwave oven.

Microwave heating is used in industrial processes for drying and [curing](https://en.wikipedia.org/wiki/Curing_%28chemistry%29) products.

Many [semiconductor processing](https://en.wikipedia.org/wiki/Fabrication_%28semiconductor%29) techniques use microwaves to generate [plasma](https://en.wikipedia.org/wiki/Plasma_physics) for such purposes as [reactive ion etching](https://en.wikipedia.org/wiki/Reactive_ion_etching) and plasma-enhanced [chemical vapor deposition](https://en.wikipedia.org/wiki/Chemical_vapor_deposition) (PECVD).

Microwave frequencies typically ranging from 110 – 140 GHz are used in [stellarators](https://en.wikipedia.org/wiki/Stellarator) and more notably in [tokamak](https://en.wikipedia.org/wiki/Tokamak#Radio-frequency_heating) experimental fusion reactors to help heat the fuel into a plasma state. The upcoming [ITER](https://en.wikipedia.org/wiki/ITER) thermonuclear reactor is expected to range from 110–170 GHz and will employ electron cyclotron resonance heating (ECRH).

Microwaves can be used to [transmit power](https://en.wikipedia.org/wiki/Microwave_power_transmission) over long distances, and post-[World War II](https://en.wikipedia.org/wiki/World_War_II) research was done to examine possibilities. [NASA](https://en.wikipedia.org/wiki/NASA) worked in the 1970s and early 1980s to research the possibilities of using [solar power satellite](https://en.wikipedia.org/wiki/Solar_power_satellite) (SPS) systems with large [solar arrays](https://en.wikipedia.org/wiki/Photovoltaic_module) that would beam power down to the Earth's surface via microwaves.

[Less-than-lethal](https://en.wikipedia.org/wiki/Less-than-lethal) weaponry exists that uses millimeter waves to heat a thin layer of human skin to an intolerable temperature so as to make the targeted person move away. A two-second burst of the 95 GHz focused beam heats the skin to a temperature of 54 °C (129 °F) at a depth of 0.4 millimeters (1⁄64 in). The [United States Air Force](https://en.wikipedia.org/wiki/United_States_Air_Force) and [Marines](https://en.wikipedia.org/wiki/United_States_Marine_Corps) are currently using this type of [active denial system](https://en.wikipedia.org/wiki/Active_denial_system) in fixed installations.

**Spectroscopy**

Microwave radiation is used in [electron paramagnetic resonance](https://en.wikipedia.org/wiki/Electron_paramagnetic_resonance) (EPR or ESR) spectroscopy, typically in the X-band region (~9 GHz) in conjunction typically with [magnetic fields](https://en.wikipedia.org/wiki/Magnetic_field) of 0.3 T. This technique provides information on unpaired [electrons](https://en.wikipedia.org/wiki/Electron) in chemical systems, such as [free radicals](https://en.wikipedia.org/wiki/Free_radical) or [transition metal](https://en.wikipedia.org/wiki/Transition_metal) ions such as Cu(II). Microwave radiation is also used to perform [rotational spectroscopy](https://en.wikipedia.org/wiki/Rotational_spectroscopy) and can be combined with [electrochemistry](https://en.wikipedia.org/wiki/Electrochemistry) as in [microwave enhanced electrochemistry](https://en.wikipedia.org/wiki/Microwave_enhanced_electrochemistry).

**Microwave frequency bands**

Rough plot of Earth's atmospheric transmittance (or opacity) to various [wavelengths](https://en.wikipedia.org/wiki/Wavelength) of electromagnetic radiation. Microwaves are strongly absorbed at wavelengths shorter than about 1.5 cm (above 20 GHz) by water and other molecules in the air.

The microwave spectrum is usually defined as electromagnetic energy ranging from approximately 1 GHz to 100 GHz in frequency, but older use includes lower frequencies. Most common applications are within the 1 to 40 GHz range. One set of microwave frequency bands designations by the [Radio Society of Great Britain](https://en.wikipedia.org/wiki/Radio_Society_of_Great_Britain) (RSGB), is tabulated below:

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| [**ITU radio bands**](https://en.wikipedia.org/wiki/ITU_radio_bands) |
|

|  |  |  |  |
| --- | --- | --- | --- |
| [1 (ELF)](https://en.wikipedia.org/wiki/Extremely_low_frequency) | [2 (SLF)](https://en.wikipedia.org/wiki/Super_low_frequency) | [3 (ULF)](https://en.wikipedia.org/wiki/Ultra_low_frequency) | [4 (VLF)](https://en.wikipedia.org/wiki/Very_low_frequency) |
| [5 (LF)](https://en.wikipedia.org/wiki/Low_frequency) | [6 (MF)](https://en.wikipedia.org/wiki/Medium_frequency) | [7 (HF)](https://en.wikipedia.org/wiki/High_frequency) | [8 (VHF)](https://en.wikipedia.org/wiki/Very_high_frequency) |
| [9 (UHF)](https://en.wikipedia.org/wiki/Ultra_high_frequency) | [10 (SHF)](https://en.wikipedia.org/wiki/Super_high_frequency) | [11 (EHF)](https://en.wikipedia.org/wiki/Extremely_high_frequency) | [12 (THF)](https://en.wikipedia.org/wiki/Terahertz_radiation) |

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| [**EU / NATO / US ECM radio bands**](https://en.wikipedia.org/wiki/NATO_radio_bands) |
| * [A](https://en.wikipedia.org/wiki/A_band_%28radio%29)
* [B](https://en.wikipedia.org/wiki/B_band)
* [C](https://en.wikipedia.org/wiki/C_band)
* [D](https://en.wikipedia.org/wiki/D_band)
* [E](https://en.wikipedia.org/wiki/E_band)
* [F](https://en.wikipedia.org/wiki/F_band)
* [G](https://en.wikipedia.org/wiki/G_band)
* [H](https://en.wikipedia.org/wiki/H_band)
* [I](https://en.wikipedia.org/wiki/I_band)
* [J](https://en.wikipedia.org/wiki/J_band)
* [K](https://en.wikipedia.org/wiki/K_band)
* [L](https://en.wikipedia.org/wiki/L_band)
* [M](https://en.wikipedia.org/wiki/M_band)
 |
| [**IEEE radio bands**](https://en.wikipedia.org/wiki/Radio_spectrum#IEEE) |
| * [HF](https://en.wikipedia.org/wiki/High_frequency)
* [VHF](https://en.wikipedia.org/wiki/Very_high_frequency)
* [UHF](https://en.wikipedia.org/wiki/Ultra_high_frequency)
* [L](https://en.wikipedia.org/wiki/L_band_%28template%29)
* [S](https://en.wikipedia.org/wiki/S_band)
* [C](https://en.wikipedia.org/wiki/C_band)
* [X](https://en.wikipedia.org/wiki/X_band)
* [Ku](https://en.wikipedia.org/wiki/Ku_band)
* [K](https://en.wikipedia.org/wiki/K_band)
* [Ka](https://en.wikipedia.org/wiki/Ka_band)
* [V](https://en.wikipedia.org/wiki/V_band)
* [W](https://en.wikipedia.org/wiki/W_band)
* [mm](https://en.wikipedia.org/wiki/Extremely_high_frequency)
 |
| **Other TV and radio bands** |
| * [I](https://en.wikipedia.org/wiki/Band_I)
* [II](https://en.wikipedia.org/wiki/Band_II)
* [III](https://en.wikipedia.org/wiki/Band_III)
* [IV](https://en.wikipedia.org/wiki/Band_IV)
* [V](https://en.wikipedia.org/wiki/Band_V)
* [VI](https://en.wikipedia.org/wiki/Band_VI)
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| Microwave frequency bands |
| **Designation** | **Frequency range** | **Wavelength range** | **Typical uses** |
| [L band](https://en.wikipedia.org/wiki/L_band) | 1 to 2 GHz | 15 cm to 30 cm | military telemetry, GPS, mobile phones (GSM), amateur radio |
| [S band](https://en.wikipedia.org/wiki/S_band) | 2 to 4 GHz | 7.5 cm to 15 cm | weather radar, surface ship radar, and some communications satellites (microwave ovens, microwave devices/communications, radio astronomy, mobile phones, wireless LAN, Bluetooth, ZigBee, GPS, amateur radio) |
| [C band](https://en.wikipedia.org/wiki/C_band) | 4 to 8 GHz | 3.75 cm to 7.5 cm | long-distance radio telecommunications |
| [X band](https://en.wikipedia.org/wiki/X_band) | 8 to 12 GHz | 25 mm to 37.5 mm | satellite communications, radar, terrestrial broadband, space communications, amateur radio |
| [Ku band](https://en.wikipedia.org/wiki/Ku_band) | 12 to 18 GHz | 16.7 mm to 25 mm | satellite communications |
| [K band](https://en.wikipedia.org/wiki/K_band) | 18 to 26.5 GHz | 11.3 mm to 16.7 mm | radar, satellite communications, astronomical observations, automotive radar |
| [Ka band](https://en.wikipedia.org/wiki/Ka_band) | 26.5 to 40 GHz | 5.0 mm to 11.3 mm | satellite communications |
| [Q band](https://en.wikipedia.org/wiki/Q_band) | 33 to 50 GHz | 6.0 mm to 9.0 mm | satellite communications, terrestrial microwave communications, radio astronomy, automotive radar |
| [U band](https://en.wikipedia.org/w/index.php?title=U_band&action=edit&redlink=1) | 40 to 60 GHz | 5.0 mm to 7.5 mm |  |
| [V band](https://en.wikipedia.org/wiki/V_band) | 50 to 75 GHz | 4.0 mm to 6.0 mm | millimeter wave radar research and other kinds of scientific research |
| [W band](https://en.wikipedia.org/wiki/W_band) | 75 to 110 GHz | 2.7 mm to 4.0 mm | satellite communications, millimeter-wave radar research, military radar targeting and tracking applications, and some non-military applications, automotive radar |
| [F band](https://en.wikipedia.org/wiki/F_band) | 90 to 140 GHz | 2.1 mm to 3.3 mm | SHF transmissions: Radio astronomy, microwave devices/communications, wireless LAN, most modern radars, communications satellites, satellite television broadcasting, DBS, amateur radio |
| [D band](https://en.wikipedia.org/wiki/D_band) | 110 to 170 GHz | 1.8 mm to 2.7 mm | EHF transmissions: Radio astronomy, high-frequency microwave radio relay, microwave remote sensing, amateur radio, directed-energy weapon, millimeter wave scanner |

P band is sometimes used for Ku Band. "P" for "previous" was a radar band used in the UK ranging from 250 to 500 MHz and now obsolete per IEEE Std 521.

When radars were first developed at K band during World War II, it was not known that there was a nearby absorption band (due to water vapor and oxygen in the atmosphere). To avoid this problem, the original K band was split into a lower band, Ku, and upper band, Ka.

**Microwave frequency measurement**

[Absorption wave meter](https://en.wikipedia.org/wiki/Absorption_wavemeter) for measuring in the Ku band.

Microwave frequency can be measured by either electronic or mechanical techniques.

[Frequency counters](https://en.wikipedia.org/wiki/Frequency_counter) or high frequency [heterodyne](https://en.wikipedia.org/wiki/Heterodyne) systems can be used. Here the unknown frequency is compared with harmonics of a known lower frequency by use of a low frequency generator, a harmonic generator and a mixer. Accuracy of the measurement is limited by the accuracy and stability of the reference source.

Mechanical methods require a tunable resonator such as an [absorption wave meter](https://en.wikipedia.org/wiki/Absorption_wavemeter), which has a known relation between a physical dimension and frequency.

In a laboratory setting, [Lecher lines](https://en.wikipedia.org/wiki/Lecher_lines) can be used to directly measure the wavelength on a transmission line made of parallel wires, the frequency can then be calculated. A similar technique is to use a slotted [waveguide](https://en.wikipedia.org/wiki/Waveguide) or slotted coaxial line to directly measure the wavelength. These devices consist of a probe introduced into the line through a longitudinal slot, so that the probe is free to travel up and down the line. Slotted lines are primarily intended for measurement of the [voltage standing wave ratio](https://en.wikipedia.org/wiki/Voltage_standing_wave_ratio) on the line. However, provided a [standing wave](https://en.wikipedia.org/wiki/Standing_wave) is present, they may also be used to measure the distance between the [nodes](https://en.wikipedia.org/wiki/Node_%28physics%29), which is equal to half the wavelength. Precision of this method is limited by the determination of the nodal locations.

**Effects on health**

*Further information:* [*Electromagnetic radiation and health*](https://en.wikipedia.org/wiki/Electromagnetic_radiation_and_health) *and* [*Microwave burn*](https://en.wikipedia.org/wiki/Microwave_burn)

Microwaves do not contain sufficient energy to chemically change substances by ionization, and so are an example of [non-ionizing](https://en.wikipedia.org/wiki/Non-ionizing) radiation. The word "radiation" refers to energy radiating from a source and not to [radioactivity](https://en.wikipedia.org/wiki/Radioactivity). It has not been shown conclusively that microwaves (or other [non-ionizing](https://en.wikipedia.org/wiki/Non-ionizing) electromagnetic radiation) have significant adverse biological effects at low levels. Some, but not all, studies suggest that long-term exposure may have a [carcinogenic](https://en.wikipedia.org/wiki/Carcinogen) effect. This is separate from the risks associated with very high-intensity exposure, which can cause heating and burns like any heat source, and not a unique property of microwaves specifically.

During [World War II](https://en.wikipedia.org/wiki/World_War_II), it was observed that individuals in the radiation path of radar installations experienced clicks and buzzing sounds in response to microwave radiation. This [microwave auditory effect](https://en.wikipedia.org/wiki/Microwave_auditory_effect) was thought to be caused by the microwaves [inducing](https://en.wikipedia.org/wiki/Electromagnetic_induction) an electric current in the hearing centers of the brain. Research by [NASA](https://en.wikipedia.org/wiki/NASA) in the 1970s has shown this to be caused by thermal expansion in parts of the inner ear. In 1955 Dr. James Lovelock was able to reanimate rats frozen at 0 °C using microwave diathermy.

When injury from exposure to microwaves occurs, it usually results from dielectric heating induced in the body. Exposure to microwave radiation can produce [cataracts](https://en.wikipedia.org/wiki/Cataract) by this mechanism, because the microwave heating [denatures](https://en.wikipedia.org/wiki/Denaturation_%28biochemistry%29) [proteins](https://en.wikipedia.org/wiki/Protein) in the [crystalline lens](https://en.wikipedia.org/wiki/Lens_%28anatomy%29) of the [eye](https://en.wikipedia.org/wiki/Human_eye) (in the same way that heat turns [egg whites](https://en.wikipedia.org/wiki/Egg_white) white and opaque). The lens and [cornea](https://en.wikipedia.org/wiki/Cornea) of the eye are especially vulnerable because they contain no [blood vessels](https://en.wikipedia.org/wiki/Blood_vessel) that can carry away heat. Exposure to heavy doses of microwave radiation (as from an oven that has been tampered with to allow operation even with the door open) can produce heat damage in other tissues as well, up to and including serious [burns](https://en.wikipedia.org/wiki/Burn) that may not be immediately evident because of the tendency for microwaves to heat deeper tissues with higher moisture content.

**History and research**

Electromagnetic spectrum (visible-light range highlighted).

The existence of radio waves was predicted by [James Clerk Maxwell](https://en.wikipedia.org/wiki/James_Clerk_Maxwell) in 1864 from [his equations](https://en.wikipedia.org/wiki/Maxwell%27s_equations). In 1888, [Heinrich Hertz](https://en.wikipedia.org/wiki/Heinrich_Hertz) was the first to demonstrate the existence of radio waves by building a [spark gap radio transmitter](https://en.wikipedia.org/wiki/Spark_gap_transmitter) that produced 450 MHz microwaves, in the UHF region. The equipment he used was primitive, including a horse trough, a wrought iron point spark, and [Leyden jars](https://en.wikipedia.org/wiki/Leyden_jar). He also built the first [parabolic antenna](https://en.wikipedia.org/wiki/Parabolic_antenna), using a zinc gutter sheet. In 1894, Indian radio pioneer [Jagdish Chandra Bose](https://en.wikipedia.org/wiki/Jagdish_Chandra_Bose) publicly demonstrated radio control of a bell using millimeter wavelengths, and conducted research into the propagation of microwaves.

Perhaps the first, documented, formal use of the term *microwave* occurred in 1931:

"When trials with wavelengths as low as 18 cm were made known, there was undisguised surprise that the problem of the micro-wave had been solved so soon." *Telegraph & Telephone Journal* XVII. 179/1

In 1943, the Hungarian engineer [Zoltán Bay](https://en.wikipedia.org/wiki/Zolt%C3%A1n_Bay) sent ultra-short radio waves to the moon, which, reflected from there, worked as a radar, and could be used to measure distance, as well as to study the moon.

Perhaps the first use of the word *microwave* in an astronomical context occurred in 1946 in an article "Microwave Radiation from the Sun and Moon" by [Robert Dicke](https://en.wikipedia.org/wiki/Robert_Dicke) and [Robert Beringer](https://en.wikipedia.org/w/index.php?title=Robert_Beringer&action=edit&redlink=1). This same article also made a showing in the [*New York Times*](https://en.wikipedia.org/wiki/New_York_Times) issued in 1951.

In the [history of electromagnetic theory](https://en.wikipedia.org/wiki/History_of_electromagnetic_theory), significant work specifically in the area of microwaves and their applications was carried out by researchers including:

|  |
| --- |
| Specific work on microwaves |
| **Names** | **Area of work** |
| [Barkhausen](https://en.wikipedia.org/wiki/Heinrich_Barkhausen) and Kurz | Positive grid [oscillators](https://en.wikipedia.org/wiki/Oscillator) |
| Hull | Smooth bore [magnetron](https://en.wikipedia.org/wiki/Magnetron) |
| [Russell and Sigurd Varian](https://en.wikipedia.org/wiki/Russell_and_Sigurd_Varian) | Velocity-modulated electron beam (→ [klystron](https://en.wikipedia.org/wiki/Klystron) tube) |
| [Randall](https://en.wikipedia.org/wiki/John_Randall_%28physicist%29) and [Boot](https://en.wikipedia.org/wiki/Harry_Boot) | [Cavity magnetron](https://en.wikipedia.org/wiki/Cavity_magnetron) |

**See also**

|  |  |
| --- | --- |
|  | [***Electromagnetism portal***](https://en.wikipedia.org/wiki/Portal%3AElectromagnetism) |
|  | [***Electronics portal***](https://en.wikipedia.org/wiki/Portal%3AElectronics) |
|  | [***Telecommunication portal***](https://en.wikipedia.org/wiki/Portal%3ATelecommunication) |

* [Block upconverter (BUC)](https://en.wikipedia.org/wiki/Block_upconverter)
* [Cosmic microwave background](https://en.wikipedia.org/wiki/Cosmic_microwave_background)
* [Electron cyclotron resonance](https://en.wikipedia.org/wiki/Electron_cyclotron_resonance)
* [International Microwave Power Institute](https://en.wikipedia.org/wiki/International_Microwave_Power_Institute)
* [Low-noise block converter (LNB)](https://en.wikipedia.org/wiki/Low-noise_block_converter)
* [Maser](https://en.wikipedia.org/wiki/Maser)
* [Microwave transmission](https://en.wikipedia.org/wiki/Microwave_transmission)
* [Microwave chemistry](https://en.wikipedia.org/wiki/Microwave_chemistry)
* [Microwave auditory effect](https://en.wikipedia.org/wiki/Microwave_auditory_effect)
* [Lens Antenna](https://en.wikipedia.org/wiki/Lens_Antenna) / [klystron](https://en.wikipedia.org/wiki/Klystron) / [magnetron](https://en.wikipedia.org/wiki/Magnetron) / [radar gun](https://en.wikipedia.org/wiki/Radar_gun)
* [Microwave cavity](https://en.wikipedia.org/wiki/Microwave_cavity)
* [Microwave radio relay](https://en.wikipedia.org/wiki/Microwave_radio_relay)
* [Orthomode transducer (OMT)](https://en.wikipedia.org/wiki/Orthomode_transducer)
* [Plasma-enhanced chemical vapor deposition](https://en.wikipedia.org/wiki/Plasma-enhanced_chemical_vapour_deposition)
* [Rain fade](https://en.wikipedia.org/wiki/Rain_fade)
* [RF switch matrix](https://en.wikipedia.org/wiki/RF_switch_matrix)
* [Thing (listening device)](https://en.wikipedia.org/wiki/Thing_%28listening_device%29)
* [Tropospheric scatter](https://en.wikipedia.org/wiki/Tropospheric_scatter)