WIKIPEDIA

Very low frequency

Very low frequency or **VLF** is the ITU designation[1] for radio frequencies (RF) in the range of 3 to 30 kilohertz (kHz), corresponding to wavelengths from 100 to 10 kilometers, respectively. The band is also known as the **myriameter band** or **myriameter wave** as the wavelengths range from one to ten myriameters (an obsolete metric unit equal to 10 kilometers). Due to its limited bandwidth, audio (voice) transmission is highly impractical in this band, and therefore only low data rate coded signals are used. The VLF band is used for a few radio navigation services, government time radio stations (broadcasting time signals to set radio clocks) and for secure military communication. Since VLF waves can penetrate at least 40 meters (120 ft) into saltwater, they are used for military communication with submarines.

Very low frequency

Frequency range	3 to 30 kHz
Wavelength range	100 to 10 km

A VLF receiving antenna at Palmer Station, Antarctica, operated by Stanford University.

Contents

Propagation characteristics

Because of their large wavelengths, VLF radio waves can diffract around large obstacles and so are not blocked by mountain ranges or the horizon, and can propagate as ground waves following the curvature of the Earth. The main mode of long distance propagation is an Earth-ionosphere waveguide mechanism.[2] The Earth is surrounded by a conductive layer of electrons and ions in the upper atmosphere at the bottom of the ionosphere called the D layer at 60 to 90 km (37 to 56 miles) altitude,[3] which reflects VLF radio waves. The conductive ionosphere and the conductive Earth form a horizontal "duct" a few VLF wavelengths high, which acts as a waveguide confining the waves so they don't escape into space. The waves travel in a zigzag path around the Earth, reflected alternately by the Earth and the ionosphere, in TM (transverse magnetic) mode.

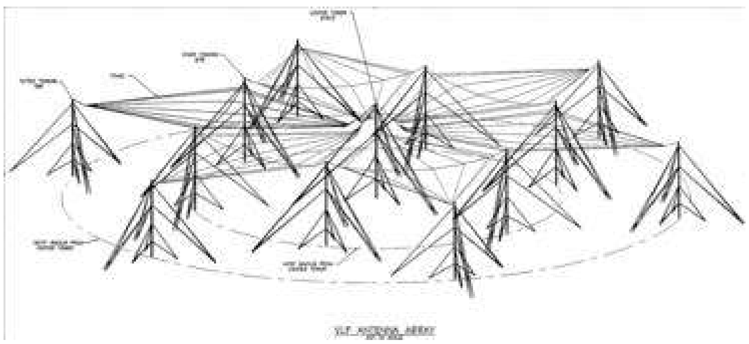
VLF waves have very low path attenuation, 2-3 dB per 1000 km,[2] with little of the "fading" experienced at higher frequencies,[3] This is because VLF waves are reflected from the bottom of the ionosphere, while higher frequency shortwave signals are returned to Earth from higher layers in the ionosphere, the F1 and F2 layers, by a refraction process, and spend most of their journey in the ionosphere, so they are much more affected by ionization gradients and turbulence. Therefore, VLF transmissions are very stable and reliable, and are used for long distance communication. Propagation distances of 5000 to 20000 km have been realized.[2] However, atmospheric noise (sferics) is high in the band,[3] including such phenomena as "whistlers", caused by lightning.

VLF waves can penetrate seawater to a depth of at least 10 to 40 meters (30 to 130 feet), depending on the frequency employed and the salinity of the water, so they are used to communicate with submarines.

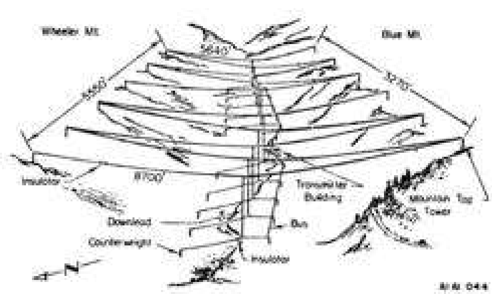
VLF waves at certain frequencies have been found to cause electron precipitation.

VLF waves used to communicate with submarines have created an artificial bubble around the Earth that can protect it from solar flares and coronal mass ejections; this occurred through interaction with high-energy radiation particles.[4]

Antennas



"Trideco" antenna tower array at the US Navy's Naval Radio Station Cutler in Cutler, Maine, USA. The central mast is the radiating element, while the star-shaped horizontal wire array is the capacitive top load. About 1.2 miles in diameter, it communicates with submerged submarines at 24 kHz at a power of 1.8 megawatts, the most powerful radio station in the world.



Another type of large VLF antenna: the "valley-span" antenna, consisting of multiple horizontal topload cables spanning a valley, fed in the center by vertical radiators. This example is at the US Navy Jim Creek station near Seattle, which transmits on 24.8 kHz at a power of 1.2 MW.

Umbrella antenna of the Omega navigation system beacon on Tsushima Island, Japan, which transmitted at 10 - 14 kHz. 389 meters high, it was dismantled in 1977.

A major practical drawback to this band is that because of the length of the waves, full size resonant antennas (half wave dipole or quarter wave monopole antennas) cannot be built because of their physical height. Vertical antennas must be used because VLF waves propagate in vertical polarization, but a quarter-wave vertical antenna at 30 kHz would be 2.5 kilometres (8,200 feet) high. So practical transmitting antennas are electrically short, a small fraction of a wavelength long.[5] Due to their low radiation resistance (often less than one ohm) they are inefficient, radiating only 10% to 50% of the transmitter power at most,[2] with the rest of the power dissipated in the antenna/ground system resistances. Very high power transmitters (~1 megawatt) are required for long distance communication, so the efficiency of the antenna is an important factor.

High power transmitting antennas for VLF frequencies are very large wire antennas, up to a mile across. They consist of a series of steel radio masts, linked at the top with a network of cables, often shaped like an umbrella or clotheslines. Either the towers themselves or vertical wires serve as monopole radiators, and the horizontal cables form a capacitive top-load to increase the efficiency of the antenna. High power stations use variations on the umbrella antenna such as the "delta" and "trideco" antennas, or multiwire flattop (triatic) antennas. For low power transmitters, inverted-L and T antennas are used. A large loading coil is required at the antenna feed point to cancel the capacitive reactance of the antenna to make it resonant.

Due to the low radiation resistance, to minimize power dissipated in the ground these antennas require extremely low resistance ground (Earthing) systems. Because of soil resistance and dielectric losses in the ground, the buried cable ground systems used by higher frequency transmitters tend to have unacceptably high losses, and counterpoise systems are usually used, consisting of radial networks of copper cables supported several feet above the ground under the antenna, extending out radially from the mast or vertical element.

The high capacitance and inductance and low resistance of the antenna-loading coil combination makes it act electrically like a high Q tuned circuit. VLF antennas have very narrow bandwidth and to change the transmitting frequency requires a variable inductor (variometer) to tune the antenna. The large VLF antennas used for high power transmitters usually have bandwidths of only a few tens of hertz, and when transmitting frequency shift keying (FSK), the usual mode, the resonant frequency of the antenna must sometimes be dynamically shifted with the modulation, between the two FSK frequencies. The high Q of the antenna results in very high voltages at the ends of the horizontal topload wires where the nodes of the standing wave pattern occur, and very good insulation is required. The practical limit to the power of large VLF transmitters is usually determined by onset of air breakdown and arcing from the antenna.

The requirements for receiving antennas are less stringent, because of the high level of natural atmospheric noise in the band. Atmospheric radio noise is far above the receiver noise introduced by the receiver circuit and determines the receiver signal to noise ratio. So small inefficient receiving antennas can be used, and the low voltage signal from the antenna can simply be amplified by the receiver without introducing significant noise. Loop antennas are usually used for reception.

Applications

The frequency range below 9 kHz is not allocated by the International Telecommunication Union and may be used in some nations license-free.

Since it can penetrate seawater VLF is used by the military to communicate with submarines near the surface, while ELF frequencies are used for deeply submerged vessels. Examples of naval VLF transmitters are Britain's Skelton Transmitting Station in Skelton, Cumbria; Germany's DHO38 in Rhauderfehn, which transmits on 23.4 kHz with a power of 800 kW, the US Jim Creek Naval Radio Station in Oso, Washington state, which transmits on 24.8 kHz with a power of 1.2 MW; and Cutler Naval Radio Station at Cutler, Maine which transmits on 24 kHz with 1.8 MW. Due to the narrow bandwidth of the band, audio (voice) transmission cannot be used, and text transmission is limited to a slow data rate of around 300 bits per second, or about 35 eight-bit ASCII characters per second. Since 2004 the US Navy has stopped using ELF transmissions, with the statement that improvements in VLF communication has made them unnecessary, so it may have developed technology to allow submarines to receive VLF transmissions while at operating depth.

Due to its long propagation distances and stable phase characteristics, during the 20th century the VLF band was used for long range hyperbolic radio navigation systems which allowed ships and aircraft to determine their geographical position by comparing the phase of radio waves received from fixed VLF navigation beacon transmitters. The worldwide Omega system used frequencies from 10 to 14 kHz, as did Russia's Alpha. VLF was also used for standard time and frequency broadcasts. In the USA, the time signal station WWVL began transmitting a 500 W signal on 20 kHz in August 1963. It used frequency shift keying (FSK) to send data, shifting between 20 kHz and 26 kHz. The WWVL service was discontinued in July 1972.

Flattop antenna towers of the Grimeton VLF transmitter, Varberg, Sweden

Historically, this band was used for long distance transoceanic radio communication during the wireless telegraphy era between about 1905 and 1925. Nations built networks of high power LF and VLF radiotelegraphy stations that transmitted text information by Morse code, to communicate with other countries, their colonies and naval fleets. Early attempts were made to use radiotelephone using amplitude modulation and single-sideband modulation within the band starting from 20 kHz, but the result was unsatisfactory because the available bandwidth was insufficient to contain the sidebands. In the 1920s the discovery of the skywave (skip) radio propagation method allowed lower power transmitters operating at high frequency to communicate at similar distances by reflecting their radio waves off a layer of ionized atoms in the ionosphere, and long distance radio communication stations switched to the shortwave frequencies. The Grimeton VLF transmitter at Grimeton near Varberg in Sweden, one of the few remaining transmitters from that era that has been preserved as a historical monument, can be visited by the public at certain times, such as on Alexanderson Day.

Naturally occurring signals in the VLF band are used by geophysicists for long range lightning location and for research into atmospheric phenomena such as the aurora. Measurements of whistlers are employed to infer the physical properties of the magnetosphere.[6]

VLF can also penetrate soil and rock for some distance, so these frequencies are also used for through-the-earth mine communications systems. Geophysicists use VLF-electromagnetic receivers to measure conductivity in the near surface of the Earth.[7]

VLF submarine and aircraft communication methods

High power land-based and aircraft transmitters in countries that operate submarines send signals that can be received thousands of miles away. Transmitter sites typically cover great areas (many acres or square kilometers), with transmitted power anywhere from 20 kW to 2 MW. Submarines receive signals from land based and aircraft transmitters using some form of towed antenna that floats just under the surface of the water – for example a BCAA (Buoyant Cable Array Antenna). Modern receivers use sophisticated digital signal processing techniques to remove the effects of atmospheric noise (largely caused by lightning strikes around the world) and adjacent channel signals, extending the useful reception range. Strategic nuclear bombers of the United States Air Force receive VLF signals as part of hardened nuclear resilient operations.

Because of the low bandwidth available it is not possible to transmit audio signals, therefore all messaging is done with text data at very low bit rates. Three types of modulation are used:

- OOK / CWK: On-Off Keying / Continuous Wave Keying. Simple Morse code transmission mode where the carrier is turned on and off, with carrier on representing the Morse code "dots" and "dashes" and carrier off representing spaces. This is the simplest possible form of radio transmission, but it is difficult for transmitters to transmit high power levels, and the signal can easily be swamped by atmospheric noise, so this is used really only for emergencies or basic testing.
- FSK: Frequency-shift keying. The oldest and simplest form of digital radio data modulation, with the carrier shifted between two frequencies, one representing the binary digit "1" and the other representing binary "0". For example, the frequency may be increased by 25 Hz from the carrier frequency to indicate a "1" and reduced by 25 Hz to indicate "0". FSK is used at rates of 50 bit/s and 75 bit/s.
- MSK: Minimum-shift keying. A more sophisticated modulation method that uses less bandwidth for a given data rate than FSK. This is the normal mode for submarine communications today, and can be used at data rates up to 300 bit/s- or about 35 8-bit ASCII characters per second (or the equivalence of a sentence every two seconds) – a total of 450 words per minute.

Two alternative character sets may be used: 5-bit ITA2 or 8-bit ASCII. Because these are military transmissions they are almost always encrypted for security reasons. Although it is relatively easy to receive the transmissions and convert them into a string of characters, enemies cannot decode the encrypted messages; military communications usually use unbreakable one-time pad ciphers since the amount of text is so small.

Amateur use

Radio amateurs in some countries have been granted permission (or have assumed permission) to operate at frequencies below 8.3 kHz.[8]

Radiated power from amateur stations is very small, ranging from 1 μW to 100 μW for fixed base station antennas, and up to 10 mW from kite or balloon antennas. Despite the low power, stable propagation with low attenuation in the earth-ionosphere cavity enable very narrow bandwidths to be used to reach distances up to several thousand km. The modes used are QRSS, MFSK, and coherent BPSK.

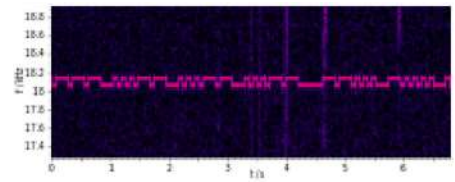
Operations tend to congregate around the frequencies 8.27 kHz, 6.47 kHz, 5.17 kHz and 2.97 kHz.[9] Bandwidths of a few tens of uHz are typical and both receiver and transmitter must have their frequency locked to a stable reference such as a GPS disciplined oscillator or a rubidium standard.

The transmitter generally consists of an audio amplifier of a few hundred watts, an impedance matching transformer, a loading coil and a large wire antenna. Receivers employ an electric field probe or magnetic loop antenna, a sensitive audio preamplifier, isolating transformers, and a PC sound card to digitise the signal. Extensive digital signal processing is required to retrieve the weak signals from beneath interference from power line harmonics and VLF radio atmospherics. Useful received signal strengths are as low as 3×10^{-8} volts/meter (electric field) and 1×10^{-16} tesla (magnetic field), with signaling rates typically between 1 and 100 bits per hour.

VLF signals are often monitored by radio amateurs using simple homemade VLF radio receivers based on personal computers (PCs).[10][11] An aerial in the form of a coil of insulated wire is connected to the input of the soundcard of the PC (via a jack plug) and placed a few meters away from it. Fast Fourier transform (FFT) software in combination with a sound card allows reception of all frequencies below the Nyquist frequency simultaneously in the form of spectrogrammes. Because CRT monitors are strong sources of noise in the VLF range, it is recommended to record the spectrograms with any PC CRT monitors turned off. These spectrograms show many signals, which may include VLF transmitters and the horizontal electron beam deflection of TV sets. The strength of the signal received can vary with a sudden ionospheric disturbance. These cause the ionization level to increase in the ionosphere producing a rapid change to the amplitude and phase of the received VLF signal.

List of VLF transmissions

For a more detailed list, see List of VLF-transmitters



Spectrogram of an 18.1 kHz VLF signal, picked up using a small loop antenna and a sound card. The vertical stripes are distant lightnings.

Callsign	Frequency	Location of transmitter	Remarks
-	11.905 kHz	Russia (various locations)	Alpha-Navigation
-	12.649 kHz	Russia (various locations)	Alpha-Navigation
-	14.881 kHz	Russia (various locations)	Alpha-Navigation
HWU	15.1 kHz	Rosnay, France	400 kW. [1] (http://www.mdpi.com/2076-3263/1/1/3/pdf)
-	15.625 kHz	-	Frequency for horizontal deflection of electron beam in CRT televisions (576i)
-	15.734 kHz	-	Frequency for horizontal deflection of electron beam in CRT televisions (480i)
JXN	16.4 kHz	Gildeskål (Norway)	
SAQ	17.2 kHz	Grimeton (Sweden)	Only active at special occasions (Alexanderson Day)
-	ca. 17.5 kHz	?	Twenty second pulses
NAA	17.8 kHz	VLF station (NAA) at Cutler, Maine [2] (http://www.random-abstract.com/radio/)	
RDL/UPD/UFQE/UPP/UPD8	18.1 kHz	Russia (various locations including Matotchkinchar, Russia)[3] (http://www.mdpi.com/2076-3263/1/1/3/pdf)	
HWU	18.3 kHz	Le Blanc (France)	Frequently inactive for longer periods
RKS	18.9 kHz	Russia (various locations)	Rarely active
GQD	19.6 kHz	Anthorn (Britain)	Many operation modes.
NWC	19.8 kHz	Exmouth, Western Australia (AUS)	Used for submarine communication, 1 Megawatt.[12]
ICV	20.27 kHz	Tavolara (Italy)	
RJH63, RJH66, RJH69, RJH77, RJH99	20.5 kHz	Russia (various locations)	Time signal transmitter Beta
ICV	20.76 kHz	Tavolara (Italy)	
HWU	20.9 kHz	Saint-Assise, France [4] (http://www.mdpi.com/2076-3263/1/1/3/pdf)	
RDL	21.1 kHz	Russia (various locations)	rarely active
NPM	21.4 kHz	Hawaii (USA)	
HWU	21.75 kHz	Rosnay, France [5] (http://www.mdpi.com/2076-3263/1/1/3/pdf)	
GZQ	22.1 kHz	Skelton (Britain)	
JJI	22.2 kHz	Ebino (Japan)	
?	22.3 kHz	Russia?	Only active on 2nd of each month for a short period between 11:00 and 13:00 (respectively 10:00 and 12:00 in winter), if 2nd of each month is not a Sunday

Callsign	Frequency	Location of transmitter	Remarks
RJH63, RJH66, RJH69, RJH77, RJH99	23 kHz	Russia (various locations)	Time signal transmitter Beta
DHO38	23.4 kHz	near Rhauderfehn (Germany)	submarine communication
NAA	24 kHz	Cutler, Maine (USA)	Used for submarine communication, at 2 megawatts. [6] (http://www.globalsecurity.org/military/facility/cutler.htm)
NLK	24.6 kHz	Seattle, Washington (USA)	192 kW. [7] (http://www.mdpi.com/2076-3263/1/1/3/pdf)
NLF	24.8 kHz	Arlington, Washington (USA)	Used for submarine communication. [8] (http://www.vlf.it/trond2/20-25khz.html) [9] (http://ludb.clui.org/ex/i/WA3248/)
NML	25.2 kHz	LaMour, North Dakota (USA)	
PNSH	14–25.2? kHz	Karachi coast, Sindh (Pakistan)	

See also

- Communication with submarines
- OMEGA Navigation System, 1971–1997
- Radio atmospheric

References

1. "Rec. ITU-R V.431-7, Nomenclature of the frequency and wavelength bands used in telecommunications" (https://web.archive.org/web/20131031020427/http://www.itu.int/dms_pubrec/itu-r/rec/v/R-REC-V.431-7-200005-I%21%21PDF-E.pdf) (PDF). ITU. Archived from the original (http://www.itu.int/dms_pubrec/itu-r/rec/v/R-REC-V.431-7-200005-I!!PDF-E.pdf) (PDF) on 31 October 2013. Retrieved 20 February 2013.
2. Hunsucker, R. D.; John Keith Hargreaves (2002). *The high-latitude ionosphere and its effects on radio propagation* (https://books.google.com/books?id=IQWHj2bgcxcC&pg=PA419). Cambridge University Press. p. 419. ISBN 978-0-521-33083-1.
3. Ghosh, S. N. (2002). *Electromagnetic theory and wave propagation* (https://books.google.com/books?id=6Mvf4-gsVycC&pg=PA89). CRC Press. p. 89. ISBN 978-0-8493-2430-7.
4. Marina Koren (May 18, 2017). "Humans Accidentally Created a Protective Bubble Around Earth" (https://www.theatlantic.com/science/archive/2017/05/wow-guys/527193/). *The Atlantic*. Retrieved May 20, 2017.
5. Seybold, John S. (2005). *Introduction to RF Propagation* (https://books.google.com/books?id=4LtmjGNwOPIC&pg=PA57&dq=cross+polarization+discrimination). John Wiley and Sons. pp. 55–58. ISBN 978-0471743682.
6. "AWDANet" (http://plasmon.elte.hu/awdanet.htm).
7. "Geonics Limited - VLF Receivers" (http://www.geonics.com/html/vlfsystems.html). Retrieved 13 June 2014.
8. "Sub 9kHz spectrum in the Amateur Service" (http://www.cept.org/Documents/wg-fm/24788/fm-15-119_sub-9-khz-spectrum-in-the-amateur-service). Retrieved 13 May 2017.
9. "Some recent milestones with amateur radio experiments at VLF" (http://abelian.org/vlf/amateur-radio). Retrieved 13 May 2017.
10. Renato Romero, IK1QFK (2008). *Radio Nature*. Radio Society of Great Britain. p. 77. ISBN 9781-9050-8637-5.

11. Mardina Abdullah; et al. (2013). "Development of UKM-SID teaching module for space science education (6th International Forum on Engineering Education 2012 (IFEE 2012))". *Procedia - Social and Behavioral Sciences*. **102**: 80–85. doi:10.1016/j.sbspro.2013.10.716 (https://doi.org/10.1016%2Fj.sbspro.2013.10.716).
12. Naval base link to jet plunge (http://www.smh.com.au/news/travel/naval-base-link-to-qantas-plunge/2008/11/14/1226318890475.html) - The Sydney Morning Herald 14 November 2008, retrieved on 14 November 2008.

Further reading

- Romero, R. (2006). *Radio Natura* (in Italian). Albino, Italy: SANDIT S.r.l.
- Klawitter, G.; Oexner, M.; Herold, K. (2000). *Langwelle und Längstwelle* (in German). Meckenheim: Siebel Verlag GmbH. ISBN 978-3-89632-043-8.
- Friese "Very low wave reception with ferrite antennas 5-50 kHz (http://www.magnet-ferritantennen.de/assets/plugindata/poola/funkamateur012006.pdf)

External links

- Longwave club of America (http://www.lwca.org)
- Radio waves below 22 kHz (http://www.vlf.it)
- VLF Discussion Group (http://tech.groups.yahoo.com/group/VLF_Group)
- Tomislav Stimac, "*Definition of frequency bands (VLF, ELF... etc.) (http://www.vlf.it/frequency/bands.html)*".
- PC-based VLF-reception
- Gallery of VLF-signals
- NASA live streaming ELF -> VLF Receiver (http://spaceweather.com/glossary/inspire.html) NOTE: As of 05/03/2014, the "Listen live" links are down, but the site has some previously recorded examples to listen to.
- VLF radio art, 1 (https://www.youtube.com/watch?v=-g6PcLEx6bs)
- VLF radio art, 2 (https://www.youtube.com/watch?v=YoVrd7aM8cI)
- VLF radio art, 3 (https://www.youtube.com/watch?v=CjVnVg4RDi0)
- World Wide Lightning Location Network (http://webflash.ess.washington.edu/)
- Stanford University VLF group (http://vlf.stanford.edu/research/introduction-vlf)
- University of Louisville VLF Monitor (http://moondog.astro.louisville.edu/index.html)
- Larry's Very Low Frequency site (http://www.vlfradio.com/)
- Mark's Live Online VLF Receiver, UK (http://www.markyd26uk.110mb.com/vlf.html)
- IW0BZD VLF TUBE receiver (http://www.qsl.net/iw0bzd/VLF_TUBE_RX.htm)
- Internet based VLF listening guide with server list (http://www.ab9il.net/vlf/vlf1.html)
- List of VLF-transmitters (http://sidstation.loudet.org/stations-list-en.xhtml)