TERRESTRIAL NATURAL AND MAN-MADE ELECTROMAGNETIC NOISE

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ABSTRACT

The terrestrial environment is continuously exposed to electromagnetic radiations which set up a "background" electromagnetic noise. For what concerns electromagnetic waves in the Non Ionizing Radiation band (NIR), i.e. for frequencies lower than 300 GHz, the background can have a natural or an artificial origin. In the first case electromagnetic radiations have generally an atmospheric or a cosmic origin while in the second case human technologies, implanted for power transmission and communications, are the non 'natural' cause. In this paper, a brief description of the natural and man-made electromagnetic noise in the NIR band has been reported. Natural noise shows a very large variety of sources that involve different physical phenomena and cover a wide range of frequency showing various propagation characteristics with an extremely broad range of power levels. Due to the technological expansion man-made electromagnetic noise is nowadays superimposed on the natural noise almost everywhere on Earth. In residential and business areas, man-made noise has increased dramatically in the last tens of years exceeding the natural one and in certain cases overwhelming the natural noise. This circumstance has brought some to consider possible negative influences on human life and living systems in general. In all cases however both contributions form the background in which the terrestrial environment is immersed and investigations and detailed measurements are still required to understand their relative power levels in the different frequency bands and their influence on life in general. Some aspects of the electromagnetic field interaction with biological systems are also presented.

1) INTRODUCTION

Natural electromagnetic noise sources exist since the origin of the Universe, therefore life on Earth has developed and evolved in a 'sea' of electromagnetic noise. Natural radio noise, for example, has been always present and maybe, in a small part, accustomed the evolution of living system. Understanding how the background noise is generated and distributed and how it interacts with living systems can contribute to the general knowledge of the secrecies of life on Earth. In the present work we consider the different frequency ranges, starting from the lowest frequencies that the ionospheric and magnetospheric cavities can sustain, up to the galactic and man-made noise in the micro-wave band. Depending on frequency, the natural noise inside the magnetospheric cavity, originates from the impinging particles and waves that interact at various level with the magnetosphere. Inside the ionospheric cavity atmospheric noise originates from the energy of the lightning discharges that produce several interesting propagating phenomena.

Human technologies implanted for power transmission and communications are the well known non natural cause of man made noise. The man-made noise, that is mainly due to the communication and broadcasting systems, electric energy transport systems, automotive ignition, industrial thermal processes and instruments for scientific/medical appliances, is distributed, albeit not uniformly, in all bands. In VLF-HF band atmospheric noise is still larger than man-made noise in the order of tenth of dB in rural areas and simply overcomes man-made noise in business areas. At higher frequency radio noise originated in the atmosphere becomes less important and cosmic noise is prevalent up to the millimetric wavelength. In general man-made noise is concentrated in certain particular frequencies in correspondence to technological applications.

Both contributions, natural and man-made, affect in some way the living systems. Exposure of biological system in a electromagnetic field induce electrical currents and fields and surface charges at the interface of electrically different media and, as frequency increases, the thermal effects are much more evident; this behavior is described by Maxwell's equations. Furthermore, if the electric properties of the biological systems are known it is possible to establish its interaction with the electromagnetic fields. A biological system is practically transparent to the static magnetic field, life on Earth, where a natural quasi static magnetic field in the range of 20-70 μT order of magnitude exists, has developed in such environment. Time varying magnetic fields interact with living systems according to their respective wavelengths and sizes. Static and slow varying electric fields inside the biological system reduce their strength of several order of magnitude. Cell membranes play a key role in protecting biological systems against large electric fields starting from static to ELF band. Higher frequencies electromagnetic waves interact with the polar water molecules which constitute generally a large fraction of the living systems. Cell membrane confers to biological systems peculiar electromagnetic properties especially at the lower frequencies. Increasing the frequency the real part of the dielectric permittivity decreases and the internal electric field is comparable with the external field, at high frequencies thermal effects become prevalent. The characterization of the natural and man-made radio noise allows us to establish also how biological systems had interacted with the electromagnetic fields. At the present time the characterization of man-made noise is important to determine how life can be affected by this new contribution that is superimposed to the natural noise in the planetary environment (figure 1).

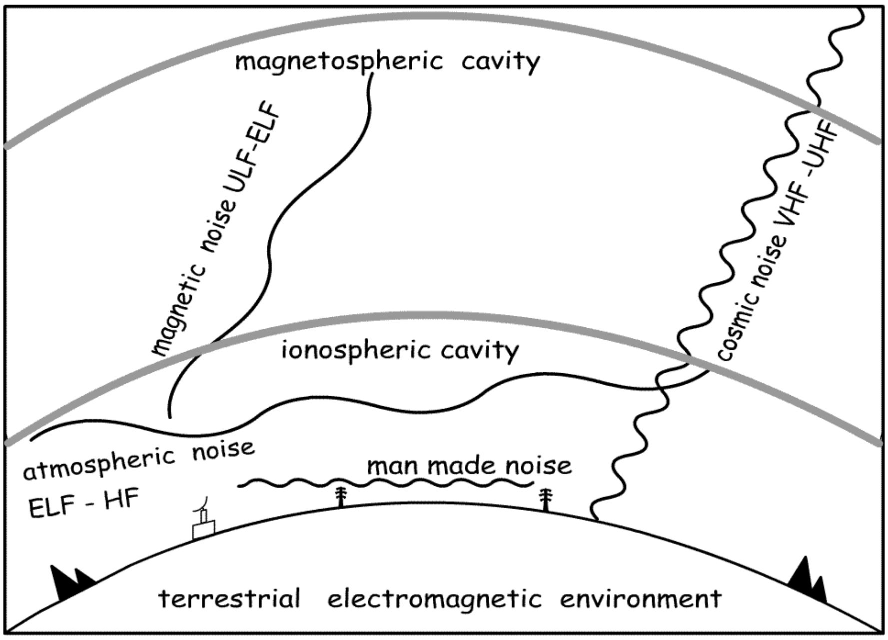

Figure 1 – A schematic pictorial of terrestrial natural and man-made radio noise sources

2) NATURAL RADIO NOISE

Non ionizing radiation (NIR) electromagnetic waves range from the mHz to 300 GHz spanning over 14 orders of magnitude (figure 2). The corresponding wavelengths range from length comparable with dimension of the solar system, for waves around the mHz frequencies, to millimeters for frequency around 300 GHz.

	frequency range	wavelength (m)	main natural radio noise souce	environment
ULF (ultra low frequency)	1 - 3000 mHz	$3x10^{11}$ - $3x10^{8}$	resonances in the magnetospheric cavity, interaction with particles of solar origin and radiative pressure with tha magnetosphere	magnetospheric cavity
ELF (Extremely low frequency)	3- 3000 Hz	10^{8} - 10^{5}	resonances in the ionospheric cavity	ionospheric cavity
VLF (very low frequency)	3 - 30 kHz	10^{5} - 10^{4}	propagation in the ioospheric cavity of of the atmospheric disharge radiate energy	ionospheric cavity
LF (low frequency)	30 - 300 kHz	10^{4} - 10^{3}	atmospheric noise	ionospheric cavity
MF (medium frequency)	300 - 3000 kHz	10^{3} - 10^{2}	atmospheric noise	ionospheric cavity
HF (high frequency)	3- 30 MHz	10^{2} - 10	atmospheric noise and cosmic noise	ionospheric cavity
VHF (very high frequency)	30- 300 MHz	10 - 1	atmospheric and cosmic noise	Earth surfaces (mainly due to the cosmic noise the penetrate the ionospheric layers)
UHF (ultra high frequency)	300 - 3000 MHz	1 - 10^{-1}	cosmic noise	as above
SHF (super high frequency)	3 - 30 GHz	10^{-1} - 10^{-2}	cosmic noise	as above
EHF (extremely high frequency)	30 - 300 GHz	10^{-2} - 10^{-3}	cosmic noise	as above

Figure 2 – NIR frequency bands and the main natural radio noise sources

Magnetic noise in ULF/ELF band and other propagating phenomena

The terrestrial static magnetic field includes also very slow time variations: secular, annual, 27 days, diurnal, and magnetic bay type variations that have very low frequency (< 1mHz); all this can be considered a sort of “magnetic” noise. Variations can be quantified in tenth of nT for the diurnal variation and hundreds of nT in the case of strong magnetic storms. At higher frequencies in this band various other phenomena, like geomagnetic pulsations take place. Geomagnetic pulsations, i.e., ultra-low-frequency (ULF) waves cover roughly the frequency range from 1 mHz to 1 Hz, i.e., from the lowest the magnetospheric cavity can sustain, up to the various ion gyrofrequencies. Pulsation frequency is considered to be "ultra" low when is lower than the natural frequencies of the plasma, like plasma frequency and the ion gyrofrequency. Geomagnetic pulsations were first observed in the ground-based measurements of the 1859 Great Aurora events (Stewart, 1861). Lower frequency pulsations are generally related to the Kelvin Helmholtz instability that takes place at the magnetopause, as generated by the solar wind interaction with the magnetosphere, or by upstream waves in the foreshock region. In the following (figure 3) geomagnetic pulsations with the intensity variation, frequency and other information are represented (Lanzerotti et al. 1990).

pulsation classes	continuous pulsations					irregular pulsations		
	Pc1	Pc1	Pc3	Pc4	Pc5	Pi1	Pi2	incoherent noise
period (s)	0.2 - 5	5 - 10	10 - 45	45 -150	150 -600	1 - 40	40 - 150	1 - 1000
frequency (mHz)	200-5000	100-200	22-100	7-22	2-7	25-1000	2-25	1-1000
intensity (nT)	1	3	10	<300	300	10	100	-
source	e.m. ion cyclotron instability in the equatorial magneto-sphere	e.m. ion cyclotron instability in the equatorial magneto-sphere	wave-particle interaction in the bow shock region	drift of protons from the nightside	magneto-pause instability	modulation of particles	substorms	ionospheric current (intensity increase with the magnetic activity)

Figure 3 – Magnetic noise sources

Other electromagnetic phenomena originate by the impinging particles on the magnetosphere that give rise to electromagnetic emission that propagate inside the magnetosphere cavity. Chorus emissions and auroral Hiss are two relevant phenomena. Chorus emissions are among the most intense plasma waves in the outer magnetosphere that propagate as far as the Earth surface and are observed at intermediate invariant latitudes. The Chorus spectral features (from 500 Hz to 1.2 kHz) consist in the succession of predominantly rising tones which resemble a chorus of chirping birds from which these emissions take their name. Auroral hiss emissions are broad, intense electromagnetic emissions which occur over a wide frequency range from a few hundred Hz to several tens of kHz occurring mainly in the auroral zone. This spreading at high frequencies is caused by the anisotropic character of whistler mode propagation (see later). The resulting tones are strongly modulated hiss-like tones.

Atmospheric noise in ELF/VLF band and related electromagnetic phenomena

Lightnings are the main source of energy for the electromagnetic background inside the ionospheric cavity. Starting from the lower band ELF (few Hz) up to several VHF (hundreds MHz) the noise originates from the energy radiate by the lightning. Several million lightning strokes occur daily from an estimated 2000 storms worldwide, and the Earth is somewhere struck 100 times a second by a lightning. The discharge is very violent and can easily reach 10.000 Amperes. The amount of energy released by each discharge can vary from units to tenth of GJ. Hence, for the duration of the discharge (less than 1 s), the powers involved in this phenomena are of the order of 1- 10 GW. The annual total released energy is in the order of 10^{19} J. If only 10% of this energy will be radiated as electromagnetic energy (figure 4) this amount of electric energy is comparable to the energy produced in 1970 by the electric power stations over the world.

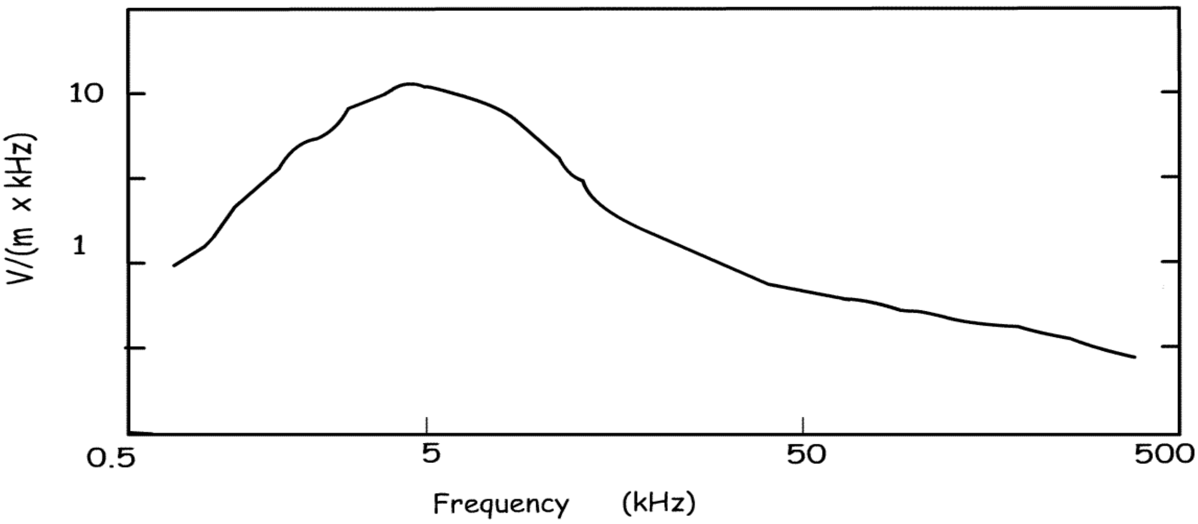

Figure 4 - Lightning frequency domain electromagnetic spectrum

The main relevant phenomena in the ELF lower band are the Schumann resonances. This phenomenon consists of a wide spectrum electromagnetic signal, composed by dumped waves of frequencies below 60 Hz. Schumann resonances occur because the Earth and the ionosphere form a natural wave guide that shows a fundamental resonance frequency at 7.8 Hz and upper harmonic components at about 15.6, 23.4 and 31.2 Hz (figure 5). The Earth-atmosphere system can be seen, from an electromagnetic point of view, as a series of shell layers of different electrical conductivity. The Earth and the ionospheric layers appear as perfect conductors with the air of negligible conductivity in between; they form an Earth-ionosphere cavity, in which electromagnetic radiation is trapped. Lightning strikes within the troposphere radiate energy into this system and the waves travel around the Earth. In the case of constructive interference, Earth-ionosphere cavity resonances are excited in the above mentioned frequency range (6-60 Hz).

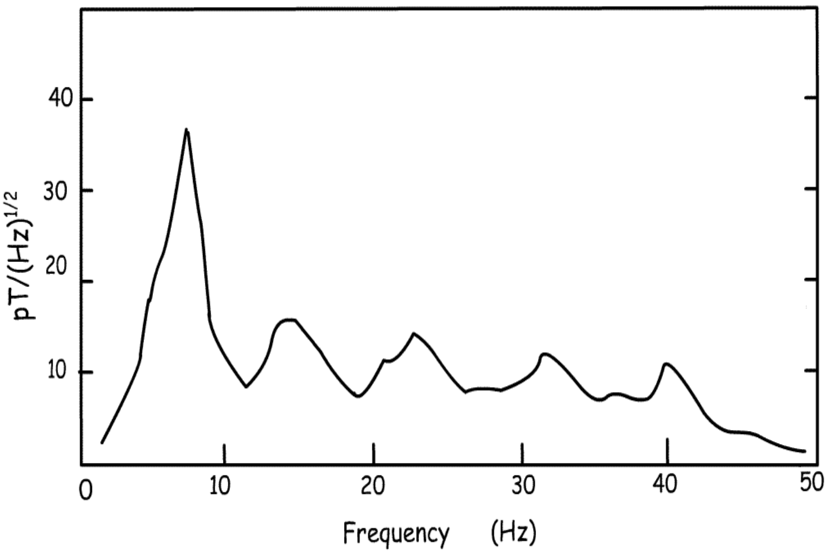

Figure 5- Schumann resonance peaks

A series of propagating phenomena that are relevant in this band of frequency are the so called spherics, tweeks and whistlers. Radio atmospherics (or spherics for short and sometime statics) are impulsive signals generated by lightning strokes that travel with a low attenuation in the Earth-ionosphere wave guide. These impulsive signals (few ms) propagate for thousand kilometers. As in a real wave guide, the Earth-ionosphere guide, can sustain the propagation of this signals with very low attenuation values. Since only the upper part of this channel varies with time the sferic propagation is determined by ionosphere conditions. Almost all AM receivers detect spherics as disturbances (sounds like pops and crashes). The more powerful the lightning stroke, or the closer the distance is to the VLF receiver's location, the louder the disturbances given by the spherics will sound. Sparks of lightning strokes are generally powerful sources of electromagnetic (radio) emission throughout the radio frequency spectrum from the very low radio frequencies up to the microwave frequency ranges and the visible light spectrum, even if the radio power is concentrated in VLF range from 0.1 to 10 kHz (figure 6).

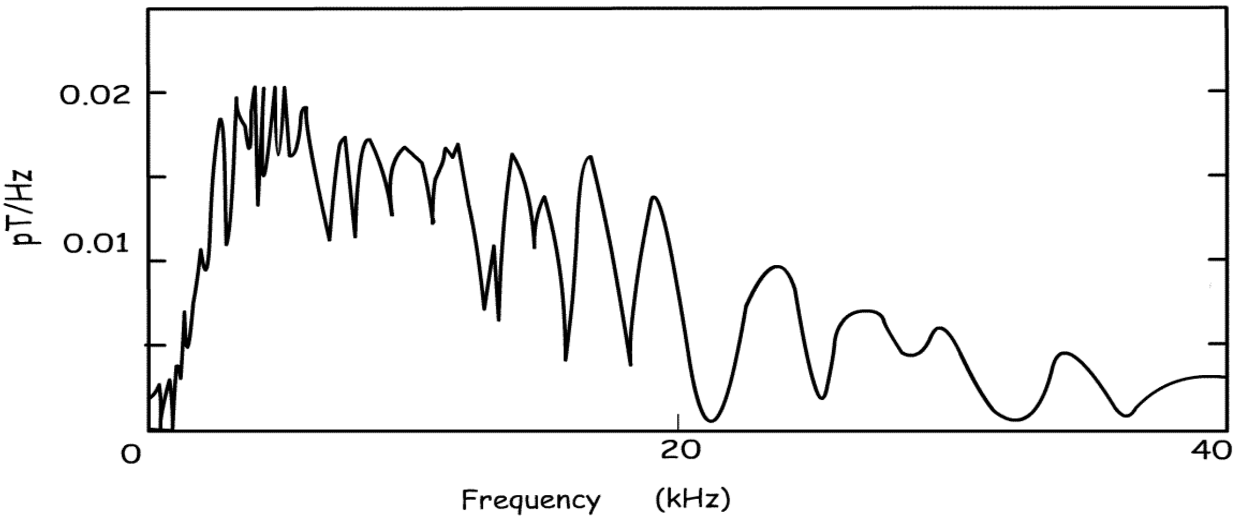

Figure 6 – Typical sferic frequency spectrum

Tweeks are spherics dispersed in frequency. Their sound is similar to a bird's song in a frequency range of 1-7 kHz (figure 7). When spherics propagate for long distances in a dispersive medium like the ionosphere their harmonic components separate along the travel (Helliwell R.A. 1965). These components penetrate at various depths the ionosphere, in such a way that, higher frequencies penetrate more than lower ones and as consequence travel for longer distances. These different paths imply different arrival times at an observer. In a spectrogram they result like a descending tone with duration of the order of 25 to 150 ms. Tweeks are normally heard in the evening after the sunset.

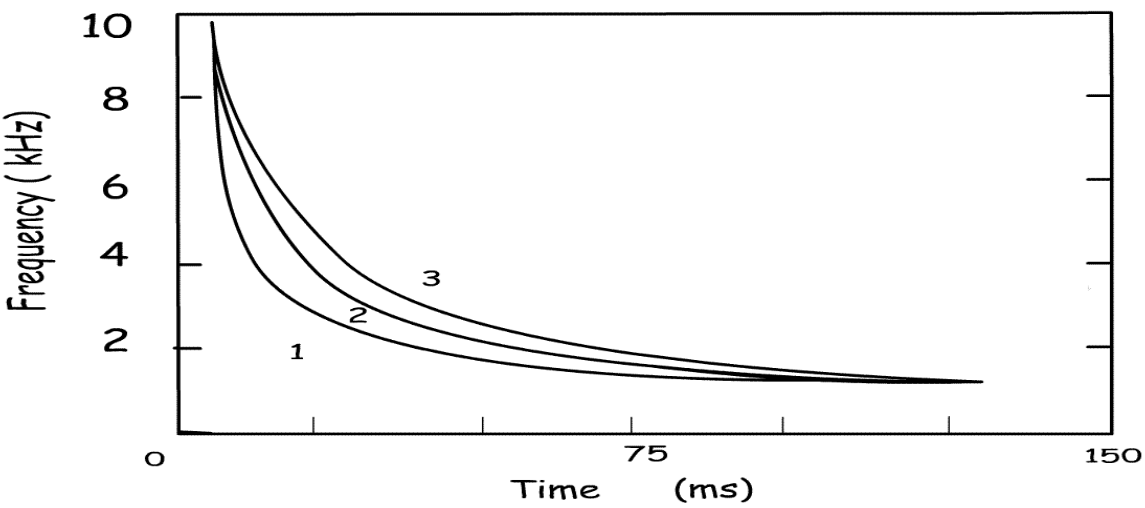

Figure 7 – Tweeks that traveled for different distances in the Earth-ionosphere waveguide shown for about 60000 km (1), more than 10000 km (2) and more than 14000 km (3) paths.

The whistlers are remarkable burst generated by lightning discharge. In fact part of the this energy escapes the ionospheric barrier and propagate through the magnetosphere. They can be heard in radio receivers as a relative long whistle decreasing in frequency, from about 6 kHz to few hundred Hz (figure 8). In the magnetosphere whistlers interact with free electrons and are forced to propagate along the Earth's magnetic field lines. The harmonic components of the signal identified as whistlers correspond to electromagnetic waves that have traveled several Earth radii arriving at different times to the observer. Lower frequencies are delayed 3-6 second with respect to the higher ones. The dispersion of a whistler depends on the length of the path over which the signal travels as well as the characteristics of the propagation medium such as its electron density.

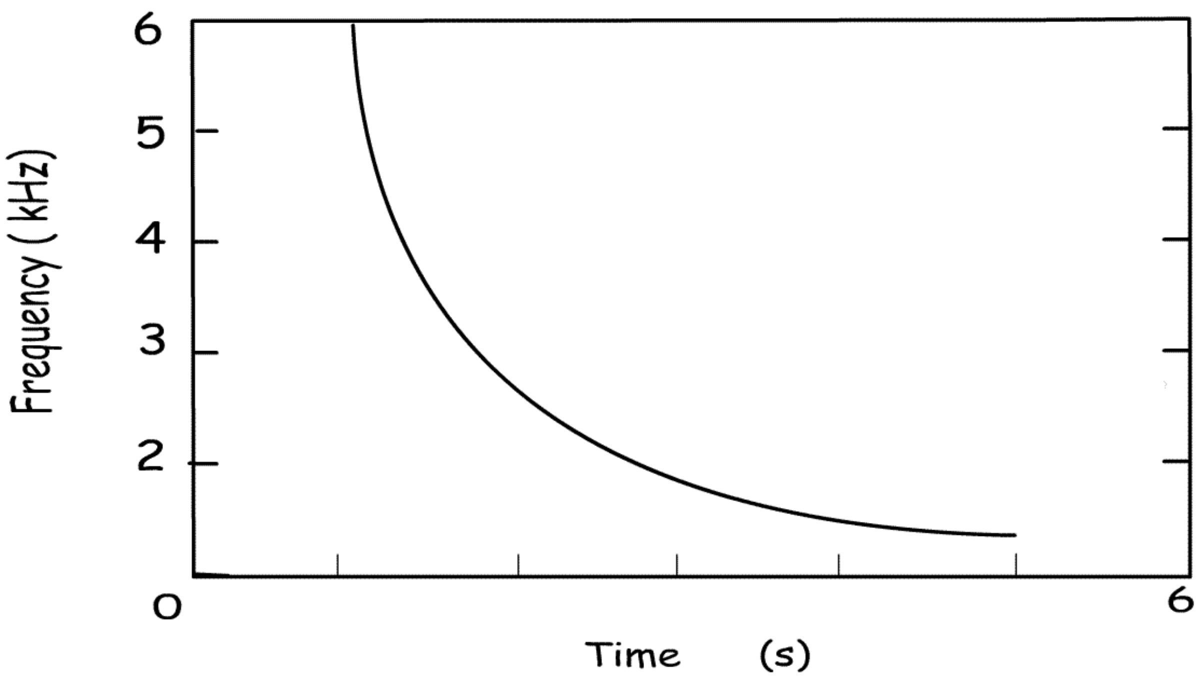

Figure 8 - Whistler spectrum

Natural LF/MF/HF noise

Also in this frequency range the natural electromagnetic noise has its main source in the atmospheric electric discharges; noise is generally decreasing in amplitude with the frequency and is affected by ionospheric conditions. Since LF/MF/HF frequencies were very soon used in radio communications and broadcasting, in this frequency range the natural radio noise was the object of scientific studies in the radio engineers community and natural LF/MF/HF noise radio measurements started very early as the radio devices developed. The electromagnetic waves radiated by impulsive lightening discharges cannot escape from the ionosphere border. Waves penetrate through the lowest ionospheric layers were they are, depending on the frequency, variously absorbed. Radio waves are reflected by the upper layers of the ionosphere up to a particular frequency, named ‘critical frequency’, that is dependent on local ionospheric condition. Moreover the incidence angle between the wave and the ionospheric layers plays an important role. In fact depending on the path geometry several propagating mode can be established. The results are summarized in figure 10 where the atmospheric noise vs. frequency is plotted. In the same figure the comic noise, that starts at frequencies greater than the of the ionosphere plasma frequency begins to appear. The cosmic noise lowest frequency depends on the ionospheric conditions i.e. on electron plasma frequency about (15-30 MHz). The amplitude of the cosmic noise decrease with the frequency even if lower frequencies are more attenuated than higher. In the 1960th a campaign of atmospheric noise measurement started by Consultative Committee International Radio (CCIR) gave the main contribution to the knowledge of background radio noise in this frequency range. 16 radiometers were installed worldwide and the results were summarized on report CCIR N.322 in 1964 and N.322-3 in 1988. The planetary atmospheric noise distribution is reported in figure 9 where cosmic noise is also reported. In the figure the strongest level are associated to the equatorial region and the weakest in Antarctica.

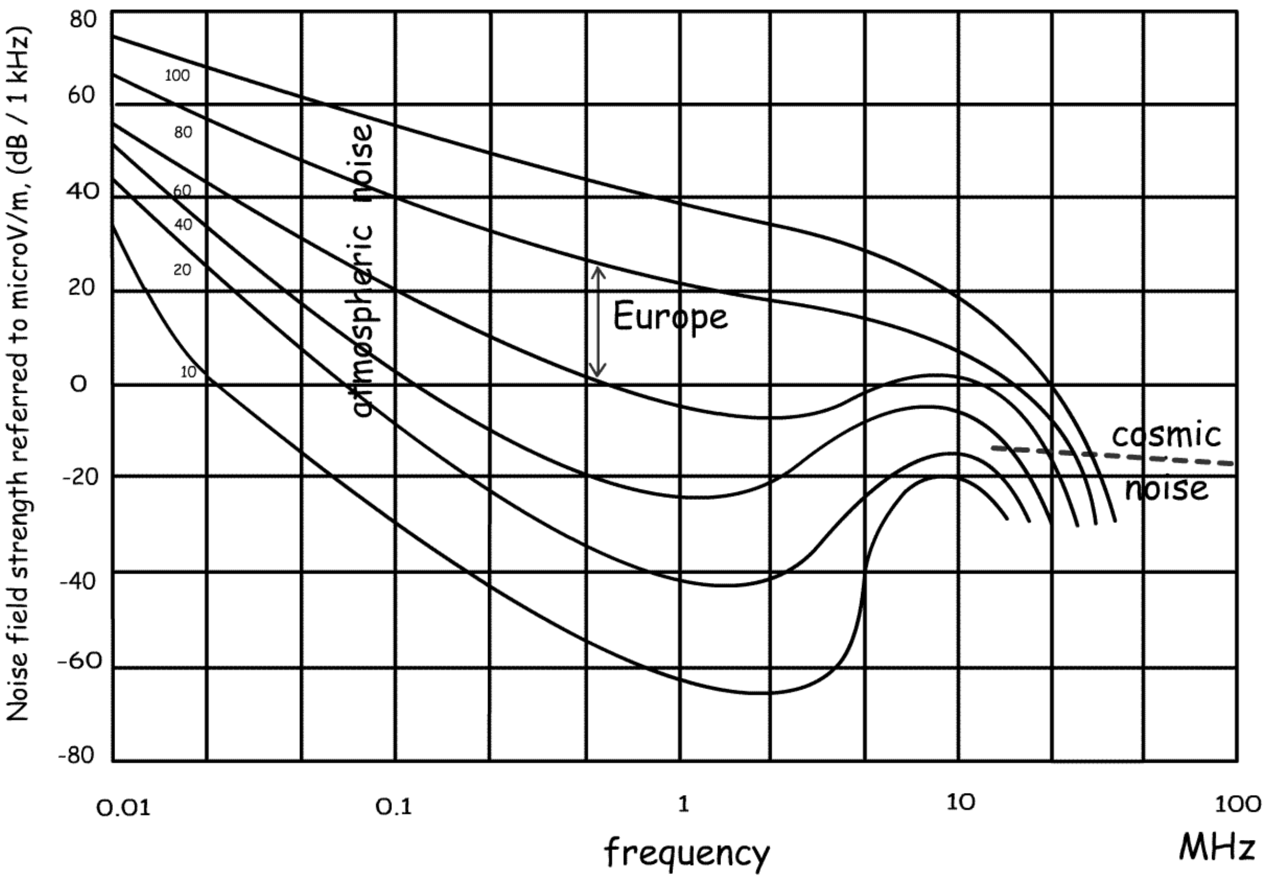

Figure 9 – Electric field strength vs. frequency for atmospheric and cosmic noise.

Natural UHF/SHF/EHF noise

In this range of frequencies the natural predominant noise is the background cosmic (or galactic) noise. In many characteristics cosmic noise is similar to the terrestrial natural noise, like distant lightning strikes, or man-made radio noise; for this reason it was difficult at the beginning of radio measurements to identify the sources. The discovery of the origin of this background noise is usually also marked as the birth of radio astronomy. In 1931 Karl Jansky built an antenna operating at 20.5 MHz and after months of careful observations he concluded that the source of the recorded noise was outside the solar system; since then those frequency bands have been carefully investigated by radio astronomers (Krauss 1988). In 1940 Grote Reber made the first radio map of our Milky Way galaxy at a frequency of 160 MHz. After that the radio emission from the Sun, Jupiter and other celestial bodies have been also identified by radio astronomers. In figure 10 the solar and other main sources are reported. Some of these sources are very strong or show a particular behavior (figure 11). The synchrotron radiation has a characteristic wide spectrum like other impulsive radio sources (Bekefi et al. 1977). Moreover galactic or stellar systems give place to strong and most common noise source: the thermal noise. Thermal noise is arising from the electrons and ions in motion in a dissipative media. Others sources are the bremsstrahlung radiation mainly due to electron proton collision (solar cromosphere, Orion nebula etc.).

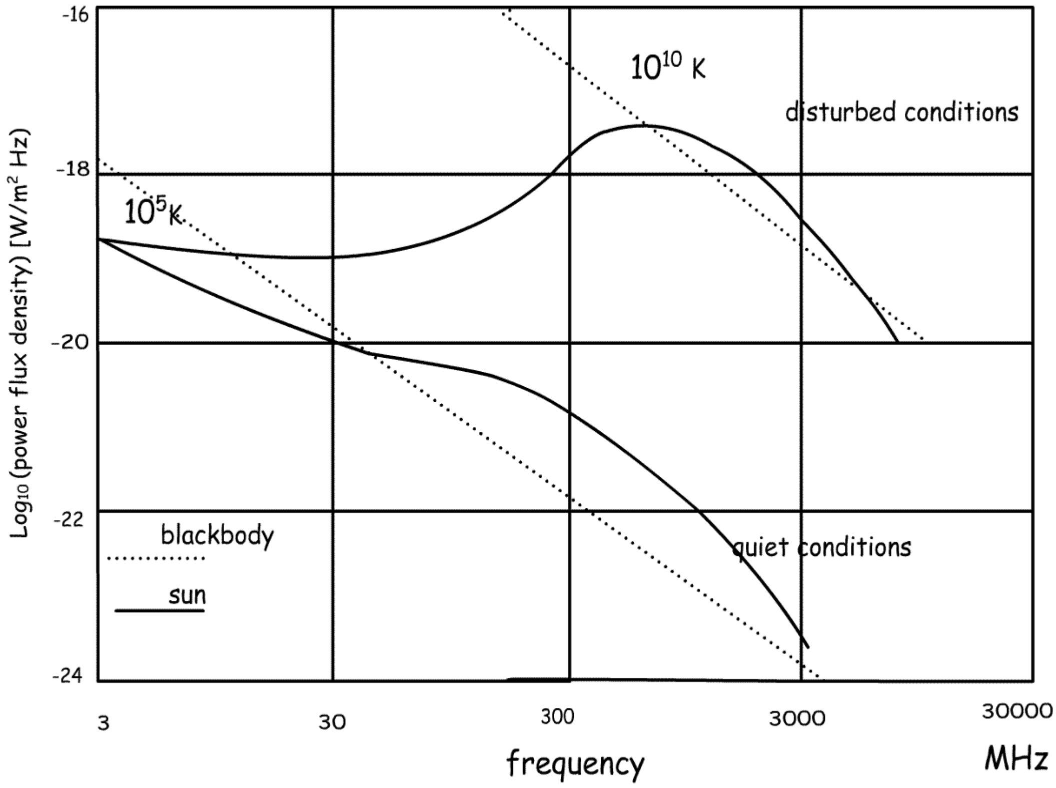

Figure 10 – Solar radio emission

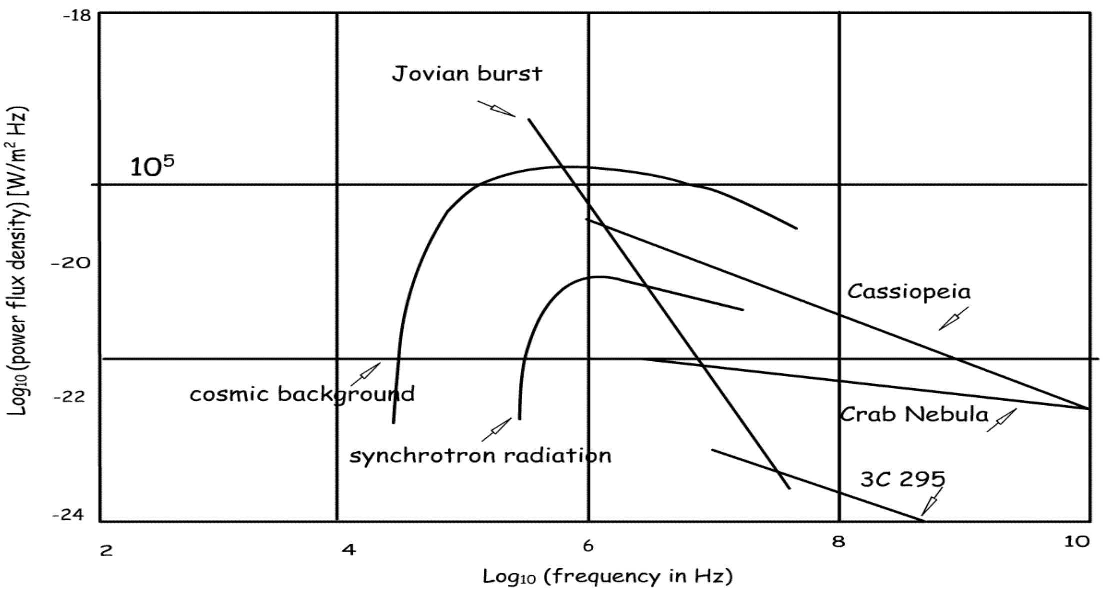

Figure 11 – Some sources of radio emission and cosmic background

The Earth is not the only planet that shows a large variety of radio signal. Almost all planets have an electromagnetic background, for instance Venus is quite similar to Earth, and the four gas giants, Jupiter, Saturn, Uranus and Neptune are natural emitters of HF radio signals. Due to its huge atmospheric disharges Jupiter is one of the major radio emitter. The sun is the most powerful electromagnetic emitter in our solar system able to generate a very broadband radio emissions. In the solar radio emission, several phenomena like flares, magnetic waves, and storms of electrically charged nuclear particles and ions directly cause and/or influence the propagation of electromagnetic waves throughout the known solar spectrum.

3) MAN-MADE ELECTROMAGNETIC NOISE

Man-made noise is noise originated by human technologies. It is strongly dependent on the distance from the sources (power lines, radio, TV communication installations and other…) that can be very variable, on frequency and on emitted power. Power and frequency in their time and spatial distribution are the quantities that better describe the man-made radio sources. Other important characteristics are the continuous or impulsive nature of the emitted waves, the modulation and the wave polarization. Man-made sources are mainly located in business, industrial and residential areas; in rural (countryside) and quiet rural the sources become scarce (report CCIR/ITU N.258-5 1990). In spite of its relevance, near the sources, depending on the frequency band, in quiet rural areas the man made noise power is on average 20-30 dB lower than the business and residential area (figure 12).

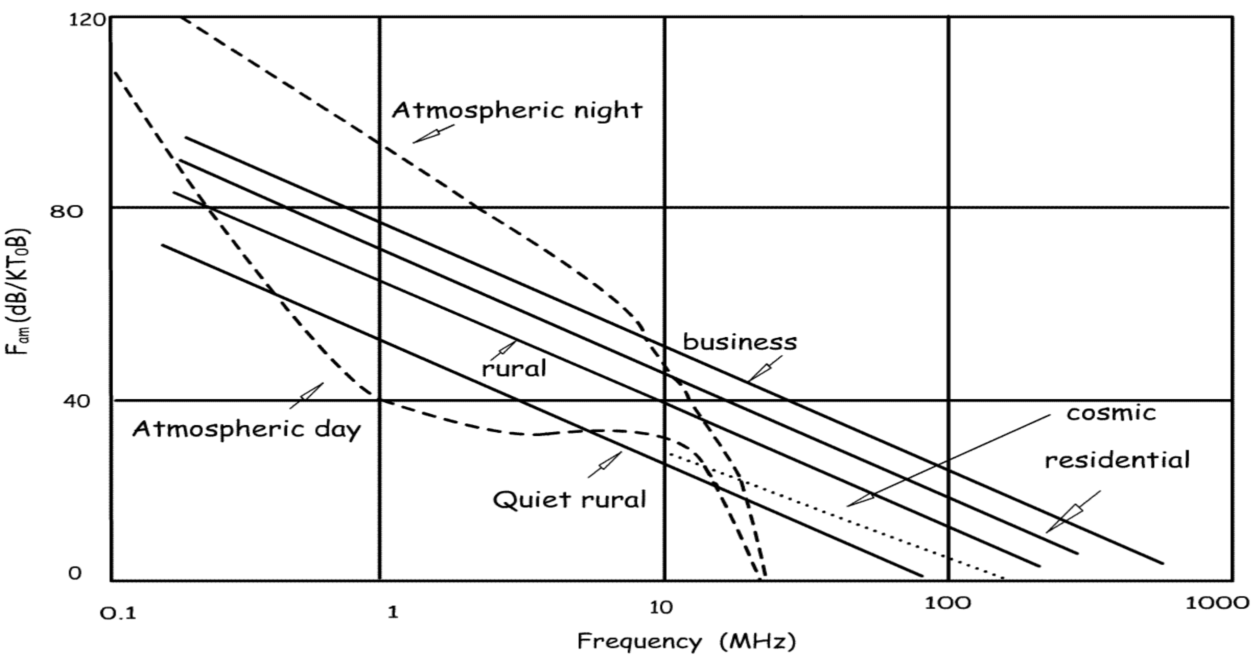

Figure 12 –Solid lines indicate median values of man-made radio noise power expressed in terms of F_{am} (dB above thermal noise at T_0 = 288 K). Atmospheric noise (dashed lines) and cosmic background noise (dotted line) are reported for comparison with man-made noise

Also in the case of electromagnetic man-made noise is convenient to discriminate the contributions in the different frequency bands where the main sources are indicated.

ELF band

In this band the strongest source of man made noise comes from the electric power lines which operate ideally at a single frequency, generally 50 Hz (60 Hz in USA). The electric and magnetic field generated at this frequency are practically decoupled and because of power lines multi-polar configuration, decrease dramatically with the distance from the lines. The power lines are now spread over the planet in all continents except Antarctica where natural ELF waves close to 50-60 Hz can be recorded with less disturbances. Also some uninhabited regions in other continents are relatively free from this kind of disturbances but in general in the ELF band the 50-60 Hz electric a magnetic fields are the strongest man-made source of noise both as emitted power and as extension of the source. In figure 13 the electric and magnetic field decay with the distance from the lines are shown.

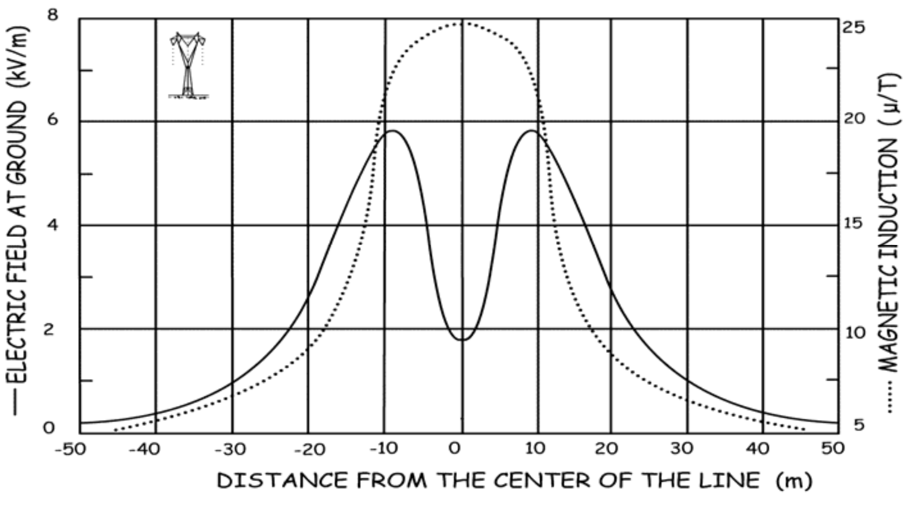

Figure 13 – Electric and magnetic induction fields at ground beneath a 380 kV power line.

VLF – HF band

As in the case of other frequencies, man-made noise emissions are due to electronic devices for indoor use, industrial and radio communication apparatuses, including broadcasting radio, since all

these equipments employ electrical oscillators that become unwanted sources of artificial radio emission.
The main localized sources are radio AM broadcasting (figure14) and some industrial equipment. Among the latter relevant sources are heaters that exploit magnetic induction and dielectric losses in the material. Other weaker but numerous sources such as automotive ignition, heavily contributes to the background noise. We have also inestimable indoor sources such as electrical household appliances, PC monitors TV etc... Other scientific and medical equipment are irrelevant in the background radio noise configuration in the considered range of frequency.

VHF – UHF band

Electromagnetic radiation in these bands are due to the broadcasting FM radio TV and mobile phone service stations (figure14) and more important automotive ignition.

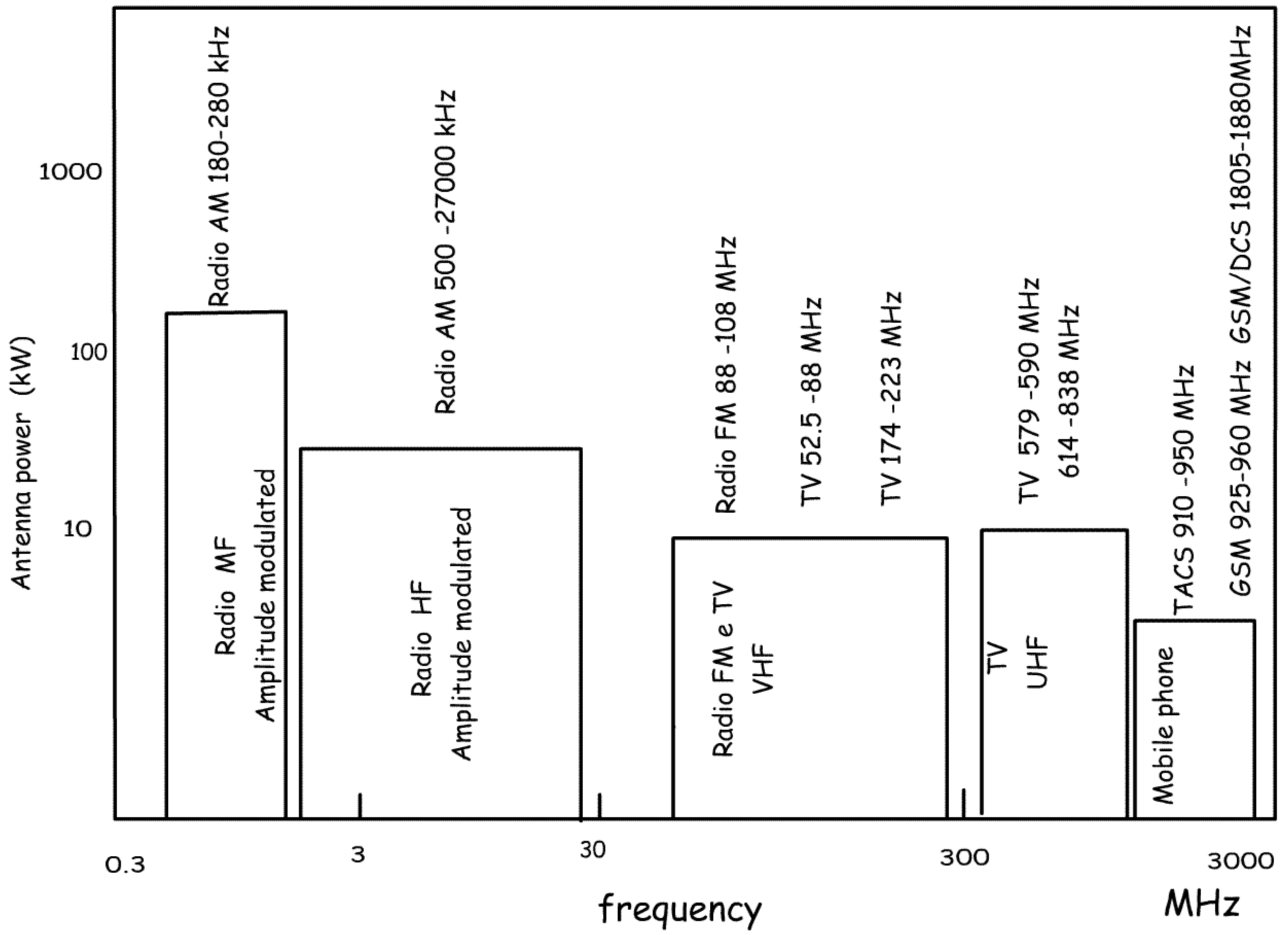

Figure 14 - Power emitted by the most common communication systems

Radar and satellite appliances do not give a very important contribution to background noise level. Main indoor sources are cordless phone microwave ovens etc.. These equipments do not give significant impact outdoor.

SHF – EHF band

Because of the complexity of the system of radio communications and limitations in industrial applications operating at these frequencies, in this range only particular equipments are employed. These bands include satellite communication systems and survey, radar systems, scientific and medical appliances, all techniques affected by intrinsic technological difficulties in the manufacturing of electrical oscillators, transmission lines, antennas etc... For this reason man-made noise is very low in SHF and EHF bands. Moreover, because of the nature of the physical emission processes to which these phenomena obey and their propagation modes SHF and EHF waves are strictly directional. Other technological applications in this range are related to passive observation and measurement like in radio astronomy.

4) CONCLUSIONS

In this paper the terrestrial natural electromagnetic noise and its main characteristics were described. Natural electromagnetic noise constitutes a background radio noise in which living systems are immersed and consequently evolved, since the origin of life on Earth. Superimposed to the natural background radio noise man-made radio noise is now strongly in occurrence. The main man-made radio noise sources and characteristics were are also described and compared with the natural ones. Artificial noise level has been constantly increasing in the last hundred years or so as the electromagnetic application have expanded. A digression of the main characteristics, features and sources, in the frequency range of non ionizing radiation, was made.

A brief excursus of the natural radio sources, starting from the lowest frequencies that the magnetosphere and ionosphere cavities can sustain, to the galactic and cosmic radio sources that penetrate the electronic density layers of the upper atmosphere, was undertaken. These studies, that have roots in the pioneer era of radio communication, when the knowledge of natural noise was essential for the assessment of an effective radio technology, have also revealed during the years their relevance in geophysical, spatial physics, astrophysics and many other research fields. In particular detailed knowledge of features of all natural electromagnetic waves current in the magnetosphere is, as expected, important for ground based communication systems, but can be relevant for example also in the design of earth-orbiting and interplanetary spacecrafts.

5) REFERENCES

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