Electromagnetic Properties of the Natural Environment

The Sun, the Cosmos and the Earth

A major source of radiation in nature is the sun. Frequencies above the ultra-violet range are harmful to living organisms and those that reach the earth are absorbed by the ozone layer in the earth's biosphere. However, according to König (1979), wavelengths below 0.29μm are able to penetrate the earth's atmosphere and reach the earth's surface; below 1.4μm, however, water vapours start to absorb the radiation, and between wavelengths of 13μm and 1cm radiation is reabsorbed by the molecules of atmospheric gases. In the range of 1cm to 100m waves again penetrate, while at about 100m absorption by ionosphere electrons begins (see Fig. 1, windows I and II). There are, according to König (1979), experiments which indicate that waves in the ULF range, with a period of about 10 to 20 seconds, also reach the earth's surface. Such signals do, however, mainly show properties of field fluctuations.

Another source of radiation is the cosmos. A small part of this radiation reaches the earth's surface where it is absorbed in the atmosphere and in the earth's crust, which in turn results in the production of terrestrial radiation. This kind of radiation is thus emitted from radioactive minerals in the earth's crust, and radioactive corpuscles in the atmosphere supplemented by radiation intensities in the biosphere (see König, 1979, p 41).

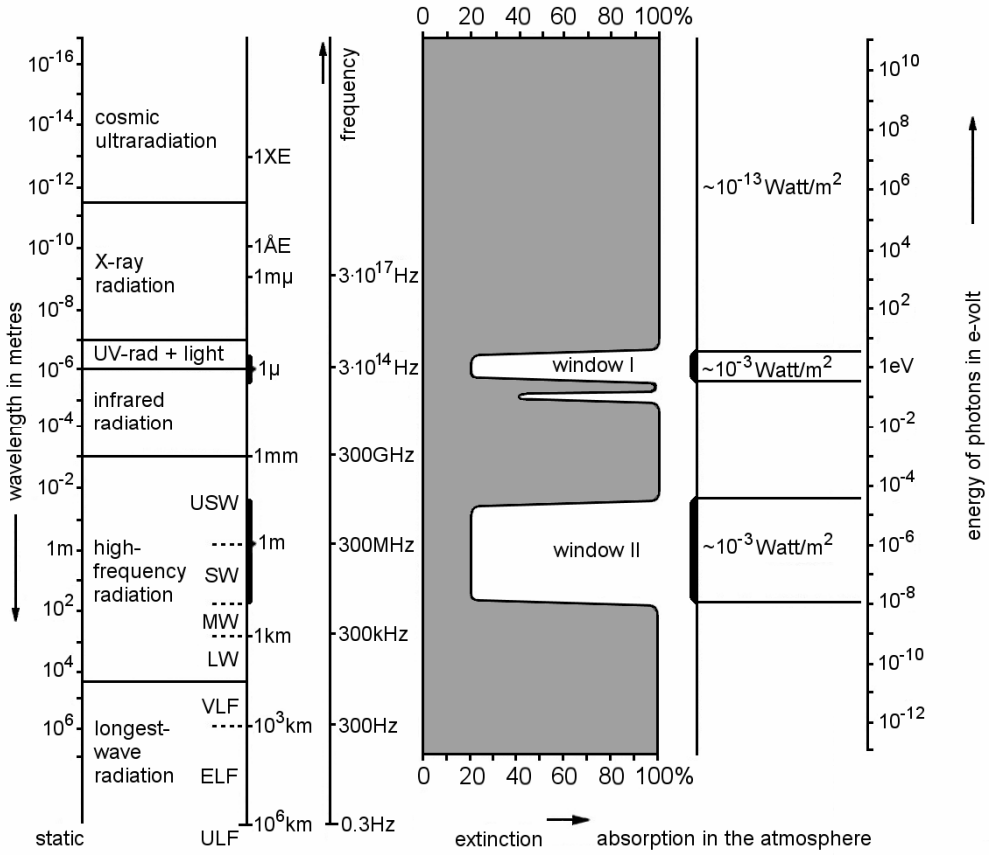
A major source of electromagnetic field fluctuations is the Earth. The knowledge that the Earth has magnetic properties stems from at least the 11th century when the Chinese used the magnetic field for the purposes of navigation. As physical science developed and magnetism became better understood, it was established by Gilbert in 1600 that the field of the Earth behaves like the field of a permanent magnet. Only in recent years has that view become modified due to evidence obtained from space explorations. It is now known that the magnetic field of the Earth is affected by the 'solar wind' (material emanating from the sun) in such a way that magnetic lines of force are pushed back at the poles, and on the night side, away from the sun, magnetic lines are extended away from the Earth thus forming a 'magnetospheric tail' (Chapman, 1951).

According to König (1979), the average intensity of the field amounts to 0.5 Oersted (Oe – that field that exerts a force of 1 dyne on unit magnetic pole). There are, however, temporal fluctuations of the order of 3-0.1 Oe produced by magnetic

storms originating in solar activity, and periodical variations caused by the motion of the sun and the moon as well as seasonal changes.

The origin of the magnetic field of the Earth is still debatable, but the most popular theory at the present is that it is set up by electric currents in the interior of the Earth. Although the electrical conductivity of the core is unknown, it is postulated that it is the motion in the electrically conducting fluid that maintains the field. In 'dynamo theories' it is suggested that magnetism is a fundamental property of rotating matter, and 'that the corresponding fundamental dipole moment is proportional to the angular momentum' (Chapman, 1951, p 30). It has also been shown that part of daily magnetic field variations, and time variations of other periods, are of internal origin. Analyses of internally produced field variations has, in fact, aided the study of the electrical properties of the Earth. It has been established that the conductivity of the Earth's mantle increases with depth, and that there are lateral variations in conductivity produced by local variations in the structure of the Earth's crust and mantle. The surface of the Earth carries an overall negative charge.

Figure 1: Electromagnetic Field Radiation in the Biosphere



Intensities of field radiation in the biosphere and position of optical windows with respect to frequency in the atmosphere.

After König, 1979

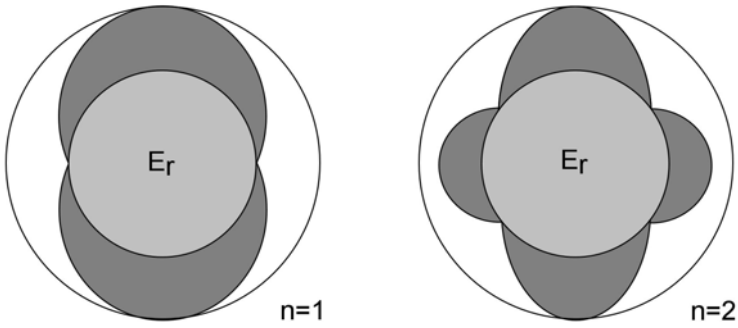
The Atmosphere

As outlined by König (1979), in the atmosphere there are the electrically charged air ions, electric space charges, the atmospheric electric field, conduction and convection currents, and discharges in the form of corona currents and lightning. There are considerable fluctuations in the intensity of the atmospheric electric field; however, it is greatest at the earth's surface, ca 100 V/m, decreasing to ca. 30 V/m at an altitude of 1 km, and to 10 V/m at 10 km up to a potential difference of ca. 220 kV between the earth and the ionosphere. Due to the conductivity of the air ions, there is a corresponding fair-weather electric current transporting positive charges downwards to the earth and negative charges upwards. This fair-weather current is compensated by lightning discharges when negative charges are transported from clouds to earth and positive charges stream upwards and form space charges (having the effect of reducing the electric forces).

Lightning discharges also have the effect of producing electromagnetic waves, mainly in the ELF and VLF ranges. These appear in the form of a 'high-frequency component' involving frequencies between 1 kHz and 30 kHz, followed by a 'low-frequency component' consisting of waves of frequencies below 2 kHz with gradually increasing amplitude. Within the high-frequency component, waves in the VHF range are produced to some extent. However, the intensity of these waves decreases with increasing frequency and there is a sharp decline of frequencies above 100 MHz. VLF waves of frequencies between 1-10 kHz and above, on the other hand, tend to travel along the magnetic lines of force produced by the earth's magnetic field, between the two points on the earth's surface which are connected by the lines of force. These produce signals known as 'whistlers' which can be picked up by appropriately tuned radio receivers positioned in the opposite hemisphere.

The low-frequency component of the lightning discharge is mainly responsible for the production of ELF waves. These are propagated as more or less strongly attenuated waves in the space between the negatively charged earth and the positively charged ionosphere, which provides a wave-guide for the signals. Certain wavelengths travel around the earth with relatively little attenuation due to the fact that 'standing waves' are set up in the earth-ionosphere space – the 'cavity resonator'. The circumference of the cavity resonator is 'approximately equal to the wavelength which an electromagnetic wave with a frequency of about 7.8 Hz would have in free space' (König, 1979, p 34). It is the waves of this frequency and its harmonics at 14, 20, 26, 33, 39 and 45 Hz which form the 'standing waves' known as 'Schumann resonances' (see Fig. 2).

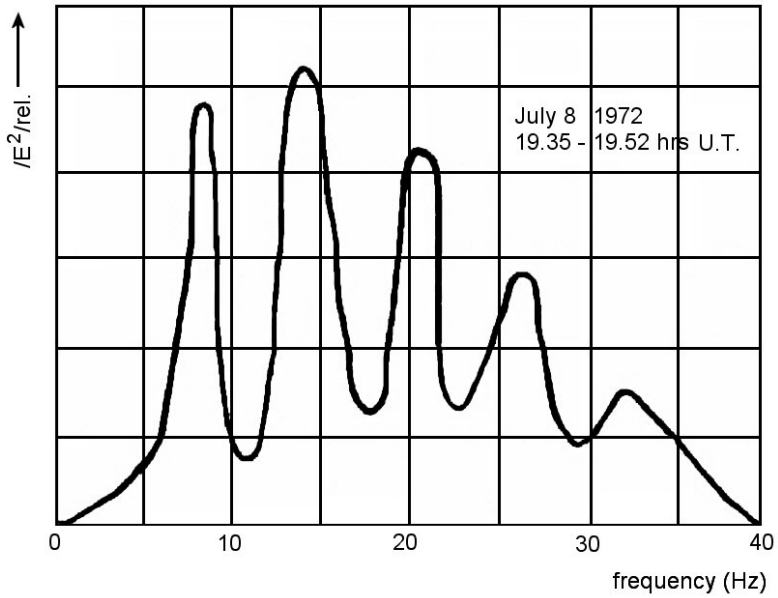
Figure 2: Schumann oscillations



Field configuration of the electric component of the Schumann oscillations occurring as 'standing waves' for the modes n=1 and n=2.

After König, 1979

Fig. 3: Spectrum of the vertical electric field of natural signals (noise) in the ELF range



Lightning stimulus causes the so-called Schumann oscillations in the (spherical) cavity resonator earth-ionosphere, electromagnetic radiation in the form of 'standing waves'.

After König, 1979

Organisms

As far as the electromagnetic properties of organisms are concerned, these are becoming increasingly acknowledged. The view that biological systems have magnetic properties was expressed as early as in the 16th century, particularly in the writings of Paracelsus, and subsequently in the medical literature of the 18th

and 19th centuries. In 1791 Galvani wrote on 'animal electricity'. He observed that injured tissue would generate electrical currents which were steady state, or DC (direct current) in character. Du Bois Reymond found in 1849 a way of observing the nerve action potentials, which are AC (alternating current) in character. According to Becker (1974), the vast majority of neurophysiological investigation thereafter was related to the AC potentials produced by the active transport of charged ions – chloride, potassium and sodium – across the nerve membrane, with little attention being paid to other forms of electrical activity. However, in recent years, increasing attention has been given to DC potentials.

Burr (1972) has established, with the aid of voltmeters and electrodes, that every living organism possesses what he has termed an L-field (life-field) – a voltage difference between two points on, or close to, the surface of the living form. These are, according to him, 'pure voltage potentials which can yield only an infinitesimal amount of direct current' (p 14), and which have nothing to do with alternating currents found in the heart and brain.

The patterns of equipotential DC field lines in human beings have been established by Becker (1962). By measuring the DC potentials on the intact surface of the skin at multiple points, he has found that there is a complex field pattern which is spatially related to the anatomical arrangement of the nervous system. It was suggested that the spinal cord generates a direct current which flows through the emergent nerves. This was substantiated by the fact that a transection of the spinal cord of frogs (which show a similar field pattern to that of human beings) led to a pronounced change in potential on the limbs, while transection of the nerves going to the limbs reduced the potential to zero. It was proposed that the charge carriers are non-ionic, ie not charged atoms, and probably units the size of electrons; and that currents are due to the movement of electrons along the nerve as opposed to the radial motion of ions in the action potential. Sensory nerve fibres were found to have a positive potential at the peripheral end, while motor fibres had a negative potential.

Apart from the central nervous system as a whole, there is evidence that electromagnetic fields are created by individual nerve cells. Lorente de No (1947) found that an electromagnetic field that accompanied neural impulses was formed around a sciatic nerve of a frog situated in a conducting medium. Experimental evidence for the existence of an electrostatic field in the air surrounding a sciatic nerve trunk was subsequently brought forward by Burr & Mauro (1949). A probe was positioned as close to the active nerve as possible without touching it, and gradually withdrawn from the nerve at 1mm intervals until no trace of electrical activity could be detected.

Claims have also been made by Seipell & Morrow (1960) for the success in measuring voltages due to the magnetic component of an electromagnetic field close to an excited nerve of a frog. This was confirmed by Gengerelli et al. (1961) in

experiments where coils used for the detection of magnetic fields were found to produce a signal which preceded the impulse detected by conventional electrodes, located at the same region of the nerve, by approximately 5 milliseconds. They hypothesised that:

> *'the nerve impulse is preceded by a geometrical reorientation of the membrane molecules, to permit flow of the local action currents responsible for the phenomenon of nerve propagation. If we posit that the molecular units constituting the nerve membrane are electrically charged, any motion of these, be it of translation or rotation, will be accompanied by magnetic lines of force' (p 324).*

Other authors, Khvelediдze et al. (1965) for instance, have according to Presman (1970), been unable to detect a magnetic field around nerves. Presman emphasises the fact that there are difficulties involved in recording such very small signals, and that measurement is a very difficult methodological and technical problem.

Electromagnetic fields have also been detected in the vicinity of whole organs. In electroencephalography (EEG), electrodes applied to the surface of the scalp measure the potential fluctuations that arise from integral nervous activity in the brain. Frequencies between 0.5-60 Hz have been recorded in this way. It has been established that certain frequency ranges can be correlated with conscious, emotional and pathological states. Hence, deep sleep is characterised by frequencies between 0.5-3 Hz (delta waves); frequencies between 4-7 Hz (theta waves) are often 'associated with disappointment, frustration and excitement, and is also found in children, psychopaths and epileptics' (Breithaupt, 1971, p 18); 7-12 Hz (alpha waves) occur in relaxed states when eyes are closed and thoughts are following an associative pattern; 12-16 Hz (alpha waves) occur during phases of light sleep; 16-30 Hz (beta waves) and 30-60 Hz (gamma waves) are associated with tense alertness and concentrated thought. Magnetoencephalography (MEG), on the other hand, is used for the measurement of magnetic activity in the brain. Electromagnetic activity in the heart is measured with electrocardiograms (ECG) and magnetocardiograms (MCG).

Electromagnetic fields produced by active nerves, muscles and heart of frogs, as well as human muscles and heart, have according to Presman (1970), been measured by Gulaev (1967). The recorded fields, which were termed 'electroauragrams' were claimed to have been detected at distances of up to 25cm from the object.

There is also evidence which indicates that electromagnetic waves are emitted by organisms. According to Presman (1970), Volkers & Candib (1960) have carried out investigations in which low and high frequency radiation in the range of 10-15 kHz were observed during muscular contraction in humans. Similar experiments, but by a long-range method, were carried out by Malakhov et al. (1965), in which an antenna was placed at a distance of 1cm from a human forearm muscle. Weak

emissions at 3 kHz in the form of random pulses ca. 1 microsecond long were produced by a contracted forearm muscle.

A phenomenon described as 'ultraweak photon emission' has been the subject for investigations during the last thirty years. According to Ruth (1979), the first investigators to discover weak emissions of light from germinating plants were Colli & Facchini (1954). With the aid of a photonmultiplier they established that emissions from seedlings of wheat, beans, lentils and corn varied between 700 cps (counts per second) and 250 cps, with a background of 130 cps, and covered a spectral range of 400-600nm. Other investigators (Perelygin & Tarusov, 1966, Shtrankfel'd et al., 1968, Blokha et al., 1968, Shlyakhtina & Gurvich, 1972) have detected emissions from animal tissues, such as that from a contracting frog heart – ca. 10 cps – isolated frog muscles, and mouse liver. In addition, an excited sciatic nerve of a frog has been found to emit light when placed in front of a photonmultiplier (Artem'ey et al., 1967). Emissions have, according to Popp (1979), been detected among all plants and animals investigated – ca. 90 species in all – except for some algae, bacteria and protozoa. The radiation intensities are of the order of a few hundred to two thousand photons per cm^2 per second, and there is an increase with phylogenetic complexity, in contrast to 'bioluminescence' which is more common among simpler organisms. The spectral range is spread at least over the region from infrared to ultraviolet – yeast cells show radiation between 250 and 380nm, plants in the blue-green range, and animal tissues in the blue-green and the red part of the spectrum.

According to Zhuravlev et al. (1973), results from experiments suggest that this kind of radiation may be produced by mitochondria (an organelle within cells) and that cells emit photons mainly before cell division. Konev et al. (1966) detected a maximum of emissions ca. one hour before cell division. Photon emission has also been shown to be dependent on oxygen concentrations (Veselovskii et al., 1963) and temperature (Shlyakhtina & Gurvich, 1972). It has been shown that there are 'upper critical temperature points' and 'lower temperature glow limits' where otherwise steady photon emissions decrease in intensity up to the points of thermal death when there is a sudden increase in photon emission. Death of biological tissue caused by chemical substances has also been shown to be accompanied by a flash of photon emission (Perelygin & Tarusov, 1966).

Such, then, are some of the electromagnetic properties of the environment and of organisms embedded within it. Proposals as to ways in which organisms respond to the weak fields in the natural environment may provide clues to mechanisms involved in the apparent response of organisms to manmade non-ionising radiation.

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