Radiofrequency Exposure Near High-voltage Lines

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Many epidemiologic studies suggest a relationship between incidence of diseases like cancer and leukemia and exposure to 50/60 Hz magnetic fields. Some studies suggest a relationship between leukemia incidence in populations residing near high-voltage lines and the distance to these lines. Other epidemiologic studies suggest a relationship between leukemia incidence and exposure to 50/60 Hz magnetic fields (measured or estimated) and distance from the main system (220 or 120 V). The present work does not question these results but is intended to draw attention to a possible concurrent cause that might also increase the incidence of this disease; the presence on an electric grid of radiofrequency currents used for communications and remote control. These currents have been detected on high- and medium-voltage lines. In some cases they are even used on the main system for remote reading of electric meters. This implies that radiofrequency (RF) magnetic fields are present near the electric network in addition to the 50/60 Hz fields. The intensity of these RF fields is low but the intensity of currents induced in the human body by exposure to magnetic fields increases with frequency. Because scientific research has not yet clarified whether the risk is related to the value of magnetic induction or to the currents this kind of exposure produces in the human body, it is reasonable to suggest that the presence of the RF magnetic fields must be considered in the context of epidemiologic studies. — *Environ Health Perspect* 105(Suppl 6):1569–1573 (1997)

Key words: radiofrequency radiation, induced currents, conveyed waves, power lines, magnetic fields, epidemiologic studies

Introduction

The Istituto Superiore Prevenzione e Sicurezza del Lavoro (Rome, Italy), where we work, is under the Ministry of Health and is concerned with research on safety in workplaces. In addition Institute investigators are called on as expert witnesses for state organizations and in civil and criminal courts. The experience we have acquired experimentally indicates that radiofrequency (RF) magnetic fields are emitted from power lines. The frequencies we have observed vary from 112 to 370 kHz. The emissions are stable in frequency and are amplitude modulated by unintelligible signals. These RF fields have been detected near high-voltage lines (150–380 kV) using a long-wave radio receiver. It was also possible to measure their intensity. At first there was some doubt about the origin of these magnetic fields: It was first hypothesized that corona and disturbances caused by load interruptions might be responsible for the excitation of the resonant frequencies of the lines. It was even hypothesized that RF currents generated by fluorescent lamps might somehow travel backward toward the high-voltage lines. All these hypotheses have been discarded. Corona and load interruptions produce a wide spectrum of frequencies, whereas the emissions we identified are of constant frequency and are amplitude modulated. The idea that RF currents attributable to fluorescent lamps might travel backward was proven to be technically impossible.

Data Transmission by Conveyed Waves

Based on information we obtained from other institutions but that is still incomplete, we concluded that the RF magnetic fields we identified were due to the lines being used for data communication systems. These systems are based on so-called conveyed waves that are produced when an RF generator feeds a transmission line out of tune.

An inductor is wired between the 50/60 Hz power generator and the line to obtain the desired impedance and RF current flow over the line. A condenser is used to couple the RF generator to the line.

Recently our Institute received a letter from Ente Nazionale Energia Electtrica, the Italian electricity company, which referred to a specific case in which the company admits using transmissions on power lines (*1*). The letter also specifies power and frequencies. According to these data, transmission power is set to 10 W for each channel. This information is insufficient, however, to give a quantitative idea of the phenomenon because the line impedance at the working frequency should also be given. Indeed, the most useful information to be determined would be the value of RF magnetic induction near high-voltage conductors. Therefore, it is necessary to determine the RF current that flows in these conductors rather than the RF power. According to information still to be confirmed, the RF current value should be around 10 mA. Frequencies used in this specific case range from 104 to 288 kHz. According to further information from Soreq NRC, Radiation Safety Division (*2*), 160 and 400 kV Israeli lines are used to transfer information. The frequency range is 30 to 450 kHz, maximal transmission power 20 W, each signal no more than 10 W, line impedance 400 Ω, and RF current 150 mA. These data might lead one to conclude that this phenomenon is negligible in terms of possible health effects, but we will show that this is not true.

Induction of Currents in Conductors and Living Tissues Exposed to RF Magnetic Fields

Let us consider an ideal loop inside a conductor, in which the area S is crossed by a magnetic flux $\varnothing$. If $\varnothing$ varies with time, an electromotive force e (EMF) will be generated inside the loop, according to Equation 1.

$$e = d\varnothing/dt \qquad [1]$$

If magnetic induction B is a sinusoidal function of time, with frequency f and the

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Abbreviations used: RF, radiofrequency; EMF, electromotive force; IRPA, International Radiation Protection Association; μT, microtesla; nT, nanotesla; pT, picotesla.

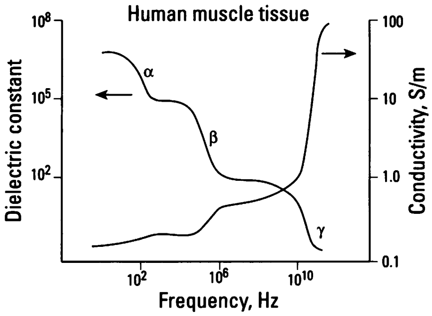

Figure 1. Frequency dependence of the dielectric constant and conductivity of human muscle tissue. Dispersion α: origin, polarization of counterion layer at cell surface or polarization of intracellular structures connected to the plasma membrane (tubular structures). Dispersion β: origin, polarization of the cell membrane or polarization of cellular organelles (mitochondria, nucleus). Dispersion γ: origin, polarization of tissue water. Adapted from Schwan (*4*).

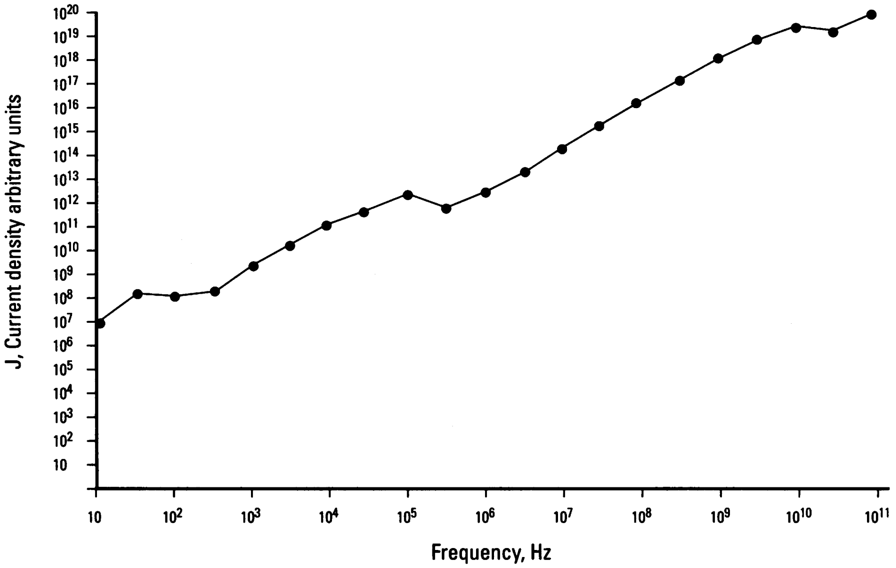

Figure 2. Capacitive current density in a toroid of human muscle tissue (unitary radius) exposed to a unitary magnetic induction.

conductor is wound *N* times around *S*, Equation 1 becomes

$$e = 2\pi fNBS \qquad [2]$$

If the conductor that we consider is human muscle tissue, we can set $N = 1$ in Equation 2; in this case the internal currents will depend on the electrical characteristics of the tissue.

At the frequencies we are concerned with, electric conductivity and dielectric constant are the important parameters. Data on these parameters and their dependence on frequency can be found in the literature. We considered the data from Tenforde and Kaune (*3*) and Schwan (*4*). Figure 1 shows the pattern of dielectric constant and electric conductivity of human muscle tissue as a function of frequency.

At very low frequencies, a few Hertz, for example, the dielectric constant of the plasmatic membrane is very high (*3*). This implies that at these frequencies the currents flowing through the body follow an extracellular pathway, i.e., the interior of the plasmatic membrane is shielded from applied fields by the plasma membrane. At frequencies around 50 Hz the dielectric constant decreases, although it still remains rather high. With the onset of phase *β* (from 100 kHz to 10 mHz) these shielding properties become weaker and the membrane starts to be crossed more intensively by the currents. Cytoplasmatic resistance then becomes an important parameter in determining the passage of ionic currents through organized tissue structures.

Induced Currents in Human Tissues

The data available on dielectric constant and conductivity can be used together with Equation 2 and the laws of electrotechnics to determine the pattern of current density versus the frequency in the ideal loop, which is composed exclusively of human muscle tissue, when exposed to a uniform magnetic field.

Figure 2 shows the outcome of this process—the pattern of the capacitive current density, which is the component of the current advanced in phase by one-quarter period with regard to EMF that yields the current. This kind of current is related to phenomena of orientation of molecular electric dipoles contained in the circuit. The result is that this current density increases with frequency if induction is constant. In other words, as long as the frequency increases, smaller values of magnetic induction can produce the same value of current density.

Techniques of Measurement

Commercial instruments usually used for measuring 50/60 Hz fields have bandwidths of a few kHz and are not suitable for measuring RF fields. There is also a problem of sensitivity because the intensity of the RF fields produced by conveyed waves is very low. An inductive probe connected to a spectrum analyzer allows the detection of the RF magnetic fields (Figures 3, 4) but the readings should be corrected according to the ratio between the spectrum analyzer input impedance and coil impedance at each frequency. We measured the fields by means of resonant circuits (L-C circuits), which can be tuned to the frequencies used by the conveyed waves. The instrument is made up of three elements: a metallic box with a calibrated variable condenser and scale by which the circuit can be tuned; a copper coil wound on an insulating spool, which also functions as a probe; and an RF detector. A series of these interchangeable coils allows coverage of the entire frequency range. The signals are measured by an oscilloscope (Figure 5). The resonant circuit is connected to the oscilloscope directly without intermediate coaxial cable. This reduces the minimum capacitance value of the resonant circuit and ensures a maximum range of tunable frequencies. The structural arrangement of the coils shields the coils from electric fields and a thin conducting layer of graphite-based lacquer surrounds the coil. This shield must be grounded.

A 16-cm diameter coil appears to be of sufficient size. The number of turns in the coil varies according to frequency range. For instance, a coil with 280 turns wound in one layer allows detection of fields between 47 and 159 kHz. At resonance the EMF developed in the coil is multiplied *Q* times at the output, where *Q* is the quality factor of the parallel resonant circuit. The value of *Q* for a coil like the one previously described is about 13, but it is possible to

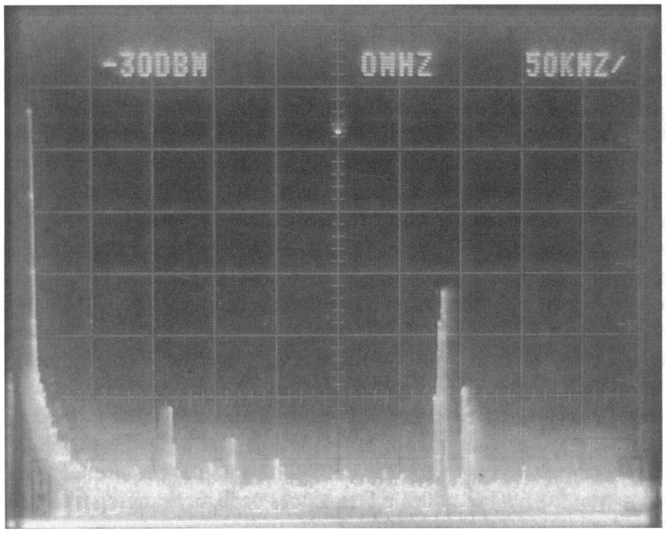

Figure 3. Spectrum analysis of RF signals present just under one high-voltage line.

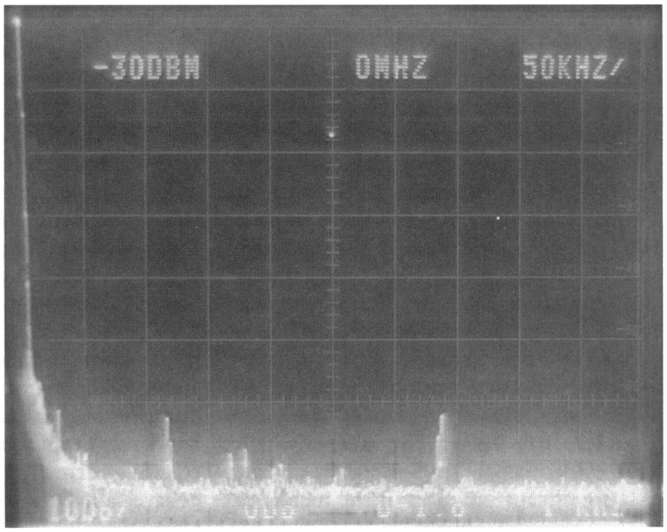

Figure 4. Spectrum analysis of RF signals present 100 m away from one high-voltage line.

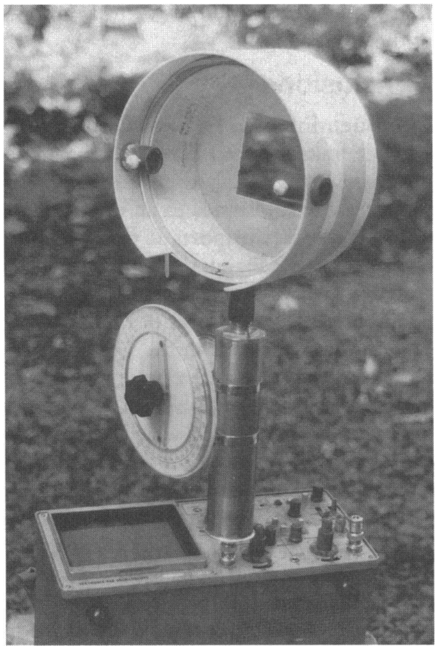

Figure 5. Oscilloscope supporting variable condenser and coil.

Table 1. RF and 50-Hz magnetic induction B at various sites near power lines (150–380 kV).

Site	50-Hz magnetic induction, B (μT)	RF magnetic induction, B (pT)	Distance to the line, meters
A, Italy	2.4	308 at 112 kHz	8
B, Italy	5	120 at 179 kHz	14
C, Italy	–	197 at 270 kHz	18
D, Italy	1.1	270 at 270 kHz	28
E, Italy	4	123 at 175 kHz	13
F, Italy	1.6	120 at 370 kHz	45
	1.6	105 at 136 kHz	45
G, Sweden	–	200 at 330 kHz	18
H, Italy	0.8	438 at 136 kHz	19
	0.8	155 at 291 kHz	19
	0.8	97 at 370 kHz	19
K, Italy	1	116 at 150 kHz	18
	1	32 at 243 kHz	18

take measures to increase the value of Q considerably. Therefore, the instrument is fairly sensitive although it is simple. In our case, 10 pT is the smallest value of magnetic induction that can be measured using an oscilloscope with normal characteristics.

This system also allows us to measure the 50/60 Hz magnetic field. At these frequencies the resonant L-C circuit is completely out of tune and therefore near a power line the voltage at the ends of the circuit is the sum of two signals. The first, at 50/60 Hz, is considered without any factor; the second signal, at RF, is superimposed on the first and varies in amplitude according to the tuning but assumes the maximum value at resonance (i.e., Q times the RF EMF).

Values of RF Induction Measured under High-voltage Lines

We took several RF magnetic field measurements near high-voltage lines. In most cases the working voltage of the lines was not known. Once it was determined that characteristics of these RF fields were not related to line voltage, knowing the voltage rating of the lines became less important. On the other hand, in a recent experiment we found that even a buried medium-voltage (20 kV) line emits RF magnetic fields with characteristics similar to those found near high-voltage lines, so it is likely that conveyed waves are also used on medium-voltage lines whether buried or on poles.

Table 1 shows the characteristics of RF magnetic fields found at various sites. Distances to the transmission lines vary because it was almost impossible to take measurements at equal distances from the lines. Values ranged from 32 to 438 pT. Another measurement was made at Juliaborg, near Stockholm (Sweden), at the 25th International Congress on Occupational Health 15–20 September 1996.

In all cases the intensity of RF magnetic induction B decreases with distance to the high-voltage lines. At 207 kHz intensity decreases as shown: 17.6 m (265 pT); 20.2 m (203 pT); 26.6 m (135 pT); 34.8 m (81 pT); 43.7 m (54 pT); and 53 m (47 pT).

Implications for Radiation Protection

Let us consider the limit value (100 µT) that the International Radiation Protection Association (IRPA) recommends not be exceeded in exposure of populations to 50/60 Hz fields. According to Figure 2, at constant magnetic induction there are four orders of magnitude between the capacitive current density induced at 50/60 Hz and that induced at 100 kHz. This means that at 100 kHz a field strength of 10 nT produces the same order of magnitude of capacitive current density produced by 100 µT at 50/60 Hz. Note that 10 nT is 30 times less than 0.3 µT, the value at which some epidemiologic studies suggest statistically significant increases in the incidence of leukemia occur (*5–8*).

Although it is true that the values of RF magnetic induction we found are about two orders of magnitude smaller than 19 nT, it is also true that electric current at 100 kHz can penetrate much more deeply through the plasmatic membrane than current at 50/60 Hz.

Implications in Epidemiologic Studies

Many epidemiologic studies (*5–28*) suggest a relationship between incidence of diseases like cancer and leukemia and exposure to 50/60 Hz magnetic fields. No epidemiologic study has yet considered this kind of exposure to RF magnetic fields, which may occur together with the 50/60-Hz exposure. Conveyed waves seem to be widely used on high-voltage lines. In Sweden their presence has been verified experimentally; in other countries like Portugal and Israel, it was noted the characteristic inductors were placed at the ends of high-voltage conductors, a sure sign that the RF communication system is used in these countries as well. In the United States this system may also be in use but because of the many independent electric companies, it is not easy to determine the extent of its use. In addition, it is also likely that this transmission system is used on medium-voltage lines, which in some countries like Italy are buried under built-up areas, whereas in others are supported on pylons. In Italy, for example, we discovered a medium-voltage line buried under the built-up area of a village. The line was emitting amplitude-modulated magnetic fields at 125 kHz.

Finally, some regions of Italy use a remote-reading system for electric meters; this system also uses conveyed waves. Characteristics of this system are not known and it also is not known whether the system is used in other countries.

There is an almost complete lack of information and awareness, both in Italy and in other countries, about the degree of diffusion of conveyed waves along electric networks. From a physical standpoint the RF magnetic field of conveyed waves behaves almost the same as the 50/60 Hz magnetic field: it can cross buildings without strong attenuation. In fact, in both cases the eventual attenuation or disappearance of the electric component does not alter the magnetic component. The latter can only be altered when it crosses a good conductor of electricity and building materials are not good conductors. This fact was confirmed experimentally in the case of the medium-voltage buried line we examined.

In summary, we conclude the following. The Scandinavian epidemiologic studies (*5,12*) examined a population residing near power lines. Therefore, it is likely that in the homes of the exposed subjects an important ratio might be found between the RF components of the magnetic field attributable to conveyed waves and the 50-Hz components. With regard to the studies performed in the United States, which were based on proximity to much lower voltage distribution lines, it would be necessary to verify the usage of conveyed waves on medium-voltage lines.

Currently there is considerable disagreement among scientists on the mechanism of interaction that determines negative effects on health at low-magnetic field intensities. Possible hypotheses are either direct action of the magnetic field or a complex mechanism mediated by the currents induced in the biologic systems exposed. To emphasize the importance of investigating this last possibility further, the following two assumptions are made: *a*) for exposures to 50/60 Hz magnetic fields, leukemia incidence starts to increase at magnetic induction intensities around 0.2 µT, and *b*) this effect is the induced current density produced because of this magnetic induction.

Under these assumptions, we also must admit that the same incidence of illness is produced at lower values of magnetic induction if the frequency is higher. It was shown before that passing from 50/60 Hz to 100 kHz, a value of magnetic induction 20,000-fold lower, is capable of producing the same density of the capacitive component of current. This means that in passing from 50/60 Hz to 100 kHz the threshold for the same illness could be lowered from 0.2 µT to values probably ranging from 10 to 100 pT.

Values of RF magnetic induction around these orders of magnitude are frequently found near power lines. In fact, in our experiments we found magnetic induction levels of about 50 pT 50 m from one of these lines.

Conclusions

In epidemiologic studies investigating possible links between 50/60-Hz magnetic field exposure and cancer or links between the disease and distance to an electric network, it appears important that possible exposure to RF magnetic fields joined to conveyed waves be considered. This may be important even in cases of exposure not due to power lines, as in the U.S. studies, which are based on proximity to much lower voltage distribution lines. For example, the use of conveyed waves is theoretically possible on medium-voltage lines, either for remote control of substations or for the remote reading of electric meters.

Because the use of conveyed waves on electricity networks is a secondary use, it is logical that epidemiologic studies be limited to the main effect, i.e., the search for possible effects of 50/60 Hz fields. If it is found that RF magnetic fields are also capable of increasing leukemia incidence, RF magnetic fields must be considered a confounding factor with regard to the main effect.

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