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ELECTROMAGNETIC FIELDS AND THE VITAL ENVIRONMENT

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NOTICE

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FOREWORD

The primary purpose of this book is to acquaint the reader with the fundamental problems which are encountered in evaluating the possible influence of radio waves on living matter, with particular emphasis on man and the protection of the human organism against such effects. /7

Since this is the first publication of its kind in this country, we have begun by covering the topic from all possible standpoints; in the limited space of this volume, this has necessarily produced a very brief summary of the individual areas. In order to help the reader to orient himself in studying the literature, and especially to aid him in understanding the reasons for the frequently contradictory results of biological observations which are presented herein, we are placing particular emphasis on fundamental problems in physics and biophysics. In view of the relatively large amount of literature published in this field prior to 1965, it was necessary to select only a few of the basic works for inclusion among the references at the back of the book. We also incorporated our own data and observations, acquired in the course of working on this problem at the Institute of Labor Hygiene and Occupational Diseases in Prague.

Several sections of the book demand concentrated attention and an understanding of basic concepts of mathematics, physics, biology and chemistry.

The first two chapters are intended as a sort of introduction to the problems involved, while subsequent parts were written so that physicians and electronics technicians (for whom this book is primarily intended) can obtain as much information as possible and gain valuable guidance for further study in the course of their work.

At this point, we would like to thank in particular Prof. J. Teisinger, DrSc, Director of the Institute; Prof. J. Roubal, DrSc, Head of the Labor Hygiene Department; and Dr. P. Pachner, CSc, Head of the Scientific Methodology Division of the Labor Hygiene Department, for their kind assistance, support, and valuable suggestions during the final revision of the manuscript. We also thank all those who contributed to the successful publication of this book.

Prague, Sept. 1966 The Authors

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1. INTRODUCTION

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We know that the entire frequency spectrum of electromagnetic waves can affect living matter, and is therefore biologically active. The mechanism of this effect, however, is not the same over the entire known spectrum, which presently extends from very low frequencies up to 10^{24} Hz (i.e., waves with wavelengths greater than $3 \cdot 10^{-15}$ meters).

Under the influence of radiation at wavelengths shorter than 2500 Å, it is possible to assume the occurrence of ionization of molecules in the irradiated object. This radiation band is therefore referred to as ionizing radiation. The non-ionizing radiation band, extending from very low frequencies up to 10^{12} Hz, is referred to as the radio-wave band. The wavelengths of the latter are consequently greater than 0.3 mm, and their effective energy (due to the relatively low frequency) is insufficient for ionization of molecules. According to another system of classification, the radio-wave band includes all coherent radiation[1] whose wavelength is less than the above-mentioned 0.3 mm. Here, too, are the waves of laser radiation.

The problem of the biological effects of electromagnetic waves, which occupy the band of ionizing radiation, is generally treated together with corpuscular radiation. From the practical standpoint of protecting human beings exposed to it, we shall be concerned in particular with the science called radiation hygiene.

In our book, we shall deal exclusively with the other, non-ionizing portion of the electromagnetic wave spectrum, consisting of radio waves. Hence, in the chapters which follow, the term electromagnetic waves (fields) will be understood to refer only to the above-mentioned section of the spectrum.

Electromagnetic waves were discovered in 1888 by Heinrich Hertz; despite the skeptical views of their discoverer, these waves have found extensive practical application, so that a great many generators of such waves can be found in every well-developed nation and constitute an ever-increasing environmental factor (Fig. 1).

Their practical use has attracted the attention not only of technicians and physicists, but of chemists, biologists, and physicians as well, all of whom are interested in whether the longer electromagnetic waves produce chemical and biological changes simi-

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* Numbers in the margin indicate pagination in the foreign text.

[1] Coherent radiation is emitted by radiators, all of whose elementary dipoles vibrate at a constant frequency with no mutual displacement in time (i.e., they vibrate in phase).

lar . . . ose caused by sources of ionizing radiation. The first experimental work in the field of investigating the effects of high-frequency (H.F.) electromagnetic waves on living and non-living /10
matter dates from the end of the last century, when in 1895 Danilevskiy observed the effect of such a field on neuromuscular preparation.

After that time, the number of works in this field grew steadily until the first peak of interest in this problem occurred during the decade from 1930 to 1940. During this period, much valuable work was done, mainly research on the effects on the physical and chemical properties of matter and certain simple biological systems. Substantially less attention was devoted to purely medical problems, such as the effect of H.F. fields on man.

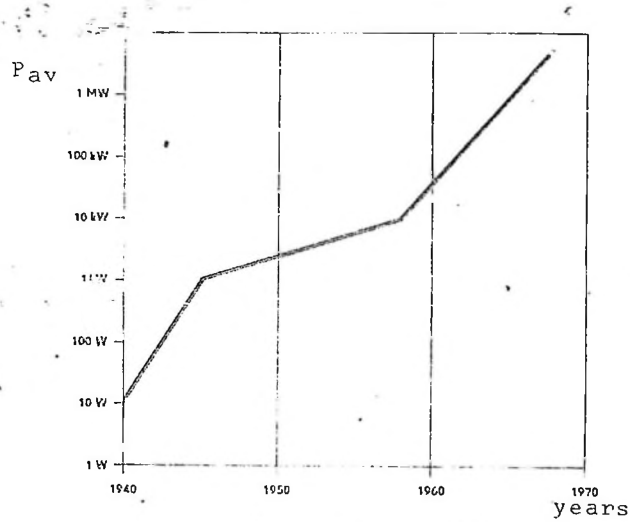

Fig. 1: Increase in the Average Power of Generators Operating at a Frequency of 3 GHz [169].

World War II brought a violent conclusion to the successful development of experimental work in several laboratories. In the majority of the latter, work was not resumed after 1945; it happened that many experimental discoveries fell into complete oblivion or were "rediscovered" in later years.

Following 1945 and the explosion of atomic bombs at Hiroshima and Nagasaki, workers studying the biological effects of radiation devoted their attention practically exclusively to sources of ionizing radiation, both in wave form (X-rays, γ-rays) and corpuscular form (α and β-particles, etc.). It is only in recent years that interest has again begun to develop in studying H.F. electromagnetic radiation from a field of radio waves as an agent that could be biologically active. This interest was stimulated by the discovery that animals and plants decline and die in electromagnetic fields with minimal power density in the centimeter (cm) band, and by the complaints of workers at radar stations that they were experiencing certain subjective difficulties. It is therefore understandable that until quite recently the majority of papers dealing with the effects of cm waves described experiments with animals and not with human subjects. However, a number of laboratories have recently begun a systematic study devoted to problems of basic research into the biological effects of H.F. fields, with particular stress on the primary biophysical mechanisms of this effect. This interest was stimulated partly by the increasing number of workers with such equipment, and partly by the discovery of possible non-thermal effects of hf fields on organisms. /11

The largest groups of scientific workers and laboratories devoted to studying this problem are located in the USSR and the USA. In both countries, special stress has been placed on the problem of the effects of cm waves. In the Soviet Union, however, there is also a group of special laboratories where a still higher frequency range (above 30 kHz) is studied. Recently, workers in the United States have also started work on basic research connected with waves longer than cm waves. In the case of such waves, it is possible (even easier) to separate the thermal effects from the non-thermal ones. In the United States, research has been conducted on a broad front since 1957 under the sponsorship of the Department of Defense in conjunction with the Research Laboratory of Practical Medicine at Cape Kennedy, established as part of the rocket research base. For this reason, it is natural to expect that not all results would be published in detail. It is understandable, too, that other countries where such work was also conducted intensively would be valuable sources of information regarding new discoveries, which could be obtained with minimal difficulty. Despite these obstacles, about 1000 articles in this new and very promising field have already been published.

Along with the Soviet Union and the United States, it is also necessary to mention Poland, Italy, and recently England as well, as countries where work is in progress on the problem of the effects of H.F. fields on biological systems. Here in Czechoslovakia too, much work has been devoted to this problem. At the Institute of Labor Hygiene and Occupational Diseases in Prague, a special high-frequency department was organized. Since 1961, this department has dealt exclusively with research into the primary effects of electromagnetic fields on the human organism and the protection of individuals against these effects. The clinical aspects of the problem constitute the particular field of interest of a group of workers at the Institute of Labor Hygiene and Occupational Diseases and the Occupational Disease Clinic in Bratislava.

The results of research in this field not only serve to protect the health of workers exposed to the effects of radio waves in the course of their daily work, but can also be used to clarify some other points which are still unclear (in bioclimatology and biometeorology, for example).

The purpose of this book is to acquaint the reader with the most important of the basic problems which crop up in the course of investigating the effect of electromagnetic waves on living tissue, with special emphasis on man, and to create in him a profound interest in these questions. We have gone into somewhat more detail in those chapters which are of basic significance for identifying the basic biophysical effects and in those sections which are intended primarily for nurses and technicians who work with generators of high or very high frequency electromagnetic waves (H.F. or V.H.F.), or who build such equipment, and are therefore intended as practical guides. Nevertheless, even these chapters require careful reading since they serve as texts or directions for action.

The clinical aspects of the problem are mentioned only for the sake of information, since very thorough publications have recently appeared in the USSR and Poland, dealing especially with this point [163, 182, 282]. A similar book is being prepared here in Czechoslovakia. /12

2. THE ELECTROMAGNETIC FIELD AS A PHYSICAL ENVIRONMENTAL FACTOR

2.1 Physical Properties of Electromagnetic Waves

In order that the discussion which follows may be easier to understand, let us briefly summarize the fundamental aspects of the nature and characteristics of electromagnetic waves, naturally limiting ourselves to the absolutely necessary concepts which will be discussed later in the text. More detailed information is readily available elsewhere, in [185] for example. /13

Despite all of the differences among the various spectral ranges of electromagnetic waves (see Table 1), the same rules hold for all of these bands: they can be bent, broken up, or dispersed, and they are polarized. The reason for the specific variations may be nothing more than a different ratio of the wavelength to the dimensions of the environment or to a small part of the substance, or a different energy content as was already mentioned in Chapter 1.

The fundamental characteristics of waves can best be explained in an isolated case, in which the electromagnetic wave is plane (in practice, this means tracing the propagation in a small area, actually a short distance) sufficiently distant from the generator. Every magnetic wave is characterized by the magnitude and direction of its components, electrical ($\underline{E}$) and magnetic ($\underline{H}$). An overall picture of the frequency and direction of both components of a wave at a certain moment in time is presented in Figure 2a, while the pattern of the electric and magnetic lines of force at points where the wave has its maximum (looking in the direction of propagation of the wave) is shown in Figure 2b. These illustrations are suitable for explaining several important facts.

The electrical and magnetic components of a field are mutually perpendicular, and both are also perpendicular to the propagation direction. The magnitude of the components changes each instant along the propagation direction in the form of a sine wave. The latter is made up of parts which repeat themselves periodically, hence the names period, cycle and oscillation. The number of oscillations in one second is the frequency $\underline{f}$; the length of one oscillation is equal to the wavelength λ (Fig. 22). The correlation between the frequency $\underline{f}$ and the wavelength λ is expressed with the aid of the propagation velocity $\underline{v}$ as follows:

$$f = \frac{v}{\lambda} \qquad (2.1)$$

TABLE 1: DIVISION OF ELECTROMAGNETIC WAVE SPECTRUM INTO BANDS IN THE RADIO WAVE REGION /14

Band Number[2]	Band-width[2]	Metric Desig-nation of Wave Band	Abbre-viation	Desig-nation of Wave Band by Length	General Designation of Frequency Bands
3	300-3000 Hz	decamyria-meter waves			low frequency (L.F.),
4	3-30 kHz	myriameter waves	mam		audio-frequency
5	30-300 kHz	kilometer waves	km	long waves (L.W.)	(A.F.)
6	300-3000 kHz	hectometer waves	hm	medium waves (M.W.)	high frequency (H.F.)
7	3-30 MHz	decameter waves	Dm	short waves (S.W.)	radio frequency
8	30-300 MHz	meter waves	m	very short waves (V.S.W.)	(R.F.)
9	300-3000 MHz	decimeter waves	dm	microwaves	very high
10	3-30 GHz	centimeter waves	cm		frequency (V.H.F.)
11	30-300 GHz	millimeter waves	mm		microwaves
12	300-3000 GHz	decimilli-meter waves			

[2] According to Czechoslovak State Standard 345352.

where we can express v as follows

$$v = \frac{c}{\sqrt{\varepsilon_r \mu_r}} \quad (2.2)$$

where ε_r is the relative dielectric constant of the medium, μ_r is /15
the relative magnetic permeability of the medium, and c is the speed of light. The propagation rate is therefore a function of the properties of the medium in which the wave travels. In a vacuum (and in air as well, for all practical purposes) electromagnetic waves travel with the speed of light c, i.e., 300,000 km/sec; in other media (water, for example), the rate is always slower [44]. Equation (2.2) does not allow for the conductivity of the medium; in reality, however, the propagation rate depends on it. For example, in an aqueous conducting solution with a conductivity of 4 mks/m, the propagation rate changes to such a degree that a wavelength of λ = 2000m in air becomes a wavelength of λ = 4m.

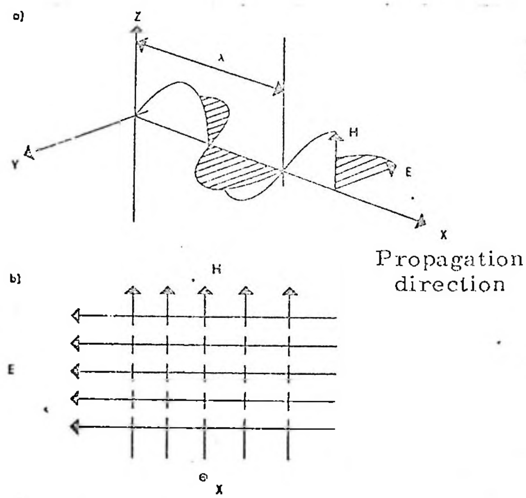

Fig. 2: Plane Electromagnetic Wave: (a) Course of Electrical and Magnetic Components of Wave; (b) Orientation of Intensity of Electrical and Magnetic Fields of Plane Wave.

Two sine curves of any frequency are in phase if their maxima and minima occur at the same instant. The waves are said to be 180° out of phase when the minimum of one (maximum negative value) and the maximum of the other (maximum positive value) occur simultaneously.

The electrical and magnetic components of the field are quantities of periodic resistance and flow. It is therefore possible to define the so-called impedance (apparent resistance) of a medium as follows:

$$Z = \frac{|E|}{|H|} = \sqrt{\frac{\mu^*}{\varepsilon^*}} \qquad (2.3)$$

where ε^* is the complex dielectric onstant of the medium and μ^* is the complex magnetic permeability of the medium (Z = 377 Ω in air). /16

The plane in which the vector (i.e., the value determined by the magnitude and direction) of an electric field $\bar{E}$ lies is called the polarization plane. In Figure 2, the electromagnetic wave is polarized on the level (horizontally).

In order to explain some other features, let us move from the propagation of electromagnetic waves in a free medium to their propagation along a conductor. One of the simplest and commonest types of conductor is one which is divided into two parallel channels, the so-called two-channel conductor. After an A.C. source is connected, a wave process begins to travel along the conductor, carrying electromagnetic energy with it. The movement of the wave along the conductor produces alternating flow and resistance in the latter. The ratio of the amplitudes of the resistance and flow is constant for all points in a conductor and is one of the characteristic parameters of every conductor. It is called the characteristic impedance or wave resistance of the conductor. If the conductor is not terminated, by a resistance equal to its own characteristic impedance, the load resistance causes echoes, so that in addition to the progressive waves, traveling from the source to the resistance, a portion of the energy travels in the opposite direction, producing standing waves in the conductor. The echo is best characterized by the so-called standing wave ratio s, i.e., the ratio of the maximum to the minimum voltage in the conductor.

From the standpoint of the source which is connected to the conductor, it is also necessary to have resistance which is the same as that of the conductor at the point where the source is connected, i.e., at the input resistnace or (more generally) the input impedance. In other words, the concept of impedance takes in not only the usual load composed of the real part (resistance) and the non-existent or imaginary part (inductance or capacity), but in extreme cases, its own real resistance as well. In practice, use is also made of the concept of normalized impedance, which (in the case of an input impedance) is its ratio to the characteristic impedance of the conductor.

The two-channel conductor is not the only type of conductor, nor is it applicable to all frequencies. In the cm wave region, for example, such conductors would become radiators; it is for this reason that coaxial or waveguide conductors are used for them. Even when the ratios in these conductors are very complex, it is still possible to apply the above concepts.

In principle, a waveguide is a tube of conducting material, usually oblong in cross section. In addition to phenomena similar to those encountered in other types of conductors, waveguides have many specific characteristics; for example, they act as highpass filters (not carrying energy at frequencies lower than the critical frequency of a given size waveguide). A precise idea of the nature of the field within a waveguide can be obtained from a simple concept regarding the physical process of wave propagation. The field inside a waveguide can be thought of as a consequence of the movement of a plane electromagnetic wave, propagating between the walls of the waveguide, alternately slanting upward and downward. In as much as the components of the wave, which create the actual field in the waveguide, move at an angle other than 90° to the axis of the waveguide, the propagation rate of the energy along the waveguide is less than the speed of light. At the same time, the field of the wave components is formed in such a way that the wavelength in the waveguide is greater then the wavelength in a free medium. /17
At frequencies which are much higher than the critical frequency the waveguide may contain higher order waves and the field within the waveguide will assume a different form.

The concepts regarding propagation in a waveguide as the result of successive reflections of wave components off the walls of a waveguide can be used for all other waves, as well as for other shapes of waveguides besides oblong ones (circular, dielectric, etc).

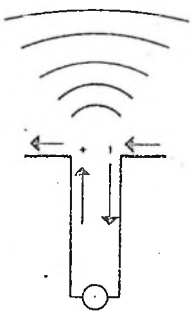

Fig. 3. Schematic Representation of Conduction in a Closed Dipole.

Antennas are attached to conductors for purposes of radiation. In the simplest case, for example, the conductor can be terminated in a dipole (Fig. 3). If waves are traveling along the conductor to which the dipole is attached, the same pattern of resistance and flow occurs in it as in the conductor, so that an electromagnetic field is formed around the dipole. This field spreads into the environment in the form of electromagnetic waves. Maximum radiation is obtained when the length of the dipole is a multiple of half the wavelength of the H.F. signal being conducted. The dipole can be thought of as the fundamental element on which almost all antenna systems operating in the H.F. band are based. Generally speaking, the entire radiation field produced by an antenna system can be thought of as a combination of the individual fields formed by the elements of such a system, viewed as elementary dipoles. In the vicinity of the antenna, there is an induction field in addition to the radiated field. At distances which are short relative to the wavelength (or short relative to the dimensions of the antenna, if the latter is a large one), the electrical and magnetic induction fields will be much stronger than the radiated field of the antenna. The induction field produces mainly waste energy, which is sent out during one half of the period (oscillation) and returns to the source (antenna) during the other half.

Since it decreases inversely as the cube of the distance (approximately), it is negligibly small at relatively large distances from the antenna and therefore is not considered to be a radiated field. It differs from the latter in other ways as well: the electrical and magnetic fields in the induction area are not proportional to one another, nor are they in phase with one another. At short distances from an antenna in the form of a dipole (and in extreme cases, also in the radiated field of the capacitor, which can actually be thought of as a dipole with an included angle of 0°), the electrical induction field is much stronger than the magnetic induction field. On the other hand, in the vicinity of a loop antenna (or even in the field radiated by an inductance), the magnetic induction field is the stronger of the two. /18

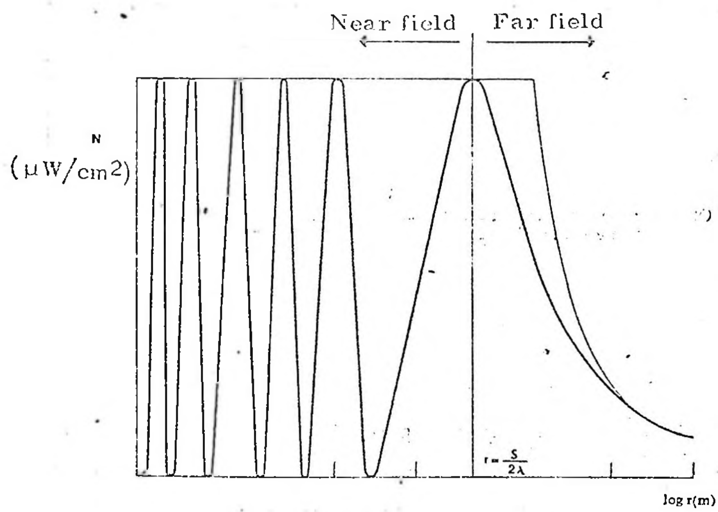

Fig. 4. Power Density as a Function of the Distance from the Transmitting Antenna [169]

In view of the existence of an induction field, the area around the antenna (i.e., the radiating elements) is divided into two parts, the near field (or induction field) for $r \ll \frac{\lambda}{2\pi}$ and the far field (or radiation field) for $r \gg \frac{\lambda}{2\pi}$ (appropriately, there is also an area of contiguity where r is equal to $\frac{\lambda}{2\pi}$). From the above, it is clear that this division is not adequate.

In the V.H.F. band, especially for cm waves, dipoles are rarely used. This is due, among other things, to the fact that other types of conductors are employed. Unlike the H.F. band, where the basic element of the antenna is a thin conductor (wire) through which the current flows, the main part of an antenna used for the V.H.F. band is usually a flat surface from which the energy of the electromagnetic waves is propagated into the environment. The simplest forms of such a flat antenna are (for example) the open mouth of a waveguide, a horn or parabolic reflector, on dielectric lenses like those in optical reflectors, etc.

Complex relationships also exist in the vicinity of antennas operating in the V.H.F. band. This is best illustrated by Fig. 4, which clearly shows the curve of power density as a function of the distance from the transmitting antenna. Here again the division of the area around the antenna has its qualifications, but due to the large size of the antenna relative to the wavelength, other criteria must be employed. To determine the boundary between the near and far fields, we use the expression $r = \frac{S}{2\lambda}$, where S is the area of the mouth of the antenna [169]. /13

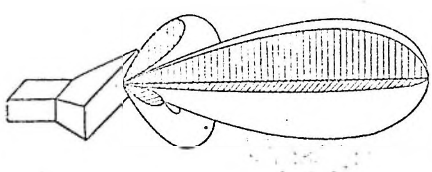

Fig. 5. Simplified Intensity Diagram of a Horn Antenna

From the standpoint of the radiation of antennas into the environment, it is important to have a so-called radiation diagram or characteristic. A spatial intensity diagram is a surface defined by the ends of a point conductor, which extend from the antenna in different directions and have a size which is determined by the field intensity in the individual directions. Figure 5 shows the spatial intensity diagram of a horn antenna. Instead of the spatial intensity diagram, however, it is conventional to use only plane diagrams, which show the relationship between field intensity and direction in two mutually perpendicular planes (one usually coinciding with the polarization plane (plane E) and the other perpendicular to it [plane H]). In Figure 6, the plane intensity radiation diagrams are in planes E and H. In addition, use is frequently made of power directional diagrams; in this case, the sizes of the abovementioned conductors are proportional to the output in each direction. The size of the largest conductor whose axis forms the electrical axis of the antenna is customarily assigned a value of 1 and the sizes of the other conductors are then measured relative to it; the result is called a relative diagram. The desired frequency of the relative power diagram is the angle between the conductors whose magnitude is about 3 db. less than the maximum frequency (i.e., 0.5 in the power diagram and 0.707 in the intensity diagram). It is represented by $\Theta_{3\ db.}$ and is also called the width of the array. The width of the diagram on the level of the first zero Θ_0 is the angle which the conductors form with the smallest area (Fig. 6).

It is possible to get a very good idea of the directional power of the antenna from the radiation diagrams. However, to avoid having to use all the diagrams, it is conventional in work with antennas to use the term antenna gain, represented by $\underline{G}$. It is mainly a product of the directionality and efficiency of the antenna. The directionality is given by the ratio of the powers which must be applied to an omnidirectional antenna and to a directional antenna in order to produce an electromagnetic field of constant magnitude in a given direction for both antennas. The efficiency of the antenna is then expressed by the power which the antenna radiates and the power fed to the antenna.

All of what we have said here regarding the radiation charac- /20
teristics of transmitting antennas is equally valid for receiving antennas as well. From the so-called reciprocity theorem, used in circuit theory, it is possible to determine that the radiation diagram of an antenna used for transmission is constant, even when it is used as a receiving antenna (this reciprocity is invalid, however, for the extension of the fields in the vicinity of the antenna.). It is therefore necessary to introduce still other concepts when discussing receiving antennas.

From the standpoint of wires (rather, single-conductor antennas), the so-called effective height (a length) of the antenna is very important. An electromagnetic field induces so-called electromotive force (e.m.f.) in a receiving antenna, and the ratio of the combined e.m.f. to the field intensity is actually the effective height of the antenna. From the standpoint of energy reception by an antenna, it is significant that only part of the energy is transmitted to the load. It is also necessary to consider the losses in the antenna leads, losses in nearby insulation, as well as those losses which are produced by so-called secondary emission. The latter is caused by the fact that when a current passes through the antenna, radiation commences regardless of the fact that the current is produced by induction by H.F. waves passing through, or by some other means. Therefore, the antenna operates mainly with a distorted field (other sufficiently conductive objects in the field behave similarly).

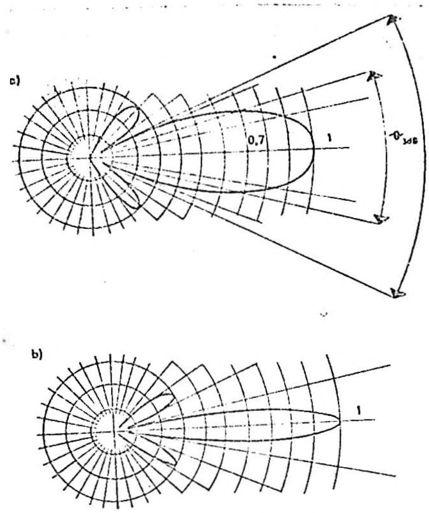

Fig. 6. Plane Intensity Diagrams; (a) in plane E, (b) in plane H

The concept of an effective height does not apply to plane antennas at all; instead, the so-called effective area of the antenna is involved. On the basis of the already mentioned value of the antenna gain G, the relationship $S_{ef} = \frac{G\lambda^2}{4\pi}$. The effective area and the effective height of an individual antenna are linked by rather simple conversion equations. /21

Characteristic structures or generators which emit electromagnetic energy are (in principle) so-called oscillators, i.e., vacuum tubes and oscillator circuits (made up of inductances and capacitances). The frequencies generated by them are then customarily rectified (amplified, modulated, etc.). Depending on the frequency band (as well as other factors), the generators have fairly diverse designs (i.e., connections and structure). Vacuum tubes of conventional types (diodes, triodes, pentodes) and oscillator circuits made up of normally used inductances and capacitances are employed for working with meter (and sometimes decimeter) waves (i.e., essentially the H.F. band). In the V.H.F. band, however, these components are not usually usable. This is prevented primarily by the high resonance frequency of the vacuum tubes (the effect of the inductances of the leads and the interelectrode capacitances makes itself evident here) and the inertia of the electrons (one of the consequences is the power loss). For these reasons, special vacuum tubes (for example, the cylindrical, beacon, and planar types, etc.) are employed in the V.H.F. band

(and frequently at the end of the H.F. band as well). Planar tubes are triodes with coaxial leads, from which it follows that the oscillator circuits must have (not only for this reason) other forms (mainly coaxial or hollow resonators, i.e., sealed, perfectly shielded surfaces with suitable dimensions according to the desired frequencies). For use at higher frequencies, vacuum tubes are made with a "conducting" frequency circuit in one unit, so that in the case of classical vacuum tubes it is largely only a matter of the name. Here belong, in particular, the hollow magnetrons, klystrons, platinotrons, carmatrons, permactrons, carinotrons, etc. The technology of millimeter waves extends into the field of quantum mechanics; the further we go toward higher frequencies, the further we progress from classical radio technology. In the short-wave band, so-called molecular resonance frequencies are employed, wh... energy from outside is applied to electrons in a given mate...; causing them to move to a higher energy level; when they return to the lower level, the electrons can cause emission of electromagnetic waves. All quantum generators (masers) work on this principle, either in liquid or solid phase, as do generators of coherent radiation in the visible, such as lasers.

2.2 Properties of Electromagnetic Waves from the Viewpoint of Hygiene; Characteristics of Fields and Definition of Concepts.

In the preceding chapter, the concept of field intensity was employed without defining it; it was also stated that an electromagnetic wave is characterized by the magnitude of its components. The two are directly related. The intensity of electromagnetic waves actually expresses the intensity of an electrical field and also (from the standpoint of uses for hygienic purposes,) gives information, in agreement with current technical practice, in volts per meter. The field intensity expressed in this manner is numerically equal to the e.m.f. induced in a conductor 1 meter long, if its waves travel at the speed of light. The concept of field intensity can be used in principle over the entire spectral range of electromagnetic waves. In accordance with what was stated in the preceding section, it is necessary to distinguish between necessity and possibility. In the H.F. band, in the majority of cases it is necessary to measure only the field intensity (more precisely, that of the electrical or the magnetic field). On the other hand, it is possible to measure the two components simultaneously. For this reason, in the V.H.F. band we replace the concept of field intensity by another, namely the power density, expressed in microwatts per cm^2. From the name itself it is clear that the power density is numerically equal to the ratio of the power passing through a surface (in μW) to the size of this surface (in cm^2). /22

The field intensity E and the power density N are linked by the admittedly simple transformation equation

$$E = \sqrt{3,77 . N} \quad (V/m, \mu W/cm^2) \qquad (2.4)$$

which can be used, however, only in a remote region where the mutual relationships between the electrical and magnetic components of the field are unambiguously expressed by (2.3).

Both the field intensity and the power density (devices for hygienic purposes have deinite specific difference in these factors with regard to current technical practice) are only a means for operation or irradiation, which is awarded fundamental importance from the hygienic standpoint (cf. Chapter 6).

In this connection, it is important to mention the nature of the oscillation of electromagnetic waves. Among their fundamental parameters are frequency, phase and amplitude (size of the oscillations). Essentially, then, in the course of operation, one of these parameters can change in a definite rhythmic manner, i.e., undergo so-called modulation. From the hygienic standpoint, the most important is amplitude modulation (if the amplitude during the entire period of activity of the generator operates constantly from the instant it is started until the time it is shut off, it is called constant or continous wave (cw) operation); in particular, we are concerned with a special case, pulse modulation. The classic example is pulse modulation in radar. Figure 7 is a schematic representation of the pulse modulation cycle which is repeated automatically /23 between the times when the apparatus is switched on and off. Another of the fundamental parameters of pulsed operation is the pulse width δ (i.e., the period when the oscillations are produced) and the repetition frequency f_{rep} (i.e., the reciprocal value of the time in which the pulses repeat themselves, the so-called repetition period τ). Modern radars use f_{rep} values between 100 and 3000 pulses per second and a δ value between 0.1 and 20 μs. The working function, i.e. the product of the pulse width and the repetition frequency, is in current practic approximately between the frequencies 10^{-2} to 10^{-5}. Also often used is the concept of the so-called keying ratio, i.e., the ratio of the pulse width to the pause between two pulses. This is encountered mainly at frequencies lower than those at which radars operate (i.e., it is possible to identify the concept of keying ratio and working function with a low percentage of error). For evaluation of the nature of the oscillations, it is therefore suitable to use the concept of the keying ratio. From the hygienic standpoint, it is possible to use for pulse operation, all equipment operting with a keying ratio less than 0.1, and for c.w. operation, those pulse devices whose keying ratio is equal to 0.1 or greater than 0.1.

The instantaneous radiated (pulse) power of a pulse generator can be very high, even when the average emitted power per unit time is relatively low. This has to do with the mutual relationship between the average and pulse powers (the average power is also given

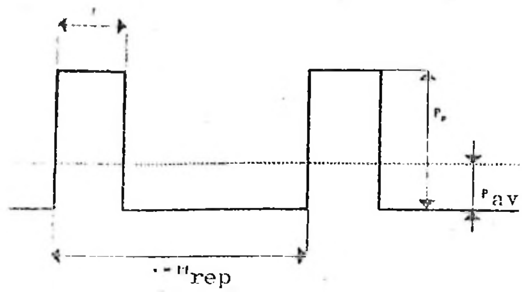

Fig. 7. Representation of Basic Parameters in Pulsed Transmission

as the product of the pulse power and the working factor).

Referring back to what we said in the preceding section (2.1), it is necessary to stress the need for at least a general knowledge of the complexity of the situation in the near field.

From the hygienic standpoint, it is important to point out that although in the far field there is a decrease in field intensity linearly with distance, while the power density decreases as the fourth power of the distance, it is possible to have reciprocal conversion; in the near field, however, this is not the case. It is most important in measuring the power density in the vicinity of large antenna systems; at a certain distance from the antenna, it may be possible to measure a greater power than at a short distance. This apparently paradoxical result however is completely in accord with theoretical conclusions and corresponds to the pattern of the power density in the near field (see Fig. 4). The situation is generally complicated (the same is true for the far field) and it is /24 possible to have secondary radiation as a consequence of the presence of conducting objects in the near field. At the same time, if this kind of conducting object causes interference in another workplace (this usually involves some of the tubing in the installation), the secondary radiation can cause the situation to deteriorate even where direct radiation is not involved. This usually occurs if the linear dimensions of the secondary emitter are close to a multiple of half the wavelength of the frequencies produced by the nearby H.F. generator. In the V.H.F. band, mainly at cm wavelength, there is a tendency toward echoes. In this case, it is necessary to be sure that there are no reflections from ideally conducting objects (such as telephone lines), or any disturbing dielectrics (people, trees, etc.).

3. LIVING TISSUE IN AN ELECTROMAGNETIC FIELD

3.1 Introduction of Electromagnetic Energy into an Organism

In studying the behavior of living tissue in an electromagnetic field, the most important electrical characteristics of the latter are the complex dielectric constant ε^*, the complex magnetic constant μ^*, and the conductivity σ. In an isotropic linear medium, with the aid of the above constants, it is possible to express the relationships between the components of an electromagnetic field. In all materials (except ferromagnetic ones) $\mu^* = \mu_0$, where μ_0 is the magnetic permeability of a vacuum; ε^* and σ remain as fixed constants, whose values for various times as a function of frequency can be found in numerous papers together with the methodology of their measurement [220, 230-232, 234, 236, 237, 241, 243]. At the same time, it has been established that the thermal coefficient of the electrical conductivity of tissue varies with the frequency and is always negative. A highly detailed discussion of the frequency responses of several tissues is presented later on in this chapter. /25

One of the fundamental problems to be solved with regard to the irradiation of an organism is that of determining the so-called effective value, in other words, finding the frequency which is absorbed by the organism or induced into it, and possibly conducted through it. Attention is concentrated primarily on absorption, although the possibility of induction along conducting pathways in the organism (the nervous and cardiovascular systems) and the further spreading of the energy is a very interesting topic for study. Induction obviously occurs mainly at low frequencies, so that it would be possible in working with the latter (for example) to begin with the propagation of electromagnetic waves by a conductor into a dielectric [273]. In any case, however, this solution is beyond the scope of this book, even in its simplest form.

In discussing absorption, it is necessary to begin by defining the characteristic impedence of a given medium in terms of known electrical parameters (individual parts of the body can then be thought of as isotropic and homogeneous). Assuming that the behavior of $\underline{E}$ and $\underline{H}$ in time is harmonic (sinusoidal, for example), we can write the equations for the phase constant α and the attenuation constant β [172]:

$$\alpha = \omega\left[\frac{\mu_0\varepsilon'}{2}\left(\sqrt{1+\left(\frac{\sigma}{\varepsilon'\omega}\right)^2}+1\right)\right]^{1/2}$$
$$\beta = \omega\left[\frac{\mu_0\varepsilon'}{2}\left(\sqrt{1+\left(\frac{\sigma}{\varepsilon'\omega}\right)^2}-1\right)\right]^{1/2} \qquad (3.1)$$

where ε' is the real part of the complex dielectric constant, and $\omega=2\pi f$ is the cyclic frequency. The phase constant α characterizes the shift of the phase ratios and the attenuation constant β indicates the drop in the amplitude of the oscillations during passage of a wave through a given medium. Knowing these two values, we can determine unambiguously the characteristic impedence Z of the medium for plane waves, propagating in one direction only: /26

$$Z = \frac{\omega \cdot \mu_0}{\alpha^2 + \beta^2} (\alpha + j\beta) \tag{3.2}$$

where j is an imaginary unit ($j=\sqrt{-1}$).

Some conclusions can be drawn from the assumption that the wave propagates in one direction which is vertically incident on a system of plane layers (the latter is semi-infinite), forming a very simple model of a body. Although this representation is only a highly approximate one (especially with regard to the relationship between the dimensions of the principal planes of discontinuity and the wavelength), it is adequate for obtaining some insight into the mechanisms involved. Obviously, as a result of the numerous reflections at the boundaries of the layers, two waves are always produced (an exception is the latter semi-infinite medium): one travels in the same direction as the incident wave and the other travels in the opposite direction. The problem consists in determining the percentage of absorbed or reflected energy.

The answer can be found essentially by one of two methods: the first is based on an assumption of the juncture of the tangential components of fields E_y and H_x at all boundaries, a situation which can be described by $2n$ equations (n-1 being the number of layers). The method of solving this system of equations is given (for example) in [253]. The other method, which consists in establishing the input impedance of the system of layers, is much simpler and is valid for any type of wave. We shall not give a detailed description of it here, but advise those who are interested to consult the literature [172, 176]. Calculation of the input impedence is extremely tedious and complicated; hence, it is advantageous for a qualitative solution to employ the Smith impedence circuit diagram [185]. This procedure is a highly graphic one and makes it possible to get a very clear idea of the influence of individual layers on the resultant coefficient of reflection and absorption.

It has already been mentioned that for the sake of simplicity we shall be using a "model" of a body in the form of plane layers. In the case of vertically incident energy, it is obvious that this method provides an idea of the maximum possible absorption. It is therefore the best one for hygienic purposes.

A three-layer model to represent skin, fat, and muscle is the best kind to use when studying a body. The thicknesses of the individual layers can be determined from a knowledge of the weight and specific gravity of the individual parts of the body. In view of the differences between individuals, it is necessary to make several types of three-layer models, i.e., various combined thicknesses of layers [172, 176, 233, 240]. By making the model several layers thicker, an idea of the effect of clothing on absorption can be gained [173].

For the sake of comparison, it is also interesting to examine a case in which the model consists of only one layer having the characteristics of muscle [172, 176, 233].

The above experimental methods and models cannot possibly be considered the only ones. It is always necessary to keep in mind the specific purpose of the study. In seeking qualitative data on the maximum possible absorption and the effect of constituent parameters, including clothing, the above models may be considered suitable. Another problem would be to trace the dependence of absorp- /27 tion on the orientation of a body in an electromagnetic field. In the latter instance, it would be necessary to use a model in the shape of a cylinder, a rotating ellipsoid, etc. [68]. Here again, however, due to the complexity of the problem, it is impossible to determine the effect of constituent parameters (clothing, for example). Hence, we shall dispense with the concept of maximum possible absorption in the study of hygienic effects and give precedence to the models described above, regardless of the fact that the study of the effect of the orientation of a body in a field is questionable because of the unusually complex relationships to the polarization of the field in the individual's work area.

3.2 Effect of Thickness and Order of Layers (Constitution) on Absorption

In order to be able to determine the specific quantity of incident energy on the basis of measurements of the field intensity, or power density, it is necessary to have some idea of the frequency dependence of absorption. For this purpose, the required electrical parameters of the individual layers must be found. The values α and β can be calculated with the aid of (3.1) (see Figs. 8 and 9). The values ε_r, σ listed in Table 2 [239, 240, 275] were used in the calculation. Average values were used for the σ value of fat, due to the water content.

Good agreement was found when the desired values of α and β were compared with the measured values [57, 58] (Table 3). The characteristic impedance of the individual layers was then determined with the aid of (3.2).

According to the criteria in Section 3.1, the equivalent layer thicknesses were selected as follows: skin (l_k) = 0.1 to 0.5 cm;

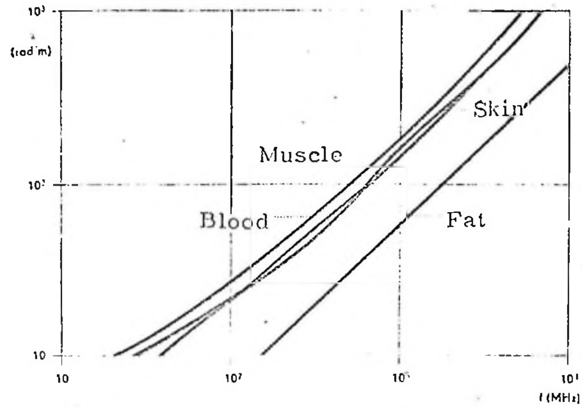

Fig. 8. Phase Constant α in Various Media as a Function of Frequency /27

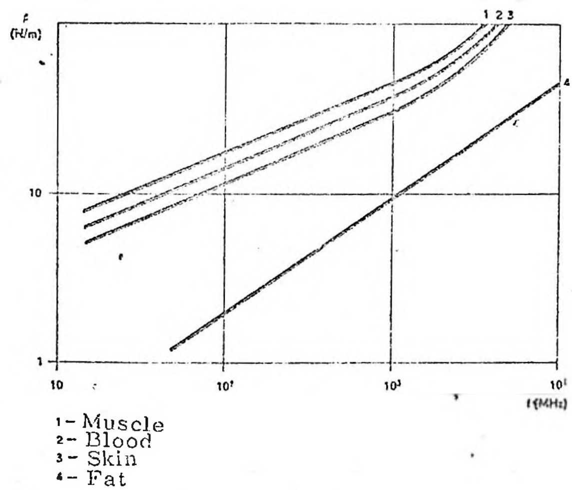

Fig. 9. Attenuation Constant β in Individual Layers as a Function of Frequency /28

TABLE 2. ELECTRICAL PARAMETERS OF PARTS OF THE BODY /28

f (MHz)	Skin ε_r	Skin σ(S/m)	Fat ε_r	Fat σ(S/m)	Muscles ε_r	Muscles σ(S/m)
25	150	0.65	27	0.020	115	0.666
50	100	0.70	12.5	0.029	90	0.768
100	75	0.75	7.5	0.033	73	0.87
200	57	0.80	6.5	0.050	56	1.00
400	48	0.85	6.0	0.059	53	1.14
700	45	0.95	6.0	0.067	52.5	1.31
1000	44	1.10	6.0	0.100	50.5	1.35
1500	43.5	1.3	6.0	0.111	50.0	1.42
3000	42	2.4	6.0	0.167	47.0	2.22
5000	40.5	4.0	5.5	0.222	44.0	4.35
7000	39	5.0	4.95	0.333	42.0	6.67
8500	37	7.0	4.5	0.370	40	8.33

TABLE 3. MEASURED VALUES OF ATTENUATION CONSTANT β AND PHASE CONSTANT α [57,58] /29

Cloth	λ = 10 cm		λ = 3 cm	
	β (N/cm)	α (rad/cm)	β (N/cm)	α (rad/cm)
Blood	0.65	4.6	2.9	13.5
Skin	0.81 0.65 0.73	4.1 4.5 4.6	2.65	12.1
Fat	0.21 0.20	1.45 1.70	0.49	4.0
Muscle	—	—	2.5 2.7	11.7 11.6
Bone marrow	—	—	0.79	5.1

Note: measurement error for $\beta \pm 5\%$, $\alpha \pm (1 \div 2)\%$, Temperature = 37.5°C

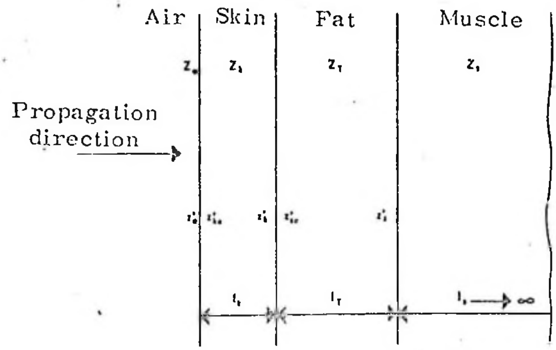

Fig. 10. Three-Layered Material

fat (l_t) = 0.6 to 1.95 cm; muscle ($l_s \to \infty$ (in view of the considerable attenuation in muscle layers). For the model called "muscle", $l_s' = 23$ cm and $l_s'' \to \infty$.

In the case of a three-layer model (Fig. 10), it is possible to obtain a solution by using the Smith diagram to give the values of standardized impedances at the individual boundaries and then obtain from them the amount of energy absorbed. The results indicate that the dependence of absorption on frequency has the form of an oscillation in all cases, as expected. The maxima and minima have /30

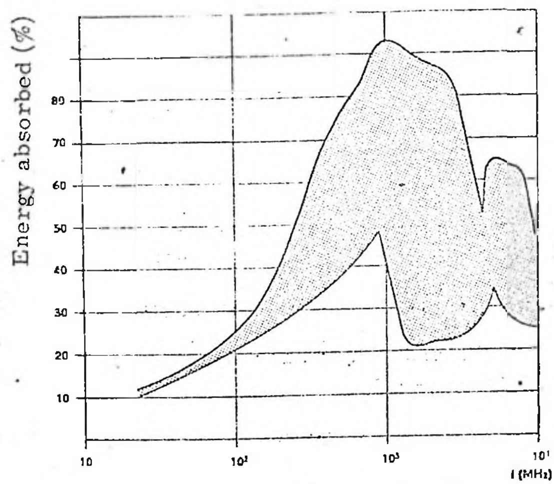

Fig. 11. Total Representation of the Dependence of Absorption on Thickness, for Various Layer Thicknesses in All Possible Combinations

different positions, depending on the thickness of the layers. In the case of considerable thicknesses, the layer shifts the phase of the first maximum and minimum toward lower frequencies; at lesser thicknesses, on the other hand, the phase shift is in the direction of higher frequencies. The amplitude also changes. The phase shift of the second maximum has an inverted appearance; the same is true for the amplitude. The situation is thus considerably complicated; this is best shown by Figure 11, which gives the total results for all possible combinations of layer thicknesses. It is significant in this reagrd that the differences in absorption are considerable. Deviations occur in about 65% of the boundary cases.

The "muscle" (a sigle-layer model with the characteristics of muscle) is represented in Figure 12. Working with the "muscle" revealed that for $\underline{f}$ [illegible] MHz, a layer of muscle with a thickness $\underline{l}_s' = 23$ cm absorbs all non-reflected energy and does not allow any to pass through into the medium (air) beyond. At the same time, of course, this means that for $\underline{f}$ > MHz the idea of a muscle layer with an effective thickness $\underline{l}_s' = 23$ cm is identical to the concept of a semi-infinite layer. Differences in absorption for $\underline{f} < 100$ MHz at the above-mentioned thicknesses of muscle layers are not substantial; they can generally be, characterized by the fact that the decrease in absorption in the direction of lower frequencies is greater for a semi-infinite muscle layer. A representative curve showing absorption as a function of frequency for a semi-infinite layer of muscle is shown in Figure 13. /31

Of the two cases which we have discussed, the three-layer model is the more accurate one from all points of view. We determined in our own analysis that the three-layer model is not considered invariable with regard to the thickness of the layers; with it, one can simulate not only any average type of individual, but the boundary cases as well. A change in skin thickness can be represented similarly, with different degrees of vascularization, since skin and blood have essentially similar electrical parameters (see Figs. 8 and 9). The subcutaneous fatty layer exhibits somewhat more complex parameters, and one would be correct in expecting different water contents as well as different thicknesses. Of course, this circumstance is not important in a qualitative analysis, so that parameters for an average volume of water are assumed. In view of the field perturbation at $\underline{f} < 1000$ MHz, the results obtained for low frequencies must be used only for orientation purposes; still they do make it possible to draw some general conclusions.

A model of the body in three-layer form (i.e., individual layers) does not include the influence of radiation; it is to be expected, of course, that some changes in absorption will be produced by expanding the model in this direction. Such an expanded model obviously has a very large variety of forms, with regard not only to the different parameters of the three layers, but to the clothing as well. In addition, it is necessary to take into account the various air spaces, which complete the entire picture. In order to

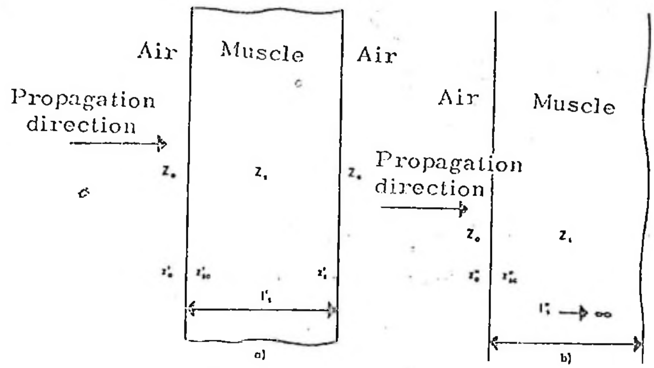

Fig. 12. Representation of a "Muscle": (a) Finite Thickness of Muscle; (b) Semi-infinite Layer of Muscle.

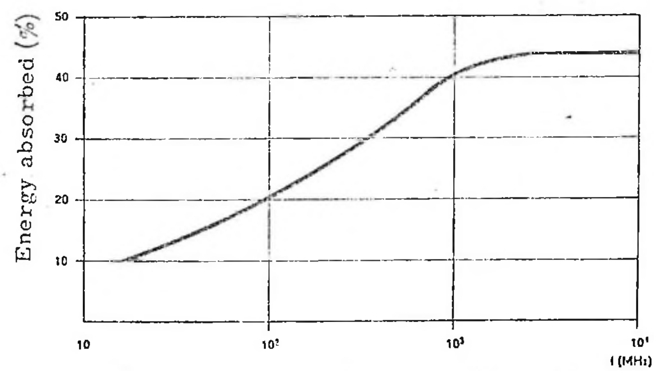

Fig. 13. Absorption vs. Frequency for "Muscle" (Semi-infinite Layer).

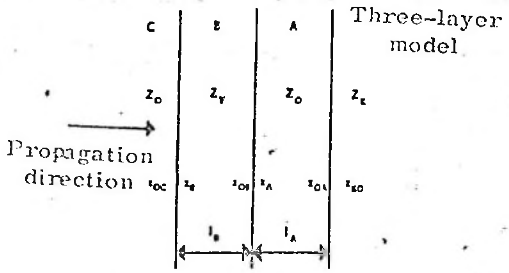

Fig. 14. Representation of System I: Three-Layer Model-Air Space-Clothing

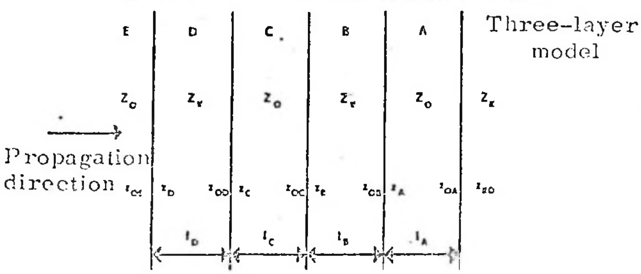

Fig. 15. Representation of System II: Three-Layer Model-Air Space-Clothing-Air Space-Clothing

study the effect of the number of layers, separated by air spaces, as well as the effect of changes in the thicknesses of the tissue layers and the air spaces, it is suitable to solve two fundamental systems: (I) a system consisting of a three-layer model, an air space and clothing; (II) a system consisting of a three-layer model, air space, clothing, air space, and more clothing (Figs. 14 and 15). /32

Once again, the investigation can be conducted aualitatively by means of the Smith impedance diagram, in a manner similar to that used for the three-layer model itself, e.g., on the basis of the determination of the input impedance of the system of layers [173].

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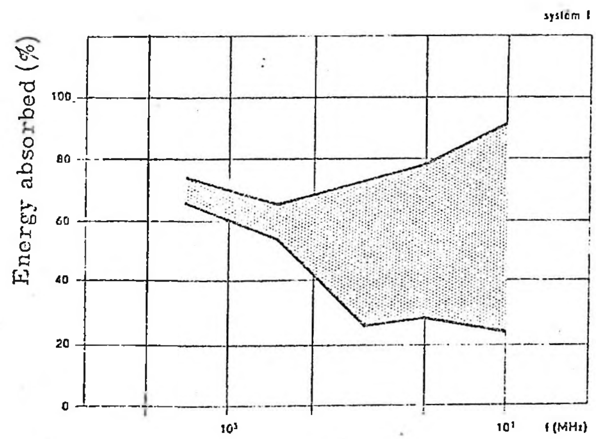


Fig. 16. Envelope of the Maxima and Mainima of the Frequency Dependence of Absorption in System I

In our own study, attention was focused primarily on tracing the effect of changes in the layer thickness in both systems; a total of 54 combinations in the following range was investigated: l_A = 1-5 mm, l_B = 1-10 mm, l_C = 1-5 mm, l_D = 5-10 mm. As far as the electrical parameters of the clothing are concerned, it would be theoretically unsuitable from the standpoint of maximum reflection to have a high dielectric constant ε_r and a small loss angle tan δ (understood to be in a frequency range expressed in GHz units). In this manner, considerable reflection of the incident energy would be guaranteed. This conclusion generally cannot be drawn for a broad frequency band, due to the possibility of varying layer thicknesses. On the basis of these considerations, clothing was chosen with a dielectric constant in the range of GHz units, ε_r = 4, and /34 insignificant loss. Wool fibers have approximately the desired dielectric constant in the give range; on the basis of results obtained with this typical material, it is possible to conduct further analysis properly.

The general results for an expanded model thus defined are shown in Figures 16-19. Figures 16 and 17 show the absorptivity of the entire system, while Figures 18 and 19 show the percentage of absorbed energy in our three-layer model beneath clothing (the average constitutional type was always employed). For the sake of clarity, we have shown only the envelopes of the maximum and minimum frequencies. To allow comparison, we have plotted in Figures 18 and 19 the frequency dependence of absorption for the three-layer model alone, without the clothing (average consitutional type).

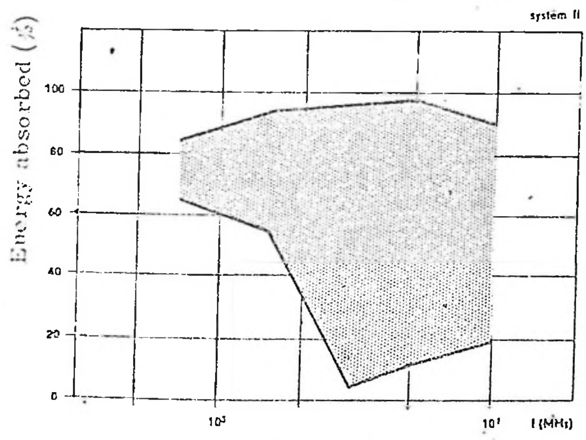
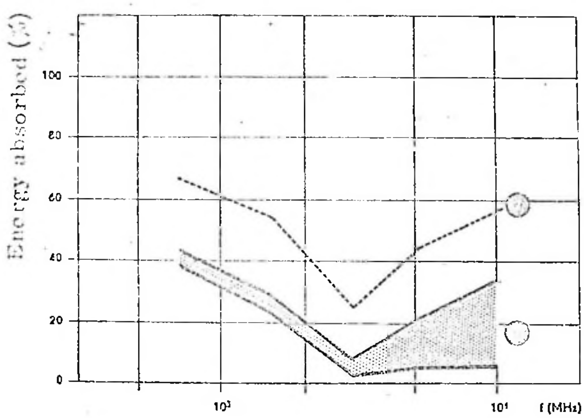


Fig. 17. Envelope of Maximum and Minimum Frequency Dependence of Absorption in System II

An analysis of the graph showing absorption as a function of frequency leads to several important items of information: (1) In any arrangement of the system, the amount of absorption in each case is less than for a solid three-layer model; (2) the shape of the frequency curve remains constant, as in the case of the solid three-layer model (although this need not be a general rule), and (3) the percentage of absorbed energy decreases with an increase in the number of layers (including air spaces).

It is also evident from the calculations that a decrease in absorption in the 70-1500 MHz range is produced by rather thin layers, while in the 8500 MHz range thicker layers are required (to be precise, layer D). In the vicinity of 3000 MHz, it is difficult to draw any general rule. Similarly, it is possible to expect analogous results in other types of three-layer models.



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19. Graph Showing Frequency Dependence of Absorption in a Three-Layer Model (Average Constitutional Type): (1) Beneath Clothing and an Air Space (System I); (2) Without Clothing

Hence, judging by the results shown in Figures 18 and 19, the /36
curve showing the frequency dependence of absorption in a solid three-layer model is also valid for the shape of a curve showing absorption in a three-layer model in Systems I and II. Consequently, it cannot be said that in the vicinity of 3000 MHz there will always be a minimum, as would appear at first glance from the figures, because the frequency curves of absorption for other types of three-layer models have significantly different shapes. In general, however, on the basis of the results obtained by studying all versions of the model, we can definitely say that the frequency dependence of absorption is extremely complex and involved. The sole exception

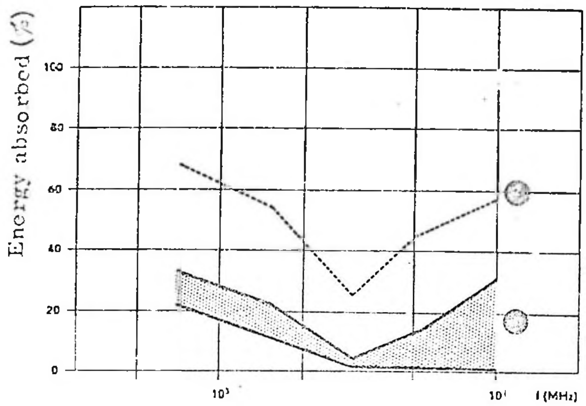

Fig. 19. Curve Showing Frequency Dependence of Absorption in a Three-Layer Model (Average Constitutional Type): (1) Beneath 2 Layers of Clothing and an Air Space (System II); (2) Without Clothing

in the practically single-layered model with the characteristics of muscle, where the results obtained represent an average quantity of absorption. Applying these findings in practice, however, would not be too rash, in view of the possibility of the considerable variations found in other models. In fact, these variations (actually the results obtained by studying the three-layer models) indicate that at the present time it is not practical from the hygienic standpoint to equate the measured field intensity (the power density) and the energy actually acting on the body, if the constitutional parameters of the irradiated individual are not known. The only thing that could be considered is the fact that absorption by the body in the case of any irradiated individual decreases to a degree that increases with the number of layers of clothing (and air spaces as well); in other words, clothing (to a certain degree) serves as a protective medium (if the energy in a field is represented by 100%, no more than 75% will penetrate the body, i.e., the measured values could be multiplied advantageously by a coefficient of 0.75%). Obviously, the protective powers of clothing differ at different frequencies, and the coefficient might sometimes be lower. In general, it is difficult to find a combination of layers of clothing which would ensure minimum absorption over a wide frequency range. In addition, it is impossible to conceive of such an arrangement of layers and thicknesses which would not be so stiff as to retard movements of the body. The frequency dependence of absorption must be kept in mind, in view of the fact that it cannot be one of the factors by which one can explain the differences in sensitivity of individuals to the presence of electromagnetic energy. In addition, this circumstance is of practical significance nowadays for the use of microwave diathermy (it would be desirable to have equipment such that both the power and the frequency were adjustable).

In conclusion, it is now clear that the data from individual observations and research in the field of the effects of electromagnetic waves on man can be generalized only if other constitutional parameters are brought into the discussion. From the methodological standpoint, it follows from the results (the protective power of clothing) that in order to measure the field, it is necessary to measure and record the values at the level of the head; when this cannot be done, the results at other levels are given precedence. In this regard, the existing methodology requires some improvement [285].

4. BIOLOGICAL EFFECTS OF ELECTROMAGNETIC WAVES AND THEIR MECHANISM

/37

4.1. Influence on the Human Organism and on Other Vertebrates

The increasing development of the application of radio waves for diverse purposes has continually raised the number of individuals who are involved professionally with this physical factor. Chronic exposure to electromagnetic waves can lead to subjective and objective complaints in persons working with both V.H.F. [21, 81,101,109,117,119,126,184,224,225,274-277,280] and H.F. generators [51,111,135,147,157,183,245,246]. The most important of these is the effect of V.H.F. fields on the eyes and reproductive organs (in men), since these are located close to the surface of the body and are readily accessible to the effects of electromagnetic waves. In addition, the nervous and cardiovascular systems can be affected, since they not only lie relatively close to the surface of the body, but also have the same conductivity as water.

The best-known effect produced by the absorption of H.F. energy in biological material is the heating of the latter [34]. It is the relatively high-intensity[3] H.F. fields which are generally used for heating purposes. The most conventional (and experimentally easy to achieve) extension of these applications is the elevation of the temperature of the entire body [228,245], which proceeds with increasing intensity and duration of the radiation [90,279,282]. Numerous authors have studied the influence of H.F. on the temperature of skin and subcutaneous tissues [40,80, 138], muscles [95,142], and the eye. Brief heating produces maximum heat on the surface of the body (skin); often this can lead to local superficial burns. The heat decreases inversely with depth. On the other hand, prolonged heating generates maximum heat in deep-lying muscles [195]. The temperatures of the internal organs and blood flowing away from irradiated organs [282] also increase. When high-intensity fields (40 to 100 mW/cm^2) are applied, the blood vessels are seriously damaged and there may be hemorrhaging in the internal organs [40,283]. Some organs may even be seriously injured without the entire organism being overheated. This occurs especially in those cases when some parts of the organism possess so-called dimensional resonance. In other words, if some part of the object being subjected to electromagnetic waves corre-

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[3] High-intensity: ordinarily measured in hundreds of volts per meter in the H.F. band or hundreds of microwatts per square centimeter in the V.H.F. band. Low intensity: ordinarily measured in tens of volts per meter in the H.F. band or tens of microwatts per square centimeter in the V.H.F. band.

sponds in its dimensions to the wavelength (or some whole multiple of half of it), standing waves will arise in that part. Concentrated H.F. energy can also affect implanted metal [165,195,209].

At a certain level of intensity, thermal equilibrium is reestablished, thanks to the thermoregulatory capacity of the organism [139,280]. If the intensity is high, thermoregulation is unable to maintain the temperature of the organism within the required limits, so that it overheats and dies [169,283]. The period of survival can be prolonged considerably by maintaining the normal temperature, cooling the organism during exposure [7,41]. /38

It should be pointed out that a reliable idea of the influence of an electromagnetic field on man cannot be gained from data obtained exclusively in experiments on animals. It is necessary to take into account the somewhat different thermoregulatory system and the various coefficients of absorption for both heat and H.F. in different organisms [137].

Subjective complaints of individuals working in H.F. fields. Workers complain of pain in the head and eyes, combined with a flow of tears, weariness accompanied by overall weakness and dizziness at more advanced stages. At night, they have shifting moods and are frequently irritated and unsociable. These individuals may undergo a hypochondriac reaction and have a sense of fear. Occasionally they suffer from nervous tension or (on the other hand) spiritual depression combined with a suppression of intellectual functions, especially impairment of memory. In advanced stages there may be pronounced sluggishness and an inability to make decisions. The individuals complain of a pulling sensation in the scalp, loss of hair, pain in the muscles and in the area of the heart (combined with pounding of the heart), and asthma. Not infrequently, there are complaints of difficulty in the sphere of their sex life. The subjects may notice mild trembling of the eyelids, tongue and fingers, increased perspiration of the extremities, dermographism[4] and brittle fingernails. A single exposure can cause a drop in the resistance of the organism [259,279]. As far as the dependence of the H.F. effect upon sex is concerned, women are usually more sensitive to this factor than men [64,190,262]. Reference has been made to a decrease in lactation in nursing mothers [186, 195].

After a certain period of time has elapsed following exposure (sometimes as long as several weeks or more), the organism usually

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[4] Dermographism ("writing on the skin") is hypersensitivity to mechanical stimulation. When repeated mild friction of the skin is performed, red spots appear immediately because there is local irritation and inflammation. Some persons have this increased stimulability since birth. It is quite common in neurotics.

returns to its original (physiological) state: all subjective and objective complaints vanish. This phenomenon is generally referred to in the literature as regeneration [195,279].

Effect on the eyes; experiments on animals. The maximum thermal effect of electromagnetic waves is observed in the V.H.F. region, as determined by experimental heating of the eye, and depends on the frequency [195] and heat distribution within the eye [39,142]. Tests of this nature have shown that the temperature rises faster than the power density [26]. Such heating leads to various degrees of damage to the eye [17,107,161,259], even causing cataracts on the lens and cornea [215]. A cataract will appear immediately at sufficiently high power densities and during a single exposure, when it is necessary to have a period of exposure which is inversely proportional to the power density [137,227,269]. However, even in the case of a single exposure to such intensities, a cataract can appear on the lens one to sixty days after exposure [195,213]. Indeed, the eye can be damaged by repeated irradiation at levels below the critical threshold [14,26,27,30]. This is indicative of the cumulative biological effect of V.H.F. [132,279]. A pulsating field is more effective than a constant field from the standpoint of cataract production [26,27]. All of the damage to the eye occurs during its exposure to radiation. In the case of irradiation of the entire body by intensities close to the lethal level, there is no damage to the eye [20,31,195], even when the radiation is of a pulsed variety [142], provided that the latter is not allowed to reach the eye. /39

Effect on the eye in man. No eye damage was found in individuals working with H.F. radiation [21]. On the other hand, however, a high percentage of damage was observed in individuals working in V.H.F. fields, especially among radar crews [12,28,29]. In a number of cases, both unilateral and bilateral cataracts have been described [99,225,279,280]. Soviet authors warn that chronic exposure to radiation on the order of mW/cm^2 is sufficient to produce cataracts in man [195]. The first symptom detected in such individuals is a flow of tears and tiredness in the eye [280], combined with changes in vision, especially a decrease in sensitivity to color (blue in particular) and difficulty in detecting white objects. In these studies, the authors used a projection perimeter [283]. A weak H.F. field also lowers the threshold of sensitivity to light stimuli in an eye which has become dark-adapted [116]. The change in the threshold of sensitivity is the same for pulsed and constant fields [280]. Changes in intraocular pressure were also observed as the result of chronic exposure to cm waves [279]. At sub-threshold intensities, there is a drop in the vitamin C content of the lens and the fluid in the anterior chamber [195]. In the event of acute development of a cataract, the activity of adenosintriphosphatase and pyrophosphatase in the lens was considerably reduced [37].

In the light of these facts, warnings have quite justifiably been issued regarding the application of cm waves for therapeutic purposes, especially in connection with diseases of the eye [99, 213]. In experiments using models in which the development of heat within an eye exposed to a V.H.F. field was followed, the model was made of 30% gelatin or polystyrene foam [100]. Several investigations have dealt with the factors causing eye damage. At higher intensities, it is obviously heat damage which is involved, combined with coagulation of protein in the lens; disturbance of metabolic processes occurs at lower intensities. An important role in this process has been ascribed to glutathione. In addition, damage to tissue respiration and the oxidation-reduction mechanism can lead to the formation of cataracts [195].

Nervous system. The subjective complaints of persons working in H.F. fields are primarily concerned with the nervous system. Hence, considerable attention has been directed toward the changes in the central nervous system under the influence of this factor; the reader will find details in several of the papers in the bibliography [142,195,205,279,280,282,283]. In clinical and laboratory studies [64,122,123] of the effects of H.F. and V.H.F. fields on the human organism, the researchers monitored the activity of the central nervous system (CNS) at both high and relatively low field intensities. These changes were recorded on an EEG in individuals, the majority of whom had worked for long periods of time in H.F. and V.H.F. fields [64,248]. EEG records are presently the best objective method for detecting the early stages of damage to the CNS produced by electromagnetic waves [53,112,122-124]. The complex of changes in the nerve functions caused by damage inflicted on the CNS by low-intensity H.F. and V.H.F. fields is characterized as a syndrome of asthenic type [47]. In only one case has a severe /40 neurotic syndrome with further functional aberrations been described, in an individual who worked for ten years in the field of a short-wave generator [35].

At higher intensities of the H.F. or V.H.F. field, the asthenic syndrome is not often evidenced by disturbances of the cardiovascular vegetative regulation [61,102]. Functional changes, although sporadic, have described in individuals who were systematically irradiated by an H.F. field with a wavelength measured in tens and hundreds of meters [183,194,228]. Here, too, are the most frequent neurotic symptoms,, referred to as "short-wave hangover" [51,64]. Interesting, albeit drastic, are those experiments which describe damage to the human brain when the head is exposed to the radiation from a powerful transmitter [115]. When the test subject was emotionally upset or absorbed in creative labor, the parameters of the radiation emerging from his brain changed. At the same time, it was noted that a powerful H.F. field can produce hallucinations. When other authors irradiated the cerebrum of a healthy individual, they observed an involuntary motor reaction [142]. The above functional changes have the usual reversible character, so that after the cause (i.e., the influence of the H.F. field) is removed, the subject returns to his normal state. In serious cases, there is a possibility of considerable improvement of the overall condition through appropriate treatment [35]. It is only in isolated cases that the changes may be progressive in nature [46,195].

The behavior of animals can be changed completely by the action of an electromagnetic field. Agitation [180], excitement, and increased motor activity [142] have all been observed, sometimes with the result that timid animals become aggressive [116].

Low intensities have been found to make animals sleepy. When the head of a hen was exposed to an H.F. field, the fowl became nervous, would not eat or drink, and stood where it was placed until it fell down exhausted.

The experiments in which the reflex activity of animals exposed to H.F. fields was studied are also interesting. In the case of dogs, it was found that low intensities, insufficient to produce discomfort in the animals, did evoke both conditioned and non-conditioned refluxes [142,208]. At higher intensities, however, there was a pronounced decrease or extinction of conditioned reflex activity, or else the period required for development of reflexes was prolonged; in some cases, it was necessary to use stronger stimuli to cause reflex activity to appear [11,79,159,208]. For example, we observed the loss of all taught behavior in a dog with police training, after the animal had lived six months in an environment with a strong H.F. field. The results are not unambiguous, however, because in the case of dogs with simultaneously produced taste and defense reflexes, the latter were retained [142]. In animals as well as human subjects, the EEG was used to detect changes in the electrical activity of the brain during exposure to an H.F. field [276]. The effects on the reflex activity in the case of single and chronic exposures of the organism to an H.F. field are most likely due to changes in interneural connections [143,168,279, 283]. It is possible to find degeneration of the neurons in the cerebral cortex and basal ganglia, the pons, the medualla oblongata, and (in come instances) the cerebellum, as well as histological and chemical changes in the vicinity of the nerve fibers [20,143,228].

Effects similar to those produced by cm waves are caused by substantially lower frequencies [12]. The reaction of the cortex to an H.F. field is the same as that evoked by the use of bromides or caffein [142]. Studies have also been made of the functional /41
state of (and changes in) the excitability of neuro-muscular preparations in H.F. fields [39], and of the influence of an H.F. field on the rheobase and chronaxy in both animal and human subjects. There have also been descriptions of various effects of constant and pulsed fields and the influence on the effects of bromides and caffein.

The reactivity of the entire nervous system in animals is disturbed by an H.F. field. For example, the sensitivity to touch and sensations of pain is reduced [223,228]. The analgesic effects of H.F. fields are produced by suppression of the conductivity of the affected nerve. A number of papers have dealt with the effect of H.F. fields on the threshold of stimulation and the latent period of the medullary nerves [142]. The visual analyzer is also affected by an H.F. field, as was established quite some time ago [51,116, 225]. When an H.F.field is acting on the auditory analyzer, the sensitivity decreases even at low intensities, with a simultaneous prolongation of the latent period. At such low intensities, however, auditory acuity may even be increased somewhat. Irradiation of the cerebellum in man can produce short-term changes in the spatial perception of sound without any change in the threshold of stimulation. Sensitivity also decreases (i.e., the threshold level of stimulation increases) when an H.F. field acts on the olfactory analyzer [225]. This decrease in the sensitivity of smell in persons working with H.F. radiation can be one of the early signs of the effects of cm waves [279]. In cold-blooded animals (sharks), the action of an H.F. field causes deterioration of the ability to "scent" or otherwise find food [287]. Use of very high intensities of V.H.F. fields causes damage to the interoreceptor apparatus.

Reproductive tissue. After the eyes and nervous system, the genital organs are most sensitive to H.F. fields. Significant changes occur mainly at high field intensities in the cm wave region [17,30,82,113,137]. It is primarily thermal injury to reproductive tissue which occurs at these intensities. Increasing the temperature of the male and female gonads results in morphological changes [83] and possible degenerative processes in these organs. The changes are the same as in thermal trauma [82]. Thus (for example) the walls of the blood vessels supplying the reproductive organs may contract, or else there may be direct damage to the ovaries and testes. Histological examinations have revealed interruption of spermatogenesis in several phases of the process [282]. These morphological changes can then lead to a modification of the reproductive cycle, a decrease in the number of offspring, sterility of the latter [79], or an increase in the number of females born.

No decrease in fertility was noted in persons working in H.F. fields [12,36,280]; as far as the number of children born is concerned, however, there was a distinct majority of girls. Nonuniform results were obtained in a study of the effects of H.F. and V.H.F. fields on the menstrual cycles of women. Disturbance of the latter is mentioned as one of the signs of the action of an electromagnetic field on the organism [182], although the results of several studies of women working 3 to 11 years in V.H.F fields did not support this theory [24,186].

It appears that the action of H.F. fields on pregnant women and female animals increases the percentage of miscarriages [222]. The offspring of female rabbits subjected to the action of an H.F. field showed definite functional aberrations and a higher mortality rate in comparison with those from a control litter [30].

A case of embryopathy in the case of a fetus in the womb of a woman treated during pregnancy with shortwave diathermy has been described. When the child was born, it showed changes in the upper and lower extremities: the upper extremities lacked ossification centers [30]. Other authors also state that H.F. fields definitely impair embryogenesis in both humans and animals, particularly in the initial stages. The development of the fetus is retarded, congenital defects appear, and the life expectancy of the infant is reduced. The effect is cumulative and the thermal effect plays a definite role [160]. /42

Circulatory system. Periodic exposure to high-intensity H.F. fields leads to changes in the circulatory system [195,279,280,283]. Disturbances of the blood circulation have been described [80], evidenced by a change in blood flow [216]. Usually it is an increase in flow which is described, proportional to both the intensity and the duration of exposure [214]; a decrease is observed only in denervated extremities. These phenomena are related to vasodilation. Clearly, a change in the blood flow and vasodilation will affect the blood pressure [262]. The latter rises slightly at first and then begins to fall [5,11,98,224]. This effect can be very pronounced and last for several weeks following exposure. Negative results have also been reported in studies of persons working with radar, however [224]; the heart rate also changes [141]. Depending on which part of the body was exposed, the rate may be either accelerated or retarded [11,198,199]. The EKG is used for objective study of changes in cardiac activity. One effect of the H.F. field is to reduce the conductivity of the coronary circulation, resulting in changes in the EKG, characterized as changes of the sinusoidal bradycardia type, sometimes combined with sinusoidal arhythmia [245]. Aberrations in vascular reactions, such as oscillation of vascular tonus [61], have also been reported.

Soviet authors [279] have divided the symptoms of chronic exposure to cm waves (the level of vasomotor disturbances) into three stages: (1) the initial, compensated stage; (2) the stage of gradual changes; (3) the stage in which changes proceed rapidly. The degree of change depends on the intensity and duration of exposure to the V.H.F. field.

The above changes in circulatory functions are reversible, but a case has been described in which the changes in the EKG continued even after the influence of the field had been removed, although the other functions returned to normal [280].

Changes in the blood picture. A number of authors state that the blood picture is not affected noticeably by the action of an H.F. field [12,36,143,195]. Others, however, have mentioned changes [105,107,224,276] both in the white [79,95,98,156,200,225,279] and red blood pictures [104,224], as well as a drop in hemoglobin [79].

The osmotic resistance of erythrocytes is quite negatively affected [195]. When cm waves are allowed to act on a suspension of erythrocytes, their shape and volume change; further exposures sometimes lead to hemolysis [73,245]. Cell walls treated in this manner have electrical characteristics different from those which have been subjected to conventional osmotic hemolysis. The time required to spin down blood is reduced by exposure to an H.F. field [195]. The prothrombin time (according to Quick) is reduced [229]. The increased coagulability produced by the changes in the vessels can even lead to the formation of thromboses.

Several authors have studied the effect of microwave radiation on the hematopoetic organs [42,121].

Effect of H.F. fields on other organs. The effects on the circulatory system produce significant acceleration (sometimes retardation) of the breathing rate [11,195]. In addition, hemorrhaging and bleeding can occur in some internal organs [20,195]. /43

A number of authors have studied the effects on the kidneys, adrenal glands, and liver [20,92,195]. They found decreased filtration in the renal tubules, perhaps due to degeneration of the epithelial walls of the distal and proximal renal tubules. In addition, there was increased activity of the adrenal cortex, hemorrhaging in the liver, and degeneration of hepatic cells. Persons working in H.F. fields (especially women) showed an enlargement of the thyroid gland, not related to the clinical picture of hyperthyroidism. Increased incorporation of radioactive iodine was also detected in studies of the function of the thyroid [190,262,279,280].

Since there is dimensional resonance in several parts of the organism, only partial injury to the organs may occur; thus, for example, there may be neurosis of the intestine [20,224].

Exposure to an H.F. field does not produce histological changes in bone marrow or variations in the incorporation of labelled calcium and phosphorus into irradiated bone [56,106,250].

Some histological changes in muscle following chronic irradiation have been described [158]. Higher intensities lead to morphological changes not only within the organism, but also in the paws and ears of experimental animals [195,259]. No histological changes were found following a single exposure [282].

Biochemical changes. The effects of electromagnetic fields are reflected by changes in the metabolism of highly diverse tissues [251]. A number of experiments have been devoted to sections of the cerebral cortex [8,93]. Under the influence of a pulsating field, the glucose level falls and oxygen consumption rises [133,154]. At the same time, there is an increase in CO_2 content, lactic acid, and the level of inorganic phosphate, while the amount of macroergic structures decreases. Considerable aerobic glycolysis takes place. Changes in the alkaline reserve and the blood pH have also been noted [33,127]. In unanesthetized rabbits, the activity of succinodehydrogenase and cytochromoxidase is slightly affected, while in anesthetized rabbits (in which the basal metabolism has been lowered) the H.F. field raises the tissue respiration activity to normal levels [118]. The effect of an H.F. field on oxidation processes in man has been studied in [22].

Even at relatively low intensities, the activity of cholinesterase in the blood and other organs is reduced [279]. Hence, we may assume that the effect of the H.F. field is to raise the level of acetylcholine in some parts of the organism, which could be of great significance in the development of vegetative changes.

Several changes in the composition of the blood plasma have been described [18,252]. A number of authors mention a decline in total proteins, with a simultaneous decline in the albumin - globulin ratio [9,82,280]. The change in the latter is probably caused by the increase in gamma globulin which has been observed [62,82,224,244,279] and may be related to the change in the decomposition of tissue proteins. This finding is more of an exception than the rule, however. In some cases, a rise in the histamine level in the blood was detected [97,200,280], but this also raised the resistance of the organism to ionizing radiation. H.F. fields also affect the glycemic curve [195,229,279] and the breakdown of glycogen in the liver [82,116]. In healthy individuals, only slight changes were observed in the levels of sugar, cholesterol and lipids in the blood, but there was a pronounced decrease in all three components and a deterioration of the subjective complaints following application of H.F. to diabetics [92]. It is likely that the changes in sugar and phosphorus found in the blood of rabbits are caused by a disruption of sugar metabolism [195]. /44

A drop in the level of ribonucleic acid (RNA) in the spleen (and later in the liver and brain) of rats were observed after chronic irradiation with microwaves. The amount of desoxyribonucleic acid (DNA) remained constant [283]. Other authors report that a single irradiation of rats reduced the activity of both ribonuclease and desoxyribonuclease, but increased the level of both acids (especially RNA) [282]. A single exposure was followed by increased activity of both enzymes in skin cells and dermatic derivatives [283]. An increase in the RNA level was observed in the lymphocytes of workers with H.F. generators; this corresponds to an increase in the number of monocytes in the blood picture since they contain the great majority of the RNA (young cells) [245]. Fibrinolytic activity was observed to increase in young persons (and decrease in older ones) following irradiation, while it is otherwise the same in both groups [15]. The effect on the activity of other enzymes was also studied [91].

On the basis of the biochemical changes (mainly in sugar metabolism) under the influence of an H.F. field, several authors have expressed the theory that research in this direction might possibly be the way to a successful cancer cure [19,116]. The effects of an H.F. field on cancer patients have actually been observed [60,164]. A group of scientists from the French Academy has published a report on a successful cure of cancer in rats, which were exposed to the effects of alternating H.F. fields of various frequencies [217,218, 219]. This report, however, was received with some skepticism by specialists in oncology. From the experiments described, the authors came to the conclusion that the effect of an H.F. field changes the metabolism of tumorous tissues [179], not only retarding the growth of primary saromas, but also inhibiting the development of secondary tumors and the production of metastases.

4.2. Influence on other Organisms

The effects of electromagnetic waves have been studied in several invertebrates, even in such unicellular organisms as bacteria and protozoa, and in plants as well.

Effect on invertebrates. When various kinds of insects were exposed to H.F. fields, the resultant overall reaction was similar to that observed in experiments with mammals. The first reaction is discomfort, and attempting to escape; this is followed by disturbance of motor coordination, stiffening, immobility, and (after a certain interval) death [87,195]. The period of exposure required to produce death is very much a function of the type of insect. *Drosophila*, for example, will survive longer than 30 minutes, while certain tropical species can live only a few seconds at the same field intensity. The effect cannot be attributed to the thermal effect, because if heat alone (50°C) is applied instead of the /45 H.F. radiation, the sensitivity of the two species is reversed. Changes have also been noted in the concentrations of a great variety of metabolic products. Radiation from an H.F. field also affects embryogenesis: the period required for a butterfly to complete its metamorphosis is changed [107], gastrulation is accelerated and the growth of plutean larvae from fertile eggs of *Paracentrotus lividus* was also speeded up by irradiation.

Effect on unicellular organisms. Unicellular organisms react differently to H.F. fields. Immobile organisms arrange themselves parallel to the lines of force of the field at low frequencies, while at higher frequencies they are sometimes perpendicular to the direction of the field. Mobile organisms have a fixed frequency response. They move along the lines of force of the field at low frequencies and at right angles to them at higher frequencies [51, 257]. When the external force ceases to act on them, they usually return to their initial positions. In some kinds of amoebas and a few larger microorganisms, changes in external and internal structures were observed (orientation of subcellular particles). The directional change of structures in the amoeba has been called by some authors a certain kind of "structural schizophrenia". In the proper field, an amoeba can be made to divide and die. Interesting experiments have also been performed on paramecia; it has been found that irradiating a paramecium with a pulse or a series of pulses of direct or alternating current produces the so-called "electric shock reaction", a sharp braking motion. The application of microwave impulses of suitable (threshold and super-threshold) intensity produce reactions of a uniform variety. When microwave pulses of subthreshold intensity are employed, no reaction is elicited, but the sensitivity of the paramecium to the effects of the pulsed direct and alternating current is increased (the threshold of sensitivity is lowered) [201,204]. The dependence of the reaction threshold upon the duration of the d.c. pulse and the frequency of the a.c. pulse corresponds to the dependence in the case of stimulation of nerve and muscle tissue, which only serves to support the theory of the existence of some kind of structure in the paramecium which has been disturbed. The influence of an H.F. field on growth, viability and other metabolic processes in unicellular organisms has been studied in several papers [66,75,94, 144]. Here again, dependence on frequency or intensity was found. Growth is slow at low frequencies; at higher frequencies, growth is retarded and eventually halted so that the organism perishes. When a culture of cardiac fibroblasts from a chick embryo was irradiated, however, growth was found to be accelerated [195]. The effect of the H.F. field may be to lower the infective power of bacteria and to inactivate certain viruses [192,195]. However, such inactivated viruses do not possess the vaccination power, which is not lost in normal inactivation by heat [181].

Views regarding the mechanism of the action of electromagnetic fields on unicellular organisms are not uniform among all authors [66,94,144,201,257].

Effect on plants. In periods when the intensity from natural sources is at its maximum, growth of wood in trees has been observed. This growth is two or three times greater than that during a period of minimum intensity. Nevertheless, at high field intensities (for example, near the antennas of relay stations or U.S.W. links), growth is inhibited and so-called "U.S.W. paths" appear [120]. These paths are produced by the effect of radiation on the cell-division rate[5] and a change in the number of individual phases of /46

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[5] (1) Mitosis is indirect division, the commonest mode of cell division. In mitosis, the complex division apparatus is formed and division takes place in several phases. The chromosomes are morphological elements of mitotic division which are found in the nucleus of every cell and contain DNA. They have a complex structure, not yet well understood in detail. After the cell goes

(footnote 5 continued on next page)

div[illegible] [illegible]]. An H.F. field with an intensity of 10^{-4} to 10^{-2} V/m is sufficient to accelerate division, but the division rate falls off beyond 0.1 V/m. At the same time, chromosome changes become evident [90,94,107]. Various changes in the nuclear apparatus, caused by exposure to a pulsed H.F. field, were detected in the cells of a growing garlic plant. The radiation produced linear shortening of the chromosomes, the development of pseudochiasma, links between nuclei, and the appearance of an irregular covering on the chromosomes. Daughter cells with different amounts of nuclear material were also found, as were amitotic divisions. Ionizing radiation and certain chemical substances cause similar phenomena. Chromosome charges are dependent on the frequency of the H.F. field employed, the power, the exposure time, and the direction of the cell axes relative to the field direction, and are permanent. It now [illegible] that the H.F. field is another mutagenic factor, one which can be well regulated and affords the opportunity of making delicate adjustments and changing chromosomes [94,257]. Thus, the very low intensities of the H.F.field, which do not produce any noticeable damage, still can produce genetic changes which will extend through several generations. The effects on growth are accompanied by diverse biochemical changes to which the influence of the H.F. radiation contributes [130,148].

Dependence of biological effects upon field parameters. From the brief discussion above regarding the effects and action of electromagnetic fields on living organisms, and even after a detailed study of the works in the bibliography, it is still impossible to come up with a concise and (so far as is possible (unambiguous conclusion. If we keep in mind the fact that the biological effects of radio waves are dependent on a number of factors (of which the most important are the field intensity, characteristics, and exposure time), it becomes clear that not even the final answer will be unambiguous and will differ more or less (or even be to the contrary); the latter, as the above summary shows, is not a rare event. From the sections which follow, describing several important factors which depend on the field parameters, it is possible to gain some idea of the difficulty of getting a correct and objective appraisal of the end effect.

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footnote 5 continued

through mitosis, two new cells (so-called "daughters") are formed from each cell, with the same content of nuclear material (they have the same number of chromosomes).

(2) Amitosis is direct division, a less common form of cell division. In amitosis, there is no formation of a dividing apparatus as in the case of mitosis: the nucleus simply divides into two equal new nuclei, or else smaller pieces separate from it; sometimes it breaks up completely into many parts. Amitosis does not always involve the simultaneous division of the entire protoplasm (i.e., the whole cell): giant multinuclear cells may result. Some authors believe that amitosis is a pathological event, while others see it as equivalent to mitosis.

The frequency dependence of the biological effects can differ according to the above-mentioned mechanism of the effects. It appears that the complex biological effect of electromagnetic waves from a relatively low-intensity field is not too dependent on frequency, provided the energy acting on the organism is always of the same magnitude, although the individual active mechanisms can exhibit a pronounced frequency dependence. In principle, there are two other effects: thermal and non-thermal. It must be em- /47 phasized that the non-thermal effects cannot be separated from the thermal ones, which predominate at high intensities and depend upon the energy transmitted. Thermal effects increase sharply with increasing frequency and are most important in the range of the so-called microwaves. Due to the slight depth of penetration of microwaves, which accounts for their considerable damping in tissues, the eyes and (in men) reproductive organs are most seriously damaged. Non-thermal effects are produced primarily by the instantaneous amplitude of H.F. radiation. Its significance increases with repeated exposure to radiation at relatively low intensities, especially in radiation from pulsed fields, in which the total power output is relatively low but the instantaneous amplitude is quite high.

In this situation, the non-thermal effects tend to overshadow the thermal ones. On the basis of our present knowledge of the primary biophysical mechanisms of the non-thermal effects of electromagnetic waves, we can say that the primary effects involve the macromolecular and cellular levels in particular. It is mainly a question of influencing the colloidal structure of the cellular contents and other colloids in the body, and also affecting the electrical conductivity of the cells, which can be of primary importance for the function of the central nervous system. The frequency dependence of these two active mechanisms will not be the same, and our present knowledge of them is still very incomplete. We do know, however, from experiments on the effects of electromagnetic waves on isolated colloidal components, that the frequencies and intensities required to produce the effects depend on the composition of the colloids.

The frequency dependence of the biological effects of H.F. and V.H.F. fields has been studied by many authors [17,279]. As far as the thermal effects are concerned [41,195,210], the relationship depends upon the fact that the electrical characteristics of individual tissues vary with the frequency [240]. This change is monotonic, i.e., it proceeds without any maxima or minima. For the body as a whole, however, there is a certain optimum range of frequencies at which the heating reaches a maximum [69,235]. This is due to the finite dimensions of the body, which is not a homogeneous structure, and the frequency dependence of the dielectric constant, the so-called dispersion, of the tissue layers. The frequencies for maximum heating of the human body lie in the range of very short and centimeter waves. In general, it may be said that heating of tissue increases with frequency. In addition, a number of other effects are most pronounced at high frequencies. Thus, retardation of motor reaction is greater at 75 MHz than at 0.3 MHz, as are changes in the central nervous system [280]. Changes in the growth of bacteria as a function of frequency have also been described [63]. As far as the circulation of the blood is concerned, it has been found to increase in the cm wave region, while it falls relative to normal at relatively low frequencies [195]. In the latter instance, however, it was probably more a matter of the influence of two different field intensities. The same assumption can be made in describing the differences in sensitivity of the auditory analyzer between the 10 and 3 cm wavelengths. This is indicated by the observation that there is no difference in the effect of these waves on the endocrine system or the central nervous system [279].

Far more significant than the frequency dependence is the effect of the diverse character of the emitted signal. The latter must be either non-modulated (so that the electromagnetic field is continuous, with a more or less constant amplitude [cw operation]), /48
or modulated. The boundary case of an amplitude-modulated signal is pulse modulation.

Let us imagine an experiment in which we have two generators, operating at the same fundamental frequency; one is non-modulated, the other is in pulsed operation. If the average radiated power of the two devices is the same, there will be no difference in the thermal response of the organism to this divided field [279]. Nevertheless, we can detect a distinct effect. In the case of a single exposure of rats to radiation with a power density of approximately 200 mW/cm^2 in the 10 cm range, cw operation of a generator will not produce any visible effect in the experimental animals even after 30 minutes, while pulsed operation (pulse width = 1 μs, repetition frequency = 1000 Hz) will cause death of the rats after 3 to 4 minutes [151]. Postmortem examination reveals only considerable enlargement of the spleen; the histological appearance of the principal organs (including the brain) is normal. In addition, the response of an experimental animal to pulsed-wave radiation is characteristic from the very beginning and indicates the dominant influence of electromagnetic waves on the central nervous system. Hence, from the biological standpoint, a pulsed field is more effective than a cw field. This conclusion has been reached independently in the USSR, USA, and CSSR [118,145,151,254].

It might be suggested that the considerable biological activity of pulsed fields is due to non-thermal effects [118]. Mention has already been made of the difference between the effects of non-modulated and pulsed fields on the development of cataracts [26,27, 215], morphological changes in the links between neurons [280], and on the rheobase and chronaxy [142]. In these experiments, cm waves were usually used in pulsed operation. However, meter waves have also been employed to demonstrate the considerable biological activity of a pulsed field, for example, on oxidation processes in tissue [118]. Increasing the average power density of the field widens the difference between the effects of continuous and pulsed fields, and the thermal effect begins to predominate [20].

It has already been stressed that the H.F. field, in its different manifestations, can have both a stimulatory and damping effect, at the same time maintaining a given frequency and field characteristics. This depends on its intensity and period of exposure. At high powers, the effect is governed by the field intensity and period of exposure, while at low intensities or brief exposures it can lead to oscillation of the effect.

A number of parameters affect the biological effects of an H.F. field. In this respect, it is evidently a matter of indifference how the field is produced. Besides the various types of man-made H.F. generators, there are also those fields which originate in natural sources. One such powerful source is the sun; in addition to rays of heat and light, it also emits radio waves over the entire width of the spectrum. The intensity of this radiation can (within certain limits) reach values which are sufficient to evoke biological effects [6]. In addition, the sun emits corpuscular radiation; when the latter reaches the upper layers of the atmosphere, it can produce short H.F. pulses in the range from 10 to 50 kHz [50]. Similarly, large movements of air caused by various factors (mainly fronts with labile moisture boundaries) from H.F. fields in a fixed frequency range.

Today there are a number of papers available which deal with the biological effects of this range of frequencies [51,187,188, 288]. It is interesting that statistically significant evidence has been presented regarding the effect of such fields on the mortality rate of the population [51], the birth rate, traffic mishaps, and industrial accidents [6]. /49

Laser radiation. Following the invention of the laser, a source of coherent electromagnetic radiation in the visible region of the spectrum, the biological effects of these rays began to be studied [49,256,284]. It was found that laser radiation, like low-frequency electromagnetic waves, has both thermal and non-thermal bioligical effects and has its greatest effect on biologically complex macromolecules (proteins) [62].

When pulsed laser radiation is applied to the eye, ultrasonic waves are generated in the skull, which produce vibration of the brain, the cerebrospinal fluid, and the bones of the cranium; piezoelectric recordings can be made from the bones at the base of the skull [2,43].

In comparison with the effect of classical light sources operating on a single frequency, whose radiation is non-coherent and which can be used practically only to produce thermal effects, it was found that laser radiation has specific chemical and electrochemical effects of a non-thermal nature [260]. The hypothesis has been suggested that the mechanism of this effect is similar to that of radio waves.

Action of electromagnetic waves combined with other factors. In operating H.F. generators, high-voltage power supplies are used to run the vacuum tubes in the final stages. Above approximately 20 kV, there is bound to be a flow of anode current which will produce rtg radiation [145]. Measurements made on various V.H.F. generators have shown that peak values up to 50 r/min can be produced. The effect of the combined influence of an H.F. field and rtg radiation was therefore studied; it was found that in such a case the damage to a biological object is more serious than when each factor is allowed to act independently [195,264]. The magnitude of the effect was also measured by successive exposure to an H.F. field and ultraviolet radiation [114], as well as gamma sources [200]. The level of joint action of fields with different frequencies appears to be dangerous [76].

Irradiation of an organism in an H.F. field can also have significant effects on certain chemical substances, such as medicines, so that their powers are increased or even destroyed [116].

4.3 Influence on Physical and Chemical Properties of Substances.

As long ago as 1890, two years after Hertz' work, it was found that when electromagnetic waves strike iron filings, their electrical resistance decreases [72]. The same effect was reported by several authors, but none could explain it. Still, this effect served as the basis for the so-called "coherer", the first detector of electromagnetic waves.

Later, detailed studies were made of the effect of H.F. fields on the behavior of colloidal systems of diverse compositions, and it was found that they lead partly to instantaneous changes and partly to gradual ones. The most sensitive instantaneous change /50
is the migration of colloidal particles in the electrical field produced by an H.F. field. For example, the field from a nearby radio transmitter is sufficient to affect a colloidal solution of As_2S_3 [270]. Relatively weak fields cause changes in cell division [120]. Several changes do not appear immediately, however. Thus, several hours after exposure, there may be signs of disturbance of the stability of the colloidal solution, clustering of the particles, and their flocculation. In the sensitization of an NaCl solution, the effect of the H.F. field takes the form of accelerated flocculation. Fatty emulsions behave similarly. An H.F. field can also speed up the curdling of milk. Inasmuch as the intensity of the H.F. field emitted by natural sources increases sharply before a storm, this fact is related to the well-known observation that milk

curdles easily under such conditions [51].

At a certain field intensity, colloidal and larger disperse particles link up together (the phenomenon called pearl-chain formation). All of these chains have their lengthwise axes in one direction, that of the lines of force [131]. A theory explaining this phenomenon has also been devised [132,257]. In an aqueous solution, charges are distributed which are bound to the water molecules. Under the influence of an electromagnetic field, these charges attempt to align themselves with it, but since each colloidal particle is dissolved, the water molecules drag the colloidal particles along with them [177]. The above effect of an H.F. field can also take the following form: induced dipoles appear and attract one another with their unoccupied ends, forming a chain under the influence of electrostatic forces. The magnitude of force fields formed in this manner has been derived for aqueous and non-aqueous particles dispersed in various media [72]. It has been shown both theoretically and practically that even very low frequencies suffice to produce the phenomenon of chain formation in colloids [242].

Because a suspension of unicellular organisms in a fluid medium is similar in its electrical characteristics to a colloidal solution, the effect of H.F. fields on this system was also observed [268]. Pulsed apparatus is used in the majority of such experiments today, although it does not operate on cm waves. The reason for this is to protect the living organisms against the thermal effects of the H.F. field. It was found that dead and live non-motile unicellular organisms behave exactly like colloidal solutions of inorganic or organic particles, i.e., they form chains [94,275]. It was noted a long time ago, however, that non-symmetrical particles first align themselves with the lines of force, and only then form chains.

When motile microorganisms are irradiated, their spatial orientation is upset; they then move in a given direction, as described above. It is interesting that the frequency at which the direction of their movement changes, and the minumum field intensity required for this phenomenon, depend on the type of microorganism and can be very different for two different varieties. An attempt was made to explain this occurence on the basis of the theory of a non-homogeneous dielectric [115]; at the same time, the time constant for chain formation of colloidal particles was also studied [226]. It is interesting that the rate of chain formation is the same for both cw and pulsed fields, depending only on the average power [277]. The problem as a whole has not been solved yet; at the present time, considerable attention is being devoted to this question in many laboratories, because there is a wide range of possible applications both in practical use an in many theoretical disciplines.

An electromagnetic field can also evoke changes in the charac- /51
teristics or composition of several substances [116]. Thus, a long-lasting drop in the surface tension of water has been observed to

be caused by frequencies in the vicinity of 10 kHz [189]. Waves in the 20-70 cm range influence the crystallization rate of certain inorganic substances. A list has been drawn up, containing a group of materials whose crystallization was given maximum acceleration at a certain frequency [261]. The number of crystals is increased, but their sizes are smaller than would be obtained without the influence of the V.H.F. field. No abnormal crystals were found [272]. On the basis of the movement of crystals in an alternating field, their electrical properties can be determined [72]. Some molecules can be set to oscillating by the action of an H.F. field [220]; at a certain frequency, this can lead to resonance phenomena. Thus, for example, inversion of pyramidal molecules of ammonia has been recorded at a frequency of 23,870 MHz (i.e., λ = 1.26 cm). This phenomenon has been put to practical use in the regulation of highly precise clocks. Hydrogen ions can absorb H.F. energy relatively well within certain limits in the ranges 2.5 to 8 MHz and 16 to 44 MHz.

In the case of glycogen, an interesting occurrence involving a change in the polarization plane of light has been described. The angle of rotation of this plane at that frequency is proportional to the intensity of the field [59,115]; this could be used for dosimetric purposes.

Many authors have studied the effect of H.F. fields on protein molecules in vitro. Changes were found in the average molecular weight of a mixture of proteins. This effect is reversible, but more uniform than when heat is used [140]. As far as the specific effect of V.H.F. fields on the denaturing of proteins is concerned, the frequency dependence will hold here as well. Under the influence of cm waves, no specific effect whatsoever has been observed [132], while in the meter-wave range this effect was expected [19] or was actually observed [96]. Mention has already been made of the influence of an H.F. field on the separation of blood serum in experiments in vivo. It is interesting that such irradiation of blood in vitro makes it possible in subsequent electrophoretic separation to achieve a decrease of the albumin fraction and an increase of the gamma-globulin fraction in particular. This phenomenon has been compared to the effects of ultraviolet light, which reduces the albumin level three times more than an H.F. field.

The electrical characteristics of molecules, especially the dielectric constant, can be changed substantially with increasing frequency [137] and a complex solution [86]. The related change in the dipole moment makes it possible to explain the effect of the H.F. field on the reaction time [187]. A method has been devised which will employ this phenomenon to measure extremely rapid ionic reactions [74].

The above experiments make it possible (to a certain extent) to ascribe the increased proteolytic activity of pepsin to the influence of an H.F. field with λ = 8 meters, in which a pronounced frequency dependence was observed. On the other hand, it was not possible to detect any influence of an H.F. field on the activity of diastase at constant temperature [130]. Crystalline α - amylase can be completely deactivated at a temperature of 37.5° C when exposed to an H.F. field with a frequency of 12 to 16 MHz [129]. The activity of phosphatase (but not fumarase) can be affected similarly [188]. In experiments with enzymes, heat may not be the deciding factor, but it is a critical one all the same so that the results must be interpreted carefully from the standpoint of non-thermal effects.

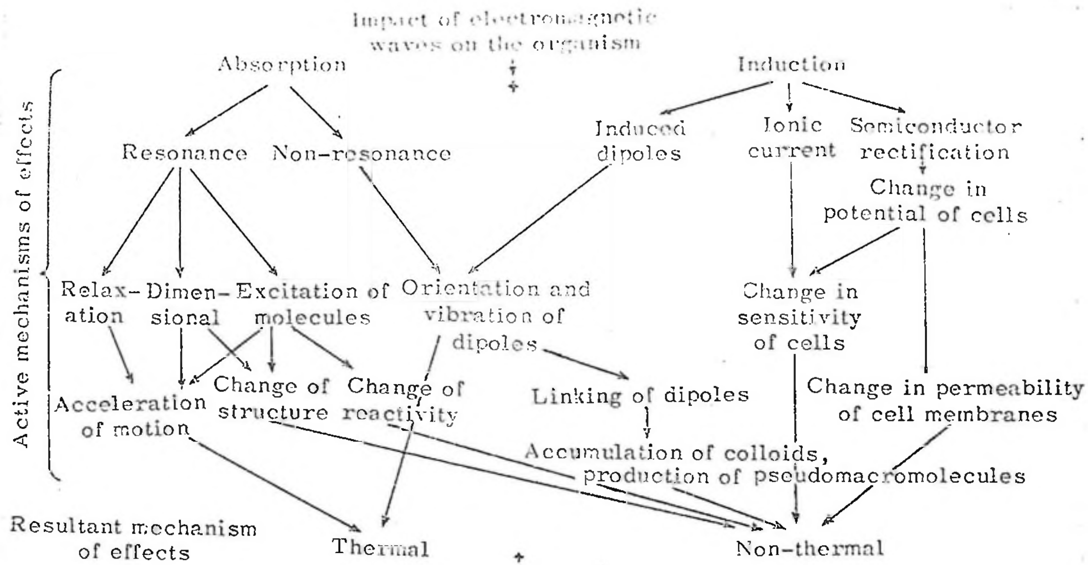
It was discovered in the USSR that irradiation of tars with an H.F. field reduces their cancerogenic activity as much as 95%; the investigators propose that this method be applied in industry [45]. /52

The increased number of experimental studied has led to the development of a methodology for irradiating test objects with both cm waves [195-197] and low frequencies [142]. If, at the same time that the test object is being irradiated, we also measure some of its characteristics (especially the electrical values) and use electronic equipment in the experiments, it is necessary to watch out for any possible influence of the results of induced H.F. currents on the parts of the measurement apparatus.

Biological effects are studied not only by physiological and biochemical methods, but also by modern methods of physics (for exa ple, nuclear magnetic resonance and electron spin resonance).

4.4. Mechanism of Effects

There is no uniform explanation for the resultant mechanism of the effects of electromagnetic waves. The reason for this is that there may be a whole series of independent primary mechanisms, some of which may be acting jointly at any one time on a given parameter. The complexity of the resultant effects of electromagnetic waves on the organism is best shown by Table 4. With changes in the field parameters, the character of the individual acting processes can change substantially [166,202,205,283]. We have already mentioned that there are two kinds of effects, thermal and non-thermal. There is no sharp dividing line between them, however. This stems from the nonuniformity of views on the scope of the concept of "non-thermal effects" (frequently labelled as specific). The majority of authors understand this concept to mean the effect of electromagnetic waves of a field intensity so low that they do not produce a significant increase in the temperature of an irradiated object. Of course, this is a highly unobjective definition and does not provide any explanation of the basis of the phenomenon. The thermal effect is produced by the increased heat in the system (or part of it) with increased molecular


Impact of electromagnetic waves on the organism
Absorption
Induction
Resonance
Non-resonance
Induced dipoles
Ionic current
Semiconductor rectification
Change in potential of cells
Active mechanisms of effects
Relax-ation
Dimen-sional
Excitation of molecules
Orientation and vibration of dipoles
Change in sensitivity of cells
Acceleration of motion
Change of structure
Change of reactivity
Linking of dipoles
Change in permeability of cell membranes
Accumulation of colloids, production of pseudomacromolecules
Resultant mechanism of effects
Thermal
Non-thermal

... influence of impact and friction.

It is much more accurate to consider non-thermal, those effects which stem from the primary non-thermal (not involving motion) mechanisms of the effects of electromagnetic waves on an irradiated system, without regard for the field intensity. Because the electrically charged particles (or ions), molecules with a dipole, or colloidal particles are always in motion in an alternating field, and because ionic and colloidal solutions including molecules with dipoles are a necessary part of a biological system (primarily water, but also organic compounds, such as amino acids), it is never possible in such systems to separate a thermal effect from a non-thermal one.

Under suitable conditions (conductivity, dielectric constant, frequency, ... nature of the field), and with specific features of the organism, the non-thermal effect can definitely dominate the thermal one and thus be the biologically effective factor. At the present time, the actual mechanisms of the non-thermal effects of an electromagnetic field are the focus of considerable research. /54

When H.F. energy strikes the surface of a body, some is reflected and some penetrates to be absorbed. The reflection is dependent on the electrical characteristics of the tissue which the H.F. field strikes. As the radiation passes through the tissue, its wavelength changes because there is a change in its rate of propagation, which depends on the dielectric constant and the conductivity of the medium.

If a dipole is located in the electrical field, this will cause it to orient itself. If the field is alternating, the dipole will begin to vibrate in rhythm with the frequency of the field. The greater the dipole moment of the dipole, the greater the energy required for its vibration. The result is an increase in temperature. In fact, an increase in frequency also results, for the rate of vibration of the molecules with dipoles increases and the losses produced by friction likewise increase.

The power thus consumed per unit volume (W/cm^3) is given by the following equation [247]:

$$N_0 = 0{,}556 \, . \, f \, . \, E^2 \varepsilon_r \tan \delta \qquad (4.1)$$

where ε_r is the average dielectric constant of the tissue, $\tan \delta$ is its loss factor, f is the field frequency in MHz, and E is its gradient in kV/cm. Hence, the heat (and therefore the thermal effect) increases with the frequency and intensity of the field.

Practical experiments with animals have shown, however, that because of thermoregulation the frequency dependence is not so pronounced and shows up distinctly only at high field intensities [152].

Mention should be made at this point of another way in which H.F. waves enter the organism. This second pathway is called "electromagnetic induction".

An H.F. voltage is induced in conductors located in an electromagnetic field. This voltage (with certain losses) can then be carried by the conductor to locations where the electromagnetic field itself does not exist. The losses produced in a unit length of the circuit are dependent primarily on the resistance of the conductor, the immediate environment around the conductor, and the frequency of the H.F. current flowing through the conductor. This is true for a conductor of the first order.

The electromagnetic field generates ionic currents in the organism. Lazarev has proposed the hypothesis [136] that the influence of the field increases the ion concentration in the vicinity of the cell membranes, which could result mainly in the accumulation of protein molecules (sometimes causing them to come out of solution). It is also noteworthy that a change in the ion concentration, if it is sufficiently great, causes a change in the biological characteristics of the cells. The action of the electrical field on the charge of the particles leads to their compulsory movement. This means that the order of the system is changed. If the field vanishes, the system requires a certain time to return to its original state. This interval is called the relaxation time, and depends on the size and charge of the particles, as well as the characteristics of the medium and the temperature, according to the relationship

$$\tau = \frac{Ra^2}{2kT} \quad (4.2)$$

where R is the coefficient of friction of the particles for a given set of conditions, a is the radius of the ionized atmosphere, k is Boltzman's constant, and T is the absolute temperature.

If the period of the field changes in accordance with relaxation of the particles, transfer takes place and the absorption of energy is at its maximum. The relaxation resonance now appears, at the frequency /55

$$f = \frac{12kT}{\eta a^3} \quad (4.3)$$

where η is the visconity of the medium.

Thus, for example, for water molecules which have a relaxation period on the order of 10^{-11} seconds at resting temperature, the absorption of energy reaches its maximum in the frequency range from 10^9 to 10^{11} Hz, corresponding to wavelengths of 30 cm to 3 mm [166]. Such absorption has been observed in experiments [220]. In the case of proteins, the relaxation time in an aqueous solution is on the order of 10^{-7} seconds, which means that the resonant absorption of energy lies in the range of frequencies on the order of 10^6 Hz. This agrees with the experimentally determined frequencies for the action of an H.F. field on the properties of gamma globulin, described by Bach et al. [9], although the authors do not mention this circumstance. It would then be possible to explain the selected frequency changes observed in the electrophoretic and antigenic properties of gamma globulin in terms of the influence of the H.F. field, as the destruction of the structure by the action of the relaxation absorption of energy, which in turn can lead to a shift in the reactivity of several functional groups in the molecule. An explanation of this sort also agrees with the temperature dependence of the effective frequency [cf. (4.3)], as the above authors have pointed out.

The spatial resonance of large molecules in the microwave region is closely related to the relaxation resonance. In evaluating a possibility of this kind (disputed by many authors), it is necessary to appreciate the nature of the relationship between the wavelength and the frequency of the electromagnetic waves in a given medium.

We have already mentioned in Chapter 2 that the wave length is largely dependent on the dielectric constant and the conductivity of the medium, but indirectly. It has been determined that some systems, among which it is necessary to include ionic conduction, have an enormously high dielectric constant, running up to many thousands [1]. We can therefore assume that in such a medium, microwaves can have a wavelength comparable to the size of the macromolecules. We can then assume the possibility of a direct spatial resonance of the molecules, which theoretically can lead to mechanical deformation or damage [166].

Direct damage to molecules by resonance phenomena seems to be highly unlikely, since a very intense field would be required.

It is possible, however, to excite molecules by the absorption of a quantum of energy [195]. This increases the potential energy of the molecules. A return to the unexcited state can take place either by transfer of the energy to another, unexcited molecule (which leads to an increase in the latter's motion, and therefore to a thermal effect), by radiation of the energy, or (finally) by the reorganization of certain parts of the molecule. The latter form of energy loss leads to a change in at least some of the characteristics of the molecule.

This type of absorption of electromagnetic waves in the non-ionizing portion of the spectrum is known, as we have said, in ammonia (for example), where there are 12 frequencies in the range from 2 to 4 GHz (i.e., λ = 15 to 7.5 cm) at which molecules can be excited. Radiation of energy leads to a reversal of the tetrahedral structure of the NH_3 molecule.

One more fact remains to be considered. Excited molecules /56 very readily participate in a number of chemical reactions such as oxidation, fission, etc. This phenomenon occurs in the range of wavelengths on the order of 0.1 mm.

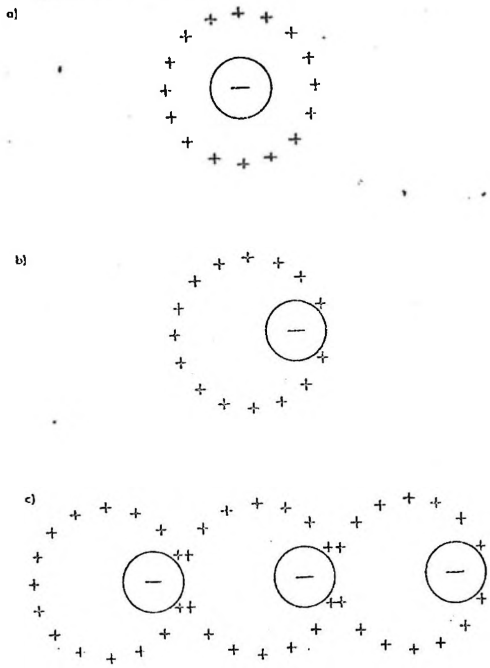


Fig. 26. (a) A Negatively Charged Particle (-), Together With One That has Two Electrical Charges (+), Forms an Electrically Neutral Whole. (b) An Induced Dipole Which Arises When a Charged Particle Enters an Electrical Field. (c) Linking of Oriented Dipoles in the Direction of an Electrical Field.

Mention has already been made of the orientation of molecules with dipoles in an electrical field. This takes place as the result of the attraction between unlike electrical charges and repulsion between like charges. In the case of large molecules with dipoles (for example, proteins), as the frequency rises (above the relaxation frequency), their oscillation in the rhythm of the field becomes increasingly more difficult; above a certain frequency, they come to rest in some fixed average position. This will depend primarily on the shape of the molecule and the distribution of the charge. However, because the charge distribution of the dipole cannot be considered fixed at a certain exact place, there will be a "charge cloud" moving about the molecule at the oscillation frequency. This can also lead to changes in the reactivity at the corresponding centers of the molecules.

The concept of the "resonance theory" also includes the interesting ideas in regard to the biological effect of electromagnetic waves, referred to as a non-thermal effect in the cyclotron resonance of several notable varieties of molecules in the organism [257]. Here it is mainly a combination of the electromagnetic field with the magnetic field of the earth. This idea is still purely speculative, without any kind of experimental foundation. /57

The particle charge (ionic or colloidal), under certain conditions, forms around itself an electrical double layer, composed of ions with opposite charges. The result is a whole which appears electrically neutral from outside (Fig. 20a). The electrical field then contains a nucleus (i.e., the original charged particle) and a double layer, each part of which is drawn with a certain force in opposite directions, giving rise to an induced dipole which is a priori oriented in the direction of the electrical lines of force of the field (Fig. 20b). It is generally known that the greater the field intensity, the more pronounced the differential between the two charges in the dipole. In the event of a chance encounter between dipoles oriented in this manner, there is an attraction between their free ends that leads to linking of the particles (Fig. 20c). This phenomenon, known in colloids for a long time [131,177], has recently received considerable attention again [257, 268] precisely because of the effect of H.F. fields on the organism. It also appears that it may be possible in this way to explain (albeit partially) the recently discovered genetic changes evoked by high-frequency electromagnetic fields [94].

The chain formation of colloidal (and coarsely dispersed) particles, unlike all previously suggested mechanisms, can explain certain effects of biological agents at low frequencies. The effect described has been verified experimentally in the frequency band from 0 to 100 MHz [257].

A careful study of this phenomenon leads to the idea that it may be possible to have chain formation not only of colloidal particles, but of molecules as well. This could lead to the creation of some pseudomacromolecules, whose presence would be revealed by a change in the response of the organism. Thus, for example, if there is chain formation by the ions or molecules which normally are capable of transport through semipermeable membranes, this sort of process is retarded or even prevented as the length of the chains increases. From outside, this phenomenon can then appear as though there had been a change in the permeability of the membrane, as one can actually conclude from some experimental reports [280].

The permeability of a membrane can actually be changed under the influence of an H.F. field on the basis of a shift in polarization, which can also produce purely electrical phenomena as are described later on in this chapter. All theories proposed thus far have certain shortcomings. They are unable, among other things, to explain the oscillation of the effects, such as occur (for example) in the change of sensitivity of nerve cells (shifts under certain circumstances first toward the positive and then toward the negative).

Phenomena of this kind can also be explained by a change in the electrical characteristics of nerve cells [152,153].

Many parts of the organism can be assigned to the category of semiconductors on the basis of their electrical characteristics. From this point of view, the factor of primary importance is their asymmetrically nonlinear volt-ampere characteristic curve, which represents current as a function of voltage (Fig. 21). In some cases, even in a certain part of this characteristic curve, an increase in current does not correspond to an increase in voltage, but to a drop instead. In such cases we say that we have a region of negative resistance (segment A in Fig. 22). /58

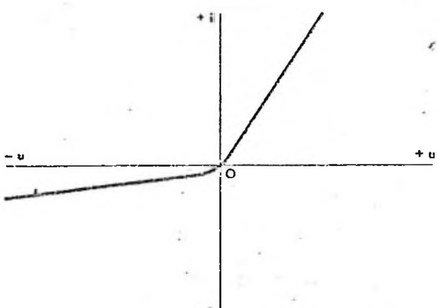


Fig. 21. Typical Case of Asymmetrically Nonlinear Volt-Ampere Characteristic Curve.

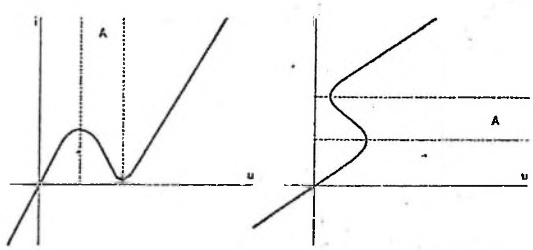


Fig. 22. Volt-Ampere Characteristic Curve With a Region of Negative Resistance (A).

A common feature of all systems with an asymmetrically nonlinear characteristic curve is that when an alternating signal is fed to them, it causes their asymmetric distortion and the production of a d.c. voltage. It is used to detect an a.c. signal. All semiconductors have this property.

It has recently been found that a great many organic compounds have semiconductor properties [109]. Many of them occur in organisms (for example, hemoglobin, desoxyribonucleic acid, etc.). /59
Finally, it has been established that nerve fibers and many other cells behave like nonlinear elements [32,84,85], sometimes with a region of negative resistance [146]. At a certain value of the potential (the so-called working point) and a definite amplitude of the alternating signal, asymmetric distortion can result.

The biologically important semiconducting systems can now be divided into three groups:

(a) Direct, i.e., with electronic conductivity;

(b) Indirect, i.e., with ionic conductivity, and

(c) Mixed.

The direct semiconductors are those systems where the nonlinear element is actually one molecule or group of similar molecules (a polymer). In these semiconductors, the nonlinearity has a conductive nature, and such a semiconductor (either by itself or doped with majority charge carriers) is an asymmetrically nonlinear element simply because its resistance in a certain region of the imposed voltage depends on the direction in which the current is flowing. This group includes all organic semi-conductors, whose semiconductor characteristics are produced by the arrangement of the molecule, mainly the π electrons.

The conductivity in such materials is of the electronic variety.

There is still another group of nonlinear elements, in which ionic conductivity prevails.

If a polarizable element is irradiated in such a system, the passage of an a.c. current (with organized movement of the ions) will lead to the production of a polarization potential, which will affect the volt-ampere characteristic curve of the system. In the case of a cell, the membrane acts as this kind of polarized element. If it is not a charge carrier in and of itself, the system of the form solution-membrane-solution (assuming similar compositions of both solutions and structural symmetry of the membrane) will have the highest symmetrically nonlinear volt-ampere characteristic curve. If the system also contains a source of potential (this can be, for example, the structural polarization of the membrane or unequal concentrations of some ion on either side of the membrane), the working point of the system is displaced so that the symmetry of the volt-ampere characteristic curve is disturbed. This produces asymmetrically nonlinear resistance with powers of rectification and a characteristic curve similar to that of a semiconductor.

As we have already seen, asymmetrically nonlinear resistances distort an alternating signal so that a d.c. component appears, i.e., rectification takes place. In direct semiconductors, the rectification effect is produced by different conductivity, dependent on the direction of the current; in indirect semiconductors, on the other hand, the rectification effect is produced by the polarization potential of the system; here the distortion can be thought of as adding to (or subtracting from) the potential of the system, the instantaneous voltage of the alternating signal (according to the polarity of the half-wave). Due to the lack of symmetry, the result is an alternating current with positive or negative sign, which changes the polarization potential of the membrane. In reality, both of these factors can combine, so that a group of mixed semiconductors is the result. We know that from /60 the physiological standpoint, living cells have an electrical charge. Under its influence, there is no linking of ions or amphoteric compounds such as proteins, either within a cell or in the immediate external environment of a cell membrane.

If the potential of a cell changes, its microstructure changes as well; the cell is no longer in the physiological state which one would expect on the basis of its characteristics. If it is a controlling cell (nerve cell), the activity of other cells in the organism may be affected as well. The greater the change in the characteristics of the cell relative to normal, the more pronounced the shift from equilibrium, and the greater the influence on the entire state and behavior of the organism. The influence of the actual degree of the change in potential on the behavior of the cell usually is expressed in terms of the position of the working point. This is most dramatically evident in the case of nerve cells.

Similarly, we can say that the organism as a whole (i.e., every cell) has the ability to maintain its equilibrium to a certain degree, subject to interference both from without and within. However, this ability is limited partly by the time factor, i.e., the organism can defend itself for only a certain period of time, and partly by the degree of deviation from equilibrium. The time factor is an inversely proportional quantity, i.e., the greater the disturbance of equilibrium, the shorter the period of time during which the organism can cope with this abnormal state. It should also be mentioned in this regard that the mutual relationships are nonlinear.

In view of the fact that even relatively small functional units of the organism are composed of a multitude of cells, in which we can expect qualitatively different electrical characteristics, the resultant volt-ampere characteristic curve of such a unit can have a shape which produces a different charge in potential (or sign), depending on the magnitude of the incident a.c. signals. A more detailed discussion of this matter would exceed the scope of this book, and interested readers are herewith referred to the literature [153].

On the basis of all existing theories, the effect of H.F. fields on the organism can take the form of a change in the arrangement of a number of molecules both inside and outside the cell; we can also expect an influence on the passage of molecules through the cell membranes. There is no splitting of molecules and consequent production of new substances foreign to the organism, as confirmed by experimental data.

Also in accord with these findings is the known reversibility of signs of damage (obviously, this is true only to a certain degree, provided the entire organism is not destroyed, or at least a part of it). Because the circulatory and nervous systems are the most conductive parts of the organism, the H.F. current is maximum along these pathways (produced by induction and conduction). It is also necessary to keep in mind the maximum possible changes in tissues, whose cells undergo maximum asymmetric distortion and are sensitive to deviations from the normal state of affairs. It is likely that this is particularly true of the cells in the nervous system. The mechanism described earlier can change both the characteristics and behavior of a cell, but since we are talking about control cells, these changes are evidenced in the organ which is controlled. Thus far, there have been no reports whose results could be interpreted as contradicting these hypotheses. On the contrary, many papers present data which both directly and indirectly support these ideas.

Thus, Rejzin [142] for example, found that an H.F. field can have an effect on a neuromuscular preparation and on the irradiated area as well. This has been ascribed to the so-called "diffuse field" of the tissue, which is nothing more than that. The powerful electromagnetic induction along conductive pathways in the organism has recently been put to use for measuring blood flow [271]. Induction and conduction can be demonstrated by a simple experiment, in which the head of a rat is placed in the field of an H.F. generator. The field is so strong (1 MHz, for example) that a flow can be seen. The lengthwise axis of the body of the experimental animal is aligned with the propagation direction of the field, so that the tail is in a very weak field and cannot be injured by the field. Under the influence of conduction, a glow appears at the tip of the tail. /61

According to Tarusov, the semiconductor nature of a cell, suggested by theory, can be judged (for example) on the basis of conductivity during the resting state [254]. This is also in agreement with the finding that the thermal coefficient of resistance of tissue is always negative, which is one of the characteristic features of a semiconductor. When an H.F. field is allowed to act on a neuromuscular preparation, the cathod excitation is increased and the anode excitation is decreased. This is indicative of a change in the charge on the cell in an H.F. field, in the light of the theory described above. The change in the charge in such a field can be readily measured. In accordance with the experiments cited above, an H.F. field affects the electrical negativity of a nerve [142]. This work has evidently fallen into obscurity, for suggestions are just now being made that an organism (i.e., parts of it) can function as a detector of electromagnetic waves [202,279].

Finally, measurements have provided the actual volt-ampere characteristic curves of living cells [178], which have the appearance of the characteristic curves of classical semiconductors: they are asymmetrically nonlinear, often with a region of negative resistance.

Mention should also be made of some conclusions which stem from the theories proposed regarding the mechanism of the biological effect of H.F. fields. It has been said that a change in the charge on a nerve cell is of the highest consequence for the entire organism, since it changes its physiological state and its controlling function as well. Of course, the effect of the H.F. field on the organism depends on the state of the central nervous system, as was pointed out long ago [142,208]. The threshold level of the H.F. field will differ for stimulation and inhibition of the C.N.S. Experiments in which rats were given a psychotone are in perfect agreement on this point, but the field intensity required to kill the experimental animals was significantly less.

On the other hand, it was found that the H.F. field energy required to produce uniform damage to the organism is much greater when the animal is under the influence of a narcotic. The effect of such substances, which have both stimulatory and inhibitory actions on the C.N.S., may be thought of as a shift in the working point on the characteristic curve of the cell, or as a change in the ability to transmit control signals to the organism. It might be assumed in fact that all other factors affecting the parameters of the compensatory system of the cell not only can weaken or intensity the effect of electromagnetic waves, but can even influence the functional capacity of the cell. Such a combination factor must take the form not only of the effect of certain chemical substances, but also of physical factors, as well as changes produced by regressive structures in the organism due to influences of a psychic nature.

At this point, a comparison is in order between the cancerogenic effect of certain chemical substances and their structure. /62
All of these substances have π - electrons in their molecules; these electrons are closely related to the semiconductor properties

of the molecules [54]. The question then arises as to whether the semiconductor nature of these substances plays an important role in their cancerogenic effect, and whether this effect is intensified or attenuated by the presence of an electromagnetic field.

In the case of nonlinear elements, the modulated signal can be detected, so that low-frequency detection can occur. Thus, we can explain Freye's observation which mentions the ability in persons (including the deaf!) to "hear" an amplifier operating with pulsed modulation [70,71].

The most interesting (and from the biological standpoint, most important) conclusions can be drawn in the case of cells whose volt-ampere characteristic curve has a region of negative resistance. Hence, when the working point is in the proper position (i.e., the physiological state is normal) and is located near the peak of the characteristic curve (cf. Fig. 22), it produces a stimulus of similiar amplitude and direction, with a sudden shift in the working point, so that when this stimulus dies out the cell cannot return to its original state, but neither can it remain (so to speak) "stimulated". In other words, we can determine from such a characteristic curve that if we increase the amplitude of the stimulus from zero gradually, we will find the absolute threshold of the effect. If we reduce the stimulus from a high amplitude, it will cease to be effective at another, usually lower, threshold value.

Presman has published a hypothesis [203] which holds that there are certain processes in living organisms at all levels of existence (from the molecular to the systemic) which are initiated by internal and external electromagnetic fields. Electrical fields are undoubtedly an important factor in the control of physiological processes in organisms, as Bassett [13] has recently demonstrated for bone growth. Naturally, these phenomena are not so simple as may have been indicated. In addition, one must keep in mind that these ideas are of a predominantly speculative nature. This should not detract in any way from their significance, however, because they are very useful in further study. A more detailed discussion of these interesting problems would, alas, go beyond the scope of this book.

5. OCCURRENCE AND USE OF ELECTROMAGNETIC ENERGY

5.1 Survey of the Commonest Sources of Electromagnetic Waves

The steady development of industry is very closely linked to the development of radio and electronic technology. The most diverse applications have been found for the various forms of wireless communication (telegraph, telephone, television), the transmission of still pictures by radio (radiograms), detection and determination of the position of various objects and their distances (radar, radio rangefinding), remote control of mechanisms (radio telemechanics), long-range transmission of measurement data (radio-telemetry), as well as radionavigation, radioastronomy, radiometeorology, radiospectroscopy, uses in nuclear physics, medicine, etc. Radio waves are also widely employed in industry. Their uses include the production of heat through the absorption or induction of electromagnetic waves in various materials. In all these cases, the generation of H.F. electromagnetic energy is either an end in itself or serves as a tool for further applications. In general, the source of the H.F. fields by which a person is irradiated need not be an artificial generator: natural sources can play an important role as well. Thus, for example, pulsed electromagnetic waves arise primarily ahead of a cold front or before a storm. The following brief example will show that this is not an unimportant factor in the environment. It is estimated that about 1800 storms are taking place on earth at any one time. This means there will be, let us say, 20 flashes of lightning each second, whose average power is 10^{12}W. If this power were distributed uniformly over the entire surface of the earth, about 2kW of radiated power would strike every square kilometer. Measurements have shown that the intensity of a field at a distance of 20 km ahead of a cold front can be as high as 150 V/m. /63

Obviously, the number of H.F. and V.H.F. generators within the territory of the CSSR today is considerable. If we examine only the incomplete data which were available at the end of 1963, the total installed H.F. power (not counting radar installations), will be found to amount to more than 10 MW [170]. Even at that time, there were in operation in the CSSR more than 50 types of H.F. industrial generators with a total number of units in the thousands, located in dozens of factories and workshops. Generators for dielectric heating were in the majority. In view of subsequent developments, it is obvious that these figures have been exceeded by now and can serve only for orientation.

5.2 Use of Electromagnetic Energy in Various Ranges, Medical Frequencies and Currents.

In order to obtain a better idea of the uses of electromagnetic energy, it will be valuable to review in some detail a few of their applications, placing emphasis on the most common types and the applications to which they are put. /64

Sources and generators of electromagnetic waves can be divided into two basic groups according to the frequency, i.e., H.F. and V.H.F. generators. The H.F. group contains most of the industrial generators as well as long-wave, medium-wave, short-wave, V.S.W. and television transmitters (communications transmitters); the V.H.F. group consists mainly of radars, several types of generators for dielectric heating, and generators for microdiathermy.

H.F. industrial generators are divided into dielectric and induction types. Although dielectric heating is a new field, it is already outstripping (in terms of the number of units installed) induction heating in spite of the fact that its merits have thus far not been fully exploited [247]. A source of a.c. electrical field is employed for heating, so that it is mainly a matter of voltage. The sources are mainly electronic generators with a frequency range usually extending from 10 to 30 MHz. Effective dielectric heating assumes certain minimal dielectric losses at a given frequency (given by the loss factor $\tan\delta$ and the relative dielectric constant ε_r of the material), although it itself cannot be the sole measure of the suitability of a material (matters of shape, size and the like). Dielectric heating is now the preferred method although it cannot be used to solve all problems or to heat all nonconducting materials. Hence, it is customarily used in processes that would otherwise be unfeasible, primarily in the automation of production. Dielectric heating is widely used in the CSSR in the synthetic materials industry, especially in the production of molded bakelite and plastics. It is also employed for high-frequency gluing and drying of wood and other materials, curing foundry cores and cast resins, and preheating grinding mixtures. Dielectric heating can be employed in a number of other fields as well, such as textiles, ceramics, glassmaking, papermaking, and the food industry. As mentioned earlier, heat is produced in the material by means of an electrical field between the working electrodes or in some kind of capacitor. Selection of the proper electrodes depends primarily on the size, shape, and type of material; their design generally is determined by the type of heating (general or selective etc.) The electrodes are usually made of copper, aluminum, brass, or duralumin; they can be either contact electrodes (completing the circuit simultaneously) or can have an air gap (the material is free to move). The arrangement of the equipment can be such that the working electrodes are mounted in the same unit with the generator, or are located in a working unit outside the main generator housing. The following description will provide a good idea of some of the types of equipment.

The GUR 2K high-frequency dielectric preheater (Fig. 23)[6] is /65

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6 Figures 23 to 37 were provided by the Electrothermal Equipment Factory.

intended for direct dielectric heating (such as is required for drying materials), which takes place inside the cabinet. The built-in generator operates at a frequency of 27.12 MHz with an H.F. power of 2 kW (adjustable). The entire operating cycle is automatic; only an initial impulse must be provided by a push-button. Likewise, the drawer of the preheating chamber opens automatically when heating is complete.

Fig. 23: GUR 2K Generator for Dielectric Heating.

Fig. 24: GU 6B Generator for Dielectric Heating.

The GU 6B high-frequency dielectric preheater (Fig. 24) has a similar purpose. Here again, the source is built in and operates at a frequency of 20 MHz with a maximum H.F. power of 4 kW (also adjustable). The heating interval can be set with a timer.

The GU 7B high-frequency thermionic source serves as a unit which can supply H.F. energy for various pieces of working equipment, mainly in the woodworking industry, where it is used to cure glued joints. H.F. curing takes place in a suitable press, sometimes with the material clamped together. The connection between the generator and the working equipment is usually in the form of a coaxial cable. The main generator operates at a frequency of 17 MHz /66
with a maximum H.F. power of 4 kW (adjustable in 4 steps).

The EDS 4A high-frequency welding press (Fig. 25) is used for joining thermoplastic materials, mainly PVC in its numerous industrial forms. The device is equipped with a built-in thermionic H.F. generator; the welding cycle is completely automatic (the heating and cooling intervals are controlled by a timer). The built-in generator operates at a frequency of 27.12 MHz with a maximum H.F. power of 500 W (adjustable). The movable upper electrode is controlled either by an electrohydraulic device and a push-button, or by a foot pedal, depending on the model. The generator shuts off automatically when the weld is complete.

Fig. 25: EDS 4A Generator for Dielectric Heating

The EDL 1 high-frequency welding press is also intended for joining thermoplastic materials. It is designed as an independent unit with multiple uses. It is equipped with a built-in generator operating at a frequency of 27.12 MHz with an H.F. power of 2 kW (coarse and fine adjustments are possible). The welding cycle is completely automatic and controlled by a timer and microswitch. The movement of the upper electrode and the welding pressure are controlled hydraulically. The lower electride can be adjusted to shift the support prior to the welding cycle in order to facilitate preparation for the weld.

The CUR 4 high-frequency dielectric generator is used as a unit which supplies H.F. energy for various pieces of working equipment. It operates at a frequency of 27.12 MHz with a maximum H.F. power of 4 kW, and has both coarse and fine adjustments. /67
For welding thermoplastic materials, the EDL 4 welding press is connected to the GUR 4 by means of a coaxial cable. In this instance too, the welding cycle is completely automatic (as in the EDL 1). The welding pressure, time, and thickness of the weld can be set and regulated on the device. The press can be equipped with an attachment, the S4 two-position automatic adjustable table, which allows easier preparation of the material to be welded and shortens the handling time in assembly-line production. The entire welding set-up, consisting of the CUR 4, EDL 4, and S 4, is shown in Fig. 26.

Fig. 26: Combination of GUR 4 Generator and Attachments EDL 4 and S 4.

The CU-25 high-frequency thermionic source is also an independent unit intended for supplying H.F. energy for various working equipment using dielectric heating. It operates on a frequency of 13 MHz with an H.F. power of 25 kW (coarse adjustment is possible). Inasmuch as it is used primarily for drying, an open-ended dryer (the EDV 2) was built for this purpose. The high-frequency supply to the dryer passes through a coaxial cable. The usual materials treated in the dryer include textiles, wood, foam rubber, and other mineral or organic substances. The material to be dried moves on an aluminum chain conveyor through the H.F. field, between two charged electrodes whose gap is adjustable. The dryer is provided with an exhaust fan. The controls for the entire dryer are mounted on a single panel.

The high-frequency industrial equipment for continuous dielectric heating and drying (Model GUR 100) is used for similar purposes. In order to increase the capacity several fold, several GUR 100 units can be combined to form a production line with a common conveyor. One complete H.F. unit consists of an H.F. generator which operates at a frequency of 18 to 20 MHz with an H.F. power of 100 kW. Regulation of the H.F. power and the speed of the belt is continuous. The equipment is remote-controlled.

The GU 02 portable H.F. source, with hand-operated tongs EDR 1 (Fig. 27), is used in the packaging industry, in installing build- /68
ing insulation, and occasionally for making fine welds in various other fields. The generator operates at a frequency of 27.12 MHz with a maximum H.F. power of 180 W. It is connected to the tongs by a flexible coaxial cable. The welding tongs are made in the shape of a pistol: the upper electrode is fixed, the lower one is spring-loaded. The source itself can be used for other purposes in conjunction with the proper working equipment.

Fig. 27: GU 02 Portable Generator with EDR 1 Manual Tongs.

Induction heating uses sources of alternating magnetic fields to heat conductors [247]. In contrast to dielectric heating, current is involved here. The frequencies of the generators used for induction heating are much lower (usually 300 to 500 kHz). This depends mainly on the so-called depth of penetration of the H.F. current which increases with a drop in frequency. The conventional frequencies given above are suitable for superficial heating, especially of objects that are thin-walled, have rough surfaces, or a small area.

It should be mentioned that, in general, the depth of penetration does not always have to be fixed. As long as the period of heating is sufficient for the absorption of the heat in the material, only the amount of energy applied is necessary. For this reason, it is necessary to combine properly the values of frequency and power. Induction heating is relatively widely used in the CSSR for tempering, annealing, brazing, and sealing metal and glass. There are also many applications in molding and machining,

chemical processes, drying painted metal parts, heating powdered materials, heating non-conductors with a heating circuit made of metal parts, etc. We have already mentioned that an alternating /69
magnetic field is employed in induction heating. Induced currents which penetrate the surface layer are produced in conducting objects placed in the heating drawer. The path of these induced currents has a certain active resistance, so that the heat is proportional to the square of the local current density. Between the heated surface layer and the cold interior, there is a temperature differential which causes loss of heat to the interior. The choice of a suitable inductor depends primarily on the type of operation for which it is intended, in other words, each inductor (in principle) has one application. From this it is clear that there is a vast number of varieties and types, which can be divided into four main groups: inductors moving around the outside of an object, inductors applied to the surface, inductors applied to a cavity, and finally inductors fitted only to a part of an object. Of course, it is clear that there can be combinations of the groups. The inductors are usually made of copper; however, in view of the high current levels, they are cooled by running water (inside the inductor), air, spraying, or partial submersion. As in the case of /70
induction heating, equipment is used in which the inductor forms a single unit with the main generator, or the latter component is connected to various attachments. A description of several types is provided below for the reader's information.

Fig. 28: GV 6A Generator for Induction Heating

The GV6 A generator (Fig. 28) is designed for induction surface heating of metal objects or other electrically conductive objects, as well as for zone refining. It is also suitable for annealing the internal parts of vacuum tubes during evacuation, for brazing small parts, etc. The maximum H.F. power of the generator is 4 kW (adjustable in 4 steps), with a working frequency of 3 to 4.5 MHz. The parts to be heated are placed directly in the heating inductor, held in a clamp in the upper part of the generator. For zone refining (of germanium, indium, aluminum, antimony, gallium, tin, etc), the EZK 2 semiautomatic attachment can be connected to the generator by a coaxial cable. The device is operated in a horizontal position, while the actual zone formation takes place in a protective atmosphere (reduction or inert). A characteristic feature is that the more mobile the heating elements, the more the material retains its division into zones during refining. The EZK 1 vertical instrument (Fig. 29) is connected to the GV6A generator for suspended zone refining of silica.

The type GV 10 generator can also be used for zone refining (maximum power = 10 kW, frequency = 3 to 4 MHz). A setup with an EZK 3 horizontal attachment is shown in Figure 30 (it is quite obviously equipped with a shielded cable).

The GV 21 high-frequency generator is suitable for various kinds of thermal processing, especially for surface and local tempering, hardening, brazing, annealing, smelting, forging, and the like. In the case of small diameters, the material can be completely heated through. The generator operates at a frequency of 0.45 MHz with a maximum H.F. power of 30 kW (again, there are both coarse and fine adjustments). The parts to be heated are placed directly in the heating inductor, fastened to a clamp on the H.F. transformer on the front wall of the generator, or (in various attachments) connected to the generator. Of the mass-produced attachments, some in particular are intended for connection to the GV 21 generator: for example, the universal semiautomatic tempering machine EKS 30 (Fig. 31) is used for various kinds of tempering of structural components, and occasionally for brazing and annealing. Following initial adjustment of the device, the main operating cycle is controlled automatically and the operator is required only to exchange the parts. The device is connected to a generator by a coaxial cable; the R4A vertical automatic tempering machine is intended for series and individual tempering of gears, pins, cams, and other machine parts. In this device, too, the entire operating cycle is completely automatic; the UKS 2 universal turret semiautomatic tempering machine is intended for bulk, surface or local tempering of small to medium-sized parts, although it can also be used for annealing or brazing. After loading the supply bin, the operator in some cases can allow the machine to run through the operating cycle completely automatically.

The GV 201 high-frequency generator is used for surface or local tempering, drawing, brazing, annealing, smelting, preheating, forging or shaping. It operates at a frequency of 0.45 MHz, with a maximum H.F. power of 85 kW, with coarse and fine adjustment. The GV 201 generator takes (in addition to the attachments which fit the GV 21 [EKS 30, R4A, UKS 2]) several other mass-produced attachments, of which the following are the most important: The P1 semiautomatic tempering machine is intended for assembly-line surface tempering of parts, which can be passed through an inductor on one side. The P2 vertical semiautomatic tempering machine (Fig. 32) is intended for various kinds of induction heating of long machine parts. The operator is required only to exchange the material being tempered; the EKR 2 vertical semiautomatic tempering machine is intended for series and individual induction tempering of crankshaft parts for automobile and tractor engines. The entire operating

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Fig. 29: EZK 1 Attachment.

Fig. 30: Combination of GV 10 Generator and EZK 1 Attachment.

cycle is completely automatic. The EKR 3 horizontal tempering /72
machine (Fig. 33) is intended for series and individual induction tempering of main and connecting rods, often for the push rods in motors. The operating cycle is likewise automatic. The EKN 5 tempering machine (Fig. 34) is intended primarily for tempering gears, and occasionally for various types of pulleys; the EPH semiautomatic brazing machine is used for assembly-line brazing of laminations onto the shanks of lathe cutters. The machine has a turret-type layout, and practically the entire operating cycle is automatic. Its use in conjunction with the GV 201 generator is illustrated in Fig. 35.

In communications installations it is important to see that the main generator (or group of generators, on which there need not be imposed the condition of a uniform operating frequency) is usually located in a special place from which two-conductor or coaxial cables can carry the H.F. energy to an antenna, usually located outside the building (or on its roof). Similarly, in most cases the H.F. energy is also carried to so-called antenna equivalents (dummy antennas), generally located in the room. The amplifier cabinets (especially at the final stage) usually have a glass window to allow them to be monitored during operation. The duties of the operator consist primarily of adjusting, tuning and checking the functioning of the transmitter during operation. Transmitter

Fig. 31: EKS 30 Attachment.

Fig. 32: P2 Attachment. /73

Fig. 33: EKR 3 Attachment.

sites usually contain a separate, central control position, while the other parts of the building are occupied by the quarters of off-duty personnel (in cases where it is necessary to live at the transmitter site).

The operating frequencies run from tens of kHz to tens of MHz, often with provision for switching to a rather broad band. The H.F. power output varies from tens of W to hundreds of kW. The operating cycle, the type of operation, the purpose and type of transmitters and antennas come in a great many different varieties, and cannot be described in greater detail here.

Radars have found increasing applications in the CSSR, especially in recent years (this is true also for non-military applications), mainly in aircraft operations. This is understandable, since the steady growth of air traffic places heavy demands on its safety and ease.

A radar emits a narrow beam of electromagnetic waves into space. When the waves strike some object capable of reflecting them, part of the energy is reflected and picked up by the receiving

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Fig. 34: EKN 5 Attachment.

Fig. 35: Combination of GV 201 Generator and EPH-1 Attachment.

antenna of the radar (usually only one antenna is used for both transmission and reception, with automatic changeover). The radar does not emit electromagnetic waves continuously, but only in very short pulses. From the known rate of propagation of the waves and the time required for the reflected impulse to return, the distance to the object can be found. The successive recurrence of the pulses (repetition frequency) is set so that the individual pulses have time to return following reflection (even from a very distant object) before the next impulse is given. The distance is reckoned from an indication which is based on the same principle as the oscilloscope. Along with the distance, the device also displays (on other indicators, for example) the location of the antenna, so that information on both the range and location of the target can be obtained. /75

In addition to the pulse-type radars, steady-wave instruments are also used in radio rangefinding. They can operate either with an unmodulated wave (operation is based on the Doppler principle and has the disadvantage that it can be used only to track a moving target), or with a frequency-modulated wave.

The transmitted and reflected signals have different frequencies owing to the time shift; the difference is directly proportional to the distance to the reflecting object; this principle is suitable for altimetry. The pulse-type radar (models OR-2, RL-2D, and RP-2E) is the one most widely used in the CSSR.

The OR-2 long-range surveillance radar is intended for tracking the movement of aircraft along flight paths in the vicinity of an airport for distances up to 150 km [249]. It operates on a wavelength in the 10 cm band (frequencies from 2800 to 2900 MHz) with a pulsed H.F. power of 700 to 850 kW, and gives the range, azimuth, and direction of travel of the aircraft. The pulse width is 2μs, and the repetition frequency is 600 Hz. Most of the equipment is located in an antenna building at the airfield. In addition to the antenna system, the building houses the duplicate equipment for the transmitter and receiver, as well as the indicator unit for monitoring operations. The antenna systems turns at the rate of 0.5 to 1.0 rpm (with possible vector scanning through 30, 60, and 120°) with elevations from -5° to +15°; the beam width in the horizontal plane is 0.92°.

The RL-2D control radar is capable of tracking an aircraft until it comes within range of the landing radar, showing the range, azimuth and course. It also provides information on the meteorological situation in the vicinity of the airport. It operates on a wavelength in the 3 cm band (frequency from 9400 to 9600 MHz), with a pulsed H.F. power of 150 to 200 kW. The pulse width is 1 μsec, and the repetition frequency is 1 kHz. The main part of the equip- /76
ment (antenna system, the duplicate sets of equipment for transmission and reception with the monitoring indicator unit), as in the preceding type, are located in or on the antenna building. The antenna system rotates at 15 or 30 rpm, with elevations from -2° to +10°; the beam width in the horizontal plane is 0.7°.

The RP-2E landing radar operates on the principle of rapid mechanical sector scanning of the azimuth and elevation, with two identical and independent antennas, and makes it possible to bring an aircraft right down on the runway. It operates at a wavelength in the 3 cm band (frequency 9400-9600 MHz), with a pulsed H.F. power of 150 to 200 kW.

The pulse width is 0.5 μs, the repetition frequency is 2 kHz, the azimuth sector is 30° and the elevation sector is 10°. The antenna aperture angle in the horizontal plane is 0.8°, while in the vertical plane it is $\mathrm{cosec}^2\phi$ up to 25°. The majority of the equipment is again located in the antenna building, which in this case is generally underground (only the antenna system project above the surface).

The operation of antenna installations for Types RP-2E and RL-2D radars does not require a permanent crew (merely occasional maintenance and replacement of elements); the equipment is remote-controlled from a control tower [249].

Certain other types of radars are used in the CSSR in various types of civilian transport aircraft, and for marine navigation, radioastronomy, teaching purposes at colleges, measuring the speed of automobiles, etc.

In recent years, dielectric heating with V.H.F. has also begun to be used for certain applications. Thus, for example, the GU 2 MB ("Industron", Fig. 36) microwave preheater for laminating films is used for direct heating of film (material in loose and tablet form). The generator is an air-cooled magnetron which operates at a frequency of 2375 MHz and a power of 2 kW (adjustable in five steps). The heating interval is governed by a timer.

Another version of this device is the GU 2 MS electronic range (Fig. 37), which is designed for heating foods by means of microwaves. This machine allows modern and rapid preparation of foods without a loss of nutritional values and without overcooking in oil. The cooking times in the oven of the range vary from 20 seconds to 6 minutes. The generator is of the same variety as the preceding. Similar types of V.H.F. generators are used in agriculture (to dry grain, for example).

The PREMA Microdiatherm apparatus, Model 10 I4 [191], is used for microwave diathermy. It is intended for electrical treatment in laboratories for both therapeutic and experimental purposes. The generator is a magnetron which operates at a frequency of 2450 MHz with an H.F. power adjustable in eight steps from 50 to 210 W. The device is supplied with two attachments (circular and rectangular); the irradiation time is adjustable from 0 to 40 minutes. In Figure 38, the Microdiatherm is shown with the circular attachment in place.

This survey of the most important Czech-built equipment utilizing H.F. and V.H.F. energy is intended only as a brief outline. It is therefore understandable that the subject is far from exhausted; the scope of this book does not allow more complete coverage of the topic. It should be emphasized, however, that it is not possible in practice to forget the other, less well-known applications. In particular, it is necessary to emphasize the production or repair facilities for the generators where normal operation often subjects

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Fig. 36. GU 2 MB Generator for Microwave Dielectric Heating

Fig. 37. GU 2 MS Electronic Range

Fig. 38. "Microdiatherm" 10 I4, Generator for Medical Applications

the workers to conditions which are harmful in contrast to conditions in other factories. To a certain extent, this is the case for effects on research and development personnel, although there is no need for them to work with high-powered radiation. /78

5.3 Possible Sources of Harmful Burns

Aside from its possibly negative influence on the state of the health of man, there is no reason to believe that the use of H.F. and V.H.F. energy in the majority of cases is such an important contribution that it is (even for certain organizational and technical measures for protection of personnel) any more suitable and profitable than retention of the old principles of technology and production, and even daily activities. In the communications media, primarily radio and television, the sociopolitical function of the latter must be considered from this standpoint.

In order to make it possible to search for ways and means which serve to lower the level of the field to the necessary degree but still allow it to be used properly, it is necessary to know the possible sources of undesirable or harmful radiation.

All equipment containing an H.F. or V.H.F. generator has several parts which are or can be osurces of radiation and can contribute to a high level of field in a workplace. Most important is the generator itself, in which some of the radiation sources are the oscillator (in particular), i.e., the vacuum tubes and oscillator circuit, and (sometimes) the power amplifier or output H.F. transformer. Improper grounding cna result in undesirable radiation from the main mental housing of the generator. In the case of magnetrons, the cathode lead can radiate if it heats up. Another important element is the load, i.e., the part of the equipment which receives the energy which is produced. A distinction must be made here; there are loads in which radiation is a functional phenomenon (antennas), and there are others which are not supposed to radiate (the working elements of H.F. industrial generators, i.e., the inductance and plates of a capacitor, as well as the crystal in an ultrasonic generator and various kinds of artificial or equivalent loads, such as conductors, resistors, etc.). Another important element from the standpoint of radiation is the connecting cable which transmits energy from the generator to the load. If it is well made and maintained, it cannot radiate; unfortunately, these cases are quite a rare exception.

In general, then, the connecting cable is one of the biggest sources of undesirable radition. In the V.H.F. band, where coaxial cables and waveguides are used as the principal power leads, care must be taken to avoid undesirable radiation at connection points (flanges and connectors), not to mention the possibility of radiation from open ends, various slits, and around cell-type tubes.

A general summary of possible sources of radiation classified according to frequency ranges is given in Table 5 along with other data.

TABLE 5. GENERAL SUMMARY OF USES OF ELECTROMAGNETIC WAVES, RADIATION SOURCES, UNITS OF MEASUREMENT, MAXIMUM PERMISSIBLE DOSES, AND PROTECTIVE MEDIA

/79

Frequency	High Frequency (H.F.)	Very High Frequency (V.H.F.)
Used in industry, science and technology	1. Thermal processing of metal (tempering, smelting, soldering, etc.) 2. Thermal processing of dielectrics (drying wood, heating synthetic films, etc.) 3. Communications 4. Medicine	1. Radar 2. Radionavigation 3. Relay communication 4. Radioastronomy 5. Radiometeorology 6. Radiospectroscopy 7. Nuclear Physics 8. Communications, etc.
Radiation source	1. H.F. Transformer 2. Bypass capacitor 3. Connectors and power leads, antennas 4. Inductor or operating capacitor 5. Slits, slots, etc.	1. Antennas 2. Radiators 3. Individual blocks 4. Slots, etc.
Measurement units	Field Intensity E in V/m	Power Density N in $\mu W/cm^2$
Maximum permissible radiation level $E(V/m) \cdot t(hrs)$ or $N(\mu W/cm^2) \cdot t(hrs)$.	Operator (8 hrs or less) 80 Other personnel (24 hrs or less) 72 (30 kHz–30 MHz) 24 (30–300 MHz)	cw operation 200 pulsed operation 80 cw operation 60 pulsed operation 24
Protective media	1. Shielding of individual H.F. elements (a) Sheets or wires (b) Coaxial & supply cables etc. 2. Complete shielding of H.F. generator	1. Non-radiating load, protected ends 2. Shielding of compartment 3. Open shielding (a) Metal (b) Absorption covering 4. Protective goggles 5. Protective clothing

6. MAXIMUM ADMISSIBLE FIELD INTENSITY AND RADIATION AND THEIR DETERMINATION

6.1 Establishment of Maximum Admissible Radiation

From the standpoint of protecting personnel against the possible harmful effects of electromagnetic fields, it is necessary to determine the threshold values for the biologically effective field intensity. As far as the thermal effect is concerned, there is agreement on the fact that power densities from 10 to 15 mW/cm^2 suffice for warming the organism, in the case of both animals [55] and man [195, 279, 280], which is in agreement with theoretical calculations [238].

Generally speaking, values different from the above can be obtained in observing individual active influences. Thus, for example, an intensity of 10 mW/cm^2 is required to produce cataracts, 1 mW/cm^2 will alter the sensitivity of the auditory apparatus, and only 0.6 W/cm^2 will suffice to produce skin problems. In the cm wave region, however, power densities as low as 0.1 mW/cm^2 [125] will have biological consequences. Histopathological changes can be expected at frequencies below 100 V/m [82]. The entire organism is likely to suffer harmful effects when subjected to fields with intensities above 10 V/m [135]. Many processes are still more sensitive, especially cell division, which is accelerated at field intensities as low as 10^{-4} V/m; the rate of division decreases at frequencies above 0.1 V/m [120].

The total field intensity is not a sufficiently good measure of the threshold of effectiveness, however; there is definitely a time factor involved as well. The organism has an absolutely certain method of defense against hostile external influences. Its limit can be expressed by the relationship

$$K_n = f(N_n, t_n) \qquad (6.1)$$

This expression states that the measure of the ability of an organism to resist a given n is proportional to the quantitative value of that agent N_n (here we have an expression of the field intensity or power density) and to the period of its action t_n. If the value of the function on the right-hand side of (6.1) is smaller than the corresponding value of K_n, there will be no harmful effects on the organism.

There still remains the question of the value of the factor K for electromagnetic waves in man, and the form of the function f.

[illegible] demonstrated [100] that in the case of chemical [illegible] [illegible]ermal injury, and harful ionizing radiation, this function is given by the product of two variables. From the suggested analogy, for the influence of radio waves in the V.H.F. band, we can write

$$K_{VHF} = N'.t' \tag{6.2}$$

and in the H.F. band /81

$$K_{HF} = E'.t' \tag{6.3}$$

The primed values are maximum for preserving equality of both expressions, while $\underline{K}_{HF}$ and $\underline{K}_{VHF}$ represent the maximum admissible radiation in those ranges.

The product of the actual field intensity and the period of action is then called the irradiation $\underline{O}$. For cm waves, for example, we will have

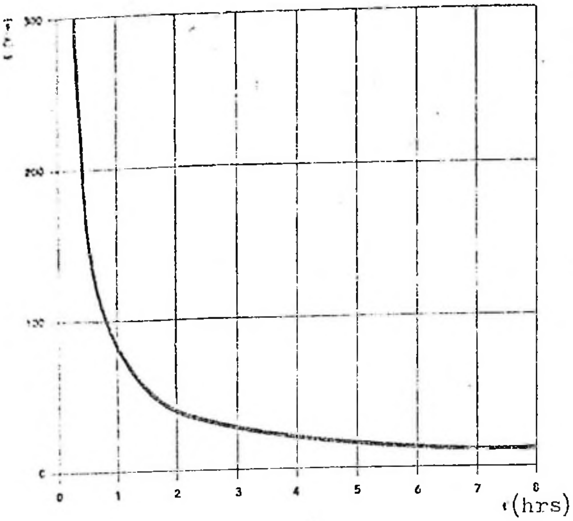
$$O_{VHF} = N.t \tag{6.4}$$

It is evident that in practice it is necessary to ensure that the irradiation does not exceed the maximum permissible value, so that

$$O \leq K \tag{6.5}$$

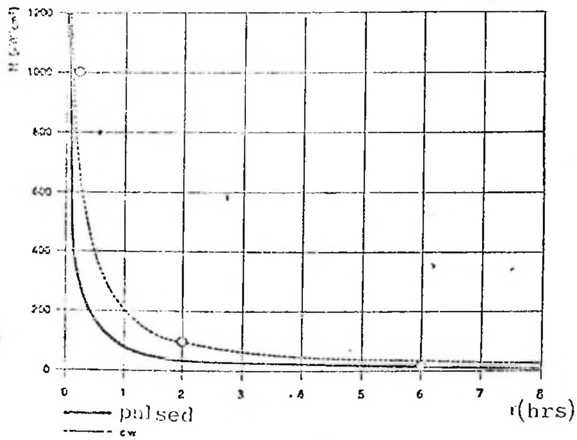
The values of the maximum permissible radiation $\underline{K}$ for both ranges have been established on the basis of published information on biological effects, with the knowledge that they can produce only a certain average sensitivity of the organism at average active field parameters. In view of this, workers in both the CSSR and USSR have also taken into consideration a certain safety factor.

In practice it is desirable to use graphic representations of maximum frequencies like those for the H.F. band (Fig. 39), for V.H.F., and for both kinds of operation in Fig. 40. In the latter, the circles represent the maximum permissible power density accepted in the USSR for 6-hour, 2-hour, and 15-minute exposures.



Maximum Permissible Field Intensity
H.F. Band for Various Periods of Expo-
During the Working Day.

...ent of values demonstrates the correctness of our exposures. /82



...Permissible Power Density in the V.H.F. Band for
... of Exposure to Radiation During the Working Day as
... CSSR. Curve 1 Represents Continuous (cw) Trans-
... 2 Represents Pulsed Operation; 0 = Maximum Permiss-
... CSSR and Poland.

TABLE 6. SUMMARY OF ESTABLISHED OR SUGGESTED VALUES OF MAXIMUM PERMISSIBLE FIELD INTENSITY FOR ELECTROMAGNETIC WAVES. /83

Country author	Frequency in MHz	Maximum permissible intensity	Remarks
USA: Ely, T.S., Goldman, D.E. (1957)	3000	100 mW/cm^2	Entire body
		150 mW/cm^2	Eyes
		5 mW/cm^2	Testes
USA: U.S. Army (1958)	all	10 mW/cm^2	--
USA: Schwan, H.P., Li, K. (1956)	1000	30 mW/cm^2	Entire body
	1000-3000	10 mW/cm^2	Entire body
	3000	20 mW/cm^2	Entire body
USA: General Electric	700	1 mW/cm^2	--
USA: Bell Telephone Laboratories (1956)	750-30,000	1 mW/cm^2	--
USA: Mumford, W., (1956)	--	0.1 mW/cm^2	--
NATO: (1956)	--	0.5 mW/cm^2	--
Sweden: (1963)	87	222 V/m	--
	87	25 V/m	--
England	300	0.01 mW/cm^2	--
Federal Republic of Germany: (1962)	--	10 mW/cm^2	
USSR: (1965)	0.1-1.5	20 V/m	
		5 A/m	
	1.5-30	20 V/m	
	30-300	5 V/m	
	>300	0.01 mW/cm^2	6 hrs. daily
		0.1 mW/cm^2	2 hrs. daily
		1 mW/cm^2	15 min. daily
Poland: (1961)	>300	0.01 mW/cm^2	Entire workday
		0.1 mW/cm^2	2-3 hrs. daily
		1 mW/cm^2	15-20 min. daily
CSSR: (1965)	>300	0.025 mW/cm^2	Continuous operation } for 8 hrs.[7]
		0.01 mW/cm^2	Pulsed operation }
	1.01-300	10 V/m	
USA: (1966)	10-100,000	1m Wh/cm^2	Every 6 min.
Canada: (1966)	10-100,000	1m Wh/cm^2	Every 6 min.

7 For shorter exposures, see Figs. 39 and 40.

In Table 6 we have assembled the presently known established or suggested values for the maximum permissible field intensities. Considerable differences are evident in the various approaches to the problem of biological effects and the protection of workers against this danger [157, 162]. In the USA, there is considerable lack of accord in establishing the maximum attainable intensity [20, 265]. Many authors advocate a value at which the heating of the organism is just at the bearable point [36, 90, 125, 137, 281]. There are others, however, who advocate that the latter intensity be referred to as the "tolerance value" and that the maximum permissible value should be a power density of 1 mW/cm^2, suggested as a standard by Bell Telephone Laboratories [155]. The bioligical effects can be expected to make their appearance at an intensity of 0.1 mW/cm^2, which is another value used in the USA [125]. This takes account of chronic exposure with the involvement of nonthermal phenomena. This, too, is a correct viewpoint. In addition, in both the USSR and CSSR, a safety factor of 10 has been chosen, so that the value 10 $\mu W/cm^2$ has been chosen for the maximum permissible field intensity for the entire working day in the cm wave range [77, 279].

For non-pulsed operation, we chose a value of 25 $\mu W/cm^2$ as being demonstrably less risky, using 10 V/m as the maximum intensity of the electrical component. /84

The maximum permissible intensity of the magnetic component of the field has been established only in the USSR, and even then only for a very limited frequency range.

6.2. Specificity of Determination of Field Intensity with Respect to Current Densities and Radiation

It might appear at first glance that the problems involved in determining the radiation, which consists mainly in determining the field intensity or the power density indirectly, are in no way difficult or new, and can generally be solved by current methods of technical practice. In reality, however, it must be pointed out that this view is valid only to a certain degree. Several examples will suffice to demonstrate this. In the first place, it is obvious that not everyone (and therefore, not everything) is affected in the same way by the presence of an electromagnetic field. This point has already been discussed in Chapter 3. It should be emphasized in this connection that the frequency dependence of absorption, expressed as a ratio, need not automatically agree with the response of the organism. The problem becomes still more complex in other ways, too, when we realize that it is almost (but not completely) impossible to include the non-thermal effect in the above-mentioned frequency dependence of absorption.

In addition, the body occupies "slightly" more space than one would assign to a point object. This means, however, that it is necessary to know the total value of the energy received, i.e., from all directions and without regard to polarization. The fact that the body is not a point object need not be an obstacle (at least not in measurement) if it is viewed from the standpoint of a generator in the so-called far field (as we shall see later on, it is of practical significance only in the cm wave band); in the majority of cases, however, it is necessary to take into consideration the presence of individuals in the so-called induction or near field, where the field itself is highly inhomogeneous (in addition to being affected by the presence of a body). Even if this problem could be overcome somehow and measurements made (for example) in the immediate vicinity of the body, it would still be likely that the configuration of the field around the antenna would be changed in some manner by the effect of an object being brought close to the antenna. This would have an effect on both the sensitivity and the characteristics of the antenna (changes in the original characteristic radiation function and in the impedance). An attempt to resolve this problem (at least in rough approximation) has been made [110], and the results do show a very definite change in impedance (an increase in resistance).

Another difficulty is that conventional measurements of field intensity in the near field are usually either so sensitive that measurements are impossible without a special reduction of the sensitivity, or (on the other hand) they are so low in sensitivity that they may lead to further errors. Likewise, an absolute measurement of radiation by calculation is more of an orientation, if indeed it is used at all (as it is, for example, directly in the near zone, where the complex nature of the relationship cannot be found by calculation, especially when the radiation factor is not properly defined).

The combination of all these requirements or still unsolved /85
problems appears quite pessimistic and negative from the standpoint of practical applications. However, the steady development of applications for H.F. and V.H.F. energy, together with the accompanying growth in the number of persons who come into either direct or indirect contact with electromagnetic fields, make it necessary to find at least temporary methods for determining radiation levels. It is clear that the situation can be resolved only by some compromise, i.e., to cover at least some of the requirements by appropriate measurement, and then attend to the others by taking up the methodological aspects of the matter or using graphs. At the same time, efforts must be made not only to improve existing equipment as well as methods, but also to use known mechanisms of the effects as a basis for finding other methods of measurement that could be used to replace those used at present.

What, then, is the current state of affairs, and what approach should be taken to solve the problem as a whole?

To begin with, the entire spectrum with which we are concerned must be divided into two bands, the H.F. (up to 300 MHz) and the V.H.F. (above 300 MHz). There are two reasons for this: (1) In the H.F. band, where the dimensions of a body are much smaller than the wavelength, the electrical and magnetic components of the field are used for differential absorption [68]; (2) in the H.F. band, there are places at which the value of the field is customarily determined, especially in the so-called induction region, where the mutual relationship between the electrical and magnetic components of the field is not explicitly defined. From this it follows that in the H.F. band it is necessary to consider the E and H components separately, while in the V.H.F. band it is the total power or power density which must be considered. It is generally true that both methods can be used in practice from approximately 100 to 300 MHz. In view of the accepted standards in the CSSR, only the contributions of the electrical component of the field will be discussed in the following text with respect to the H.F. band.

In regard to the complex and ambiguous nature of absorption, as well as the still unsolved problems surrounding other possible pathways by which electromagnetic energy can reach the organism, and (finally) the unknown frequency response of the organism in the presence of electromagnetic energy, there is no sense (especially from the medical standpoint) in determining the difference between the measured field intensity, or power density, and the energy actually absorbed in the body. This is generally true for personal measurements, and it is the principal criterion in selecting measuring instruments. In making personal measurements, especially in the V.H.F. band, it is generally necessary to determine the frequency dependence of the absorption as one of the factors by which it is possible to detect individual differences in sensitivity of personnel to the presence of electromagnetic energy.

In both bands, it is conventional nowadays to use wide-band meters whose sensitivity is not necessarily restricted to only one polarization or direction of incidence of the energy. It is highly unrealistic to try to satisfy these demands under all conditions, so that it is necessary to distinguish between the practical viewpoint and the conditions under which the measurements are usually made. From this it then follows that the requirement for a wide-band meter is actually necessary only in the H.F. band, where it is usually required at a certain workplace to determine the field produced by the action of a generator operating at various frequencies (not to mention the usual presence of higher harmonics of the basic frequency). The requirement of sensitivity at various polarizations and non-directionality with maintenance of the desired sensitivity of the meter, however, is bypassed in this /86
method by measuring the maximum value of the field intensity at a given location. This is usually a temporary expedient, with disregard for the economic standpoint (the same is also done in the case of all equipment for making measurements in this frequency

[illegible]e V.H.F. band, the situation is made easier by the fact that in the great majority of cases it is a question of the operation of individual generators, so that the problem of harmonic frequencies is not involved and the need for a wide-band meter becomes superfluous. Usually, the polarization and direction of incidence of the radiation are the same. There does exist, however, a special situation where this is not true. The solution then depends on the selection of the proper antenna and method of measurement.

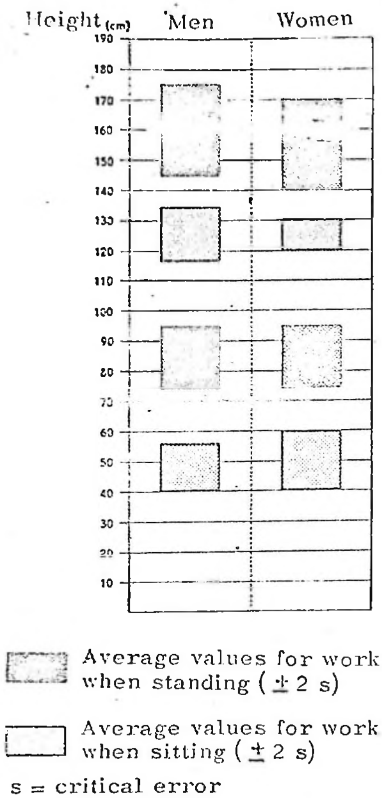


Fig. 41. Zones of the Head and Reproductive Organs During Work in Standing and Sitting Positions.

The finite dimensions (in particular, the height) of the body can be employed in making measurements at various heights. This is because the organs which are most sensitive to the effects of a field (besides the nervous system) are the genital organs and the eyes; the measurements are carried out at a certain working position of the body in a given location, at heights which correspond to the positions of the organs in question during work in either a sitting or standing position. Useful anthropometric data for men were obtained from the work by M. Prokopec [207], while the values for women were taken from a paper by S. Titlbachova [258]. The values, together with the given scatter, are combined in Fig. 41. It is evident that on the whole, there is no difference between men and women insofar as these data are concerned, and that a similar antenna installation can be made without regard to the sex of the workers at a given site. In accordance with these data, it was found that measurements must be made at the following depths below the surface of the ground: 50, 85, 125 and 160 cm. For evaluation from the hygienic standpoint, the highest measured value at one of these heights is then taken as the critical one (generally the value at the level of the head must be taken in any case). In view of the fact that the antenna itself is not a point, the measurements at these heights involve absorption and scattering among the individual workers. In the case of work only in a standing or sitting position, all of the measurements can be made for a given working position, but it is necessary to have a control in the form of a check to ensure that no extreme values are measured at other points. In making specific measurements, it is desirable /87 to perform them in the usual workplace with no personnal present in the immediate vicinity of the antenna (this is particularly important for the H.F. band).

The specificity of the measurements and the solution of the problems related to it combine to create a task which is both extensive and complex. It is evident that the information hitherto available on this subject has not been sufficient to allow it to be viewed from all angles, and that now the task of estimating the radiation will require a certain period of research and development. Hence, it is essential to unify our measurement methods and take maximum advantage of available equipment in order to be able to compare results at all levels (including biological data).

6.3. Apparatus and Equipment for Detecting Fields; Analysis of Individual Factors and Methods.

Under present conditions, especially as far as the desired accuracy for hygienic purposes is concerned (with an eye toward a uniform solution), measurement apparatus and equipment can be classified from the purely technical standpoint rather than from the indicators used. Hence, whenever the term "meter" is used in the text which follows, it should be understood to mean the equipment in the sense given above.

For the H.F. band, a device is required which will permit wide-band measurement of a high value of field intensity (in hundreds of V/m). From the analysis, a necessary part of which is answering the question of what means can be employed for a rapid and easy determination of the desired components of a given device, it was found that it would be possible to use for this purpose a non-resonant H.F. voltmeter with an external diode probe and several attachments [67, 171]. In this regard, one should avoid certain arrangements which would disturb the normal operation of the voltmeter. Admittedly, certain complications do arise in connection with the nonsymmetric input into the voltmeter, and also in connection with the need to use a rod antenna; otherwise, this method is most effective under existing conditions. When using a BM 388 universal voltmeter (made by Tesla at Brno) together with its accessory rod antenna (100 mm long and 6 mm in diameter) at the input of the diode probe, we will have the following expression for the determination of the field intensity E:

$$E = U_{in} \frac{C + C_2}{lC_2} = kU_{in} \qquad (6.6)$$

where $\underline{U}_{in}$ is the voltage measured by the voltmeter, $\underline{C}$ is the input capacitance of the voltmeter, $\underline{l}$ is the distance between the rod antenna and the nearest grounded object; $\underline{C}_2 = \underline{C}_1 + \underline{C}_1$, where $\underline{C}_1$ is the capacitance between the rod antenna and the voltmeter itself, /88 and C_1' is the capacitance between the rod antenna and the ground. According to this equation, the measured values on the low-frequency side of the band will be several percent higher than the real values, which is no problem in the case of measurements for hygienic purposes. A positive error will be obtained when making measurements in the vicinity of a great many transmitters operating simultaneously on different frequencies. It is clear that the coefficient $\underline{k}$ in a given voltmeter depends only on the value $\underline{C}_2$, i.e., on the dimensions of the antenna (diameter and length) and its distance from nearby grounded objects. This means that the following condition must be satisfied:

$$l_a \leq \frac{30}{f_{max}} \tag{6.7}$$

where $\underline{l}_a$ is the length of the antenna in meters, and $\underline{f}_{max}$ is the maximum frequency (in MHz) in the frequency range in question.

Fig. 42: Complete Set of Equipment for Measuring Field and Radiation Intensity.

The equipment described above makes it possible to measure field intensities up to a value of approximately 2000 V/m in the frequency range from 30 kHz to 300 MHz, and the data obtained will show the level of the field intensity at a given instant. To measure radiation during a given time interval, recording equipment can be attached to the H.F. voltmeter to indicate variations in field intensity as a function of time. The radiation can then be determined /89 by integrating the curves obtained. A complete set of equipment is shown in Fig. 42.

A completely different set of problems must be solved in the V.H.F. band. Unlike the situation in the H.F. band, measurement consists in determining the power absorbed by a given area. The power density can then be calculated by dividing the power by the area.

Under uniform conditions (which prevail in practice in the great majority of cases), when it is necessary to make measurements

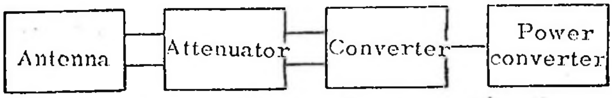


Fig. 43. Block Diagram of a Power-Density Meter.

at a single frequency on the basis of uniform linear polarization and negligible reflections, some of the equipment currently in practical use can be employed in making the measurements. A block diagram of such an arrangement appears in Fig. 43. In selecting the measuring equipment, it is necessary first of all to select a device for measuring the power, which involves finding a suitable transducer with some kind of element which serves to convert V.H.F. energy to an equivalent value that can be measured. With the desired measurement accuracy and very low power, it follows that we can exclude calorimetric and pressure methods, which are employed for measuring powers on the order of a watt or more. This leaves the bolometric method, which converts the changes in V.H.F. energy into changes in heat, indicated by a change in resistance. The most suitable devices that change their resistance with temperature are thermistors, whose advantages include the ability to measure pulsed currents (long time constant), the ability to withstand high peak overloads, sufficient power sensitivity, as well as a reduced tendency to break down (negative thermal coefficient). The transducers are made in the form of waveguides (best if tuned) or coaxial thermistor holders.

TABLE 7: VALUES OF THE GAIN G AND THE EFFECTIVE AREA S_{eff} OF THE COMMONEST TYPES OF ANTENNAS.

Type of antenna	G	S_{ef}
Elementary dipole	1.5	$0.12\ \lambda^2$
Half-wave dipole	1.64	$0.13\ \lambda^2$
Pyramidal horn (optimum)	$6.1\ \frac{S}{\lambda^2}$	0.49 S
Circular horn (optimum)	$6.5\ \frac{S}{\lambda^2}$	0.51 S
Parabolic	$(6.3 - 7.5)\ \frac{S}{\lambda^2}$	(0.5 - 0.6) S

The following items should be kept in mind in selecting an antenna; the wavelength, method of delivery of energy, and the sensitivity of the entire apparatus. A directional antenna should be as small as possible and have a sufficient power gain. Horn antennas are generally used for wavelengths shorter than 10 cm, while dipoles (and occasionally logarithmic structures) are employed for longer waves. Nomograms for rapid designing of several antennas are given in [167], while Fradinov [65] provides information on more accurate designing of horn antennas; logarithmic structures are covered in [48]. Table 7 lists the power gain G and effective area S_{eff} for the commonest types of antennas. /90

In measuring the power density, it is conventional to measure the radiation at a fixed distance from the device and then gradually approach it (either bringing the meter closer to the device, or vice versa), in order to determine the maximum permissible value. It is also possible to proceed by reducing the power radiating from the device and converting the results to obtain a value for full power. Occasionally, however, it is not possible to use any of the above methods, and an attenuator must be placed in the circuit, both to limit the input range and to protect the measuring equipment. Various types of variable and frequency-independent attenuators with minimal power losses are employed for this purpose.

Fig. 44. Complete Set of Equipment for Measuring N (OMC 900 02 Meter).

Most measuring (evaluating) equipment is made up of a d.c. heating circuit for establishing the working threshold of the thermistor, an L.F. oscillator with an automatically balanced bridge (one of whose arms is formed by the thermistor), and an L.F. voltmeter, which shows the changes in amplitude of L.F. oscillation caused by V.H.F. power incident on the thermistor in μW directly, thus giving the power density in W/cm^2 directly.

A complete set of equipment for measuring the power density is shown in Fig. 44. /91

The actual evaluating equipment is built rather from the standpoint of laboratory application, where (for example) the problem of obtaining power from a wall socket or batteries or the question of weight are of no concern. In some cases, however, simple circuits can be used; the most suitable of these is the unbalanced bridge. In measuring constant (i.e., cw) processes, it is possible to use a still simpler method. If the characteristics of a crystal diode are used to detect V.H.F. signals, a d.c. microammeter will suffice as an evaluating device. In this case, a crystal holder (untuned if possible) serves as the transducer. Similarly, a variation of the standard method [286] can also be used for making measurements in the H.F. band.

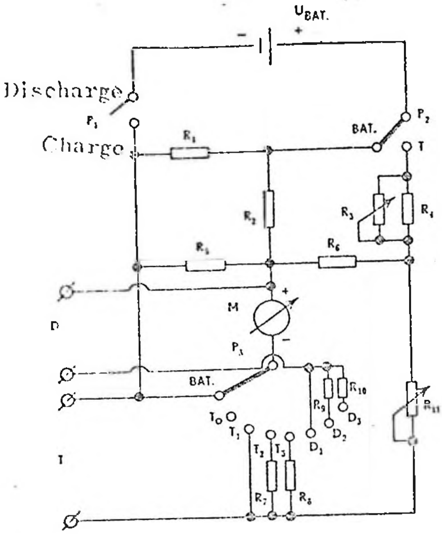


Fig. 45: Circuit Diagram of A Simple Meter.

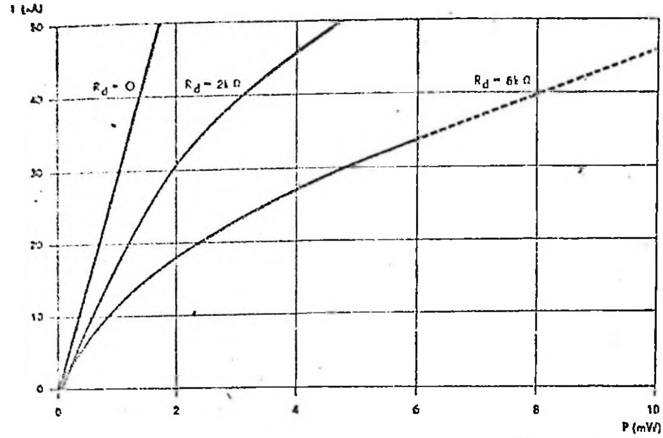
A practical circuit diagram for both types of simple evaluating equipment [174] is shown in Fig. 45. Typical calibration curves for the thermistor section of the apparatus are shown in Fig. 46 and for the diode section in Fig. 47. The overall appearance of the equipment is shown in Fig. 48a. This equipment is not mass-produced, but is easily assembled in any workshop and will serve well for making orientational measurements.

However, a suitable and simple measuring device is manufactured in the CSSR for more precise measurements. This is the field-intensity meter (for measuring power density), Type QXC 900 05 (made by Tesla at Pardubice), with its accessories (probes and antennas): it is /92
capable of making measurements of power density from 1 to 150 $\mu W/cm^2$ (and higher, if an attenuator is installed). A probe of this kind can be used in any microwave band. Figures 48a and b show the equipment for making measurements in the 3 cm band. One /93
indisputable advantage of this equipment is the fact that it is transistorized, uses batteries, and is light; it can also be calibrated directly in units of power density. In all other types of equipment, it is necessary to calculate the power density from the measured power.

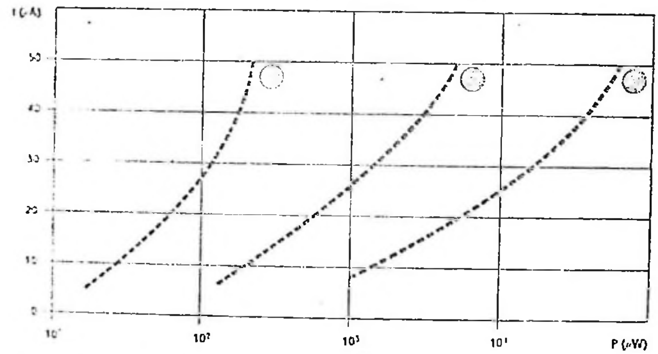
In order to determine the power density N from the measured power P_{av}, assuming that the efficiency of the transducer $\eta = 1$, we can use the equation

$$N = \frac{K_T P_{av}}{S_{eff}} \qquad (6.8)$$

where the loss K_T is actually due solely to the imperfect matching of the holder and the resultant reflection of a portion of the /94



Calibration Curves for Thermistor Section of a Simple Meter.



Typical Calibration Curves of QCV 222 Diode Holder (with Diode) in Series with DHR 5/50 μA: 1-R=0, 2-R_9, 3-R_{10}.

energy. Knowing the ratio of the standing waves s of the K_T can be found from the equation

$$K_T = \frac{1}{1 - \left(\frac{s-1}{s+1}\right)^2} \qquad (6.9)$$

When using an attenuator, it is necessary to include in K_T the value of the indicated loss. The effective area of the antenna S_{eff} can be found at a known value of the gain G by means of the expression

$$S_{eff} = \frac{G\lambda^2}{4\pi} \qquad (6.10)$$

Due to the fact that no conditions have been set in advance in this case for the form of the radiation characteristic of the antenna, there is no justification for combining in some manner the measurement results from two directions (for example), and using only the highest measured value in each case. The same method could be used when making measurements at two or more frequencies. The use of this method is completely guaranteed only if the maximum measured value is substantially greater than the balance.

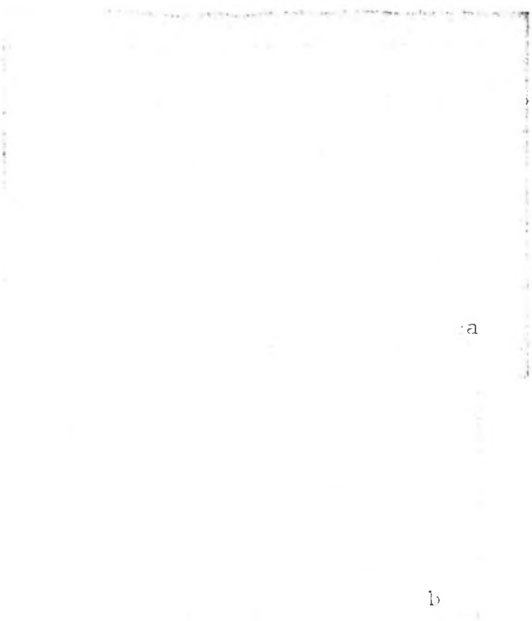


Fig. 48: Overall View of a Simple Meter: (a) Built with the Circuit in Fig. 45; (b) Battery-Powered Meter QXC 900 05 with Attachments for 3 cm Band.

It has already been pointed out that this case is the one most often encountered in practice.

In order to take into account the possibility of more conventional situations, the following section deals with possible solutions for such cases. Using the same block diagram of the equipment (Fig. 43), and with the possibility of employing conventional measurement methods, we shall deal primarily with the characteristics of the antenna and methods of evaluating the results.

In doing so, let us begin with the relative power diagram of the antenna which we are using [150]. If the power diagram of the antenna can be approximated by the function $\cos^p \Theta$, where $p = 2$ and the diagram is symmetrical in relation to the polar axis (direction $\Theta = 0$), then by means of progressive measurements in six directions (on an x, y, z system of coordinates, this would correspond to going forward and backward along all three axes) and arithmetic addition of the results from individual measurements, it is possible to obtain the total value of the power, as well as its components acting in different directions in space. This value can then be introduced into (6.8). The case where the relative power diagram can be approximated by the function $\cos^{p}\Theta$ is an important case of a conventional radiation characteristic which is non-symmetric with respect to the polar axis. For all other cases (i.e., when $p \neq 2$), measurement is subject to a certain error whose maximum value can be found from the equation

$$\Delta = \left| 1 - 2^{\left(1 - \frac{p}{2}\right)} \right| . 100\,(\%) \qquad (6.11)$$

For purposes of hygiene, we use only the case where $p \leq 2$ (Fig. 49), because in the other instances the possibility of measuring the value of the power density would be less than reality. In general, a necessary prerequisite is that constant conditions be maintained /95
to exclude the time dependence (continuous operation of generators in the range of interest for the entire measurement period). The receiving antenna is (for example) a logarithmic spiral on a conical surface, having a vertex angle of 20° and a slope angle of about 69° [52], assuming that it is possible to maintain K_T/S_{eff} = const within the desired frequency range (a suitable frequency response for the loss of the attenuator or the number of standing waves in the transducer, etc.).

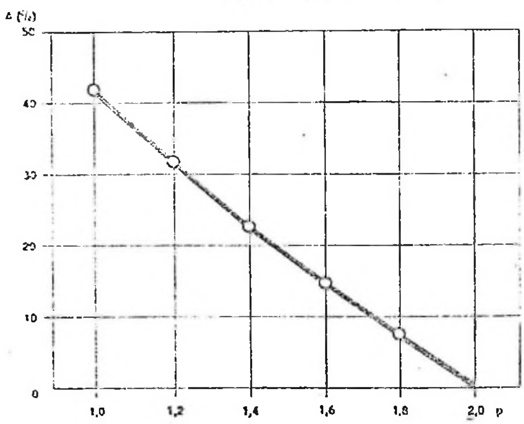


Fig. 49: Measurement Error Δ for $p \leq 2$.

In the V.H.F. band, it is necessary in certain cases to determine the power density and radiation in the vicinity of rotating or sector antennas (radars), where it is clear that the resultant values must be lower relative to the radiation from a fixed antenna (due to the form and width of the radiation characteristic and the size of the angle scanned). The actual determination is made on the basis of a combination of experimental and theoretical findings for both fixed and rotating (i.e., sector) antennas. Of all factors involved, the most important is the selection of the desired accuracy. This follows from the assumption that the thermal time constant of the irradiated part (body) is long relative to the period of observation.

In installing an antenna, it is possible (for example) to proceed from the measurement of the maximum value of N (i.e., on the axis or plane of the electrical axis of the antenna, with an eye toward possible changes in elevation) at a given spot, and then make corrections according to the equation /96

$$N_{rot} = N.K_{rot}, \tag{6.12}$$

$$K_{rot} = \frac{\Theta_{eff}}{\psi_{rot}} \tag{6.13}$$

where N_{rot} is the value of the power density in the vicinity of the rotating antenna, Θ_{eff} is the so-called effective width of the beam ($\Theta_{3dB} < \Theta_{eff} < \Theta_0$) in a given horizontal plane, and $\psi_{rot} = 360°$ [169]. The resultant radiation during one revolution O_1 is then given by the formula

$$O_1 = N_{rot}.t \tag{6.14}$$

where the period of production of V.H.F. energy t in seconds is given by the following equation (for the far field):

$$t = \frac{\Theta_0}{6n_{rot}} \tag{6.15}$$

Here Θ_0 is the width of the beam in a given horizontal plane at the level of the first zero, and n_{rot} represents the number of revolutions per minute of the transmitting antenna, so that the number of individual oscillations is given by the fraction $\psi_{rot}/360$. This is because of the so-called unified form of the characteristic curve; consequently, the value is slightly higher than reality. It must be emphasized that the effective beam width mentioned above is constant only in the far field (in the near field, it is always smaller and varies with distance).

A very accurate (though laborious and time-consuming) method involves the determination of the radiation characteristic of the transmitting antenna in a given horizontal plane, where it is possible according to (6.15) to include any lateral lobes that may appear during the period of operation t and then use integration to find the resultant radiation.

In some cases it is not possible (for procedural or other reasons) to stop the antenna during the measurements, or else a rapid, informative measurement is sufficient. This means that measurements cannot be made during normal operation of radars. In this case, too, it is highly desirable to establish the period of operation t. Various methods can be used for this purpose, the best being that in which t is calculated from the oscillographic representation of the characteristic curve (with a single pulse on the time base). For orientation, however, it is a good idea to perform the calculation according to (6.15). Another task is to analyze the response of the measuring equipment to the received signal. It is important to determine whether the apparatus is capable of recording the actual maximum value in a short time interval; this is the same as finding the amount of distortion caused by the inertia of the individual elements in the equipment. Only the maximum error can be found from the measuring apparatus, because the analysis of the response can likewise be carried out only at the maximum setting. An example of a typical curve of the maximum values of response to a received signal as a function of the operating time t is shown in Fig. 50. In the case of a linear scale on the meter, we can write /97

$$\frac{P_{2\,max}}{P_{1\,max}} = \frac{N_{2\,max}}{N_{1\,max}} = b(t) \quad (6.16)$$

or

$$N_{1\,max} = \frac{1}{b(t)} N_{2\,max} \quad (6.17)$$

where P_{1max} and N_{1max} are the actual maximum values of the power, or the power density, and P_{2max} and N_{2max} are the measured maximum values. The value N_{1max} then has essentially the same value as N in (6.12), so that in further calculations we can use (6.12) as well as (6.15) under constant conditions.

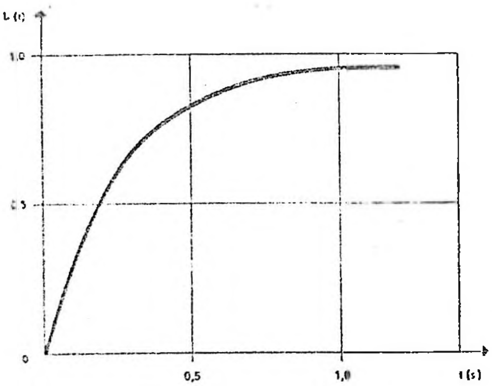


Fig. 50: Typical Curve of Maximum Values of Response of Measuring Equipment to a Received Signal as a Function of the Operating Time t.

In determining the operating time t according to (6.15), it is necessary to emphasize that it is valid only for the far field. In the near field, it is necessary to take into account the effect of the finite size of the receiving antenna (or body), as well as the distance between the receiving and transmitting antennas. When using a horn antenna with a quadrilateral mouth having side a (for the sake of simplicity, and with an eye toward possible vertical or horizontal polarization), the additional time t_d is given approximately by the equation /98

$$t_d = \frac{\alpha_1}{6n_{rot}} \qquad (6.18)$$

where $\alpha_1 = 40.5 \frac{a}{r}$ for $\psi_{rot} = 360°$, and

$\alpha_1 = 0.1125 \frac{a}{r} \psi_{rot}$ for $\psi_{rot} < 360°$;

r is the distance between the antennas. The resultant operating time t_p is then obtained as follows:

$$t_p = t + t_d \qquad (6.19)$$

In practical cases, the value $b(t)$ (Fig. 50) is usually measured on the steep part of the curve (low values of t and hence of t_p). Hence, the inaccuracy in determining the period of operation shows up as a rather significant error, not to mention further discrepancies caused by the approximation of the radiation characteristic of the transmitting antenna. This means that the latter method is actually suitable only for orientational measurements of radiation. In all cases, it is necessary to proceed with extreme caution when evaluating and applying the results. While pulsed operation as such is biologically more active than cw operation, it is mainly double pulsed operation that is mainly involved in the case of rotating or sector antennas; the question of biological activity continues to remain open and evaluation is carried out primarily from the technical standpoint. Inquiries dealing with this problem have been made recently in the USSR [283].

The survey of devices and methods for measuring radiation in the H.F. and V.H.F. bands, conducted in this section, is obviously not exhaustive. Its main purpose was to focus attention on the best methods of measurement, including the above-mentioned shortcomings and problems, which have not yet been solved satisfactorily. The two basic methods and the types of equipment which have been described herein and suffice in the majority of cases meet the requirement of uniform operation during measurement, established by the decree of the Surgeon General of the CSSR [286] for measurements in workplaces. Thanks to the examples which are included in the description of measurement, the decree is quite instructive. It is a good idea to note also that it is worthwhile comparing it to calculations, since this makes it possible to learn in which region the maximum permissible values can be expected, so that measurement can begin there. To the extent that it is necessary to make measurements in the near field, an objective estimate of the situation requires a quite detailed measurement to be made, i.e., in various locations close together. In determining the power density in the vicinity of a radar, it is necessary to keep in mind the possible influence of the terrain, i.e., to find out in which direction the highest values will lie, and then proceed to establish forbidden areas around the antenna. The number of details discussed in previous chapters is so great that they cannot all be accommodated in a single method.

To round out the conclusion of this section, some remarks are in order to regard to using calculations. All in all, we can say /99 that calculation alone can be used only in those special cases where the radiating element and its parameters are precisely defined; in other words, it is possible only in the vicinity of transmitting antennas. Even then, a certain degree of limitation and simplification is required.

For example, in the H.F. band and in the case of the commonest type of antenna, the half-wave dipole, the effective value of the field intensity E can be obtained approximately in the near field by the equation

$$E \doteq \frac{\sqrt{P_v}}{\lambda} \sqrt{\frac{49}{\left(\frac{r}{\lambda}\right)^2} + \frac{1{,}2}{\left(\frac{r}{\lambda}\right)^4}} \tag{6.20}$$

where P_V is the radiated power. For the far field, the second term beneath the radical can be dropped, so that the resultant equation has the form

$$E = \frac{7\sqrt{P_v}}{r} \tag{6.21}$$

or, as is more conventional for other types of antennas and propagation along the electrical axis,

$$E = \frac{5{,}5\sqrt{P_v G_v}}{r} f(\Theta, \Phi) \tag{6.22}$$

where G_V is the power gain of the transmitting antenna, and $f(\Theta, \Phi)$ is the relative intensity directional diagram. In the near field, at the edge of the characteristic, the loss in field intensity is approximately a third of that given by (6.20).

In the V.H.F. band, the situation in the near field is complicated to the extent that even relatively small changes in distance give rise to basic changes in the power density (see Fig. 4). Hence, only the basic equation is used in the calculations; it gives the approximate maximum values in the near field along the electrical axis of the antenna:

$$N_{max} = (3 - 4) \frac{P_{av\ V}}{S_{eff\ V}} \qquad (6.23)$$

where $P_{av\ V}$ is the average emitted power, and S_{eff} is the effective area of the transmitting antenna. Assuming 100% reflection from the ground, the resultant power will be quadrupled. To calculate the power density in the far field, we can use the simple relationship (without the influence of reflection from the ground)

$$N = \frac{P_{av\ V}\, S_{eff\ V}}{\lambda^2 r^2} \qquad (6.24)$$

Since it is necessary to find the power density away from the axis of the characteristic, we can estimate it in the near field as being a tenth of the value on the axis as given by (6.23), while in the far field it is obtained from (6.24): /100

$$N = \frac{P_{av\ V}\, S_{eff\ V}}{\lambda^2 r^2}\, p(\Theta, \Phi) \qquad (6.25)$$

where $p(\Theta, \Phi)$ is the relative power directional diagram.

6.4. Measuring Devices used Abroad and the Possibilities for an "Ideal" Means of Measurement.

As we mentioned earlier, modern devices and methods of measurement cannot be considered completely accurate, especially when they are viewed from the standpoint of their use for hygienic purposes. The same holds for the devices and methods of measurement which are used abroad, in the USSR, USA, and Poland.

In the USSR, the Type IEMP-1 wide-band measuring device is used for the range from 100 kHz to 300 MHz, and is capable of measuring the field intensity from 4 to 1500 V/m (in the 100 kHz - 30 MHz band) and from 2 to 600 V/m (in the 10 MHz - 300 MHz band). In addition, it is used for measuring the magnetic component of the field (the USSR has standards for the maximum permissible value of the magnetic component of the field). The relative error in measuring E varies from 25 to 45%. The additional error is less than 10 V/m for each 100 V difference in potential between the antenna location and the rest of the apparatus. Two types of antennas are used for measurement (a dipole and a biconic antenna); the minimum allowable distance of the antennas from surrounding objects during measurement is 10 cm. The use of symmetric antennas has the significant advantage that greater accuracy can be obtained when making measurements in the vicinity of surrounding objects, not to mention the simpler method of evaluating the measurement results. On the other hand, the use of two antennas has the practical effect of limiting the wide-band response of this meter. The instrument is powered by batteries, is readily portable, and measurements can be made very easily.

The Type PO-1 MEDIK adjustable meter is used for the 300 (or 150) to 16,700 MHz range; its measurement scale extends from 0.074 (or 0.017) μW/cm^2 to 316 mW/cm^2 (i.e., the maximum range, which is generally not guaranteed at all frequencies). The device is equipped with a total of 11 antennas (9 horns and 2 logarithmics), 6 coaxial attenuators with adjustable constant damping, as well as 6 thermistorized holders (2 coaxial, 4 waveguide) for different frequency ranges. A special stand is also provided with the device. The instrument can be powered by batteries or line voltage; the batteries are included with the accessories. The /101 wide range of accessories contributes to the excellent reputation of this meter, although it would appear that the range of sensitivity is unnecessarily wide (the latter fact also contributes to making the instrument not especially portable). One disadvantage of the device is its use of a bridge circuit. It is actually a so-called "balanced bridge", which in practice means that measurements can be made only when changes in power density during measurement do not have to be considered (this means, for example, that measurements cannot be made in the vicinity of a rotating antenna).

The method of measuring the field intensity and the power intensity is similar to the basic method employed in the CSSR, in which the maximum meter errors are determined at a given location by setting the antennas of the meter to the desired position (this includes measurements at different heights). A specific method for making measurements in the presence of powerful reflections or other structures (in the V.H.F. band) has not been established in the USSR; the results are always cumulative. In evaluating the data, there is a difference in that the simple values of E and N are used directly as critical values in the USSR, and not in the form of a product with time to indicate radiation.

In the USA, the problem of making measurements for hygienic purposes in the H.F. band has not been dealt with at all; there are no standards for this band. However, there is one type of special wide-band meter used for these purposes in the Army (the "field intensity meter", with no type designation; it is not mass- produced). It is intended for making measurements in a frequency range from 3 to 30 MHz, with the possibility of measuring field intensities up to 400 V/m (in 5 stages). It uses a very short rod antenna, which allows measurements to be made practically without regard to the distance from surrounding objects.

In the V.H.F. band, on the other hand, there are many different types of devices for measuring the power density. The overwhelming majority use mass-produced thermistorized bridges, and are equipped with calibrated antennas and attenuators similar to those used in the CSSR. In view of the present lax standards in the USA, however, the considerable emphasis on high instrument accuracy is hard to understand. On the other hand, though, it is precisely because of these lax standards that it is frequently necessary to make measurements even in the near field of a radar, so that this kind of measurement has been developed in great detail in the USA, including the theoretical aspects; see [16], for example. Such a special type of device is the AN/USM-82, Model NF-157, a portable wide-band thermistorized meter for measuring power density. It covers a frequency band from 200 to 10,000 MHz with a measurement error of about 1 mW/cm^2 to 1 W/cm^2 and an accuracy of ± 1 dB. Wide-band response is not obtained simultaneously over the entire band, but in three subsections, in which the condition K_T/S_{eff} = const is satisfied. For frequencies from 200 to 800 MHz, a dipole is used whose output is a section of circular waveguide having a suitably fitted damping characteristic (a so-called subcritical waveguide); two conical horns with adjustable concentric probes are used for frequencies from 750 to 4000 MHz and from 3750 to 10,000 MHz.

Another interesting type is the simple "densiometer", Model 1200. It is intended for measurements in the frequency range from 200 to 10,000 MHz in 5 subsections; the latter are not tunable, however. Four antennas are used (1 special one for frequencies /102 from 200 to 225 MHz and from 400 to 450 MHz, and 3 horns). The measurement error can be as high as 20 mW/cm^2, and the principal electrical circuitry is analogous to that of our simple meter (cf. Fig. 45). A very important aid is the relative level meter, consisting of a 1N21 crystal detector, a unidirectional measuring circuit, and antenna probes of different lengths. It is used for preliminary orientation in finding locations with a maximum field level.

From the methodological standpoint, it is interesting to note the approach in the USA to an evaluation of the total power, or the power density at a given point, if we take into account the strong reflections or activity of many transmitters with different operating frequencies [169]. In the event of a strong reflection, the total incident power is determined as the square of the product of the roots of the two partial powers (assuming that the field intensities are in phase). If we look at this process only from the viewpoint that the directional characteristic of the receiving antenna is not being defined, it is difficult to consider it legitimate. In measurements at different frequencies, the resultant power is expressed as the arithmetic sum of the components measured at individual frequencies, as mentioned above. Even this procedure can be used only for orientation.

A total of three devices are used in Poland for the H.F. band (for measuring the electrical component of the field). The Type MPE-1 with 6 antennas and a measurement range from 1 to 200 V/m is used for the 150 kHz- 3 MHz band (in 5 steps). The Type MPE-2, also with 6 antennas and the same measurement range, is used for the 3 - 30 MHz band (in 5 stages). Finally, the Type MPE-3, with two antennas and a measurement range from 1 to 100 V/m, is used for the 30 - 240 MHz band (in 6 stages). They are all adjustable transistorized meters, using dipoles as antennas (which can be tilted to the horizontal plane). It is necessary to apply a correction factor to the indicated value; this factor depends on the frequency (given a measurement accuracy of +6 dB). The Polish adjustable meters have the advantage that they can be used to determine the structure of the maximum radiation during operation and then gradually to eliminate it, i.e., they allow it to be regulated. However, since this procedure cannot be applied in all cases to the H.F. band, attention is being focused currently on the design of wide-band meters.

To make measurements in the V.H.F. band, the Poles use the Soviet PO-1 MEDIK, which has the advantage of a complete set of equipment and is not dependent on line voltage for its power (it has been calibrated for direct reading and plans have been made to change some parts of the equipment).

As far as the methodology of measurement is concerned, everything holds true which was mentioned in the case of the USSR. In making measurements in the vicinity of rotating antennas, the Poles have attempted to measure simultaneously the average mean value, while we in Czechoslovakia have attempted to follow very accurately the entire course of the radiation characteristic and to find the total average radiation through integration. The difference here lies not so much in the measurement methods employed but in the evaluation, which has to do with the fact that we use the product of power density and time as the critical value, while the Poles use only the instantaneous average value.

From this brief discussion, it is apparent that the measuring instruments, processes, and methods employed in practice abroad /103 are not too different from our own. The same cannot be said of the evaluation of the results, however.

On the whole, the current trend in the development of measuring instruments could be summarized in terms of the following criteria: (1) compactness, (2) accuracy, (3) adequate sensitivity, (4) independence of frequency over a broad range, (5) stability, (6) low price. The fact remains, however, that fulfillment of these purely technical requirements still falls far short of solving the problems involved in measurement, and it has now become evident that the critical factors are low price, adequate sensitivity, and compactness. There is no need to insist on the other conditions at extreme parameters, but to proceed on the basis of the practical conditions under which measurements are actually being made. We can assume that the time has passed when it was possible to achieve uniformity in approaches to measurement; the required values are obtained only for orientation. We have now reached a new stage, in which the task is to discover new ways and principles for measuring on the basis of known or identifiable mechanisms of the effects. Obviously, it is difficult to draw a dividing line between these two stages; they must be (and actually are) blended.

Several foreign writers have called attention to possible methods of obtaining the most accurate estimate of the exposure of the body to electromagnetic energy. Mumford, for example [169], suggests the possibility of a calorimetric method (using an absorber), or measuring the radiation pressure. This is not an ideal solution, however, since this method gives only the frequency dependence, the dependence on polarization, and the direction of incidence of the radiation, and leaves the problem of the sensitivity of such equipment unsolved, not to mention its principal shortcoming, namely, no indication of the possibility of compensating for or imitating the physical characteristics of a body from the standpoint of the absorption of H.F. or V.H.F. waves. In Holland [116], attempts have been made to solve this problem by introducing beneath the skin, a small capsule containing a glycogen solution having a precise concentration and viscosity; the rotation of the optical polarization plane is then measured. This procedure is generally applicable only to animals, in which it is alleged that accurate measurement results can be attained (thus amounting to an explicit method of H.F. dosimetry) [120]. It was also possible to evoke ionization phenomena in rarefied gases [255]. Thus, for example, a glass sphere filled with helium, nitrogen, hydrogen or argon could be used as a non-directional field-intensity indicator in the 50-5000 MHz band, and occasionally at higher frequencies as well.

We could cite still other examples, but even without them it is clear that they would be premature, and that some decisive finding must be awaited from the results of further biophysical research. In this manner, the problem of personnel dosimeters will be solved sooner or later.

7. HYGIENIC AND TECHNICAL PROBLEMS INVOLVED IN WORING WITH GENERATORS OF ELECTROMAGNETIC WAVES; ORGANIZATION OF WORK WITH THEM. /104

7.1 Means of Attaining a Desired Field Intensity.

The means of attaining a desired field intensity can differ according to the frequency range as well as the type and purpose of the equipment employed. In the industrial generators produced until recently, the question of harmful radiation was given practically no attention, because the conditions of uniformity and expediency were not important. In the last decade, however, efforts have been made to at least get rid of undesirable radiation and avoid interference [3, 4, 211], but not all those measures were adequate from the hygienic standpoint. It was only in the years 1964-1965 that radical changes were made in this regard [25, 263].

An analysis of data from the majority of measurements has shown [111] that the level of the field intensity in the near field, where the operating personnel are usually located, depends on the power of the generator, the nature of the elements, and the degree and character of the shielding of the H.F. elements (i.e., those elements which can radiate). On the basis of the latter criteria, we can divide generators (in principle) into four groups [135]:

1. Generators with unshielded operating (and other H.F.) elements.

2. Generators with unshielded operating elements.

3. Generators with shielded operating elements, but with the other H.F. elements unshielded.

4. Generators with all elements shielded completely.

It has been found that in all cases where the shielding is not complete or is poor (for example, improperly grounded), the field intensity can reach a value of tens of volts per meter [25, 170, 263].

Analyses have also be conducted of the vertical structure of the field, and it was found that in all cases [except (4) above] the entire body is irradiated (but not completely homogeneously). In dielectric heating, $\underline{E}$ is always greater than in induction heating (though the radiating structures are generally limited to the applicator electrode). The majority of industrial generators used in the CSSR can be classified under one of the first two categories above. It therefore depends on the technology and working processes and the resultant period of action of H.F. during the workday, whether the maximum permissible radiation value will be exceeded. Where such is the case, it would be an undoubtedly radical solution to the problem to eliminate the effects of the H.F. field on the organism solely by sutomation of the processes, which would do away with the need for persons to remain in the vicinity of the electromagnetic /105 field; this certainly cannot be accomplished overnight at the present time. Nor can the problem be solved by enclosing all of the equipment (including the work area) in a shielded box; this measure would benefit those in the surrounding areas, but the crew in the box would find themselves in a still stronger field, due to reflection phenomena.

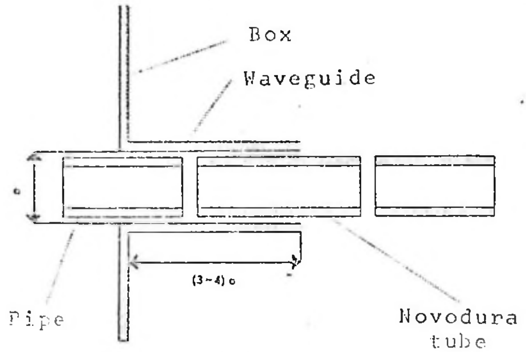


Fig. 51. Example of How to Run Water, Air, and Gas Lines Through Shielding.

For basic equipment to shield against electromagnetic radiation, we can consider [134]:

(1) Shielding the radiant structure.

(2) Shielding the work area.

(3) Local protective shielding.

Owing to the wide variety of existing working conditions, it is not possible to provide extensive recommendations for construction of future devices. Our attention will be focused instead on the basic equipment which is presently missing and yet, in the overwhelming majority of cases, is able to reduce the number of cases of radiation injury to workers substantially.

Shielding for the radiating equipment can take many forms, including the following: shielding the oscillator (primary) area, shielding the work area, and shielding the equipment as a whole. The primary area (oscillator tubes, banks of capacitors and inductances) together with the rectifiers should be placed in a single shielded cabinet. This eliminates the need to shield the wiring between the individual components. The shielding itself should be made from sheet metal (copper and aluminum are best), with a minimum thickness of 0.5mm; individual sheets must be joined to form a continuous conductor (soldered or welded, either continuously or with spaces a maximum of 5 to 10 mm long between welds). When it is necessary to /106 shield individual elements of H.F. equipment (capacitors, coils, etc.), insulating covers or boxes made of sheet metal or screening can be used.

The shielding for the operating circuits can take a number of different forms. Thus, for example, the inductance can be shielded most uniformly by a cylindrical cover (the so-called waveguide filter) where the distance between the windings on the inductance and the walls of the cylinder must be at least equal to the radius of the coil [134, 194]. The material is copper or brass with a thickness of at least 0.5 mm. One variety of this method is used, for example, in the EZK-1 equipment at CKD (Prague). Similarly, it is possible to shield the operating capacitor in dielectric heaters.

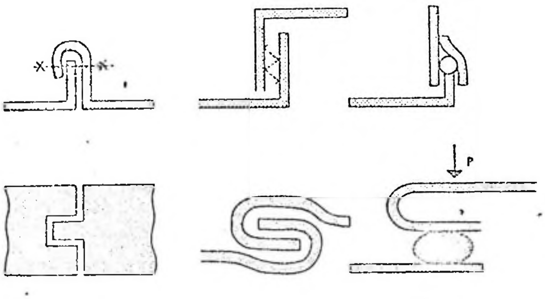


Fig. 52. Examples of Joints in Shielding.

Another method of shielding is the movable cover, raised and lowered manually or automatically, or the fixed cover with doors (made of the same materials as above). The process can be observed through a small window provided with a screen, made of brass for example, with a good electrical contact on the outside edge. Satisfactory results are obtained with wire diameters from 0.1 to 1 mm and an area of 1 to 10 mm. However, a necessary condition is that there be a perfect conductor link with the grounded chassis of the generator; otherwise, the circuit can make the situation still worse. In the event that it is necessary to have gas and heating pipes run through, the cover can be provided with a conical lid to provide ventilation. An example of this is the shielding in presses of the EDL-1 type [278]. The press, with a removable heater, is covered on all sides by aluminum plates; the upper part is attached to the upper plate of the press and moves with it, while the lower and side parts are attached to the base of the press. On the front part of the press (where the operator stands) there is a device which automatically opens and closes the aperture for introducing material into the field of the capacitors.

Shielding of a two-conductor power cable can be accomplished with a metal tube or casing (the wall must be at least 0.5 mm thick). It is generally most economical to use coaxial cable. As long as the power lines between the generator and the equipment are short, it can be limited to one shielding cover combined with a load.

Shielding of the equipment as a whole is done with the same materials and similar methods. In addition (and this must be /10 emphasized once again), the entire assembly must be well grounded. With total shielding, it is generally necessary to keep in mind that further measures may be necessary [3]. The fact is that various power or control cables extend into the shielded area; there are also signal lamps, meters, control shafts, ventilation openings, pipes for air, gas and water, etc. All of these elements not only disturb the integrity of the walls, but can lead to unwanted coupling effects. To guarantee a constant H.F. potential between the above elements and the inner surface of the shield, lead-in capacitors, filters, etc. are used. The meters, push buttons, and signal lamps, so long as they are mounted directly on the shielding, may be powered by accessory lines from a filtered source. Control shafts which pass through the shield are best interrupted by a length of insulated rod. The aperture in the shield must be provided with a tightly fitted bearing, utilizing a friction disk or roller. In constructing shielded pipes for water, air, or gas, it is necessary to utilize the characteristics of the waveguides to make them into high-pass filters (so that frequencies below the critical value will not travel along the waveguide). An example of this is shown in Fig. 51. Ventilating holes must be shielded with screening; lengthwise slots, which can act like slot antennas at higher harmonic frequencies, are not as good. We have already mentioned that the shielding can be multi-layered; in this case, one must adhere to the principle of one connector between individual stages, so that compensatory currents will not arise to disturb the shielding effects. It is also necessary to have a perfectly conducting link between the individual sections of the shielding, mainly in the case of demountable or removable parts. Figure 52 shows some examples of actual joints.

In general, it should be emphasized that there are a number of instances where shielding according to the above criteria cannot be performed sufficiently well (mainly in the case of total shielding). Thus, for example, in equipment for welding sheets or covers out of thermoplastic materials, only a small part of the object is placed between the welding electrodes, with other sections being fed in manually as needed. On the other hand, the entire heating assembly (electrodes plus handle) is attached to a movable supply of H.F. current, and a very large object can be heated locally. In another case, the equipment is on a movable heater where the material to be processed travels continuously in at one side and out at the other. In such situations, often nothing more is done than to shield the work area with a screen cage or to use local, limited shielding (for example, a cover for the hand which manipulates the electrodes). In some kinds of induction heaters, it is possible to leave the inductance unshielded, because shielding of other parts of the equipment makes it possible to achieve the desired result. Moreover, in the case of induction heaters, it turns out that $\underline{E}$ reaches higher values only in the immediate vicinity of the inductance. In general, the magnetic component of the field will be greater there as well, but we are not concerned with its measurement at the present.

In other possible arrangements, it is necessary to pay attention to the need to eliminate possible formation of secondary radiation from places where higher levels of field intensity can be expected (this applies to storage or installation of a wide variety of objects). All outlets to adjacent areas or locations, used for any purpose whatsoever, must be arranged so that they do not act either as conductors or antennas (obviously, if this is not their primary purpose). In the event that generators are used as elements in an assembly line, it is necessary to be sure that the level of /108 radiation does not exceed the permissible level for other workers elsewhere along the line [285]. The same applies in the case where an unshielded generator can operate without constant supervision in some independent location or at another site. It is then necessary to shield the entire area or to enclose the generator in a shielded cabinet. The area can be shielded with metal lining on the walls, ceiling, and floor; the windows can be covered with screening. The metal joints must be in good electrical contact with one another and the entire area must be grounded. Standard cabinets of Types STK 1 to 6, made by ZEZ at the Rychnov nad Nisou plant, are suitable for use as shielded cabinets for the 0.15 to 230 MHz range (ensuring attenuation of 80 to 100 dB). During operation of the generators, the doors of the chamber or shielded area abviously must be closed. The length of the crew's stay inside is limited to the time during which the permissible radiation level is not exceeded.

The above measures are in reference to protection in areas with operating industrial generators, but undoubtedly a great many of these measures can also be applied to work in the communications field and to other kinds of transmitters as well (with the exception of V.H.F. transmitters, to which the next section is devoted). While sheet metal is generally used for shielding heaters, screening is prevalent in radio engineering. It can be installed conveniently in rooms and buildings housing transmitters, on the ceilings and walls (under the plaster). It strong undesirable radiation is produced by the feed wire connected to the upper part of the transmitter cabinet, it can often be effectively covered over with a grounded wire screen, parallel to the ceiling, and precisely at the height of the upper part of the transmitter cabinet. It is often useful to screen over the observation windows in the walls of the transmitter cabinet (final stage). Plates and foil are used mainly in smaller rooms or chambers, in which H.F. coils, feeders, capacitors and the like are operating. Fixed work areas must be located as far as possible from the radiating devices or inside of shielded chambers, etc.

In television transmitters and relay stations, excessive field intensity levels are not usually encountered in the control rooms, according to presently available information. This has to do with the different kind of construction of the transmitters, and is attributable mainly to the fact that the feeders are coaxial (i.e., shielded) and do not give off undesirable radiation.

Another important group is that of the V.H.F. generators. The basic principles for developing means of protection lead to measures similar to those for generators operating at lower frequencies:

(1) Reduction of radiation in the immediate vicinity of the radiating device;
(2) Shieldong of the radiating device;
(3) Shieldong of the work area;
(4) Personnel protection devices.

Depending on the nature of the radiating device, its power, and the character of its activity, it is possible to use some of the above principles of protection or any combination of them [77, 78, 134, 279].

Compact or woven shielding made of metal, or of absorbent material, is widely used as a protective medium. Such materials can /109 be used as any one of the four principal types of devices listed above.

Compact metal shielding ensures the required attenuation of energy in all cases. In selecting it, one need be guided only by design requirements. In the majority of cases, it will suffice to use a thin metal foil (measured in hundredths of a millimeter), provided the material has the required mechanical properties, uniformity of soldering, etc. Shielding made of wire screen has shielding characteristics that are worse, but not so bad that its use can be ruled out. The degree of attenuation depends on the parameters of the screen (wire diameter, hole size) relative to the wavelength. The degree of attenuation for various types of screening is shown in Table 8 [279].

TABLE 8. AMOUNT OF POWER ATTENUATION BY WIRE SHIELDING

3 cm band			10 cm band		
Wire Diameter (mm)	Number of Holes per cm^2	Attenuation (dB)	Wire Diameter (mm)	Number of Holes per cm^2	Attenuation (dB)
0.53	16	28	0.2	64	20
0.45	25	35	0.18	144	23
0.36	64	38	0.08	441	35
0.25	81	42	0.08	551	41
0.2	169	49			
0.14	186	47			
0.075	441	46			
0.08	559	50			

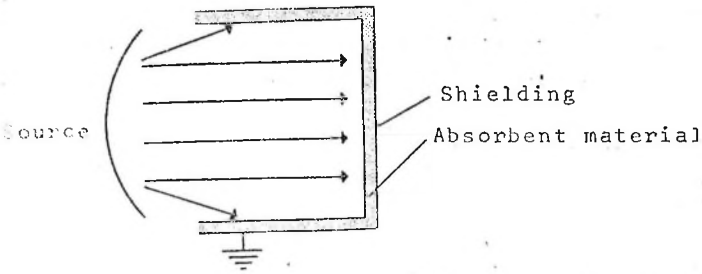


Fig. 53. "π-type" Open Shield

[illegible] many cases it is desirable to use absorbent material (absor- [illegible]. Wide-band absorbers are made of some porous material in [illegible] lossy material is suspended (it is necessary to have relative- [illegible] loss angles and low dielectric constants). One absorber /110 [illegible] kind is a mat made of curled hair impregnated with a solu- [illegible] liquid rubber and soot, so that it conforms to the impedance [illegible] space. As a rule, the thickness of absorbers is about one [illegible] the maximum useful wavelength measured in air (28 cm for [illegible], for example). This kind of absorptive material reflects [illegible]n 2% of the incident power. Satisfactory characteristics [illegible] obtained even with a layer of fine wooden shavings, soaked [illegible] mixture of oil and graphite, and applied to surfaces by sprink- [illegible] a thin layer of adhesive [103]. To be sure, there are [illegible] types (for example, egg cartons made of compressed paper, [illegible] layer of graphite painted on them) and suggestions for de- [illegible] construction of absorptive walls and rooms [128, 134].

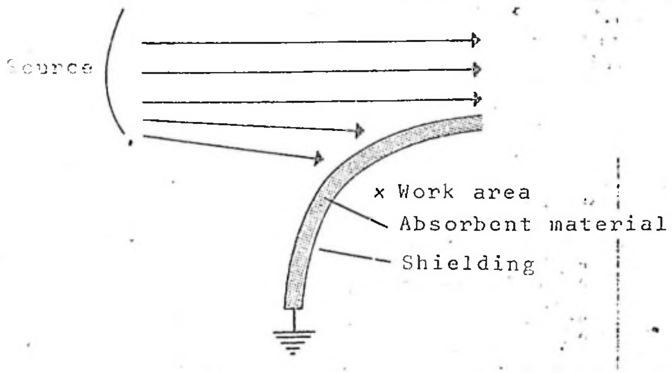


Fig. 54. Shielding of a Work Area

Other means for limiting radiation are wireless loads and damping terminals (waveguide and coaxial), in which the damping and absorbent material is graphite and mixtures of the latter with various fillers (cement, sand, rubber, plastics, etc.), iron filings with bakelite added, ceramics, etc., wood, and water. These media are produced commercially, but unfortunately not in sufficient amounts and varieties.

As we have already said, all of these protective media have multiple uses. When tuning and testing generators and transmitters, it is necessary to change the radiation directly at the instrument; for this purpose, we can use wireless loads and damping terminals (used for average power levels from fractions to hundreds of watts). To reduce the radiation in production areas, the radiation from the equipment can be cut off by means of foil, screening, or absorbers. In the case of non-directional radiation (slots, connectors of /111 waveguides or coaxial cables), the shielding is made in the form of boxes; in directional radiation (antennas), open shielding can be used, covered with absorbent material to prevent reflections (Fig. 55).

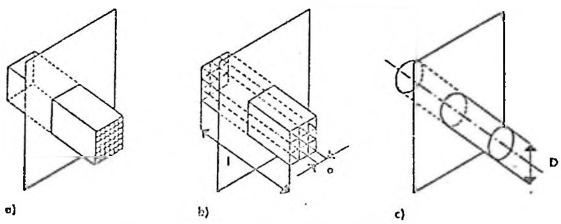


Fig. 55. Inspection Holes and Ventilation Openings in Closed Shields: (a) Tube with Two Screens; (b) Grating of Waveguide; (c) Tubing

The dimensions of shielded chambers and open shielding are considerably determined primarily by the dimensions of the structure and the work area. The smallest possible dimensions are generally set by the level of the radiated power (the possibility of penetra- /112 tion must be excluded). If the conditions of the production process do not allow a direct reduction of the radiation or shielding of the apparatus, the work area itself must be shielded (Fig. 54), and occasionally the surrounding area as well. Sometimes the walls in a building cut down the incident power sufficiently; some approximate values for damping by sections of buildings are listed in Table 9 [279].

In designing shielded equipment (mainly closed rooms), it is necessary to keep in mind the outlets and ventilation openings, as

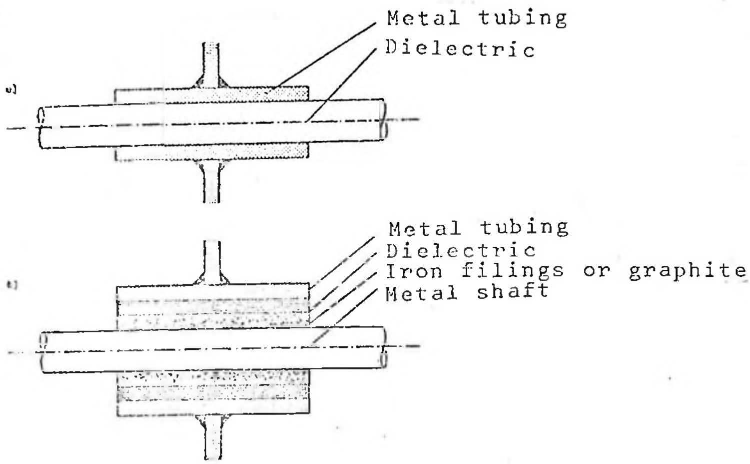


Fig. 56. Construction of Outlets for Control Elements: (a) Waveguide; (b) Coaxial

TABLE 9. DAMPING BY SECTIONS OF A BUILDING

Section	Damping at 3 cm (dB)	Damping at 10 cm (dB)
Outside Wall (70 cm)	21	16
Inside Wall (15 cm)	12	8
Floor (80 cm)	22	20
Double Window	13	7

well as the need to control the device inside the shield. Of course, the screen shielding is usually sufficient for ventilation and outlets, but sometimes it will be necessary to use for this purpose subcritical waveguides similar to those for industrial generators [77, 134, 194]. The lengths of the waveguides are selected according to the required degree of damping of the energy, as well as the damping characteristics of the waveguide. Figure 55 shows several examples of outlets and ventilation openings. Outlets of the type shown in Fig. 56 can be used for control elements. The first (a) is essentially a waveguide filled with a dielectric. The second type of design for outlets consists of a coaxial connector whose damping (when filled with iron filings) reaches values of about 10 to 15 dB/cm [77, 194].

In some processes (such as the production of magnetrons), it is often necessary to inspect the waveguides. In such cases, instead of looking directly, it is necessary to use a device like a periscope. It is simpler, however, to use directional couplers or simple waveguide elbows (a section of waveguide bent so that the plane of bector H is retained, and with the plane of vector E turned through 90°, so that the profile of the waveguide is retained) with a slot in the middle of the wide side of the waveguide [90]. In this arrangement, the slot does not radiate, so that it can be used as an inspection hole without risking damage to the eye. Table 10 lists the power levels on oblong waveguides for different values of power density N [267].

TABLE 10. POWER LEVELS IN OBLONG WAVEGUIDES (P = NA/2) /113

Band	Type of wave-guide	Cross-sectional Area A (cm^2)	Power P(mW) for:			
			N_{max}= =10 mW/cm^2	1 mW/ /cm^2	0.1 mW/ /cm^2	0.01 mW/ /cm^2
S(10cm)	VO 72	24.58	123	12.3	1.23	0.123
X(3cm)	VO 22	2.32	11.6	1.16	0.116	0.0116
Ka(1cm)	VO 7	0.25	1.29	0.129	0.0129	0.00129

Protective aids for personnel are also used to ensure reduction of the effects of eletromagnetic waves. The basic idea of giving each worker a protective device to guarantee him complete freedom of movement under conditions when other measures are impossible is a reasonable one. It must be said, however, that in this regard one cannot speak of generally successful results. Thus, for example, protective clothing made of metallic fiber, wire matting, or metal foil (Fig. 57) must be sealed; it can have practically no openings, does /114 not allow sufficient ventilation, and is therefore totally unfit for wear from the standpoint of health [149]. Better outfits than these, however, have not yet been produced as far as we know. In the CSSR,

Fig. 57. Protective Clothing (USA) [277]

such clothing is known by the name of "coveralls for protection against centimeter radiation". Even normal clothing provides some measure of protection (see Section 3.2). Protective goggles are also helpful. Here are many varieties of the latter, of which the best are those incorporating a gold film evaporated on glass, which is then vovered with wire mesh on both sides (the thickness of the gold film, according to [78], should be 0.3μ). To a certain extent, so-called "reflex goggles" can be satisfactory. Wire mesh alone can also be used in place of glass (Fig. 58). It should be stressed that protection of the eyes becomes most urgent in persons who wear normal eyeglasses since there is the possibility of concentration of energy by the lenses [69, 224]. In connection with the protection of the eyes, mention should be made here of the protective measures to be taken against the boilogical effects of lasers and optical masers, i.e., equipment which emits light beams. Measures taken should conform to the following rules [256, 284]: none of the workers should have to remain in an exposed area or in a suitable surrounding area; it is strictly forbidden to look in the direction of the laser beam axis or in directions where reflections of the beam might be expected; observation of the lenses of the laser equipment is likewise forbidden; in working with lasers, the area should be lit as intensely as possible so that the eye will adapt to the smallest opening of the pupil; in the even that excessive light strikes it, the risk of damage of the organs of sight will be reduced; same components of electrical equipment can retain an undesired charge, so that it is desirable to construct the components in such a manner that the charge will leak off; persons working with lasers and similar /115
equiment must be carefully examined by an eye doctor; to protect the sight of the employees, they must wear goggles which filter the dangerous frequencies out of the light spectrum. It should always be kept in mind, however, that such protection may not be 100% effective.

Fig. 58. Czech-Made Protective Goggles (Type 57-G) with Wire Mesh Eyepieces.

7.2. Further Means of Reducing the Effects of an Electromagnetic Field.

Of course, there are various other work areas and locations where the methods described thus far usually cannot be used. This situation occurs mainly in work related to the dimensioning (or generally, the use) of antennas in open spaces, or when starting up generators. It is desirable to tune and adjust generators without their radiating into space (by adding equivalent loads), at the minimal possible power levels, as well as to arrange the directional characteristics of the antenna to favor lower levels. These requirements are of course the same for both the H.F. and V.H.F. bands. In addition, it is necessary to locate the antenna system away from places where there are solid surfaces (cement, asphalt, and the like) and to give preference instead to absorbent surfaces, especially grassy areas [224]. It is also necessary to limit the practice of pointing fixed antennas (during testing or repairs) toward nearby inhabited areas. The fundamental rule is this: the higher the antenna is located and the greater its angle of elevation (in the positive direction), the better.

In the area surrounding transmitting antennas, at locations where the field intensity or power density reaches values acceptable for an 8-hour workday (for the crew), it is advisable to post signs bearing the inscription "DANGER! HARMFUL RADIATION!" (in black letters on an orange background), in order to prevent unnecessary loitering of unauthorized persons in the area. In choosing an area, one must proceed on the basis of results of measurements made during normal operation of the transmitter (for example, in the case of the low-mounted radar antenna systems described in Section 5.2, this area extends several tens of meters in all directions). If there should be any public buildings in this area, it is necessary to make measurements to be sure that the radiation level inside such buildings does not exceed the level permissible for the population.

If this is not the case, some are of the measures described in Section 7.1 will have to be taken. Basically, however, one should avoid such situations in setting up new transmitters.

Obviously, any protective device (or procedure) must first be tried out or otherwise evaluated as to its usefulness and suitability (frequency range, power, etc.) At the same time, the appropriate necessary check of its technical parameters must be made, and it must comply with any further safety rules and technical standards.

In the development, production and supply of new H.F. and V.H.F. generators, it is important at the same time to find and ensure all conditions required from the standpoint of protecting the health of those using the generators. In particular, it is necessary in designing new generators of H.F. and V.H.F. fields /116 to have all the protective equipment required to allow their use for the purpose for which they were intended. In testing the prototypes of new H.F. and V.H.F. generators, it is the duty of those responsible for checking production to see that there are no deficiencies as far as safeguarding the health of the workers is concerned. The technical specifications should include a report with data on measurements and information on required operating conditions. The obligation of the sales guarantee is to prescribe on the form, the required procedures to ensure conformity with hygenic conditions.

Of the organizational methods generally employed, mention should be made of the need for preventive periodic inspections as described in Handbook No. 113/1958 Sb., and the transfer of personnel (or changes in their work regime), in whom signs of damage due to electromagnetic radiation are evident, to another work area. Workers exposed to H.F. or V.H.F. in the course of routine work [285] must not run a risk at the same time of being exposed to ionizing radiation (i.e., doses exceeding 0.5 rem annually). Similarly, combination with other harmful agents is not desirable. If it is not possible to avoid the latter, so that there is reasonable certainty that the effects of the other agents and those of H.F. and V.H.F. radiation will have a mutually reinforcing effect, the responsible branch of the Hygienic and Epidemiological Service can reduce the highest attainable value of the harmful agent and H.F. and V.H.F. electromagnetic waves at the work area.

The highest admissible values of radiation set for workers do not apply in the case of irradiation of patients for medical treatment (diathermy, for example), where specific rules are required.

In the case of work areas (assembly rooms, factories) where work is in progress involving danger from H.F. and V.H.F. radiation, the management is required to distribute and post detailed safety-hygienic warnings, depending on the concrete conditions and working procedures in the plant.

It is naturally a good idea (and even a necessary one) for the producers and users of H.F. and V.H.F. generators to be able in their own way to measure the radiation in work areas where such generators are used, and in the vicinity (in adjacent work areas, etc.). It is a fact that working conditions and procedures change very rapidly, new equipment of different design is installed, the power level may change, there may be come new attachments installed, new protective measures may be taken, etc. Obviously, it is not possible in each individual case for measurements to be made only by the representatives of the Hygienic Service. In view of the large number of generators and plants where H.F. and V.H.F. energy is used, this would be beyond their power. Hence, the initiative must be taken in a number of enterprises which have the required equipment or have some other means of measurement [25, 263]. For example, the Radio-communications Inspection Agency has offices in Praque and Bratislava. It should also be emphasized that the staffs of the Hygienic and Epidemiological Services are authorized and accredited to check the measurements made by individual enterprises or institutions.

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