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PROTECTION FROM THE EFFECT OF RADIO WAVES (in the Maritime industry)

BY

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- USSR -

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PROTECTION FROM THE EFFECT OF RADIO WAVES

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CONTENTS

PAGE

CONTENTS (Continued) Page

FOREWORD

Powerful devices which emit electromagnetic energy are being widely introduced at the plants of the shipbuilding industry and in the maritime fleet. In connection with this development, new and complex problems are arising with respect to labor safety procedures for the people who service these devices.

This paper is the first effort to generalize data gathered by the author on labor conditions of workers who tune, regulate, test and operate high-frequency and superhigh-frequency devices.

The research was performed at the Laboratory of Physical Factors of the State Scientific Research Insitute of Labor Hygiene and Professional Diseases directed by Candidate of Medical Sciences Yu. A. Osipov, in the section for improvement of labor conditions of the TsNIIMF [Central Scientific Research Institute of the Maritime Fleet] under the direction of Candidate of Technical Sciences Ye. P. Zagorskaya with active assistance of the Electroradionavigation Chamber, the Basin Sanepidstantsiya [Sanitary and Epidemiological Station] and the Division of Labor Safety Procedures of Baltic State Maritime Steam Navigation and also the Division of Communication and Radio Navigation and the Labor Safety Inspectorate of Black Sea State Maritime Steam Navigation.

The book encompasses a broad class of problems; however, as a result of its limited size many theoretical and practical aspects have not found reflection here. The purpose of the book is to discuss radiation sources, familiarize the reader with methods of measuring radiation, and present an idea of possible intensities of irradiation during various types of operations and its biological effects. Primary attention has been given to selecting effective measures for protection from irradiation by radio waves.

The author takes this opportunity to express his sincere appreciation to all who assisted him in gathering and processing the research data providing the basis for this book. He also expresses gratitude to reviewers M. M. Semov and A. V. Bogdanov for vital remarks when reviewing the manuscript and to A. A. Mikhaylova and S. S. Ivanov for their assistance in organizing the material.

All comments on the book and suggestions should be addressed to Sudostroyeniye Press: Leningrad, D-65, Ul. Gogolya, 8.

CHAPTER I
ELECTROMAGNETIC FIELD DISTRIBUTION IN INDUCTION AND RADIATION ZONES

pp 5-10

The basis for the two laws of electromagnetic field theory discovered by D. Maxwell can be formulated in the following way: any variation of a magnetic field with time causes the appearance of an electric field and, inversely, any variation of an electric field with time causes the appearance of a magnetic field. The aggregate of a variable electric field and the variable magnetic field continuously connected with it is called an electromagnetic field.

The electromagnetic wave emission in space is formed on connecting a conductor to a source of alternating EMF. The best converters for converting the energy of an alternating EMF source into electromagnetic wave energy are antennas, the oscillatory circuits of tube generators and other special devices.

Theory and experience show that the electric and magnetic field intensity vectors in an electromagnetic wave are perpendicular to each other and to the direction of propagation.

In Figure 1 we have graphs of the variation of the electric field intensity E and the magnetic field intensity H of an electromagnetic wave propagated in the OY direction.

The distance which the wave moves in a time interval equal to one oscillation period is called the wavelength. The wavelength λ is equal to the product of its propagation rate c times the oscillation period T:

$$\lambda = cT. \qquad (1)$$

The oscillation frequency f is defined by the relation

$$f = \frac{1}{T}.$$

From this, the wavelength and oscillation frequency are related by the equation

$$\lambda = \frac{c}{f} . \quad (2)$$

Electromagnetic waves are propagated at the speed of light Generally speaking, the propagation rate of an electromagnetic wave in a medium with a dielectric constant ε and permeability μ is defined by the following expression (in the MKSA [meter-kilogram-second-ampere] system of units)

$$v = \frac{1}{\sqrt{\varepsilon\mu}} . \quad (3)$$

For air (free space)

$$\mu = 4\pi\cdot10^{-7} \text{ henries/m; } \varepsilon = \frac{1}{4\pi\cdot9\cdot10^{9}} \text{ farads/m,}$$

Therefore, substituting these values in formula (3), in the CGS system we obtain

$$v = 3\cdot10^{8} \text{ m/sec} = c \text{ or } v = \frac{c}{\sqrt{\varepsilon\mu}}$$

(for air $\varepsilon = \mu = 1$ and $v = c$).

The electric and magnetic fields in a propagated electromagnetic wave continuously interconvert. They are related mathematically by the expression

$$E\sqrt{\varepsilon} = H\sqrt{\mu} .$$

From this,

$$\frac{E \text{ volts/m}}{H \text{ amps/m}} = \sqrt{\mu/\varepsilon} = 377 \text{ ohms or } E = 377H,$$

where 377 is the number called the wave impedance of free space.

In field theory, two radiation zones are considered around any source of electromagnetic waves: the near zone or induction zone and the far zone -- wave zone -- or the emission zone.

The induction zone encompasses the region of space directly adjacent to the radiation source at distances appreciably less than the wavelength ($< \lambda/2\pi$). There is no defined relation between the electric and magnetic components of the electromagnetic induction field, and they can differ from each other by many times ($E \neq 377H$). The intensities of the electric and magnetic components in the induction zone are 90 degrees out of phase: when one of them reaches a maximum, the other is minimal (Figure 1,b). In the emission zone the intensities of both field components coincide with respect to phase, and they are proportional at any point in time. The mathematical relation E = 377H is meaningful only for the emission zone.

The electromagnetic fields in the induction zone have an energy which converts alternately from electric to magnetic energy and back. On going away from the radiation source these fields damp (are attenuated) rapidly. The intensity of the electric field component in the induction zone is inversely proportional to the distance to the third power, and the intensity of the magnetic component is inversely proportional to the distance squared.

In the emission zone the intensities of the electric and magnetic components drop comparatively slowly: inversely proportional to the distance to the first power.

Thus, the extent and boundary of the induction and emission zones are determined by the wavelength or the electromagnetic emission frequency.

Table 1 contains data on the approximate distances of the induction zone for high, ultrahigh and superhigh-frequency electromagnetic radio waves.

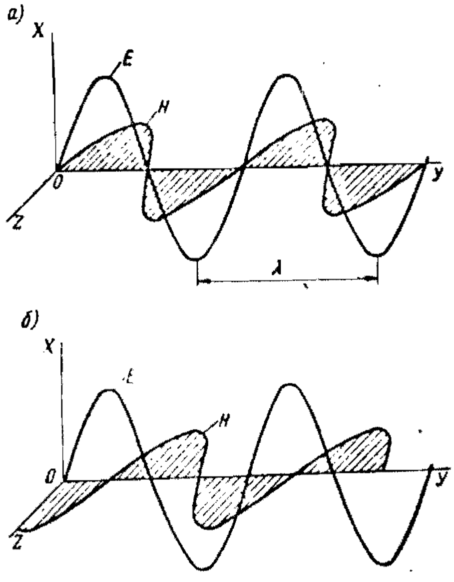

Figure 1. Graphs of variation of intensity of the electric field E and the magnetic field H of an electromagnetic wave in the emission zone (a) and in the induction zone (b).

The radio wave classification presented in the table is convenient and most useful in the practice of studying the effect of radio waves of various bands on the human organism, the more so since the adopted terms for radio wave spectra indicated in OST [All-Union Standard] 7768 of 27 December 1934, have at this time become obsolete. According to the classification, the radiofrequency emission band with frequencies of 100 kilohertz to 30 megahertz (wavelengths of 3 km to 10 m) is called the "high-frequency" band. The band with frequencies of 30 to 300 megahertz (wavelengths of 10 to 1 meter) is called the ultrahigh frequency band, and the band with frequencies of 300 to 300,000 megahertz (wavelengths of 1 meter to 1 mm) is referred to by the term superhigh frequency band which is widely used among radio engineers. In foreign publications microwaves belong to this band.

The distances of the provisional induction zone are presented in the table. As is obvious from these data, people working with induction and dielectric heating devices and also servicing radio communications stations operating on medium and short-wave bands are in the range of high-frequency induction fields which are propagated to a distance approximately 1.6 to 500 meters from the radiators. Inasmuch as interchanging electric and magnetic fields of different magnitude affect the workers in the induction zone, the irradiation intensity is estimated by the magnitudes of the intensities of the electric and magnetic components of the field separately.

Table 1
Radio wave spectrum

Radio wave band	Oscillation frequency	Wavelength	Provisional induction zone
High frequency:			
Long waves	100 to 300 kilohertz	3-1 km	500-160 meters
Medium waves	300 kilohertz to 3 megahertz	1-0.1 km	160-16 meters
Short waves	3-30 megahertz	100-10 meters	16-1.6 meters
Ultrahigh frequency	30-300 megahertz	10-1 meters	1.6-16 cm
Superhigh frequency:			
Decimeter waves	300-3,000 megahertz	1 meter to 10 cm	16-1.6 cm
Centimeter waves	3,000-30,000 megahertz	10-1 cm	1.6-0.16 cm
Millimeter waves	30,000-300,000 megahertz	10-1 mm	1.6-0.16 mm

In the SI [international system] system of units adopted at this time, the electric field intensity is measured in volts/meter, and the magnetic field intensity, in amps/meter.

In accordance with the "sanitation rules for working with sources of high and ultrahigh frequency electromagnetic fields" No 615-666 of 1 February 1966, the electric field intensity in the work areas should not exceed the following limiting allowable magnitudes of irradiation:

In the high-frequency band

For induction heating devices:

20 volts/meter -- with respect to the electric component;

5 amps/meter with respect to the magnetic component;

For dielectric heating devices, radios, and so on:

20 volts/meter -- with respect to the electric component;

In the ultrahigh-frequency band

5 volts/meter -- with respect to the electric component;

magnetic component not standardized.

In connection with the short wavelengths involved, the work areas of personnel servicing superhigh frequency devices are in the emission zone where the field intensity is estimated by the magnitude of the power flux density, that is, the amount of energy incident per unit surface. The power flux density is expressed in watts, milliwatts and microwatts per square centimeter (watts/cm^2, milliwatts/cm^2, microwatts/cm^2).

According to the "Temporary Sanitary Rules for Working with Centimeter Wave Generators" (No 273-58) the irradiation intensity at the location of the workers using centimeter and decimeter wave generators should not exceed the following maximum permissible values:

With irradiation:	microwatts/cm^2
For an entire working day	10
No more than 2 hours in a working day	100
No more than 15-20 minutes in a working day under the condition of mandatory use of protective glasses	1000

For a physical hygiene evaluation of the conditions of irradiation of service personnel, the nature of the radiation has significance along with the wavelength or frequency of the field. High-frequency industrial heating devices are continuous-action sources in contrast to radar which emits a pulse energy flux.

The service personnel working within the range of high-frequency fields propagated from industrial heating devices are irradiated by current fields created by the fundamental frequency of the generator and fields caused by inadequate filtration of the oscillations and the occurrence of a significant number of harmonics.

The oscillations emitted by high-frequency devices are usually modulated.

Radios on board ships operating, for example, in the telegraph mode on the same frequency as high frequency industrial heating generators emit the wave energy flux discontinuously in series of undamped oscillations of different duration (dot, dash -- to 120 signals per minute).

A still more complex field is emitted by radar operating in the pulse modulation mode. Energy is emitted in a series of pulses with very short time intervals (microseconds and less). In addition, from the point of view of effect on the organism a pulse energy flux can also be continuous or discontinuous depending on the type of operations. The nature of irradiation can depend on the number of turns of an antenna around its own axis, the scanning angle, and so on.

It must be considered that an electromagnetic field propagated from high frequency industrial heating devices or from a radio antenna is propagated comparatively uniformly in all directions (a circular radiation pattern), at the same time as the radar sets form a concentric beam of directional radiation. This fact has significance when determining the local or general nature of irradiation considering the distance from the radiator at which the work areas of the service personnel are located.

The nature of the electromagnetic field distribution in the facility or on the open deck of a ship is affected by metal structural elements of the ship superstructures and masts, various metal cables, rails, and so on. The external electromagnetic field (radiator field) induces an EMF in metal objects which causes the appearance of high-frequency currents in them. The currents induced in the metal structural elements create a high frequency electromagnetic field of secondary radiation in the surrounding space.

Thus, the intensity of irradiation of the personnel located near the emitting systems in a facility or on the open deck can be increased appreciably as a result of reemission of the wave energy by the metal objects.

In cases where the reflecting object has dimensions commensurate with the wavelength, resonance emission which is highest with respect to intensity can occur. This occurs most probably during operation of superhigh frequency devices. The intensity of the secondary superhigh frequency emission will be higher the higher the electrical conductivity of the reflecting object.

In the presence of intense external fields, inductions can be formed in a lighting system, in telephone lines, various metal tubes and central heating batteries which, in the absence of special filters or grounds, transport significant currents to adjacent settings. As measurements have demonstrated [3, 12], the intensity of irradiation of the personnel not directly connected with work on a high-frequency industrial heating device can exceed the allowable sanitary norm as a result of induced currents and secondary emission.

In estimating the labor conditions of people who work with high and superhigh frequency devices, the irradiation intensity has primary significance. This irradiation intensity is characterized by the qualitative parameters of the electromagnetic field provisionally defining the zone of intense effect, the nature and duration of radiation, and the presence and location of metal objects changing the field distribution pattern. The irradiation intensity when working with electromagnetic radio wave emitters depends on many factors, above all, on the power of the device, the distance from the work areato the radiation source, the nature of scanning, the arrangement of the emitting elements with respect to each other and the presence of metal objects near the radiators.

CHAPTER II

METHODS OF DETERMINING THE INTENSITY OF IRRADIATION BY HIGH AND SUPERHIGH-FREQUENCY ELECTROMAGNETIC WAVES

pp 11-24

§ 1. Measuring the Intensity of the Electric and Magnetic Components of a High-Frequency Electromagnetic Field in the Induction Zone

The effect of radio waves on the organism of man is taken to be characterized by the irradiation intensity. The irradiation intensity when working with high and ultrahigh-frequency sources is estimated by the magnitude of the electromagnetic field intensity.

The electromagnetic field in the induction zone, that is, at a distance from the radiation source which is small by comparison with the wavelength has characteristic features which require special devices for measurement.

At the present time industry is manufacturing field intensity meters designed to measure the radio interference field in the emission zone (wave zone) where the field intensity is insignificant; therefore, they are highly sensitive and equipped with comparatively large antennas. Inasmuch as there is an invariant relation ($E = 377H$) between the electric and magnetic components in the emission zone, it is sufficient to measure one of them to determine the other.

Usually the magnitude of the electric component of the high-frequency electromagnetic field is estimated by an interference field meter. In view of the fact that the electric and magnetic field components in the induction zone are not related by a defined relationship, it is necessary to measure them individually. The Leningrad Labor Protection Institute of the VTsSPS [All-Union Central Trade Union Council] has developed a special device -- the IEMP LIOT for measurements in the induction zone. It has used the device for many years. The device offers the possibility of separate measurement of the electric and magnetic field components [94].

The IEMP LIOT device is a nonresonance type device, and it is designed to measure the effective intensities of the electric field within the limits from 4 to 2,000 volts/meter in the frequency band from 100 kilohertz to 300 megahertz and the magnetic field within the limits from 0.5 to 500 amps/meter in the frequency band from 100 kilohertz to 1.5 megahertz.

The instrument includes three pickups and an amplifier with battery feed. For measuring the electric field intensity there are two pickups with dipole type antennas one of which is designed for measurements in the 100 kilohertz to 30 megahertz band, and the other, in the 30-300 megahertz band. The pickup for measuring the magnetic field has two frame antennas. The choice of the pickup is determined by the specific measurement conditions.

Let us consider the circuitry of the meter (Figure 2).

At the input of the electronic amplifier there is a limit switch ПК for measuring the intensities of the electric and magnetic field components.

The meter has highest sensitivity when ПК is set to position 5 for measuring the electric field and position 3 for measuring the magnetic field. The rectified current then goes through two active capacitance filters R_1-R_5 and C_1-C_5 which block the 50 hertz voltage and the high-frequency voltage fed to the tube amplifier L_1, L_2 and L_4.

The operation of the tube amplifier is based on conversion of the direct-current voltage (B_a, B_s, B_n) into variable voltage by means of a vibrating-reed converter -- the relay PП-4 which is excited by the generating tube L_3. The vibration frequency of the PП-4 relay is about 200 hertz. The amplified current is rectified by the contact of the relay PП-4, and it is measured by a microammeter μA. The resistance R_{16} is used for feedback, and the capacitors C_9 and C_{11} and the resistance R_{12}, to eliminate excitation.

When measuring the magnetic field intensity, the EMF occurring in the loop is proportional to the frequency. The amplification and measurement of the rectified voltage are realized just as when measuring the electric field intensity.

By means of a button switch ПК the microammeter μA can be used to control the voltage of the A battery H, the anode battery A, and the feed voltage of the relay P. The rheostat CП is used to regulate the feed voltage of the PП-4.

The magnitude of the measured intensity of the electric or magnetic field components is determined by the calibration curves in accordance with the deflection of the instrument pointer.

In avoiding significant errors when measuring the electric or magnetic field components, the dipole or frame, respectively, should not approach surrounding objects to a distance commensurate with the dimensions of the dipole or frame (in practice, a distance less than twice or three times the length of the dipole or diameter of the frame). High intensity (about 10,000 volts/meter) interference created by 50 hertz electric fields and also electrostatic fields can occur during the measurements. However, in spite of the indicated deficiency, the instrument is stable in operation, simple and convenient to use, and therefore it is widely used both for experimental and practical purposes.

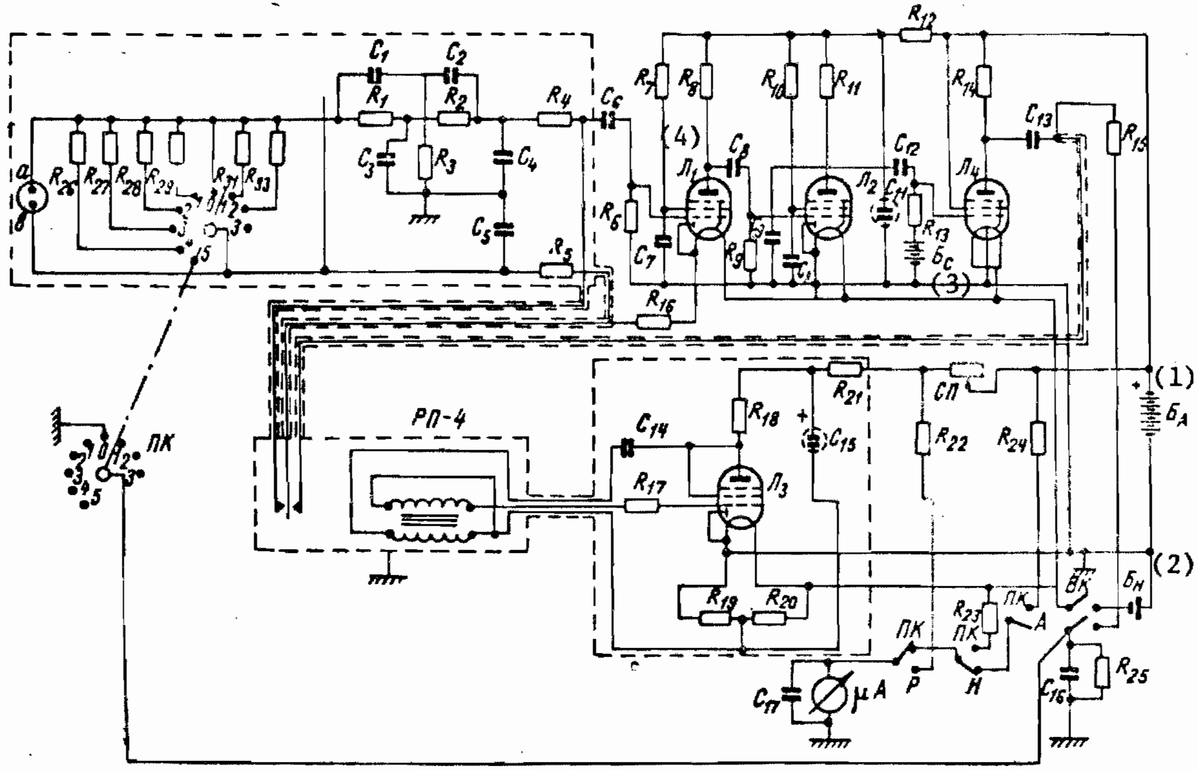

Figure 2. Electric circuit diagram of a device for measuring field intensity.

Key: 1. B_a 3. B_s
2. B_n 4. L...

The IEMP LIOT instrument can be used to measure the effective values of the intensity of electromagnetic fields emitted by devices for high-frequency industrial heating of metals and dielectric materials and the intensities of electromagnetic fields near the emitting elements of radios and other equipment operating in the continuous mode. In the case of sinusoidal variations of the field components with time the instrument has an error of no more than 20 percent. The IEMP LIOT is unsuitable for measuring the field intensities near high frequency devices operating in the pulse mode.

If it is necessary to measure the electromagnetic field intensity near devices operating at frequencies below 300 megahertz in the continuous and pulse modes, it is possible to use the analog device P3-2 (Medik-2).

The frequency band of fields measurable by the P3-2 instrument with respect to electric and magnetic components is 200 kilohertz to 300 megahertz for continuous and modulated oscillations and 30-300 megahertz for pulse oscillations.

The measurement limits of the effective intensities for continuous and modulated oscillations with respect to the electric component are 0.5-3,000 volts/meter; with respect to the magnetic component, 0.06-500 amps/meter, and for pulse oscillations, 20-10,000 volts/meter and 2-2,500 amps/meter, respectively. The instrument error is 30-50 percent of the measured value (under normal conditions) considering corrections to the frequency and modulation parameters.

Both instruments are portable, they are operated by one health physics officer, and they can be used for taking measurements under laboratory, shop and field conditions and directly on board ship.

The most significant deficiency of the P3-2 instrument consists in limiting the measurable fields to a frequency of 200 kilohertz; therefore, it is impossible to use it for field measurements near high-frequency industrial heating devices, especially late models, and other devices operating in the 60-100 kilohertz band.

This gap is partially filled by an instrument for measuring the intensity of the electric and magnetic field components in the induction zone in the 50 hertz to 100 kilohertz frequency band also built by the Leningrad All-Union Scientific Research Institute of Work Safety [37]. The device permits measurement of the electric field components at a frequency of 50 hertz within the limits of 200-3,000 volts/meter, at a frequency of 100 kilohertz within the limits of 5-3,000 volts/meter and the magnetic field component at a frequency of 50 hertz within the limits of 20-3,000amps/meter and at a frequency of 100 kilohertz within the limits of 0.5-300 amps/meter.

In addition to instrument checking of the field intensity near radiation sources in industrial practice, especially when tuning ship radio transmitters, frequently field intensity indicators are used.

A neon tube is the simplest indicator. However, it has a high, unstable ignition voltage amounting to about 50 volts and more, and it is suitable only for recording significant field intensities greatly exceeding the maximum permissible values.

§ 2. Measuring the Superhigh-Frequency Power Flux Density

When working with superhigh-frequency radiation sources (millimeter, centimeter and decimeter waves), the service personnel are, as a rule, in the wave zone, that is, at distances appreciably exceeding the wavelength. The irradiation intensity is determined by the magnitude of the superhigh-frequency oscillation energy per unit time through a unit area perpendicular to the direction of wave propagation. This value is called the power flux density.

Industry is manufacturing radiotechnical devices which can be adapted for measuring the power flux density. These devices are called power meters.

By using auxiliary high-frequency elements in the form of antennas, attenuators, directional attenuators and other high-frequency elements making up these instruments, it is possible to determine the power flux density with sufficient accuracy in the work areas for servicing the superhigh-frequency devices.

In Figure 3 we have block diagrams used when measuring the power flux density and field intensity of superhigh-frequency emission. A schematic of a high-frequency wave guide channel 4 when taking measurements by means of a horn antenna 2 appears in Figure 3,a. In order to measure the power flux density, it is necessary to connect a horn antenna with known effective surface S_{eff} to the input of a low-power meter 3 through auxiliary high-frequency elements (required depending on the intensity of the measured field or power of the radiator 1). If S_{eff} is unknown, it is determined from the relation

$$S_{eff} = \frac{G\lambda^2}{4\pi} \quad cm^2,$$

where G is the gain of the antenna o.e.

λ is the wavelength, cm.

The gain G is usually given in the antenna certificate.

The effective surface of the antenna depends on the frequency; therefore, in order to obtain a smaller measurement error it is expedient to calibrate the antenna with respect to frequency within the band limits in which the measurement is taken (8-12 cm, 3-3.5 cm, and so on). The most exact measurement results are obtained when using antennas with S_{eff} = 5-50 cm.

As the measuring antenna it is recommended that an antenna with a wide radiation pattern and relatively small geometric dimensions be used in order not to introduce strong distortions into the measured field.

All the elements of the high-frequency channel connecting the antenna with the meter must be matched.

In the case of using high-frequency cable (for example, in the standard instrument 31-IM), it is necessary to consider its attenuation which can reach several decibels per meter.

After measuring the total absorbed power by the instruments, it is easy to calculate the power flux density by the formula

$$\rho = \frac{P}{S_{eff}},$$

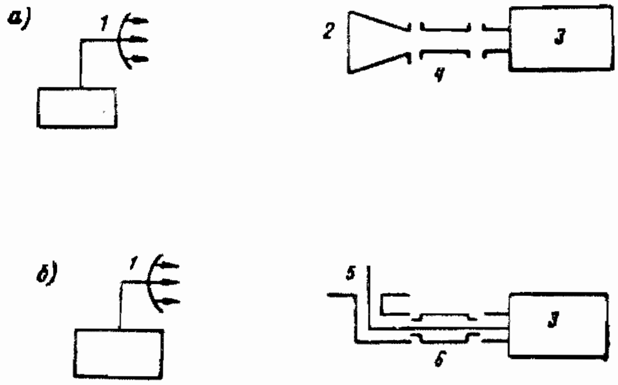

Figure 3. Block diagrams used when measuring the power flux density (a) and the field intensity (b) of superhigh-frequency emission.

where ρ is the power flux density, microwatts/cm^2;

P is the measured power, microwatts;

S_{eff} is the effective absorbing surface of the antenna, cm^2.

In Figure 3,b we have a schematic for measuring the intensity of the superhigh-frequency electric field by a rod antenna 5. There is such an antenna in the RT-10 device. The coaxial high-frequency channel 6 usually used for measurements in the long wave part of the centimeter and decimeter wave ranges differs from the wave guide channel only with respect to dimensions and design of the coaxial parts.

Knowing the field intensity, the power flux density can be calculated by the formula

$$\rho = \frac{E^2}{377} \text{ watts/m}^2,$$

where E is the electric field intensity, volts/meter.

Low power meters offer the possibility of estimating the irradiation conditions of people working with superhigh-frequency radiation sources with sufficient accuracy. However, it is necessary to consider that a number of these industrially produced meters do not have complete shielding of the circuitry. This leads to additional errors when taking measurements especially within the range of strong fields. In order to eliminate this error, the instrument is checked by placing it in the field with the inlet closed. If the indicator of the low-power meter deflects, it is necessary to provide additional shielding of the instrument. For this purpose, it is placed in a metal box shield the peepholes of which can be closed by a grid. This type of shielding was carried out when measuring intense fields by means of the VIM-1 instrument.

Use of low power meters in a broad frequency band is accompanied by difficulties since each of the meters is designed for taking measurements in a defined narrow frequency band and does not always provide the required power measurement limit.

An all-purpose meter for measuring the power flux density and field intensity of centimeter and decimeter radio waves was developed for the first time in 1957-1958 by the Laboratory of Physical Factors of the Leningrad State Scientific Research Institute of Labor Hygiene and Professional Diseases. This meter was manufactured jointly with superhigh-frequency engineering specialists [48].

It is possible to consider some operating inconvenience as a result of absence of battery feed among the deficiencies of the device.

This deficiency is eliminated in the industrially manufactured PO-1 device (Medik-1) designed for measuring the power flux density in the superhigh-frequency band. The instrument is a device comprising a superhigh-frequency power meter and a set of measuring antennas. The power meter, in turn, consists of a thermistor bridge and a set of remote thermistor heads. Attenuators are used to expand the measurement limits. The block diagram of the power flux density meter is presented in Figure 4.

In order to use this device, the antenna is placed in the measured field. The high-frequency energy taken by the antenna goes to the attenuator and the thermistor head. Part of the power is dissipated in the attenuator, and the rest is absorbed by the thermistor. In the case of low emission intensities, the thermistor head is connected directly to the antenna. The thermistor is included in a direct current measuring bridge by means of which the measurements are taken. The circuit diagram of the power meter consists of a double thermistor bridge, a 60 kilohertz generator and two measuring instruments.

The power flux density ρ is defined by the formula

$$\rho = \frac{Pn}{S},$$

where P is the reading of the power meter, microwatts;

S is the effective surface of the antenna, cm^2;

n is the attenuation of the attenuator.

The power flux density meter PO-1 has a set of antennas (11 of them) of the horn and logarithmic types thanks to which it is possible to take measurements in the 150 to 16,700 megahertz band. This corresponds to wavelengths of 200.0-1.8 cm. The power measurement limits of the device are 50-8,500 microwatts. The measurment error using the compensation method is (2-4 percent) ± 5 microwatts. The device is fed from an AC 220 volt network and from storage batteries.

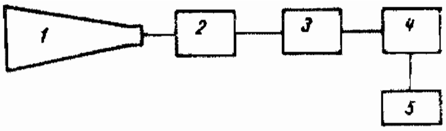

Figure 4. Block diagram of the power flux density meter type PO-1. 1 -- antenna; 2 -- attenuator; 3 -- thermistor head; 4 -- power meter; 5 -- feed unit.

It is possible to consider operating inconvenience under production conditions among the deficiencies of this instrument. This applies especially to ship conditions in view of the awkwardness of its antennas (in the decimeter wave range) and also complexity of calibration and null instability.

Measurements of the intensity of irradiation by electromagnetic radio waves in the superhigh-frequency band, especially at high power, must be taken with the power of the emitting device reduced by n times. In order to obtain its true value, the measured power density flux is increased as many times.

If several emitting devices on different frequencies are operating simultaneously in a facility, then the power flux density is measured on each frequency separately and the results are summed.

When using centimeter wave generators, in accordance with the "Temporary Sanitary Rules" No 273-58 it is necessary to measure the power flux density no less than once every two months. In the majority of cases, and especially when working in open areas, the number of measurements can be reduced if the boundary of the danger zone where the power flux density exceeds the allowable is determined. The absence of precise power flux density data near the superhigh-frequency emission source and lack of knowledge of the limits of the danger zone can lead to excessive restriction of operations near the radiators.

The boundary of the danger zone or magnitude of the field where the power flux density does not exceed the allowable can be determined by the following formula:

$$R_{\text{н}} = R\sqrt{\frac{P}{P_{\text{allow}}}}^{*},$$

where $R_{\text{н}}$ is the distance from the source at which the irradiation does not exceed the allowable, meters;

---

[*] This formula is applicable only under the condition that $R > \frac{D^2}{\lambda}$, where D is the largest geometric dimension of the transmitting antenna, meters; λ is the wavelength, meters.

R is the distance from the source at which the measurement is taken, meters;

ρ is the measured power flux density, microwatts/cm^2;

ρ_{allow} is the allowable power flux density, microwatts/cm^2.

In addition to power flux density meters, Soviet industry also manufactures field indicators. Thus, the P2-2 type indicator of dangerous electromagnetic field intensities is designed for measuring the power flux density levels of superhigh-frequency oscillations in open space, in closed facilities (cabs, containers, motor vehicle bodies, compartments, and so on) under production, ship and field conditions.

The instrument provides for measuring the power flux density in the presence of continuous, AM, FM and pulse-modulated superhigh-frequency oscillations in the 300-16,000 megahertz frequency band. The operating frequency band of the instrument is covered by logarithmic-periodic (300-2,500 megahertz band) and horn (2,500-16,000 megahertz band) antennas with coaxial leads.

The indicator offers the possibility of measuring the power flux density within the limits of the allowable norms from 10 to 1,000 microwatts/cm^2.

The Shipbuilding Administration, the Administration of the Medical Service, the Federal Communications Commission and other organizations and companies in the United States, England and France dealing with problems of measuring dangerous doses of superhigh-frequency radiation also build instruments for measuring the power flux density in individual frequency bands.

The medical and technical controlling services in the USA have used a B-86-B$_1$ type power indicator built by the Sperry Microwave Electronics Company since 1961. It reacts to pulse and continuous emission with linear and circular polarization in the 400-10,000 megahertz frequency band [108].

The new Densitometer type indicator model 1,200 [119] is the most portable instrument with battery feed. It is manufactured with seven antennas covering frequencies from 200 to 11,000 megahertz [119].

Cottingham [104] reports on construction of a monitor for determining intense emission of radar consisting of an input channel, a detector, an amplifier and a pointer indicator.

An analogous device made of semiconductors with battery feed and built in a pistol-shaped housing is manufactured by the English company G. and E. Bredley, Ltd. [126].

The foreign and Soviet power flux density meters or indicators used up to now offer no possibility of measuring the superhigh-frequency energy acting on the organism of man under various conditions of periodic emission. They are based on measuring the mean emission intensity. The readings of instantaneous values of the instruments vary within broad limits as a result of beam scanning or rotation of the antenna. The basic criteria in determining the harmfulness of the active factor should be, above all, the intensity and duration of emission. For this reason, the possibility of integrating the energy flux in case of its periodic effect would greatly facilitate solution of the problem. As Metze and Shoene report [119], this device was built in 1962 by the Bissett Berman Company on the basis of a unique electrolytic integrating element. The device integrates the energy levels of superhigh-frequency irradiation over a time interval of 30 seconds and gives the reading result in digital form (in joules per square centimeter).

The electolytic element is a miniature electrochemical device which integrates the direct current flowing through it by electrolytic transfer of matter. By Faraday's law, the amount of matter transported from one electrode to another is directly proportional to the product of the current passing through the electrolyte in time, that is, the total charge Q. Consequently, if there is a known quantity of coating substance on one of the electrodes of the element capable of electrolysis and if a direct current of known magnitude is passed through the element, the process of transport of matter from one electrode to the other takes a time which can be exactly predicted. The operating schematic of the element is depicted in Figure 5.

Figure 5,a reflects the state of the element when all the soluble material M is deposited on the anode A made of a noble metal not subject to electrolysis. In this state the element easily transmits a direct current from the batteryE connected through the resistance R. This takes place because the deposited matter is easily converted to solution to the extent that electrolysis deposition of the substance takes place on the cathode. The voltage drop on the element during the deposition time is 30-50 millivolts. When all the substance is transferred to the cathode K (Figure 5,b), the internal resistance of the element increases sharply (Figure 5,c). The voltage drop on the element increases to the voltage on the battery terminals inasmuch as there is no soluble material on the anode leading to the formation of ions -- charge carriers.

The entire electric charge which passes through the element only changes the location of the material capable of electrolysis, and, consequently, the element is also passive and is not a source of energy. This feature insures relatively independent operation of the instrument with respect to temperature conditions.

The integrating element has the following characteristics: the range of integrating currents is from 0.01 to 100 microamps; the minimum measurable charge is 1 microcoulomb (1 microamp·sec); the range of read-out currents is from 10 to 100 microamps.

The operating principle of the instrument, with the exception of using an electrolytic element, is the same as for the majority of power flux density meters. The superhigh-frequency emission energy received by the antenna is fed to an ordinary thermistor bridge with temperature stabilization, but the

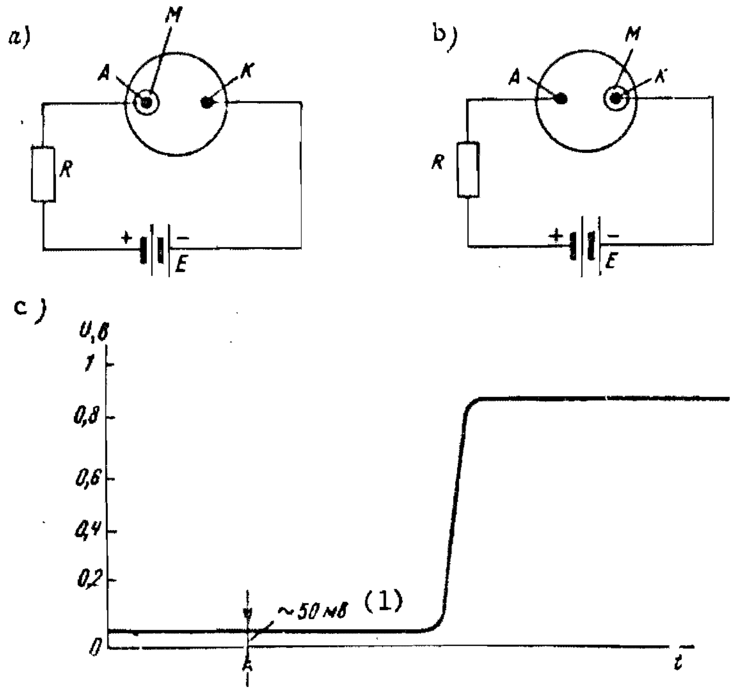

Figure 5. Operating schematic of an electrolytic element: a -- state of the instrument at the beginning of the integration cycle; b -- state of the instrument with respect to the course of the cycle; c -- variation of voltage on the element.

Key: 1. ~50 millivolts

unbalanced current of the bridge is recorded in the given case every 30 seconds not by an ordinary indicator but by an indicator in the form of an integrating electrolytic element. At the end of each period the element is switched to the read circuit; then the element is again connected to the measuring circuit for the next measuring session.

Such devices can be used to estimate the periodic irradiation when it is necessary to establish the total dose of electromagnetic superhigh-frequency emission affecting a man.

In estimating the possible irradiation intensity far from the emission source frequently approximate calculations are used. Thus, Shinn [129] proposes estimating the power flux density at the points of the far zone (radiation zone) located in the direction of maximum radiation of the antenna from the expression

$$\rho = \frac{180 P_{\text{л}}}{D^2}\left(\frac{R}{r}\right)^2,$$

where ρ is the mean power flux density, milliwatts/cm^2;

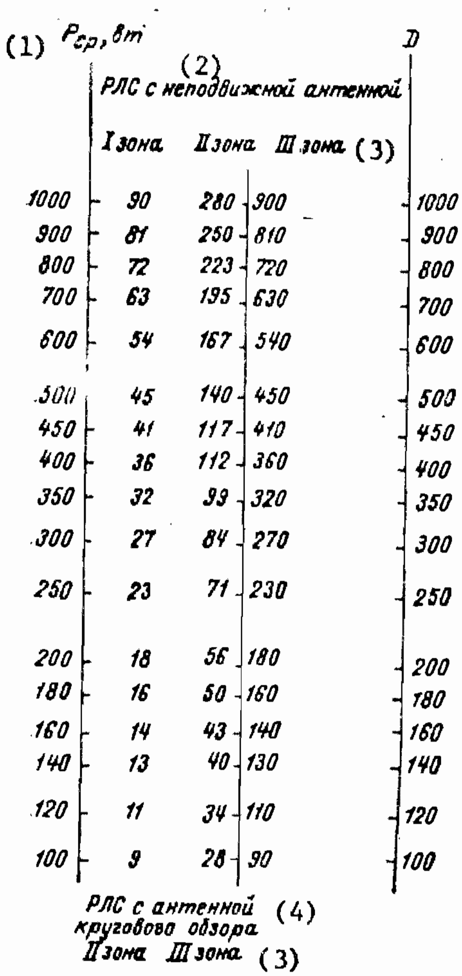

Figure 6. Nomogram of S. Ya. Zarzhevskiy and O. N. Karelin for determining the safety zones around radar.

Key:
1. P_{ave}, watts
2. radar with stationary antenna
3. zones
4. radar with circular scanning antenna

P_a is the power fed to the antenna of the transmitting line, kilowatts;

D is the antenna diameter, meters;

$R = \frac{D^2}{2\lambda}$ is the radius of the near zone, meters;

λ is the wavelength, meters;

r is the distance from the antenna, meters.

This equation is correct for all distances exceeding twice the radius of the near zone (induction zone). The absolute maximum of the power flux density occurs at a distance of 0.5 R from the antenna, and it is equal to 347.4 P/D^2.

In order to obtain the magnitude of the mean power flux density at the point of the far zone located in the direction of the maximum emission of the antenna or a radar or other pulse transmitter it is necessary that the value obtained rfrom the presented equation be multiplied by the duty factor 1/Q (where Q is the off-duty factor).

The Calculation techniques which can be used approximately to determine the distances of the danger zones near antennas of various types are also presented by Tolles and Horwath [134], Mumford [122], and so on.

In determining the intensity of irradiation near radar stations Allen [101] proposes a nomogram by means of which it is possible to find the irradiation intensity for a known width of the beam radiation pattern, pulse power and repetition rate. However, it is more convenient to use the nomogram proposed by S. Ya. Zarzhevskiy and O. N. Karelin [29] for determining the dimensions of the safety zones around radar with stationary antennas and circular scanning antennas. This nomogram is calculated considering the maximum permissible values of the superhigh frequency radiation (Figure 6). According to this nomogram, the boundaries of the safety zone are determined by the following formula:

$$R = \sqrt{\frac{P_{cp} D}{4\pi p}},$$

R is the distance from the antenna;

P_{cp} [P_{ave}] is the average power emitted by the antenna;

D is the directive gain of the antenna;

ρ is the power flux density.

The values of P_{ave} and D are taken from the radar log.

If the pulse power of the radar P_{pulse} and the off-duty factor Q are given in the log instead of the average power, then P_{ave} is calculated by the formula

$$P_{ave} = \frac{P_{pulse}}{Q}.$$

Example.

P_{ave} - 180 watts; D = 700. The inside boundaries of the safety zones around the radar are at the following distances:

Zone	Irradiation time	Distance, meters
I	$\geq$ 15-20 minutes	99-32
II	$\geq$ 2 hours	320-99
III	Working day	< 320

It is permissible to be in zone I at the indicated distances from the radiation source only under conditions of using protective glasses, and closer than 32 meters, only in protective clothing.

A neon tube can also be used as an approximate index of the presence of an intense superhigh-frequency field. According to the data of foreign authors [20], the existing neon tubes have an ignition threshold from 5 to 6 milliwatts/cm^2.

Thus, the presently used instrument methods of determining irradiation intensity when working with superhigh-frequency devices can be supplemented by calculation methods or determinations by nomograms. Calculations of the irradiation intensity, for example, for people who work with high frequency heating devices are difficult as a result of the sharp nonuniformity of the the field near the radiation source. Such calculations are mathematically possible only with rough assumptions.

CHAPTER III
ELECTROMAGNETIC HIGH AND SUPERHIGH-FREQUENCY FIELDS IN WORK AREAS

pp 25-75

§ 1. Electromagnetic Fields Near Tube Generators for High-Frequency Heating of Metals

Instrument evaluation of the intensity of irradiation of people working with superhigh-frequency steel heating devices is possible in practice only after development of a special field intensity meter in the induction zone.

At this time a great deal of information has been published [44, 50, 51, 64, 69, 74, 84, 96] which gives a quantitative characteristic of radio wave irradiation of people working with various induction heating devices. However, it is impossible to say in advance what the irradiation intensity can be on changing the technological process and, especially, when introducing new developments (high-frequency plasma generators, and so on) which can be accompanied not only by radio wave emission but also by such biologically active physiological factors as radiant energy, ultraviolet radiation, increased ionization of the environment, and so on [3, 12, 70].

Devices operating at frequencies from 60 to 800 kilohertz with a maximum power of 400 kilowatts, which can be obtained in an anode circuit, are being used for high frequency heat treatment of metals.

Sources of electromagnetic radio waves of high-frequency induction heating devices can include the following depending on their structural peculiarities and type: operating elements (melting or quenching inductors), various elements of the generator circuit included in the high-frequency current circuit (induction coils of oscillating circuits, feedback coils, capacitors, anode chokes, tube anodes, certain measuring instruments, and so on) and also buses and conductors bringing high frequency energy to the inductors.

Soviet industry has manufactured high-frequency heating devices for several decades; therefore, the large variety of their structural execution has led to the idea of classifying them by nature of shielding. Of course, the nature of shielding of the device is, as a rule, the basic criterion of e estimating the intensity of irradiation of service personnel.

In Figure 7 we have the block diagrams of induction heating devices for metals (5) divided into four groups with respect to nature of shielding.

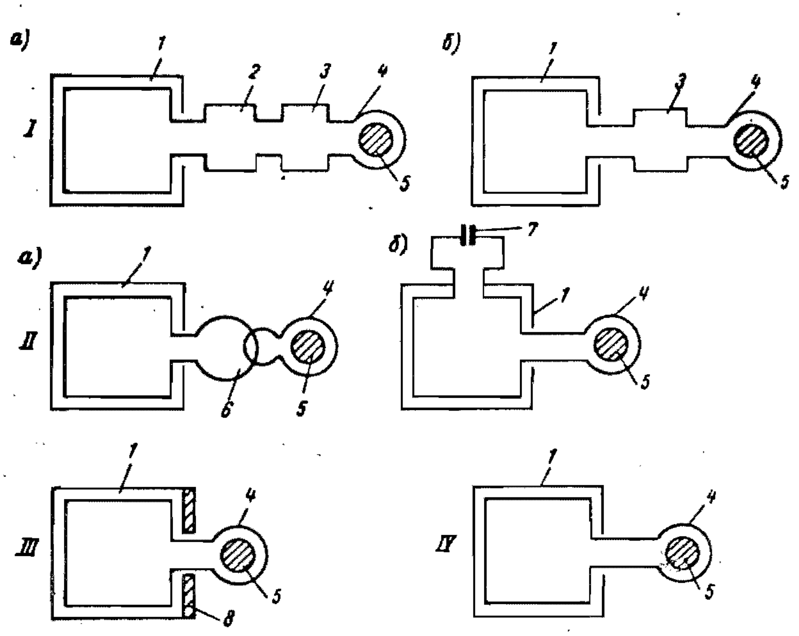

Figure 7. Block diagram of induction heating devices differing with respect to nature of shielding. Ia, b -- devices of the first group with an unshielded operating inductor and oscillatory circuits 2, 3; II -- devices of the second group with unshielded operating inductor and matching high frequency transformer (a) or circuit capacitor banks (b); III -- device of the third group with unshielded operating inductor and wood front control panel; IV -- device of the fourth group with only the operating inductor unshielded.

The first group includes old type devices (G-4-42, GLZ-61A, GZ, GL, and so on). They have the most unsatisfactory shielding. The step-up anode transformer of these devices, the thyratron rectifier, generator tubes and certain other elements of the generator circuit are placed in a metal housing, and the oscillatory circuits emitting an intense electromagnetic field 2 and 3 with capacitor banks are outside the bay 1 and not shielded at all (they are in wooden boxes).

The irradiation intensity when working with such devices is hundreds and thousands of volts per meter with respect to the electric component of the field and several hundreds of amperes per meter with respect to the magnetic component [51].

The highest value of the field (up to a thousand or more volts per meter) is observed near the oscillatory circuits of the device. Therefore, it is undesirable to place devices of the first group in common facilities since people not connected with working on the device may be subjected to intense irradiation.

The second group includes devices with an unshielded (in addition to the operating inductor 4) high-frequency matching transformer 6 (LGZ-100, LGPZ-30, LGPZ-60, LZ-107, LZ-207, and so on) or capacitor banks of the oscillatory circuit 7 placed on the top of the generator bay (LG-60A, GZ-46, and so on). These devices are most numerous, and they are encountered most frequently in industry, especially since the newly built series of devices (LZ-107, LZ-207, and so on) operating at frequencies of 60-70 kilohertz have no shielding not only of the matching transformer 6 but the basic operating element.

The measurements taken near the emitting elements of this group show that the magnitudes of the field (near the transformer) reach tens and sometimes hundreds of volts per meter with respect to the electric field and tens of amperes per meter with respect to the magnetic field.

When working with devices of the second group (Figure 7,IIb), the presence of high intensity of the electric component of the field (with minimum magnetic component) at the level of the worker's head and high intensity of the magnetic component of the field in the vicinity of the midsection of the trunk is characteristic. This distribution pattern of the field is obtained as a result of absence of shielding of the capacitor bank (installed on the top of the bay) of the oscillatory circuit and the operating inductor.

The third group includes devices with an unshielded operating inductor 4 and a wood front control panel 8 (LZ-43, LZ-46, GZ-48, and so on). Although the high-frequency elements of the generator circuit are also included in a metal bay, they remain unshielded in practice inasmuch as the bay of the device has no metal front panel.

The field intensity when working with these generators reaches the following values in the work areas: 60-90 volts/meter with respect to the electric field and 15-20 amps/meter with respect to the magnetic field.

The fourth group includes devices types LGZ-100-53, LPZ-100, LGZ-200, LGZ-10, LGZ-10A, LG-7, LG-3, LZ-37, LP-67, and so on. They are assembled so that all the high-frequency elements are in the bay. Only the operating elements in the form of the melting or quenching inductor are outside the bay. This group includes a large series of 60-70 kilohertz quenching devices manufactured in recent years.

When working with such devices used for quenching metals the irradiation intensity is appreciably less than when working on all other devices. As a rule, it does not exceed hundreds of volts per meter and tens of amperes per meter at distances of 0.25-0.5 meters from the radiation source.

The magnitude of the field intensity can be increased if a multiturn inductor with the same oscillatory power of the generator is used instead of a single-turn inductor [91]. Measurements show that near the single-turn quenching inductor of the LZ-37 device, a field of 40-60 volts/meter is formed at the same time as under other equal conditions a multiturn inductor creates a field up to 120-150 volts/meter. By comparison with a quenching inductor, a multiturn melting inductor creates fields in the operator work area which are reckoned at several hundreds of volts per meter and tens of amperes per meter.

The high-frequency energy transmission line executed in the form of copper buses or tubes can also be a radiator of electromagnetic waves. Such lines are used in cases where it is necessary to remove the inductor to some distance from the device. Sometimes the high frequency energy emitter can be a measuring instrument included in the high frequency current circuit and mounted on the generator control panel (LGZ-100, LGZ-200, and others).

The metal bay of the device usually has gratings, peepholes and often, simply slits, which upsets the shielding effect as a result of which field intensities reaching hundreds of volts per meter and tens of amperes per meter can be observed next to the bay. This fact must be considered when placing the work tables in the facility where high-frequency heating takes place.

The field distribution pattern in the work area when servicing a device without sufficient shielding can vary, as has been pointed out, as a result of secondary emission formed by metal objects. Thus, according to measurement data, when building up cutting tools on the LZ-107 device the intensity of irradiation of the man operating the device was 36 to 40 volts/meter with respect to the electric field; in the presence of a large number of cutting tools on the work table the irradiation intensity increased to 58-60 volts/meter.

Thus, the intensity of the electric component of the high-frequency electromagnetic field in the work areas for servicing induction heating devices having a different degree of shielding can be tens, hundreds and in individual cases even thousands of volts per meter. The magnetic component does not, as a rule, exceed 100 amps/meter.

§ 2. Electromagnetic Waves Near Tube Generators for High-Frequency Heating of Dielectrics

Operating electrodes in the form of different types of capacitors and also all remaining high-frequency elements of a generator circuit can be, above all, a source of electromagnetic radiation of high-frequency devices for dielectric heating in the absence of shielding.

At the present time, two basic areas of application of dielectric heating have been defined: drying of wet materials and heat treatment of plastics. The first operation is realized most frequently on devices types GS-48, GS-46, GLE-61A and others with a power of tens of kilowatts operating in frequency bands to 1 megahertz.

Until recently, for purposes of heat treating plastics, devices type LGD-1, LGYe-3B, LGYe-10A, LGD-30, and so on with power from one to 30 kilowatts and a frequency of 10-30 megahertz were series manufactured. Now the indicated devices have been replaced by LGD-12, LGD-62, LGD-32, LD1-4, and so on in which higher frequencies are used.

The dielectric heating devices, just as induction heating devices, are combined into three groups for convenience of investigation. In Figure 8 we have the block diagrams of the devices which give an idea of the nature of their shielding.

The first group includes devices designed for drying wet materials, wood, yarn, and so on. They include devices type GS-48, GS-46, and so on. Structurally, they are in the form of a metal bay 1 with a wood front panel 4 on which measuring and control instruments are installed. The electromagnetic field formed by the high-frequency elements of the generator circuit placed inside this bay freely penetrates the wood panel. In addition, the side walls of the bay have holes in the form of windows and gratings.

The intensity of the electromagnetic field in the work areas for servicing such devices can reach several hundreds of volts per meter (up to 500 and more) and tens of amperes per meter in direct proximity to the control panel or the installed windows located opposite the induction coil 6 or the capacitor banks 5. The absence of shielding of the front panel of the dielectric heating devices, just as induction heating devices, leads to the formation of high field intensities in the work area.

The operating elements in the form of electrodes (drying capacitors) 2 in this type of device are mounted in special, as a rule, metal chambers. The chamber is loaded through doors equipped with electromagnetic blocking and usually not connected with the generator area. Observation of the drying process is carried out through special peepholes which are frequently simply covered with glass. As measurement experience shows, the electric component of the field near the peepholes can be within the limits of tens and sometimes hundreds of volts per meter with an insignificant magnetic component which does not exceed 0.5 amps/meter.

An intense electromagnetic field (sometimes up to 100 volts/meter) is formed throughout the entire facility where the generator is installed and from where the drying process is controlled (in Figure 8 outlined by the dotted line). In addition to the above indicated causes, the presence of large fields in this facility is explained by the absence of shielding of the buses 3 which transmit the energy of the high-frequency currents to the operating electrodes (capacitors). In some devices of this type (Figure 8,Ib) the capacitor banks of the oscillatory circuit are outside the bay and fastened on the top. The GLE-61A devices and so on used for drying (Figure 8, Ic) have an unshielded inductive coupling coil 6 on the front control panel outside the bay.

The electromagnetic field intensity inside the facilities where generators of the described types are installed vary sharply vertically. As

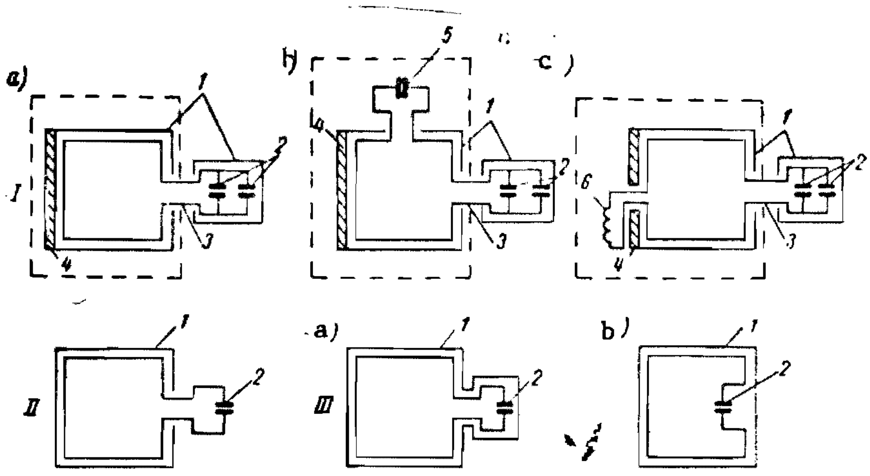

Figure 8. Block diagrams of dielectric heating devices with various natures of shielding. I -- devices of the first group with wood front control panel and builtin high-frequency elements (a), with unshielded capacitor banks (b) and with an unshielded inductive coupling coil (c); II -- device of the second group with unshielded only operating electrodes; III -- devices of the third group completely shielded with operating capacitors outside the bay (a) or built into it (b).

measurement data show, when working with the devices, the block diagrams of which are depicted in Figure 8, Ib, the presence of an intense electric field at a height of 1.6-1.8 meters from the floor is noted (that is, at the level of the worker's head), and when working with devices presented in Figure 8,Ic, an intense electric field, and especially, a magnetic field at a height of 0.5-1.25 meters from the floor (at the knee and chest level).

The devices of the second group (UKV-3, DKV-2, LGS-0.2, and so on) are used, as a rule, for welding products made of plasticized resin. Not only the operating electrodes have shields. All the remaining electrodes of the generator circuit are included in the metal housing (shield) 1. The intensity of the electric component of the field near the operating electrodes is usually no more than 60-70 volts/meter. At a distance of 1.5-2 meters the magnitude of the field intensity does not exceed the allowable.

Devices of the third group (LGD-30, LGD-12, LGD-62, LGD-32, LGD-1, LGD-2, LD1-4, and so on) which are most widespread at the present time are completely shielded. The operating capacitors 3 of the devices are either taken outside the generator bay (Figure 8, IIIa), or they are built into it (Figure 8, IIIb).

The measurements of the field intensity in the shop where there are 40 such devices demonstrated practical absence of irradiation of the personnel. An insignificant field (its electric component) near the peepholes or gratings next to the sidewalls of the generators are noted only in individual cases [74].

Thus, separation of the devices into groups with respect to nature of shielding offers the possibility of approximate representation of the field distribution pattern near the radiation sources of the high-frequency heating devices manufactured by plants for the last decades and widely used up to now at shipbuilding plants.

The field distribution pattern indicates that the shielding of the induction heating devices and devices used for drying dielectric materials is in a number of cases inadequate and therefore a drop in intensity of the fields of both the electric and magnetic components to the maximum permissible values is required.

§ 3. Electromagnetic Fields in the Radio Rooms of Ships

Radio Room Equipment

In accordance with the requirements of the USSR Registry with respect to equipping ocean-going ships with radios, all ships for long-range navigation and navigation abroad are equipped with medium and shortwave transmitters. Ultrashortwave radios are installed on the ships for local communications. In addition, each ship is equipped with an emergency transmitter.

The ship radios are different with respect to purpose, amount of equipment installed, power of this equipment and technical characteristics. There are ship stations on which up to 10 radio transmitters are used [83]. The basic transmitter most widespread on the ships of the MMF [Ministry of the Maritime Fleet] is the Blesna-SV type transmitter which operates in the frequency band of 365-550 kilohertz. This corresponds to wavelengths of 822-545 meters. Along with the Blesna-SV transmitter, working transmitters type Blesna-KV or Blesna-KVM are used. These latter transmitters operate in the frequency band of 4,000-22,720 kilohertz which corresponds to wavelengths of 75-13.21 meters. The Blesna type radio transmitters have an antenna power of 250 watts.

The 100-watt combination transmitters type YeRSh or YeRSh-R are widespread on ships. In the YeRSh type radio there are two transmitters -- medium and shortwave -- installed in a common housing with feed from a common rectifying unit. The former operates in the frequency band of 365-550 kilohertz, and the latter, in the 1,500-24,000 kilohertz band, which corresponds to wavelengths of 200-12.5 meters.

In recent years, 300-400 watt transmitters type Volkhov and Il'men, kilowatt transmitters types PSD-1 and PSK-1, and 250 watt transmitters PSD-0.25 and PSK-0.25 began to be installed on the ships of the maritime fleet. The medium and shortwave transmitters type RFT with a power of 800 watts and many others have also become widespread.

Transmitters type ASP with a power of 50-60 watts are used as emergency transmitters.

Thus, radio transmitters of various types are installed in the radio room of a ship, and short and medium-wave transmitters are operated continuously.

Work Area of the Radio Operator

Communications transmitters are installed in the radio room in such a way that the work area of the radio operator is between them or in direct proximity to them (Figure 9). The feeder lines for transmitting energy to the antenna are suspended, as a rule, on the overhead of the radio room above the head of the operator or near him. These lines are either open in the form of hollow copper tubes (for transmitting medium and shortwaves) or in the form of a shielded cable (for transmitting shortwave signals). Sometimes (most frequently on tankers) the feeder line for transmitting medium-wave signals is made shielded in the form of a high frequency chute. Such elements of the feeder channel as the antenna switches, commutators, and so on are not shielded. For operating convenience, the antenna switch is installed above the head of the operator.

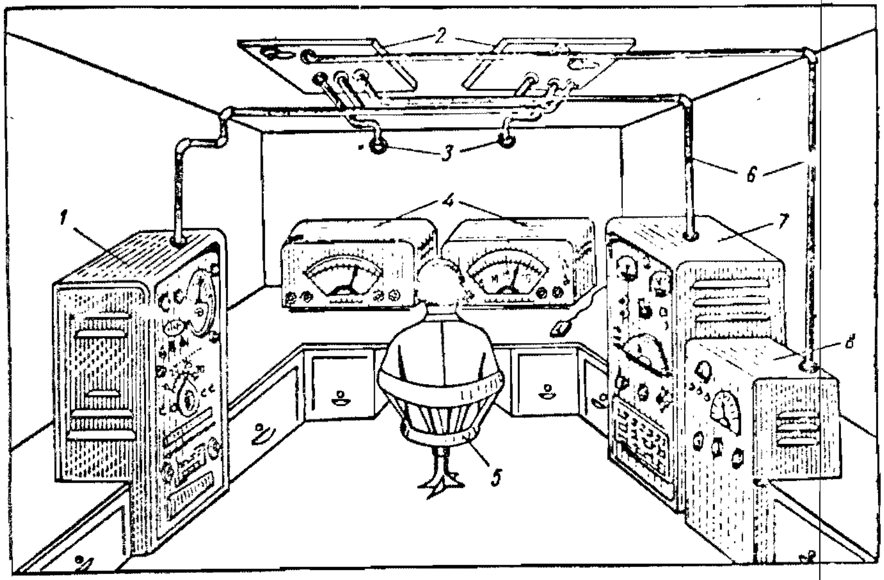

Figure 9. Arrangement of the equipment and the operator work space in the radio room. 1 -- medium-wave transmitter; 2 -- antenna switches; 3 -- wall tubes; 4 -- radio receivers; 5 -- operator chair; 6 -- energy transmission feeder lines; 7 -- shortwave transmitter; 8 -- emergency transmitter to the antenna.

Radiation Sources

A significant part of the energy in the radio room is emitted by the high-frequency feeder [79] the large losses of which are explained by the application of asymmetrical antennas on ships and the absence of appropriate matching of the input impedance of the antenna with the wave impedance of the feeder.

The electromagnetic energy emitters are also high-frequency elements of the transmitter circuit which frequently does not have reliable shielding. The electromagnetic field penetrates loose places in the joints of the housing sheets, the peepholes or gratings.

According to theory, the slits in the shield the length of which is appreciably less than the length of the electromagnetic wave should not give any emission. In practice, obviously, as a result of the formation of harmonics, fields of high intensity are created in direct proximity to the slits.

The metal housing of the transmitter can be a source of radiation to a lesser extent. The formation of the high-frequency potential in the transmitter housing is a consequence of closure of the antenna currents to the ship's hull and leakage of them from the ship's hull to the transmitter housing along the ground bus or as a result of induced currents from the absence of a feeder shield.

Radio Room Area

In accordance with the "Rules for Radio Equipment on Maritime Ships" of the USSR Registry, radio rooms must have sufficient size for convenient placement and safe servicing of radio equipment. However, in practice this requirement is frequently not satisfied. On ships of the third and, especially, fourth group, the area of the radio room is so small (less than 4 m^2), that the feeders emitting high-frequency energy are as close as 0.5 meters from the operator's head. The feeder lines are frequently run around the entire radio room which increases the high-frequency field intensity in the room by many times as a result of multiple reflections. When planning and designing radio rooms it is necessary to select the required area considering that the work area of the radio operator is far away from open feeder systems when it is impossible to make them shielded.

The high-frequency field distribution in the radio room with defined powers depends on many causes and, above all, on the type of feeder lines used, the magnitude of the losses in them, the location of the antenna switches, the location of feeder lines, the feeder line length, the arrangement of wall tubes, the area of the radio room and presence of metal surfaces in it forming secondary emission. By measurements it has been established that the highest values of the high frequency field intensity occur near unshielded feeder lines transmitting energy to the antenna [39, 40, 43, 47, 136].

The intensities of the electric field component noted near the high-frequency channels of medium-wave transmitters vary within the limits of a thousand and more volts per meter at the same time as the high-frequency fields near the channels of shortwave transmitters does not as a rule exceed 500 volts/meter, and only in individual cases can it reach a thousand or more volts per meter.

The intensity of the magnetic component of the medium-wave high-frequency field in the work area of the radio operator varies within the limits of units of amperes per meter.

Smaller values of the high-frequency field intensity from feeder lines for transmitting shortwave energy by comparison with the values from feeder lines transmitting medium waves, under other equal conditions, indicate more successful design of the high frequency channel of shortwave transmitters.

During operation of the radio on radiation, the operator is in the zone of a sharply nonuniform field. This is confirmed by measurement. The intensity of the electric component of the high-frequency field in the work area varies within broad limits: from hundreds and thousands of volts per meter at the head level to units of volts per meter at the level of the radio operator's legs. A sharp decrease in field intensity in the work area vertically is explained by the location of basic emitting elements on the overhead of the radio room directly above the radio operator's head.

The conditions of irradiation of the radio operators were investigated on ships for various purposes: passenger, cargo, tankers and ships of the auxiliary fleet (rescue ships, icebreakers, production training ships, light ships, and so on) on several shipping lines of the country.

Passenger Ships

The radio rooms of the investigated passenger ships were equipped with radios type YeRSh-R (L'vov, Belinskiy, Kolkhida, and so on), the Mackey Radio (Petr Velikiy), the PSD and PSK (Krym, Rossiya) and the RFT (Admiral Nakhimov, Mikhail Kalinin, Latviya, and so on).

The IEMP LIOT instrument was used to study the irradiation conditions. For the measurements the antenna dipole was brought no closer than 0.2 meters to the emitting systems. By noting the successive direction of the antenna dipole, the direction and polarization of the high-frequency fields formed inside the radio room were established.

The electric and magnetic field components were measured near the emitting systems and, in turn, in the work areas of the ship's radio communications operators, on the transmitter control panels, near the feeder lines and around the radio room. The electric field intensity was measured at three levels above the deck (1.6, 1.0 and 0.5 meters) at various distances from the radiator under conditions of continuous keying.

It must be pointed out that the measurements of the high-frequency intensity, especially in the radio room, were complicated by the presence of a large number of metal surfaces creating secondary emission.

In Figure 10 we have the intensities of the electric component of the high-frequency field in the radio room of one of the diesel-powered passenger ships during operation of the RFT transmitter in the medium (a) and short (b) wave band. The measurements were taken at frequencies of 410 and 4,900 kilohertz. The radio wave energy transmission lines are made unshielded in the form of copper tubes (depicted by the bold-face lines in the figure), and they are installed almost over the operator's head. As is obvious from the figure,

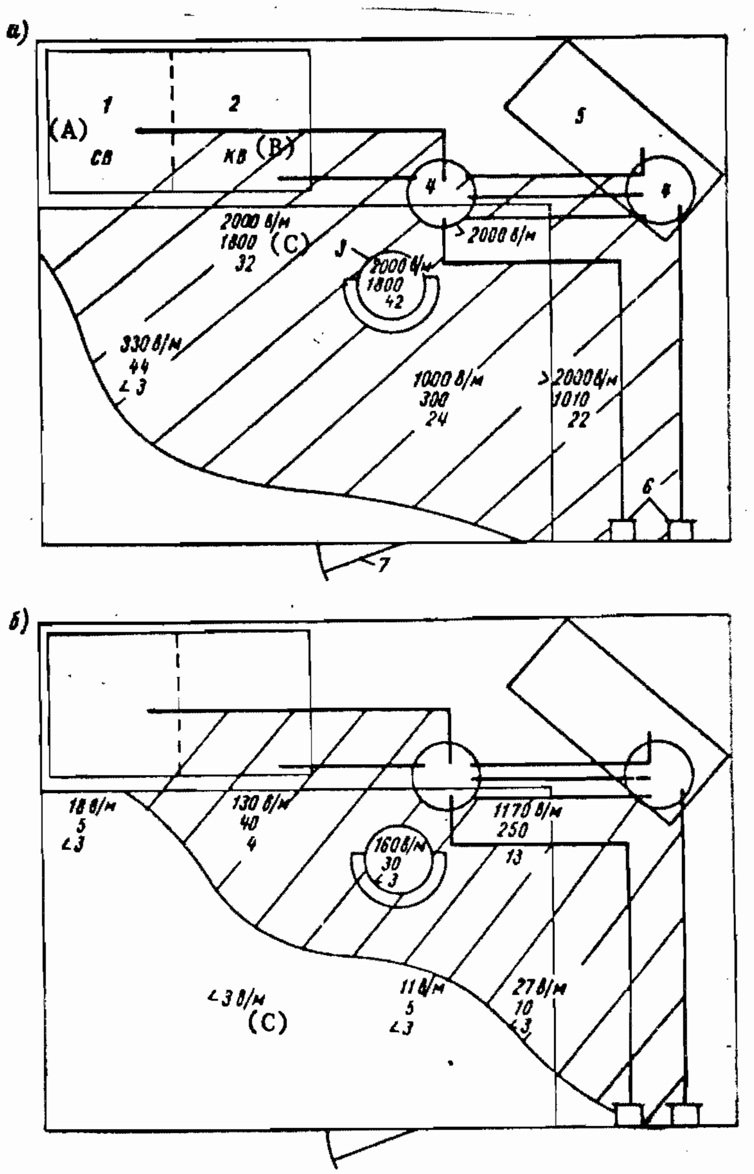

Figure 10. Magnitudes of the intensity of the electric component of the high-frequency field in the radio room of a diesel-powered passenger ship during operation of the RFT type transmitter in the medium (a) and short (b) wave band. 1, 2 -- combined medium and shortwave transmitter type RFT (P_{rated} = 800 watts); 3 -- radio operator's chair; 4 -- antenna switches; 5 -- emergency transmitter (P_{rated} = 60 watts); 6 -- wall tubes; 7 -- door to the radio operator's room.

Key: A. medium wave
B. shortwave
C. volts/meter

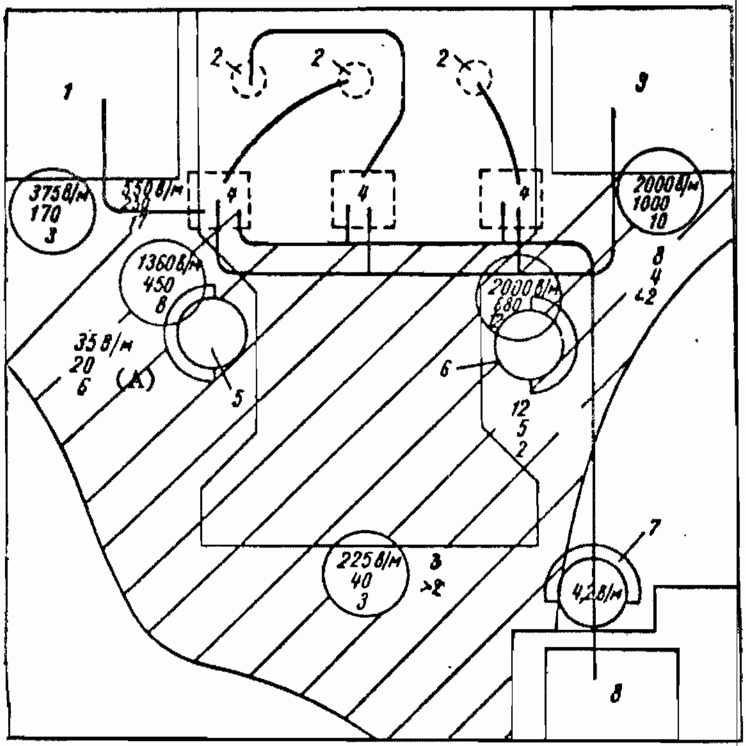

Figure 11. Intensity of the electric component of the high-frequency field in the radio room of a passenger liner when using three antenna switches. 1 -- shortwave transmitter type RFT (800 watts); 2 -- wall tubes; 3 -- medium-wave transmitter type RFT (800 watts); 4 -- antenna switches; 5-7 -- radio operator's chair; 8 -- emergency transmitter.

Key: A. volts/meter

the highest intensities of the electric component of the high-frequency field are observed in direct proximity to the transmission feeder lines just at the point where the radio operator's chair is located (2,000 volts/meter near the medium-wave transmission lines and 160 volts/meter near the shortwave transmission lines).

During operation of a medium-wave transmitter the intensity of the field in the area (1.5-2.0 meters from the radiators) at a height of 1.6 meters above the deck is several hundreds of volts per meter; during operation of the shortwave transmitter, the field intensity does not exceed several volts per meter.

The medium-wave field intensity measured in the radio operator's cabin adjacent to the radio room with the door closed was 220-12 volts/meter at various points at a height of 1.6 meters at the same time as the shortwave field intensity at the same points did not exceed 3 volts/meter.

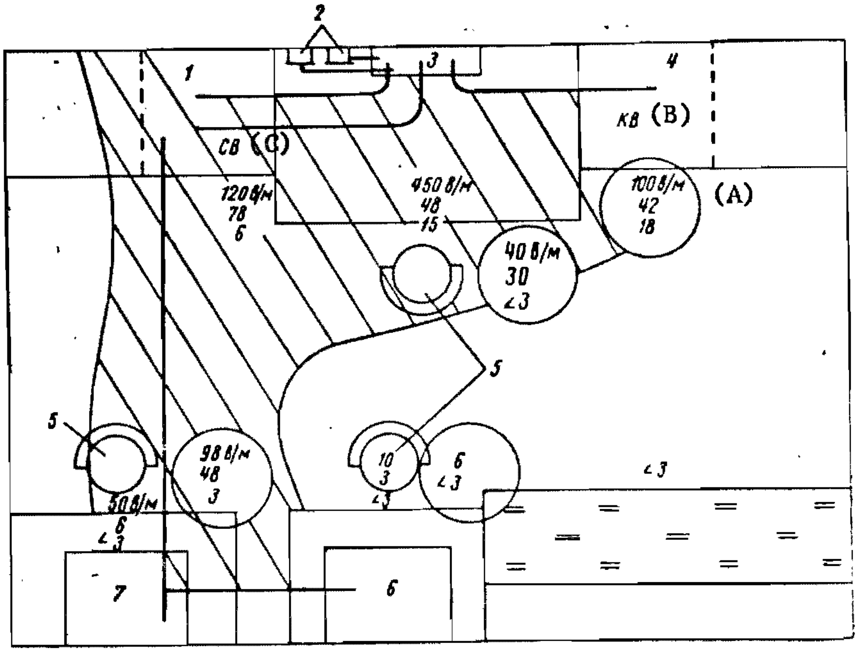

Figure 12. Intensities of the electic component of the high-frequency field in the radio room of a passenger liner with location of the switch on the radio room bulkhead. 1 -- medium-wave transmitter type RFT (800 watts); 2 -- wall tubes; 3 -- antenna switch; 4 -- shortwave transmitter type RFT (800 watts); 5 -- radio operator's chair; 6 -- Blesna-KV transmitter (250 watts); 7 -- emergency medium-wave transmitter (25 watts).

Key: A. volts/meter B. shortwave C. medium wave

On all the investigated passenger ships the feeder lines were executed unshielded. The conditions of labor of the operators on the ships where the feeder lines (illustrated by bold-faced lines on the figure) were installed on several antenna switches located near the work areas instead of one (Figure 11) turned out to be especially unfavorable. In the figure it is obvious that the work space 5 of one of the operators on the shortwave transmitter 1 side during operation on emission of the medium-wave transmitter 3 (the numerical values are circled) is in the range of a field of up to 1,360 volts/meter. In the given case the intense (2,000 volts/meter) field in the work area 6 of the operator at a distance of 2.5-3 meters from the operating transmitter is explained by unsuccessful selection not only of the design but also the installation of the high-frequency channel. It must be noted that on some passenger liners built in recent years (Mikhail Kalinin, Mariya Ul'yanova, and so on) the radio equipment was installed in appreciably larger areas, it is distinguished by more careful structural execution, and the antenna switches are mounted on the bulkheads, which reduces irradiation. However, the transmission feeder lines stretched around the facility create high-frequency fields with an intensity of tens and sometimes hundreds and more volts per meter in the adjacent work areas (Figure 12).

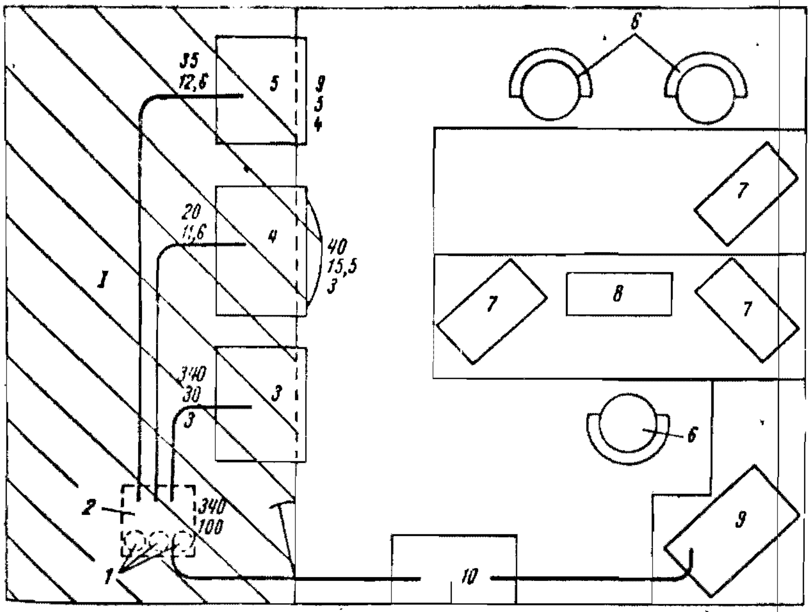

Figure 13. Intensities of the electric component of the high-frequency field in the radio room of a diesel-electric passenger ship with communications transmitters removed to a shielded area I. 1 -- wall tubes; 2 -- antenna switch; 3 -- TSK type transmitter; 4 -- long-wave transmitter type ASD (250 watts); 5 -- shortwave transmitter type PSK (250 watts); 6 -- radio operator's chair; 7 -- receiving equipment; 8 -- control panel; 9 -- emergency transmitter.(60 watts); 10 -- medium-wave transmitter -- Telefunken (200 watts).

It is interesting to note that during operation of a medium-wave transmitter near the feeder and in the work area of the operator of the transmitter 7, a field much greater with respect to magnitude is created for the same approximate power than when operating a shortwave transmitter (the numerical values are circled).

On one of the investigated ships (Figure 13) the radio transmitters and feeders (illustrated by the bold face lines) with the antenna switches were installed in a shielded area, and the control panels were taken into the radio room. This almost entirely excluded irradiation. Insignificant fields with respect to intensity occur only near the control panel at the nean tube included in the high frequency current circuit and opposite the peephole.

Ships of the Tanker Fleet

A study of the conditions of irradiation of the radio operators working on ships of the tanker fleet revealed a somewhat different field distribution pattern in the radio rooms than on board passenger ships. On the investigated ships 250 watt Soviet transmitters type PST, PSK, Blesna-SV, Blesna-KVM and 300-500-watt transmitters types NSD-135E and NSD-113RH built by a Japanese company were used.

With the usual standard arrangement of the radio equipment, the operator of the Blesna-SV radio can be in range of a field the maximum intensity of which does not, as a rule, exceed 1,500 volts/meter (at a distance of 0.25 meters from the feeder). The average values of the fields in the range of which the operator is located for the most part of his working time usually are 620-12 volts/meter (1.2-0.5 meters from the floor).

When operating the Blesna-KVM radio on radiation, the operator can be in range of a shortwave field with an intensity of approximately 10 to 400 volts/meter.

The radio operators working on the combination transmitter NSD-135E built by a Japanese company are subjected to intense radiation. The radio equipment in the radio room is installed in such a way that open feeder lines (illustrated by the bold face lines in Figure 14) for transmitting energy to the antenna and the antenna switches are located directly above the operator's chair although the design of the transmitter permits switching of the antennas directly on the control panel. As a result, the intensity of irradiation of the operator's head (Figure 14) when operating the radio in the medium-wave band is about 375-2,000 volts/meter, and when operating on the shortwave band, 90-340 volts/meter. The measurements were taken at frequencies of 410 kilohertz and 17 megahertz.

A large group of tankers types Kazbek, Ochakov, Makhachkala, Krasnovodsk, and so on are equipped with Soviet radios types PSD and PSK with an output power of 250 watts. It must be stated that in the radio rooms of these ships a high-frequency chute of circular cross section used for energy transmission practically excludes irradiation of the operator. The greatest (up to 24 volts/meter) value of the field is noted only in direct proximity to the transmitter peepholes. The intensity of irradiation of the operator in the permanent work area does not, as a rule, exceed the allowable.

Dry Cargo Ships

Numerous measurements taken on cargo ships of series and nonseries design with the most varied arrangement of radio equipment in the radio rooms and transmitter powers from 100 to 1,000 watts also revealed the presence of intense fields in the transmitter service areas and in the permanent work areas of the operators.

In all the radio rooms equipped with Blesna-SV and Blesna-KVM radios there are fields the intensities of which are hundreds and sometimes thousands of volts per meter.

The greater part of the measurements were taken with the ship moored in port, sometimes with incomplete emitted power of the transmitters or when operating them on the emergency antenna. Thus, on individual ships types Dzhankoy, Leninskiy Komsomol and Leninogorsk, for incomplete emitted power of the Blesna-SV transmitter the field intensity in the operator's work area measured at 1.2-1.6 meters from the deck is 450-1,600 volts/meter on the average.

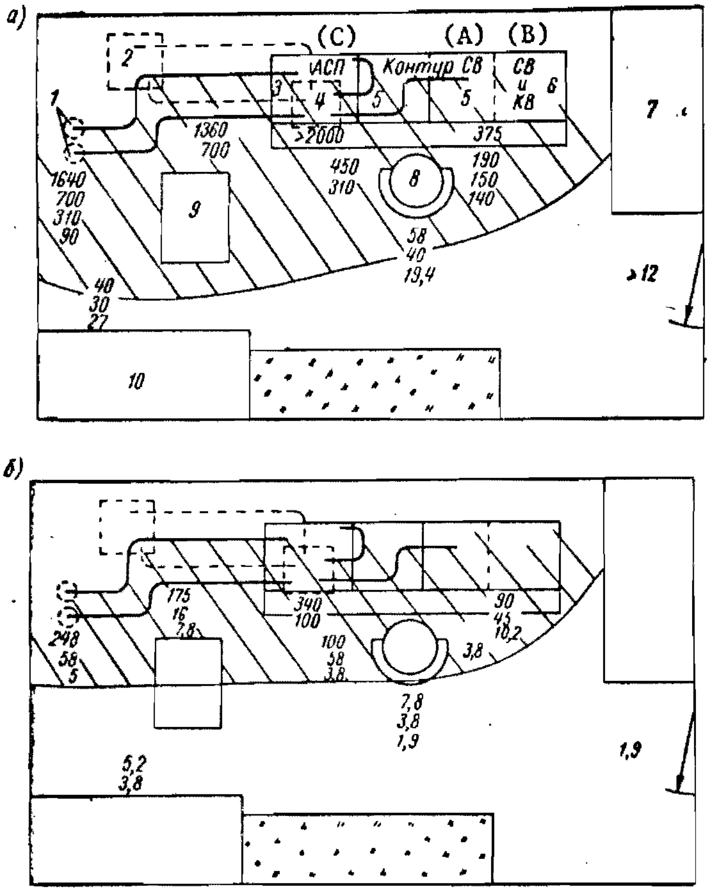

Figure 14. Intensity of the electric component of the field in the radio room of a tanker when operating the NSD-135E transmitter in the medium-wave band (a) and the shortwave band (b). 1 -- wall tubes; 2 -- emergency transmitter NSD-113RH; 3, 5, 6 -- NSD-135E transmitter unit; 4 -- antenna switch; 7 -- radar room; 8 -- radio operator chair; 9 -- chair with typewriter; 10 -- work table.

Key: A. medium-wave circuit
B. medium-wave and shortwave
C. ASP

The measurements taken when operating the transmitters on the emergency antennna (Labinsk) revealed the presence of approximately the same fields with respect to intensity in the radio room as when working on the main antenna.

The highest values of the field (Figure 15) are noted near powerful radios type RFT with unshielded transmission lines.

On a large number of ships the shortwave transmission line is executed in the form of a shielded high frequency cable. In this case, the shortwave radiation of the operator is greatly reduced. However, the shielding of only one feeder does not always insure the required radiation drop. Near the transmitter if the bay has an upper wall which is raised for cooling, peepholes or gratings, the field intensity can be several tens of volts per meter. In addition, when operating the transmitter on various frequency bands the intensity of irradiation of the operator can vary. Thus, in Figure 16 it is shown that when only the transmission line is shielded and there is insufficient shielding of the transmitter (the top of the chassis is raised) and antenna switch, the maximum intensity of irradiation of the operator measured at a frequency of 16,816 kilohertz was 9 volts/meter, at the same time as on a frequency of 22,600 kilohertz (the numerical values are circled on the figure) the shortwave field intensity increased by more than four times (38 volts/meter).

On two ships of the Latvian shipping line, high-frequency field intensities were measured during operation of RFT and YeRSh-R radios on a mast antenna. Here, the field intensity near the feeder lines and in the operator's work area on medium waves was approximately within the same limits as during operation of such transmitters on a beam antenna. The field intensity on shortwaves turned out to be much less (42 volts/meter by comparison with 125 volts/meter). This is obviously explained by smaller losses in the devices channeling the energy.

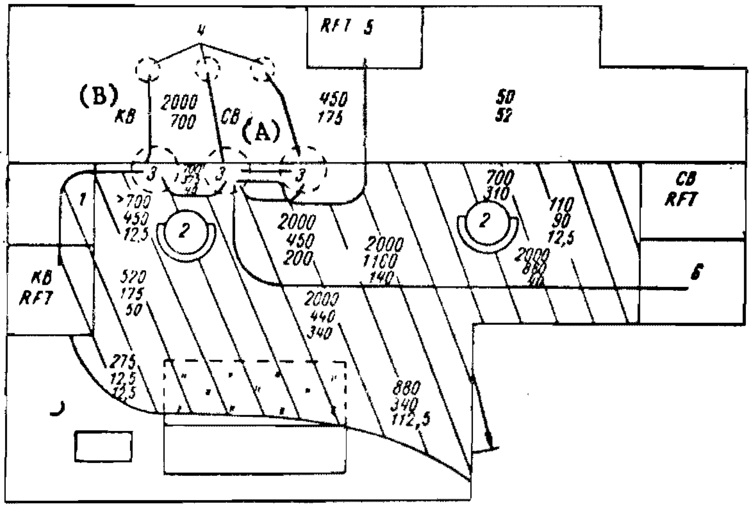

Figure 15. Intensity of the electric component of the field in the radio room of a diesel-powered cargo ship during operation of a medium-wave transmitter. 1 -- shortwave transmitter type RFT (800 watts); 2 -- radio operator's chair; 3 -- antenna switches; 4 -- wall tubes; 5 -- emergency transmitter; 6 -- medium-wave transmitter type RFT (800 watts).

Key: A. medium wave
B. shortwave

Studies made on training-production ships type Zenit with a carrying capacity up to 2,000 tons also revealed the presence of fields in the radio rooms of these ships. Usually such ships are equipped with two radio rooms one of which is a training room. It is equipped with several 250 watt transmitters loaded on dummy antennas which are installed on the tops of the transmitter bays. As measurements show, the medium-wave field intensity in the training radio room can be several hundreds of volts per meter near the dummy antennas and transmission lines and several tens of volts per meter in the work areas. The shortwave field intensity does not, as a rule, exceed 20 volts/meter.

In the radio rooms of ships where transmitters with low (100 watts) emitted power are installed, the maximum medium-wave field intensities near the feeder are determined as hundreds (up to 800) of volts per meter at the same time as the shortwave field intensity does not exceed 290 volts/meter.

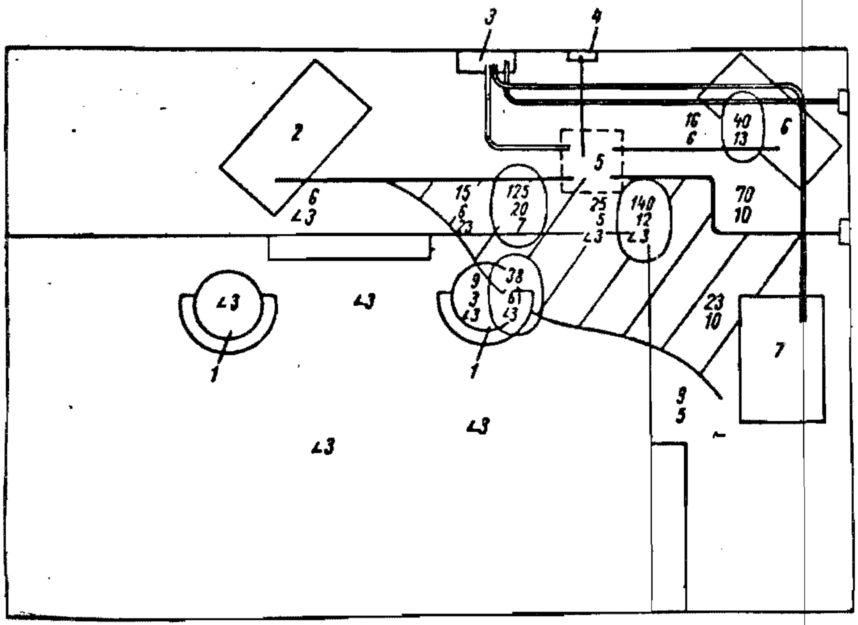

Figure 16. Intensity of the electric field component in the radio room of a cargo ship when operating a shortwave transmitter with a shielded feeder. 1 -- radio operator's chair; 2 -- Blesna-SV transmitter (250 watts); 3 -- commutator; 4 -- insulator for the main antenna; 5 -- antenna switch; 6 -- emergency transmitter; 7 -- Blesna-KV transmitter (250 watts). ═══ shielded transmission line (high-frequency cable), ▬▬ unshielded transmission line.

Ships of the Auxiliary Fleet

The ships of the auxiliary fleet include rescue and salvage tugs, pilot boats, icebreakers, and so on.

The radio rooms of tugs, rescue and salvage ships and pilot boats are usually equipped with 100 and, rarely, 200 watt transmitters. Icebreakers, as a rule, have high-powered radios (800-1,000 watts). Open energy transmission lines to the antenna, just as on other ships, are installed above the operator's chair.

The intensity of the electric component of the high-frequency medium-wave field in the work areas most often does not exceed 420 volts/meter, and the average values vary within the limits of 200-260 volts/meter. Here, the intensity of the magnetic component of the field measured at the same points with maximum value of the electric component does not exceed 5 amps/meter.

The intensity of the electric component of the high-frequency shortwave field in the work areas of the operators is within the limits of tens of volts per meter, and it sometimes reaches a hundred volts per meter.

The main thing that distinguishes the radio rooms of the ships of the auxiliary fleet is their small area. Usually almost the same amount of radio equipment as on other ships is installed in an area of 4-5 m^2. Therefore, the electromagnetic field remains intense throughout the entire radio room as a result of multiple reemissions.

The conditions of labor of the radio operators of the auxiliary fleet, especially pilot boats and icebreakers are characterized by being in the range of high-frequency fields for a longer time as a result of intense radio traffic.

On the whole, when estimating the irradiation conditions of radio operators, the time spent in the range of the field must be considered as a function of the irradiation intensity, and in special cases it is also necessary to consider the purpose of the ship, the region and duration of its trip and, what is especially important, the predominant use of the frequency band and the transmitter power.

Thus, under caravan conditions during icebreaking the radio operator on the icebreaker, who maintains intense radio contact with the shore and regulates the subscriber traffic within the caravan, can, under certain conditions, be in fields of periodically varying frequency bands (from medium to shortwave) longer than operators on the other ships of the caravan.

Emergency Transmitters

In addition to the main and operating transmitters in the radio rooms of maritime ships, emergency transmitters are also installed. Emergency transmitters have lower oscillating powers, but the leads are open lines, and as a result of losses they form radiation in the work areas.

The greatest intensity of the electric fields near emergency transmitters of the ASP type and open lines does not, as a rule, exceed 100 volts/meter; the magnetic field intensity is less than 0.5 amps/meter.

Ultrashortwave Radio Telephones

These sets are installed at the present time on almost all ships, and they are used for communications at short distances. The radio telephone uses FM oscillations for which the transmitter carrier frequency is modulated by the audiofrequency spectrum. From the point of view of labor safety this

Table 2

Mean values of the intensity of the electric field component in radio rooms during operation of individual types of marine radios

Radio designation	Transmitter power, watts	Frequency band, kilohertz	Intensity, volts/meter			Remarks
			At the operator's chair (1.6-0.5 m from the deck)	At the transmitter control panel (1.6-0.5 m from the deck)	At various points in the facility (1.6 m from deck	
PSK(R-641)	1000	3000-24000	3	6.8-3	8.2-3	6.8 — at the transmitter peephole 8.2 — along the radio cable at a distance of 0.2 m
PSD-0.25	250	100-600	365-24	1300-10	22-8	Feeder lines not shielded
PSK-1	1000	3000-24000	400-100	250-20	14-12-3	48 and 96 volts/meter — near open feeder lines
RFT	800	410-510	450-78	14-5	48-3.2	Irradiation is created as a result of induction in the nonoperating feeder
RFT	800	4000-22350	98-12	10-3	96-3.6	
RFT (emergency)	800	410-510	320-12	93-15	38-3.2	1640 and 248 volts/meter— near the antenna wall tubes
NSD-135E	300	405-535	420-23	375-19.4	1640-58-12	
NSD-135E	500	4000-23000	100-3.8	90-3	248-7.8-3	
Volkhov	300	400-535	400-18	362-14	86-12	
Il'men'	400	1500-24000	3	8-3	3	Feeder lines made of radio cable
Blesna-SV	250	410-512	1600-220	470-12	220-50-12	Mean values taken with respect to 8 ships
Blesna-KVM	250	2840-22720	380-30	98-18	38-12-3	
155-B, Federal Telegraph	200	350-550	1250-38	420-21	700-88-8.2	Measurements were taken under actual trip conditions during good weather
155-B, Federal Telegraph	300	600-750	1600-43	450-32	430-39-3.8	700 and 430 volts/m — near the wall tubes
YeRSh	100	365-550	420-18	120-28	570-24-3.2	570 and 170 volts/m — near the wall tubes
	100	2175-17400	80-21	220-24	170-12-3	
ASP-4	60		375-6.5	870-36	850-115-7.6	850-320 and 115 volts/m -- along the feeder at a distance of 0.2 m and at the wall tubes
ASP-2-0.06	60	410-512	120-8	78-26	320-18-3	

method of operation is the most unfavorable: whereas in the telegraph mode of operation the emission of electromagnetic waves takes place only on pressing the key, in the telephone mode the operator is irradiated continuously during transmission of the radiogram. It is considered that by comparison with AM oscillations, working with FM oscillations is equivalent to increasing the transmitter power by approximately nine times.

In recent years ultrashortwave radio telephone transmitters have been installed in the radio rooms of ships. A high-frequency radio cable practically excluding irradiation is used as the conducting channel for these transmitters.

As studies have demonstrated, ultrashortwave radios with a shielded feeder do not create emission exceeding the permissible values.

In conclusion, Table 2 is presented in which the mean values of the electric field intensity obtained during operation of certain types of marine radios in the radio rooms of 52 ships of various series and purposes are presented. As is obvious from the table, the transmitter power is not the basic criterion determining the possibility of irradiation of the radio operator. In the absence of shielding of the feeder lines, the defining factors are the distances of the work area from the emitting systems, structural features and general arrangement of the radio equipment in the room.

§4. Electromagnetic Fields of Radio Communications Antennas on the Decks and Superstructures of Ships

In accordance with the Rules for Radio Equipment of Maritime Ships of the USSR Registry, primary, emergency and working antennas are installed on each ship corresponding to the primary, emergency and working transmitters. These transmitters and antennas are subdivided into medium wave, short wave and ultra short wave according to the frequency band. With respect to the antenna feed system they can be symmetrical and asymmetrical.

The radio communications equipment on ships is installed and operated considering the characteristic features and, above all, limited possibilities for arrangement of the antennas on board the ships. The insufficient space on the ship does not make it possible to provide sufficient spacing for the antennas or suspension of them at a certain height. Ship antennas are located among large metal objects of various shapes and sizes which form secondary emissions.

Radio communications antennas on ships can be single wire or multiwire (vertical or inclined beam of the L or T type), cylindrical, rod, and so on. The horizontal parts of L and T type antennas are suspended in the span between the masts. On large ships beam antennas are sometimes located between the mast and the bow of the ship.

The dimensions of the primary medium wave antenna are limited to the height of the masts, the spacing between the masts or the mast and the bow of the ship. Thus, the primary antennas are usually suspended between the foremast or the mainmast at a height of 10-20 meters. In this case the horizontal part of the antenna is extended along the ship and can be no more than 70-80 meters and the vertical part, no more than 15-20 meters.

In individual bands, the vertical conductor is the basic emitting section of the radio communications antenna. Antennas designed for operation on the shortest waves are suspended directly above the superstructures.

Rod antennas for operation on the shortest waves are installed on low superstructures or on columns. Short wave antennas designed for operation on longer waves of the band are installed on masts, smokestacks, and so on. Thus, radio communications antennas are located most frequently in the midsection of the ship over the superstructures. Usually the radio rooms are located on the bridge decks or one deck below. The drops of L or T type antennas are attached to the side bulkheads of the radio room or on the bridge which forms the ceiling of the radio room.

During, operation of the radios, the entire ship and, primarily, the superstructures and decks are in range of the electromagnetic field emitted by the antenna. It is entirely understandable that the magnitude of the electromagnetic field intensity will be greatest near the antennas and their drops. Here, for example, beam antennas operating in the middle wave band create an intense field which is distributed along the entire length of the ship in contrast to short wave rod antennas or especially, ultra short wave antennas the intense fields of which are concentric near the rod.

In recent years, top-loaded vertical antennas have become widespread. According to measurement data, intense fields are detected only near the mast antenna.

Under ship conditions an electromagnetic field is created not only by the antenna current but also by the currents arising in the metal objects surrounding the antenna. In addition to the primary emission of radio communications antennas on board ship, there is also a significant secondary emission field.

High-frequency currents are induced in the metal superstructures of various deck devices and also in the metal cables or antennas not used at the given time.

In the vicinity of the top deck structures where the intensity of the primary field is especially high, the highest currents, and, consequently, the largest secondary emissions with respect to magnitude, will be created in the metal structural elements. The increase in the reflected (secondary) emission becomes especially noticeable during operation of short wave antennas for emission. The reflected emission increases with an increase in frequency. The same antenna operating on different bands forms reflections of different magnitude from the same structural elements. This is explained by the fact that in the short wave band the mast and boom dimensions become commensurate with the emitted wave length.

The intensity of the secondary emission also depends on how the radiator is connected to the hull of the ship. For example, a metal cable insulated on both ends is excited on even harmonics, that is, its resonance wave is approximately twice its length. A cable which has one end connected to the hull of the ship and the other insulated is excited on odd harmonics, that is, its resonance wave is 4-5 times longer than its geometric length [89]. Thus, the intensity of irradiation of the crew on the open top decks and superstructures can be increased as a result of reemission of radio wave energy by metal masses.

The nature of irradiation of the crew on the deck can vary depending on the location and height of suspension of the antenna, the emission power and frequency and also the presence of metal structural elements, their dimensions and arrangement with respect to each other and the antennas. Therefore, it is a very difficult problem to determine the field intensity on a ship considering the enumerated specific cases.

As a result of numerous measurements performed on the decks of ships of different architecture it is possible to state that the highest values of the electric component of the high-frequency field reckoned in hundreds of volts per meter are fixed primarily on the topbridge near the antenna drops, chutes, various navigation instruments, antennas not operating at

Table 3. Intensity of the Electric Component of the Field in the Radio Room and on the Decks of the Cargo Ship Fizik Vavilov (Leninskiy Komsomol Class Ship) During Operation of Blesna-SV and Blesna-KVM Radios

Name of Location	Frequency Band	Measurement Location	Intensity at the following height from the deck (meters)						Remarks
			1.6		1.0		0.5		
			E, volts/meter	H, amp/meter.	E, volts/meter	H, amp/meter	E, volts/meter	H, amp/meter	
Radio Room	Medium Wave	In the work area	1520.0	2.3	400.0	0.6	38.0	<0.5	
		Control panel for the Blesna-SV type transmitter	1500.0	5.3	1160.0	3.8	42.0	0.7	
		Control panel for the Blesna-KV type transmitter	520.0	0.5	240.0	0.5	12.0	<0.5	Trams-mitter not included
		In the facility	140.0-9.0	0.85-0.5	62.0-5.0	0.5	23.5-4.0	--	
	Short wave	In the work area	138.0	--	40.0	--	4.0	--	
		Control panel for the Blesna-KVM type transmitter	1750.0	--	16.0	--	6.0	--	
Wheelhouse and chartroom	Medium Wave	In the center, next to the instruments	20.0	--	8.0	--	--	--	With the medium wave transmitter on; metal overhead
Top Bridge	Medium Wave	Next to the compass and other instruments, in the center of the bridge	78.0-30.0	<0.5	62.0-25.0	<0.5	5.4-4.0	<0.5	
		Next to the ventilation column and searchlight	140.0-30.0	<0.5	90.0-12.5	<0.5	11.0-10.0	<0.5	On the port side

Table 3. con't. Intensity of the Electric Component of the Field in the Radio Room and on the Decks of the Cargo Ship Fizik Vavilov (Leninskiy Komsomol Class Ship) During Operation of Blesna-SV and Blesna-KVM Radios

Name of Location	Frequency Band	Measurement Location	Intensity at the following height from the deck (meters)						Remarks
			1.6		1.0		0.5		
			E, volts/meter	H, amp/meter	E, volts/meter	H amp/meter	E, volts/meter	H amp/meter	
Top Bridge	Medium Wave	Near the antenna drop	520.0	<0.5	160.0	<0.5	40.0	<0.5	
		Near the rails	170.0	<0.5	140.0	<0.5	100.0	<0.5	
		Near the compass and other instruments, in the center of the bridge	15.5-7.0	<0.5	10.4-4.0	<0.5	4.0	<0.5	
		Near the ventilation column	32.5	<0.5	13.7	<0.5	10.4	<0.5	
		Near the antenna drop	27.5	<0.5	5.4	<0.5	4.0	<0.5	
		Near the rails	10.0	<0.5	9.8	<0.5	5.4	<0.5	
Conning Bridge	Medium Wave	Next to the engine telegraph compass and other instruments	300.0-30.0	1.2-0.5	115.0-12.5	<0.5	40.0-7.5	<0.5	On the aft section of the bridge
		In the forward section of the bridge wings	16.0	<0.5	10.0	<0.5	<4.0	<0.5	
	Short Wave	In the center	9.0	< 0.5	7.0	--	<4.0	--	
		Next to the compass and other instruments	12.0-5.0	--	4.0	--	<4.0	--	
		On the wings of the bridge	<4.0	--	<4.0	--	<4.0	--	

Table 3. con't. Intensity of the Electric Component of the Field to the Radio Room and on the Decks of the Cargo Ship Fizik Vavilov (Leninskiy Komsomol Class Ship) During Operation of Blesna-SV and Blesna-KVM Radios

Name of Location	Frequency Band	Measurement Location	Intensity at the following height from the deck (meters)						Remarks
			1.6		1.0		0.5		
			E, volts/ meter	H amp/ meter	E, volts/ meter	H amp/ meter	E, volts/ meter	H amp/ meter	
Boat Deck	Medium Wave	Near the boat	8.0	<0.5	4.2	0.5	<4.0	<0.5	On the port side next to the superstructure
		In the center of the bridge	<4.0	--	<4.0	---	<4.0	--	
		Near the boat	<4.0	--	<4.0	--	<4.0	--	

the given time, near the ventilation pipes, rails and other metal enclosures. In this case, the magnetic component of the high-frequency field does not exceed 15 amps/meter. In Table 3 we have the most characteristic results of measuring the intensity of the electric and magnetic components of the field on the cargo ship Fizik Valilov. When evaluating the irradiation conditions it is necessary to consider that the personnel servicing the navigation instruments are, as a rule, on the top bridge periodically and for short periods of time. Obviously, the presence of intense fields is especially undesirable on passenger ships where the top decks are used as promenade decks.

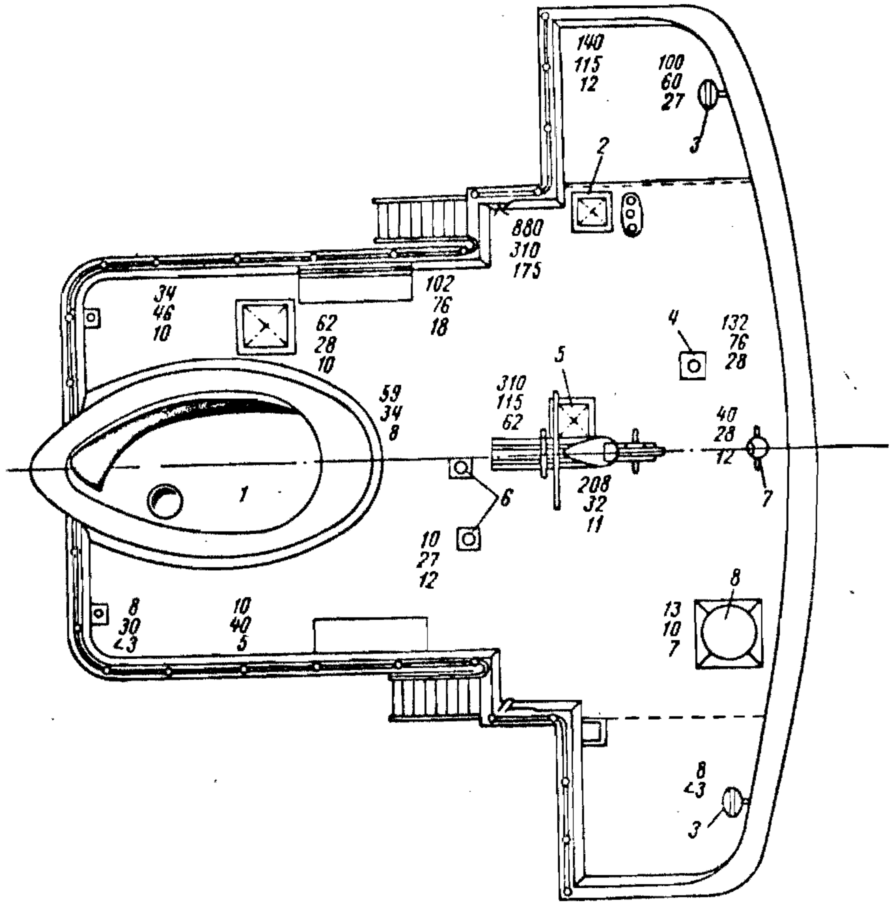

Figure 17. Intensities of the electric field component on the top ridge deck during operation of a medium wave transmitter for emission. 1 -- smokestacks; 2 -- antenna column; 3 -- search light; 4 -- fire fighting equipment; 5 -- direction finder; 6 -- ventilating pipes; 7 -- gyrocompass instruments; 8 -- radar

As an example of field distribution on the top bridge, a standard drawing (Figure 17) on one of the cargo ships is presented. The intensities of the electric component of the high-frequency medium wave field during operation of a 800 watt radio for emission are denoted.

It is obvious from the figure, the highest (up to 880 volts/meter) value of the field was measured at a height of 1.6 meters from the deck near the antenna drop. On the entire port wing of the bridge the field intensity is no less than 100 volts/meter. Its highest values occur near the direction finding antenna, the ventilation tubes, the gyrocompass and other metal objects. Along the rails the magnitude of the field on the port wing side reaches 155 volts/meter, and in the aft section of the bridge 40-46 volts/meter.

Figure 18 gives an idea of the intensities of the electric component of the high-frequency field on the conning bridge deck of the same ship. In the center of the port and starboard wings of the bridge, peloruses are installed on metal bases. A secondary emission field is formed near the peloruses. The navigation officer who stands watch on the bridge is in range of the high-frequency field of highest intensity when using the instrument. The same time as the field as a whole on the bridge does not exceed a few tens of volts per meter, near the pelorus it can reach hundreds of volts per meter as a result of reemission.

The field intensity increases near the antenna fair-lead installed on the side bulkhead of the superstructure in which the radio room is located. However, at a distance of 1.5 meters from it, the magnitude of the field drops sharply and next to the rails it is only 30-40 volts/meter.

The starboard wing and aft section of the bridge, just as the top bridge are in range of a field of appreciably lower intensity. The magnetic component of the field on the conning bridge is below 0.5 amps/meter.

The intensity of the field formed during operation of a short wave transmitter on the bridges and decks of ships is appreciably lower than during emission of medium wave transmitters of the same power. Thus, on the top and conning bridges of various types of ships, especially near the instruments and the forward bulkhead (wind breaker), the short wave field intensity is approximately tens of volts per meter and in rare cases (only near the antenna drops or fair-leads), hundreds of volts per meter.

On some ships, for example, on Kazbek type tankers and others, the conning and navigating bridges are located below the metal deck (overhead) of the top bridge which to some extent plays the role of a shield. The field intensity on such bridges does not in practice exceed ten volts/meter. On passenger ships, the lower decks, as a rule, are also "shielded" by metal overheads. The intensity of the high-frequency field of medium and, especially, short waves, as experience shows, does not exceed five volts/meter and in rare cases ten volts/meter.

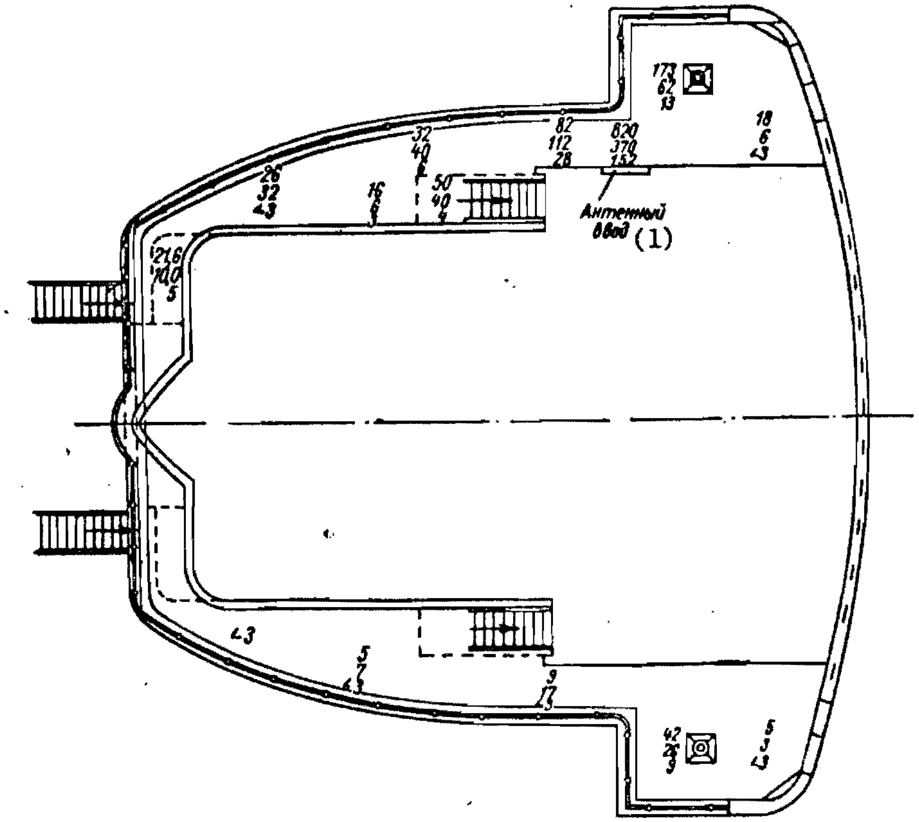

Figure 18. Intensities of the electric component of the field on the conning bridge deck during operation of a medium wave transmitter on emission.

Key: 1. antenna fair-lead

The highest intensities of a medium wave high-frequency field on the boat decks of ships is observed near the keel blocks of the boats located next to the decks on which the antenna fair-leads are installed.

On the main decks of ships only insignificant fields with respect to magnitude (less than five volts/meter) are formed primarily near the holds, sides and other metal surfaces.

However, attention must be given to tankers which have metal long walk bridges along the ship raised above the surface of the main deck sometimes by as much as several meters. As measurements show, the intensity of the medium wave high-frequency field on the long walk bridges (especially near the rails) of the main decks of tankers can be a hundred or more volts per meter.

On the lower bridges of some ships there is a secondary emission field which is formed by metal guys. Thus, on the Sibiryakov icebreaker the secondary emission formed by the metal guy during operation of a short wave transmitter on a rod was 220 volts/meter on the port side where the rod was located and 50 volts/meter on the opposite, starboard side.

In conclusion, it can be stated that the highest intensity of an electric field up to hundreds and sometimes thousands and more volts per meter occurs near the antenna drops and metal masses on the top bridges and decks during operation of a medium wave radio. Here, the magnetic component of the field can reach ten and even fifteen amps/meter.

In contrast to medium wave radios, short wave radios form fields which are smaller with respect to magnitude the maximum values of which on the top bridges, for example, do not exceed several hundreds of volts per meter.

The irradiation conditions of the navigation personnel standing watch on the open conning bridge near the antenna fair-leads and various metal objects and instruments are less favorable.

The deck crew on the lower decks are subjected to less intense irraiation not, as a rule, exceeding ten volts/meter. Only tankers constitute an exception. Irradiation up to 100 volts/meter and more is possible on the long walk bridges. There is practically no irradiation on the lower decks of passenger ships.

§5. Superhigh-frequency Electromagnetic Fields of Radar Antennas on the Decks of Ships

The navigation radar and other radar on maritime ships are a source of emission of superhigh-frequency electromagnetic waves. The ship navigation radar emits electromagnetic waves 2, 3 and 10 cm long and it operates in the pulse emission mode with a pulse length (depending on the range scale and type of radar) from 0.1 to 1 microsecond. The power of the radar pulse is 80-100 kilowatts.

Pulse operation of the radar is realized by a transmitter in the form of a generator of powerful high-frequency pulses. These pulses go to the antenna along a high-frequency channel. This antenna radiates them into space.

The radar antenna is both a transmitting and receiving antenna. During operation of the radar on reception the antenna sends the energy of the echoes received by it to the receiver. The receiver converts the signals into video pulses observed on a display.

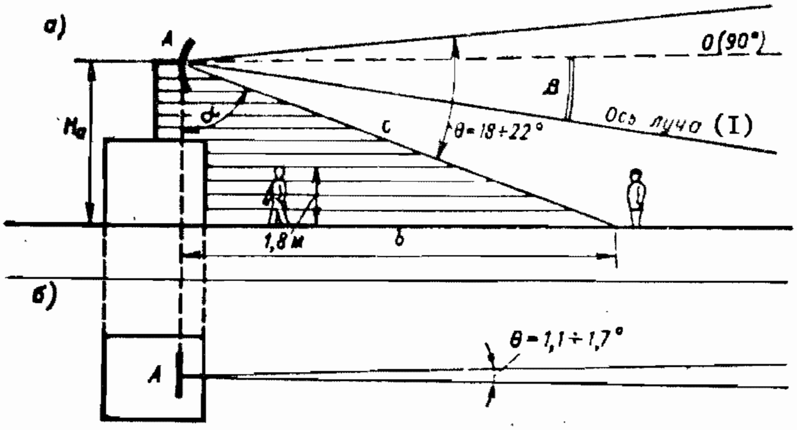

Figure 19. Schematic representation of a radar beam and formation of the "blind spot" (the crosshatched region): a -- side view b -- top view. A -- antenna; H^a-- height of the antenna above the top bridge; β -- angular aperture of the antenna.

Key: I. beam axis

The instruments making up a radar are the following: transmitter, receiver (or transponder when they are installed in one bay), display and other elements. They are installed in special individual areas and also in the chart room or wheelhouse. The radar antenna is on deck and it is installed, as a rule, on the top or upper bridge. The length of the high-frequency transmission line from the radar transmitter to the antenna usually does not exceed 20 meters.

In contrast to radio communications antennas, radar antennas turn around their axis making 12-24 revolutions per minute, and they emit a powerful energy flux in the form of a beam (Figure 19). When scanning the space around the ship the beam is directed horizontally so that the members of the crew standing watch on the open decks (especially the top decks) can find themselves in a zone of intense electromagnetic field irradiation from the radar antenna.

The width of the radiation pattern of a ship's radar antenna in the horizontal plane is 1.1-1.7 degrees, and in the vertical plane, 18-22 degrees (taken with respect to the half power level).

From Figure 19 it is obvious that directly next to and under the antenna there is a zone of sharp field attenuation where the electromagnetic field does not exist in practice. This zone is provisionally called the "blind zone" (it is crosshatched in the figure). On going away from the radiation source the man gets into the directional beam zone where the irradiation intensity can be significant. Inclination of the antenna toward the plane of the water (increasing the negative angle β from the axial line downward) reduces the size of the "blind zone" and, inversely, raising the antenna (increasing the positive angle β from the axial line upward) increases the size of the blind zone. The blind zone also increases with an increase in height of installation of the antenna. A man in the zone of the directional beam axis is subjected to maximum irradiation.

Radar antennas are installed in a special area of the upper or top bridge on a column or on a special mast (tripod). The designers select the height of the column or the mast, as a rule, without considering the possibility of irradiation of the deck crew. On heavy cargo ships the radar antennas are frequently installed on comparatively low masts (1.2, 2.5 and 4 meters above the level of the top bridge), and on passenger liners, they are more frequently at a height of 6.5 meters from the upper or top bridge deck.

Sometimes the radar antennas, especially on large-displacement cargo ships are installed on masts 11-16 meters high. As research has demonstrated, this is not justifiable from the hygiene point of view.

Studies of the conditions of irradiation of the deck crew with superhigh-frequency fields performed on ships for various purposes [42, 43] show that when the radar antennas are installed on columns 1.2-2.5 meters above the deck of the top bridge, the power flux density can be hundreds and sometimes thousands of microwatts per square centimeter.

Installation of the antenna on a standard mast 1.10 meters high leads to intense irradiation of the crew, especially on the top bridges of light-load ships with low superstructures.

In Table 4 we have data from investigations of several ocean-going tugs where the radar antennas type Stvor are installed on standard masts 1.2 meters above the top bridge decks.

As is obvious from the table, the irradiation intensity on the top bridge as a result of primary emission of the antenna can be up to several hundreds of microwatts per square centimeter. Besides the basic emission of the antennas it is necessary to note the formation of stray radiation which is explained by the presence of side lobes of the radiation pattern. As the measurements show, behind and to the side of the antenna the formation of a superhigh-frequency field with an intensity of no more than 18 microwatts/cm^2 is possible.

Thus, the deck crew of tugboats standing watch on the top bridge with the antenna installed at 1.2 meters high can be subjected to irradiation by a superhigh-frequency field of hundreds and tens of microwatts per square centimeter.

The lower decks and bridges of tugboats are more frequently shielded by the superstructures, and the irradiation on them does not exceed ten microwatts/cm^2.

Measurements of the power flux density performed on cargo ships where the antennas are installed at a height of 4.5 meters from the back of the top bridge showed that the irradiation of the crew on the top bridges and decks is comparatively low, and only in the vicinity of the stern or bow of the ship can the irradiation intensity reach tens of microwatts per square centimeter.

On cargo ships with one deck superstructure where the antennas are 6.5 meters and more high, the irradiation intensity does not, as a rule, exceed the allowable. This cannot be said of large passenger ships where with an antenna height of 6.0 meters above the upper bridge the power flux density at various points of the bridge is tens and sometimes hundreds of microwatts per square centimeter. This is explained by the fact that the irradiation conditions of the crew on the open decks or bridges are evaluated by several factors in addition to the basic factor of height of installation of the antenna. These factors include the architectural features of the ships. Thus, the irradiation intensity will differ on ships of different length with one or two superstructures with the antenna installed at the same height. Under defined conditions on ships with one superstructure the members of the crew on the lower decks will be subjected to less irradiation than on ships with two or three superstructures.

In Table 5 we have the largest mean values of the power flux density obtained on 32 ships of different architecture. The power flux density data are combined with respect to height of the radar antennas above the top deck. It is this height and not the total height of installation of the antenna above the lower deck which has basic significance in determining the irradiation intensity, especially on the top decks and superstructures.

As is obvious from the table, the highest values of the power flux density occur on the top bridge of the ship in the case of installation of the antenna at minimum height (1.2 meters).

With the antenna installed at a height of 2.5 meters, the power flux density is reckoned, as a rule, in tens and sometimes hundreds of microwatts per square centimeter, and it can reach 263 microwatts/cm^2. The highest values of the power flux density on the lower decks do not exceed 15 microwatts/cm^2.

In the column corresponding to installation of the antenna 6.0 meters high we have the data for the power flux density obtained on large passenger liners from parabolic radar antennas type Neptun and Neptun-M. As measurement experience shows, at a distance of 20 meters and more from the antenna on the top bridge of the passenger ship the power flux density reaches 63 microwatts/cm^2.

On the upper bridge, the density of the power flux reflected at various angles is 30-143 microwatts/cm^2, and on the boat deck of a passenger liner, in the aft section it is 18 microwatts/cm^2.

Table 4. Values of the Power Flux Density on the Decks of Ocean Going Tugs

Measurement Location	Power Flux Density Microwatts/cm^2	Remarks
Top Bridge	262-490	On the bridge at various points
Upper bridge	4-6	Shielded by the superstructure
Main deck	4-9	Forward section in the vicinity of the windlass and foremast

Table 5. Highest Mean Values of the Power Flux Density on the Decks of Ocean-going Ships as a Function of Height of Installation of the Antenna

Name of Deck	Power Flux Density Microwatts/cm^2					Remarks
	1.2 meters	2.5 meters	4.5 meters	6.0 meters	11.0 meters	
Top Bridge	420	263	18	63	--	420 microwatts/cm^2--at a distance of 1.5 meters from the antenna in the beam range
Upper Bridge	6-30	20	6	143	--	143 microwatts/cm^2--reflected energy flux at a distance of 1 meter from the smokestack
Boat Deck	2	11	15	18	--	18 microwatt/cm^2--only in the aft section of the deck
Main Deck	9	13	7	--	--	As a rule, in the vicinity of the forecastle

In Figure 20 we have the zones of increased(more than 10 microwatts/cm^2) intensity of irradiation on the decks of one of the passenger liners with its antenna installed at 6.0 meters above the top bridge deck. The lower decks of the ship (not shown in the figure) are either shielded by the superstructures and no superhigh-frequency field is formed, or their irradiation is minimal, and the defined values of the power flux density do not exceed 10 microwatts/cm^2.

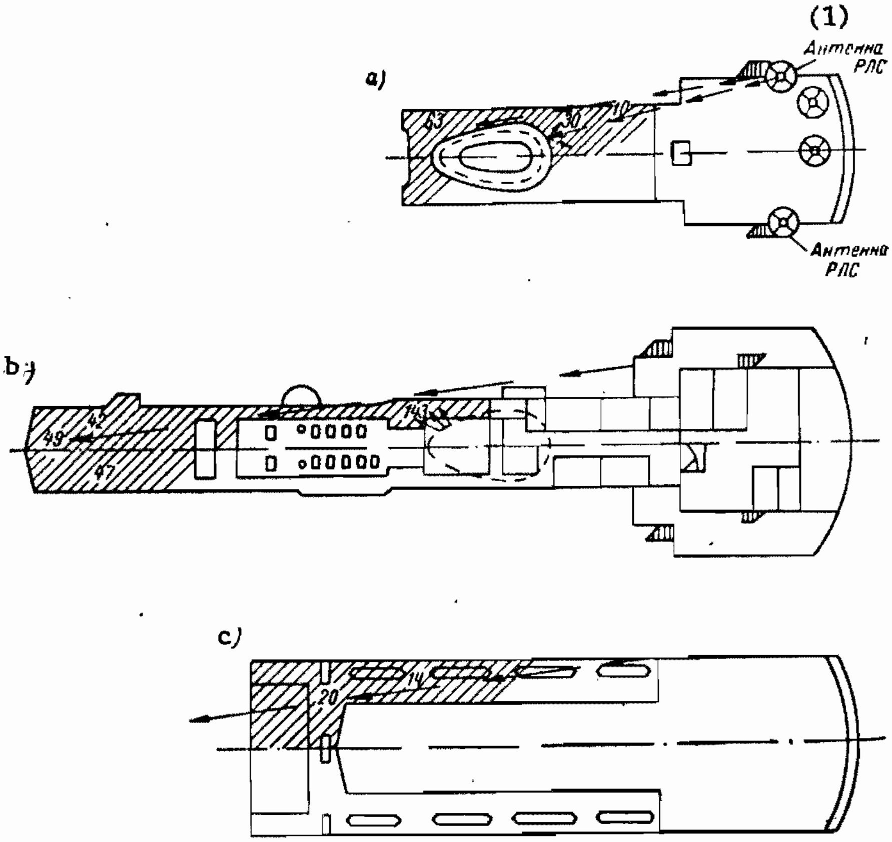

Figure 20. Zones of increased irradiation intensity (crosshatched) on the deck of a passenger liner with the antenna installed six meters above the deck of the top bridge; a -- top bridge; b -- upper bridge; c -- boat deck

Key: 1. Radar antenna

The measurements taken on ships where the radar antennas are installed on masts 11 and even 14 meters above the top bridge level showed that the ship does not fall into the zone of intense irradiation, and in practice it is in the "blind zone" where the radiation is minimal.

A sharp increase in the power flux density can occur as a result of reflection of the superhigh-frequency wave flux from various metal and non-metallic objects installed on the bridges and decks. The degree of effect of these objects is difficult to determine. The intensity of the secondary superhigh-frequency emission will be higher the higher the electrical conductivity of the reflecting objects. Therefore, the presence of a large number of superstructures on the decks can cause the formation of zones where the irradiation intensity will exceed the maximum permissible value by many times.

The picture of the superhigh-frequency field distribution on the ship varies depending on the height of the antenna, the ship architecture, the presence of shielding and reflecting surfaces, the magnitude of the angle of inclination of the antenna, the length of the emitted wave, the type of antenna, its aperture, geometric dimensions, gain and other parameters. In addition, constant redistribution of the superhigh-frequency field takes place as a result of rotation of the antenna around its own axis. Therefore, irradiation of the crew falling in the range of the beam is not continuous but varies as a function of the RPM of the antenna, that is, it takes place periodically and discontinuously so that the actual irradiation time turns out to be less than the total period.

In conclusion, it is necessary to state that the distribution pattern of the superhigh-frequency fields on the decks of maritime ships presented on the basis of numerous studies indicates the possibility of intense irradiation of the crew especially on the top bridges with low installation of the antennas. This fact must be emphasized all the more since the existing tendency toward increasing the power of radar transmitters and expanding the frequency band of the waves can lead to intense and biologically more effective irradiation of the crew.

When evaluating the conditions of possible irradiation of the crew by a superhigh-frequency field from a radar it is necessary to consider the height of the antennas of the upper bridge and the architectural features of the ship. It is necessary to consider that an installation height of 4.5 meters for the antenna is insufficient for cargo ships with one deck superstructure and especially for ships having two deck superstructures. As for passenger ships, installation of the antennas at 6 meters above the top bridge also does not exclude irradiation of the crew by a superhigh-frequency field.

§6. Magnetic Fields in the Living Quarters and Service Compartments of a Ship

In accordance with the "Rules for Radio Equipment of Maritime Ships" of the USSR Registry, the radio room is made of metal, that is, its overheads, deck and bulkheads are welded from sheet metal on which an inside finish is applied. In this form, the radio room is a metal chamber with openings (windows and doors) which, in the absence of shielding of the emitting elements, to a certain extent localizes the electromagnetic field formed inside it. From the point of view of labor safety, this shielding of the facility inside which operations are performed with open emitting systems should not be carried out. However, the shield is all right if radiation inside the radio room is excluded. The very existence of the metal shield of the room can explain the absence of an intense high-frequency field in the living quarters and service areas adjacent to it.

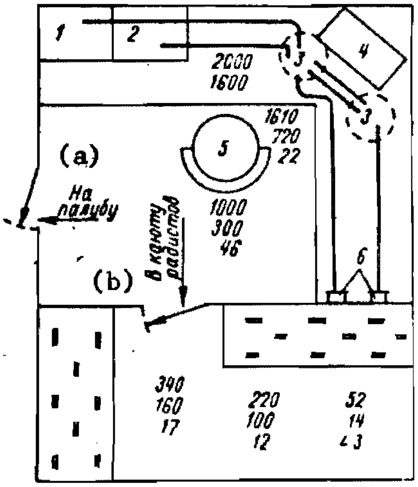

Figure 21. Intensity of the electric component of the medium wave field (410 kilohertz) in the area adjacent to the radio room (the radio operators' cabin) in the case of insufficient shielding. 1 and 2 -- combined receiving and transmitting radio (100 watts) types 1410, 2102; 3 -- antenna switches; 4 -- emergency transmitter; 5 -- radio operator's chair; 6 -- antenna insulators

Key: a. to the deck
b. to the radio operators' cabin

The intensity of possible irradiation of an operator in radio rooms of various series of ships has been investigated in §3 of this chapter.

On the basis of numerous measurements of the field it has been established that high-frequency irradiation in the living quarters of the ship is practically absent. Only the facilities adjacent to the radio room usually on old ships constitute an exception. For example, in the radio operators' cabin (Figure 21) which is located in the area adjacent to the radio room, a high-frequency field is detected the intensity of the electric component of which sometimes reaches hundreds of volts per meter. The high-frequency field from the radio room penetrates into the radio operators' cabin through the wooden door. The field intensity is determined by the open feeder lines and wall tubes installed near the bulkhead of the cabin or directly above the door. The situation is different in the nonadjacent service areas. In the wheelhouse or chartroom if they are located near the antenna fair-leads and drops, the magnitude of the electromagnetic field can sometimes exceed 20 volts/meter. The field penetrates into these rooms through the overheads which are made of wood on old ships. In addition to the external field, the irradiation intensity here will be determined by secondary emission from the metal surfaces of the instruments. This conclusion was drawn on the basis of measurements of the fields on ships at their moorings in port when other radio technical instruments were not in operation. Measurements taken on ships under way revealed the possibility of formation of high-frequency fields (up to 3-5 volts/meter) near such instruments as tachometers and sonic depth finders. The most obvious source of field formation is the induction occurring as a result of closure of high-frequency currents through the ship's hull, metal decks, bulkheads, pillars, and so on.

Thus, the ship's crew in the living quarters (with the exception of the operators' cabins adjacent to the radio rooms and having wooden doors are not subject to high-frequency irradiation.

In the service areas located next to the radio room, especially in the chart room and wheelhouse equipped with a large number of radio technical devices, the formation of a high-frequency electric field is possible the intensity of which usually does not exceed several tens of volts per meter. The magnetic component of the field does not exceed 0.5 amps/meter.

§7. Electromagnetic Field in the Shipping Line Transmission Centers

Marine radio transmitting equipment must provide for communications to distances ~~to~~ thousands of kilometers. For this purpose, of powerful modern transmitters and efficient directional antennas are used in the shore radios of the ports and shipping lines. In contrast to ships' antennas, the antennas of the shore radio centers operate under more favorable conditions. Application of symmetrical antennas offers the possibility of obtaining high efficiency by comparison with ships' antennas. This, in turn, increases the radiation power.

The transmitters installed in the investigated shore radio centers have either symmetrical output through the feeder attachment or asymmetrical output made by a shielded cable, which leads to comparatively low values of the high-frequency field intensity. The most powerful short wave transmitters have output through a protective filter for supressing ultra short wave harmonics. Individual mean values of the high-frequency field intensity obtained during short-term emissions at one of the transmitting centers of the country are presented in Table 6.

From the table it is obvious that at the transmitter control panel and at the control panel located in the center of a large instrument room, the intensity of the electric component of a high-frequency field is a maximum of 62-22 volts/meter. In a small instrument room with medium-wave transmitters of foreign types (Wilcox Electric Company) with a power of 1.5 and 0.5 kilowatts, the electric field intensity near the control panel is up to 125 volts/meter with 7amps/meter of magnetic field.

During operation of these transmitters in the center of the room a field of up to 25 volts/meter is detected. Near Soviet transmitters the electric field intensity does not exceed 11 volts/meter with practical absence of the magnetic field.

Table 6. Intensities of the electric component of a high-frequency field in the rooms of a radio transmission center

Measurement location	Emission power of the transmitter, kilowatts	Radio wave band	Distance to the radiator, meters	Intensity of electric component of the field, volts/meters	Remarks
Large instrument room:					
At the worktable	5	Short wave	1.0-2.0	46.0-30.0	Along the wall tube and at the rear walls of the short wave transmitters
Near the sidewalls	10	Short wave	1.0-2.0	30.0-14.0	
At the transmitter control panel	5	Short wave	0.5-1.0	62.0-46.0	
At the wall tube under the feeders	5	Short wave	1.0-2.0	90.0-21.6	
At the control panel	5	Several transmitters operating simultaneously	3.0-6.0	22.6-7.0	In the center of the room
Small instrument room:					
At the transmitter control panel	1.5	Medium wave	0.5-1.0	125.5-70.0	At the same points the magnetic field is up to 7 amps/meter
In the wall tube and at the transmitter control panels	1	Medium wave	0.5-1.5	11.0-<3.0	
In the center of the room	0.5	Medium wave	3.5-4.0	25.0-<3.0	
Chief engineer's office				6.5-<3.0	Areas next to a large instrument room, brick wall, stuccoed
Laboratory				<3.0	
Transmission Center chief's office				<3.0	

Thus, the personnel servicing the transmitters of shore radio centers can be subjected to irradiation by a high-frequency field exceeding the maximum allowable by several times.

It is necessary to consider the possibility of irradiation of personnel not directly related to servicing the transmitters and located in the instrument rooms of the radio center or in adjacent facilities or sometimes facilities next to them.

Measurements taken in the antenna fields of radio centers revealed maximum values of the electric field of 20 volts/meter with practical absence of a magnetic field.

§8. Electromagnetic Fields of Shore Radar

Shore radar is installed for navigation purposes connected with passage of a ship through narrow places, travel in fog, approaching shore, and so on. In the Gulf of Finland, for example, at the approach to Leningrad several radars are installed which are designed for pilot purposes. The shore radar of the Ministry of the Maritime Fleet, just as the ship radar, operates on the same frequency bands except with higher emission power.

The shore radar is located in a special building, and its basic units are placed in individual facilities. The transmitters are installed in a shielded area to which only service personnel are permitted access.

The radio wave energy transmission line from the transmitter to the antenna is in a metal chute and the transmitting-receiving antenna is placed in a special area on the roof of the building. The radar antenna has the property of directional radiation and it rotates continuously in the horizontal plane at 8 rpm.

Investigation of the conditions of labor of personnel working in a facility where transmission units are installed demonstrated that the operation of devices with the tops of the instruments closed is not accompanied by irradiation in practice. Irradiation by superhigh-frequency radio waves is possible during tuning and regulation of the equipment when the operation is performed with the doors of the devices open. For example, when regulating a magnetron, the irradiation of the hands of the worker can be up to 100 microwatts/cm^2.

Dangerous soft x-radiation is formed by vacuum tubes operating in the high-voltage mode (above 10 kilovolts). This radiation is eliminated by a metal shield or lead glass with a metal grid. As recent research has shown, inside individual bays of radar transmitters there is comparatively intense soft x-radiation. O. A. Stykan [87], who performed such measurements by the method of individual photometric control, determined the total dosage of x-radiation in a bay of radar units as 5 roentgens in 21 hours and 0.5 roentgens in 6 hours of actual operation of the equipment. This corresponds approximately to a dosage of 238 and 83.5 milliroentgens/hour. Such irradiation of personnel can occur only under exceptional conditions: repair, tuning or regulation of the transmitter units with the tops open.

The duty personnel are not subjected to indicated irradiation by a high-frequency field or x-radiation.

The situation is different with directional radiation of the radar antenna. The fact is that improper selection of the location of the radar can lead to irradiation of the population especially if the radar is installed on shore and the populated area is on a high place. Studies which have been made have revealed the possibility of such a case. Measurements made at a distance of 200 and 500 meters from the radar building revealed the presence of a field of up to several miliwatts per square centimeter.

§9. Electromagnetic Fields During Manufacture and Repair of Ship Radios and Radar

All the operations connected with irradiation when manufacturing and repairing marine radios and radar can be subdivided into several steps:

1) Operations performed in the production shops of the manufacturing plants;

2) Regulation and tuning in the shop of the shipbuilding plant or special repair rooms of the shipping lines;

3) Tuning, regulation or repair directly on board ships;

4) Checking and testing under operating conditions during sea trials.

The indicated operations are performed by groups of specialists each of whom can under certain conditions be subjected to irradiation by a high or superhigh-frequency electromagnetic field.

Tuning and Regulation of Communications Transmitters

The studies made in the production shops of the plants when regulating and tuning ship communications systems demonstrated the possibility of irradiating the personnel with superhigh-frequency fields up to several hundreds of volts per meter.

When regulating individual cascades of marine transmitters, the tuners are subjected to high-frequency irradiation. This operation is performed on special test units equipped with power sources, measuring and control equipment and dummy antennas.

In Table 7 we have the intensities of the electric and magnetic components of the medium and short wave high-frequency field in the work areas of tuners for type YeRSh and Blesna radios.

As is obvious from the table, tuning the fifth and sixth amplification cascades and the antenna circuits of the transmitters on open test units is accompanied by the highest irradiation. The antenna circuit of the type YeRSh transmitter was tuned on a dummy antenna in the form of a 55-70 ohm resistance with a capacitance of 20 picofarads installed on the top of the bay.

When estimating the possibility of irradiating the tuners under plant conditions it is necessary to consider the regulation sequence of the individual units for which irradiation can be minimal or entirely absent. However, under mass production conditions where regulation is carried out on test units, irradiation is possible as a result of operation of other transmitters with open units or on an open load.

Thus, the tuner of a ship communications transmitter in the production shop of the plant is subjected to high-frequency irradiation the intensity of which varies periodically within broad limits.

Regulation and tuning in the shop of a shipbuilding plant or in a special repair room of the shipping line are also accompanied by irradiation, the intensity and duration of which, as has been established, are somewhat less than in the production shop of the plant.

During the sea trials the personnel are subjected to the least irradiation.

Tuning and Regulating Radar

Research has established that the first steps of the operations which are performed in the plant shops and electroradionavigation rooms of the shipping lines are the most unfavorable. The tuning of the radar units under the conditions of the plant or the room is carried out basically with the top removed. During operation the tops serve as a shield localizing the electromagnetic field.

The sources of radiation of the superhigh-frequency field can be open radiating systems, the cathode leads of magnetrons, the leaks in flange couplings, various structural openings and slots in the elements of the wave guide channel. The basic emitter of a superhigh-frequency field is the magnetron generator. The pulse power of the magnetrons of marine radar is 80-100 kilowatts in the 3 centimeter and 10 centimeter bands. The cathode leads of the magnetron which are placed in a glass bulb which is transparent to electromagnetic waves can be a source of harmful radiation. The radiation and luminescence from the cathode of the magnetron mount were studied by White, Bamford and Buck [137]. They detected the basic combination frequencies of the signals and their harmonics capable of having a harmful effect on man.

The high-frequency lead of the magnetron is connected to the wave guide transmission line, and it is shielded sufficiently in practice.

However, during tuning it may turn out that the magnetron lead is open. In such cases the high-frequency energy will be emitted into the area where the service personnel are located.

In Table 8 we have the results of measuring the power flux density near the transmitters of marine radar with an output power of 100 kilowatts per pulse. As is obvious from the presented data, with the high-frequency output of the magnetron open the irradiation intensity can reach thousands of microwatts per square centimeter. It must be pointed out that working with the magnetron output open is not, as a rule, permitted. However, in special cases this work must be done using individual devices.

The operation of powerful transmitters can be accompanied by side effects, for example, in the form of increased content of positive and negative ions in the air of the chamber as the result of possible breakdowns, discharges, corona on high-voltage lines, and so on.

The measuremements of the quantitative ion content in the shielded chamber during tuning and regulation of magnetrons and modulator tubes demonstrated that fifteen minutes after including the device with the fan shut off the number of positive ions increased by almost twenty times. It must be noted that the negative ions increased the resistance capacity of the organism and have a beneficial effect on it at the same time as positive ions inhibit the vital activity of the organism. Their harmful effect consists in the fact that even very low intensities during prolonged irradiation cause ionization of the cells of the organism, disrupting their normal functioning. In addition, it is necessary to consider that the tuner can be subjected to the combined effect of a superhigh-frequency field and x-radiation.

Electron tubes operating at high voltages are a source of x-radiation. They include rectifying diodes, modulator tubes, generator tubes type GMI, hydrogen thyratrons, magnetrons, and so on.

The high-voltage rectifying diode, the anode voltage on which reaches tens of thousands of volts can be compared with an x-ray tube having an incandescent filament and an anticathode. The electrons emitted by the incandescent cathode are accelerated in the direction of the anode, and they hit it at high speed. When they hit the anode, part of the energy is converted to the energy of the x-radiation which occurs.

The intensity of the x-radiation of the tube is proportional to the square of the anode voltage, the current passing through the tube, and the atomic number of the anode material:

$$I = KU_2iZ$$

where k is the proportionality coefficient;

Table 7
Field intensity in the production shop of a plant when tuning marine radios

Measurement location	Distance to the radiator, meters	Intensity		Remarks
		E, v/m	H, a/m	
1. YeRSh-R				
At the control panel	0.2	17	--	At a frequency of 1,500 kilohertz with the walls of the unit closed and maximum power
	0.4	<3	--	
	1.0	<3	--	
At the front panel	0.2	24	--	When operating several transmitters simultaneously
	0.4	14	--	
	2.0	<3	--	Induction in the open unit of an adjacent transmitter
From the variometer unit of the 5th and 6th cascades	0.2	32	--	Unit open
	0.3	112	--	
	0.5	63	--	
	1.0	9	--	
On the anode side of the K-71 tube	0.2	69	--	
	0.5	62	--	
	1.0	7	--	
On the variometer side	0.2	362	--	At a frequency of 24,000 kilohertz
	0.3	216	--	
On the anode side of the generator tubes	0.2	380	--	
	0.3	170	--	
At the dummy antenna	0.2	32	2.8	With the unit closed at a frequency of 365 kilohertz
	0.3	22	1.2	
	1.0	<3	<0.5	
	1.5	<3	--	
At the front panel of the transmitter	0.2	2.8	<0.5	With the unit closed at a frequency of 365 kilohertz
	0.4	12	<0.5	
	1.0	<3	<0.5	
On the generator tube side	0.2	430	10	With the walls of the unit open
	0.5	68	0.7	
On the variometer and tube anode side	0.2	560	11.6	
	0.5	116	0.9	
On the variometer and tube anode side	0.2	582	13	At a frequency of 405 kilohertz
	0.5	112	1.2	

Table 7 (continued)

Measurement location	Distance to the radiator, meters	Intensity		Remarks
		E, v/m	H, a/m	
2. Blesna-KVM				
At the control panel	0.2	<3	--	With walls of the units closed for an equivalent power at f = 2,840 kilohertz and P = 100%
On the equivalent power side	0.2	22	--	
At the control panel	0.2 0.4 1.0	208 52 <3	-- -- --	With the walls of the unit open
On the variometer side	0.2 0.4	246 42	-- --	
On the tube side	0.2 0.4	240 58	-- --	

U is the voltage on the anode;

i is the anode current;

Z is the atomic number of the anode material.

The modulator tube forms the commutator in the transmitter circuit.

In Figure 22 we have the shape of the voltage pulse of the modulator tube GMI(a) and the hydrogen thyratron (b), and the schematic of occurrence of x-radiation is presented (c).

During the commutation of high anode voltages on the pulse fronts there are times when the current buildup rate is high. At these times it is possible to assume the presence of maximum x-radiation (Figure 28,c).

When estimating the possible x-radiation it is necessary to consider that in circuits with tubes having a hard vacuum (series GMI), radiation is formed in the sections of the leading and trailing edges of the pulse, that is, at the voltage buildup and decay times whereas in circuits with thyratrons only the leading edge has significance as a result of complete decay.

A magnetron can be a source of soft x-radiation. The magnetic system of the magnetron has a strong shielding effect, but, in spite of this, the

Table 8
Power flux density (PFD) when tuning a 100 kilowatt pulse radar transmitter

Measurement location	Distance from radiator, meters	PFD, microwatts/cm^2	Remarks
Work area of the tuner	0.2	4330.0	High-frequency output of the magnetron open
	0.4	4000.0	
	1.5	1190.0	
In the area at various points	3.5	182.0	
	7.0	32.0	
Work area of the tuner	0.1	204.0	Magnetron loaded on a dummy antenna, the primary location of radiation is the cathode outputs
	0.2-0.4	64.0-62	
	0.6	46.0	
	1.0	28.0	
In the area at various points	1.5	16.0	
	2.0	3-5.0	
Work area of the tuner	0.2-0.4	3.0-2.0	With the walls of the transmitter closed by gratings
	0.6	--	

radiation intensity of a powerful magnetron even beyond the limits of the outer metal wall 2 mm thick can be up to several hundreds of milliroentgens per hour [126].

The actual possibility of existence of x-radiation in the work areas of the tuners of marine radar units is confirmed by measurements performed by the MRM-1 type instrument.

According to the "Sanitary Rules" No 333-60, 25 June 1960, the maximum permissible dose of penetrating radiation and x-radiation with total irradiation is a dose of 100 millirems per week. This corresponds to a dose of 2.8 milliroentgens/hour during a 6-hour working day.

The x-radiation measurement data [60] for 15-100 kilowatt kenotrons used when testing cables demonstrated that the dose intensity can reach 0.91-1,200 microroentgens/second.

Thus, workers who tune and regulate a radar transmitter unit under certain conditions can be in the range of an intense superhigh-frequency field and soft x-radiation. In addition, when working in shielded chambers with the ventilation off it is necessary to consider the possible increase in the number of positive ions in the air.

With the doors of the transmitter unit closed, the irradiation by a superhigh-frequency field is practically nonexistent. The measurement data

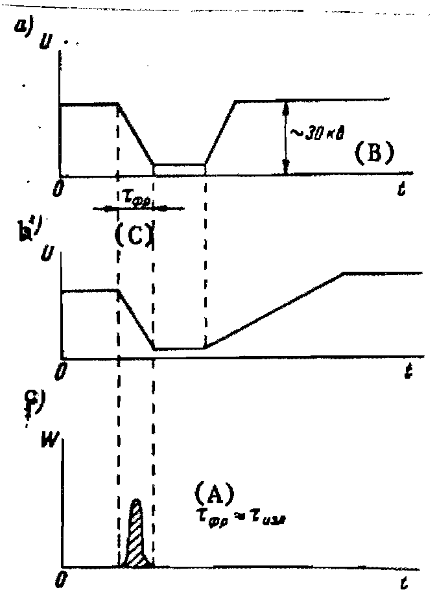

Figure 22. Graphs of the voltage pulse of modulator tubes series GMI (a) and the hydrogen thyratron (d), and also the approximate diagram of formation of x-radiation (c). τ_{fr} is the decay time or buildup time of the voltage on one of the pulse fronts; τ_{rad} is the approximate duration of the x-radiation pulse; W is the x-radiation intensity.

Key: A. $\tau_{fr} \approx \tau_{rad}$ B. kilovolts C. τ_{fr}

show that only in direct proximity to the walls of the transmitter (gratings) can the power flux density be 2-3 microwatts/cm^2.

When estimating the harmful effect of a superhigh-frequency field or soft x-radiation on the tuners and regulators of ship radar it is necessary to consider the time they spend in the irradiation zone beginning with the total work time. It is difficult to determine the exact time that a tuner is in the zone of intense irradiation, but one thing is for sure: carefully performed tuning and regulation of radar units under shop conditions decreases the time of being in the irradiation zone during mooring and sea trials.

The operating conditions in the production shops of the plants when the radars are assembled and their final tuning and testing are carried out in practice have been investigated here. Individual radio technical devices of the radars and the antennas are tested in special laboratories where the radiation sources are relatively low-power measuring oscillators. The intensity of irradiation when working with measuring oscillators with violation of the safety engineering rules, especially in antenna laboratories, can constitute tens, hundreds and sometimes thousands of microwatts per square centimeter.

The conditions of irradiation of workers who tune and test radio technical devices for radar by electromagnetic superhigh-frequency fields were described in 1961 and 1962 [49, 74, 75].

CHAPTER IV
BIOLOGICAL EFFECT OF RADIO WAVES

pp 76-88

§ 1. Thermal and Nonthermal Effect

Research in the biological effects of radio waves is now being conducted both in our country and abroad. More and more people are being attracted to creation, manufacture and operation of new powerful radios and radar with which all modern maritime, river and lake ships are being equipped.

In one chapter it is difficult to elucidate all aspects of the complex problem of the biological effect of radio waves. However, it is necessary that every worker connected to some degree with devices which emit electromagnetic radio waves into the surrounding space know the basic manifestations of the biological effect. The effect of electromagnetic radio waves on an animate organism is explained by its thermal or specific effect which cannot be explained only by heating of the tissues.

Foreign researchers are giving basic attention to the effect of electromagnetic radio waves beginning with the thermal effect, that is, heating the animate organism by the field energy.

The research performed in our country, in contrast to foreign research, is based on a complex of dynamic studies of the reactions of the organism to the effect of low irradiation intensities, and, especially, in the superhigh-frequency range, recognition of the cumulative biological effect in the case of chronic explosure to low power flux densities.

An animate organism the tissues of which comprise various colloids and electrolytes is an imperfect dielectric or poor conductor. The basic interest connected with the effect of radio waves on the biological environment is manifested in induction of high-frequency ion currents or high-frequency ion oscillations in the tissues of the living organism which cause either irritation of the tissue cells or heating of the tissues. The effect of the radio waves depends on the oscillation frequency, intensity and time in the irradiation zone.

Researchers in various specialties -- clinical doctors, physiologists, hygienists, chemists, physicists and engineers -- are studying the effect of radio waves and standardization of individual frequency bands. Proper statement of the research requires defined theoretical concepts of absorption of electomagnetic energy by the human organism.

In this respect, it is of greatest interest to calculate the absorption of power by the human organism in an electric field for frequencies of 100 kilohertz to 10,000 megahertz performed in 1963 by V. A. Franke [94]. The calculation was made for semiconducting models of uniform material close with respect to form to the human body the electric parameters of which coincided with the parameters of the muscle tissue. The specific resistance ρ and relative dielectric constant ε of the muscle tissue were taken from reference [135]. V. A. Franke investigated various cases of orientation of a model with respect to direction of propagation of an electromagnetic wave and the force lines of the field.

As a result of the calculation, he obtained the curves in Figure 23. On the graph the frequency f is plotted on the x-axis in hertz, and the effective absorbing surface of the model F is plotted on the y-axis in square meters. The magnitude of F is numerically equal to the power in watts absorbed by the model in a plane wave field under the condition that the power flux density in the incident wave is 1 watt/m^2.

For an arbitrary value of the power flux density σ the absorbed power W in watts can be found by the formula $W = \sigma F$. The value of σ is expressed in watts per square meter.

V. A. Franke calculated that at frequencies below 10 megahertz the power absorbed by the body for any orientation of it is proportional to the square of the frequency. At higher frequencies when the wavelength is comparable to the dimensions of the body (the meter wave band), resonance maxima of power absorption can occur.

These maxima occur on orientation of the axis of the model along the electric force lines of the field.

In the 300- to 30,000 megawatt band the absorbed power depends weakly on the frequency and is approximately 10 times less than the absorbed power at the point of the first resonance maximum.

A. S. Presman [78] made an approximate estimate of the relation between the magnitudes of the fields, their intensities and the currents induced by them for the frequency band from 100 to 1,000 kilohertz. On the basis of calculating the current density induced in the human body under the effect of electric and magnetic components of the field it is possible to estimate the probability of occurrence of a thermal effect.

The amount of heat formed in the human body in electric and magnetic fields is estimated approximately from the relations

$$Q_E \approx 0{,}24 j_E^2 \rho t v \approx 3{,}5 \cdot 10^{-18} \cdot f^2 E^2 \quad \text{cal/min};$$

$$Q_H \approx 0{,}24 j_H^2 \rho t v \approx 3{,}5 \cdot 10^{-14} \cdot f^2 H^2 \quad \text{cal/min},$$

where ρ is the specific resistance of the tissues;

v is the volume of the human body.

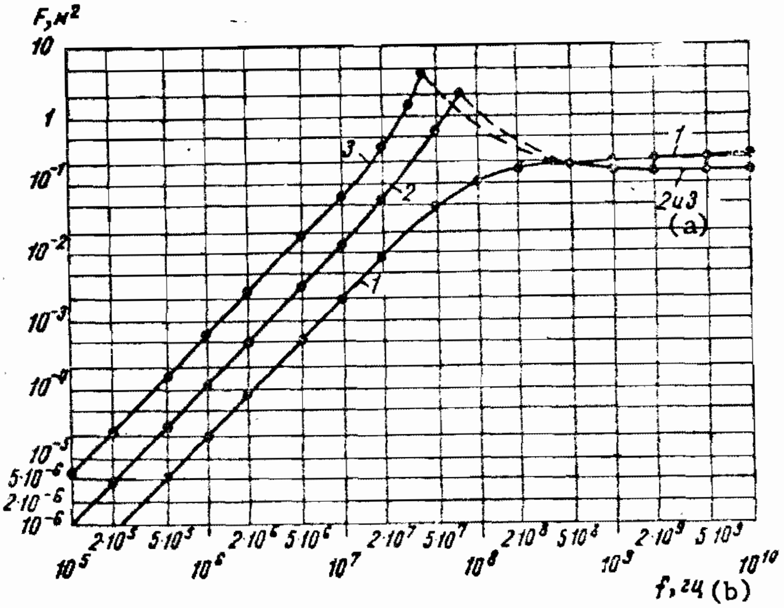

Figure 23. Total effective absorbing surface of the model F. 1 -- the model in free space and oriented along the magnetic force lines; 2 -- the model is in free space and oriented along the electric force lines; 3 -- the model is in the conducting plane and oriented along the electric force lines.

Key: a. 2 and 3 b. f, hertz

The current density j_E induced in the surface layers of an ellipsoid by an electric field with halfaxis dimensions of a = 0.9 m and b = 0.15 m (the approximate dimensions of the human body) is

$$j_E \approx 1{,}3 \cdot 10^{-13} \cdot f E \ \text{amps/cm}^2,$$

where E is measured in volts per meter, and f is in hertz.

The maximum density of the current induced by the magnetic field is

$$j_{H(max)} \approx 3.3 \cdot 10^{-11} \cdot f H \ \text{amps/cm}^2,$$

where H is measured in amperes per meter.

The mean value

$$j_{H(\text{mean})} \approx 1.3 \cdot 10^{-11} \cdot fH \text{ amps/cm}^2.$$

Knowing the frequency of variation of the electric or magnetic fields and measuring the values of the field intensity in the work area, it is possible approximately to estimate the current density, that is, to determine the biological effect of the electric and magnetic components of the field separately.

This separate determination of the effectiveness of the biological effect is required, as has been pointed out, when working with high-frequency industrial heating devices where an inductor (the magnetic field is high) or capacitor (the electric field is high) can be used as the working element.

Then, by comparing the density of the current induced by the electric field with the maximum density of the current induced by the magnetic field, we obtain

$$\frac{j_{H(\text{max})}}{j_E} \approx \frac{3.3 \cdot 10^{-11} \cdot fH}{1.3 \cdot 10^{-13} \cdot fE} \approx 250$$

An analogous comparison with the mean density of the current induced by the magnetic field is provided by the expression

$$\frac{j_{H(\text{mean})}}{j_E} \approx \frac{1.3 \cdot 10^{-11} \cdot fH}{1.3 \cdot 10^{-13} \cdot fE} \approx 100.$$

A. S. Presman showed that the biological effectiveness of a magnetic field is hundreds of times higher than the effectiveness of an electric field. It is obvious that when selecting the standardized irradiation with respect to the magnetic component of the field (5 amps/meter by comparison with 20 volts/meter) for devices for induction heating of metals, in addition to the experimental and clinical data calculated data were also used.

The characteristic values of the current density and heat release occurring under the effect of the electric and magnetic fields in the human body calculated by A. S. Presman for a frequency of 500 kilohertz with defined intensities do not exceed 1.6 milliamps/cm^2 and 90 cal/min, respectively.

The maximum values of the current density obtained are appreciably less than the threshold values for irritation of the nerve cells. If we begin with the data of N. K. Vitte [9] on heat exchange, then the calculated maximum values of heat generation (90 cal/min) are still insufficient for noticeable heating of the body. However, complex ion processes occurring in the medium surrounding the cell and inside it under the effect of a current are hardly indifferent to functioning of the cell itself.

The described calculation procedure was first used by Professor V. Arkad'yev in 1928 [2] when studying the effect of electric and magnetic fields on a human placed in a solenoid of the D'Arsonval' apparatus. Subsequently, biological activity under various conditions of irradiation was calculated by J. Stratton [86], L. D. Landau and Ye. M. Livshits [52].

In Table 9, in accordance with the measurement data, we have the calculated values of the current densities and quantity of heat formed in the body of radio operators on maritime ships in the case of insufficient shielding of radiators.

Table 9

Values of the current density and quantity of heat occurring in radio operators under the effect of electric and magnetic fields

f, kilohertz	E, volts/m	H, amps/m	j_E, amps/cm^2	j_H, amps/cm^2	Q_E, cal/min	Q_H, cal/min
510	500	5	0.033	0.08	0.23	0.23
	2000	20	0.13	0.34	3.6	3.6
17360	500		1.1		262.0	
24000	500		1.6		504	
500 (for Presman high-frequency heating)	300	50	0.02	0.08	0.09	22
	1000	100	0.07	1.6	0.9	90

Notes. f -- field variation frequency;
E -- intensity of the electric components of a high-frequency field in the induction zone;
H -- intensity of the magnetic component of a high-frequency field in the induction zone;
j_E -- current density induced by an electric field in the human body;
j_H -- current density induced by a magnetic field in the human body;
Q_E -- quantity of heat generated in the human body under the effect of an electric field;
Q_H -- quantity of heat generated in the human body under the effect of a magnetic field.

Under ship conditions when operating a medium-wave transmitter with an unshielded feeder, the radio operator is irradiated basically by an electric field, and the current density formed in his body is expressed in hundredths and thousandths of a milliampere per square centimeter at the same time as appreciably lower currents occur in the body of people working in the range of fields formed by industrial heating devices. As a result of the effect of the magnetic field in the body of the radio operators, currents are formed the density of which is j_H = 0.08 to 0.34 milliamps/cm^2 at the same time as when working with industrial high-frequency heating generators the current density reaches 1.6 milliamps/cm^2.

The quantity of heat generated in the body of a radio operator under the effect of electricity and magnetic fields is up to 3.6 cal/min by comparison with 0.09 and 90 cal/min in people working with induction heating devices in industry.

Comparison of the current densities coccurring under the effect of the magnetic component of the field shows that in ship radio operators the biological manifestation is less effective on medium waves than in people working with high-frequency industrial heating devices. Whereas in the latter case it is necessary to give serious attention to the biological effectiveness of the magnetic field, under radio room conditions there are no grounds for it.

The data obtained when performing the calculation on shortwaves and calculated for maximum values of the electric field intensity provide a basis for proposing the occurrence of a thermal effect in radio operators, who work on long trips basically on shortwave transmitters.

Thus, the absorption of electromagnetic energy of the radio waves and generation of heat in the organism (with significant irradiation intensities) basically depend on the frequency of the active factor. In addition, inasmuch as the tissues of the organism (bones, muscles, brain, liver, and so on) having different conductivity are heated differently, a selective thermal effect is possible when individual tissues and organs are heated more than others. The heating of deep-lying tissues can cause thermal burns, and this is especially dangerous since the outer integuments (of the skin) remain insensitive.

Schwan and Li [127] demonstrated that the depth of penetration of the electromagnetic energy at a frequency below 100 megahertz does not depend in practice on the thickness of the skin and fatty layer under the skin. At these frequencies approximately 30-40 percent of the energy of the incident irradiation is absorbed in the tissues. At frequencies of 100-300 megahertz, the thickness of the skin and the fatty layer becomes comparable to the wavelength, and the amount of absorbed energy varies from 20 to 100 percent depending on their thickness. At frequencies above 3,000 megahertz, the basic part of the energy is absorbed by the skin.

The thermal effect of radio waves is studied experimentally as the thermal reaction of the organism. It must be stated that the data which have been published up to now, especially foreign data, are interpreted differently by the researchers. The fact is that it turns out to be difficult to establish the relation between the increase in body temperature or temperature of the organ and the organism's reaction as a whole to this increase. However, the or- thermal effect of electromagnetic radio waves in a living organism in the presence of significant irradiation intensities is indisputable, and it is recognized by all researchers.

As for the nonthermal specific effect of radio waves, there is no united opinion with regard to this question. Many researchers consider that the shifts occurring in the organism of people who work under irradiation conditions which cannot be connected with a rise in temperature in the organs and tissues still provide no grounds for thinking in terms of the specific effect of the electromagnetic field, but this is explained by the "point" heating of individual structures or the microthermal effect. That which is called the nonthermal specific factor of the effect of radic waves must, in reality, be accepted as microheating of the tissues not subject to ordinary measurements. Yu. A. Osipov [71] considers that the specific effect (in the sense of juxtaposition with respect to form of energy to thermal), although theoretically possible, still has no convincing physiological confirmation.

§2. Characteristic of High-Frequency Oscillations and Duration of Irradiation for Various Forms and Modes of Operation

For correct estimation of the electromagnetic field affecting the organism, it is necessary to know the characteristic of high-frequency oscillations and also the time spent in the irradiation zone. From this point of view, forms of radio frequency oscillations used under various operating conditions are of interest.

In the marine radio service using shore and ship radios, the following types of high-frequency oscillations are used:

1) Nondamping oscillations when the high-frequency current of the radio receiver does not vary with respect to amplitude during transmission of the signal;

2) Modulated oscillations when the fundamental frequency (carrier frequency) of the radio transmitter is modified by an audiofrequency which varies the amplitude of the high-frequency current. The high-frequency modulated oscillations are emitted by the radio into space with discontinuities in the operating cycle of the telegraph key;

3) Oscillations modulated by the audiofrequency spectrum corresponding to voice, music and singing. This type of oscillation is radiated into space continuously during the entire radiotelephone transmission time.

Modulated oscillations where the high frequency current goes to the antenna discontinuously and is emitted in series of nondamping oscillations of different length have found the broadest application. For the telegraph transmission procedure, depending on the signal, short series correspond to dots and long series, to dashes. In the case of absence of a shield, during sending of the signal the radio operator in the room is subjected to irradiation by an electromagnetic field of defined magnitude which does not vary during the process of signal transmission. The mean transmission rate (operation on a key) is 120 signals (dots and dashes) per minute. Consequently, during transmission of a radiogram the radio operator is subjected to irradiation 120 times per minute. The sending time alternates randomly: a dash is equal to three dots with respect to time, the interval between signals of the same letter is one dot, and the interval between two letters, three dots (one dash), and the interval between two words is five dots.

In order to determine the continuous irradiation time of a ship radio operator, it is necessary to calculate what time is spent on sending radiograms per day.

The results of processing the trip logs of some cargo ships for long range and short trips show that the average continuous irradiation time considering the correction for tuning the radios, and so on is from 30 minutes to 1 hour per day. On days before holidays the load increases, and the irradiation can last 2 hours and more. The greatest irradiation time (3-4 hours per day) is noted during cruises when the change of subscribers is especially frequent.

Several watch logs have been processed in addition to the cruise logs in order more precisely to define the irradiation time.

In the watch log the radio operator records the time expended on realizing communications (qso) and sending radiograms (rdo), and he indicates the frequency band.

Thus, on board the Metallurg Bardin on the tenth trip, the irradiation time per day was 1.5 hours on the average. Here, the shortwave irradiation time lasted approximately 1 hour, and medium-wave irradiation time, 0.5 hours. A similar calculation for the diesel cargo ship Pavlin Vinogradov showed that during a trip of 14 days the irradiation time was 2.6 hours per day.

These data consider only the time of continuous irradiation excluding the breaks between signals (in the telegraph mode of operation). Actually, the radio operator is in the range of the field which continuously disappears and reappears in the operating cycle of the key (120 times per minute), that is, a longer time determined by the time of operation of the transmitter on emission.

During operation of the transmitter in the radiotelephone mode the operator will be irradiated during the entire transmission, that is, a longer time than in the telegraph mode.

It is undoubtedly the case that a time study performed on ships would give a clearer picture of the time the radio operator and other members of the crew spend in range of the high-frequency field from radios.

As research has shown, the service personnel of shore radios are in range of a less intense field which does not differ with respect to nature from the field of ship radios. This is explained by the fact that the work areas of the personnel servicing the transmitting rooms of the radio centers are not stationary, and frequently the transmitters are controlled from the central panel which is a significant distance from the transmitters.

During intense radio traffic the transmitters (more frequently shortwave, just as for ship radio traffic) operate continuously. Therefore, unless safety measures are observed the shore radio personnel will be subjected to irradiation during the entire work day.

People working with industrial heating devices under plant conditions are, as a rule, subjected to continuous irradiation by a high-frequency field of nondamping or modulated oscillations.

The alternating current, variable voltage and electromagnetic field created by a high-frequency generator can have either constant or variable amplitude.

In spite of the application of filters, high-frequency industrial devices, in contrast to radios, create a large spectrum of harmonics which are imposed on the fundamental frequency fields. Unfortunately, as a result of absence of special devices which would offer the possibility of measuring the high-frequency fields of individual harmonic components near industrial heating devices, it is impossible to judge their magnitude. However, in the case of a biophysical estimate of the active factor obviously it is necessary to consider the presence of harmonic components in addition to the fundamental frequency.

The tuners, regulators and personnel servicing ship and shore radar stations are subjected to irradiation of a more complex nature. The radar generator operates in individual pulses which follow each other periodically. The pulses are characterized by length, shape, repetition rate, oscillation frequency per pulse, pulse power, average power and pulse energy.

The pulse length of ship and shore radar is from 0.1 to 1 microsecond. The shape of the pulses is close to rectangular. The oscillation frequency per pulse is 10,000 and 3,000 megahertz (wavelengths 3 and 10 cm).

The pulse emission of the radar is essentially the same short signals as in the telegraph mode of operation of ship or shore radios except with shorter and constant intervals of significantly greater power and with a higher oscillation frequency within the pulse.

Irradiation during tuning, regulation and operation of radar can be directional when the person doing the work gets into the range of the directional beam of the radar antenna or other open radiating elements, and it can be stray irradiation formed by various superhigh-frequency energy leaks through the devices in which it is transmitted.

During regulation, tuning and testing of the radars in the plant shops and electroradionavigation chambers, the irradiation time variation limits are determined by the technical parameters and corresponding procedures for testing and checking individual units of the radar.

Directional and prolonged irradiation are the most dangerous.

Z. V. Gordon [18] proposes that all operations connected with superhigh-frequency irradiation be subdivided into three groups.

First group -- operations connected with the periodic effect of large irradiation intensities (0.1-10 milliwatts/cm^2 and more).

Second group -- operations connected with the periodic effect of low irradiation intensities (0.01-0.1 milliwatts/cm^2).

Third group -- operations connected with the systematic effect of low irradiation intensities.

If systematic irradiation during regulation and tuning of individual modules under plant conditions or in the electroradionavigation chambers of the shipping lines leaves no doubt, the periodic effect of the wave flux from the radar antenna as a result of its rotation around its axis is still a subject of discussion.

Actually, the duration of the directional effect from the radar antenna depends on the rpm of the antenna.

A man is in the zone scanned (in accordance with the directional diagram) by an antenna only at the times when the diagram is directed in the angular interval defining the position of the man with respect to the antenna. The intensity of irradiation in this case varies, increasing from 0 to maximum values determined by the power emitted by the antenna and then again decreasing to zero.

Let us estimate the irradiation time for the slowest rotation rate of marine antennas -- 11 rpm -- when one rotation is completed approximately in 5 seconds. If the width of the directional diagram in the horizontal plane is 2 degrees, the irradiation time per revolution is about 30 milliseconds.

At higher rotation rates, the irradiation time will be still less. It is considered that this periodic irradiation by a superhigh frequency field is less dangerous than continuous irradiation of the same intensity [10].

Under ship conditions, irradiation by a superhigh-frequency field from radar antennas is short-term, as a rule, and it depends on the operating time on emission. The operating time of the radar is determined by the navigation conditions. Irradiation is longest when navigating in fog, especially in northern latitudes when the ships move in a caravan, and so on.

The nature of the radiation, its duration of effect and its intensity are the basic criteria when developing norms for maximum permissible irradiation not causing pathological changes in the organism.

§ 3. State of Health of People Working Under Conditions of Radio-Frequency Irradiation

Numerous articles published in various medical and technical (especially foreign) journals and special publications devoted to special conferences both in the Soviet Union and abroad confirm the harmful effect of radio waves on man.

An especially detailed study of the effect of the superhigh-frequency radio band, which is considered the most dangerous, is presented in [68-70, 77, 126].

Subjectively, the effect of radio waves on man is manifested in the form of complaints of rapid fatigue, headaches, irritability, insomnia, eye fatigue, pains in the vicinity of the heart, lowering of sexual potentcy, tendency to perspire, and balding.

Objectively, the overall professional-pathological effect of radio waves of various frequency bands and different intensity is determined by changes in the central nervous system, the cardiovascular and endocrine systems, the peripheral blood system, and so on.

In addition to the general manifestations of systematic effect of radio waves on the organism of man, there are specific manifestations which occur only under the effect of defined frequency bands. Thus, organic damage to the eyes in the form of professional cataract occurs in people working with centimeter waves. Such pathological changes in the form of cataracts, affections of the testicles, necroses of the tissues — all occur under the direct effect of frequently directional superhigh-frequency radiation. The tissue temperature is increased especially easily in those organs where there are no or few blood vessels (the crystalline lens of the eye, the testicles). In the case of irradiation of the head, a pathological change as a result of direct effect of radio waves on the brain centers is possible.

It is considered that the biological activity of narrow frequency bands can vary. For example, within the limits of short and meter waves the biological activity increases with a decrease in wavelength, and decimeter waves cause greater shifts in the systems of the organism than meter and centimeter waves. Millimeter waves give rise to less expressed changes than centimeter and decimeter waves.

The study of the biological effect of radio waves of various bands is continuing in connection with the appearance of new devices, new frequency bands, radiation powers, specific nature of operation of these devices, and so on. Inasmuch as the problems of the effect of radio waves under various conditions of manufacture and operation of high and superhigh frequency devices are printed most frequently in special medical journals and are known only to a narrow circle of specialists, it is expedient to present some information from recent publications [17].

In Chapter III, for example, it is demonstrated that the conditions of labor of marine radio operators are least favorable, and in the absence of special protective measures they are subject to intense electromagnetic irradiation of the medium and shortwave band. In order to study the state of health of radio operators, N. B. Gorbonosova processed 3,985 individual dispensery charts of the crews of ocean-going vessels. As a result, it was established that out of 3,985 crew members, 290 had various diseases of a chronic nature preventing them from sailing.

On developing data on professions it turned out that a relatively large number of people with various diseases appear among radio operators. Thus, out of 215 radio operators, 50 had chronic diseases (23.2 percent). Mechanical specialists had the same level of diseases amounting to 22.3 percent. The remaining professions were characterized by a smaller number of people having chronic diseases.

The primary disruption of the state of health of ship radio operators is damage to the organs of sight whereas in the remaining professions this form of disease is encountered appreciably more rarely. Ship radio operators basically suffer from a decrease in sharpness of vision.

The work conditions of ship radio operators are connected with some sight stress when observing instruments having a scale with small numbers and when receiving radiograms with text recorded on typewriters and in a log.

The illumination of the work area of the radio operators was 100-150 lux according to measurements taken on 25 ships using incandescent bulbs, and 250-300 lux when using luminescent illumination. This corresponds to the existing norms. It must be pointed out, however, that the illumination of the instrument scales in radio rooms on some ships turned out to be 25-50 lux. Individual scales had a dark color, small numbers and inadequate illumination. However, in spite of this, it is hardly possible to assume that the indicated problems could promote loss of vision in such a large number of radio operators.

Among the diseases of the cardiovascular system occurring in ship radio operators, hypertonic disease, myocardial distrophy and disruption of the blood circulation in the brain play the leading role. All radio operators suffering from diseases of the cardiovascular system are young (from 30 to 35 years old) with five to 10 years of service. Among the diseases of the nervous system encountered in them, functional disorders of the central nervous system, vegetative neurosis, and neurasthenic syndrome are noted.

Thus, it is possible to consider it established that the largest number of people with health impairments occur among ship radio operators as compared to other marine professions.

Physiological observations in the production situation with careful evaluation of the active factor demonstrated changes in reactions on the part of thermal regulation, the central nervous system and the cardiovascular system as the most sensitive to the effect of radio frequency irradiation.

Thus, personnel servicing high-frequency dielectric heating devices (short and partially ultrashort wave bands) manifest a 0.7 degree average increase in body temperature after 3 hours of work [76]. The absolute values of the body temperature in these workers during the shift reached 37.4 and 37.8 degrees. The mean rise in temperature in people working with high-frequency devices at 400-250 kilohertz with an intensity of the electric field component of 150-250 volts/meter and the magnetic component, 30-45 amps/meter, was 0.6 degrees [84, 96]. In people working with centimeter waves in the 10 and 3 cm bands with irradiation intensities from 5 to 100 microwatts/cm^2, only normal physiological variations in body temperature are noted [73].

The results of investigating the central nervous system of people working with high, ultrahigh and superhigh-frequencies indicate relatively stable functional changes originating from the systematic chronic effect of radio waves.

In conclusion it is possible to state that a large group of Soviet research specialists in different areas: doctors-hygienists, physiologists, clinicians, chemists, physicists and engineers directed by active members of the USSR Academy of Medical Sciences Professors I. R. Petrov, A. A. Letavet, and so on have presented a complex picture of the effect of radio waves of various frequency bands on man on the basis of many years of research. They have developed servicing rules and norms for the maximum permissible irradiation intensities when servicing such devices. They have also proposed a number of safety measures which are being successfully used in various fields of engineering.

CHAPTER V
PROTECTIVE MEASURES AGAINST THE EFFECT OF ELECTROMAGNETIC WAVES OF HIGH-FREQUENCY INDUSTRIAL HEATING DEVICES

pp 89-108

The development of protective measures against the effects of high-frequency irradiation of steel became actually possible only in the 1950's when we learned how quantitatively to evaluate the harmful factor.

The creation of special devices for measuring the intensity of the electric and magnetic components of the high-frequency field in the induction zone permitted us to obtain the distribution picture of the fields for various types of work with induction and dielectric heating devices widely used at the plants of the shipbuilding industry. Depending on the conditions and nature of operations with high-frequency devices, the electromagnetic irradiation can be reduced to the limits of the allowable norms or entirely excluded.

The protection of people who work with high-frequency industrial heating devices is realized by shielding the emitting elements of the high-frequency device. The shielding can be modular (complete or incomplete) and general [51]. The necessity of shielding the entire device or individual elements of it is determined on the basis of the measurement data for the electric and magnetic components of the field in the work area of the service personnel.

The shielding of the high-frequency device is a complex design problem. Incorrect solution of it can lead to high power losses and worsening of the technical characteristics of the device. Therefore, knowledge of the basic requirements on the shields of high-frequency devices will help the designer to deal with the problems of practical application of one type of shielding or another.

§ 1. Basic Requirements of Shielding High-Frequency Devices

Metal screens are used to lower or eliminate the magnetic fields formed near high-frequency devices. The effect of such a screen reduces to the fact that the high-frequency electromagnetic field formed by the radiation source is attenuated by the field in the opposite direction created in the thickness of the shield and caused by the Foucault eddy currents.

The shield selected for shielding devices which differ with respect to emitted power and frequency must satisfy the defined requirements.

Effectiveness of Shielding. The basic characteristic of the shielding is the degree of attenuation of the electromagnetic field penetrating beyond the limits of the shield called the shielding effectiveness. The effectiveness of shielding $Э$ is the ratio of the field intensity of the electric component E_0 or magnetic component H_0 at the given point in the absence of a shield in the device to the field intensity at the same point in the presence of a shield ($E_Э$ or $H_Э$):

$$Э = \frac{E_0}{E_Э} \quad \text{or} \quad Э = \frac{H_0}{H_Э}.$$

The quality of the shield is also characterized sometimes by the permeability η -- the magnitude of the inverse effectiveness of the shielding:

$$\eta = \frac{E_Э}{E_0} \quad \text{or} \quad \eta = \frac{H_Э}{H_0},$$

and also the degree of shielding which is calculated by the following formula:

The effectiveness of the shielding depends on the thickness, specific resistance and magnetic permeability of the material from which the shield is made and also on the frequency of the electromagnetic field. The effectiveness of the shield can be estimated also by the magnitude of the so-called coupling impedance $Z_{coupling}$ which is the ratio of the high-frequency voltage on the outside surface of the shield $U_{outside}$ to the high-frequency current on the inside surface of the shield I_{inside}:

$$Z_{coupling} = \frac{U_{outside}}{I_{inside}}.$$

In order to increase the impedance $Z_{coupling}$ it is necessary to decrease the currents induced in the shield. For this purpose it is recommended that the shields be located at a defined distance from the emitting systems. For example, when shielding an induction coil the shield must not be located nearer than the distance of half the radius of the coil; otherwise, the shield will be heated and at the same time will create high power losses. It is expedient to arrange the welds and contact lines along the motion of the high frequency currents and not across. This lowers the losses at the contacts and the possibility of radiation.

Selection of the Shield Material

An important problem in designing the shield is selecting the material for manufacturing it. It is convenient to evaluate the material for the shield with respect to degree of attenuation of the electromagnetic field which can be provided by the shield. The measure of the attenuation is the depth of penetration of the high-frequency current into the thickness of the shield. When selecting the thickness of the shield it is possible to use the value chacterizing the depth of penetration of the current which is provided by decreasing the field by 100 times.

The expression for the depth of penetration of the high-frequency current into the depth of the shield has the form

$$\theta = 2{,}32\sqrt{\frac{\rho}{\mu f}},$$

where θ is the depth of penetration, mm;

ρ is the specific resistance of the shield material, ohms·mm^2/meter;

μ is the magnetic permeability of the shield material;

f is the frequency, megahertz.

From the presented formula it follows that the greater the magnetic permeability of the shield material and the higher the frequency of the electromagnetic field, the less the depth of penetration of the high-frequency field into the shield and, consequently, the thicker the shield required.

If the shield is made of nonmagnetic material, that is, $\mu = 1$, the shielding effect or depth of penetration of the current into the thickness of the shield will be determined only by the specific resistance of the material and the frequency of the shielded field.

For large values of the magnetic permeability μ at high frequencies the depth of penetration of the field into the thickness of the shield will be a total of several microns.

In Figure 24 we have the curves for the depth of penetration of the electromagnetic fields into the shield thickness for certain materials as a function of frequency calculated by S. A. Lyutov [56]. The depth of penetration curve is not presented for a steel shield in connection with the fact that the magnetic permeability of the steel at radio frequencies is a quite indeterminant value which depends on an entire series of factors and which decreases with frequency.

The required thickness of the shield therefore depends on frequency and should exceed the depth of penetration of the current into the shield material by several times. For example, for high frequency induction heating devices operating at frequencies of 250-300 kilohertz with a shield thickness of 0.3-0.4 mm, a good shielding effect is obtained [93].

For the electromagnetic shield, mainly materials with high electrical conductivity such as copper and brass are used. Aluminum and its alloys are highly appropriate materials. With good conductivity aluminum has sufficient mechanical strength and is comparatively inexpensive, and it has a low specific weight.

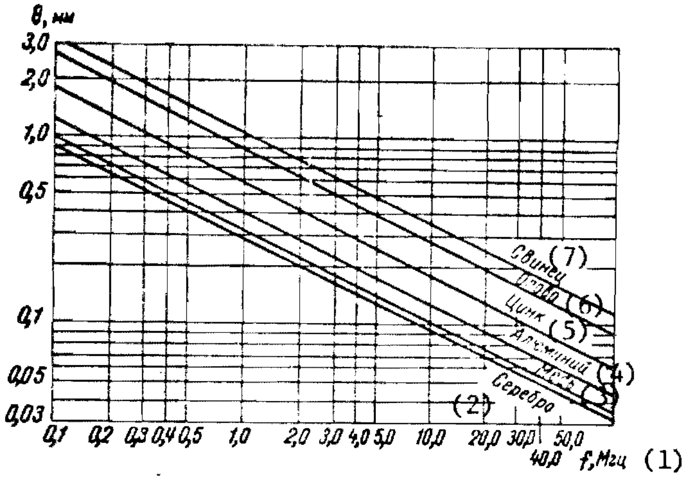

Figure 24. Curves for the depth of penetration θ of electromagnetic fields into the thickness of a shield made of various materials as a function of frequency f.

Key:
1. f, megahertz
2. silver
3. copper
4. aluminum
5. zinc
6. tin
7. lead

In Table 10 we have the depth of penetration for various shielding materials calculated by M. L. Volin [11] with attenuation of the magnetic field by 2.72 times (χ_0), by ten times ($\chi_{0.1}$) and by 100 times ($\chi_{0.01}$) by comparison with their values on the surface. On the basis of these data it is possible to state that for high-frequencies, beginning with the medium-wave band, a shield made of any metal 0.5-1.5 mm thick operates highly effectively. In the opinion of M. L. Volin, when selecting the shield thickness and material it is necessary to begin not with the electric properties of the material but to consider the mechanical strength, rigidity, corrosion resistance, convenience of joining individual parts and realization of cross contacts between them with low resistance, convenience of soldering, welding, and so on.

From the table data it follows that for frequencies above 100 megahertz, a copper, and especially a silver film less than 0.1 mm thick provides a significant shielding effect. Therefore, at the indicated frequencies it is entirely allowable to use shields made of pertinax foil or other insulation material with copper or silver coatings deposited on it.

Table 10

Depth of penetration for various shielding materials

Metal	Specific resistance, ohms·mm²/meter	Relative magnetic permeability, μ	Frequency f, hertz	Depth of penetration, mm		
				x_0	$x_{0.1}$	$x_{0.01}$
Copper	0.0175	1	10^5	0.21	0.49	0.98
			10^6	0.067	0.154	0.308
			10^7	0.021	0.049	0.098
			10^8	0.0067	0.0154	0.0308
Brass	0.06	1	10^5	0.39	0.09	1.8
			10^6	0.124	0.285	0.57
			10^7	0.039	0.09	0.18
			10^8	0.0124	0.0285	0.057
Aluminum	0.03	1	10^5	0.275	0.64	1.28
			10^6	0.088	0.20	0.4
			10^7	0.0275	0.064	0.128
			10^8	0.0088	0.020	0.04
Steel	0.1	50	10^5	—	—	—
			10^6	0.023	0.053	0.106
			10^7	0.007	0.016	0.032
			10^8	0.0023	0.0053	0.0106
Steel	0.1	200	10^2	1.0	2.5	5.0
			10^3	0.35	0.8	1.6
			10^4	0.11	0.25	0.5
			10^5	0.035	0.08	0.16
Permalloy	0.65	12,000	10^2	0.38	0.85	1.7
			10^3	0.12	0.27	0.54
			10^4	0.038	0.085	0.17
			10^5	0.012	0.027	0.054

The depthsof penetration for steel with a relative magnetic permeability $\mu = 50$ show that even at high-frequencies steel gives a greater shielding effect than nonmagnetic materials. However, in the case of application of steel shields it is necessary to consider that they can introduce significant losses into the shielded circuits as a result of high specific resistance ρ and the hysteresis phenomenon. Therefore, such shields are applicable only in cases where it is possible not to consider the losses introduced by them.

When comparing the electric properties of sheet materials made of copper and steel [27] it turns out that in the radio frequency band steel is a more effective material for a shield than copper. In addition, it is appreciably cheaper than copper. For thickness of steel and copper which are the minimum allowable from the point of view of mechanical strength (about 0.3 mm), in the radio frequency band it is possible to obtain attenuation of 70 decibels and more.

V. A. Franke [94] recommends the selection of aluminum or steel for shielding operating inductors of melting-quenching devices although, based on an example calculation, he points out that steel creates greater energy losses in the shields. Nevertheless, in order to avoid unjustifiable expenditures in each case he recommends that the calculation be performed both for aluminum and for steel and selection of aluminum if steel is unsuitable.

By using aluminum alloy for shielding high-frequency devices with a shield thickness of approximately 2.5 mm, Arnold Albin [100] obtained radiation attenuation of more than 100 decibels. Hollway [112] considers that sheet iron gives high effectiveness of shielding, especially at frequencies above 500 kilohertz.

Kiya Tsutomu [114] achieved effective shielding in the band from medium to ultrashort waves. On the basis of experimental data, he obtained the shielding effectiveness curves for various shielding materials as a function of frequency.

Shield Design

Special requirements are imposed on shield designs. The effectiveness of the shielding is decreased to a significant extent if the electromagnetic shield has slots and holes. Accordingly, when selecting the shield design it is necessary to consider its degree of electric seal, that is, the presence, arrangement and dimensions of the slots and different shape of holes. In particular, the degree of electric seal of the shield at frequencies above 10 megahertz has a greater effect on the shielding effectiveness than the parameters of the material from which the shield is made [1].

When selecting the structural designs of the shield for a high-frequency device it is considered that if there are slots in the shield the length of which is appreciably less than the length of the electromagnetic wave, then there need be no radiation. A check has demonstrated that this position is valid only for high-frequency dielectric heating devices operating on comparatively shortwaves. The shields for melting inductors or matching transformers of induction heating devices (cut with respect to the entire height in order to decrease the losses in them) almost do not attenuate the magnitude of the magnetic field in the work area and are therefore ineffective.

The minimum effectiveness of shielding by a metal housing with slots is obtained on resonance frequencies for which the length of the slots is equal to an integral number of halfwaves. Such a tuned slot is an antenna, and therefore it not only worsens the shielding effect but also leads to amplification of the field occurring beyond the shield.

Sometimes metal housings or electromagnetic shields specially developed for shielding emitting elements of high-frequency devices have a large number of round holes which are used for various purposes.

The effect of the round holes on the shielding effectiveness of the metal screen is the topic of theoretical and experimental works by M. S. Neyman [62], L. I. Mandel'shtam [57], A. G. Gurevich [23], and so on. In accordance with these papers, for any frequencies (resonance and nonresonance) the intensity of the electromagnetic field which is emitted by a round hole is proportional to its radius to the third power. For example, with a decrease in size of the holes by two times the magnitude of the penetrating field intensity decreases by 8 times. A calculation of the electric and magnetic fields penetrating slot and round holes is presented by G. Kaden [34].

By replacing the slits (required in the shield) by small round holes it is possible to reduce the intensity of the electromagnetic field near high-frequency devices. However, with an increase in the radiation frequency of electromagnetic waves (especially at ultrahigh-frequencies) the dimensions of the round holes become commensurate with the wavelength. This leads to worsening of the effectiveness of the shielding. In this case, the attenuation of the electromagnetic field penetrating the round hole is achieved by inserting a tube (connecting pipe) in the hole. This acts as a waveguide filter.

The diameter of the tubes should not exceed one-fourth of the wavelength, and their length should be five or more diameters. The tubes should be connected reliably electrically to the wall of the shield around the entire perimeter of the hole. It must be considered that it is impossible to pass open current conductors through the tube since this converts it into a coaxial cable (line).

The holes in the shield of the high-frequency device used for ventilation purposes, various peepholes and other openings sometimes are closed to some extent by metal grids soldered around the perimeter to the edge of the metal shield of the device. However, the ventilating holes covered by the metal grid can complicate air exchange; therefore, it is sometimes more advantageous to use wave guide filters.

The problem of passage of a conveyor belt into the chamber can be solved by means of wave guide filters in the case where the belt and the transport mechanism itself do not form a conductor which converts the wave guide filter into an asymmetrical feeder. Wave guide filters offer the possibility of shielding a permanently open door. The system of wave guide filters in the form of a lattice resembling a honeycomb can be used instead of the grid for shielding the windows [100].

In practice, electromagnetic shields with holes are built more frequently than solid shields. The effectiveness of a shield having several holes can be calculated approximately by the formula

$$Э = \frac{1}{\sum_{1}^{n} \frac{1}{Э_n}},$$

where $Э_0$ is the effectiveness of the shielding found under the assumption of the presence of only one hole;[1]

V. A. Franke proposed a procedure for calculating shields for operating inductors and matching transformers of high-frequency melting and quenching devices. Using this procedure, it is possible to calculate the shields of coils executed in the form of a round cylinder or rectangular parallelepiped with a square base fully closed, open at the top and bottom or only at the top and shields with holes in the sidewalls.

The shielding of the radiation source can be realized also by application of a grid screen. Grid screens require fewer material expenditures than continuous screens and, in addition, when they are used there is no necessity for special development of ventilating units, and the problems of illumination are simplified. Accordingly, the grid chambers find broad application.

The effectiveness of a single shielded chamber 3 × 2 × 2 m made of a copper grid with a wire 0.5 mm in diameter and a cell width of 3 mm at a frequency of 0.15 megahertz is no less than 64 decibels [58], and the effectiveness of the shielded chamber made of a brass grid is up to 60 decibels [87].

At higher frequencies the effectiveness of the shielding will increase, but to a defined value. This is explained by the fact that the behavior of shields made of sheet material and a grid is entirely different in some respects. The attenuation of the electromagnetic wave energy by a shield made of continuous material increases rapidly with an increase in frequency. In the case of a grid screen with an increase in frequency there is some increase in energy attenuation and it becomes constant in the frequency range of 0.1 megahertz. The dependence of the attenuation of the screening effect on frequency for continuous and grid shields is depicted in Figure 25.

An approximate calculation of the effectiveness $Э$ of a shielding chamber for frequencies up to tens of megahertz can be carried out by the equation proposed by D. N. Shapiro:

$$Э = \left(4{,}2\,\frac{R}{\lambda}\right)\cdot Э_1,$$

where $R = \sqrt[3]{3V/4\pi}$, and V is the volume of the designed chamber. The expression included in parentheses determines the dependence of the shielding effectiveness on the linear dimensions of the chamber and the wavelength λ corresponding to the generator frequency; the magnitude of $Э_1$ determines the dependence of the shielding effectiveness on the shield material.

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[1] $Э_0 = 0{,}25\left(\frac{\Sigma}{\sigma}\right)^{\frac{3}{2}}$, where σ is the area of a hole with a round or square cross-section, and Σ is the area of the entire surface of the shield.

The presented calculation formula is correct if R is much less than λ. If this condition is not observed, then the actual effectiveness will be less than the calculated effectiveness. The value of Э_1 for each frequency is found by the curve proposed by D. N. Shapiro for continuous and grid shields. A. S. Presman [77] compiled Table 11 by these curves for an approximate determination of the value of Э_1.

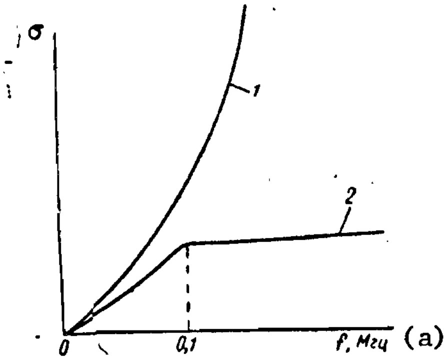

Figure 25. Dependence of the attenuation σ of the shielding on the frequency of electromagnetic oscillations. 1 -- for a shield of continuous material; 2 -- for a lattice shield.

Key: a. f, megahertz

References [23, 25, 29, 33, 90, 99, 105, 107, 108, 117, 125, 133] are also devoted to various methods of shielding invidual devices in order to localize the electromagnetic field and shield the areas from the disturbing effect of radio waves.

Application of Filters

An electromagnetic field emitted by high frequency devices induces currents in all the metal objects surrounding the device. The currents induced in the metal emit an electromagnetic field. Thus, the external electromagnetic field is reemitted into the area by metal objects. Therefore, inside the area where high-frequency generators are installed the distribution pattern of the field is complicated (the intensity increases or decreases) as a result of superposition of secondary emission fields on the primary fields.

The secondary emission field can occur also in rooms or compartments adjacent to the work compartment. In this case the radio frequency current conductors are the lighting system wiring. In areas adjacent to the radio frequency current sections, in some cases there are fields of relatively high intensity near the illuminating lights when they are on. This is especially noticeable if local lighting fixtures are used in this area for lighting the work areas.

Table 11

Effectiveness of shielding $Э_1$ of high-frequency fields by metal sheets with metal grids

Form of shield	Shield materials	$Э_1$ at a frequency of (kilohertz)				
		10	100	1,000	10,000	100,000
Metal sheets 0.5 mm thick	Steel	$2.5\cdot10^6$	$5\cdot10^8$	Greater than 10^{12}		
	Copper	$5\cdot10^6$	10^7	$6\cdot10^8$	$> 10^{12}$	
	Aluminum	$3\cdot10^6$	$4\cdot10^6$	10^8	$> 10^{12}$	
Metal grids	Copper (wire diameter 0.1 mm, cell 1.0 × 1.0 mm)	$3.5\cdot10^6$	$3\cdot10^5$	10^5	$1.5\cdot10^4$	$1.5\cdot10^3$
	Copper (wire diameter 1.0 mm, cell 10.0×10.0mm)	10^6	10^5	$1.5\cdot10^4$	$1.5\cdot10^3$	$1.5\cdot10^2$
	Steel (wire diameter 1.0 mm, cell 1.0 × 1.0 mm)	$6\cdot10^4$	$5\cdot10^4$	$1.5\cdot10^4$	$4\cdot10^3$	$9\cdot10^2$
	Steel (wire diameter 1.0 mm, cell 10.0 × 10.0 mm)	$2\cdot10^5$	$5\cdot10^4$	$2\cdot10^4$	$1.5\cdot10^3$	$1.5\cdot10^2$

Propagation of radio frequency currents over the electric network lines can take place in two ways: as a result of the inductive and capacitive effect of the external electromagnetic field on the wires and via the transformers feeding the generator, the signal and blocking control wires. For purposes of obstructing the path, electric filters are applied in both cases to the radio frequency currents. They are used for separating the currents of certain frequencies from the currents of other frequencies. The electric filters used, for example, in industrial heating devices separate the basic frequency currents of the generator from its harmonics.

The filters can be single-link and multilink. One link of the filter consists of a choke and a capacitor included in a L or П network.

The basic characteristic of any filter is the attenuation introduced by it which is determined by the ratio of the voltages on the load resistance of the emission source before and after inclusion of the filter.

The attenuation introduced by the filter is expressed in decibels, and it is defined by the equation

$$b_{intr} = 20\lg\frac{U_1}{U_2}.$$

The attenuation of the L and Π-filters can be approximately calculated for single and double-link and also for n-link filters with didentical L and C in each link [56].

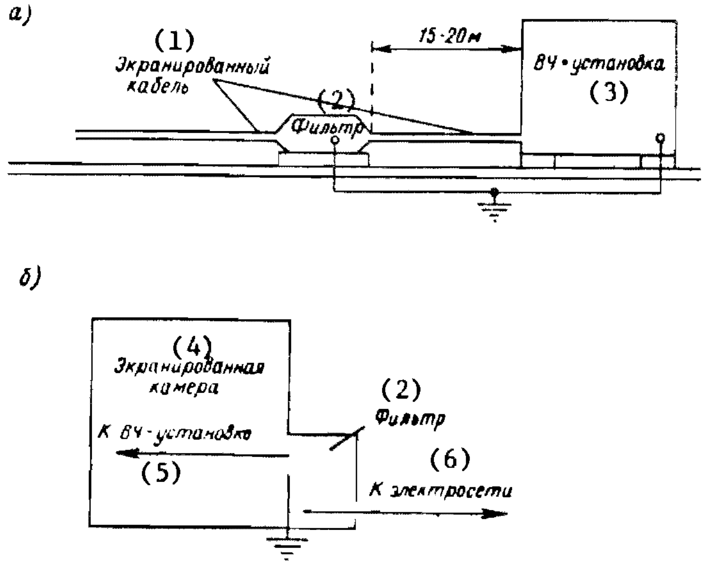

Figure 26. Location of the filter installation in the case of modular shielding (a) and with placement of the high-frequency device in a shielded chamber (b).

Key:
1. shielded cable
2. filter
3. high-frequency device
4. shielded chamber
5. to the high-frequency device
6. to the electric network

Calculation of optimal filters is based on application of rational functions, it does not require a table, and it permits construction of filters with a given degree of accuracy [131].

In practice, the attenuation which the filter provides must be of the same order as the effectiveness of the shield.

All the networks (lighting, power, telephone, and so on) must be introduced into the shielded facility via filters. In the case of modular shielding [1] it is recommended that the filters excluding the high frequency currents which can be spread over the networks be installed at a distance of 15-20 meters from the high-frequency device (Figure 26,a). The network lines from the filter to the device must have a shielded sheathing electrically connected both to the housing of the filter and to the shield of the device. When the device is placed in a shielded area or chamber the electric filter can be included in the network on the outside of the shield (Figure 26,b).

For filtering superhigh-frequency currents, Jones [113] proposes inclusion of an additional line with high attenuation containing powdered iron or salt water.

Special filters for absorbing harmonics on superhigh-frequencies have been developed by Met [117].

Grounding

The shield of the high-frequency device must be grounded at one point to the housing of the electric filter. The ground wire must be as short as possible and have inductance as low as possible; therefore, it is expedient that it be made of a large-cross section bus.

Use of the shield as a neutral wire is not allowed since this lowers its effectiveness by several times, and the shield itself becomes an emitter of an electromagnetic field.

§ 2. Forms of Shielding

In order to exclude the powerful high-frequency fields formed by industrial heating devices and interfering with radio transmission, the radio inspectorate requires shielding at the areas in which these devices are placed. However, shielding of the facilities with high frequency heating generators installed in them is not permissible if the service personnel must be inside such facilities. In this case, either modular shielding is used or overall shielding of the installation.

Modular Shielding

Reduction or elimination of the electromagnetic irradiation by modular shielding is the most effective means, and it can be achieved by efficient selection of the design and material for shielding a high-frequency device. Modular shielding is most effective not only from the point of view of improving the conditions of labor of people working on high-frequency devices but also from the technical and economic point of view.

Two types of modular shielding are distinguished: incomplete and complete.

Incomplete Modular Shielding

With this type of shielding, all the high-frequency modules of the device (the generator, circuits, high-frequency transformers, and so on) are included in the metal shields with the exception of the operating element (the melting and quenching inductors, the capacitor electrodes). This incomplete shielding is realized in the case where shielding the working element turns out to be impossible for technical reasons.

High-frequency heating devices of various designs are shielded differently.

The old type devices still used at the enterprises have no shielding of the oscillatory circuits. Thus, the melting device type GLE-61 is executed structurally in the form of several bays: a generator bay with a rectifier, an anode transformer bay, and two bays in which anode and quenching circuits with capacitor banks are placed. The melting furnace is located separately. The generator and rectifier bay is made of metal and therefore it is actually a shield, and the bays of the oscillatory circuits with the capacitor banks are made of wood and have no shielding.

As one of the methods of controlling radio interference F. E. Il'gekit and K. V. Bazhenov [33] propose that such devices be shielded modularly, improving the shielding of the existing generator bay with rectifier for this purpose (the latter does not emit a high-frequency field) by insuring reliable electrical contacts between the sheets of metal, closing the holes in the shield by a metal grid and also by applying an additional shield to the bay on the bottom side. They recommend shielding of the anode and quenching circuit bay with capacitor banks by copper or aluminum sheets in the form of a common shield for both circuits.

However, it is inexpedient to make the split recommended by the authors in the shield of the induction cathode to decrease losses: long narrow slits, especially slits across the direction of the eddy currents, form an intense field in the work area near the shield.

It is impossible to agree with the indicated authors also with respect to the fact that with careful shielding of the generator bay, the anode transformer and the circuits with capacitor banks the inductor and the melting furnace cannot be shielded. Numerous measurements have confirmed that even with careful shielding of the generator elements the melting and quenching inductors form fields which are comparatively large with respect to intensity in the work areas of the personnel servicing the device.

It is necessary to note, however, that even with such incomplete shielding of the device it is possible to achieve some reduction in irradiation.

Incomplete modular shielding of the devices (basically for hardening metal products) carried out at many of the Leningrad enterprises has on the whole demonstrated a reduction in electric field intensity by several times in the service area. Approximately the same results have been obtained by K. V. Nikonova and P. P. Fukalova [65], who carried out incomplete modular shielding of the induction heating devices for hardening products.

Shielding of the operating elements of the induction heating devices introduces definite complexities since the quenching inductor cannot always be shielded for technological reasons. However, application of a cylindrical tube in the form of a wave guide filter and realization of mechanization of the process or automatic (conveyor) feeding of parts when hardening parts of the same type can significantly reduce the field intensity in the service area.

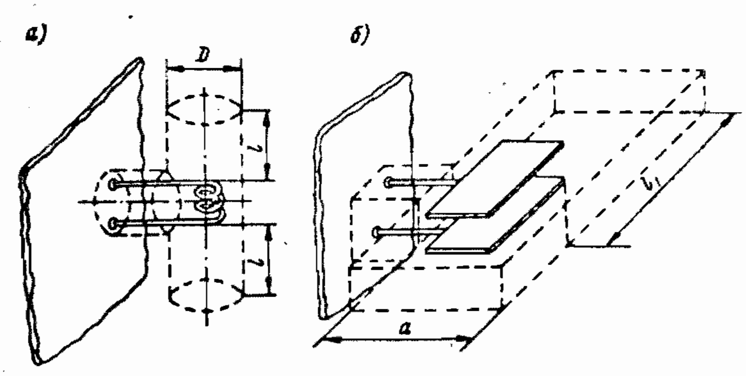

Figure 27. Shielding of an inductor (a) and a capacitor (b).

A cylindrical wave guide filter shown in Figure 27,a is used to shield a quenching inductor. The filter is an open cylinder. The effectiveness of shielding the cylinder $Э$ depends on the ratio of the distance l from the edge of the coil to the edge of the cylinder to the diameter of the cylinder D, and it can be approximately determined from the following formula

$$Э = e^{\frac{3.6l}{D}},$$

where e is the base of natural logarithms.

The dimensions of the cylindrical shield are selected so that the gap between the winding of the coil and the shield on any side is no less than the coil diameter. The cylinder can be manufactured from aluminum, steel, copper or brass no less than 0.5 mm thick.

In cases where complete shielding is impossible, in order to decrease the magnitude of the field intensity near the operating electrodes of the dielectric heating devices, a rectangular wave guide filter can be used (Figure 27,b). Its effectiveness can be defined by the formula

$$Э = e^{\frac{\pi l_1}{a}},$$

where l_1 is the distance from the edge of the capacitor plates to the edge of the tube;

a is the width of the tube.

The melting-quenching induction heating devices types LGPZ, LGZ, LGP-30, LGZ-100, LGP-60, LGP-200 and others require improvement of shielding of the generator module and additional shielding of the matching transformer and the working inductor. The newly developed series of high frequency stepped-up frequency devices (LPZ-37, LZ-37, LP-67, LZ-107, LZ-207, and so on), manufactured to replace the above-indicated devices has an identical schematic and design, and it also requires shielding. The dimensions of these new devices has been increased by comparison with those produced earlier; therefore, a decrease in size of certain elements emitting electromagnetic energy is especially expedient. The size of the inductance coils can be decreased by application of magnetically conducting cores in them which must be made of ferrites for frequencies of 70 kilohertz.

Application of ferrite cores for quenching matching (air) transformers has great significance. This offers the possibility of making the transformer with higher efficiency in the form of a small closed unit easily built into the device, and it also offers the possibility of decreasing the capacitance of the capacitor bank of the load circuit [63].

The operating elements of the high-frequency industrial heating devices obviously do not require shielding if automation of the processes is used, and control of the processing conditions, movement of the part in the elevator and exclusion of heating are realized automatically. Several such devices used to heat parts of the same type are serviced by one man the work area of whom can be at a distance from the radiator such that the field intensity will be minimal.

Complete Modular Shielding

With this type of shielding all the modules of the device, including the operating elements, are included in a metal shield. The total modular shielding is realized comparatively easily on dielectric heating devices or devices for melting metal in a vacuum. This type of shielding is usually carried out in dielectric heating devices developed in recent years. This form of shielding insures a greater degree of electric seal and therefore is more effective.

For a long time it was considered that complete shielding of a high-frequency device for melting metals was impossible as a result of high power losses of the furnace to heating the shield. However, the complete shielding of the high frequency device type GLE-61A with a melting furnace used in practice has demonstrated the groundlessness of this point of view.

Shielding of individual modules of the high-frequency device type GLE-61A with a special device shielding the furnace which could be raised and lowered [6] has been developed and put into production. The shields are made of a diamagnetic material -- type A1 aluminum which insures the required field intensity drop.

It must be noted that when selecting the material for the furnace shield, sheet steel was rejected since experience has shown that a shield made of steel 2 mm thick and installed at a distance of 200 mm from the current-carrying parts of the generator was heated approximately to 80 degrees.

The common shield for air capacitors of the anode circuit is executed in the form of individual flat sections consisting of angular frames covered with sheets of aluminum 1.5 mm thick. The sheets are attached to the angular frames by spot welding. Cut-outs and tubes in sections are provided for passage of the buses through the shield to the melting furnaces and passage of water hoses to the anode circuit.

On the whole, the shield of a melting furnace consists of a lift section, the base under the shield, the exhaust hood with an air duct, a lifting device, and the bus shield. The lifting part of the shield lowered on the furnace protects the workers from the effect of electromagnetic waves emitted by the melting inductor. The frame of the lifting section is made of aluminum angle iron covered with aluminum sheets 1.5 mm thick. The frame is 1.2 × 1.2 × 2.0 m.

For observation of the melting process there are peepholes covered with a metal grid in the frame. The shield is raised when charging the crucible and lowered by a self-braking crane with an electric motor.

The data for checking the effectiveness of the complete modular shield of the GLE-61A device are presented in Table 12.

As is obvious from the table, the effectiveness of the shield for the GLE-61A device is quite high, and it is approximately 98-99 percent. The field intensity in the service work areas is reduced to the allowable norms.

In Figure 28 we have the same shield except improved from the point of view of convenience of operation executed for the LPZ-107 device.

Figure 28. Shield of a melting furnace in the raised position.

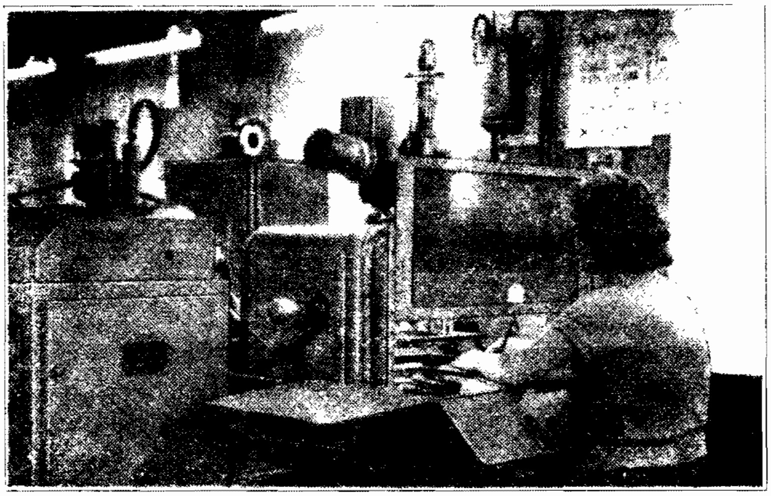

Figure 29. Shield for the operating electrodes of a device for welding plasticized resin parts with the front wall of the shield raised.

By complete modular shielding it is comparatively easy to exclude radio emission of dielectric heating devices (Figure 29). However, in order to obtain the desired effectiveness of the shielding in individual cases it is necessary to build additional shields. Thus, the rear and side walls of the generator tube compartment must be shielded by a brass fabric grid, and it is expedient to join the inside aluminum separating walls of the generator together by a copper bus which is connected to the ground pin.

Table 12
Intensity of the electric and magnetic fields near the GLE-61A device before and after shielding

Measurement locations	Dis-tance, meters	Intensity			
		before shielding		after shielding	
		watts/m	amps/m	volts/m	amps/m
Next to the melting inductor	0.2	250	54	<3	<0.5
	0.5	76	41	<3	<0.5
Next to the current-carrying buses	0.5	200	26	5	<0.5
Next to the capacitor bank of the anode circuit	0.5	500	12	6	<0.5
Next to the coupling coil and the anode circuit coil (through a hole in the metal frame)	0.5	95	11	<3	<0.5

General Shielding

General shielding of a high-frequency device insures the highest effectiveness. In the presence of general shielding the device is placed in a shielded chamber especially designed for this purpose. The shielding chambers are made of metal sheets or a metal grid.

The selection of the material for shielding is determined by the emission frequency and the magnitude of the emitted power.

The general shielding of the devices or the construction of the chambers insures high effectiveness of the protection, but it is not always advantageous from the hygienic point of view and, as a rule, requires great expenditures of materials.

By general shielding the radio inspection board means shielding of areas in which high frequency devices for industrial application are placed. From the hygienic point of view it is not allowable to shield an area without protecting the worker in it from the effects of electromagnetic fields. Accordingly, general shielding is taken here as creation of shielded chambers with the control for the high frequency device taken outside the chamber. Application of such chambers turns out to be most expedient for working with high-power devices and, as a rule, ultrahigh and superhigh-frequency devices.

In accordance with the requirements of the Sanitary Rules high-frequency devices must not create a field intensity exceeding the allowable norms in the work area.

Any shield is calculated by the selection method according to V. A. Franke [93]. A continuous shield in the form of a round cylinder or rectangular parallelepiped with a square base is selected for calculating the shields of a melting furnace, a quenching inductor or a matching transformer. Aluminum or its alloys can be recommended as the shield material because they are cheapest and lightest.

It is known that longitudinal cuts in the shield lower its quality sharply. However, it is necessary to provide a hole in the furnace shield for observing the melting process.

Shields having the form of a tube covered on one or both ends are considered in the calculation.

It should be considered that shielding a matching transformer greatly reduces the mutual inductance of the winding. This leads to an increase in the quiescent current of the transformer and requires an increase in capacitance of the capacitors of the operating circuit in order to insure normal operation of the device.

When shielding quenching inductors, selection of the shield design insuring the possibility of operating and replacing the inductors presents the greatest difficulties.

Such a shield must be calculated in the same way as the shield of a melting furnace without a core is calculated.

§ 3. Requirements on the Structure, Placement and Equipment of High-Frequency Heating Devices

"Temporary Sanitary Rules for Working with Industrial High-Frequency Heating Tube Devices" No 180-55 operating more than 10 years before introduction of the new "Sanitary Rules for Working with Sources of High and Ultrahigh-frequency Electromagnetic Fields" No 615-66 approved in 1966 provided for placement of the high-frequency devices in areas the size of which was limited in accordance with the power of the device.

At the present time the designs of high-frequency devices have changed, their dimensions have been decreased, and in connection with this the requirements on the dimensions of the facilities have been reduced. However, considering the presence of radiation in a number of cases of significant intensity, especially when working with new devices at 60-70 kilohertz, it is necessary to have a free area of no less than 8 m^2 for the unit in order to remove the service personnel from the emitting elements of the device (for example, from the induction furnace).

It is possible to locate high-frequency heating devices,completely shielded in any area beginning with the generally accepted Sanitary Design Norms SN 245-63.

The old type devices which were shielded by the plant can be placed in a facility the area of which is determined by the dimensions of the device and the presence of free space.

When locating them in the flow, the distance between the high-frequency devices and other units must be no less than 2 meters. This distance is provided in order to protect workers from possible irradiation in the absence of shielding of the emitting elements. With complete shielding of the device, this spacing can be reduced to that required for the generally accepted norms.

As has been pointed out, the requirement of building shielded areas to install high-frequency devices began with the radio inspectorate (control of radio interference). There is no necessity for placing fully shielded high-frequency devices in shielded rooms especially since shielding the facility is economically disadvantageous and worsens the hygienic conditions of labor.

The operating and newly installed devices must satisfy the requirements of the "Rules for Construction of Electric Devices" and "Technical Operating and Servicing Safety Rules for the Electrical Devices of Industrial Enterprises."

The meteorological conditions, maximum permissible levels of sound pressure and other factors of the production environment in areas with high-frequency devices must correspond to the Sanitary Norms SN 245-63 if they are placed separately. The facilities where high-frequency devices are arranged must be equipped with common exchange ventilation, and the melting-quenching devices, with local exhaust.

The new sanitary rules require mandatory measurements of the field intensity in the facilities for high frequency devices and in facilities adjacent to them no less than once a year. It is necessary to measure the field with maximum usable powers of the devices, and the measurement results must be entered in a special log with an outline of the measurement procedures. In the case of detecting fields exceeding the allowable it is necessary to take measures to reduce the irradiation intensity.

CHAPTER VI
PROTECTIVE MEASURES AGAINST THE EFFECT OF ELECTROMAGNETIC WAVES WHEN MANUFACTURING AND REPAIRING MARINE RADIOS AND RADAR

pp 109-124

§ 1. Conversion of Irradiation when Tuning and Regulating Marine Radios

The duration and intensity of irradiation of the tuner depend on the structural features of the transmitter and the type of tuning.

The standard marine radio transmitter consists of the following elements: a master oscillator, the buffer cascade of the intermediate high frequency amplifier, the modulator (usually the low frequency amplifier of the audio-frequency oscillator) and the power amplifier.

The structural design of marine radios depends on the operating condition, power and frequency range. Usually marine transmitters are of the console type and consist of power, control, modulator, generator and antenna units in a common chassis. When tuning and regulating the transmitter the blocks are taken out of the housing.

The tuning and regulation of marine radios under production conditions and during repairs are subdivided into two steps:

1) tuning and regulating individual modules of the radio transmitter;

2) overall tuning of the radio transmitter.

The sequence of regulating and tuning operations of a modern radio transmitter has been discussed well by I. M. Zarkh [30], D. M. Vayts [7] and also V. A. Nechayev, B. A. Petrov [63], and so on.

The tuner is subjected to high frequency irradiation when regulating the master oscillator, the high frequency amplifier and the power amplifier. The tuner is subjected to the greatest irradiation when selecting the elements of the oscillatory circuit of the master oscillator where the basic emitting element is a variometer (variable inductance).

When regulating the buffer cascade, the radio frequency emission creates a load equivalent consisting of a parallel included capacitor and resistance. Regulation of the high-frequency amplifier and the power amplifier is accompanied by irradiation especially when checking the tuning limits of the band by the variometer. It must be noted that application of the latter procedure is accompanied by irradiation of various frequency bands beginning with the lowest frequency of the transmitter and ending with the highest.

Tuning of the modulator designed for amplifying the low frequency input signal from a microphone or other source is not accompanied by high-frequency irradiation.

Regulation of individual modules of the radio transmitter must be carried out at specially equipped work areas equipped with power supplies, measuring and control equipment, equivalent loads, and so on. It is necessary to give special attention to the placement of the elements emitting high-frequency energy with respect to the work area.

In areas where individual modules of the transmitter are tuned, it is necessary to measure the high-frequency field intensity for each change in labor conditions, rearrangement and installation of equipment, and changes in the circuit diagram for any change in design of the protective housing.

The distances between the operating tuning units and the plan for their arrangement in the plant shop or electroradionavigation chamber where repairs are made must be determined by the magnitude of the measured high-frequency field intensity.

The high-frequency field intensity in the work areas of the tuners and regulators and in the adjacent work areas should not exceed the maximum permissible avalues.

After regulating the functional units entering into the transmitter circuit, all-around regulation of the transmitter takes place. When performing regulating operations the transmitter is loaded by a dummy antenna the type of which depends on the wavelength and the transmitter circuitry. The dummy antenna is usually installed either on the top of the transmitter or directly on the work table. As measurements show, the highest field with respect to magnitude is formed close to the dummy antenna. However, at a distance of 1.0-1.5 meters the radiation drops sharply and, as a rule, it does not exceed the allowable (the measurements were taken when tuning 100 and 200 watt transmitters types Blesna and YeRSh -- see Chapter III, § 9).

In order to exclude the irradiation of the tuner in this case it is necessary carefully to shield the load elements (the dummy antenna) and to use a well-matched high-frequency cable running from the transmitter to load.

During all-around regulation, the high-frequency modules must be installed in a common metal chassis of the transmitter. This excludes irradiation of the tuner occurring from individual elements of the generator circuit.

Thus, reduction or elimination of the high-frequency irradiation of the tuners and regulators of individual units when they are working or during overall regulation of the radio transmitters can be achieved by rational arrangement of the equipment, removal of the work area from the radiators, shielding individual modules emitting high-frequency energy in the area, procedural improvements, and in individual cases by application of remote regulation and automatic tuning methods.

§ 2. Prevention of Irradiation when Tuning and Regulating Radar

Radar is tuned and adjusted in the same sequence as radio, beginning with individual units and ending with overall regulation as a whole. The antenna feeders, generators, modulators, and so on are subjected to regulating and tuning operations.

Chapter III contains a discussion of the material from a study of the labor conditions of tuners and regulators of marine radar. References [32, 49, 75] present an estimate of the effect and physical-hygienic characteristics of the conditions of superhigh-frequency irradiation of tuners and regulators during mooring trials of marine radar, and protective methods are proposed. The irradiation of a tuner working on individual modules of a radar can be of two types: 1) irradiation occurring during work with low-power measuring generators and 2) irradiation which accompanies tuning and adjustment of powerful generators. In both cases the irradiation intensity depends on the power of the emitting device, the nature of the operations and the form of irradiation (directional, nondirectional and stray).

The sequence of operations and tuning equipment for marine radar are discussed in detail by Ya. I. Berman and B. M. Gol'din [5]. Here, only the tuning and adjustment processes which are connected with emission of superhigh-frequency oscillations having a harmful effect on the organism will be discussed in brief.

In Soviet Lliterature on protective measures when working with centimeter wave generators the following papers have been published [4, 19, 20, 22, 26, 37, 39,and 75].

Tuning Individual Radar Devices. Working with Measuring Generators

Tuning of individual modules of a radar begins with regulation and tuning of the parameters of the individual modules of the device where the superhigh frequency radiation source is a measuring generator.

In Figure 3 we have three examples of inclusion of the instrument in the measuring circuit. The tested instrument is placed in the gap of the wave guide transmission line (Figure 30,a) or at the end of it (Figure 30,b), or it is seated in a hole in the wave guide (Figure 30,c). When replacing the device, irradiation can constitute tens and hundreds of microwatts per square centimeter. This is all the more unfavorable inasmuch as the work area of the tuner is in direct proximity, and the emission can be at eye level.

Such irradiation of the tuner occurs when checking individual sections of the wave guide channel (illuminators, power dividers, and so on) which have no load at the end.

In order to exclude irradiation of the tuner, special blind flanges are installed in the wave guide channel for transmitting energy from the generator side. Before taking the device out of the line, the tuner introduces the blind flange into the wave guide, blocking the path of the superhigh-frequency energy flux. A check has shown that as a result of using blind flanges in radio technical circuits where the source of superhigh-frequency energy is a klystron measuring generator, there is in practice no radiation into space.

An example of successful use of such flanges in the low-power klystron generator systems in the centimeter range (a power no more than 5 watts) provides grounds for recommending them as one of the simplest means of protecting the tuner from the effect of a superhigh-frequency field in such systems.

When tuning the devices in the circuits where high-power measuring generators are used in order to exclude reflections of energy inside the wave guide which disturb the operation of the generator, it is expedient to use devices which will absorb the power reaching them. This requirement can be satisfied when selecting the design of the material and the geometric dimensions of the blind flange absorber. For these purposes it is possible to use wave guide attenuators with absorbing plates.

In order to eliminate irradiation when testing superhigh-frequency generators (klystrons), new generator sections with a special auxiliary shielding of the base have been developed and introduced.

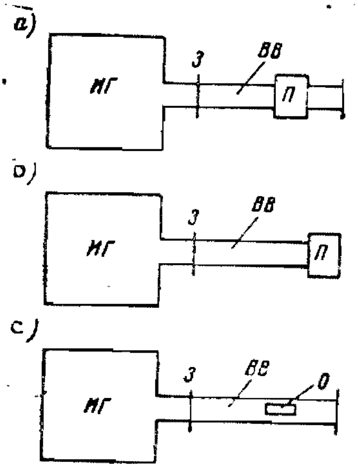

Figure 30. Block diagram of tuning of devices. иг -- measuring generators; з -- blind flange; BB -- wave guide; П -- device; O — hole in the wave guide.

Antenna Measurements

Measuring generators are also used to regulate and tune radar antenna feeders.

In the sections for taking the frequency characteristics and directional diagrams of the radiators and antenna systems it is impossible to eliminate radiation. The tuning procedure requires open emission. Thus, the superhigh-frequency oscillations emitted by the transmitting antenna must be taken up by the receiving antenna installed in the same facility at a defined distance from the former (Figure 31). During the tuning process the receiving and transmitting antennas are rotated at defined angles as a result of which the tuner standing on the receiving test unit (on the right in the figure) can be in the zone of the directional superhigh-frequency wave flux.

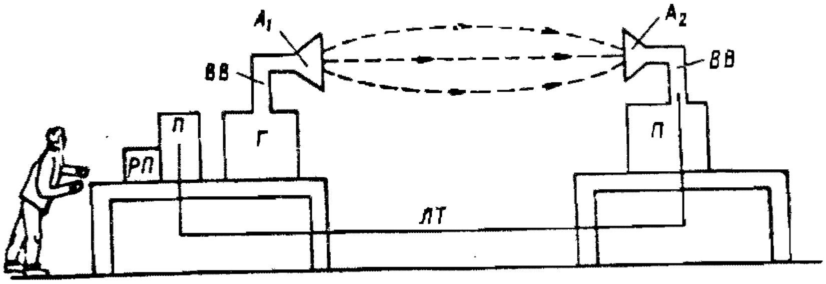

Figure 31. Schematic of tuning a radar antenna under laboratory conditions. Г -- generator; П -- receiver; РП -- recording device; ВВ -- wave guide transmission line; A_1 -- tested antenna; A_2 -- receiving antenna; ЛТ -- current line.

At the investigated laboratories the measuring units are frequently installed in such a way that the receiving antenna is rotated, and the work area of the tuner with the equipment in the form of a wave meter, angle gage and an instrument indicating the received power is located near it. Of course, this procedure for taking the directional diagrams of antennas is the worst if it is considered from the point of view of irradiation of personnel. It is possible easily to correct the situation by changing the location of the tuner and moving the recording devices to the emission side (to the left in the figure). If this shift is impossible, then it is possible to protect the person working on the unit by equipping the receiving stand with an umbrella shield. In this case the receiving antenna is taken beyond the limits of the shield (Figure 32).

The umbrella shield is covered on the emission side with a special material which absorbs the electromagnetic energy. It is impossible to make it of metal since metal, although it would protect the worker from irradiation, would introduce errors in the measurements because of the superhigh-frequency energy reflections formed by it.

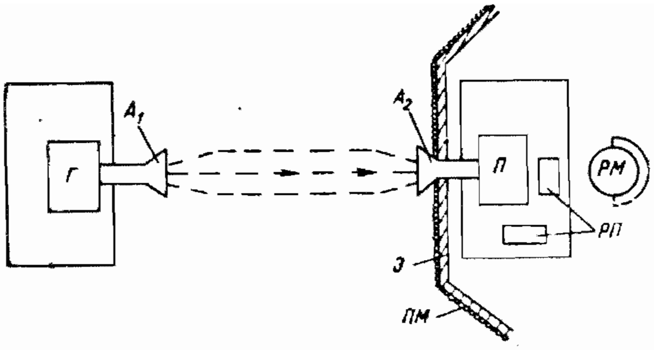

Figure 32. Scheme for tuning a radar antenna with application of an umbrella shield for protection from irradiation (top view). э -- shield; ПМ -- absorbing material; РМ -- work area; Г -- generator; П -- receiver.

The best solution of the hygienic, and, simultaneously, technical problems in antenna laboratories would be application of automatic recording of the measurement results which is used at some plants [13]. For performing these operations it is also expedient to build special nonreflecting chambers coated on the inside with absorbing material. The designs of nonreflecting chambers are described in detail in references[111, 129].

Tuning and Regulation of Individual Radar Elements Emitting High Power

The tuning and regulation of high-power radiation sources -- magnetrons, the leads of grid andanode plungers, and so on -- can be dangerous in some cases.

In the presence of mass regulation of superhigh-frequency generator tubes in the form of magnetrons under plant conditions it is necessary to have removable caps made of a metal grid which according to the data of [19] insure 20-30 decibels effectiveness of protection.

In wave guide devices, just as in other superhigh-frequency elements of radar units, distortion, breakdowns and corona can occur during regulation. In individual cases it is necessary to observe these phenomena directly in the operating units.

The protection of the tuner during the indicated operations can be insured by several means. However, above all, he must strictly observe the rule of not getting into the directional radiation flux, not looking into the open end of the wave guide without special protective glasses if he does not have a special device for this and limiting the time of exposure in the irradiation zone.

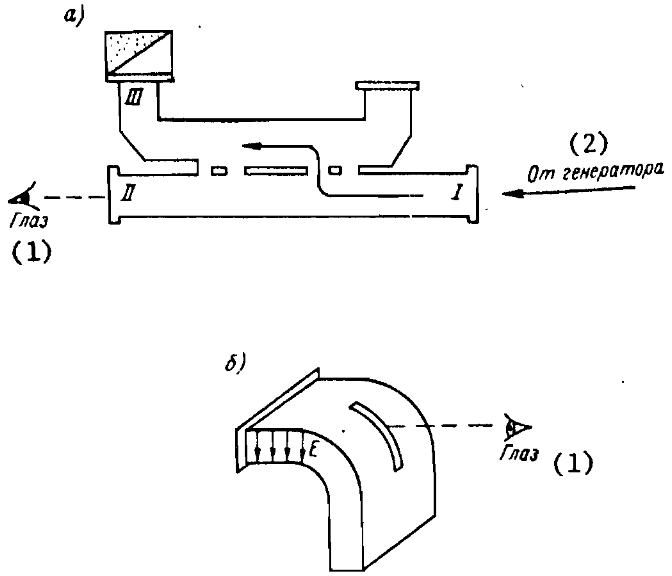

Figure 33. Special devices for observing distortion in a wave guide: a -- slot wave guide bridge; b -- bent wave guide with slot.

Key: 1. eye 2. from the generator

Inasmuch as water is a good absorber of superhigh-frequency wave energy, as a temporary measure it is possible to recommend round or square "lenses" filled with water. The "lens" dimensions and the thickness of the water layer must be selected as a function of the nature of operation and power of emission. The material for the "lens" can be glass or transparent plastic. This simple attachment is convenient for observing the distortion in the wave guide, and it can be used as an emergency device in the absence of special equipment.

Special devices for observing distortions in a wave guide have been recommended by the Institute of Professional Dieaseas of the USSR Academy of Medical Sciences (Figure 33). The former is based on the properties of a slit wave guide bridge. If such a device is connected by the arm I to the generator, the enegy does not go into the arm II but into the arm III which ends with a load. Thus, through arms I and II on the direct line of sight it is possible to observe breakdowns in the wave guide channel elements. In Figure 33,b we have a segment of a wave guide bent in the plane E with a slot in the central part of the wide wall of the wave guide. In practice, such devices satisfy the requirements only in case of ideal decoupling.

Sometimes, stray radiation occurring as a result of a poor coupling of the wave guides can easily be eliminated by applying lead gaskets between the flanges.

The antenna systems and radiators of the radar are also checked for high radiation powers when a magnetron is used as the superhigh-frequency energy generator.

In all cases where the emitted energy is not the object of study (such as, for example, when taking directional diagrams of the radiator or antenna), the radar must operate on a dummy antenna, and if this is not included in the delivered set, then it must operate on special power absorbers.

The following basic requirements are imposed on dummy antennas: the load resistance must be purely active and equal to the output impedance of the generator or transmission line at the output of which they are included. The dummy antennas for dissipating high power can have forced air or water cooling.

For wave guide transmission lines, dummy antennas are used which are in the form of segments of wave guides inside which there are absorbing plates or wedges with different notch angles for decreasing the energy reflection.

Graphite and a mixture of graphite with cement, sand, rubber and plastic, powdered iron with various fillers (wood, water and other substances), plastics, ceramics with Aquadag, and so on are used as the absorbing substances filling the cavities of the dummy antennas.

Application of power absorbers offers the possibility of lowering the intensity of irradiation of personnel in practice to the limits of the allowable norms by comparison with milliwatts per square centimeter when working on an open antenna.

In order to lower the radiation intensity, segments of wave guide lines can be used inside which inserts made of material with a high absorption coefficient are placed.

All-Around Tuning of Radar Units

Let us proceed to investigation of the conditions of labor of tuners and regulators of individual radar modules. Before installing the radar on the ship, it is tuned in the shop of the shipbuilding plant, and then it is checked several times directly on the object.

Regulation of individual modules of the radar in the plant shop and on board ship is carried out by a group of electricians from a special electrical installation enterprise.

The operations performed in the plant shop and connected with regulation of individual modules differ with respect to nature of irradiation from the operations performed directly on ships.

Tuning and regulation of the modules of a radar transmitter in the plant shop are carried out with the doors of the modules open; therefore, the tuner can be subjected both to intense superhigh-frequency irradiation and soft x-radiation which the modulator and rectifying units form (the voltage on the anodes of the tubes is above 10 kilovolts).

Tuning and adjustment of the radar modules directly on the ship are carried out, as a rule, with the doors of the transmitter modules closed, and it may become necessary to open the module only in exceptional cases.

Protection of personnel during all-around tuning of radar modules can be insured by various means depending on the nature of the operations.

The first and primary measure is exclusion of various types of stray and directional emission of the source itself. If this cannot be done, then it is necessary to protect the work area of the tuner and use individual protective devices. These include coveralls made of special fabrics and glasses.

Materials which Absorb Superhigh-Frequency Electromagnetic Energy.

Various materials which absorb electromagnetic energy are used for shields which localize and absorb superhigh-frequency fields.

It has already been stated that it is not always expedient to use shields made of metal sheets or grids when tuning, for example, open emitting systems at superhigh-frequencies since the wave reflections from the metal surface can introduce distortions into operation of the device as a whole.

The application of continuous and grid metal shields, selection of the form and material are discussed quite completely in the mentioned Soviet literature.

The simplest absorbers of superhigh-frequency energy are paints which have low reflection coefficients. In the presence of low radiation intensities sometimes it is possible to use lime or chalk paints as the absorbing material. A coating of Aquadag (a graphite colloid compound type SBG-1) gives good results.

Materials which absorb superhigh-frequency energy manufactured on the basis of polyvinyl chloride resin with a filler in the form of carbonyl iron are not thermally stable, and materials manufactured on the basis of organosilicon rubber and other materials are thermally stable. It is necessary to use the latter for intense emission where heat generation is possible.

Table 13 contains an incomplete list of absorbing materials which are used to manufacture general and individual means of protection from superhigh-frequency emission. It must be stated that the circle of absorbing materials used recently has been expanded appreciably. The greater part of them include rubber pads or plates with various fillers. Sometimes the absorbing layer includes a soft brass grid or metal foil. As a result of good elasticity which these materials have, it is easy to use them for shields of the most different designs. The narrow band materials which absorb superhigh-frequency energy insure attenuation of no less than 45 decibels [4].

Rubber pads types V2F2, V2F3, VKF-1 have become quite widespread. A part of a rubber pad (nipple rubber) type VKF-1 is presented in Figure 34. In recent years the application of new absorbing coatings based on porolon has been recommended.

For wide band absorbing shields, special radio emission absorbing ferrite plates are used. In order to protect these plates from moisture, a paint was used which serves simultaneously as a decorative coating. The electrical characteristics of the plates are retained in a broad temperature range and at high humidity.

In foreign literature there are many reports on the development of various materials which absorb electromagnetic energy. Their exact composition is not given. It is known, however, that some of them contain rubber bonded with ceramic, horse hair impregnated with carbon, and so on.

Certain forms of coatings include chemical compounds in the form of emulsions (just as in a photoemulsion) which absorb radio waves, converting the electromagnetic energy into chemical energy.

The latest reports by E. McMillan [122, 123] on the creation of new wide band absorbers of electromagnetic energy are of greatest interest. The surface of these absorbers is in the form of a two-faced pyramid at an angle of 90 degrees to each other or sharp teeth made of individual layers. The latter absorbing material manufactured from a mixture of neoprene, carboxylmethyl, cellulose and artificial graphite only reflects 1-4 percent of the radiation at frequencies of 50-200 megahertz.

Absorbing materials can be successfully used to protect the work area of the tuner. In Figure 32 the application of such materials for tuning antennas was illustrated.

Use of umbrella shields of various designs -- portable and stationary -- and shielded chambers coated on the inside by an absorbing material during tuning, regulation and testing of powerful radar insures a reduction of irradiation to the limits of the allowable norms.

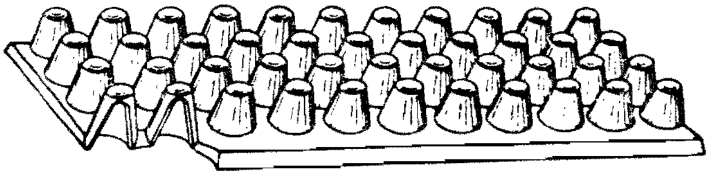

Figure 34. Part of a rubber pad type VKF-1.

Materials which Reflect Superhigh Frequency Electromagnetic Energy

Various types of materials which reflect radio waves are also used to protect the tuner from the harmful effects of a superhigh-frequency field.

Table 13

List of special materials for manufacturing general and individual devices for protection from superhigh frequency irradiation

Designation	Trade name	Unit of measure	Dimensions, mm	Weight per m^2, kg	Band of absorbed (reflected) waves, cm	Reflection coefficient with respect to power, %	Attenuation of the transmitted power, %
Radio absorbing materials							
Absorbing plates:							
ferrite	SVCh-068	m^2	60 × 60, thickness 4	18-20	15-200	3-4	96-97
based on wood	Luch	m^2	--	--	1-150	1-3	97-99
based on porolon	Boloto	m^2	--	--	0.8-100	1-2	98-99
Rubber pads	V2F2	m^2	345 × 345, thickness 11 × 14, including a pin 8-11 high	4-5	0.8-2	2	98-99
	V2Fs	m^2		4-5	0.8-4	4	98-99
Magnetoelectric plates	KhV-3.2	m^2	350-400, thickness 1-3 depending on the wave band	3.2	2	--	--
	KhV-10.6	m^2		10.6	2	--	--
	KhV-1.4	m^2		1-4	2	--	--
Graphited textolite	No369-61	m^2	--	--	0.8-16	To 50	50-70
Shielding Materials							
Glass with a current conducting layer (film resistance no more than 8 ohms/cm^2, light transmission no less than 70 %)	TU 166-63	kg	To 620 × 400, thickness from 4 and more	8 and more depending on thickness	0.8 and more	--	99
Cotton fabric with microwire	Artikul 4381	rm*	Width 700	0.3	0.8 and more	--	99
Hollow glass blocks with radio protective coating	VTU 4-63	p**	194 × 194 × 98	2.7	0.8-200	--	98
Paint	NTSO 014-003	kg	--	--	0.8-16	To 50	65-85

---

* running meter ** piece

The following materials, for example, have good reflecting properties: a metal grid made of brass wire, fabric the composition of which includes microwire or metal plated threads, glass with a current conducting coating, and so on. A metal grid is frequently used to construct special chambers which protect the tuner from intense irradiation. Chambers made of a metal grid are used to shield the radiation sources and, more rarely, to protect the work area.

The dimensions of a shielding chamber and selection of the material are determined by the dimensions of the radiation source and, what is the main thing, by the magnitude of the emitted power. For low (several milliwatts per square centimeter) power, when attenuating the radiation intensity it is possible to use a metal grid with a quite small mesh size. At high powers, shielding with a double layer of the grid or a continuous metal sheet may turn out to be required. Multilayered shields are calculated in references [28, 137]. Although the grid has lower shielding properties, it finds broader application for protection from the effects of superhigh frequency wave energy, that is, where attenuation of no more than 20-30 decibels is required.

Table 14
Values of the attenuation of wave energy by brass grids in the 3 and 10 centimeter bands

3 centimeter band			10 centimeter band		
Wire diameter, mm	No of cells per cm^2	Attenuation, decibels	Wire diameter, mm	No of cells per cm^2	Attenuation, decibels
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	559	41
0,2	169	49			
0,14	186	47			
0,075	441	46			
0,08	559	56			

As a result of complexity of calculating the energy attenuation of waves penetrating the grid, it is measured experimentally. In Table 14 we have the attenuation of various grids in the 3 and 10 centimeter wave bands.

Shielding chambers can be made of continuous sheets of metal. In the superhigh-frequency band such shields always insure the required wave energy attenuation. Therefore, when selecting the shield we are guided only by structural arguments. In many cases, a thin metal foil is used for the shield.

When designing the shielding chamber, frequently the control panel is led out to a special panel outside the shield. For this purpose, various holes are provided in the walls of the chamber for the leads of the arms controlling the operation of the device, the peepholes and ventilating openings.

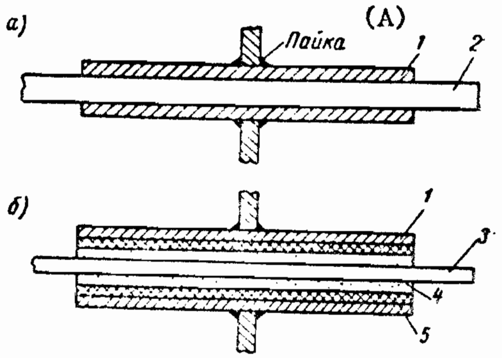

Figure 35. Leads of control arms through the walls of a shielding chamber: a -- lead of an arm made of dielectric; b -- lead of a metal arm. 1 -- metal tube; 2 -- dielectric axis; 3 -- metal axis; 4 -- absorbing material; 5 -- dielectric.

Key: A. solder

In Figures 35 and 36 we have the structural design of devices for the leads of the control arms, peepholes and ventilating openings in the shielding chambers. When necessary, it is possible to put transparent glass with a special current conducting film having shielding properties over the peepholes, doors and partitions of the chamber. The glass with the film insures no less than 70 percent transmission of light. Special glass with a molded metal grid is made for these purposes. The glass must contain two systems of parallel wires intersecting at right angles.

R. I. Kovach and L. P. Kutsenko [36] studied the dependence of the shielding properties of glass on the repetition rate of the wires and established that in order to obtain power attenuation of a radio wave by 100 times (20 decibels) the distance between the wires must be 0.8 mm.

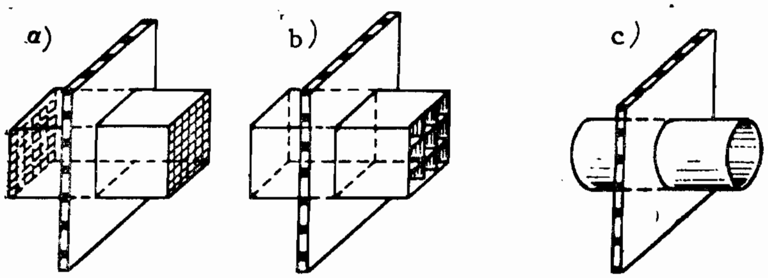

Figure 36. Structural designs of peepholes and ventilating holes in shielding chambers: a -- box with double grid; b -- rectangular lattice; c -- tube.

In the case of simultaneous emission of a superhigh-frequency field and x-rays, the peepholes must have two-layer protection in the form of a transparent lead glass and metal grid.

In order to eliminate x-radiation it is expedient to install individual high voltage modules with peepholes protected by lead glass. Shielding the tube with an iron (0.5-1.0 mm) or aluminum (3.0 mm) sleeve or lead glass 8 mm thick is an adequate protective device against the x-radiation of a kenotron occurring for voltages up to 60 kv [61].

§ 3. Individual Protective Devices

It is necessary to use individual protective devices in cases where application of other means of preventing the effect of superhigh-frequency fields is impossible. These devices are based on the principle of reflection of electromagnetic energy. It is recommended that a person working in the range of superhigh-frequency fields wear robes, coveralls and hoods made of protective fabrics.

At the present time protective suits made of special fabrics are series manufactured. The basis for this fabric is the use of the reflecting properties of a dense metal grid. Two types of fabric are manufactured: with external and concealed metallization. The latter is more convenient and is in the form of cotton cloth with fine (60 microns) copper microwires spun into the thread. The fabric provides more than 20 decibels of power attenuation, and the concealed metallization excludes the possibility of closure over the surface of the fabric which the man feels as slight warming.

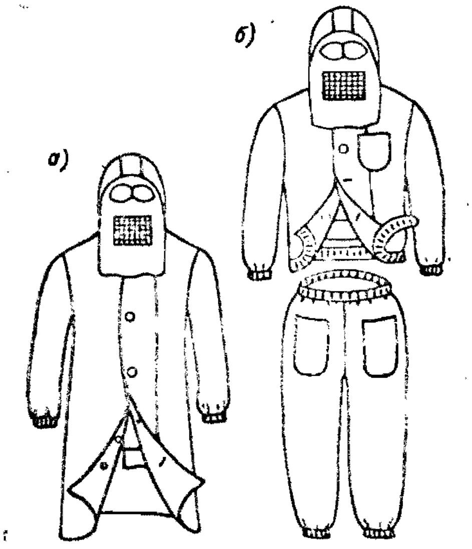

Figure 37. Protective suit against superhigh-frequency irradiation: a -- robe with hood; b -- jacket with hood and trousers.

The application of special robes with hoods made of metallized fabric for protection from electromagnetic irradiation is recommended by Marek [116], Hirsch [111], and others.

The Soviet protective suit (Figure 37) is in the form of fully enclosed coveralls with a hood in which protective glasses are installed.

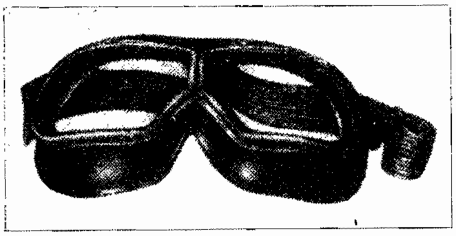

Figure 38. Protective glasses model OMZ-5.

The protective glasses used without the hood are made of special glass plates with a current conducting layer and light transparency of the glasses no less than 74 percent. The glass used in the glasses made of such plates are coated on the side turned toward the person with a thin transparent film which screens out a superhigh-frequency electromagnetic field. The films have sufficient mechanical strength and chemical stability. The frame of the glasses is usually made of porous rubber and is coated on the inside with artificial suede. A metal grid is molded in the frame to give it protective properties. In Figure 38 we see protective glasses of this type model OMZ-5.

Foreign publications contain information about the application of glasses with a thin (thousandths of a micron) gold layer applied to the glass [109, 112].

Marek [116] recommends use of glasses designed for welders for eye protection by replacing the dark glass with a metal grid or the use of finished ceramic glasses with a grid with a grid size of 1 × 1 mm.

It must be stated that application of grid and lattice glasses is possible, as tests have shown [14], for irradiation intensities of no more than hundredths of a milliwatt per square centimeter.

Only the general principles of designing protective devices required when tuning and regulating individual modules of the transmitters of modern marine radar are discussed here.

Various tuning conditions under which emission of a superhigh-frequency field occurs require application of the most varied protective devices in each individual case.

CHAPTER VII
PROTECTIVE MEASURES AGAINST THE EFFECT OF ELECTROMAGNETIC WAVES WHEN OPERATING MARINE RADIOS

pp 125-134

§1. Requirements on the Arrangement and Placement of Radio Equipment in the Radio Rooms

Measurements have established that the highest intensity of high-frequency irradiation occurs in the ship radio rooms. As a result of application of asymmetrical antennas on ships and the absence of matching of the input inpedance of the antennas with the wave impedance of the feeder, an unshielded energy transmission line from the transmitter to the antenna has high power losses and emits radio waves. The structural features of radio transmitters and a high-frequency channel and failure to always arrange the radio equipment properly promote the formation of an electromagnetic field in ship radio rooms.

The plan for arrangement of radio equipment adopted at this time and application of open feeder lines in some cases is not perfect from the point of view of labor safety. On most ships the radio room is, in practice, a metal shielded chamber in which devices emitting electromagnetic energy are placed. The presence of a large amount of equipment in the radio room complicates the situation since the metal surfaces of the devices become secondary emitters of electromagnetic energy and, at the same time, increase the intensity of irradiation of the operator. For this reason, the conditions of labor on small ships (for example, light ships, salvage and rescue ships, and so on) are especially unfavorable. On these ships the area of the radio room is small in contrast to high-tonnage ships where the radio room areas are quite large.

The conditions of distribution of high-frequency fields in radio rooms with various arrangement of the radio equipment were analyzed in Chapter III. The analysis showed that the intensity of irradiation of the radio operator with open feeder lines, especially on small ships, exceeds the allowable by ten times.

In order to avoid irradiation of personnel and to insure safe servicing, the area of the radio room must be selected as a function of the area occupied by the radio equipment and also considering the form (open or shielded) of the feeder lines used.

In accordance with the "Rules on Marine Radio Equipment" of the USSR Registry the area of the radio room must be at least twice the area occupied by the radio equipment and furniture in the plan view with a height of no less than two meters. As experience shows, this rule is not always satisfied.

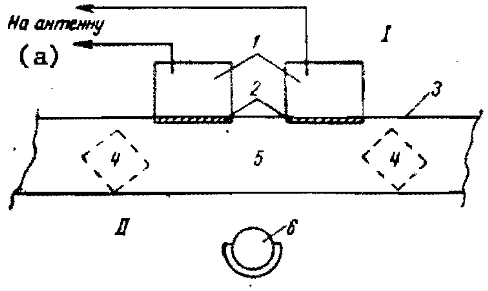

Figure 39. Placement of transmitters and open feeder lines in the shielded compartment of a radio room with control panels at the operator's work table. I -- shielded compartments; II -- radio room; 1 -- transmitters; 2 -- transmitter control panel; 3 -- shield (metal partition); 4 -- receiving equipment; 5 -- work table; 6 -- operator's chair.

Key: a. to the antenna

One method of arrangement of the radio equipment when it is necessary to use an open feeder is placement of the transmitting equipment and feeder lines in special shielded areas or enclosures (Figure 39). Here, the front panel of the transmitter must be removed to the radio room [49, 50]. In some cases it is necessary to provide additional shielding (for example, to solder a grid over it around the perimeter) for the devices connected to the high-frequency current circuit which can create radiation.

As the experience of the Black Sea Shipping Line has shown, shortening the open feeder line for transmitting energy to the antenna to 0.5 meters provides a drop in stray radiation by several times, and placement of the transmitter directly at the base of the antenna lowers the field, in practice, to limits of several volts per meter.

Thus, radio communications transmitters and the antenna commutator should be placed at the minimum possible distance from the antenna fair leads or, what is still better, at the base of the antenna. The feeder lines must have the least number of bends.

If it is difficult to shorten the feeder, then as a temporary measure, it is possible to put it against the bulkhead of the radio room behind the transmitter housing. This also lowers the field in the operator's work area by several times, but only with defined arrangement of the equipment by which such a shift is expedient.

Consequently, the radio transmitting equipment and feeder lines for transmitting energy to the antenna must be placed, considering exclusion of the possibility of irradiation of the operator.

When the radio operator quarters are placed adjacent to the radio room it is necessary to exclude the possibilities of penetration of the electromagnetic field into the quarters. Thus, the door to the quarters must be covered by a metal panel made of sheets no less than 0.5 mm thick electrically connected to the common shield of the radio room.

§2. Requirements on Devices for Channelling High-Frequency Energy

The second measure which can be taken not only when designing ships but also when operating them consists in replacing the open energy transmission feeder by a shielded feeder.

In contrast to a hollow copper tube, the shielded feeder is either a coaxial feeder in the form of a chute with round or square cross section or it is a high-frequency cable. The high-frequency chute consists of an inner cylindrical conductor and the outer conductor of the shield running along its axis. The inner conductor is connected to the transmitter and antenna, and the outer conductor, serving as the return line is grounded. The conductors are isolated by means of base insulators. In contrast to the chute where the dielectric is an interstitial layer of air, in the high-frequency cable the cavity between the inner and outer conductors is filled with dielectric.

The shielded feeder must transmit the required power with low losses, and it must have minimum emission.

At the present time industry is manufacturing a broad class of radio cables (RKS, RKG, RKPG, and so on); however,all of them are designed for transmission of only waves in the short wave band over them. The latter fact greatly limits their application.

Radio cables are characterized by constant electric parameters which depend on the design of the cable and its geometric dimensions (the running inductance and capacitance, the wave impedance, the wave shortening coefficient), and variable parameters which depend on the frequency and nature of the load (attenuation, traveling wave ratio, efficiency).

Calculation of asymmetrical and symmetrical shielded cables and their parameters as functions of the frequency and nature of load is discussed in sufficient detail by M. V. Vershkov [8].

As research has demonstrated, a radio cable has a great advantage over an open feeder: it does not emit electromagnetic waves into the radio room, and it is convenient for installation. This is especially important when replacing an open feeder by a radio cable on ships in operation. Such replacement can be carried out on reequipment or repair of the ship and sometimes when the ship is moored for a long time in port.

Shielded feeder chutes are used to transmit high-frequency energy from medium wave transmitters to the antennas.

The diameter of the inside tube of the chute is selected as a function of the transmitter power. The diameter of the outer shield must be such that the condition $C_{chute} < 0.5\ C_a$. Otherwise, the capacitive reactance of the high-frequency chute will have a shunting effect on the antenna fair-lead as a result of which the power transmitted to the antenna is decreased.

The wave impedance of a chute with round cross section is defined by the formula

$$\rho_{chute} = 138 \lg \frac{D}{d},$$

where D is the chute shield diameter;

d is the diameter of the inner current-carrying tube.

The values of D and d are expressed in the same units.

The graphs present in Figure 40 can be of practical assistance when calculating the feeder chute with round cross section.

For chutes with square cross section, it is possible to take the diameter of the circle inscribed in the square with a sufficient degree of accuracy.

The dimensions and shape of the chute cross section must be selected as functions of the highest values of the current strength and voltages on the feeder. The allowable high-frequency current strength and voltage in the feeder executed in the form of a high-frequency chute can be calculated by the following formulas:

$$I_{allow} \approx 175 d \frac{\sqrt{\tau}}{\sqrt[4]{f}};$$

$$U_{allow} = 0,182 \left(1 + \frac{0,308}{\sqrt{r}}\right) r\omega,$$

where I_{allow} is the allowable current strength, amps;

d is the diameter of the conductor, cm;

$\tau = t_2 - t_1$ is the temperature drop, that is, the difference between the conductor temperature t_2 and the ambient temperature t_1;[1]

f is frequency, hertz;

U_{allow} is the allowable voltage, volts;

r is the radius of the inside conductor, cm;

w is the wave impedance of the antenna,[2] ohms.

Application of high-frequency radio cables and chutes requires continuous shielding along the entire high-frequency channel from the transmitter to the antenna. Therefore, all the high-frequency elements which are included in the energy transmission channel must be shielded.

It is recommended that the chute shield be executed from nonmagnetic material with good electrical conductivity. For this purpose it is possible to use aluminum alloys, for example, duralumin, as the lightest and cheapest material. Individual sections of the metal shield of the chute (coupling elements, taps, elbows, and so on) can be replaced by a fine metal grid if necessary.

The high-frequency chute is either suspended on a wire or, more frequently, it is boxed into the overhead or bulkhead of the radio room.

Application of shielded feeder lines on the new tankers types Sofiya and Pekin, on the cargo ships Vytegrales, Vostok-3, Vostok-4, Iogann Makhmastal', Velikiye Luki and other ships of this series, on some icebreakers, on refrigerator ships type Yantarnyy and on the passenger ship Osetiya, as measurements show, insures almost 100 percent effectiveness of the shielding, that is, it excludes irradiation of the radio operators in practice.

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[1] The temperature drop $\tau = 40\text{-}50°$ C for high-frequency chutes should not exceed the ambient temperature in view of unsatisfactory heat exchange in a closed volume.

[2] $w = 60 \ln (R/r)$ where R is the radius of the outer conductor, cm.

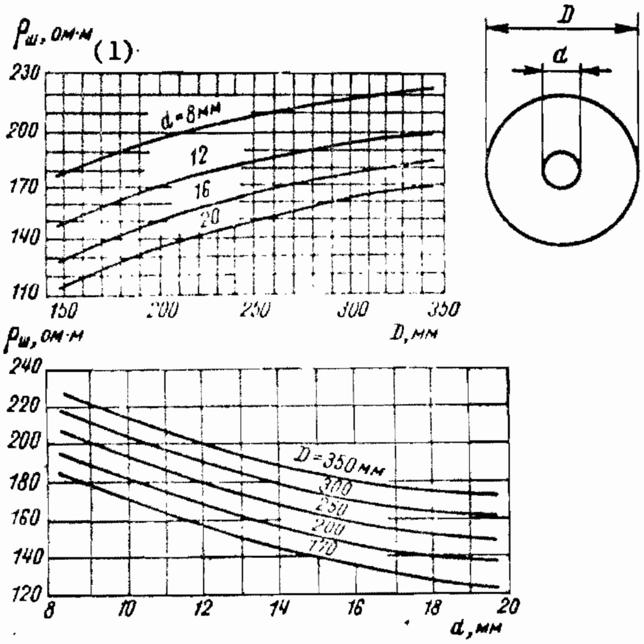

Figure 40. Graphs for determining $\rho_{\text{chute}} = f(D, d)$.

Key: 1. ρ_{chute}, ohms-meters

§3. Shielding of Radio Transmitters

Sometimes in the absence of intense radiation of the feeder or when it is shielded, the intensity of the high-frequency field near the radio transmitter housing can be 70 volts/meter. High field intensity near the transmitter is explained either by leaks in the joints of the housing (some transmitters have the top cover raised for cooling) or the presence of peepholes.

In order to eliminate radiation through the slots of transmitters, it is recommended that they be shielded by a metal grid soldered around the perimeter. The material of the grid and the cell dimensions should be selected in accordance with the emitted power and the transmitter frequency (see Chapter VI).

With an unshielded feeder when the field intensity in the operator's work area is defined as hundreds and sometimes thousands of volts per meter, a definite part of the radiation must be considered the result of secondary emission of the transmitter housing itself, which, as a result of induced currents, reemits the electromagnetic waves formed by the open feeder. Therefore, elimination of stray radiation of the feeders by application of shielded radio cables and chutes greatly decreases the induced currents in the transmitter housing.

As G. S. Shul'man and F. Sh. Benyavskiy [99] have established, the high-frequency energy inductions on the transmitter housing are, along with the above-indicated reason, the consequence of closure of antenna currents to the housing and leakage of them from the ship's hull to the housing of the transmitter along the ground bus.

In order to control the high-frequency inductions on the transmitter housing it is recommended that the housing be grounded at several points directly to the metal bulkhead, and that the shock absorber rubber be shunted by busses. The ground bus must be located directly on the bulkhead, and its length should not exceed 0.5-1.0 meters.

Special attention must be given to connecting the metal structural elements forming the transmitter housing as a whole since poor electrical contacts create slits through which an electromagnetic field is emitted into the radio room.

It is necessary to give more serious attention to elimination of the harmonic oscillations emitted by the radio transmitters since the harmonics formed can in individual cases create intense radiation. Elimination of them lowers the total intensity of the field distributed in the radio room.

§4. Application of Matching Devices

As a result of using devices for matching the input impedance of the antenna with the wave impedance of the feeder, the transmission conditions along the feeder are improved. This leads to a decrease in stray emission of the feeder and an increase in useful power in the antenna.

The difficulty of realizing matching in the antenna feeder channels of marine radios consists in the fact that the matching device must operate in the broad frequency band which automatically changes its electric parameters with a change in operating frequency.

The simplist device in the form of a compensating coil which offers the possibility of complete compensation for the antenna reactance is depicted in Figure 41. However, this device does not permit full satisfaction of the required condition of the quality of the sum of the active resistances of the antenna and matching coil to the wave impedance of the feeder.

The equipment resistance of the compensating circuit shown in Figure 41, b is

$$Z_{э} = (L_1/L)^2 \; (L/C_a R),$$

where L_1 is the inductance of the part of the coil which connects the antenna to the feeder;

L is the total inductance of the matching coil;

C_a is the capacitance of the antenna;

R is the total active resistance of the antenna and matching coil.

By varying the coupling inductance L_1 it is possible to vary $Z_{э}$ within broad limits.

In the odd resonance region on waves the length of which exceeds the proper length of the antenna, the latter has very small active resistance and large reactance which always is of a capacitive nature. In order to compensate for the capacitive reactance, it is necessary to include an inductance in series with the antenna (Figure 41, a), and in this way the antenna together with the matching coil forms a series circuit [91].

The efficiency of the antenna feeder channel with such matching coils included increases by many times, and consequently the stray radiation of the feeder near which the radio operator is most frequently located is greatly reduced.

In Soviet radios, the matching devices are used only for short wave antennas. Matching marine medium wave antennas with high-frequency shielding of the cable must be carried out when the fair-lead of the medium wave antenna must be removed a defined distance from the transmitter. Matching is realized in this case only with respect to the reactive component of the antenna resistance.

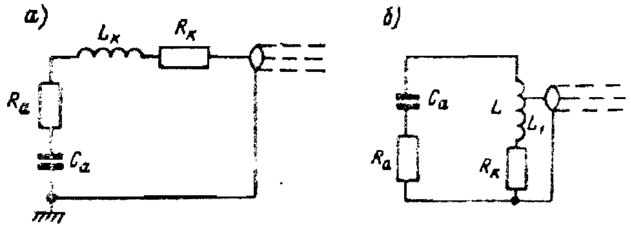

Figure 41. Schematics of series (a) and parallel (b) inclusion of a matching device in the antenna.

The German ship communications radio specialists Simon [132] Metze and Shoene [118], and others use matching in the medium wave band.

The radios of the French Navy built by Radio-Air Company and others are also equipped with matching devices which are special automatic tuning units. On a feeder with a total wave impedance of 75 ohms the standing wave ratios are no more than 16. In addition, these radios can be serviced remotely [83]. It must be stated that remote control of the transmitters, which will become widespread on naval ships in the near future is unconditionally one of the best means of excluding high-frequency irradiation in the radio room.

§5. Lowering the Irradiation Intensity on Open Decks and Bridges and in the Living and Service Quarters

In order to eliminate inductances and decrease the secondary emission by metal objects (masts, ventilation pipes, and so on) it is recommended that they be grounded and removed the maximum distance from the antennas. The metal hull of the ship, metal bulkheads, decks, pillars, and the surface of good-conducting sea water are the most reliable "grounds" on the ship.

In order to decrease the secondary emissions formed by various metal guys (guy ropes, stays and so on), it is recommended that they be broken by insulators.

The height of the antenna column must be increased by comparison with the standard height in order that the high-frequency field of highest intensity be created above human height.

It is recommended that the housing of the antenna column be made of nonmagnetic materials. The antenna fair-leads must be located farther from the sections of open deck and superstructures where it is possible for people to be for a long time.

The parts of the promenade decks of passenger ships and the top bridges where the intensity of the high-frequency field exceeds the allowable must be posted with warning signs. Obviously, the irradiation intensity on the decks and bridges of ships can be reduced by selecting the best point of installation of the antennas, reducing the number and the amount of space occupied by them and application of directional antennas which concentrate radiation in a comparatively small angle to one side of the ship.

The measurements performed on ships where mast antennas are installed have demonstrated the expediency of their application from the point of view of labor safety for a number of reasons.

It has been pointed out above that in the service and living quarters, as a rule, an electromagnetic field of radio frequency is not detected. The quarters adjacent to the radio room constitute an exception. Here it is possible for an intense field to be formed in the absence of shielding of the transmitting feeder. The radiation here can be eliminated by application of one of the methods of protecting the radio operator from irradiation or by metal plating the wood door if the compartment as a whole is metal.

In order to exclude radiation formed by interference currents propagated along wires (various devices, illuminating lamps), it is necessary to provice careful filtration of the electric feed systems and shielding of the network conductors. The shields of the conductors must be grounded.

Selection and application of the most expedient methods of protection from irradiation must be carried out in accordance with the tactical and technical characteristics of the radio transmitting equipment used [42]. Proper selection of the safety measures will help eliminate intense irradiation of the operators and the entire crew on maritime ships.

The final conclusion concerning the effectiveness of the protective measures taken on a ship must be drawn according to the results of measurements performed during the mooring or sea trials of the ship. Accordingly, the trial program for the prototypes must include an item providing for performance of these operations.

CHAPTER VIII

PROTECTION OF THE PERSONNEL OF THE TRANSMITTING CENTERS OF SHIPPING LINES FROM RADIO WAVE IRRADIATION

pp 135-138

The personnel servicing the transmitting centers of shipping lines can find themselves in the range of high and ultra high-frequency fields which are formed in the transmitter and antenna feeder areas. High-frequency emission is basically formed by unshielded transmission lines as a result of insufficient matching and balancing and low-quality shielding of the high-frequency elements of the transmitter units. At powerful radio stations the radiation sources can also include devices for adding power, separating filters, antenna commutators, and other devices of the high-frequency channel for transmitting energy to the antenna. Sometimes a high-frequency field is formed in adjacent areas in the work areas of people not connected with working on the transmitting devices. This is explained by the induced currents which are created by the external fields in the network lines, the central heating systems, and so on.

In accordance with the "Sanitary Rules for Working with Sources of Electromagnetic Fields of High and Ultra High-frequency" No 615-666, 1 February 1966, the intensity of the electromagnetic field and its electric component for radio rooms should not exceed 20 volts/meter. Chapter III contains a description of the results of measurements taken in several transmitting centers where it is indicated that exceeding the standardized field is possible.

General hygienic measures for lowering irradiation of personnel servicing the transmitting devices of radio and television centers are discussed in reference [97].

The requirements for lowering irradiation of the personnel of transmitting centers of shipping lines usually agree with the technical specifications and tactical and technical characteristics of the equipment.

Constant technical improvement of radio communications equipment is leading sucessively to a decrease in stray radiation of individual modules and systems. However, until recently designers and people working with radio transmitting equipment did not consider the requirements of labor safety. At this time, in connection with application of more and more powerful radiating radio transmission equipment the labor safety requirements are acquiring great significance.

In order to avoid irradiation of personnel directly servicing transmitting devices for radio communications, it is necessary to arrange the transmitters and feeder lines in the transmitting centers of the shipping lines rationally. In Figure 42 we have an improper (a) and proper (b) arrangement of transmitters and feeder lines. This arrangement of the transmitters and reinstallation of open feeder lines at one of the centers offered the possibility of excluding constant irradiation of the personnel at the control panel in practice.[1] For greatest irradiation safety and convenience of servicing, the control panel CP was installed in the center of the facility from which good visibility was insured. The panel was made so that the operation of the radio transmitters could be controlled standing and seated. The shape and size of the control panel are selected as functions of the quantity of equipment. As is obvious from the figure, the worktables WT are rearranged and at a distance of several meters from the location of the feeder lines.

When selecting a rational design of the control station as a function of human physiological factors and composition of the equipment in the transmitter room it is possible to use the recommendations of references [55, 84].

The transmitter and feeder devices can be placed in a separate shielded area as was proposed for ship conditions. In individual cases, when using high-power radio transmitting devices, it is more convenient to locate the work area of the operator with the control panel for the transmitters in a shielded chamber.

However, it is impossible to eliminate irradiation of the personnel for the entire working day by rational placement of equipment since the servicing of the transmitters requires the presence of someone directly next to the open feeder lines radiating high-frequency energy and the high-frequency elements of the transmitters. Elimination of irradiation is achieved by application of shielded radio cables for transmitting energy to the antenna and careful shielding of the high-frequency elements of the transmitter.

The commuting devices designed for switching antennas in the case of application of a radio cable must also be shielded.

It is necessary to shield the transmitter and its high frequency elements in accordance with the basic shielding requirements by selecting the necessary effectiveness of shielding as a function of the intensity of the radiation in the work areas. The peepholes and gratings of the

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[1] The transmitter powers are no more than 5 kilowatts.

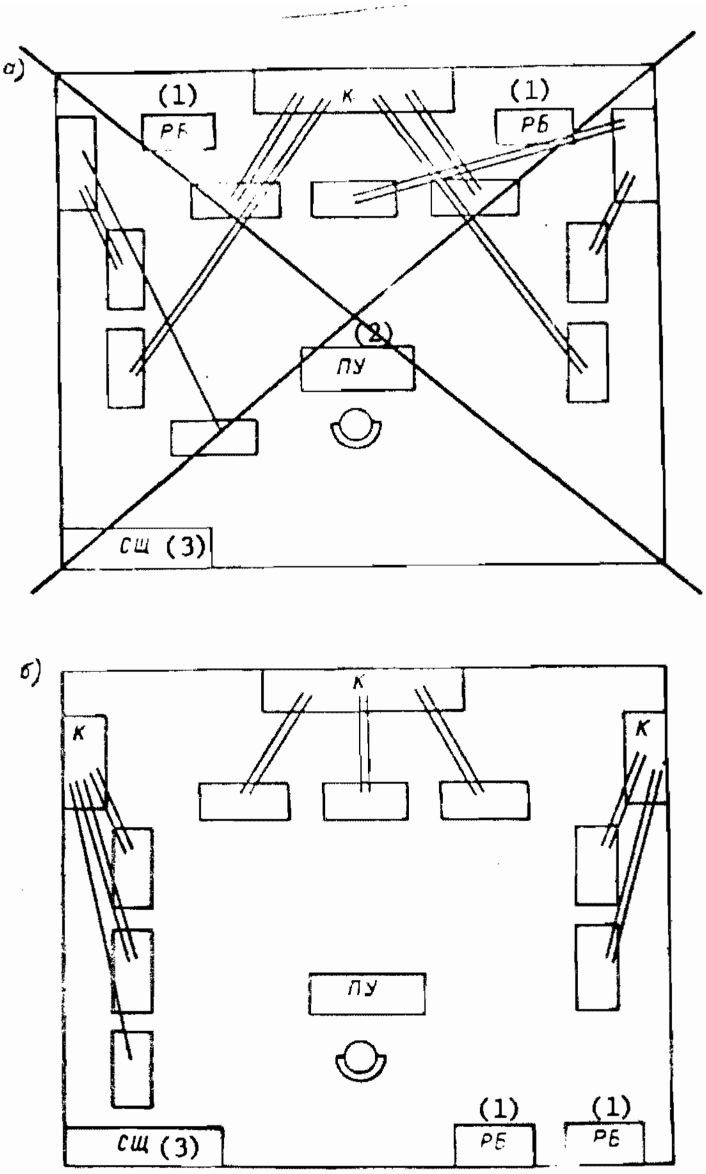

Figure 42. Placement of transmitters and feeder lines in the transmitting center of the shipping line. K -- commutators; -- power board

Key: 1. WT = Worktable 2. CP = Control panel

3. PB = Power board

transmitters can be shielded by a metal grid or a special glass with a metal plated layer (T U . 1166-63).

One of the measures for eliminating the feeder radiation is improvement of the balancing and wide band matching of the transmission line with the antenna. At the present time wide band transformers which transmit power up to several hundreds of kilowatts have been developed and are being used.

If we consider that the measured values of the high-frequency intensity in the transmitting centers of the shipping lines occur not only as a result of stray radiation but also as a result of harmonic oscillations (radiation of the transmitter at frequencies which are multiples of the natural carrier frequency), then exclusion of the latter would provide an overall drop in irradiation. The problem of supressing harmonics in radio transmitters was stated by Z. I. Model', S. V. Person, I. S. Gonorovoskiy, and others in the 1930's [15, 60]. T. Royden proposed a method of measuring the harmonics of radio transmitters, and he recommended a procedure for suppressing them [125]. Significant suppression of the harmonics of the radio transmitter can be obtained by using Π-type filters in the output circuit with shielding of the transmitter and the feed cables. If a high degree of suppression of the harmonics is necessary, then a double Π-type filter is installed in the output circuit of the transmitter. Methods of eliminating stray radiation and harmonics in portable radio transmitters have been proposed by Pinkerton, Shepherd, and so on [105].

In order to eliminate induction on electric network and telephone cables it is necessary to install filters on them the attenuation of which must be of the same order as the effectiveness of the shielding used. The cables must have shielding and ground sheathing. It is recommended that special grounds be provided for the batteries and central heating pipes and water lines in case of intense radiation of them.

In order to reduce the intensity of the field caused by penetration of energy into the generator rooms and other areas in the vicinity of the antenna field, the Sanitary Rules provide for shielding of individual parts of the buildings with metal sheets or grids laid in the walls.

CHAPTER IX

PROTECTIVE MEASURES AGAINST THE EFFECT OF ELECTROMAGNETIC WAVES OF MARINE RADAR

pp 139-143

In Chapter III it was demonstrated that the basic source of superhigh-frequency energy emission on a ship is the radar antenna.

For development of protective measures agains irradiation on ships it is necessary to determine the power flux density arising at various points of the ship, especially at points for standing watch.

It is known that sharply directional antennas of marine radar are characterized by a directional diagram which, in addition to the main lobe has side lobes. The radiation patterns of the main and side lobe of a marine radar antenna obtained by measurements give a field distribution pattern on the ship. This helps establish the danger areas of the deck near the antenna.

The measurements must be taken on the ship in directions noted in advance, approaching the antenna from the greatest possible distance. It is more convenient to select the required direction of radiation of the antenna by rotating it manually.

If it is possible to vary the angle of inclination of the antenna, then the measurements can be taken at various angles. With maximum negative angle of stabilization (see Figure 25) the "blind zone" decreases, and the irradiation conditions will be the worst.

In the design stage it is necessary to perform a preliminary calculation of the possible irradiation intensity on the ship as a function of the technical characteristics of the antenna, the height and location of its installation. For this purpose, zones are drawn on the ship's drawings (the view is taken from the side and from above) where the intensity of irradiation exceeds the standard intensity according to the Sanitary Rules.

The known simplified method of calculation permitting determination of the irradiation intensity on the ship with sufficient accuracy consists in the following.

In the space close to the antenna, in the so-called near zone (Figure 43), the emitted power in the direction of the axis remains approximately constant and is concentrated in a beam having a cross section equal to the projection of the area of the aperture of the antenna.

The extent of the near zone R_{nz} for antennas of the truncated paraboloid type can be approximately determined by the formula

$$R_{nz} = \frac{ab}{4\lambda},$$

where a, b are the linear dimensions of the transverse cross section of the paraboloid ;

λ is the wave length.

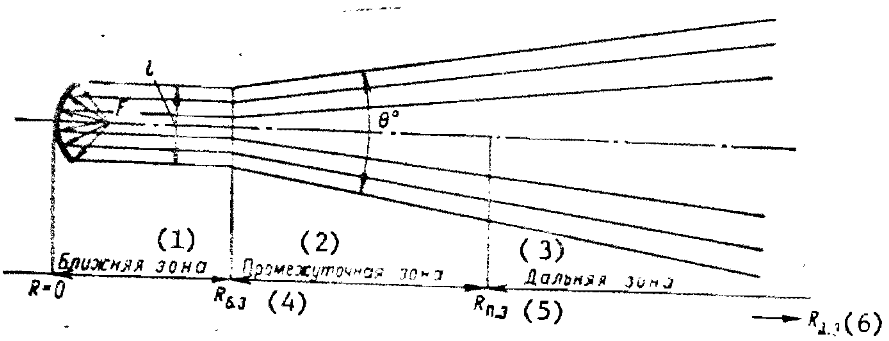

Figure 43. Radiation distribution of a radar antenna. F -- focal point of the beam; l is the beam in the near zone of radiation; θ is the angular aperture of the directional diagram of the antenna.

Key: 1. near zone 2. Intermediate zone 3. far zone

4. R_{nz} 5. R_{iz} 6. R_{fz}

The power flux densities in the center of the beam (on the axis of the diagram) ρ_{center} and on its edges ρ_{edge} at the limits of the far zone can be determined from the following relations:

$$\rho_{center} = \frac{3P_{ave}}{\Lambda_a} \cdot 10^2 \text{ microwatts/ cm}^2;$$

$$\rho_{edge} = \frac{P_{ave}}{3\Lambda_a} \cdot 10^2 \text{ microwatts/ cm}^2,$$

where P_{ave} is the average power, watts;

A_a is the area of the transverse cross section of the antenna aperture, m^2.

The average power is a function of the power in the pulse, the pulse length, and the pulse repetition rate and it can be determined by the formula

$$P_{ave} = P_{pulse}\ \tau/f,$$

where P_{pulse} is the power in the pulse, watts;

τ is the pulse length, seconds;

f is the pulse repetition rate, seconds.

The beam is expanded beyond the limits of the near zone and at sufficiently large distances from the antenna the field intensity varies inversely proportionally to the square of the distance.

The zone within the limits of which this law is correct is called the near zone, and the lower boundary for the antenna of the truncated paraboloid type is determined by the relation

$$R_{fz} >> ab/\lambda.$$

There is an intermediate zone between the near and far zones. Within the limits of the intermediate zone the power flux density in the center of the beam can be determined by the formula

$$\rho_{center} = 3P_{ave}/A_a) \cdot 10^2 (R_{nz}/R)^2 \text{ microwatts/cm}^2,$$

where R is the distance from the center of the aperture to the given point within the limits of the intermediate zone, meters.

In the far zone the field intensity in the center of the beam is determined by the formula

$$\rho_{center} = (P_{ave}G/4\pi R_2) \cdot 10^2 \text{ microwatts/cm}^2,$$

where G is the gain of the antenna.

On going away from the axis the field intensity decreases in accordance with the nature of the directional diagram, and it is

$$\rho = (P_{ave}G/4\pi R^2) \cdot 10^2 \cdot F(\theta_v;\ \theta_h) \text{ microwatts/cm}^2,$$

where F $(\theta_v;\ \theta_h)$ is the expression for the directional diagram in general form;

θ_v and θ_h are the current angular coordinates in the horizontal and vertical planes reckoned from the antenna axis.

In the center of the beam $F(\theta_v\ ;\ \theta_h) = 1$, and on the edge of the main lobe of the pattern $F(\theta_v;\ \theta_h = 0.5$ when constructing the directional diagram with respect to the half-power level.

In this case if it is necessary to determine the magnitude of the power flux density at a point located between the antenna axis and the edge of the main lobe (within the limits of the far zone) and expression $F(\theta_v;\ \theta_h)$ is unknown, it is necessary to take the larger value as the calculated value, that is, the value of the power flux density determined for the center of the beam.

If the height of installation of the antenna, the operating angle of inclination and the width of the directional diagram of the antenna are known, then it is easy to determine the dimensions of the "blind zone" in which it is relatively safe for the crew. In Figure 19 it is shown that the "blind zone" is bounded by a right triangle one of the legs of which is the height of the antenna H_a, the second leg b runs horizontally, and the hypotenuse c is the edge of the main lobe of the directional diagram. Then the angle α is

$$\alpha = 90° - (\beta + \theta/2),$$

where α is the desired angle;

β is the operating angle of the antenna;

θ is the width of the directional diagram, degrees.

The largest operating angle of inclination and width of radiation pattern of the antenna are given in the description of the radar.

In this case, when the height of installation of the antenna must be calculated, it is necessary to consider the greatest elevation of the investigated deck above the height of the main deck and the human height.

On the basis of research [43, 46, 48] confirming intense irradiation of the crew on installation of the antenna at a height of 1.2-2.5 meters from the level of the top bridge, on high-tonnage cargo ships it was recommended that the antenna be raised to a height of no less than 6 meters. On passenger ships where the top bridge has appreciably larger dimensions and is frequently executed below the promenade deck, a height of installation of the antenna of 6 meters is insufficient.

In cases where radar antennas on masts are installed appreciably above human height, the side lobes of the directional diagram, as measurements show, become dangerous whereas under other conditions they sometimes form radiation with an intensity of tens of microwatts per square centimeter.

If it is necessary to work on the open decks, near the transmitting antenna or in the range of the antenna beam, it is possible to recommend shielding of the work areas by umbrella shields coated on the radiation side with a material which absorbs electromagnetic superhigh-frequency energy.

In order to exclude or decrease the superhigh-frequency energy flux reflected from the tubes, masts, and other superstructures on the open decks (especially on passenger ships), application of special paints which absorb electromagnetic energy, various chalk and lime coatings with a defined bonding substance and also rational placement of the antennas are recommended [104].

When repairing the radar and regulating the antenna it is necessary to take care not to get into the directional flux of the waves, and if necessary it is appropriate to take individual protective measures in the form of special glasses, overalls and helmets, and so on. Sometimes, in case of prolonged use of the radar it is necessary to limit the time of standing watch on the parts of the decks where the irradiation intensity exceeds the standard value.

For constant monitoring of the radiation and taking timely measures to eliminate the harmful factor, it is expedient to equip each ship with a superhigh-frequency field indicating device.

Methods of protection from open radiation of marine radar antennas are described above. As for the transmitter and the antenna feeders located inside the areas, as the measurements show, the superhigh-frequency field is practically absent there. This indicates good shielding of the high-frequency elements of the transmitter and absence of stray radiation of the transmission line. When repairing the transmitter and doing possible operations with open emitting devices it is necessary to take all the precautions mentioned in Chapter VI.

CHAPTER X
MEDICAL MEASURES FOR THE EFFECTS OF HIGH-FREQUENCY AND SUPERHIGH-FREQUENCY ELECTROMAGNETIC RADIATION ON THE ORGANISM

pp 144-146

General health measures consist in early discovery of impairment of the state of health of members of the crew subjected to electromagnetic irradiation and stopping people from working if they have pathology corresponding to the occurrence of professional disease.

By order of the USSR Ministry of Public Health No 136-M(1957) provisions are made for preliminary and periodic (once every 12 months) medical examinations of personnel who service radio frequency devices. According to the order, contraindications for acceptance for employment to service ultrahigh-frequency devices include the following:

All blood diseases and expressed secondary anemia (below 60 percent hemoglobin);

organic diseases of the nervous system;

expressed endocrine-vegetative diseases;

epilepsy;

expressed asthenia;

expressed neuroses;

cataracts.

Neurocirculatory distonia, cardiosclerosis, hypertonic syndrome, and hypertonic disease must be added to the presented contraindications.

The same contraindications should be extended to people servicing devices in the other high-frequency bands.

The order provides for participation of therapists, neuropathologists, and ophthalmologists in medical examinations and performance of a series of laboratory studies. In an addendum to the order it is recommended that electrocardiographic studies be made during the periodic examinations. When the ophthalmologist examines people subjected to irradiation by a superhigh-frequency field, a slit light study is mandatory.

Diagnosing the chronic effect of radio frequency irradiation presents definite difficulties. This arises from the nonspecific nature of the picture of the disease especially in its initial stage. In a number of cases it is necessary to make diagnostic observations of changes in the state of health of people suspected of manifestations of the chronic effect of an electromagnetic field.

In the presence of expressed symptomatics caused by radio frequency irradiation and the absence of indications of its nonprofessional etiology in the anamnesis, data characterizing the conditions and degree of radio frequency irradiation during the process of current and past work, including professional anamnesis (length of service under irradiation conditions, detailed professional history, and so on) play the decisive role.

As has been established, manifestations of the effect of electromagnetic fields of radio frequencies are reversible: on stopping work under irradiation conditions the phenomena gradually disappear in approximately four to six weeks, and if they were caused by the effects of lower radio frequency bands, they disappear earlier. Therefore, when establishing manifestations of the chronic effect of radio waves temporary transfers to jobs not connected with the presence of electromagnetic fields are indicated.

Only especially severely atypical cases with respect to reversibility can serve as a contraindication to returning to the primary job after a temporary transfer.

There is no specific treatment for the disease caused by the chronic effect of radio frequencies. Symptomatic and general buildup treatment should be carried out depending on the clinical manifestations and degree of expression of the disease.

Calcium compounds are prescribed in the presence of vegetative disfunction phenomena. In the presence of asthenia, B complex vitamins, ascorbic acid, glucose therapy, and tonics (bromine with caffeine, injections of strychnine, duplex, tincture of ginseng) are prescribed, and in some cases barbiturates are given in small doses. Advanced forms of the chronic effect of radio frequencies can require sanatorium or health resort treatment with granting of extra leave to the patient.

The expediency of granting people who work with radio frequency emiswion sources additional leave and shortening their working day has been taken into account by the USSR labor laws.

The "List of Production Facilities Shops, Professions and Duties with Harmful Labor Conditions Working in Which Gives the Rights to Leaves and a Reduced Working Day" includes certain categories of people who work in the irradiation zone of a radio frequency electromagnetic field.[1]

In Section 22 on "Transport" it is stated that additional leave of 12 days will be granted in accordance with item 122 of the "Maritime Fleet" subdivision to marine telegraph operators of all categories and also the chiefs of marine radio stations standing direct watch (item 124).

Proper selection of the sanitary engineering, sanitary-hygiene and general health measures for jobs accompanied by radio frequency radiation to a significant extent insures effective control of the unfavorable effect of high and superhigh-frequency electromagnetic waves on workers.

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[1] The appendix to the Resolution of the State Committee of the USSR Council of Ministers on Labor Problems and Wages and the Presidium of the All Union Central Trade Union Council of 24 December 1960, No 1353/28.

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