INTERNATIONAL ATOMIC ENERGY AGENCY
UNITED NATIONS EDUCATIONAL, SCIENTIFIC AND CULTURAL ORGANIZATION
INTERNATIONAL CENTRE FOR THEORETICAL PHYSICS
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SMR.380/9

COLLEGE ON THEORETICAL AND EXPERIMENTAL RADIOPROPAGATION SCIENCE

6 - 24 February 1989

IONOSPHERIC ABSORPTION MEASURING TECHNIQUE AND RESULTS

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IONOSPHERIC ABSORPTION - MEASURING TECHNIQUE AND RESULTS

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ABSTRACT

The methodology and the basic devices for measuring the ionospheric absorption have been analyzed using methods AI, A2, A3 etc. The methods of processing of ionospheric measurements have been shown, and some basic information is provided about the selection of measuring interpretation technique. The possibilities for using absorption data in radiowave propagation, aeronomy and some other applied areas have been analyzed. Some problems open to absorption measurements have also been demonstrated together with their possibilities to be included in complex ground-space experiments.

I. IMPORTANCE OF ABSORPTION MEASUREMENTS IN RADIOWAVE PROPAGATION, AERONOMY, PLASMA PHYSICS AND COSMONAUTICS

I.I. The measurements of radiowave absorption in the ionosphere allows: i) To determine the level of a certain radiosignal after its reflection or transition through the ionospheric environment; ii) To calculate the intensity of the fields created by various radiotransmitters according to paths looked for or in given radio networks; iii) To prognosticate the lowest applicable frequency (LUF) in cases when the reflection is from E layer, the lower part of the night F -region, and in a number of a cases concerning impotant tasks of applied nature; iV) To provide output data for designing radio networks and radio paths; for estimating the relationship and interaction between radiotransmitters with equal or approximately equal frequencies, and for making up international documents of ITU and of CCIR for distribution of radio frequencies, power and other characteristics of the world global radio network. These are the basic applications of absorption measurements directly in research and the practical application of radiowaves. These measuerements, however, have more extensive cognitive significance of their own. They are used to obtain basic data about radiowave propagation in the ionosphere, for the approximations the different theories (e.g. the magnetic-ionic, see for example [1]) approach the adequate picture of interactions between electromagnetic waves and the surrounding plasma environment etc.

I.2. A number of aeronomic parameters and heliophysical characteristics are estimated by absorption measurements which will be demonstrated further in the paper. We will also illustrate the possibility to evaluate through them some basic data about characteristic values of electron density (e.g. the equivalent electron concentration - [2,3,4,5] and even to determine the whole vertical profile for electron density (see for example [4,5,6,7]). Under conditions of solar eruptions, SID effe fects, solar eclipses, nuclear explosions, passing of heavy-weight rocket systems through the ionosphere and some other special cases, absorption measurements provide the best possibilities to study these excessive phenomena. At certain distribution of electron concentration (which is obtained from other geophysical measurements, e.g.ion soundings or incoherent scatter radars, and also by means of rocket-satellite observations), from the absorption value is determined the effective collision frequency and its components - the frequency of electron-ion collisons ν_{ei} and of electron-neutral collisions ν_{en}. These frequencies, in addition to their own cognitive importance, make possible the estimation of electron and ion temperatures using methods which are to be described further in the paper. Thus absorption measurements provide abundant aeronomic information, and are extremely suitable for inclusion in projects and programs for complex studies of the Earth's Environment.

I.3. Absorption measurements by themselves are a method to study the cool Earth's plasma, and as such they rationally complete plasma laboratory studies. Some phenomena and processes develop in the ionosphere naturally and undisturbed which are difficult to reproduce in laboratory conditions because of the effects of the vessel's walls, higher electromagnetic disturbances on the Earth etc. Therefore absorption measurements in the ionosphere control, test and supplement ground plasma studies, another important feature of theirs.

I.4. From absorption measurements are obtained values for aeronomic parameters which are very useful for other applied areas, e.g. astronautics. The top of present-day standard military aircraft reached up to 38 km., and a number of Soviet and American "spacecraft" will reach a height of I00 km and even to heights of 200-350 km in orbital flights (see for example "X-30"). In a normal orbital flight, satellites burn out at heights of about I60 km (at middle geographical latitudes), at I70 km (in the equatorial regions) and at I40 km (over the Poles). Therefore, a large area from the beginning of the ionosphere (60 - 65 km at middle geographical latitudes during the day) up to about I60 km remains inaccessible to satellite "in situ" measurements. This region is studied by ground devices at heights of I00 and I30 km. Ion soundings provide representative data for this region in the daytime (there are no reflected signals in ion soundings below I00 km , and the region above I30 km is the "valley" in the intermediate E-F region which is also inaccessible for direct sounding of the Earth's surface). Thus absorption measurements are practically the only inexpensive and accessible ground radio means to study the region from 60 to 100 km, and the region from 130 up to 160 km. Another radio means are the incoherent scatter radars, 8 of which were in complete operation in 1988. It is obvious that these expensive and heavy-weight devices cannot give a global picture of the ionosphere. Rocket sounding with comparatively light-weight meteorological rockets provides information about the region considered from 60 to 160 km. Rocket soundings, however, are expensive enough, and as a rule take place once a week (this is the situation in the majority of rocket stations in Europe; the higher number of rockets lauched yearly, i. e. 56, is as a rule for experimental purposes). Hence, both for the purposes of cosmonautics and height aviation, absorption measurements are of essential importance. We are not treating here their role for estimating absorption losses, polarization changes and some other effects on the signals for communication from and to the space objects, as well as the importance of being well acquainted with ionospheric absorption to solve a number of problems and tasks of radioastronomy.

So far we have outlined a number of functions of absorption measurements stressing their importance for geophysics, radiowave propagation, cosmonautics, space physics and some other areas. To the above mentioned roles of absorption measurements can be added other ones. For example, they are used as indicators of some meteorological processes in the middle atmosphere and in the lower thermosphere. They can also be used to find out some important aspects of the processes in the middle atmosphere which is hardly accessible to study. Some absorption data directly correspond to the intensity of certain ranges of the solar X-ray radiation and can be used for heliophysical studies. In general, the data about absorption changes are good bench-marks of solar effects on the biosphere etc. Therefore, in this extremely good initiative of the International Institute of Theoretical Physics for setting up a sch college for radiowave propagation, my belief is that serious attention should be devoted to absorption measurements and the use of the information resulting from them for different fields of fundamental and applied sciences. We are further going to outline in brief the methods and means for some absorption measurements, the ways of interpretation of their results, and their application in ionospheric physics aeronomy, radiowave propagation and some other areas.

2. METHODOLOGY AND TECHNIQUE FOR EVALUATING IONOSPHERIC ABSORPTION

2.I. Definition Of Absorption. Types of Absorption.

The ionospheric absorption L is determined by the dependence:

$$(1)\quad L = -9{,}7 \ln \rho$$

where the coefficient of reflection from the ionosphere ρ is determined by the power P_α emitted from the aerial at an angle α to the horizon; by the path l of the electromagnetic beam (at beam treatment of radiowave propagation) in the ionosphere and by the intensity of field E_R reflected by the ionesphere at a certain point with the expression:

$$(2)\quad \rho = \frac{l\, E_R}{600\sqrt{P_\alpha}}$$

On its part, the reflection coefficient ρ is related to the parameters of the environment for propagation (the ionosphere) with the following dependence:

$$(3)\quad -\ln\rho = \frac{2\pi e^2}{\varepsilon_0 m c}\int_{\mu=1}^{\mu=0}\frac{N_e \nu\, dl}{\mu[\nu^2+(\omega\pm\omega_L)^2]} = \frac{2\pi e^2}{\varepsilon_0 m c}\int_{h_0}^{h_r}\frac{N_e \nu\, dh}{\mu[\nu^2+(\omega_i\pm\omega_L)^2]}$$

In the first part of the right-hand side of (3), the expression is written down as a function of the linear element dl, and in the second one reduction has been done to the vertical propagation, and integration is according to the height h. Expressions (1), (2) and (3) are classical ones and can be found in all courses, e.g. /1,4,8/. In (3), e and m are used to designate the charge and mass of electron; c - light velocity; ε_0 - dielectric vacuum constant; μ - refraction coefficient; N_e - electron density; $\nu = \nu_{eff}$ is the collision frequency; $\omega_i = 2\pi f \cos i$, f being the working frequency of the radiowave; i is the fall angle of the radiowave to the ionosphere; $\omega_L = 2\pi f_H \cos\Theta$, f_H being the gyrofrequency, and Θ is the angle between the vector of the Earth magnetic field and the radiowave direction. In (3), absorption has been determined for half of the path, i.e. the complete absorption is two times higher, h_0 and h_r are used to designate the initial and reflection height of the ionosphere, respectively.

In the practice of absorption measurements, widely applicable are the concepts deviating and nondeviating absorption. Though at present there are serious doubts as to the sensibility of these concepts - see for example /9/, still for the purposes of solving some practical tasks of applied nature, this artificial division of L is rational, and according to it we have the following:

$$(4)\quad L = L_n + L_d = \frac{4\pi e^2}{\varepsilon_0 m c}\int_{h_0}^{h_d}\frac{N_e \nu\, dh}{\nu^2+(\omega_i\pm\omega_L)^2} + \frac{\bar{\nu}}{c}(h'-h),$$

where L_n and L_d are used to designate the nondeviative and deviative absorption, respectively; the first integral in the right-hand side represents L_n, and the second member - L_d. In (4), the double transition of the radiowave in the ionosphere has already been taken into consideration; h' and h are used to designate the virtual and real heights of reflection, respectively, and $\bar{\nu}$ is averaged in the region from h_d to h, i.e. provided $\mu \neq 1$. For normal ionospheric conditions, all observed cases at $f_i \geq 1,5$ MHz in the region with h_o up to 100 km practically yield negligible deviations of μ from a unit. The result $\mu \approx 1$ is also obtained by the data of the International Reference Ionosphere in variants IRI-79 and IRI-88 for the designated rediowaves in the upper part of the midwave and short-wave range. Therefore, for considerable ionospheric parts and for large frequency ranges, the concepts deviating and nondeviating absorption make sense, though in principle it is advisable to operate using the complete expression of absorption (3) which has already been done, e.g. in /9/.

Actually, the intensity E_R is determined not only by ionospheric absorption, but also by radiowave propagation on ionospheric inhomogeneities, by the sufficient stability of parameters of aerial characteristics, by possible multi-path propagations etc. and by some other factors as well. We are further going to show some ways and technical methods to eliminate these effects, although some, even a lot of them, remain. This, by the way, is convenient for practical purposes, as for applied purposes the interest is not in the sources of decrease or increase of E_R but rather in its real value which determined the quality of radio reception. Thus, even if we fail to clear away ρ e.g. from the effects of ionospheric propagation due to inhomogeneities it is just as if we had estimated an increased absorption corresponding to this effect and reflecting the real conditions of the radiocommunication. Consequently, absorption measurements for the purposes of telecommunications (e.g. for the standardized field we are going to consider further) are fully satisfied by the E_R values including all absorbing and propagating factors. Estimating the latter and introducing corrections for propagation and other nonabsorption losses of energy is required in drawing aeronomic and ionospheric conclusions resulting from L.

2.2. Methods Of Measuring Radiowave Absorption

We can basically classify the following 7 main methods for measuring radiowave absorption: 1. Method A1 including the amplitudes of an pulse-modulated radiowave vertically emanated by a special radiotransmitter and that of the reflected and received one by a radioset. From the comparison of both the emanated and reflected intensities at suitable averaging, the absorption value is obtained; 2. Method A2, where the intensity of space radio noise is measured at appropriately selected frequencies, and absorption is obtained according to the diurnal course of this value and the respective tests; 3. Method A3, where the received intensity is registered on standard operating radio transmitters at suitable frequencies and at rationally selected radio paths, periodically comparing and standardizing being used with a signal-generator; 4. Measuring the local absorption distribution by a rocket transmitter and ground analyzer; 5. Measuring the absorption of radiowaves emitted from satellites with frequencies lower than MUF and position of the satellites above the height h_mF of the maximum concentration N_m F; 6. Absorption measurements of transionospheric signals with frequencies over MUF in the so called frequency of the segment; 7. Estimating ionospheric absorption from f_{min} frequency of ion soundings. Methods AI, and especially method A3, are widely applied in science and for telecommunication applied purposes.

2.2.I. Method AI: The principle of AI method includes transmission of pulse-modulated frequencies vertically, which are reflected by certain ionospheric parts and received back to the Earth's surface in a receiver combined in a general equipment together with the transmitter and the register-measuring part. The comparison between the accepted amplitude of the electromagnetic impulse and the transmitted one, results in the reflection coefficient ρ and radiowave absorption, respectively. The reflected amlitude of the wave continually changes because of it passing through different ionospheric inhomogeneities, the radiowave superposition, the radiowaves having covered different paths in the ionospheric environment, the effects of rotation of the polarization ellipse, and some other reasons as well. We should stress the fact that even a linearly polarized radiowave on entering the ionosphere receives elliptic polarization while moving in the ionospheric plasma, the polarization being under conditions of constant change (in particular - rotation) of its determining characteristics. Thus, even if ionospheric inhomogeneities and different ways of radiowave propagation in the ionosphere did not exist, the reflected wave would have been of changeable structure, which at fixed receiving aerial results in strong amplitude changes of the receiver entrance. Therefore, methods AI and A3 require suitable and considerable averaging, as well as some other measures we are going to consider further. We should note the fact, however, that multifrequency absorption information is far more important than that of radio frequency. Hence method AI is as a rule realized at several frequencies at a certain measuring station. We are further going to consider a concrete realization of AI method which has been used long and successfully in the USSR /I0/.

Fig.I shows a block diagram of the equiment used to determine the radiowave absorption for many frequencies and for the two magnet-ion components separately.

In the transmitting part, an automatic ionospheric station has been used to which a power amplifier has been switched in some experiments allowing to increase the power of the output cascade up to kw . The transmitter emits impulses with a length of 100 μs of 5 arbitrarily selected frequencies within the range of I - 7 MHz, with repetition frequency IO imp/s for all frequencies or 2 imp/s for one frequency. The working conditions at ten fixed frequencies have been foreseen to measure the absorption of one of the components. The transmitter output is switched to a standardrhomboid system AIA oriented to the magnetic meridian at an angle of 45°. The receiving aerials are two dipoles placed crosswise at an angle of 90° in the centre, each 45 m long and oriented in the direction of North-South and East-West. The dipoles consist of six beams placed along the generant of a cylinder with a diameter I m.

The receiving unit contains a polarization receiver /PR/ having conjugated electron adjustment with the transmitter and recorder. The system for disturbances decrease is adjusted for circular polarization and ensures the reduction coefficient about I00 for the whole range. A switch with a frequency of 2 Hz ensures the reception of the usual component during the first 0,5 s , and during the next 0,5 s - of the unusual component for the same frequencies. Besides, reception of the unusual beam takes place by switching frequencies using a special device. From each reflected signal, the background noise is calculated /in the block of the transducer amplitude - number - TAN/, as well as the disturbance which is emitted by strobing the noise at each frequency before the reflected signal of first rate frequency has come. The amplitude of the reflected signal from which the background noise has been read, is transduced into length / in the TAN block/ which determines a number, characterizing the amplitude in relative units. Then signals are distributed through the switch block /SB/ and enter the counter block /CB/ depending on the frequency and the component. The last to be counted are the total amplitude of the reflected signals and the number of accounts, which enables the direct calculation of the mean amplitude for a certain time interval.

The devisor /D/ lowers the frequency to IO Hz, which is once again decreased in the commutator - devisor /CD/, for successive starting of 5 adjusted generators situated in the heterodynes block /HB/. The frequency of this successive starting is 2 Hz. In the strobing impulses block /SIB/ strob impulses are formed for the selection of the reflected signals.

The precision of the experimental estimation of absorption is highly dependent on the precision of estimating the equipment constant and the averaging time. The equipment constant is estimated using the method developed in /IO/ according to the multiple reflections of frequencies lower than or equal to 3 MHz. For higher frequencies the polarization method for estimating the eqipment constant i s used. the former is developed in /II/. Particularly difficult is the problem of averaging the amplitude of the signal reflected by the ionosphere. On the one hand, the averaging time should be as little as possible to obtain higher dividing ability in time, and on the other - considerable time should be selected for averaging to smooth out and remove the effects of superpositionsof different signals reflected from the ionosphere, and the rapid and slow fading obtained for different reasons. The too big averaging periods remove fading and make the data measured more precise and representative. However, the too big periods can smooth out the diurnal absorption course and remove a number of geophysical and heliophysical effects. In /I0/ this averaging period is experimentally estimated as the doubled correlation radius taken at level 0,5 from the module of the autocorrelation function. In this case, an averaging period of 50 min has been obtained which coincides with the recommendations of other studies by Soviet authors. We should like to stress the fact that at such high averaging period, both the absorption AI method and all methods developed on the basis of the latter to estimate the collision frequency and other geophysical values, have proved to be in capable of obtaining rapid variations in the ionosphere. Hence, they do not provide possibilities to study the effects of solar eruptions, solar eclipses, nuclear explosions, of internal gravitation waves and other phenomena and processes with a period equal to or shorter than 90 min.

To avoid the big averaging period in measuring radiowave absorption after AI method, another method has been proposed and realized in [I0] to estimate the absorption, the averaging being done not in time, but within a certain frequency band. For this purpose, in /I2/, frequency vacillation is performed round a certain base frequency. In several works of Soviet authors, it has been theoretically proved /and after that experimentally as well by N.P. Danilkin et al/ that such a method makes it possible to shorten the period of averaging to I0-I5 min.

Here in brief I am going to describe the combined usage of ground and rocket equipment to measure electron density, absorption and collision frequency during the flight of the geophysical rocket "Vertical - 4" described in /I3/, and of a number of other geophysical rockets of this type described for example in /I2/. The conditions for launching "Vertical - 4" rocket and the basic data about its equipment are given in /I3/ and /I4/. The rocket reached a height of I5I2 km October I4th I976. The electron density Ne is measured using the method of the dispersion interfereometer. Its transmitter is mounted aboard the rocket and emits two coherent waves with frequencies of I44 and 48 MHz. The emitted signals are received on the Earth, and the changes in the phase differences among them, are registered. Depending on the changes in the phases difference in dropping the rocket /to remove all effects of its engines/, Ne (h) - the profile for heights from 82 to 628 km with measurement error exceeding I0 % , has been calculated. At the same time, measurements have been made of electron density using Lengmuire sounding, and of the total ion density using ion traps - see [I4]. At low kmk heights, the electron densities have been measured aboard the same rocket using capacity radiofrequency sounding made in GDR.

As the ionosphere is quasineutral, the indications of these devices should be equal. Actually, the differences among the ion traps, the interferemeter and Lengmuire sounding amount to 2 tmes. The maximum electron density is at a height of 220 km. About the maximum region and above it, the differences reach 60 %. However, in the submaximum region, the interferometer data are completely representative and are accepted as the basis with which the data from other devices are comparaed - see [I4]. Thus the authors in [I3] are quire right not to make use of the data of the interferometer above 630 km where the data from ion traps and Lengmuire sounding are considerably more precise because of the comparatively slow movement of the rocket. During the flight of the rocket, some measurements were made on the Earth's surface of the absorptions of the usual component of radiowaves with a polarization variant of method AI simultaneously at eight frequencies within the range of 200 - 425 KHz. We have already provided the basic information about the radiowave absorption eqhipment using AI method of o- and x- components. At the same time, pictures have been taken of polarization ionograms every 5 minute which makes it possible to obtain a complete polarization picture of these eight frequencies and to adequately realize the polarization variant of AI method.

During the experiment, 5-minute averaging of amplitudes was performed for each of the 8 channels within a period of 90 min. The frequency of the emitted impulse signals of each of the eight working frequencies changes in respect to the central frequency within the range of ± I25 KHz, with a step of 8 KHz. On the basis of the change of amplitude of the reflected signals and the xxx working heights registered on the bearing heights by an "electron height meter", the radiowave absorption values L have been estimated. The time absorption dependence L (t) built on the basis of the 5-minute measurement seances is subjected to statistical analysis. It has been found that while the experiment is conducted, the optimal averaging period for all frequencies ensuring fluctuations extinction, is I5 min. This is the reason why absorption L (t) is divided into fluctuation and regular part by creeping linear smoothing according to 3 points. The radiowave absorption values thus estimated become the initial material to obtain $\nu(h)$ profile. The fluctuation part of L (t) makes it possible to estimate the mean-square deviation of the logarithm of the amplitudes.

The error in the measurement of the frequency dependent absorption has been estimated which results in errors in estimating $\nu(h)$ profile. The errors depending on the indefiniteness of data about the equipment constant and the fluctuation part of L (t) are determined at that, The relative error in the absorption measurement during the experiment does not exceed 7 % for all frequencies.

2.2.2. **Method A2.** Method A2 consists in registering and estimating the attenuation of the natural space radio noise at frequencies higher than the maximal ones for the ionosphere (f_oF or f_oF2). Space radio noise occupies the whole radio range of changeable background level in its different parts. For the purposes of estimating ionospheric absorption, noise frequencies are as a rule looked for, i.e. $f_z > f_o F$ ($f_o F2$) if the reception is in vertical direction, and $f_r >$ MUF , if the radio receiver is in inclined position. As, if the difference $f_r - f_o F$ is small enough to work in a region in which radiowaves have a high deviating absorption, strong propagations, deviations aside and some other effects on the purity of the experiment, it is preferrable to use working frequencies for measurements according to method A2 which are with 8 - I4 MHz higher than the maximum accessible f_fF (f_oF2). The latter range between I4 and I8 MHz for middle latitudes in the middle of a winter day. On the other hand, the considerable increase of the difference $f_r - f_oF2$ (which as we have already pointed out guarantees the purity of the experiment) results in significantly lower values of absorption L, which according to (3) is inversely proportional to $\Delta\omega^2$. These low values are difficult to measure, and the conclusions drwn from them about the ionosphere and radiowave propagation are not adequate enough. For that reason, the frequency f_r for measuring space radio noise is as a rule selected between 25 and 27 MHz.

The measuring devices using A2 method have a very simple black diagram , but are difficult to produce. Their production is serial and they are produced under the name rheometers. The latter are a combination of a measuring aerial in different variants, the most common one being a field of horizontal dipoles. Preamplifiers are switched directly to this aerial to increase in advance the comparatively slight signal of space noise. The usual black diagram of a high-quality and high-stability radio receiver is developed after that for the marked frequency range (25 ÷ 30 MHz) and recorder of the radio noise thus accepted. Because of the slow changes of space radio noise during the day and night , the recorder usually types on tape using ink. The final value obtained is the total absorption L according to (3) which is identical to L_n (i.e. we can consider that $\mu \cong I$) because of the selected high working frequencies. Naturally, the integration in (3) or in the integral on the right-hand side of (4) should be done from h_o to infinity or practically up to about 2000 km. In this case, of course, factor 2, not 4 is used in front of the integral on the right-hand side of (4).

2.2.3. Method A3. We are going to considere method A3 here in more details because of its wide application and effectiveness and because of its being accessible to realize and put in practice using comparatively simple and inexpensive means. Our analysis on this problem is a shortened variant of [4,8] which are initiating monographs for measuring ionospheric absorption after method A3 and for application of the data obtained from these measurements. These monographs are also the basis for the corresponding studies in Italy, Bulgaria, GDR, Poland, Czechoslovakia, USSR, Yugoslavia and some other countries.

Method A3 uses the signals of standard working radiotransmitters at long, medium- and shor waves which are recorded at suitable distances with a rationally selected aerial and a stabilized radio receiver. The automatic amplification regulation (ARA) of the receiver is switched off, and from the demodulator output, a small-size direct-current amplifier (DCA) is switched on, from the output of which a recording signal is taken. The recording takes place in two ways: a) Analogue - with a recording device on tape; b) Digital - with evaluations of the mean, quasimaximum, peak (maximum) and quasiminimum values. Irrespective of the precise and automatically obtained information in digital recording, its independent performance is not preferrable as the analysis of records on a paper carrier reveals rich abundance of information, essentially exceeding the automatic evaluations - see for example [4,8]. This is of particular importance in solar eclipses, sunrise-sunset and SID effects etc. For the sake of completeness of system A3, it should also include the following: i) A comparator or a signal-generator to calibrate the input signal of the receiver and test the total system in absolute values of the field; ii/ A stabilizer of the supply voltage for high record stability; iii/ An automatic switch for receiver amplification. The latter is required as during the day the absorption is too high (because of the absorption of the medium and short waves in D region), and it decreases during the night. In accordance with this, it is necessary to have considerably higher (however certain!) amplification of the receiver, while during the night it should be reduced to a certain degree. As a rule, this change in the amplification tract takes place in the sunrise-sunset period. It can be performed manually as well, but is also easily realized with an automatic clockwork device.

The medium-wave measurements according to method A3 require a vertical aerial or a suitable dipole for the measured frequency. The first case according to /8/ is applicable when the intensity of the ground wave E_B in the place of reception is with at least one order lower than that of E_R wave reflected from the ionosphere. This is the way to operate at working frequency higher than 2,5 MHz and distances between the transmitter and receiver d $\geq$ 300 km. At smaller distances, it is preferrable to use a dipole or a frame aerial to remove the ground wave.

From the considerable experience gathered in /8/, a general conclusion can be drawn that in measurements according to A3 method at medium waves, it is best to select such a path as to eliminate the ground wave. This occurs at distances d > 300 km, but is also admissible at shorter distances when the equivalent soil conductivity (on which E_B is dependent) is lower. The presence of mountains, high-rise blocks of flats and massive buildings in cities etc. in the transmitter-receiver path helps to suppress the ground wave and facilitates ionospheric absorption measurements. Such is the case for example with the path Sofia - Vitosha Observatory (f = 827 km and d = 37 km) - /8,I5,I6/ and Nice - Roburent (North-west Italy with a close transmitter at f = I554 KHz and d = 80 km) - /8,I7,I8/. This, however, is not always possible, therefore at d < 300 km and f < 2,5 MHz, frame aerials are used. The latter are a series of windings, of circular or rectangular shape, which ine general are of dominant inductive nature, but of considerable own distributed capacity as well. For the measurements and selection of these aerials, refer to /I9/. The plane of the frame should be perpendicular to the transmitter - receiver direction. Because of the imperfection to compensate for this ground wave, some additional phase-compensating devices have been introduced. Decisive for the absorption are the mean values from the field coating - see for example fig.2 from /8/ for Brashov - Sofia path (f = I55 KHz; d = 370 km for September 28 th I972). In some cases the ground wave cannot be fully compensated for which requires the partial inclination of the frame until E_B is nullified.

In /8/ and some other publications, certain methods have been considered to eliminate E_B by estimating its values at certain soil conductivity. Numerous data, however, including those obtained in Italy (Nice - Roburent path) have shown that E_B has diurnal, seasonal and incidental changes, which in the Italian path considered according to /8/ have reached changes from winter to summer in proportion 2:I. If such significant changes are not taken into consideration, ionospheric absorption measurements can be compromised. It is therefore recommended to use purely ionospheric methods to determine ρ and L. In /8/ and some other publications, it is proposed for this purpose to find the field intensity when there is reflection from the sporadic E_s - layer. In that cae, in /8/ and in some other studies, the authors accept that $\rho = I$ and $L = 0$ because E_s layer has a high gradient and minimal absorption. Unfortunately, when radiowaves from E_s layer are reflected, there is always a certain (though minimal) energy transfer above this layer as well as specific conditions of reflection resulting in $\rho < I$. However, in the first crude approximation, calibration with $\rho = I$ can be used in the sporadic E_s layer. It is used in Bulgaria, Italy, GDR, Jugoslavia, Czechoslovakia and some other countries.

It is obvious that for aeronomic, geophysical and practical purposes, more important are the relative changes of ρ and L, and not only their absolute values. In /20/ the so called standardized curves L ($f_1 = f \cos i$) obtained from measurements of many years, have been proposed to calculate the relative variations of L. These curves refer to night absorption, while the transition to other conditions takes place by the frequency-amplitude characteristic of the whole receiving-recording device. This charact_eristic is obtained by sending calibrated and precise signals from the signal generator to the receiver input and estimating the output signal to the recorder.

2.2.4. Measuring the absorption and its determining factors by rockets. Most ground methods for measuring ionospheric parameters have the disadvantage of measuring integral waves on which different effects are superposed. In the subintegral functions of the waves are the plasma characteristics looked for. The direct in situ methods for direct measurements with satellites and rockets make possible the immediate measurement of ionospheric p_arameters. Naturally, the direct methods have their own disadvantages at that. The data obtained are not statistically comparable for a certain station. Time variations are difficult to study by direct methods. The rapid movement of the rocket and the uneven movement of the satellite result in certain effects from the moving body on the environment etc. Irrespective of that, the direc_t methods have certain advantages as well, and we are going to present one of them here as it has been developed in /2I/.

The first case to consider is the radial rocket movement in respect to the observation point. For the sake of simplicity is is assumed to be strictly vertical. Then measuring separately the relative amplitudes $R^{(o)}$ and $R^{(x)}$ of the usual and unusual waves, emitted from the rocket at one frequency, we have:

$$/5/\ \ln \frac{R^{(x)}}{R^{(o)}} = -\frac{\omega}{c}\int_0^{h_1} (\varkappa^{(x)} - \varkappa^{(o)}\, dh - \ln B,$$

where $\varkappa^{(o)}$ and $\varkappa^{(x)}$ are respectively the attenuation coefficients of the two waves, and the constant multiplier B characterizes the relative intensity of their emissions. Thus, by constantly observing the value $\ln[R^{(x)} - R^{(o)}]$ it is possib le to estimate the difference of the attenuation coefficients

$$/6/\ \{\varkappa^{(x)} - \varkappa^{(o)}\} = \frac{c}{\omega}\,\frac{\Delta\{\ln R^{(x)} - \ln R^{(o)}\}}{\Delta h}$$

on the analogy of the way in which from the measurement of phase differences, the differences of the refraction coefficients of these waves in a finite interval of heights Δh are estimated. The simultaneous measurement of the differences of refraction coefficients makes possible to estimate the profile of electron density with height using the method developed in [2I]. As it refers to the case when ω^2 is commensurable with ν^2, we are going to consider here the case $\omega^2 \gg \nu^2$, taking place in the middle and upper ionosphere. Then, unlike the absorption coefficients, the following expression has been deduced in [2I]:

$$/7/\ \{\varkappa^{(x)} - \varkappa^{(o)}\} \approx 2\delta\nu_o u_L\ ,$$

where:

$$\delta = \frac{\nu_{eff}}{\omega}\ ;\ \nu_o = 4\pi\frac{N_e e^2}{m\omega^2}\ ;\ u_L = \frac{\omega_H}{\omega}\cos\theta$$

At this formulation th e difference of refraction coefficients is:

$$/8/\ \{n^{(o)} - n^{(x)}\} \approx \nu_o u_L\,(1-\delta^2)$$

From the last two expressions, it follows:

$$/9/\ \nu = \frac{c}{2\nu_o u_L}\cdot\frac{\omega\{\ln R^{(x)} - \ln R^{(o)}\}}{\Delta h}$$

or

$$/10/\ \nu = \frac{m^2c^2\omega^3}{8\pi N_e e^4 H\cos\theta}\cdot\frac{\Delta\{\ln R^{(x)} - \ln R^{(o)}\}}{\Delta h}$$

Consequently, we have formulae which immediately determine ν from the results of the measurements of the amplitudes of the usual and unusual waves if the value of N_e is familiar.

If the emitter moves in a more complex curve in respect to the observation point, e.g. in an elliptic orbit, then the value of ν can be estimated by a formula on the analogy of /6/ by such a position of the satellite in which the angle between the radius-vector passing through the observation point and the tangent to the orbit, is equal to $\pi/2$, and the horizontal component of the satellite's velocity along the vision beam is equal to zero. In other positions of the satellite, formulae both for ν and for N_e hav e been deduced in [21]. The formulae are rather complex, but in a number of cases they can be simplified and used to obtain real data about electron collision ~~density~~ frequency and electron density. Such is the case for example when the orbit of the rocket or satellite and the observation point lie in a vertical plane which makes it possible to calculate the difference in Doppler beat frequencies of the usual and unusual waves Δf and the derivative of the proportion of the amplitudes of these waves, thus estimating N_e and ν directly.

2.2.5. Estimating radiowave absorption through satellite ion-sounding for sounding the topside ionosphere. A system for amplitude-frequency-time averaging of absorption has been developed in [22], the dividing ability of absorption measurements afetr AI method in a datellite variant reaching 8 - I0 min per frequency channel. This is the right place to mention the fact that in all digital present-day sounding the absolute values of the emitted and reflected amplitudes for each of the practically emitted one thousand sounding frequencies, are estimated. Absorption, however, which is easy to determine from the comparison of the two amplitudes, is not real because of the marked constant change of the polarization ellipse of the reflected signal and of the reflection properties of ionospheric inhomogeneities. Therefore, in part 2.2.I, as well as in [I0] wobbling is done of each measurable frequency with $\pm \Delta f$ to reach frequency and amplitude averaging of the reflected signals, thus abruptly reducing measurement time. In [22] this principle has been developed further with time-spatial averaging as the ion-sounding is on a satellite for external sounding of the ionosphere, and through its movement it automatically results in spatial averaging of signals.

The diagram of satellite ion-sounding with selected number of channels (from 5 to I0) for estimating absorption by spatial-amplitude-frequency averaging according to [22], is shown in fig.3. The operation of this most modern device for satellite absorption measurements includes the following: From the clock-pulse generator (I) controlling signals are sent of th e controlling inputs for the senior orders of the first programmable frequency synthesizer (6) through a counter (2). The controlling outputs of the senior orders of (2) are connected with the corresponding inputs of a second programmable synthesizer (6), thus obtaining an interconnected synchronous system. The buffer with three states (5) ensures the the second controlling inputs of synthesizer (6) taking signals from a second counter (4) which processes the clock-pulse voltages from the first counter (2). The buffer input with three states (5) obtaines control impulses from the multiplier as well (3). The latter selects frequencies from the second output of the clock-pulse generator (I), as shown in fig.3. The whole block guarantees the formation of a series of impulse modulated frequencies between e.g. I and 20 MHz (or 0,5 - I5 MHz depending on the solar activity and the possibilities of the aerial systems). The output of the second programmable frequency sythesizer (34) controls one input of the mixer (2I) in the receiving part of the ion-sounding making absorption measurements as well. Blocks (7),(8),(9) and (I0) provide amplification of the impulse-modulated transmitting frequency, which through the final step (I0) and the electron switch (I3) is sent to the satellite aerial (I4).

The signals reflected from the ionosphere are received through the switch and sent to a wide-band amplifier (I6), which on its part introduces them into the narrow-band electron controllable filter (I7). Then, using the channel from blocks (I8),(I9),(20),(2I), (22),(23),(24), (25),(27),(28) and (29) a digitalized signal is obtained for height h' of reflection of the given frequency $f \pm \Delta f$. Frequency wobbling is obtained from the interaction of A and B. The amplitude detector (26) sends signals to the third analogue high-frequency switch (30), the second input of which is connected with multiplier (3) and the buffer input with the three states (5). This switch has controlling inputs connected with the outputs for control of senior orders from the first counter (2). It is the third analogue switch (30) which controls the average temperature (3I). The latter sends signals to the block for processing of and recording of the averaged values (32). The clock-pulse input of the latter is controlled by the block for processing and recording the amplitude of moment frequencies of signal (35) and by the clock-pulse output of calibrator (36). Thus, using the recording block, suitable averaging is obtained of the amplitudes of the signals in time, of the different amplitudes, corresponding to wobbling $\pm \Delta f$ close to a given frequency, and of the changeable amplitudes due to the different location of the satellite, i.e. an amplitude-frequency-spatial averaging is obtained. The latter allows to abruptly reduce the averaging time and increase the representativeness of the data obtained for L. The calculations point to the fact that if acting rapidly enough, the system described, can reduce the averaging time to about 3 min. , which is in accordance with the averaged part of the satellite orbit about I500 km.

2.2.6. Estimating absorption through the minimal reflected frequency ionsoundings f min. This minimal frequency is affected by a number of indices: transmitter power, receiver sensitivity, soild conductivity under the aerials of ion-sounding, technical equipment of the station, radio disturbances and ionospheric absorption. Well-kept ion-sounding, however, with precise calibration and certain amplification of the receiver and optical sensitivity of the recording tape (for analogue ion-soundings the value f min according to [5,23,24,25,26,27] can serve as an excellent indicator of ionospheric absorption, provided the level of radio disturbances within the range of 0,6 - 2 MHz is low enough. For most of the developing countries this condition is fulfilled. For some regions (e.g. San Huan in Argentine - [27] the conditions are excellent for the application of f min for absorption measurements. Ev en in Europe one can find places or at least periods during the day and night when f min and L are in proportion to each other which according to [23,26.] is expressed by the dependence:

$$(II)\ L_{f_{min}} = d f_{min} - 20 \lg 2 h'_{f_{min}}$$

where: d = is a factor experimentally estimated for each ion-sounding, and $h'_{f_{min}}$ is the reflection virtual height for frequency f min.

The most difficult to estimate in the usage of f_{min} is the station constant d ; the proper knowldege and maintenance of ion-sounding is a way to solve this problem.

3. METHODS OF USING ABSORPTION DATA IN AERONOMY; ESTIMATING THE DISTRIBUTION OF ELECTRON CONCENTRATION IN THE LOWER IONOSPHERE; EQUIVALENT ELECTRON CONCENTRATION AND ITS RELATION TO AERONOMIC PARAMETERS; ESTIMATING COLLISION FREQUENCY IN THE MIDDLE, UPPER AND OUTERMOST IONOSPHERE BY ABSORPTION DATA. APPLICATION OF ABSORPTION MEASUREMENTS IN DESIGNING RADIO NETWORKS AND PATHS IN THE INTERNATIONAL DISTRIBUTION OF RADIO FREQUENCIES AND IN OTHER APPLICATION AREAS

The measured value of L in dependences (3) and (4) under certain conditions allows to find a number of subintegral parameters such as coefficient μ , certain values or even the profiles of collision frequency ν (h) or electron concentration N_e (h). In this brief analysis, we cannot reproduce the numerous aeronomic, geophysical, cosmophysical and other consequences resulting from the well known values of absorption measured with certain precision We are going to give here some examples concerning mainly their use in fundamental and applied sciences. For further details the readers are referred to the respective references.

3.I. Estimating the Equivalent Electron Concentration and N_e (h) Profile of Electron Concentration in the Day Region D by Absorption Measurements . In D region, it is as a rule considered that profile $\nu \equiv \nu_{eff}$ (h) is well-known and shows the following exponential distribution (cf. /4,5,89/):

$$(12)\ \nu \approx \nu_{en} [m s^{-1}] \approx (6,7 \pm 0,4).10^5 P_n / P_a \approx \nu_0 \exp(h - h_0)$$

where: P_n is atmospheric pressure; ν_0 is ν on the height h_0.

From the well-known profile ν_{eff}(h) and the measured absorption L as early as in /2/, the parameter of equivalent concentration N_{ae} was proposed. The latter is obtained from the integral of nondeviating absorption by the theorem of the mean value of two subintegral functions:

$$(13)\ N_{ae} = \frac{L}{CG}; \quad C = \frac{4\pi e}{mc}; \quad G = \int_{h_0}^{h_n} \frac{\nu dh}{\nu^2 + (\omega_i \pm \omega_L)^2}$$

We further proved - /4,5/ that N_{ae} is close to the mean value of the electron concentration of D region. For G , the following values have been obtained on the basis of the exponential height variations of :

$$(14)\ G = \frac{1}{P_1 \sqrt{(\omega_i \pm \omega_L)^2}} \left[\operatorname{arctg} \frac{\nu_0 \exp(-p_1 h_0)}{(\omega_i \pm \omega_L)} - \operatorname{arctg} \frac{\nu_0 \exp(-p_1 h_n)}{(\omega_i \pm \omega_L)} \right].$$

On the basis of N_{ae} , hundreds of studies have been conducted concerning the behaviour of the mean electron concentration and of the overall amount of electrons $N_{ge} = N_{ae}.\Delta h$ in D region during solar eruptions, solar eclipses, seasonal, cyclical and other variations in the lower and middle ionosphere - /4,5,8,23,24,25,26/ etc.

In general, N_{ae} is a characteristic parameter of the ionized condition and structure of the lower ionosphere.

At a certain ν(h) profile, the reverse problem can be raised and solved, i.e. to reduce the subintegral function N_e(h) from integral (3). This is a typical incoherent problem, a reverse one, in mathematics. It has its own solutions, however. The methodology of its complete solution with $\mu \neq$ I using numerical methods, is shown in /9/. In principle, analytical solutions to N_e(h) profile in D region with a guaranteed coefficient $\mu =$ I, can be reached, i.e. to find the profile looked for by applying the nondeviating absorption L_n. For this purpose, in /5,6, 7/ the following summary method of estimating the distribution of electron concentration in D region , has been developed and then repeatedly applied, on the basis of n ($n \geq 4$) absorption measurements using AI and A3 methods at frequencies reflected by the day E layer (in A3 this condition refers to the equivalent frequency f_i):

We select n - successive frequencies reflectable by E layer for which in a certain manner (see the further analysis) we divide the total absorption into L_n and L_d . If method A3 is used, the polygon formed by the n-reflection points of the respective n - paths, must be in a homogenous D region, for which according to the latest data, a horizontal region of 200 km can be considered. The unknown distribution of el ectron concentration N_e (h) is develop ed in Taylor order (MacLorain) which is reduced to power order:

$$(I4)\ N_e(h)=\sum_{k=1}^{n} a_k X^k=\sum_{k=1}^{n}\frac{N^{(k)}(0)}{k!}h^k$$

The coefficients a_k from line (I4) are determined by the n - absorption measurements, each measurement being presented in the type:

$$(I5)\ L_{nj}=\sum_{k=1}^{n} a_k J_{jk} \quad ; a_k=\frac{4\pi e^2}{mc}\ \frac{N^{(k)}(0)}{k!}$$

where: $$J_{jk}=\sum_{m=1}^{s}(-1)^{m+1}\frac{k!\,\nu_o^{2m+1}}{K_j p_1^{k+1}}\left\{\frac{1}{(2m-1)^{k+1}}\left[\frac{(p_1 h_n)^k}{k!(2m-1)}+\frac{(p_1 h_n)^{k-1}}{(k-1)!(2m-1)^2}+\frac{(p_1 h_n)^{k-2}}{(k-2)!(2m-1)^3}+\cdots+\frac{1}{0!(2m-1)^{k+1}}\right]e^{-(2m-1)p_1 h_n}\right\}$$

$$K_j=(\omega_j+\omega_L)^2$$

For ionospheric parts over I00 km, the distribution N_e (h) is as a rule obtained on a mass scale from ground ion-soundings, from incoherent scatter radars, by rocket sounding and in some other ways. The world-wide network of ion-soundings, its comparatively long exploitation (for over half a century already), enables us to consider electron concentration between I00 km and the height h_mF of concentration $N_m F$, a well-known and easily accessible parameter to measure. Thus, at a certain profile N_e (h) from the data of the multifrequency present-day measurements according to AI or A3 methods or the method developed in [28], the other subintegral component of absorption, i.e. ... ν ... can be estimated. Here in brief we are going to reproduce the basic ideas and dependencies on this latest method of finding ν(h) by using multi-frequency absorption measurements-[28]. For this purpose, we proceed from expression (4) where h_n is the boundary height, conditionally dividing the deviating from the nondeviating absorption. We are further going to proceed from the experimental formulation of absorption measurements of j frequencies in the neighbourhood of a usual or a digital ion sounding, In the second variant, digital ionsounding can beused for absorption measurements of j frequencies (where j reaches 3 - 4 at a standard I5 min ion-sounding regime or 6 - at half an hour sounding interval). If a special additional device is used to the ion-sounding itself, with serious measured taken to average the constant amplitude changes, an essential part of which have already been considered in the preceding part, the number of j frequencies can be increased.

For the sake of convenience of the analysis to follow, reflection of radio signals from F region, are proposed.

The first problem of using expression (3) is the division of absorption into deviating and nondeviating parts. For this purpose, the directions in [4,5] and in some other publications can be used or the procedure should be as follows: From the ionograms, profile N (h) is estimated, and for each frequency the respective difference $h'_i - h_i$ is known. For each measurable frequency f_i according to the data of distribution N_e (h), the operating heights for a group of frequencies $f < f_i$ are built up. For this purpose k - interval is selected as well as k - suitably selected frequencies: $f_1, f_2, f_3, f_4, \dots f_k < f_i$. The difference $h'_i - h_i$ is known from the ionogram. For each of the frequencies $f_1, f_2, \dots, f_k$, we estimate the respective electron concentrations: $N_1, N_2, \dots, N_k$ by using the well-known expression

$$(16)\ N_e\,[cm^{-3}] = 1{,}24.10^4 f^2\,[MHz^2];\ N_e\,[m^{-3}] = 1{,}24.10^{-10} f^2\,[MHz^2]$$

From the profile of electron concentration N_e (h), the corresponding heights: $h_1(N_1); h_2(N_2), \dots, h_k(N_k)$ are found. For the measurable frequency, we build the profile of the adduced /operating, virtual/ heights h', obtained for each point $N_1, N_2, \dots, N_k$ from the measurable frequency f_i. This equivalent profile for the radio beam delay with a frequency f_i in the ionospheric part below the reflection height h_i is built according to the well-known expression (see for example [21]) of the change of group velocity in respect to that of light in the ionospheric plasma:

$$(17)\ h'_1(f_i) = h_0 + \int_{h_0}^{h_1} n'(\omega_i, N)\,dh\ ,$$

$$(18)\ h'_2(f_i) = h_0 + \int_{h_e}^{h_2} n'(\omega_i, N)\,dh\ ,$$

$$(19)\ h'_k(f_i) = h_0 + \int_{h_0}^{h_k} n'(\omega_i, N)\,dh\ ,$$

$$(20)\ h'_i(f_i) = h_0 + \int_{h_0}^{h_i} n'(\omega_i, N)\,dh\ .$$

We thus obtain heights $h'_1, h'_2, \dots h'_k$ for the respective real heights $h_1, h_2, \dots, h_k$. Fig.4 illustrates in a diagram a similar height distribution. In order to estimate the boundary between the nondeviating and deviating absorption through constructions for each working frequency we have measured, the procedure is the following:

In dependences /17/, /18/,, /19/, /20/, $n'(\omega, N)$ is used to designate the group refraction coefficient .

A certain relative value is given to L_d for the given measurable frequency in respect to the total absorption, at which L_d will be considered to be negligible, e.g.

$$(21)\ L_d = (\ell\,\%).L = 0{,}01.\ell.L$$

Reasonable values of ℓ are of the order 1 ÷ 2 % bearing in mind the errors in absorption measurements and those in estimating $h'-h$. Then from the profiles $\nu(h)$ published in [23] according to the International Reference Ionosphere IRI - 79 and the curves available $h'(f_i)$ and $h(f)$ for the measurable frequecy, the height h_n is estimated for which condition /21/ has been fulfilled. The deviating absorption for each frequency begins with height $h_n(f)$.

If we have a total of j - measurable radio frequencies, then for any of the frequencies from the line $f_1, f_2, \dots, f_i, \dots, f_j$, we can write the following dependence:

$$(22)\ L_i = L_{n,i-1}\left(\frac{f_{i-1}}{f_i}\right) + \frac{K}{f_i^2}\int_{h_{i-1}}^{h_i} N\nu\, dh$$

where $K = m/\pi e c$, and in the conclusion in (22) it has been taken into consideration that in case of reflection in F region, we have:

At $j \geq 3$ as has been assumed in the majority of methods of finding N (h) profiles - see for example [3], the comparatively slight increases of N can be represented linearly, i.e.

$$(23)\ N(h_i) = N_i = N(h_{i-1}) + b(h_i - h_{i-1}) = N_{i-1} + b(h_i - h_i$$

$$(24)\ N(h) = N_{i-1} + b(h - h_{i-1})$$

The changes of $\nu(h)$ in regions E, the intermediate E - F region and the beginning of F region at $j \geq 3$ can also be represented in two reasonable approximations (compare the data for $\nu(h)$ in [23]) with exponential approximation:

$$(25)\ \nu_i = \nu_{i-1}\exp[-p(h_i - h_{i-1})]\ ,$$

$$(26)\ \nu(h) = \nu_{i-1}\exp[-p(h - h_{i-1})]$$

or with linear approximation:

$$(27)\ \nu_i = \nu_{i-1} + g(h_i - h_{i-1})$$

$$(28)\ \nu_h = \nu_{i-1} + g(h - h_{i-1})$$

If we use approximations (24) and (26), for we finally obtain:

$$(29)\ L_i = L_{n,i-1}\left(\frac{f_{i-1}}{f_i}\right)^2 + \frac{K\nu_0}{p f_i^2}\Big\{N_{i-1}\big[\exp(-p h_{i-1}) - \exp(-p h_i)\big] + b\Big[\Big(h_{i-1} + \frac{1}{p}\Big)\exp(-p h_{i-1}) - \Big(h_i + \frac{1}{p}\Big)\exp(-p h_i)\Big]\Big\} + \frac{\nu_i}{c}(h'_i - h_i)$$

In (29) averaging of $\overline{\nu_i}$ in the last member on the righ t-hand side takes place in the height region (h_n, h_i), i.e.:

$$(30)\ \overline{\nu_i} = \frac{\nu_n}{p(h_i - h_n)}\left[\exp(-ph_n) - \exp(-ph_i)\right]$$

In the second case, at linear increases of $\nu(h)$, i.e. when we use (24) and (28) in (22), we obtain:

$$(31)\ L_i = L_{i-1}\left(\frac{f_{i-1}}{f_i}\right)^2 + K\frac{N_{i-1}\nu_{i-1}}{f_i^2}(h_i - h_{i-1}) + \\ + \frac{K}{2f_i^2}(gN_{i-1} + \beta\nu_{i-1})(h_i^2 - h_{i-1}^2) + \\ + \frac{K}{3f_i^2}\beta g(h_i^3 - h_{i-1}^3) + \frac{\overline{\nu_i}}{c}(h_i' - h_i)$$

Expression (30) represents most adequately the curves shown in (23) for $\nu(h)$:

$$(32)\ \nu(h) = \nu_{ei} + \nu_{en}$$

where ν_{ei} is the frequency of collisions between elec-tons and ions, and ν_{en} - is the one between electrons and neutral particles.

From (29) or better from approximation (31), where $L_i; L_{i-1}; f_i; f_{i-1}; N_i; N_{i-1}; \nu_{i-1}; h_i; h_{i-1}; \beta; h_i'; h_{i-1}'$ and K are known, we can calculate the coefficient p from (29) or factor g from (31). Thus, the new value of $\overline{\nu_i}$ from (25) or (27) is known. For this purpose, it is necessary, in addition to profiles N (h) and N (h') which are known from the data of the ionospheric station, to have all data about the measured $L_1, L_2, \ldots, L_i, \ldots L_j$. The basis for finding distribution $\nu(h)$ is the measured absorption of the first frequency, i.e.:

$$(33)\ L_1 = \frac{K}{f_1^2}\int_{h_0}^{h_1} N\nu\,dh + \frac{\overline{\nu_1}}{c}(h_1' - h)$$

where: $\overline{\nu_1}$ refers to the region (h_0, h_1), and h_0 is the beginning of the ionosphere, determined by phase-height measurements - see /4/ or by N (h) profiles. Using the th eorem of the integral - average of two subintegral functions for L_{n1}, we have:

$$(34)\ L_{n1} = \frac{K}{f_1^2}\overline{\overline{N}}.\overline{\overline{\nu}}.$$

According to the studies of the relations between the integral average of two subintegral functions and the usual mean value, conducted in /4/, in absorption measurements in the first approximation, we can use: $\overline{\overline{N}} \approx \overline{N}; \overline{\overline{\nu}} \approx \overline{\nu}$. This approximation is precise enough at a small interval (h_0, h_1) and at exponential or linear distribution of the values considered. In such case:

$$(35)\ \overline{\nu_1} = \frac{L_{n1} f_1^2}{K\,\overline{N_1}}$$

This $\overline{\nu_1}$ refers to the average height in the interval (h_0, h_1) which is designated by $\overline{h_1}$. Its value should be approximately equal to value $\overline{\nu_1}$ in the expression for deviating absorption in the right-hand side of (33). If the two mean values of the collision frequency are not equal, we operate with the average between them correcting the proportion between the deviating and nondeviating absorptions. We compare $\bar{\nu}_1(h_1)$ with the respective $\nu_1(\bar{h}_1)$ from the distribution according to IRI - see [23]. If

$$(36)\ \nu_1(\bar{h}_1) \approx \bar{\nu}_1(\bar{h}_1)$$

with the precision of the basorption measurement, it can be considered that profile $\nu(h)$ obtained by absorption measurements is adequate to the real one. If $\nu_1(\bar{h}_1) \lessgtr \bar{\nu}_1(\bar{h}_1)$, then it follows in the respective proportion:

$$(37)\ \nu_n(h_m) : \nu_n'(h_n) = \nu_1(\bar{h}_1) : \bar{\nu}_1(\bar{h}_1)$$

that we should estimate a new corrected initial value and repeat all calculations. Thus, after a few iterations we obtain the real value of $\nu_n(h_n)$ on the basis of which the whole profile is calculated. This is done when from $\bar{\nu}_1(h)$ (which afer certain iterations is reduced to an adequate value) we calculate ν_1 by expressions (26) and (28). Besides, for the small region in interval $(\bar{h}_1, h_1)$ we can use coefficient p in formula (25) or g in formula (27) according to the respective approximations of profiles $\nu(h)$ in (27), in accordance with IRI - 79. That means that only in the first region (h_0, h_1), the shape of curves $\nu(h)$ is assumed to coincide with that of IRI - 79 but is shifted depending on the proportion of $\bar{\nu}_1(\bar{h}_1)$ with $\nu(\bar{h}_1)$. Thus, the profile from IRI in this region is perfected by shifting it to the left or right until the values measured, coincide. In all other regions: 2,3,...., i,........,j, we correct both the shape and the absolute values of profile $\nu(h)$, obtaining $\nu_2(h_2)$; $\nu_3(h)$ etc. up to $\nu_j(h_j)$ according to dependences. (29) or (31), from which we find factors p or g, and then we operate with formulae (25) or (27).

The indicated procedure makes possible to obtain profile $\nu(h)$ by several absorption measurements. It is especially effective in digital ion-soundings which can considerably increase the number of measured frequencies j, thus increasing the precision of measurements, as well as the number of points on profile $\nu(h)$, with which this vertical distribution is better described.

The presence of vertical profiles $\nu(h)$ makes possible the solution of problems of applied nature in telecommunications, telecontrol of space objects, design of radio lines and networks etc. In addition to that, under certain conditions, from profile $\nu(h)$ the vertical distribution of electron temperature Te (h) can be estimated. In this way, parallel ground methods are created to support the direct methods for estimating plasma parameters in the ionosphere and good possibilities to combine ground satellite and rocket complex measurements similar to the optimization diagrams.

The practical conclusions from absorption measurements are in the following directions: a) Estimating the intensity of field E_R for different transmitters, frequencies, powers and distances; b) Making use of the data obtained in (a) for designing radio paths and radio networks. According to CCIR, particularly difficult to estimate are the night radio networks of medium- and short-wave transmitters, for which there are not sufficient data available from experiments for absorption L. Making use of these data about the absorption L, we can determine the level and quality of radio communications between two stations. We can estimate the fading boundary between the ground and ionospheric-reflected waves (in which area the radio service has deteriorated). We can also determine the interference zone of ionospheric waves of synchronously operating transmitters in the radio network, and solve important problems of practical significance.

In radio broadcasting, the term "standardized field" is used for these problems of applied science. This is the intensity of the field created by an aerial with emitted power of 1 kw within 50 % of the time for operation. For this standardized field F (50), we have:

(38) $F(50) = 480\,\rho/\ell$ - for medium waves,

(39) $F(50) = 500\,\rho/\ell$ - for long waves,

where ρ is determined by dependence (2) from L. According to the known dependences of radiowave propagation for another emitted power P, we have a bigger or a smaller field than F (50) multiplied by $\sqrt{P}$. It has been assumed to express F (50) in db above level $1\,\mu V m^{-1}$.

Here in the end are some basic data concerning absorption changes:

a) Diurnal course

(40) $L = L_o \cos^n \alpha$

The values of n according to [26] are shown in Fig.5.

b) The value L_o changes almost linearly with solar activity (depending on the equivalent number of solar spots R). Fig.6 shows L_o estimated by f_{min} from R according to [26].

Acknowledgement: I should like to express my gratitude for this initiative to Prof.Dr.Sandro Radicella, for his experience of many years in measurements according to A3 method, - to Prof.G.Nestorov, and for the overall cooperation - to M.K.Serafimova and E.N.Serafimova.

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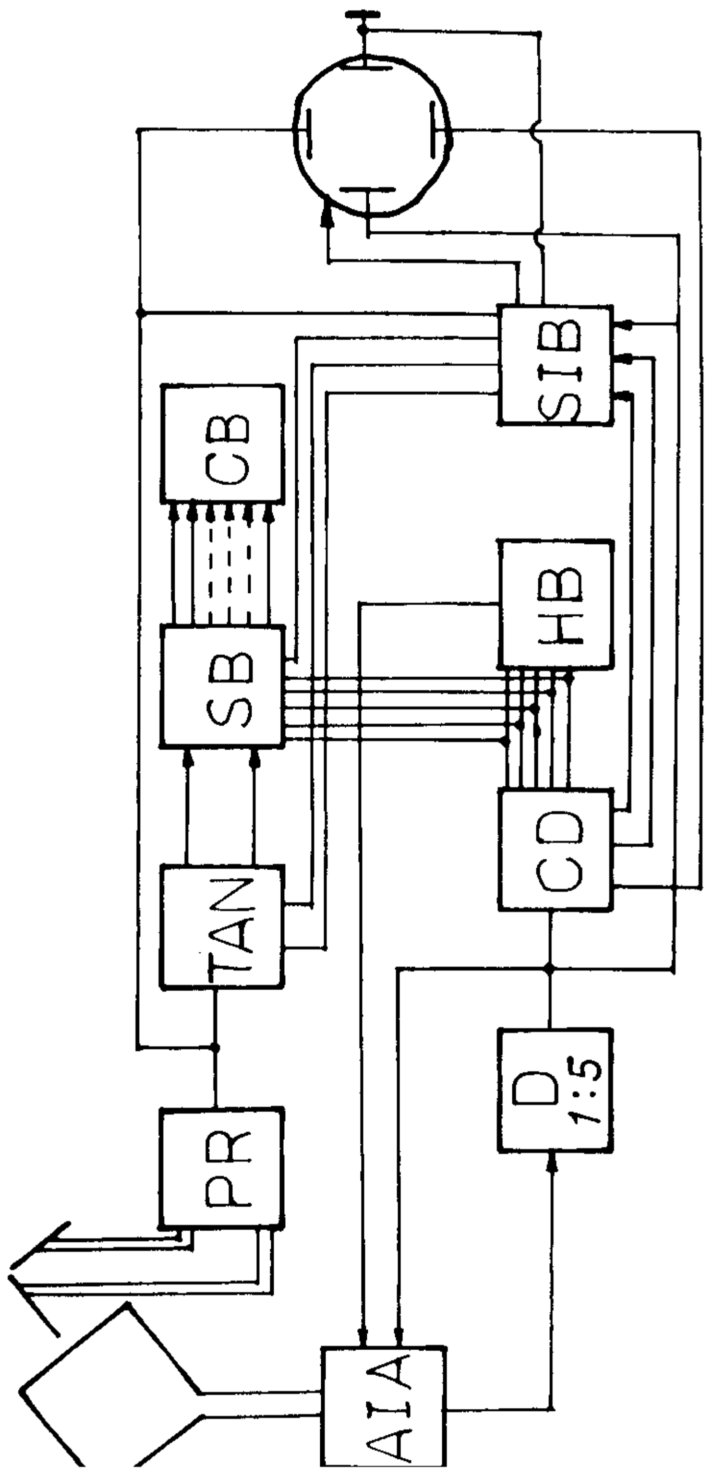


fig. 1

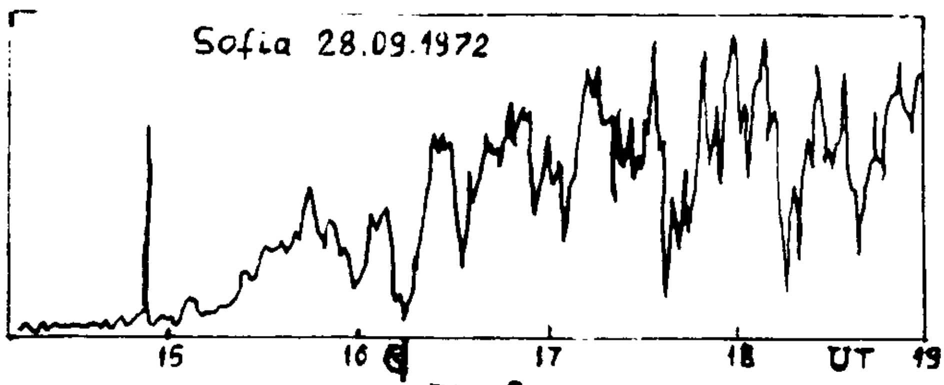
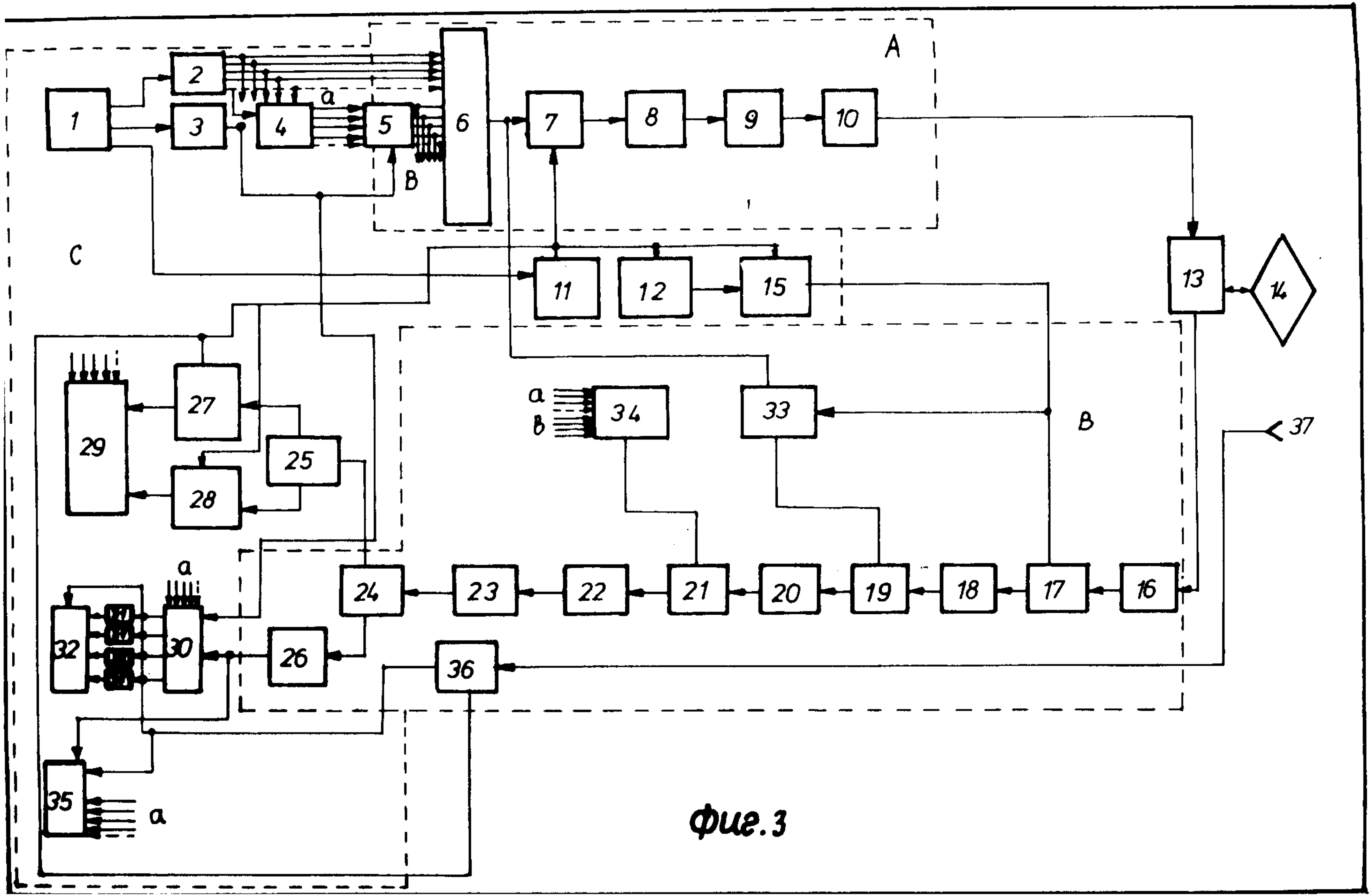


Fig. 2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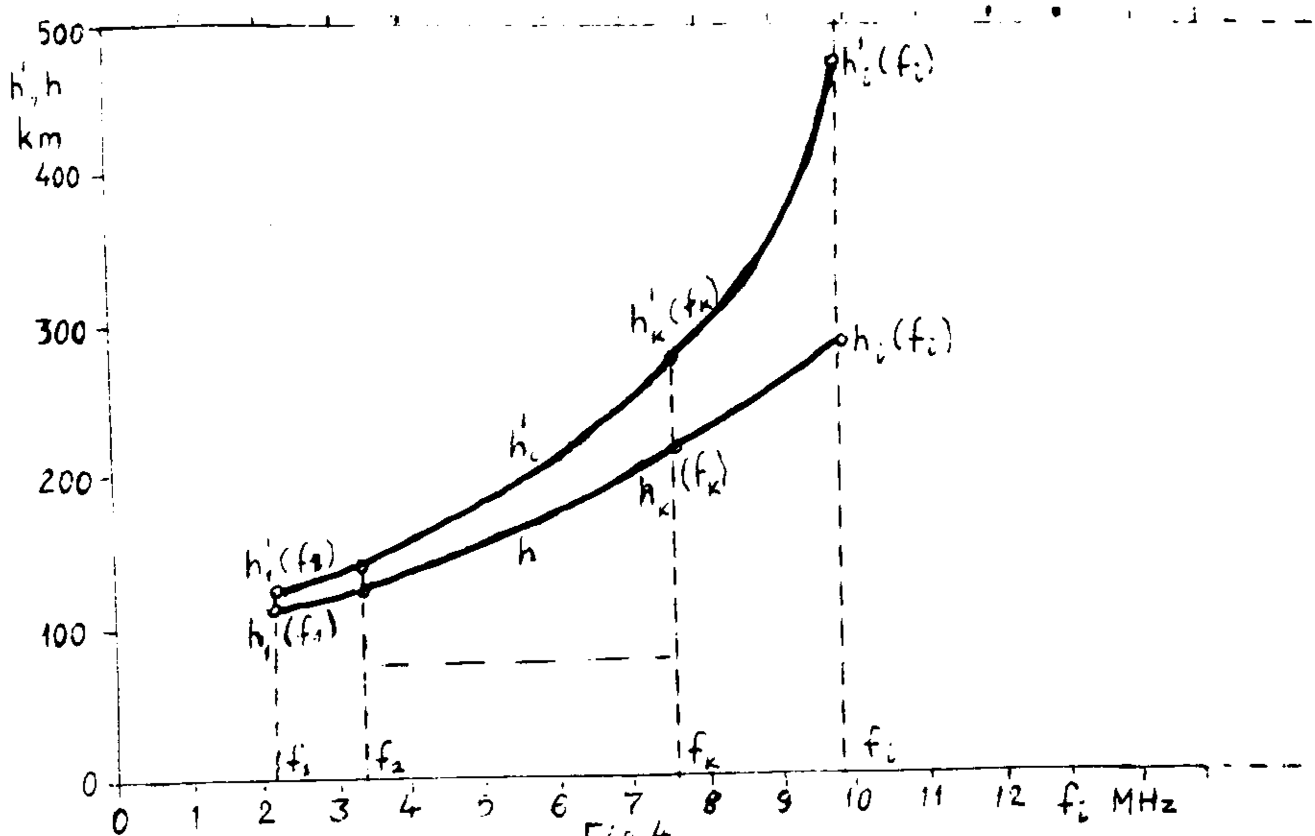
Фиг.3



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0 1 2 3 4 5 6 7 8 9 10 11 12
f MHz
h'(f)
h

Fig.4

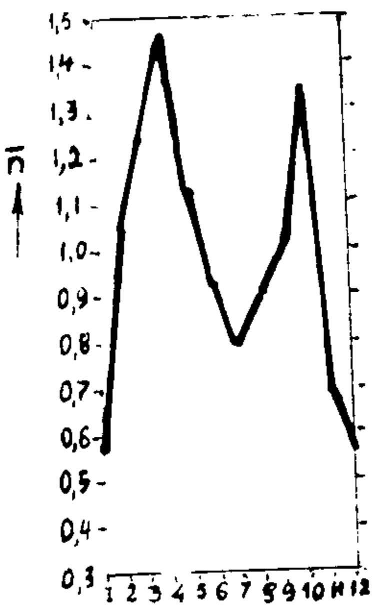

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Fig.5

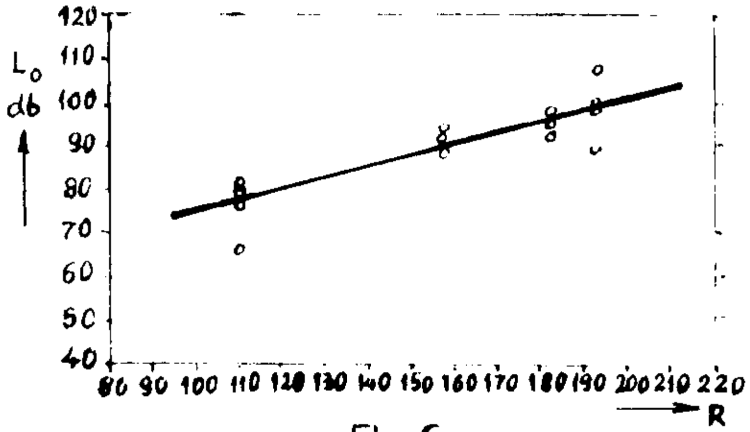

Fig. 6