CERTAIN EFFECTS WHICH TAKE PLACE WHEN A RADIO WAVE PASSES THROUGH THE REGION OF AN EXPLOSION

V. A. Vel'min, V. F. Korets,
Yu. A. Medvedev, and B. M. Stepanov

Certain nonstationary effects taking place during the passage of radio waves through a region in which an explosive charge has been detonated are described and interpreted.

The interaction of radio waves with the region of an explosion is of interest in view of the fact that a study of this process may provide useful information regarding the physical processes taking place in the inner regions of an explosion, such as are inaccessible to all other methods. Electromagnetic probing has an undoubted advantage over other probing methods in that, being essentially active, it does not introduce any serious perturbations during the measurements (weak-field conditions).

The interaction of centimeter radio waves with an explosion was studied in [1], and it was shown that a spherical shock wave was opaque if its velocity exceeded 2.4 km/sec. As the velocity of the shock wave diminished it became more and more transparent. At a certain instant of time, explosion products evidently appeared, and the interaction between the radio waves and the region of the explosion became more complicated; apart from purely diffraction effects, such as occurred when the shock wave was ideally conducting, the direct passage of the radio waves through the explosion products started exerting its own influence, and this gave rise to the problem of determining the relative parts played by these respective effects (i.e., diffraction and transmission) in the interaction of the radio waves with the explosion products. Thus, if an explosion is irradiated with a beam of radio waves of limited cross section, and a finite (small) number of Fresnel zones fall in the cross section of the beam at the point of the explosion, then, as the explosion region expands, the central Fresnel zones will successively become covered, leading to oscillations in the flow of energy at the receiving point, the frequency of the oscillations being determined by the rate at which the Fresnel zones are overlapped. An approximate estimate shows that, when a charge of 10-200 g is detonated, the effective width of the directional diagram is 10-20°; for distances of 2-3 m between the antennae, a diffraction effect may appear in the case of millimeter waves.

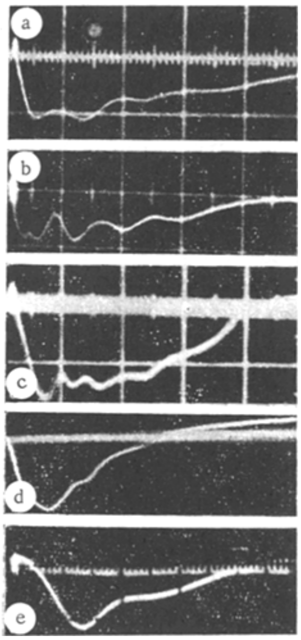

Fig. 1

The foregoing considerations served as a basis for the millimeter-wave experiments which we shall now be describing.

Description of the Experiment. Charges of the TG 50/50 type 10-52 g in weight were detonated halfway between centered horn-lens antennae working at a wavelength of $\lambda = 8$ mm. The width of the directional diagram of both the transmitting and receiving antennae was 16° (i.e., width at the half-power level); the distance between the leading edges of the horn-lens antennae was $2R = 230$ cm. The signal from the receiving anteanna was subjected to square-law detection and two-stage amplification, and recorded on an SI-33 oscillograph. The sweep

Moscow. Translated from Zhurnal Prikladnoi Mekhaniki i Tekhnicheskoi Fiziki, No. 2, pp. 136-139, March-April, 1971. Original article submitted August 4, 1970.

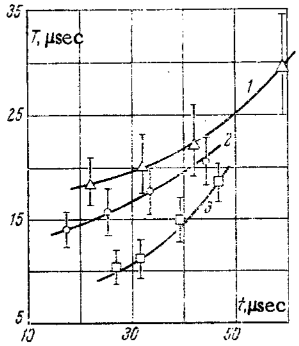

Fig. 2

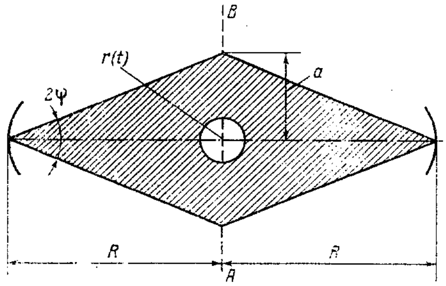

Fig. 3

was started at the instant at which the detonation wave emerged on the surface of the charge. Figure 1a, b, c shows some typical oscillograms of the envelope of the signal passing through the region of the explosion for charges of mass $m_1 = 10$ g, $m_2 = 25$ g, and $m_3 = 52$ g, respectively. Along the vertical axis we have plotted a quantity proportional to the intensity of the field at the point of recording. The upper line corresponds to the free passage of the signal. Time is plotted along the horizontal axis. The sweep period is 125 μ sec.

We see from Fig. 1a, b, and c that the level of the transmitted signal falls rapidly in the first 10-20 μ sec (depending on the mass of the charge), and then is slowly restored. Apart from the smooth signal, the oscillograms clearly show certain oscillations, the period of these increasing with time.

The period of the oscillations (averaged over a large number of oscillograms) is shown in Fig. 2 as a function of time (curves 1, 2, and 3 respectively corresponds to masses of m = 10, 25 and 52 g). The periods of the oscillations were determined as the times between two successive minima on the oscillogram. The period so measured referred to the moment of time $t = \frac{1}{2}(t_k + t_{k+1})$, where t_k is the moment of reaching the k-th and t_{k+1} the moment of reaching the k+ 1-th minimum. We see from Fig. 2 that the periods of the oscillations increase monotonically with time and diminish on increasing the mass of the charge.

Figure 1d shows an oscillogram of the envelope of a signal passing through the region of an explosion for a charge of m = 15 g (seep time 250 μsec). The experiment was carried out under the conditions already indicated, except that the width of the directional diagram of the antennae (at half power) was about 4°. On the whole, the form of the signal is the same as in Fig. 1a, although in the present case there are no oscillations. Figure 1c shows an oscillogram obtained by the detonation of a charge of mass 52 g, using radio waves in the centimeter range (λ = 3.2 cm) with the previous geometry and a directional diagram of width 10°. The sweep period was 125 μsec.

By comparing with the analogous oscillogram (Fig. 1c) obtained under approximately the same conditons but using millimeter waves, we see that, for constant experimental conditions, the oscillations vanish as wavelength increases.

Discussion of Results. We readily see from the oscillograms of Fig. 1 that, in the total signal, the oscillations (where these exist, e.g., Fig. 1a, b, and c) are practically additively superimposed on the main signal (that in which the oscillations are absent, as in Fig. 1e); the main signal represents a reduction in the level of the signal at the initial instant after the explosion, and its subsequent recovery.

The first (falling) section of the oscillogram corresponds to the period of time in which the region of the explosion is opaque to radio waves and the expanding explosion cloud gradually covers the effective cross section of the radio beam; the second section corresponds to the period of time in which the region of the explosion gradually becomes transparent to radio waves.

Subsequently we shall devote no further analysis to this signal but simply consider the oscillatory component.

The experimentally-observed oscillations in the received millimeter-wave signal, the increase in the oscillation period with time for a charge of specified mass, the vanishing of the oscillations on increasing the wavelength (for the same directional diagram), and also the vanishing of the oscillations on contracting the directional diagram at constant wavelength λ = 8 mm indicate that these oscillations owe their origin to diffraction effects arising as a result of the fact that the explosion overlaps the region of space essential to the propagation of radio waves.

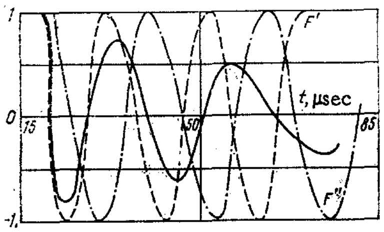

Fig. 4

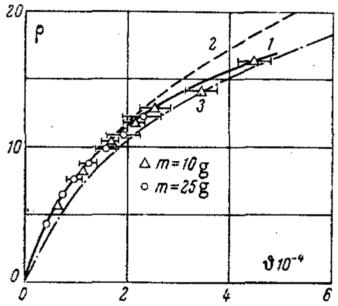

Fig. 5

For a complete quantitative description of the observed diffraction effects under the conditions of the experiments in question, we must allow for not only the amplitude but also the phase characteristics of the directional diagram of the transmitting and receiving antennae, and also the electrodynamic parameters of the region of the explosion.

However, if we are simply required to examine the time characteristics of the effects observed, the following simplified treatment is adequate. We shall consider that the directional transmitting and receiving antennae actually employed may be approximately replaced by two isotropic antennae (Fig. 3), supplemented by an opaque screen AB, passing through the center of the explosion in a plane perpendicular to the line joining the antennae, and having a circular opening with its center superposed on the center of the explosion, while the radius of the opening a equals the effective radius of the bright spot created by the real antenna $a \approx R\psi$.

If we further assume that the oscillations are associated with purely diffraction effects at a certain surface with a radius equal to the effective boundary of the explosion $r^*(t)$, and are additively superimposed on the main signal passing directly through the region of the explosion, then, since we are simply interested in the time characteristics of the oscillations (the time dependence of the oscillation period), in the analysis we may replace the semitransparent region of the explosion by an opaque disc of radius $r^*(t)$.

Using the stationary-phase method ([2], p. 53), we easily find that, in this case, the field at the receiving point will be characterized by a nonstationary diffraction factor

$$F(t) = \cos\,[2\pi\,(\lambda R)^{-1}\,(a^2 - r^{*2}(t))] \qquad (1)$$

the time dependence of which has as many minima as there are Fresnel zones within the radius a

$$n = 2R\psi^2/\lambda \quad (n = \text{number of minima})$$

For example, in the experiments just described, $2R = 230$ cm, $\lambda = 0.8$ cm, $2\psi = 16°$, $n = 5$, which coincides with the number of distinguishable maxima in frames a, b, and c (Fig. 1).

For $\lambda = 0.8$ cm and $2\psi = 4°$, $n = 0.4$, and for $\lambda = 3.2$ cm and $2\psi = 10°$, $n = 0.7$, which qualitatively explains the absence of oscillations in the corresponding frames (Fig. 1d and e). On the basis of this model the oscillation period is given by the relation

$$T(t) = \lambda\,Ra^{-2}\,t\,[1 - a^{-2}\,r^{*2}(t)]^{-1}$$

This relationship is supported by the experimental data of Fig. 2.

The instants of time t_k corresponding to the k-th minimum of the diffraction factor are determined by the condition

$$r^*(t_k) = \dot{R}\,(\psi - {}^1\!/_2 k\lambda / R)^{1/2} \qquad (2)$$

Figure 4 illustrates the oscillating component $f(t)$ of the signal shown in the oscillogram of Fig. 1a. The curve is plotted as the difference between the total curve and the same curve averaged over a period of time greater than the period of the oscillations. The same figure illustrates the time dependences of the diffraction factor calculated from Eq. (1) for the relationship r'(t), which determines the law of expansion of the leading edge of the shock wave in time (curve F'(t)) and the relationship r"(t), which determines the law of expansion of the leading edge of the explosion products (curve F"(t)) for a charge of m = 10 g. We used the empirical relationships of [4] as r'(t) and r"(t).

We see that the zeros, maxima, and minima of the curve $f(t)$ lie between the analogous points of the curves F'(t) and F"(t); at the initial instants of time the characteristic points of $f(t)$ lie closer to the corresponding points of F'(t), and later on closer to those of F"(t), which indicates that the radius of the effective surface over which the wave is diffracted first coincides with r'(t) and later moves away from it and approaches r"(t).

We note that in the present case not all the parameters determining the problem are of a purely gas-dynamic nature; apart from the initial radius $r_0 \sim m^{1/3}$ kg, there is still the size of the Fresnel zone, which is independent of the explosion characteristics, so that the results of our present experiments (the dependence of the oscillation period on the parameters) cannot be expressed in automodel form.

Equation (2) enables us to calculate the radius r* of the surface over which diffraction occurs at the instants of time t_k (R, ψ, λ, k are given, t_k are measured on the oscillogram).

This relationship (based on the results of a large number of experiments with different charge masses) is illustrated in Fig. 5 in coordinates of $\rho = r^*/r_0$, $\nu = tm^{-1/3}$ (the dimensions of ϑ are sec · $kg^{-1/3}$). Also in the same variables this figure illustrates the time dependence of the radii of the leading edge of the shock wave and the leading edge of the explosion products (curve 1 – r^*/r_0, curve 2 – r'/r_0, curve 3 – r''/r_0).

At the initial instants of time (strong shock wave) the surface r = r* coincides with the leading edge of the shock wave, and later with that of the explosion products.

Evidently the $r^*(\vartheta)$ relationship is determined by the time dependence of the state of ionization in the shock-wave/explosion products layer.

Thus, from the recorded time dependence of the oscillation period we may determine the time development of the geometrical dimensions of the region embraced by the explosion. Since in a number of cases the time dependence of the radius is completely determined by the parameter $\xi = E/\rho_0$ (E is the energy of the explosion, ρ_0 is the unperturbed gas density), this parameter may be determined from the recorded time dependences of the oscillation period.

For example, in the case of a strong spherical shock wave described by the Sedov formula, we obtain the following expression for the parameter ξ averaged with respect to all the observed oscillation periods

$$\xi = \lambda R^4 / 2\psi^2 \sum_{k=1}^{n} t_k^{-2} (\psi - k\lambda / 2R)^{5/2}$$

We also note on the basis of the oscillograms presented that for $\rho > 4$ the flow of energy to the receiving antenna associated with the diffraction mechanism of propagation amounts to ~10-30% of the flow passing directly through the region of the explosion.

LITERATURE CITED

1. V. A. Vel'min Yu. A. Medvedev, and B. M. Stepanov, "Radio echo from the region of an explosion," ZhÉTF Pis. Red., 7, No. 12, 455 (1968).
2. E. L. Feinberg, Propagation of Radio Waves Along the Earth's Surface [in Russian], Izd. AN SSSR, Moscow (1961).
3. V. V. Adushkin, "Formation of a shock wave and divergence of explosion products in air," Zh. Prikl. Mekhan. i Tekh. Fiz., No. 5, 107 (1963).