RADIO ECHO FROM AN EXPLOSION REGION

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The question of the singularities of centimeter-wave radio reflections from an explosion region has many practical applications, and is also of interest from a purely physical standpoint. On the one hand, an experimental study is expected to reveal a number of physical effects occurring when radio waves interact with a moving body having either a diffuse or a sharp boundary and having material parameters that vary in time and to continuously through a spectrum of states ranging from those of a conductor to those of a dielectric. On the other hand, there is a possibility of determining the parameters of the phenomenon from the characteristics of the radio reflections.

The first question is how long a strong shock wave continues to act like an ideally reflecting body for radio emission. A tentative rough estimate indicates that this occurs when the temperature of the shock-wave front is on the order of several thousand degrees, but an exact estimate is made difficult by the scarcity of reliable data on the ionization processes occurring at these temperatures. We consequently performed the experiments described below with spherical shock waves produced by explosion of condensed explosives.

We used in the experiments spherical charges of type TG 50/50 (50% TNT, 50% hexogen) with mass 52 g, detonated electrically by a capsule placed in their center. The explosion region was constantly exposed to a beam of 3.2-cm wavelength from a parabolic antenna having a directivity pattern ~10° wide and located 113 cm from the center of the explosion. The same antenna received the signal reflected back from the explosion region. This signal was detected, passed through a two-stage amplifier, and recorded with an S1-33 oscilloscope. On the whole the employed circuitry does not differ in principle from the balanced circuit described in [1]. We note that it is practically impossible to balance out the measurement circuit completely, so that the reflected signal is superimposed on the strongly attenuated direct signal (the latter amounting to as much as 15 - 20% of the amplitude of the reflected signal), and the envelope of the summary signal is plotted.

Figure 1a shows a typical oscillogram of the process (sweep duration 125 μsec), from which it is seen that the recorded signal contains a smooth constant-sign component with a maximum at ≃27 μsec (main signal) and an oscillating component having a characteristic period ~7 μsec, whose amplitude increases somewhat in time. This is seen more clearly from a processed copy of the same oscillogram (Fig. 1b). The amplitude of the main signal increases during the first 27 μsec following the explosion, because the shock wave has at that time a velocity (4.5 - 3) km/sec, which is sufficient to produce strong ionization on the front, so that the shock-wave surface can be regarded as ideally reflecting. The effective reflection surface increases with the radius r of the strong shock wave. It can be readily shown that in the geometry of the present experiments the effective surface is proportional to $r^2(t)$ or, using Sedov's relation for a strong explosion, proportional to $t^{4/5}$, i.e., its growth is

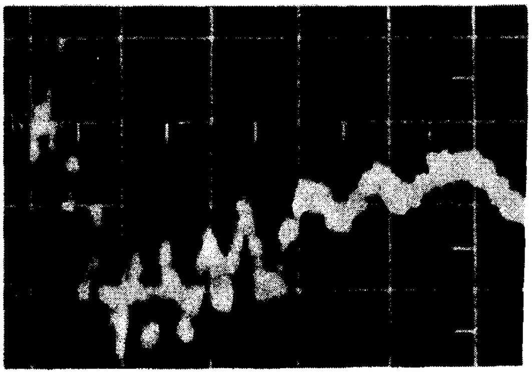

Fig. 1a

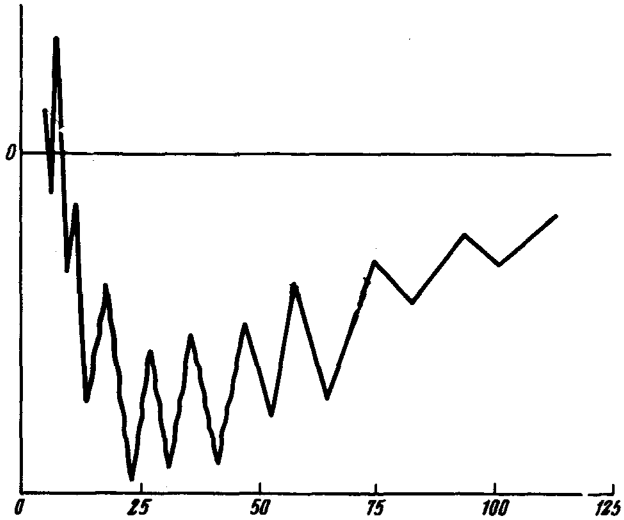

Fig. 1b

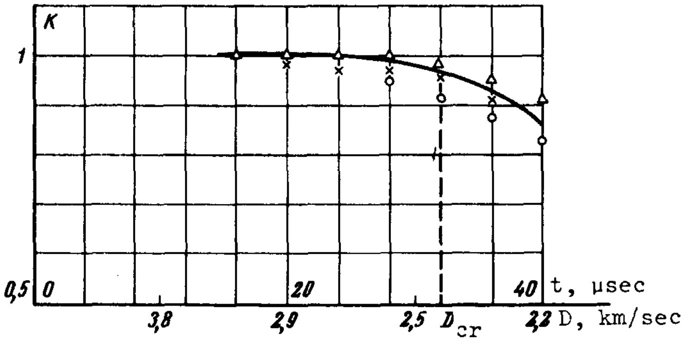

Fig. 2

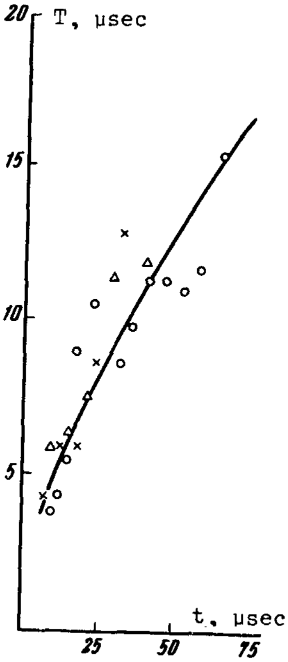

Fig. 3

practically linear, as in Fig. 1. With decreasing shock-wave velocity, the temperature decreases, the conductivity on the front decreases (much more rapidly), and the coefficient of reflection of the radio waves from the front decreases, thus explaining the maximum on the oscillogram, followed by a decrease of the reflected energy.

In light of the foregoing, we determined from the obtained data the time dependence of the effective coefficient K(t) of reflection of the radio waves from the explosion shock wave, using the relation

$$K(t) = a \frac{I(t)}{r^2(t)},$$

where the time dependence of the energy flux I(t) to the antenna was determined from Fig. 1b and from other processed oscillograms, and the radius of the shock-wave front was calculated for the employed explosive charge from the empirical relations of [2], which further measurements had shown to describe satisfactorily the conditions of our experiments; α is a constant determined by the condition $K \to 1$ as $t \to 0$. The results are shown in Fig. 2, which also indicates the values of the shock-wave front velocity D, calculated from the data of [2]. We see that $K \simeq 1$ at $t < 30$ μsec. Thus, the shock wave reflects 3.2-cm radio waves like an ideally conducting body so long as its velocity does not drop below $D_{cr} \simeq 2.5$ km/sec.

To explain the oscillating signal component it was assumed to be due to beats resulting from the addition of the direct and reflected signals with the Doppler-shifted frequency. Then the period of the oscillations T equals the period of the beats

$$T(t) \sim \frac{\lambda}{D(t)}, \tag{1}$$

and increases with time, owing to the decrease of the shock-wave velocity, thus explaining the observed decrease of the oscillation frequency.

Figure 3 shows the experimental T(t) plot (the oscillation period was taken to be half the sum of the periods to the left and to the right of t) 1), the interpolation formula for which is $T(t) \sim t^{\alpha}$, $\alpha = 0.61 \pm 0.08$. On the other hand, Eq. (1) and Sedov's formula yield 2) $T \sim t^{0.6}$, i.e., the T(t) dependence is in good agreement with the theory.

For $t = 40$ μsec and $D \simeq 2.2$ km/sec [2] we obtain from (1) $T \simeq 15$ μsec, as against the experimental value $T(t \simeq 40\ \mu\text{sec}) = 12$ μsec (see Fig. 3).

From the obtained shock-wave velocity D_{cr} we can determine the energy characteristics of certain high-temperature hydrodynamic phenomena.

For example, by investigating the radio reflection from the fireball produced by optic breakdown in a laser beam, in experiments similar to those of [3-5], and by recording the instant t_{cr} of cessation of radio reflection from the strong shock wave, we can determine the

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1) In Figs. 2 and 3 the data of each of the experiments are marked by different symbols.

2) The value $\alpha \simeq 0.6$ is obtained for the values of t under consideration also from the data of [2].

the laser-pulse energy E consumed in the production of the shock wave

$$E = \rho\left(\frac{5}{2} D_{cr}\right)^3 t_{cr}^3,$$

where ρ is the initial gas density.

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[3] G. A. Askar'yan, M. S. Rabinovich, M. M. Savchenko, and A. D. Smirnova, ZhETF Pis. Red. 1, No. 6, 18 (1965) [JETP Lett. 1, 162 (1965)].

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[5] G. A. Askar'yan, M. S. Rabinovich, M. M. Savchenko, and V. K. Stepanov, ibid. 5, 150 (1967) [5, 121 (1967)].

ERRATA

Article by V. A. Vel'min et al. Vol. 7, No. 12, p. 355, line 10:
Instead of "vary in time and to continuously" read "vary in time and go continuously"