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Reflection of micro-waves from earth's surface

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ABSTRACT. Interesting examples of coefficient of reflection from flat ground (aerodrome runway) have been described. These observations also indicate the satisfactory performance of the radar set installed at Dum Dum airport for meteorological purposes.

Different aspects of the occurrence of reflection phenomenon have been discussed. A review of the work done in this respect in other countries has also been made.

1. Introduction

Towards the close of World War II, detailed experiments on the measurements of reflection coefficients for S (10 cm) and X (3 cm) band micro-wave had been carried out. In the laboratory and field experiments, mostly one way C.W. path was used. Interference patterns were studied by recording field strength as functoin of distance with both receiver and transmitter heights held constant. In these experiments both horizontal and vertical polarization were used. A correlation (Burrows and Attwood 1949) has been observed between wind direction with respect to the path and the magnitude of the reflection coefficient. When the wind was blowing along the path, low values of reflection coefficient were obtained. When the wind was blowing across the path high values were observed, when it was blowing obliquely with respect to the path intermediate values were observed. This correlation suggests that the low values are due to back scattering.

An interesting example of coefficient of reflection from very flat ground is offered by radar observations. Strong and well defined mirror image of the targets are quite common due to reflection from the flat ground. When the ground based high power (250 KW) meteorological radar installed at Dum Dum airport was used to track thunderstorms, instances of specular reflections from the flat section of the runway of the airport were noticed on a number of occasions. This phenomenon had not been noticed with the medium power (30 KW) radar which had been in use at the airport for the last 4 years. The observance of this phenomenon, therefore, gives an indication of the satisfactory performance of the new radar set.

2. Theoretical considerations

Following Burrows and Attwood (1949), if E is the field strength of the direct wave, ρ the ratio of the amplitude of the reflected wave to that of the incident wave in the vicinity of the reflecting surface, then at the position of the receiver, the total field strength in the case of reinforcement is given by

$$E_{\max} = E + K\rho E \tag{1}$$

where K is a correction factor taking into account the directivity of the transmitting and receiving antennae as well as the increased path length of the reflected ray as compared to that of the direct ray. In case of phase opposition

$$E_{\min} = E - K\rho E \tag{2}$$

$$\therefore \rho' = K\rho = \left(\frac{E_{\max}}{E_{\min}} - 1\right)\left(\frac{E_{\max}}{E_{\min}} + 1\right)^{-1} \tag{3}$$

If $K=1$,

$$\rho' = \rho = \left(\frac{E_{\max}}{E_{\min}} - 1\right)\left(\frac{E_{\max}}{E_{\min}} + 1\right)^{-1} \tag{3a}$$

Thus the values of ρ can be found out from eqution (3a).

The generalised Fresnel equations (Stratton 1941) for horizontally and vertically polarised waves are

$$\rho_h\ e^{-j\phi_h} = \frac{\sin\psi - \sqrt{\varepsilon_c - \cos^2\psi}}{\sin\psi + \sqrt{\varepsilon_c - \cos^2\psi}} \tag{4a}$$

$$\rho_v\ e^{-j\phi_v} = \frac{\varepsilon_c \sin\psi - \sqrt{\varepsilon_c - \cos^2\psi}}{\varepsilon_c \sin\psi + \sqrt{\varepsilon_c - \cos^2\psi}} \tag{4b}$$

where ρ_h and ρ_v are the magnitudes of the complex reflection coefficient for the horizontally and vertically polarised waves respectively, ϕ is the phase lag of the reflected wave behind the incident wave, ψ is the angle of lag of the reflected component behind the incident component of the electric field and ε_c is the complex dielectric constant of the electric field.

The complex dielectric constant can be written as

$$\varepsilon_c = \varepsilon_r - j\varepsilon_i \tag{5}$$

where ε_r and ε_i are the real and imaginary parts of the dielectric constant respectively. ε_i can be written as

$$\varepsilon_i = 60\,\lambda\,\sigma \tag{6}$$

where λ is the wavelength of the incident radiation expressed in metres and σ is the conductivity of the dielectric medium in mhos/metre.

$$\text{Then, } \varepsilon_c = \varepsilon_r - j\,60\,\sigma\lambda \tag{7}$$

In order to obtain the value of the complex dielectric constant the absorption coefficient was directly measured. It was found that for very dry sandy ground the values of ε_r, ε_i and σ which best fitted the observational data were 24·0, 3·56 and 0·66 mhos/metre respectively.

The values of conductivity and reflectivity of different types of soil and water for different wavelengths have been measured by earlier workers (Kerr, Fishback and Goldstein 1951).

It has been seen that except for very dry ground

$$|\varepsilon_c| >> 1 \tag{8}$$

Using this approximation, equations (4a) and (4b) can therefore, be written as

$$\rho_h\ e^{-j\phi_h} = \frac{\sin\psi - \sqrt{\varepsilon_c}}{\sin\psi + \sqrt{\varepsilon_c}} \tag{9a}$$

$$\rho_v\ e^{-j\phi_v} = \frac{\sqrt{\varepsilon_c}\,.\sin\psi - 1}{\sqrt{\varepsilon_c}\,.\sin\psi + 1} \tag{9b}$$

At grazing incidence, $\psi = 0$, from equation (9a) and (9b)

$$\rho_h\ e^{-j\phi_h} = \rho_v\ e^{-j\phi_v} = -1 \tag{10}$$

This shows that at grazing incidence, the reflection coefficient is independent of the properties of the surface, *i.e.*, of ε_c as long as ε_c remains finite.

Now, it is seen from equation (9a), that as ε_c increases without limit, $\rho_h\ e^{-j\phi_h}$ approaches -1 for all values of ψ. But the situation is different for vertical polarisation. If we assume that ε_c is real (the earth is a perfect dielectric, thus ε_i is zero), it will be seen from equation (9b) that $\rho_v = 0$, when $\sin\psi = 1/\sqrt{\varepsilon_r}$. When ψ is less than this critical value, $\phi_v = \pi$, but at the critical angle it decreases abruptly to zero, and remains so for all larger values of ψ. When, however, ε_c is complex, ρ_v can decrease only to a minimum value greater than zero reaching the minimum at an angle smaller than $\sin^{-1}(1/\sqrt{\varepsilon_r})$. At the same time, ϕ_v decreases rapidly from a value somewhat less than π to a much small value and thereafter slowly to a minimum value. As ε_c becomes large, the critical angle approaches zero, the minimum value of ρ_v approaches unity and

$$\rho_v \, e^{-j\phi_v} \longrightarrow 1$$

In the presence of finite conductivity, this condition can be approached only at grazing angles well above the critical angle.

At normal incidence $(\psi=\pi/2)$,

$$\rho_v \, e^{-j\phi_v} = -\rho_h \, e^{-j\phi_h} = \frac{\sqrt{\varepsilon_c}-1}{\sqrt{\varepsilon_c}+1} \qquad (11)$$

It may be noted that at normal incidence, a vertically polarised field becomes horizontally polarised. Therefore, the ratio of reflected to incident field for both cases

$$= \frac{1-\sqrt{\varepsilon_c}}{1+\sqrt{\varepsilon_c}} \qquad (12)$$

Next, let us consider the effect of the roughness of the surface. So far we have considered the surface to be smooth. If h be the height of an irregularity of the surface and ψ the grazing angle, then, according to Rayleigh, the path difference between the incident and the reflected ray

$$\triangle R = 2\,h \sin\psi \qquad (13)$$

and the phase difference

$$k\triangle R = \frac{4\pi h}{\lambda} \sin\psi \qquad (14)$$

If this phase difference is small, the effect of roughness is small and the surface is effectively smooth. Increasing h/λ or ψ increases the path difference and weakens the resultant reflected field. When $k\triangle R=\pi$, the direct and reflected rays are in phase opposition. In order to divide rough from smooth surfaces, Kerr *et al.* (1951) suggested a limiting value of $\pi/2$ for $k\triangle R$, which gives as a criterion

$$h \sin\psi < \lambda/8 \qquad (15)$$

for the surface to be considered smooth. It may be pointed out that the above consideration does not give a quantitative statement of the effects of roughness. It has excluded the local diffraction effects when the roughness elements are of comparable size to the wavelength.

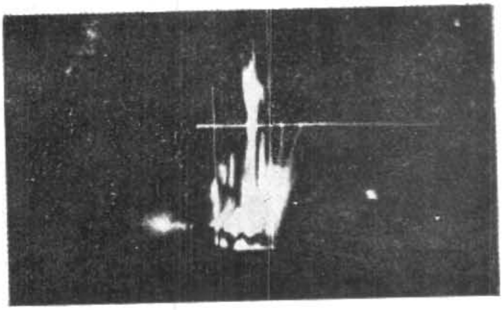
3. Radar observations

A high power (250 KW, peak) Japanese Radar (J.R.C. type NMD-451 A) working on 3-cm waveband has been in operation at Dum Dum airport for meteorological purposes from 1 May 1958. The radar is capable of tracking thunderstorms from a maximum distance of about 200 miles. The beam width of the radar is quite narrow (*viz.*, 1°·2). The aerial of the radar is located at a height of about 50 ft from ground level and can be tilted vertically from —3° to +90°. Whenever any thunderstorm is noticed on the radarscope, the heights of the thunderstorm cells are found out by scanning the aerial vertically. In doing so, specular reflections were noticed on a number of occasions. Fig. 1 shows the occurrence of such phenomenon as seen on the radarscope on 9 June and 16 July 1958.

To find out the heights of the cloud cells, the aerial beam of the radar is pointed to any chosen direction and is then tilted vertically. Two types of presentations for determination of heights are available in the present radar equipment, *viz.*, Range Elevation Indication (REI) and Range Height Indication (RHI). REI presentation is obtained by tilting the aerial from —3° to +90°. The height so obtained is, however, approximate due to the width (1°·2) of the radar beam. RHI presentation is obtained by tilting the aerial from —3° to +30° for targets upto a maximum range of 100 km.

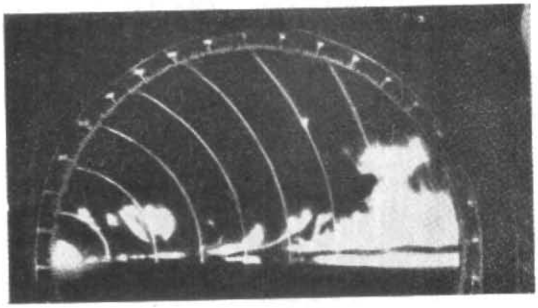
4. Discussion

The runway of the airfield is hard and sufficiently smooth for different grazing angles (from 1° to 3°) excepting some portions towards SW, W and NW.



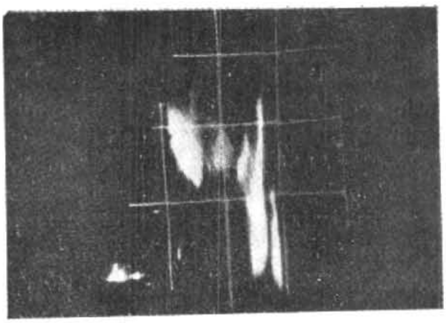
348°N R—20 km H—7·3 km

Fig. 1(a). 9 June 1958, 1746 IST



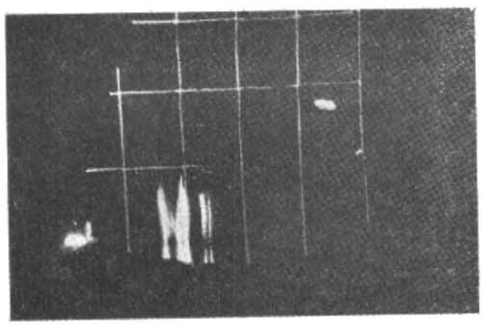
350°N R—5 km

Fig. 1(b). 9 June 1958, 1751 IST



305°N R—20 km H—5 km

Fig. 1(c). 16 July 1958, 1631 IST



028°N R—20 km H—5 km

Fig. 1(d). 16 July 1958, 1655 IST

Fig. 1. Radarscope pictures of the Storm Detecting Radar as obtained at Dum Dum airport

Figures in the left hand bottom corners indicate azimuth (°N) and those in the right hand bottom corners indicate range (R) and height (H) in km. In Fig. 1(a), variable height marker is at 7·3 km.

As stated earlier, the antenna of the radar is located at a height of about 50 ft from the ground. The distances from the transmitter to the points of reflection on the ground for grazing angles 1°, 2° and 3° are 955, 477 and 318 yds respectively.

It can be seen from above that the reflecting surface for the grazing angles from 1° to 3°, can be treated as smooth in all directions except for the sectors from southwest to northnorthwest.

It has been seen (Kerr *et al.* 1951) that for a given wavelength the conductivity increases with the increase of moisture content of the ground. Hence if the ground near the Dum Dum airport is regarded as sufficiently moist, we may assume the values

$$\sigma = 10^{-2}\text{ mhos/metre},\quad \varepsilon_r = 30,\quad \varepsilon_i = 0\cdot 6$$

Then from equation (4a) for horizontally polarised wave, as in the present case, the reflection coefficient for $\psi = 3°$ comes out to be

$$\rho_h e^{-j\phi_h} \doteqdot -0\cdot 996$$

This value is of the same order as obtained in other countries for similar conditions of ground. The magnitude of the reflection coefficient is high and one could expect a good amount of reflection from such a moist ground.

The radarscope presentations on 16 July 1958 (Figs. 1c and 1d) are quite interesting. It is seen that when the aerial beam of the radar was pointed to the WNW (305°), no reflection could be obtained from a cloud as high as 9 km whereas specular reflection was obtained from a small cloud only 4·5 km high in the NNE (028°). This is obviously due to the nature of the reflecting surfaces, *i.e.*, buildings and trees in the WNW and grassy ground in the NNE.

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