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Time-Domain Electromagnetic INPUT* Response of a Conducting Horizontal Thin Sheet

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Abstract. The time-domain response of a conducting horizontal thin sheet to the airborne electromagnetic INPUT system is obtained from the corresponding step-function response. In the INPUT system the primary signal is generated by a large horizontal loop antenna mounted on the aircraft as a series of alternate half-sine wave pulses. The thin sheet model will be useful for the interpretation of conducting overburden, swamps and thin clay covers overlying a highly resistive substratum. As an aid to interpretation, the channel amplitudes and the channel amplitude ratios are illustrated.

Key words: INPUT System — Electromagnetic Response — Conducting Thin Sheet.

1. Introduction

In airborne electromagnetics the conducting overburden poses serious problems. This is particularly true in the Indian subcontinent where the resistivity of the top layer, consisting of sedimentary rocks, alluvial soil or even weathered granitic and basaltic rocks, varies between 10 ohm-m to about 100 ohm-m. While working in electromagnetic models, Braekken and Sakshang (1973) have reported that "in various pyrite fields, and outspokenly those of Norway, it is rather common situation that ores are occuring in connection with extensive sheet-like formations of conducting material. That may be graphite sheets or disseminated ore layers of presumably sedimentary origin. This makes it of considerable importance to know the effect of such conductive sheets". With this view in mind, an earlier simple model of single — turn conductive horizontal circuit (Mallick, 1972) has been improved to include a conducting thin horizontal infinite sheet. Homogeneous half-space, layered half-space and thin sheets have been described from various view points by Morrison, Phillips and

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* INPUT (*IN*duced *PU*lse *T*ransient) is the registered trade name of an airborne electromagnetic system used by Barringer Research Ltd., Canada.

O'Brien (1969); Nelson and Morris (1969); and Becker (1969). In the present analysis, the time-domain response of the conducting and thin infinite sheet to the INPUT system is derived by the method of superposition from the step-function response.

2. Primary INPUT Signal

In the Barringer's INPUT system, the primary signal is sent from a large horizontal loop antenna mounted on an aircraft as a series of alternate half-sine wave pulses. The pulse width is 1.5 msec, and the quiet period between two pulses is 2.0 msec. During this quiet period, sampling is made (Mark V version of Barringer's INPUT system) for a duration of 200 μsec at mean delays of 300, 500, 700, 1100, 1500 and 1900 μsec. These six points in time are termed channels. A complete description of the system is given by Ward (1967). The primary INPUT signal has the following form:

$$\begin{aligned} F(t) &= H_0 \sin \omega t && 0 \quad < t < 1.5 \text{ msec} \\ &= 0 && 1.5 < t < 3.5 \text{ msec} \\ &= -H_0 \sin \omega t && 3.5 < t < 5.0 \text{ msec} \\ &= 0, && 5.0 < t < 7.0 \text{ msec} \end{aligned} \tag{1}$$

with $\omega = 2\pi/T$. $T = 3.0$ msec is the period of the continuous sine wave. Fig. 1 shows the transmitting coil mounted on the aircraft, the receiver bird towed behind, the excitation pulse, and the position of the sheet.

3. Principle of Superposition

Any continuous function can be assumed to be made up of a number of step-functions. The pulse, defined in Eq. (1), can therefore be replaced by several step-functions. Once the response of a step-function is known, the response of the continuous pulse can conveniently be evaluated by the method of superposition described below:

Let $F(t)$ be the continuous pulse and $H(t)$ the step-function response. The response in the INPUT system, i.e. the response due to the continuous pulse will be

$$H_i(t) = H(t)\, F(O^+) + \int_0^t H(t-\tau) \frac{\delta F(\tau)}{\delta \tau}\, d\tau\,. \tag{2}$$

This is referred to as Duhamel Integral (Weber, 1957). For the half-sine pulse given by Eq. (1), $F(O^+) = F(T/2) = 0$. From Eq. (2) the response is then obtained as

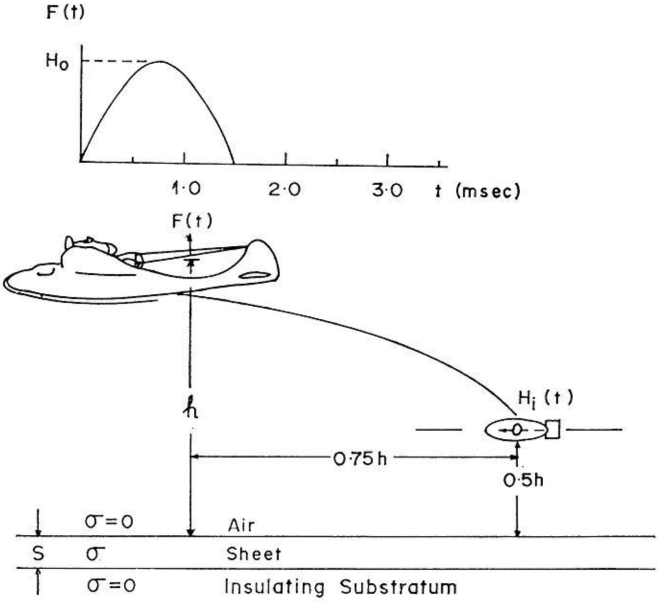

Fig. 1. Schematic diagram of the airborne electromagnetic INPUT system together with thin sheet model (bottom) and primary (exciting) signal (top). σ is the conductivity of the sheet

$$H_i(t) = \int_0^t H(t-\tau)\,\frac{\delta F(\tau)}{\delta\tau}\,d\tau \qquad \text{for } 0 < t < T/2 \tag{3a}$$

in the presence of the primary field, and

$$H_{\mathrm{INPUT}}(t) = \int_0^{\frac{T}{2}} H(t-\tau)\,\frac{\delta F(\tau)}{\delta\tau}\,d\tau \qquad \text{for } T/2 < t \tag{3b}$$

when the primary field is taken off.

4. *Step-Function Response of the Infinite Sheet*

Induction currents in a thin, conducting infinite sheet and their decay under the influence of resistance and selfinductance are described by Jeans (1963). Grant and West (1965) have derived the same results in greater detail and have illustrated the response of different coil systems for a continuous sinusoidal source field.

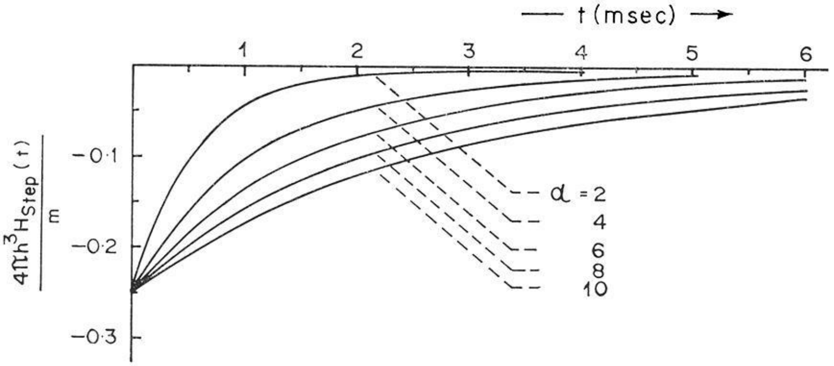

Fig. 2. Step-function response of a thin horizontal infinite sheet. $\alpha = \mu_0 \sigma s h$ is given in msec

Suppose a very thin sheet of conductance σs (σ = conductivity and s = thickness of the sheet) lies in the plane z = O, above an insulating half-space as shown in Fig. 1. If the primary source is an oscillating magnetic dipole, which varies step-wise in time and is oriented in an arbitrary direction at (x_0, y_0, h), the secondary field at another point (x, y, z) is (Grant and West, 1965)

$$\vec{H}^{(s)} = -\frac{1}{4\pi}\left[\nabla\left\{\vec{m}.\nabla_0\left((x-x_0)^2+(y-y_0)^2+\left(z+h+\frac{2t}{\sigma\mu_0 s}\right)^2\right)^{-\frac{1}{2}}\right\}\right] \quad (4)$$

where m is the magnetic dipole moment, and the operators ∇_0 and ∇ operate at the source and the observer respectively. μ_0 is the magnetic permeability of the air and equals to that of the sheet and the insulating substratum.

For the Barringer INPUT system, the transmitting magnetic dipole is vertical and the secondary field is recorded by a vertical coil in the bird towed behind the aircraft as shown in Fig. 1. The axis of the receiver coil is horizontal and along the flight direction. For such a transmitter-receiver combination $H_{\text{step}}(t)$, the step-function response, can be obtained from Eq. (4):

$$\frac{4\pi h^3}{3m} H_{\text{step}}(t) = -\left[\beta^2 + \left(1+\eta+\frac{2t}{\alpha}\right)^2\right]^{-5/2}\left(1+\eta+\frac{2t}{\alpha}\right), \quad (5)$$

where $\beta = (x - x_0)/z$, $\eta = z/h$ and $\alpha = \sigma\mu_0 sh$.

Fig. 2 shows the response due to step-function excitation for a system with transmitter at a height h, the receiver at 0.5 h and the transmitter-receiver horizontal separation 0.75 h for several values of α.

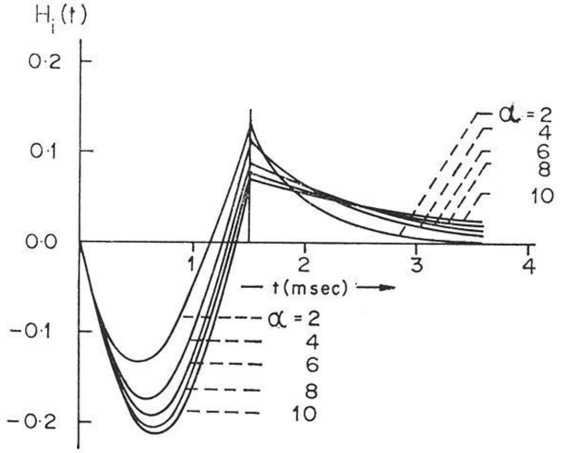

Fig. 3. INPUT response of the sheet. The values of α are the same as in Fig. 2

It can be observed from Fig. 2 that the conductance is inversely related to the decay constant of the transient field.

5. *INPUT Response*

The INPUT response of the sheet is obtained from the step-function response given in Eq. (5) by applying the principle of superposition (for example, see Mallick, 1973a and 1973b):

$$H_{\mathrm{INPUT}}(t) = -\frac{3m}{4\pi h^3}\left[\int_0^t \left\{\beta^2 + \left(1+\eta+\frac{2(t-\tau)}{\alpha}\right)^2\right\}^{-5/2} \cdot \beta\left(1+\eta+\frac{2(t-\tau)}{\alpha}\right) \cdot \omega \cos \omega\tau \, d\tau\right] \left\{1+u(t-T/2)\right\}, \tag{6}$$

where $u(t-T/2)$ is the delayed unit step-function.

$H_{\mathrm{INPUT}}(t)$, from now on to be written as $H_i(t)$, has been computed and in being shown in Fig. 3 for the same geometry of transmitter, receiving bird and the sheet, and for the same values of α as in Fig. 2. Similar to the step-function response, the INPUT response decays more rapidly for smaller values of α.

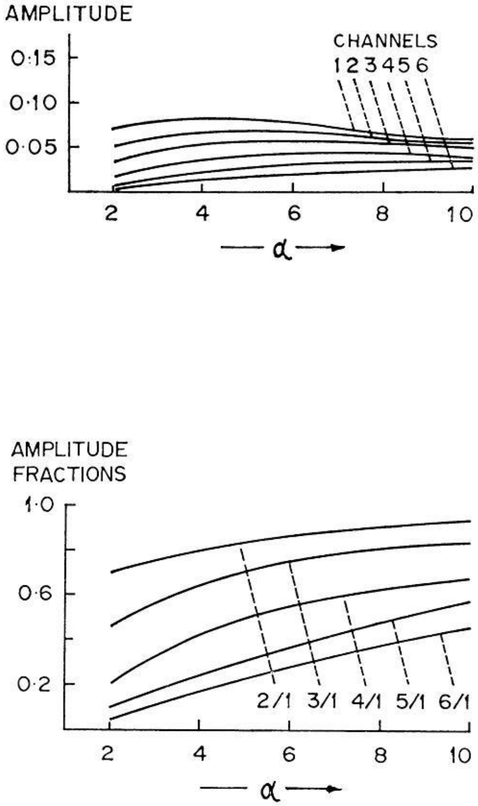

Fig. 4. The channel amplitudes in units of $\frac{3\,m}{4\,\pi b^3}$ (top) and the channel amplitude ratios as fractions of the first channel amplitude (bottom)

6. Channel Amplitudes and Channel Aplitude Ratios

As a possible aid to interpretation of field data, the channel amplitudes in units of $\frac{4\pi b^3}{3m}$ and the channel amplitude ratios (as fractions of the first channel amplitude and indicated by 2/1, 3/1 etc.) are illustrated at the top and the bottom of Fig. 4 respectively. The range of α is chosen between 2.0 and 10.0 msec, as in Figs. 2 and 3, since the response reaches its resistive limit for $\alpha < 2.0$ msec and its inductive limit for $\alpha > 10.0$ msec (Grant and West 1965, p. 502). The analysis of Grant and West has, however, been made for a continuous sinusoidal field.

The amplitude ratios can be matched with the field data for a system where the magnetic field is recorded. The NGRI version of the INPUT system is such a system; it records the field and its time-derivative (voltage developed in the receiver coil) as well.

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