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SHORT NOTE

A Simple Interpretation Aid for Downhole Time-Domain Electromagnetic Anomalies

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Abstract

The transient magnetic fields in a borehole near a plate-like conductor can be simulated with a simple current loop in the plane of the conductor. The shape of the response with depth in the hole is related to the position and orientation of the current loop, so that characteristics of the response such as the zero-crossing separation can be used to predict the location of the current loop and therefore the location of the conductor in which the current circulates. Physical model results verify the application of the characteristics in this way.

Key words: downhole EM, current filament, nomograms, scale modeling.

Introduction

This paper details the preparation and application of a simple interpretation aid which can be used to find the distance and relative orientation of the source of a downhole time-domain electromagnetic (DHEM) anomaly. The procedure assumes that such a source can be represented by a plate which in turn is modelled at any particular time by a current filament. By studying the behaviour of DHEM responses using physical models, Woods (1975) and Parums (1984) both observed systematic variations which could be generally explained using simple models of the source of the anomaly. Woods, for instance, used the qualitative model of a line of current induced near the edge of a plate to explain the systematics in field variations which he observed. Parums also referred to this model, and used it to justify making measurements of such quantities as peak amplitude ratios and zero-crossing widths and relating them to the distance to, and orientation of, the model target with respect to the borehole in which the observations were made. These empirical observations confirmed that relationships exist between measured characteristics and properties of the target position, but the relationships are obscured, presumably by measurement error and possibly by model-associated limitations on the quantities being measured. The purely mathematical technique discussed in this paper eliminates some of these problems.

Filament loop model

The interpretation method described here assumes that at any instant of time the shape of the anomalous field in a borehole near a plate conductor resembles the field of a loop of current with finite radius (Fig. 1a). This current loop model is used to study numerically the way in which characteristics of the observed field, such as those described by Woods (1975) and Parums (1984), would vary with plate position. This does not imply that there is in fact a single current filament (Nabighian, 1979, Barnett, 1984).

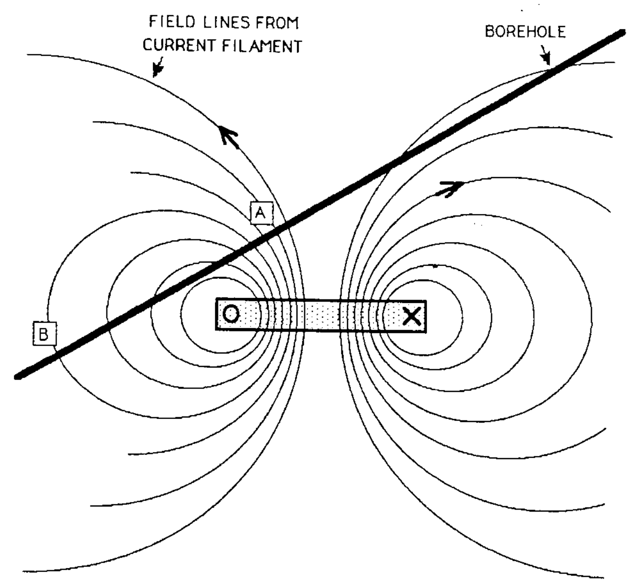

FIGURE 1a
Cross-section sketch of the magnetic field (faint lines) arising from a current loop (O–X) confined within a plate conductor (stippled). A borehole (heavy line) passes close to the conductor. The axial magnetic field (the component of the field parallel to the borehole) changes sign near A and B, and the distance between these points can be seen to depend on the relative position and orientation of the borehole.

The expression for the field due to a circular loop of current is widely known (e.g. Smythe, 1968); for example

$$B_\rho = -\frac{\mu\cdot I}{2\cdot\pi}\cdot\frac{z}{\sqrt{(a+\rho)^2+z^2]}}\cdot[-K+\frac{a^2+\rho^2+z^2}{(a-\rho)^2+z^2}\cdot E]$$

$$B_z = \frac{\mu\cdot I}{2\cdot\pi}\cdot\frac{1}{\sqrt{[(a+\rho)^2+z^2]}}\cdot[K+\frac{a^2-\rho^2-z^2}{(a-\rho)^2+z^2}\cdot E]$$

where I is the current in a loop of radius a, K and E are complete elliptic integrals, and ρ and z are cylindrical coordinates.

A simple computer program was written to predict the field component along a line (representing the borehole) in a plane perpendicular to the current loop (representing the conductor). The plane contained the centre of the loop, but the line did not intersect the loop, that is, the borehole did not intersect the conductor. Responses were computed for different orientations and distances from the loop. Note that only field ratios are used in the interpretation scheme. The strength of the current in the loop is therefore irrelevant, so that in turn the orientation of the loop with respect to the energizing field — and the method of energizing — is irrelevant.

Characteristic curve generation

Hundreds of profiles were generated using this computer program. Simple numerical interpolation methods were used to find the zero positions, extreme values, and positions of extreme values of the component field along the line. It was soon realized that characteristic curves (e.g. Grant and West, 1965, p. 273) would be an economical method of depicting the relationships which were emerging from the numerical study. The only parameters controlling the shape of the curves in this model are the angle between the borehole and the plane of the current loop, and the distance between the borehole and the current loop. This latter was normalized with the current loop radius for computation purposes. Observations in the borehole (Fig. 1b) were reduced to the following three parameters: the ratio between the amplitudes of the "deeper" of the two sidelobes and the main, central peak (SPR); the ratio of the amplitudes of the two sidelobes (SSR); and the zero-crossing distance (Z).

Two sets of characteristic curves were constructed. On one, the dip (d) and distance (l/a) were mapped onto SSR vs SPR observation space (Fig. 2). On the other, the same quantities were mapped onto SSR vs Z/a space (Fig. 3).

By entering observed SPR and SSR values onto Fig. 2, an estimate for the dip can be obtained, together with a value for l/a. Plotting these values on Fig. 3 (SSR is only a check) a value for Z/a is obtained. Since the actual value for Z in the borehole is observed, the current filament radius a can be found, as well as the distance l between the borehole and the filament.

Examples and testing

To provide a controlled test of the method, data were taken from the physical model study by Parums (1984) of the DHEM response of a plate in air. Parums used a Sirotem instrument (Buselli and O'Neill, 1977) for data acquisition, and scaled lengths with a factor of 1000. The transmitter coil used was 20 cm square, which scales up to a field loop 200 m square.

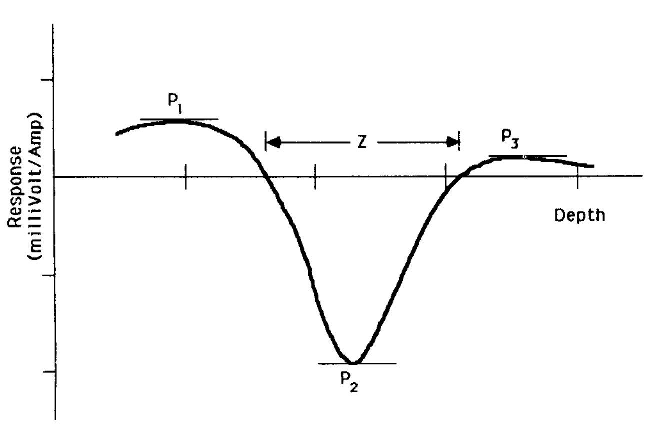

FIGURE 1b
Sketch of the loop-generated axial magnetic field in the simulated borehole. P1, P2, P3 and Z are quantities measured. The origin for the depth scale is arbitrary.

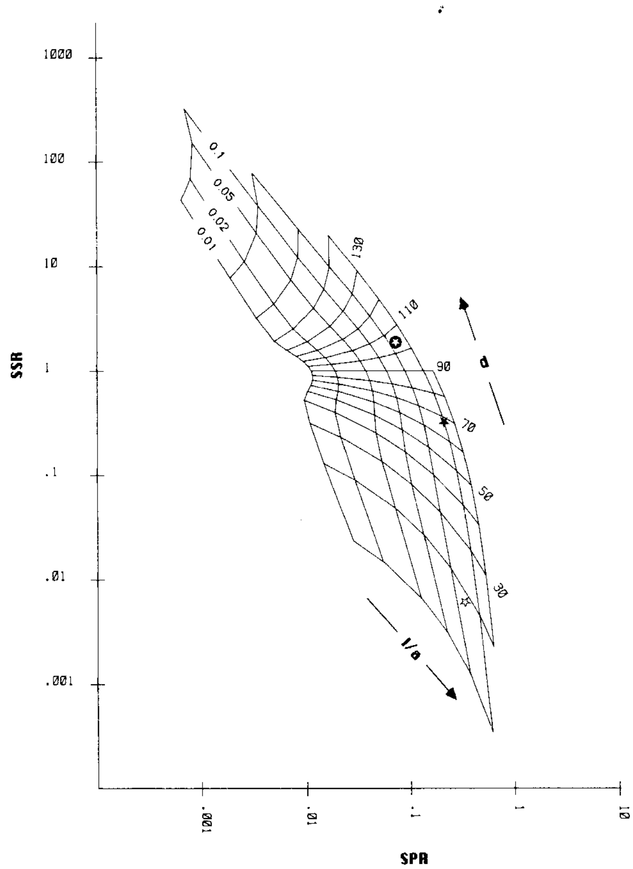

FIGURE 2
Characteristic curve for sidelobe/peak ratio (SPR) versus sidelobe/sidelobe ratio (SSR). The model quantities mapped are dip (d) and normalized distance (l/a).

The conductor was 30 cm square (i.e. 300 m). The data shown here are those from channel 8 (nominal delay 4.2 milliseconds). Three cases are selected in which the characteristics can be measured with confidence. The response as a function of depth is shown in Fig. 4. The agreement between the actual and interpreted dips is excellent, as is the distance (l), bearing in mind that the offset in the physical model is the distance between the plate edge and the borehole. The distance to the equivalent filament should therefore always be at least as great as the distance to the conductor. The interpreted radii (a) of 150, 200, and 125 metres match quite well with the approximate plate radius of 150 metres.

Conclusions

Two comments can be made about this study. Firstly, the usefulness of physical model studies is demonstrated in that the modelling provides a suite of relevant data generated in a controlled way, but independent of any mathematical/numerical/computational assumptions which might also affect the proposed interpretation scheme. Secondly, the method outlined in this paper could serve as a compact method for initial interpretation of appropriate downhole anomalies.

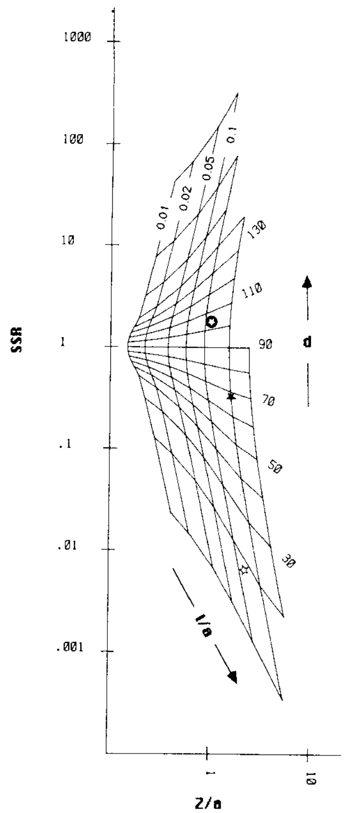

FIGURE 3

Characteristic curve for sidelobe/peak ratio (SPR) versus normalized zero-crossing width (Z/a). The model quantities mapped are dip (d) and distance (l/a).

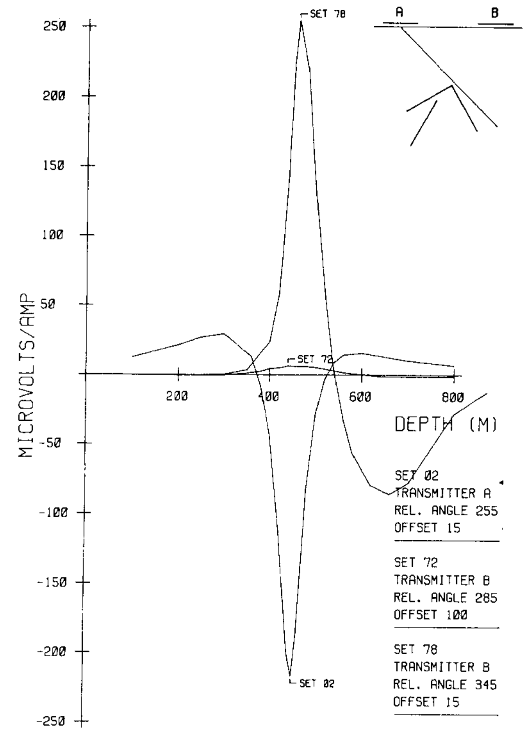

FIGURE 4

Axial DHEM response for three physical models (from Parums, 1984). The sketch in the upper right corner shows the relative positions of the transmitter coils, the borehole, and the plate for the three cases shown. 'Offset' refers to the distance of the plate edge from the borehole. 'Rel angle' is the angle between the plate and borehole, measured anticlockwise from the downhole direction.

TABLE 1

	Observed data			Interpretation			Model	
Set	SSR	SPR	Z (m)	d (deg)	l (m)	a (m)	d (deg)	offset (m)
02	1.9	0.071	150	105	45	150	105	15
72	0.34	0.21	300	70	100	200	75	100
78	0.0056	0.34	270	20	30	125	15	15

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