Smoke Rings

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Introduction

A loop with a d.c. current flowing is laid on the ground (the transmitter). Field lines due to this loop are shown in figure 1. The d.c. current is abruptly shut off. By E.M. theory, when one abruptly interrupts the current in the transmitter, a system of induced currents is generated in the halfspace, such as to preserve the magnetic field that existed before switch off. Nabighian (1979) has shown that at any given time after switch off, this system of induced currents can be represented by a simple current filament, i.e. a line of current flowing in the ground. This line of current has the same shape as the transmitter loop, it moves downward and outward with an increasing velocity and diminishing amplitude. Figure 2 shows a schematic of the line of current in the ground at three different times after switch off. The equivalent line of current moves downward and outward at an angle of 47 degrees with a velocity given by

$$V_z = \frac{2}{\sqrt{\pi \sigma \mu \tau}}$$

Note that the maximum current density moves at an angle of 30 degrees. This is the result given by Lewis and Lee (1978). The equivalent line of current which is obtained by integrating over the current density moves at 47 degrees.

Smoke Rings for a 100 Ω-m Halfspace

Substituting actual values and computing times, distances, etc. gives one a feel for dimensions in the real world. Taking a 100 Ω–m homogeneous halfspace, figure 3(a) shows the movement of the equivalent line of current in section form with measurements in metres and milliseconds. The current

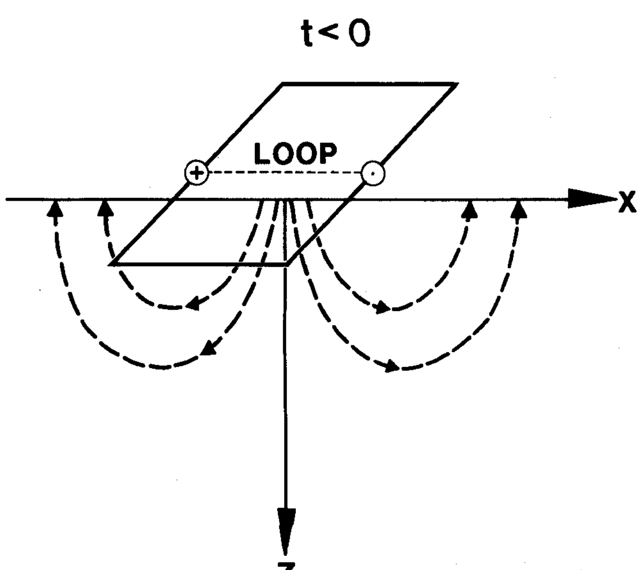

FIGURE 1
Magnetic field lines due to a d.c. current in a rectangular loop

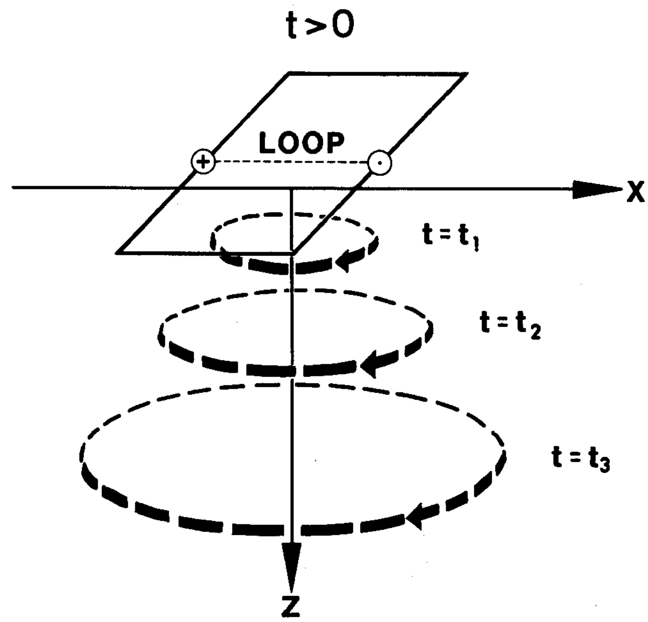

FIGURE 2
Induced lines of current in the halfspace

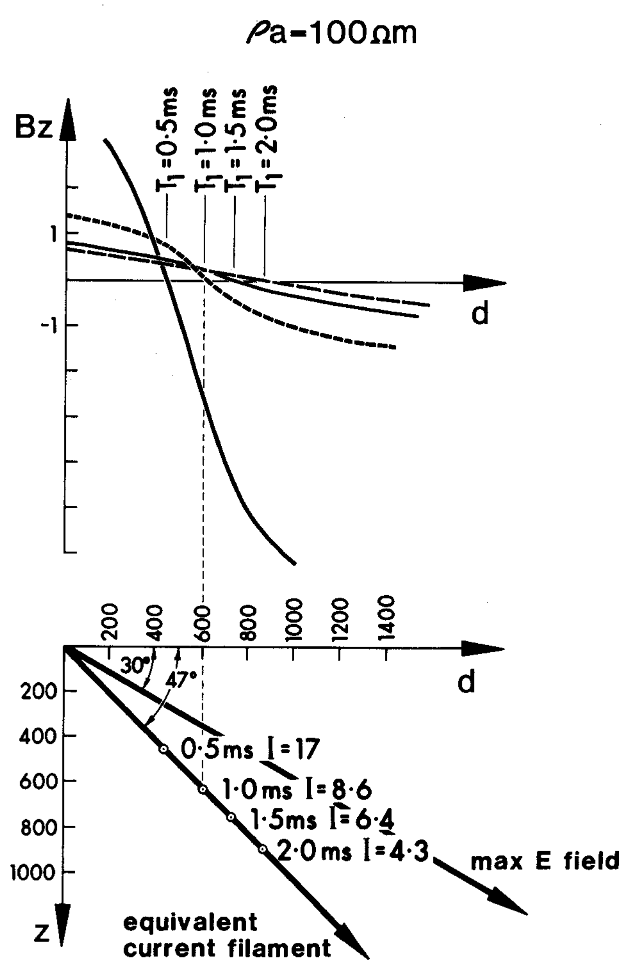

FIGURE 3a
Bottom: Movement of equivalent line of current

FIGURE 3b
Top: Magnetic field seen by a receiver coil

values and B_z are arbitrary. A receiver coil is placed at d = 600 m measuring the vertical component (Z positive down):

At τ = ½ ms the line of current is between the receiver and the loop flowing out of the page. The B_z field seen by this coil will be negative and can be read off the plot, figure 3(b) for the ½ ms equivalent current filament. At τ = 1 ms, the equivalent line of current is directly below 600 m. Reading the value of B_z off the plot shows a zero field. (This can easily be verified using the R.H. rule.)

At τ = 1½ ms, the equivalent line of current is behind the receiver coil and B_z is now positive.

At τ = 2 ms, B_z is still positive.

At $\tau \gg$ 2 ms, B_z has fallen to zero.

Transferring the B_z values for times of ½, 1, 1½, 2 and much greater than 2 ms to a B_z, τ plot generates a theoretical decay curve — figure 4. This theoretical decay curve of B_z versus τ is of limited value because we cannot measure it. We can only measure the time derivative as a response from a coil. The time derivative is given by the dashed line in figure 4. This time derivative is the actual transient decay measured in the field. Note that the actual position of the equivalent line of current cannot easily be deduced from the time derivative curve. Decay plots from a conductive area of Western Australia (approximately 30 Ω–m) are shown in figure 5. Loop centre was at 450 W. The smoke ring theory predicts the shape of these decay plots quite accurately.

References

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LEWIS, R., and LEE, T., 1978. The transient electric fields about a loop on a halfspace. *Bull. Aust. Soc. Explor. Geophys.*, 9, pp. 173-177.

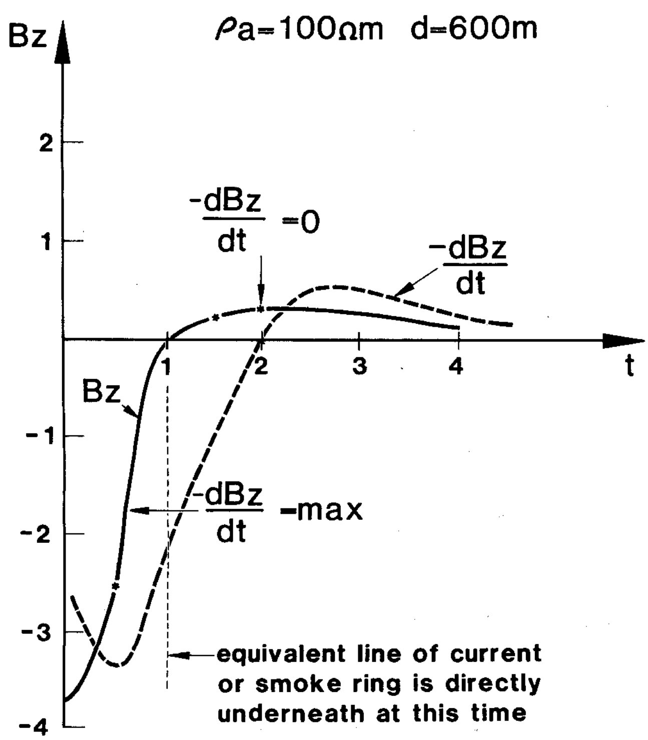

FIGURE 4
Theoretical decay curves

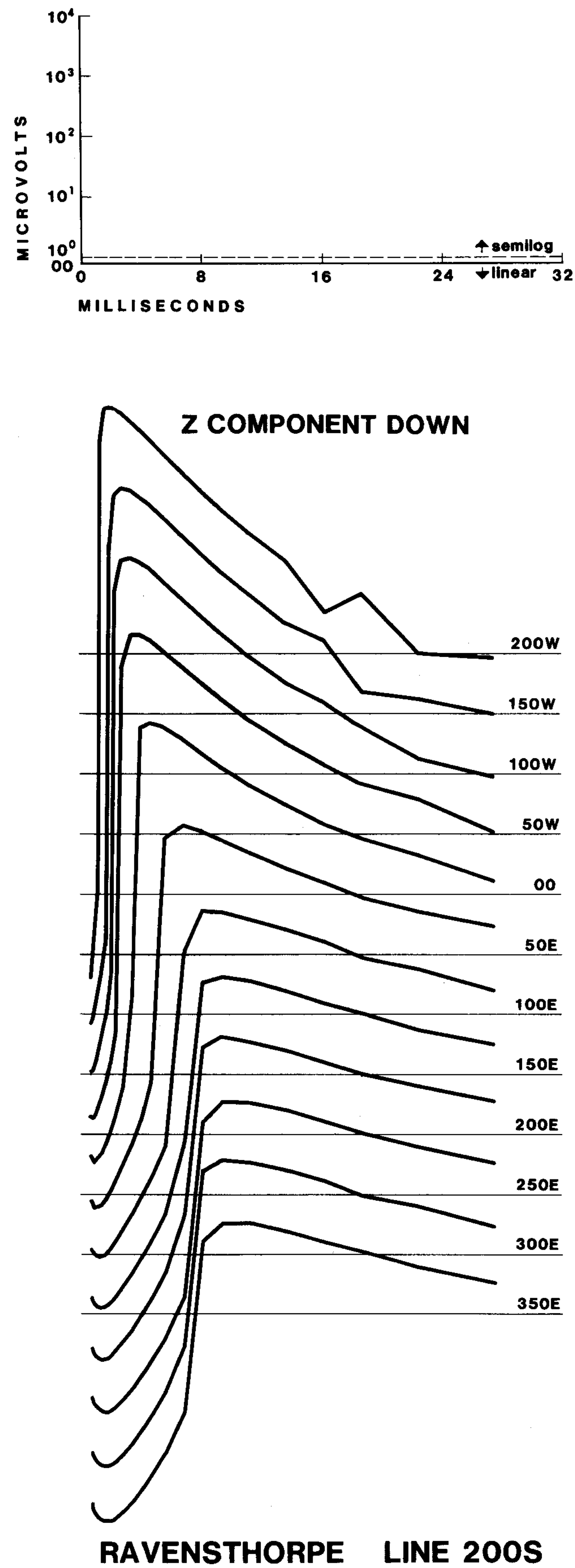

FIGURE 5
Decay plots — Ravensthorpe, W.A.