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Long Wire Electromagnetic Measurements (Turam EM)

Ole Bernt Lile

Abstract

In Scandinavia, EM measurements have traditionally been popular in sulfide ore exploration. The EM methods using a stationary cable loop or a long wire on the ground surface were called Turam. The wire was grounded by electrodes at the ends. The name, Turam meaning two coils, got the name after the measurement system using two coils measuring the quotient and the phase difference of the vertical field. The measurements were performed in the frequency domain, with frequencies around 400 Hz. Using a large cable loop or a long wire grounded at both ends has advantages as energizing transmitter, which should be utilized in deep exploration. The fall-off rate for the primary field is small, and the electric field can be directed in line with strike direction or the direction of the axis of the mineralization. Examples of the interaction between the energizing cable and the conducting half-space are illustrated by computed models. The grounding points can be shifted with repeated measurements for each grounding position. Both man-made and geological noise can be reduced in this way. Field examples are given in the chapter.

Keywords: EM Turam, electromagnetic, cable configurations, gathered current

1. Introduction

In Scandinavia, electromagnetic measurements have been the dominating class of methods in exploration for metal sulfides since the 1920s. Moving source-moving receiver, Slingram, a lightweight instrument system, became very popular. It was applied for reconnaissance mapping of outcropping conductors under a relatively thin overburden and was successful in the discovery of several orebodies in Sweden.

The other EM method that became popular was Turam. This method used a stationary EM source, large wire loops on the ground, or a long single wire, which was grounded by electrodes at each end. In this chapter, we shall look at the principle of coupling between the wire and a conducting half-space and of coupling between a good conductor (orebody) and the conducting half-space.

2. Long wire electromagnetic measurements (Turam EM)

The electromagnetic method using a long wire or a large loop on the ground surface as energizing device was developed in the 1920s. The advantage using either a large square loop or a single grounded wire is lower fall-off rate of the primary field

and thereby larger depth penetration. Current gathering in long conductors is also an advantage in deep exploration [1]. Due to the measurement technique using two coils, the method was called Turam, meaning two coils in old Swedish [2, 3]. There are several publications describing both the theory and field results of this method [4–6]. The measurements were carried out in the frequency domain with a fixed frequency. During the last 40–50 years, there has been a revolutionary development of electronic instrumentation making it possible to work on several frequencies simultaneously in the frequency domain or applying short transmitted pulses and record the response in several channels representing windows with increasing time delays during the pause between the pulses. The time it takes to transmit one pulse and record several channels is in the order of milliseconds, and therefore, a large number of pulses can be used at one measurement station, and the responses in all the channels are stacked. The stacking improves the signal/noise ratio considerably.

Physically, there is no difference between frequency domain measurements with several frequencies and time domain measurements in several time delay channels. Short delay channels correspond to high frequencies in the frequency domain and vice versa.

This article will only deal with measurements in the frequency domain.

3. A long wire on the surface of a conductive half space

A single wire grounded at both ends and connected to an alternating current (AC) generator will set up an alternating magnetic field (primary field), which will induce a voltage in the ground. This will in turn produce inductive currents in the

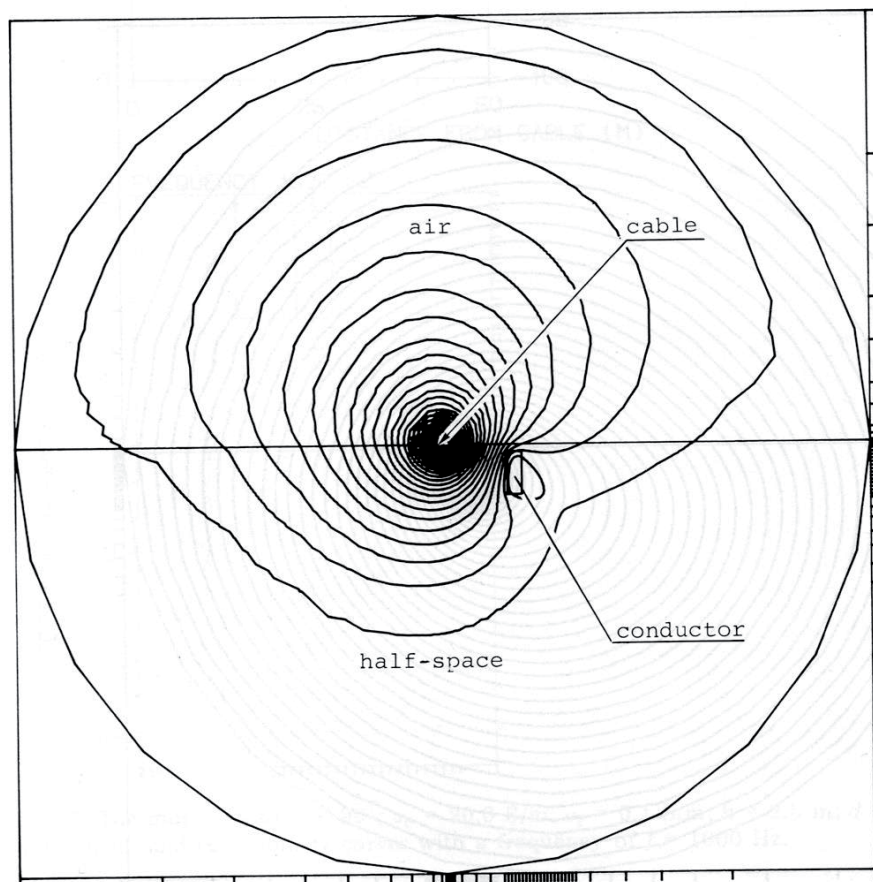


Figure 1.

The total magnetic field from a cable on the surface of a conducting half-space with a conductor [6].

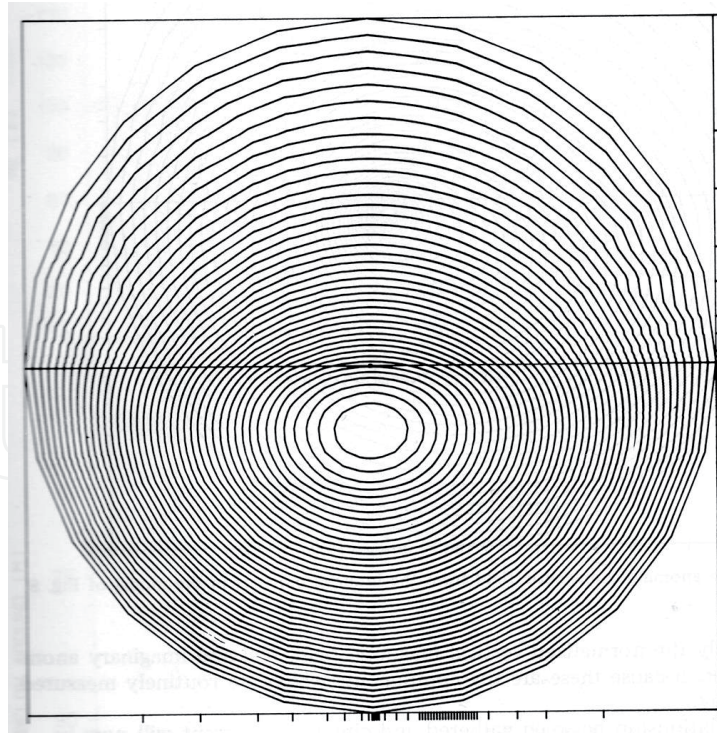


Figure 2.
Secondary magnetic field from induced currents in a conducting half-space [6].

conductive half-space with its own magnetic field (secondary field). This secondary magnetic field is opposing the primary field in the ground, thus weakening the magnetic field from the wire. The resulting field will not penetrate as deep into the ground as in free space and will be phase-shifted relative to the primary field. **Figure 1** shows the resultant field calculated for a two-dimensional model of the half-space and a conductor [6].

The secondary magnetic field alone can be computed and displayed. **Figure 2** shows the induced magnetic field from currents in a conducting half-space without conductor [6]. The induced currents in the ground create a circular pattern of the magnetic field with the vortex below the cable. The depth of the vortex is approximately half the skin depth.

4. Current gathering

Current gathering in long conductors is one of the main advantages with the Turam energizing techniques. This makes deep exploration possible. If it is possible to obtain galvanic contact with a conductor in the ground, one should use this as one of the grounding electrodes of the energizing cable. Lile et al. [6] investigated how gathered currents could be modeled by a two-dimensional computer model. **Figure 3** shows how the anomalous magnetic field lines in the ground are influenced by gathered current in a nearby conductor.

In field measurements, we usually want as much gathered current as possible. Therefore, it is preferable to connect one of the electrodes to the mineralization. However, in some cases, the field from gathered currents can mask anomalies, which may be more interesting. By using grounded electrodes, it is possible to have full control of the current distribution in the half-space and in the mineralization.

In **Figure 4**, the amount of current in the conductive body is 5% of the total current in the half-space. In this case, the edges of the body are outlined. With shallow flat conductors, it is important to have strong induced current at the edges of

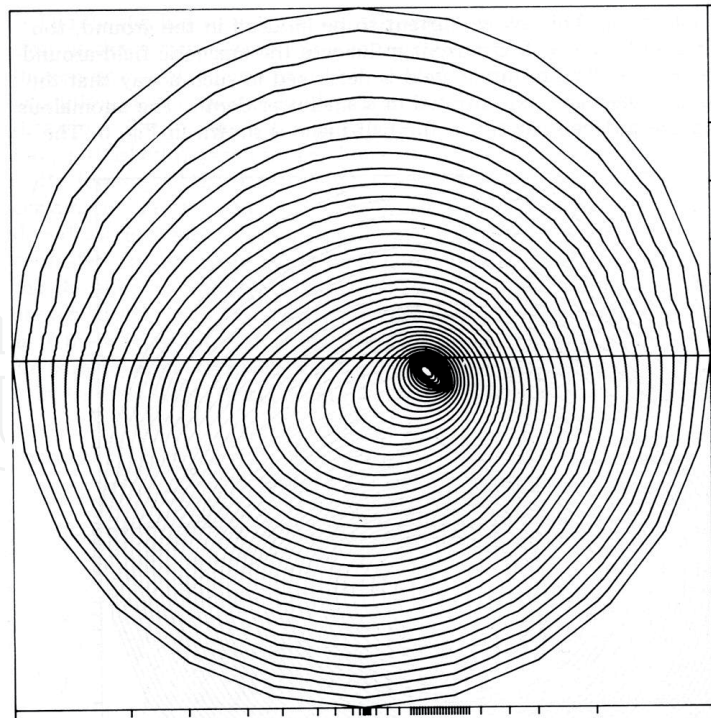


Figure 3. This figure shows the magnetic field from the induced currents in the half-space and in the long conductor situated in the half-space. The model is the same as shown in **Figure 1**. The good conductor gathers current from the half-space resulting in moving the vortex to the conductor. In this case, the amount of current in the conducting body is 30% of the total amount of current in the half-space [6].

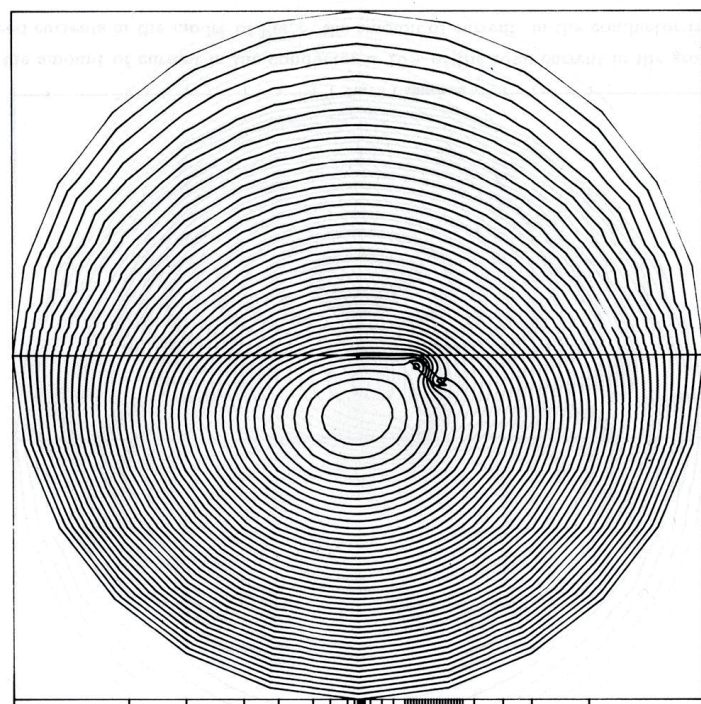


Figure 4. The amount of gathered current in the conductor is dependent on the conductivity of the body relative to the half-space and the length of the conducting body. In this case, the amount of current in the conducting body is 5% of the total current in the half-space [6].

the body to be able to outline the conductor. The gathered current in the conductor should in such cases be weaker. A cable loop on the ground surface can serve as the transmitter of the primary field.

5. Variable grounding points

In areas where man-made or geological noise is present, interpretation of the data may be difficult. Man-made noise may be conducting structures in the ground or on the surface, which creates anomalies which mask anomalies one is looking for. Geological noise may be varying thickness of conducting overburden or shallow conductive structures in the ground. One method to neutralize such anomalies may be to do measurements at the same stations twice, with variable grounding of the energizing cable.

Lile et al. [1] investigated this technique in a mining area where the orebody was cut by a large fault and the goal was to find the down faulted continuation. The conditions regarding man-made noise were extremely difficult. The exploration area was cut by a main road with heavy traffic, and a railway was situated in parallel and close by the road.

The wire could not be laid parallel to the strike direction because we could not cross the railway and the main road (E6).

In this example, we needed to detect the secondary magnetic field from a sulfide conductor at great depth. Long grounded cables were chosen for energizing the half-space in the exploration area.

Figure 5 shows that we could use a deep ventilation shaft to make two grounding electrodes in weak sulfide zones at approximately 350 m depth. In addition, we made two grounding points at the ground surface, one far away grounding to the north (E) and one to the west, close to the mine (E(0)).

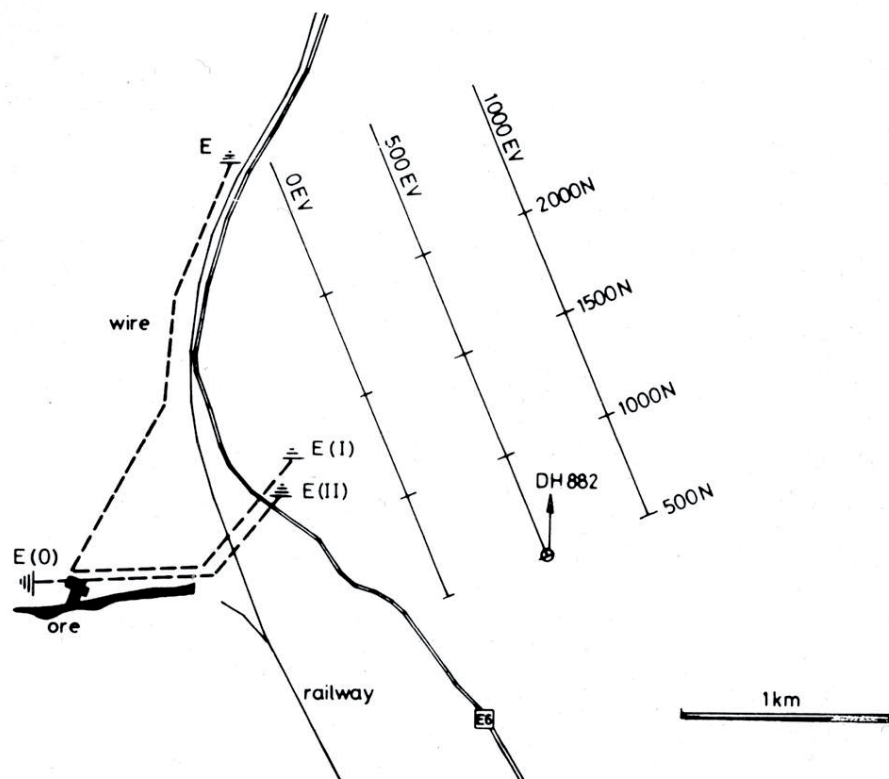


Figure 5.

This is a map showing the situation. The orebody was cut by a NS-fault, dipping 55° to the east, outcropping a couple of 100 m to the west of the railway, and cutting the orebody at 350 m depth. The exploration area was within the grid to the east. The generator was situated at the mine. The picture shows four grounding points. The electrodes to the north (E) and to the west (E(0)) are at the ground surface. The primary magnetic field created by the current in the wire on the surface is needed for the measurements in the grid to the east of the road. The current wire to electrodes E(I) and E(II) goes through a ventilation shaft to a weak sulfide zones at 350 m depth.

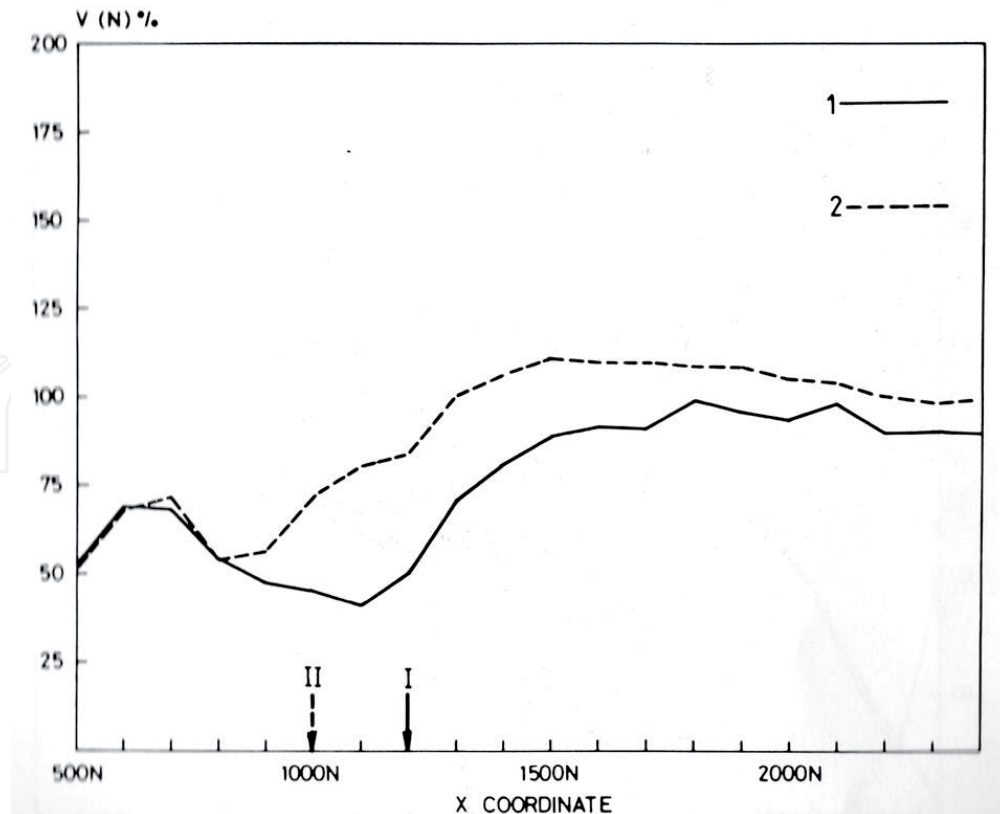


Figure 6.

Normalized vertical field along profile 600 EV. Curve 1 has been measured with the grounding electrode E(I) and curve 2 with the grounding electrode E(II) at 350 m depth (Figure 5). The curves were interpreted as anomalies from conductors at Positions I and II, at depth between 500 and 1000 m. However, a diamond drill hole (DH 882), shown in Figure 5, did not hit any conductor, and the exploration was terminated.

The primary field in the grid came from the long cable between the mine and the electrode to the north (E).

Here only one profile is presented. Profile 600 EV is situated approximately in the middle of the grid. The grounding point to the north (E) was used for all the measurements. A normal vertical field, $V(0)$, was measured with the cable between electrode E and electrode E(0) on the ground surface to the west. At the same points in the grid, the vertical field was measured with the grounding electrodes in the mine, E(I) and E(II), connected to weak sulfide zones. These measurements were then normalized with $V(0)$ as reference and displayed in percentage (Figure 6).

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Author details

Ole Bernt Lile
Norwegian University of Science and Technology, NTNU, Trondheim, Norway

*Address all correspondence to: obl@ntnu.no

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