GEONICS LIMITED
1745 Meyerside Dr. Unit 8 Mississauga, Ontario Canada L5T 1Cb

Tel: (905) 670-9580
Fax: (905) 670-9204
E-mail: geonics@geonics.com
URL:http//www.geonics.com

Technical Note TN-10

EM37 GROUND TRANSIENT ELECTROMAGNETIC SYSTEM: CALCULATED DEPTH OF EXPLORATION

J.D. McNeill

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INTRODUCTION

Enough survey experience has now been obtained with the EM37 to permit a fairly accurate estimate of the average noise levels as a function of delay time. Given these noise levels it is a straightforward matter to calculate the depths at which various types of target can reasonably be expected to be detected. This technical note deals with two types of targets of survey interest: the first is a thin conducting plate situated in free space and the second is a horizontally stratified earth or more specifically, a two-layered earth in which we wish to determine the depth to which we can detect and/or electrically resolve the substrate.

It is assumed that the reader is familiar with Geonics Technical Note TN-7 "Applications of Transient Electromagnetic Techniques".

SYSTEM NOISE CHARACTERISTICS

It will be recalled from Technical Note TN-7 that the target is excited by rapidly terminating the current flow (and thus the primary magnetic field) from a large loop transmitter. The resultant induced emf causes eddy current flow in the target; these currents are detected by measuring the time rate of decay of their magnetic field during the interval that the transmitter is off. System noise, which is also present during this period, limits the ability to detect very small signals and thus, in many cases, limits the depth of exploration.

A plot of the typical behaviour of the system noise when measuring the decay of the vertical magnetic field component is given in Fig.1. The units are given in volts/m^2; the values shown are approximately the RMS output of a coil of one turn and of area one square meter lying flat on the ground. Also indicated in the figure are the locations of the first 18 gates when operating at a base frequency of 30 Hz.

The design of the EM37 is such that under virtually all conditions the system noise limit is set by atmospheric noise rather than circuit noise. The values shown in Fig. 1 are the average of values taken over many survey days and represent a reasonable minimum value. On particularly noisy days the measured values might be substantially higher. The integration time was typically 34 seconds (= 2^{10} periods at 30 Hz) and the average was taken over four measurements, for two of which the reference polarity was reversed to remove the affect of small DC offsets in the later time channels.

We see from the graph that the noise is largest at earliest times (where the gates are narrowest), and that it decreases with time out to about 2 msec becoming approximately constant of the order of $2\text{x}10^{-10}$ volts/m^2 for later times.

At 3 Hz the effective integration time is reduced by a factor of ten (i.e. over one-tenth the number of cycles) however we are usually only concerned with the noise in the last ten channels, each of which is now a factor of ten longer in time. The net result is that in general the measured system noise stays at about the $2\text{x}10^{-10}$ volts/m^2 referred to above.

Since we are assessing the capability of the EM37 to detect deep targets we can assume, for the case of the plate model, that the response in any channel falls off approximately as the cube of the depth, all other factors remaining equal; that is

$$S_o \cong kd^{-3} \qquad (1)$$

where S_o = output signal
d = target depth
k = a constant

Let us define the maximum exploration depth as that value at which the signal-to-noise ratio falls to a value R. Then if N is the noise in a given channel the minimum detectable signal $S_{min} = RN$, or

$$RN = kd_{max}^{-3} \qquad (2)$$

$$\text{and } d_{max} = \left(\frac{k}{RN}\right)^{1/3} \tag{3}$$

We see that, assuming the exploration depth is limited by system (atmospheric) noise and not be geological noise, the maximum exploration depth will be relatively unaffected by increases in the noise since the depth varies approximately as the cube-root of the noise amplitude.

For the case of the horizontally layered earth the measurement is even more insensitive to the system noise, for we can show in this case that the maximum depth to which we can detect the top of the second layer is inversely proportional to the fifth-root of the minimum detectable signal, rather than the cube-root as above. In this instance quite large increases in noise make relatively little difference to the maximum achievable depth.

Since for either a confined target or a homogeneous or layered earth at the late stage the measured signal is decreasing rapidly with time in practice one usually finds that (assuming sufficient power in the transmitter) the initial signal-to-noise ratio is excellent, and that it maintains a high value for a certain length of time dependent on the characteristics of the target, after which it suddenly deteriorates, often within two or three gates.

THIN PLATE MODEL

The EM37 response from a vertical thin plate was determined using the University of Toronto "thin plate" program. The geometry of the survey configuration is shown in Fig. 2a, where the plate response was measured as a function of radial distance R and depth d. When surveying for targets at great depth one generally uses the vertical magnetic field component since the atmospheric noise is a minimum for this component. However for simplicity the calculated quantity was the time rate of change of the horizontal secondary magnetic field since it is a maximum directly over the target (unlike the vertical component which exhibits the usual cross-over behaviour over the target). For vertical plate targets which are situated at a distance below the receiver coil comparable to the target dimensions the maximum response of both components is essentially the same and no appreciable error results.

Fig. 2b shows the transient decay for a 40 mho conductor of dimensions 300 x 300 m, chosen to simulate a reasonably conductive, moderately large orebody. We see from the graph that such a body would probably just be detectable (again, in the absence of geological noise) to depths of the order of 500 m when it is situated at 600 m from the loop centre. At this depth the signal-to-noise ratio is approximately unity however the target response will be visible on several channels thus improving the detectability.
Fig. 2c shows how the response varies with depth for the same plate, now situated at 1200 m from the loop centre. We see that in this case the maximum depth would probably be around 200 m, the reduction being caused essentially by the decrease in the primary field at the larger distance from the transmitter.

It is well known that with a Turam-type transmitter loop the coupling to a plate target is sensitive to target orientation. Fig. 3a from MacNae(1) shows the direction of the primary field at various points in a vertical plane running through the centre of the long side of the transmitter loop (which again has dimensions 300x600m). Figure 3b indicates the magnitude of the field as a function of position in the same plane (the major contours represent a magnetic field strength of 10^{-2}, 10^{-3}etc. amp/m). Study of these figures shows that the geometry of Fig. 2 is neither the best nor the worst coupling; for example if the target dips at 20° at a depth of 500 m and a radial distance of 600 meters the coupling will be very poor and the resultant response completely undetectable. Conversely if the target is horizontal and lies 500 m below the transmitter loop the resultant response will be well over an order of magnitude greater than that indicated on Fig. 2b.

To assess the response to square targets of different size, we employ the fact that the initial amplitude of the response from a target of side "a" and conductivity-thickness S is (assuming the geometry to be held constant) proportional to a^2/S and the late-time time constant is proportional to aS. As the target becomes less conductive the time constant decreases but this is partially compensated for by the increase in the initial amplitude: Fig. 2b suggests that the response from a less conductive target at a depth of 500 m will just be detectable down to values of perhaps 10 mhos. On the other hand an increase in the target conductivity-thickness will make it difficult to detect at such a depth. Likewise an increase in "a" will improve the detectability whereas any reduction will once again make the target undetectable.

Taking these facts into account one may reasonably say that the exploration depth for moderately large, conductive targets is of the order of 500 meters for targets located within a few hundred meters of the transmitter loop.

HORIZONTALLY STRATIFIED EARTH MODEL

The technique of transient sounding in the near zone was described in detail in Technical Note TN-7. Examination of Figs. 19 and 20 of that Note shows that in general it is necessary to obtain the curve of apparent resistivity out to values of d/h of about 30 in order to fully resolve the two-layer geometry. Conversely, if the apparent resistivity curve is essentially constant with $t^{1/2}$ to a given time t_m we know that d/h is still less than 10 to time t_m. This allows us to calculate the minimum depth to an interface.

Using these criteria it is straightforward to calculate, given the upper layer resistivity, the system noise level, and the maximum available transmitter dipole moment the following depths; (1) the maximum depth to which we can fully resolve a relatively resistive (with respect to the uppermost layer) substrate, (2) the maximum depth to which we can fully resolve a relatively conductive substrate, and (3) the maximum depth to which we can state that there has been effectively no change in resistivity with depth. Fig. 4a illustrates these depths as a function of upper layer resistivity for a transmitter dipole moment of 4×10^6 amp $-m^2$ (easily achieved with the EM37) for an assumed resistivity contrast $\geqslant 5$.

We see for example, that if the upper layer is 100 ohm-meters it is possible to (1) fully resolve a 500 ohm-meter layer to a depth of 430 m, (2) fully resolve a 20 ohm-meter layer to a depth of 650 m and (3) determine (in the case of a homogeneous half-space) that there has been no significant change in resistivity down to a depth of 1700 m. If the upper layer were more resistive, for example 1000 ohm-meters, it is possible to resolve a relatively conductive layer to great depth, vis. 1000 m, and we note that it is still possible to resolve a relative insulator to 700 meters.

SUMMARY

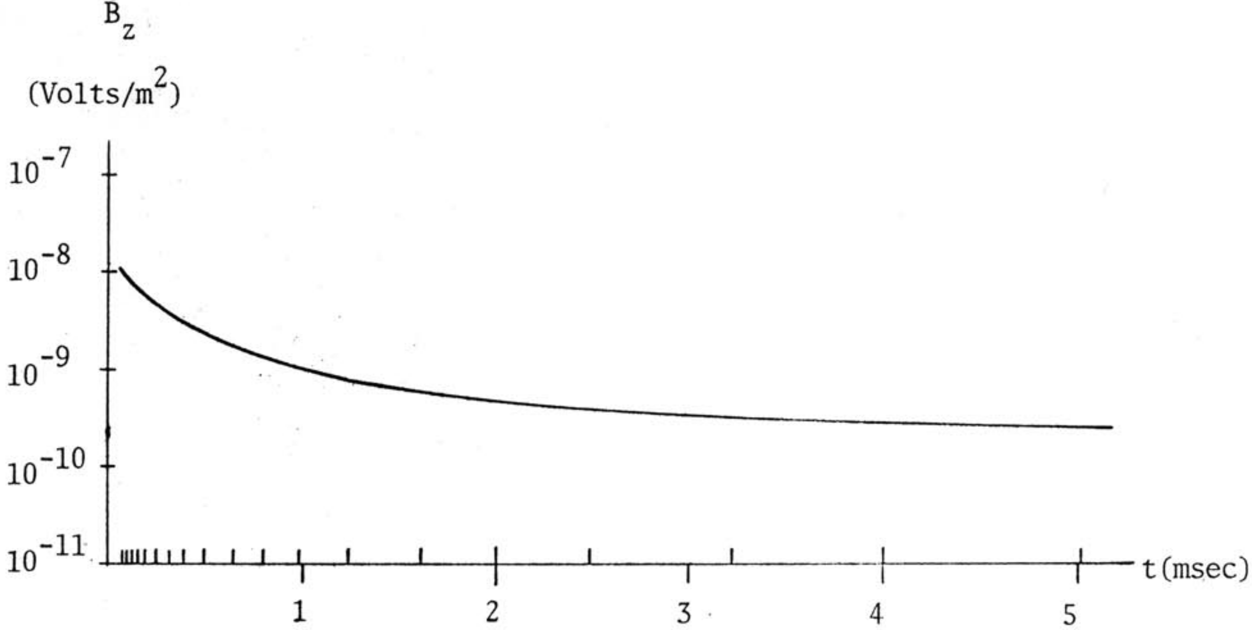
This technical note demonstrates that, using a ground transient electromagnetic system such as the EM37, it is now possible to explore to depths of the order of 500 m and beyond depending on the application.

Two points must be borne in mind: the first is that the thin-plate model responses were calculated in air. In general the effect of conductive overburden or host rock is to reduce the effective exploration depth by either attenuating or simply obscuring (as a result of lateral and vertical changes in the environmental resistivity) the response from potential survey targets. Either or both effects can reduce actual exploration depths to a fraction of the values calculated using free-space models. However, as pointed out in TN-7, when using transient systems some of the obscuring effects of environmental variations will be removed, or at least relieved, particularly when using high-powered systems with large bandwidth and high resolution, for then the transient decay curves can be analysed both at early time to characterize the overburden/host rock response, and at late time where the response from the orebody and the environment start to separate out.

The second point refers to the horizontally stratified earth model. Fig. 4b illustrates, for the same models as Fig. 4a, the latest time to which the measurement must be made in order to resolve or detect the models as indicated. Once again we see that measurement must be made over a wide range of time, particularly when we realize that these curves are for the interface at maximum depth and that for shallower depths the corresponding times are much earlier. A large number of gates, covering a wide span of time, are necessary in order to adequately measure over a reasonable range of depths and resistivities.

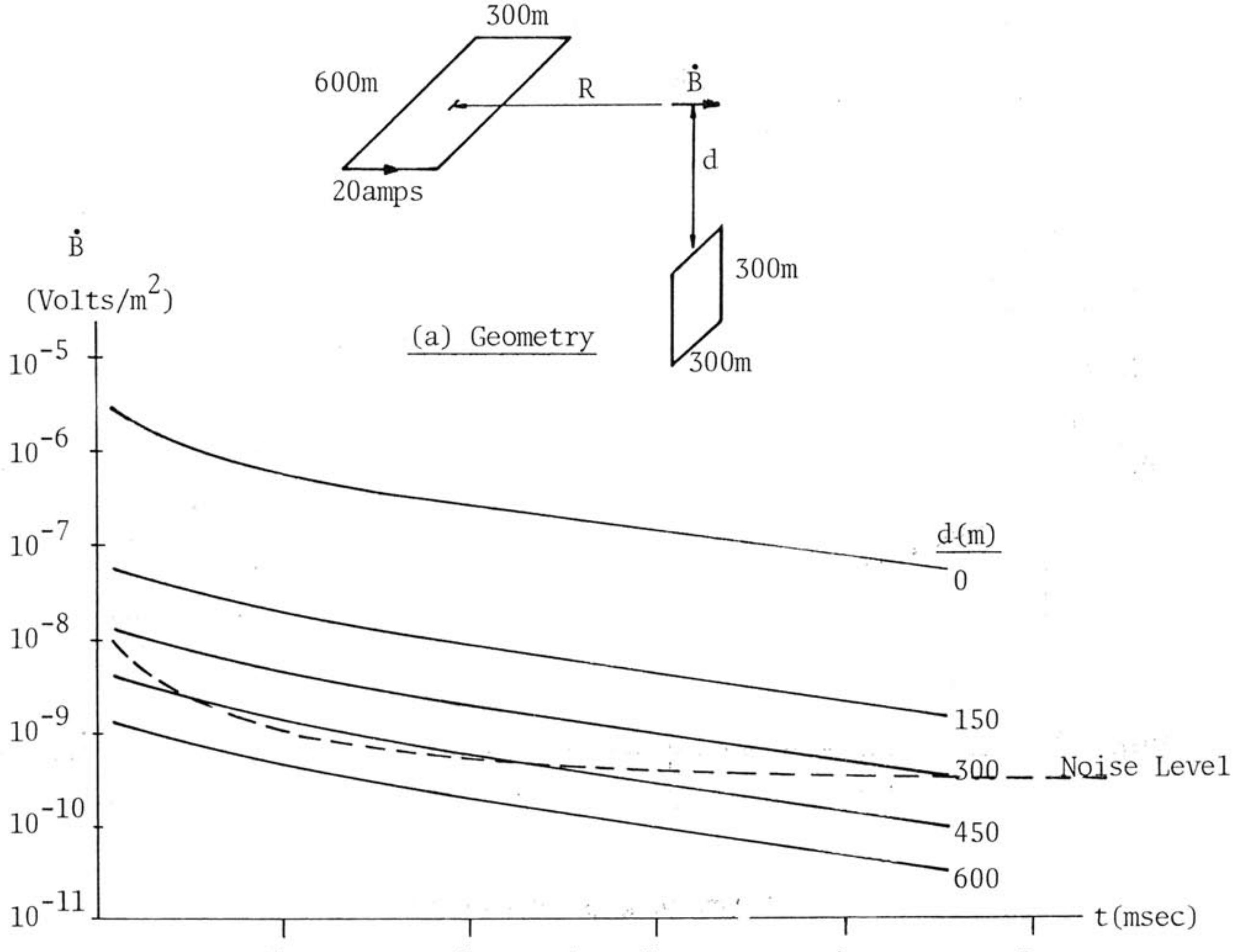
In summary it is anticipated that the new generation of high powered, large bandwidth, high resolution transient electromagnetic survey systems will in fact yield substantial increases in effective exploration depths.

(1) J.C.MacNae An Atlas of Primary Fields due to Fixed Transmitter Loop EM Sources.
University of Toronto Research in Applied Geophysics No.13 May, 1980.



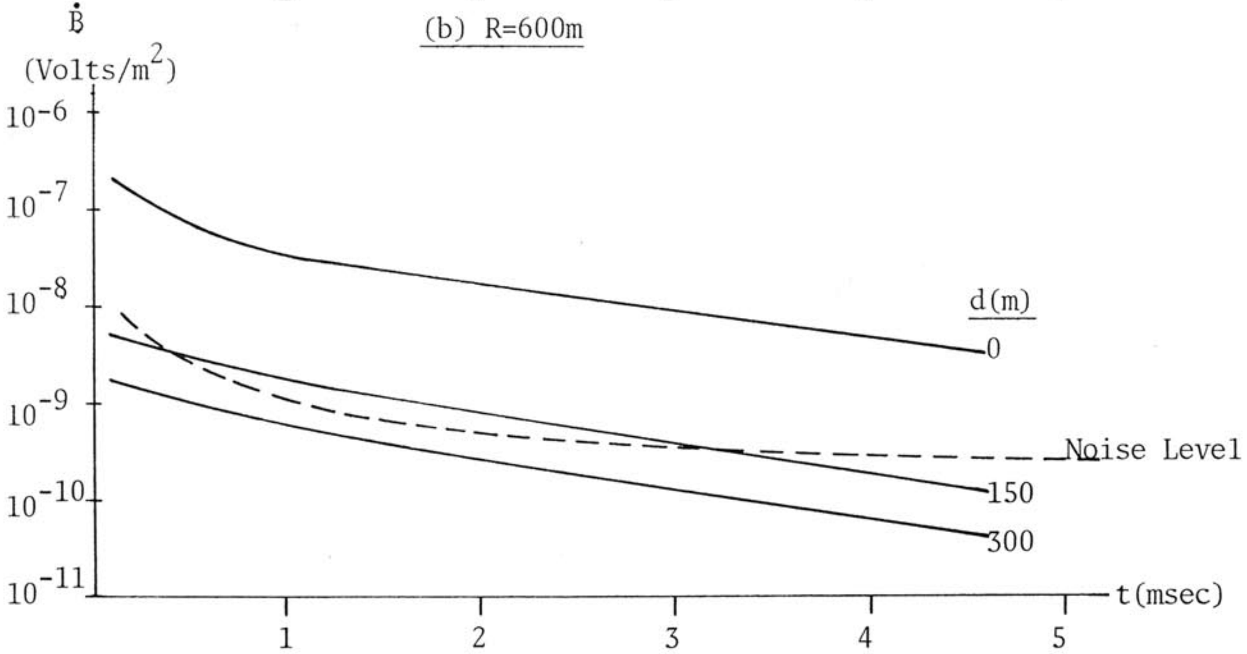
Average System Noise
(30Hz)

Fig.1



(a) Geometry

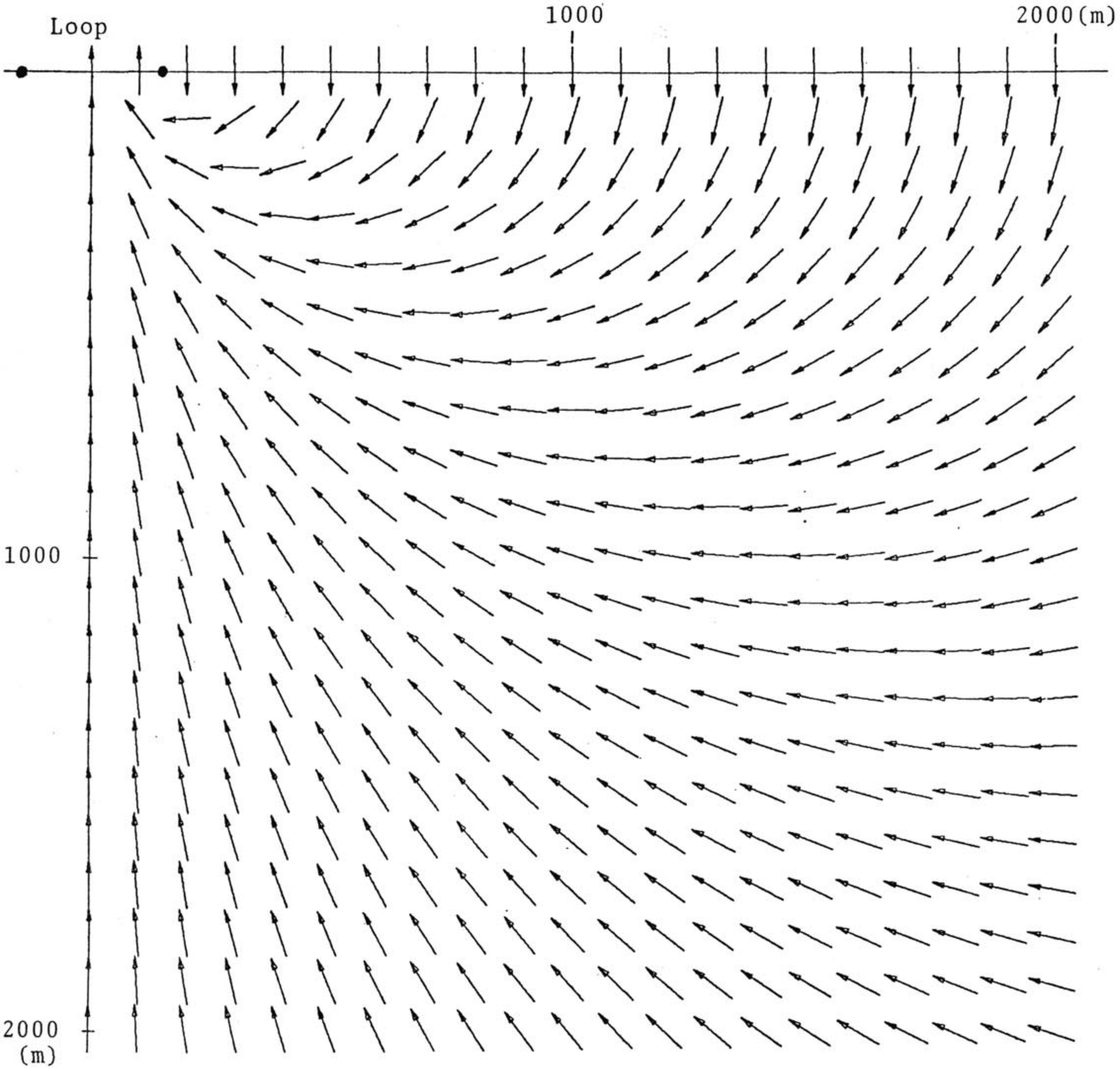
(b) R=600m



(c) R=1200m

Vertical Plate Response
(S=40 mhos)

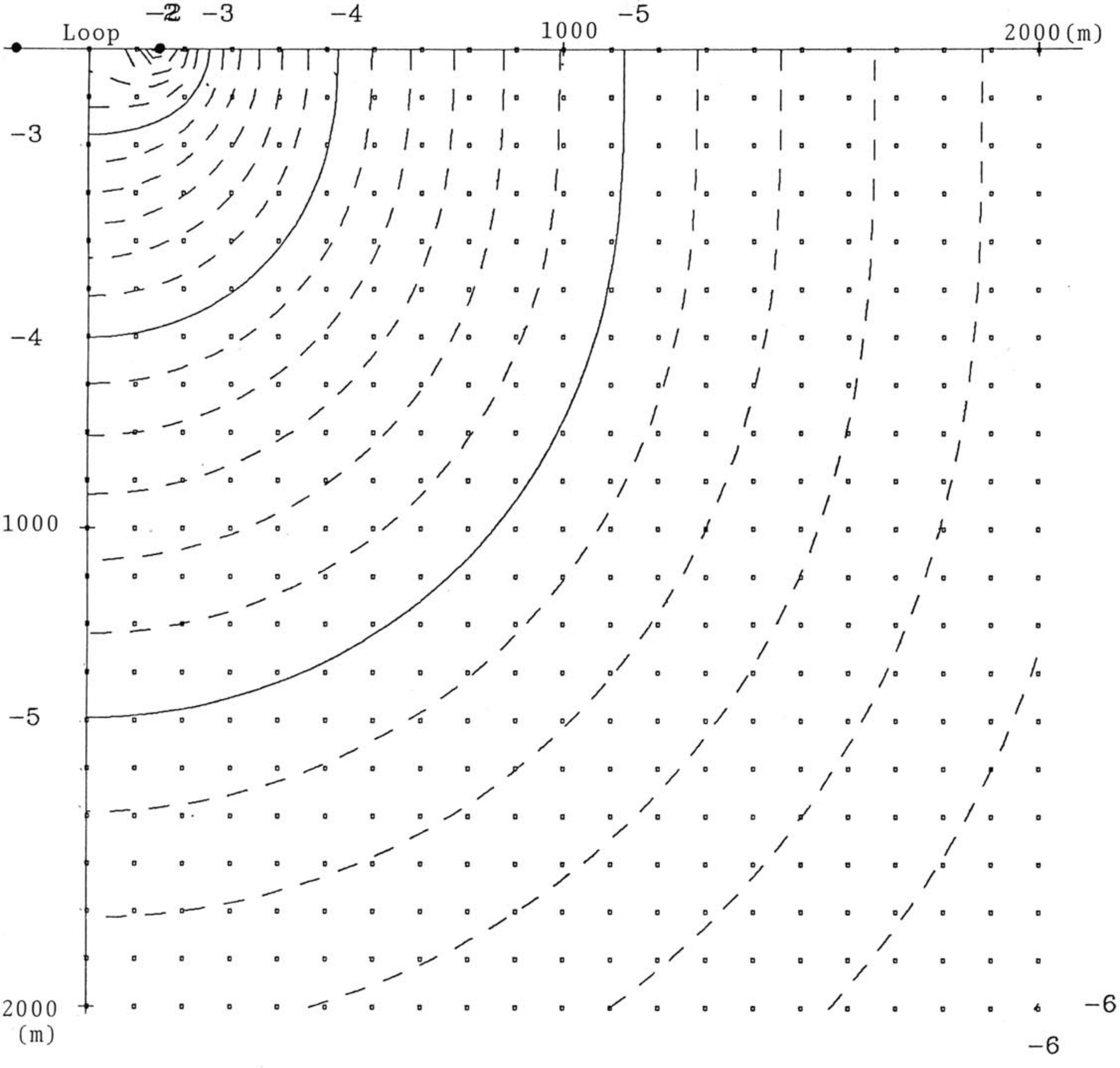
Fig. 2



Primary Magnetic Field Direction

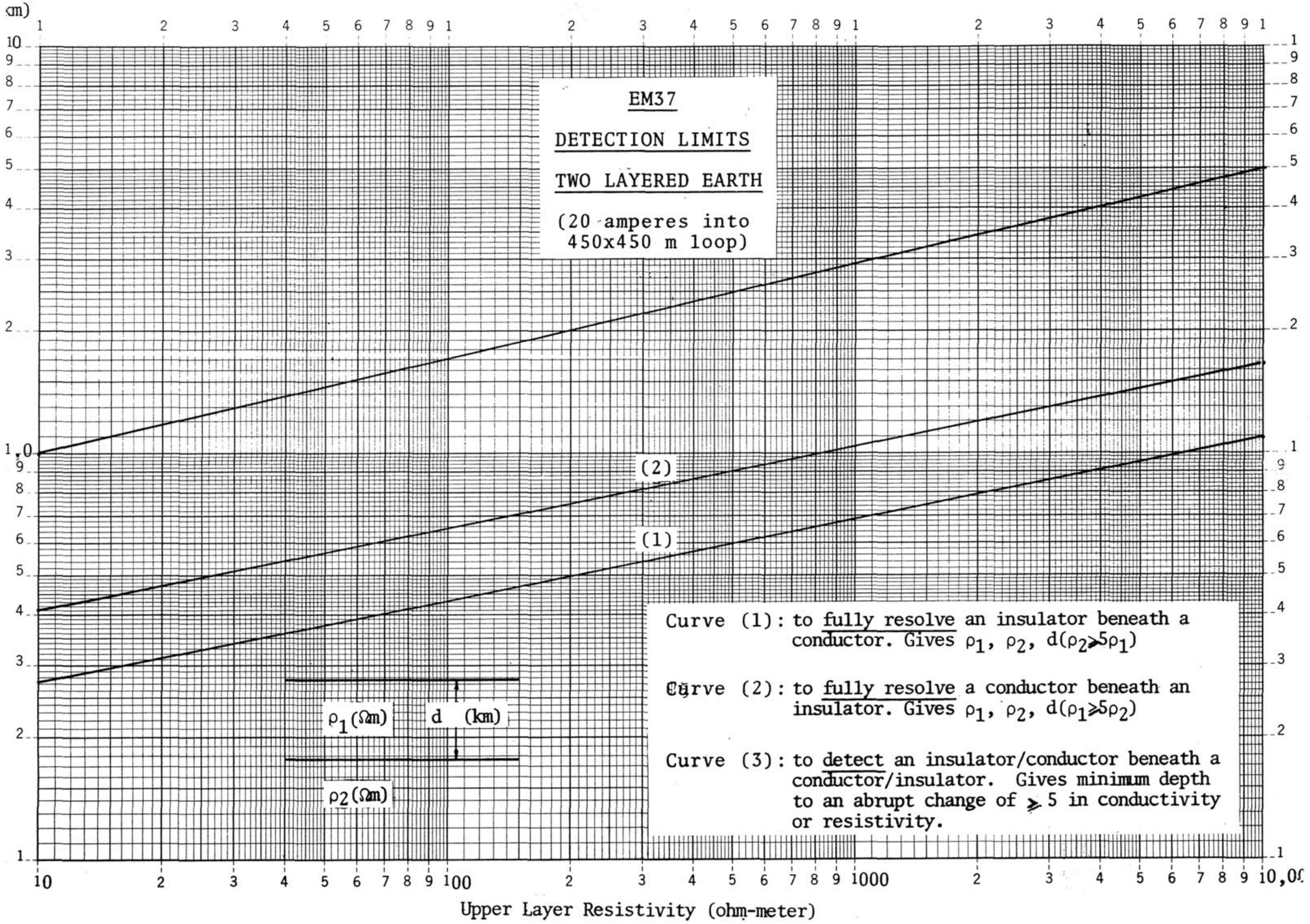
(300x600 m loop)

Fig. 3a



Primary Magnetic Field Strength (amp/m)
(300x600 m loop, 1 amp)

Fig. 3b



EM37

DETECTION LIMITS

TWO LAYERED EARTH

(20 amperes into 450x450 m loop)

Curve (1): to fully resolve an insulator beneath a conductor. Gives ρ_1, ρ_2, $d(\rho_2 \geq 5\rho_1)$

Curve (2): to fully resolve a conductor beneath an insulator. Gives ρ_1, ρ_2, $d(\rho_1 \geq 5\rho_2)$

Curve (3): to detect an insulator/conductor beneath a conductor/insulator. Gives minimum depth to an abrupt change of $\geq$ 5 in conductivity or resistivity.

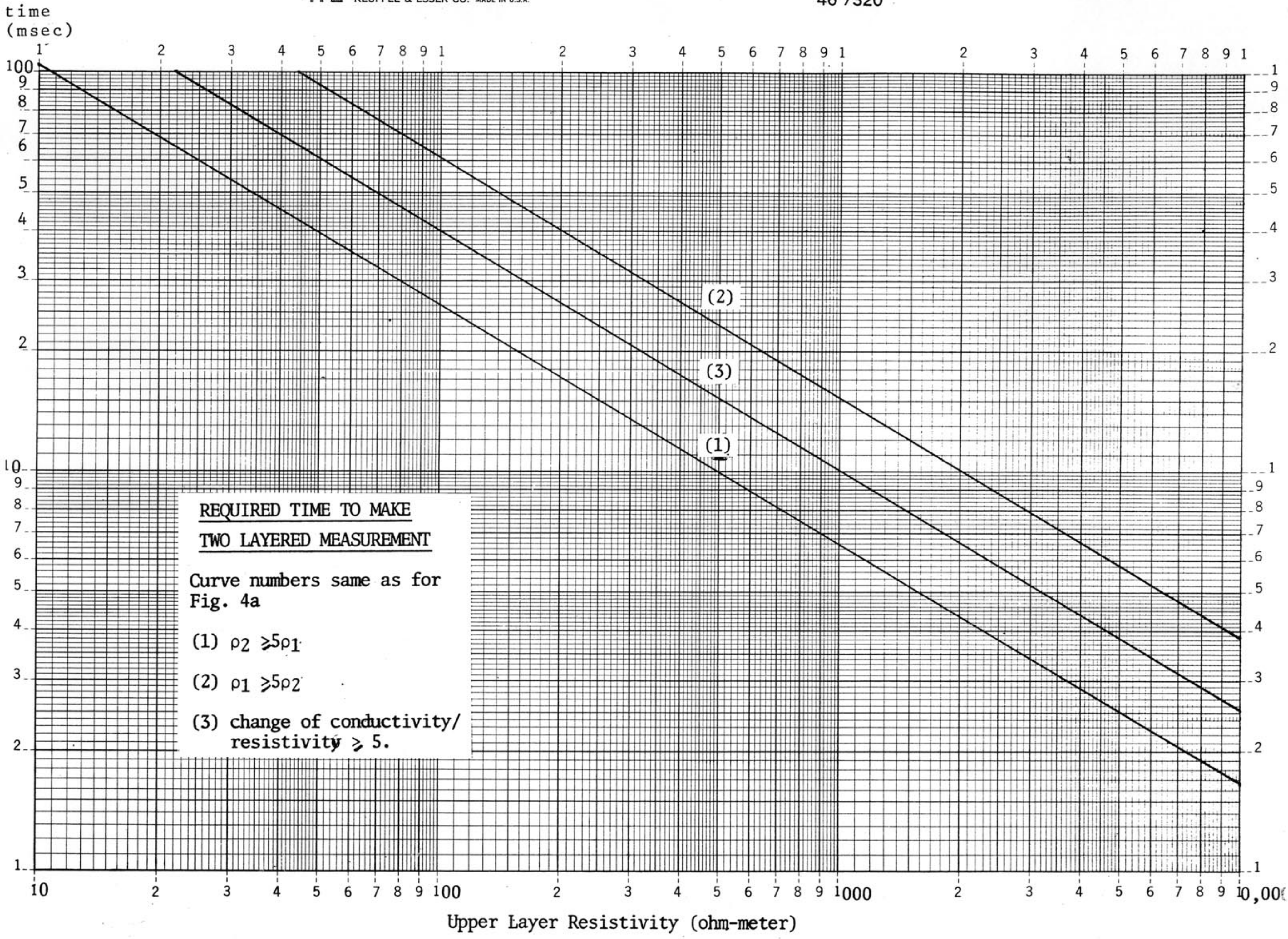

time (msec)
100
10
1
10
100
1000
10,000
1
Upper Layer Resistivity (ohm-meter)
(1)
(2)
(3)
REQUIRED TIME TO MAKE
TWO LAYERED MEASUREMENT
Curve numbers same as for Fig. 4a
(1) ρ2 ≥5ρ1
(2) ρ1 ≥5ρ2
(3) change of conductivity/resistivity ≥ 5.

Fig. 4b