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13. ABSTRACT (Maximum 200 words) The following report summarizes efforts on "Characterization of Pulsed Electromagnetic Induction (EMI) System". Specifically the effort focused on evaluating the operational characteristics of the EM-63 pulsed electromagnetic induction (EMI) system manufactured and sold by Geonics Ltd. at 8-1745 Meyerside Drive, Mississauga, Ontario L5T 1C6 (Web site: http://www.geonics.com).				
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Enclosure 1

Final Report for:

Characterization of
Pulsed Electromagnetic Induction (EMI) System
Research Agreement No. W911NF-05-1-0496

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1.0 Introduction

The following report summarizes efforts on “Characterization of Pulsed Electromagnetic Induction (EMI) System”. Specifically the effort focused on evaluating the operational characteristics of the EM-63 pulsed electromagnetic induction (EMI) system manufactured and sold by Geonics Ltd. at 8-1745 Meyerside Drove, Mississauga, Ontario L5T 1C6 (Web site: <http://www.geonics.com>).

A significant part of the effort was consumed in returning the EM-63 to the manufacturer for repairs. In particular we discovered that the transmitter current pulse did not conform to the manufacture’s specifications. As discussed in greater detail below, the correct transmitter current waveform consists of a positive current pulse followed (temporally) by a negative current pulse that in turn is followed by a short duration positive current pulse. Measurements indicated that the transmitter current waveform on our EM-63 had only a positive current waveform. It was necessary to return the EM-63 to the manufacturer twice for repairs since we discovered that the transmitter current waveform was still not correct after the first repair effort.

2.0 Specifics of the EM-63 Transmitter Waveform (Before and After Repairs)

Figure 1 shows the result of measuring the EM-63 transmitter current waveform with a TCP 202 Textronix current probe. Notice that the waveform consists of only positive going pulses. In particular the current period is approximately 133 ms and the duration of a current pulse is about 33 ms. Figure 2 shows a zoomed in view of the one pulse while Figure 3 shows a zoomed in view of the transmitter current turn off (both before repairs). It should be noted that the current turns off is a well defined linear ramp lasting approximately 130 μ s. It is important that the slope of the waveform not change during turnoff in order to avoid inducing a polarity change in the target induced voltage. A polarity change in the object induced voltage will reduce overall system sensitivity.

Figure 4 shows the EM-63 current waveform after the instrument was returned (for the second time) to Geonics Ltd. for repairs. Note that the “repaired” waveform consists of a positive pulse followed by a negative pulse followed in turn by a half width positive pulse. The first and second pulses have an approximately equal duration of 33 ms while the last pulse is around 16 ms in duration. All pulses are separated in time by approximately 33 ms resulting in a waveform period of approximately 150 ms. Measurements indicate that the waveform period is not fixed but varies randomly about a mean value of 150 ms. System noise is reduced by varying the waveform period.

3.0 Circuit Characteristics of the EM-63 Receiver Coils

A HP 89410A vector signal analyzer was used to measure the input impedance of the three EM-63 receiver coils. It was determined that each coil has approximately the same parameters. Measurements indicate that at 1 kHz that the receiver coil resistance is approximately 9.41 Ω while the receiver coil inductance is 865 μ H. Figure 5 compares the actual (measured with the analyzer) imaginary part of the coil’s input impedance with

the coil's reactance assuming that the coil's inductance is 865 μH at all frequencies over the measurement bandwidth. Note that at the lower frequencies (say below 4 kHz) the two curves do not differ appreciably while above 4 kHz the parasitic capacitive reactance of the coil causes the actual coil reactance to deviate significantly from the ωL value. Figure 6 shows the magnitude of the input impedance (in dB) versus frequency out to 500 kHz. Note that the resonance frequency of the coil occurs at approximately 200 kHz. One can estimate the coil parasitic capacitance from $f_r = \left[2\pi\sqrt{LC}\right]^{-1}$ obtaining a value of 732 pF (using a coil inductance of 865 μH and a resonance frequency of 200 kHz).

The significance of the receiver coil parameters in pulsed EMI design can be simply explained. The receiver coil is typically connected to a high gain operational amplifier in order to boost the weak target signal. Under these conditions second order interactions between the coil inductance and capacitance will cause oscillations to occur that interfere with detection. Typically these oscillations are eliminated by placing a resistor in parallel with the receive coil. When this is done the receiver coil sees the lower impedance of the resistor instead of the extremely high input impedance of the operation amplifier and thereby undesirable oscillations are eliminated.

4.0 EM-63 Preamplifier

Figure 7 displays a digital photograph of the EM-63 preamplifier. The EM-63 preamplifier has two purposes: first it routes the wires from the transmitter electronics contained in the console (the part of the instrument that hold the pro 4000 field computer) to the transmitter coils and secondly it amplifies the weak signal picked up by the receiver coils and passes the amplified signals back to the analogue-to-digital card in the pro 4000 field computer. As can be seen from Figure 6 there are basically three identical amplifier sections containing two op-amps each. We have used an oscilloscope to measure the output signals (at the left "nine pin connector" in Figure 6) and observed the expected analogue decaying exponential associated with each receiver coil. It should be possible to convert these signal directly into digital form and thereby avoid being forced to use the time gates chosen by the manufacturer. It is also interesting to observe the six LT-1028 transistor operational amplifiers by Linear Technology Inc. (in the silver TO-5 "cans"). Most likely each receiver coil uses a pair of LT-1028's. One will discover when investigating the specification sheet for the LT-1028 that it is an ultra low noise high precision device. In particular it can be trimmed to have very low dc offset and has very low DC offset drift. If the DC offset of the receiver coil amplifier is too high it can drastically reduce the overall dynamic range of the instrument. Essentially what happens is that as the target's exponential response decays there will be a point in time at which it reached the noise floor of the op-amp or the DC offset of the op amp (whichever is greater). If the DC offset is too high then dynamic range of the instrument will be significantly reduced relative to what could be achieved with a lower DC offset device.

5.0 Example waveform from the EM-63

Figure 8 shows an example waveform measured with the EM-63. In this case the target is a copper low with a diameter of about 1 ft and a cross-sectional area of a 1 square

centimeter. Additionally, Figure 9 shows the response of a 2 inch diameter steel cylinder long steel cylinder that is 8 inches long. A couple of observations can be made regarding this data. First, in the case of the copper loop the EM-63 is able to make measurements over six orders of magnitude from 10,000 mv down to 0.1 mv -- at least under conditions when the target is fairly close to the receiver coil. As mentioned above the instrument needs to be able to make measurements soon after the transmitter coil turns off and the receiver DC offset must be carefully controlled in order to make measurements over such a wide dynamic range. The response of the copper loop is described by a simple exponential function and so when plotted using a logarithmic ordinate and linear abscissa a straight line results. On the other hand the steel cylinder has a more complex response function and decays more quickly in early time and more slowly later in time. This response is indeed indicative of ferrous objects.

6.0 Conclusions

Overall progress on this effort was somewhat hampered by the fact that the EM-63 instrument that we received was found to be defective. In particular the transmitter electronics had to be repaired by the manufacturer (twice) before a fully functional unit was finally acquired. Furthermore, much of the understanding of the detailed operation of the instrument had to be referred from measurements via "reverse engineering" since most companies (including Geonics) strive to protect trade secrets and are thereby not inclined to share detailed circuit diagrams of their instruments. Although originally designed and manufactured some years ago the EM-63 is still an excellent geophysical instrument and offers the user a full time history of the eddy current response on an object. This data when combined with accurate positioning and fused with other geophysical instruments like the basic magnetometer offers an opportunity for advanced discrimination over what could be achieved with less well designed instruments.

It is this author's opinion the data acquisition technology currently used by is somewhat outdated. Modern data acquisition methods exist that allow wireless transfer of the instrument's data to a very light-weight hand held unit.

EM-63 Waveform Before Repairs

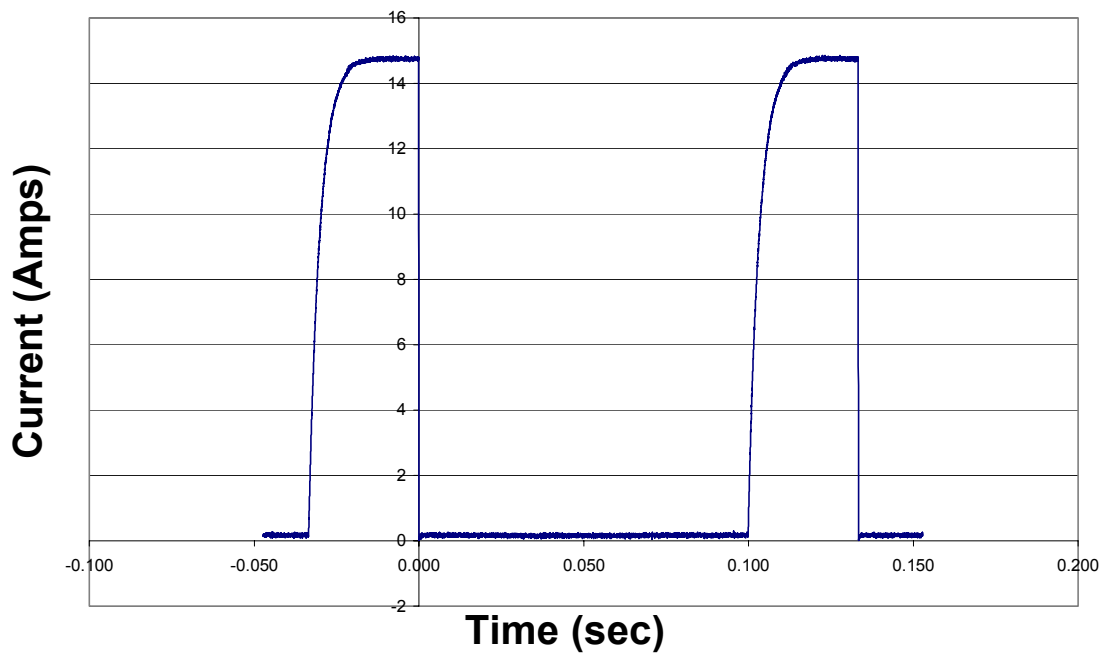


Figure 1. EM-63 Waveform Before repairs.

Zoomed in View of Transmitter Pulse (before repair)

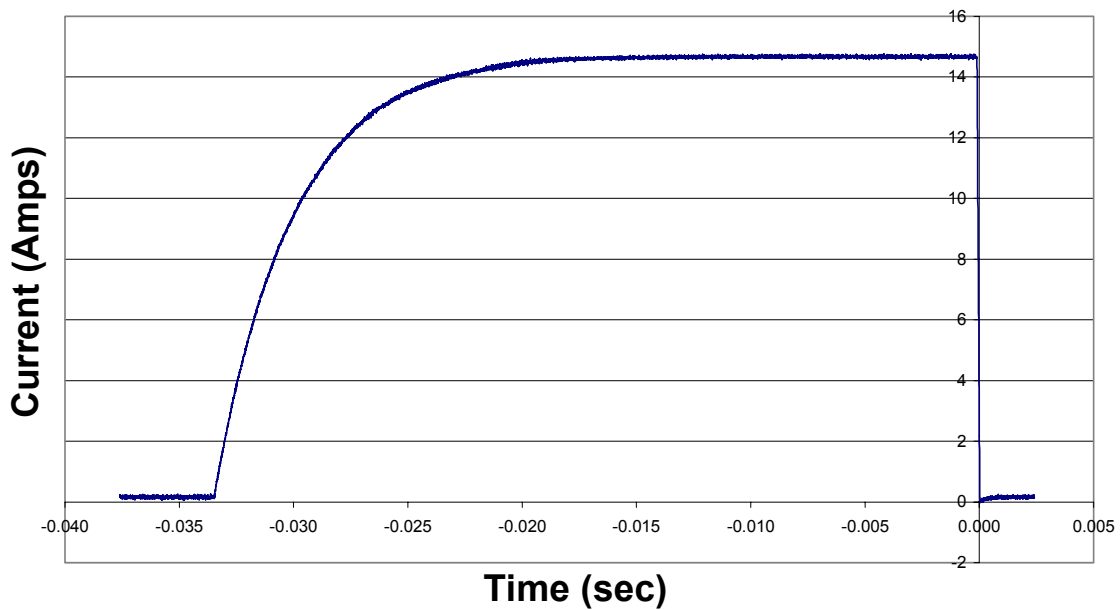


Figure 2 EM-63 Waveform with Zoomed in View of Transmitter Pulse (Before Repairs)

Zoom in Of Transmitter Current Turn Off (Before Repairs)

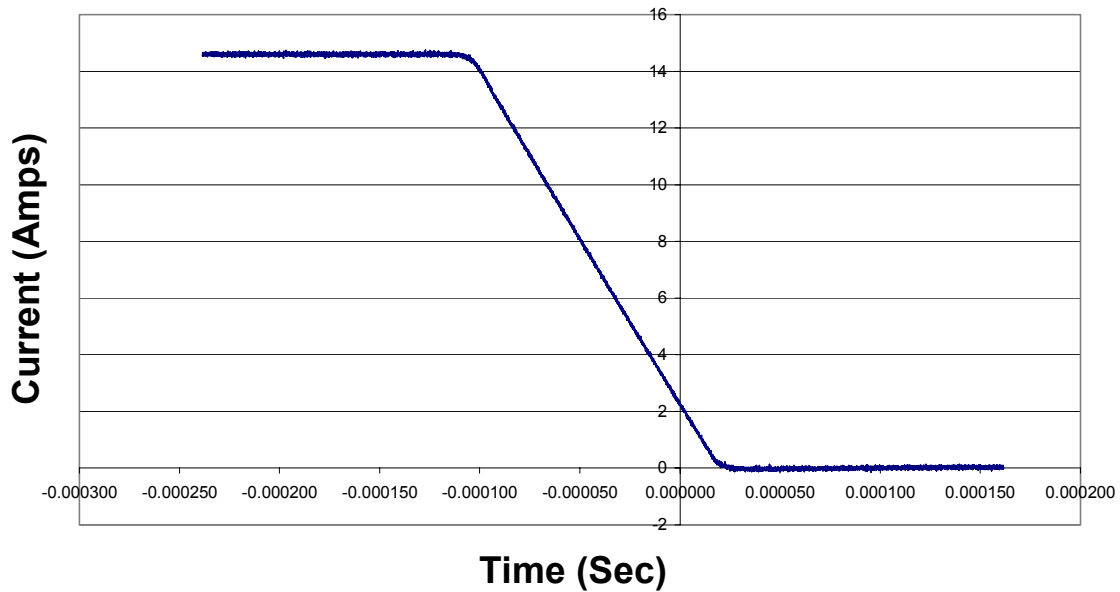


Figure 3. Zoomed in view of EM-63 Transmitter Current Turn Off. Notice that the current turns off in a linear ramp lasting approximately 100 μ s. Notice also that the current does not undershoot but rather maintains a constant slope all the way to zero amps.

EM-63 Current Waveform After Repairs

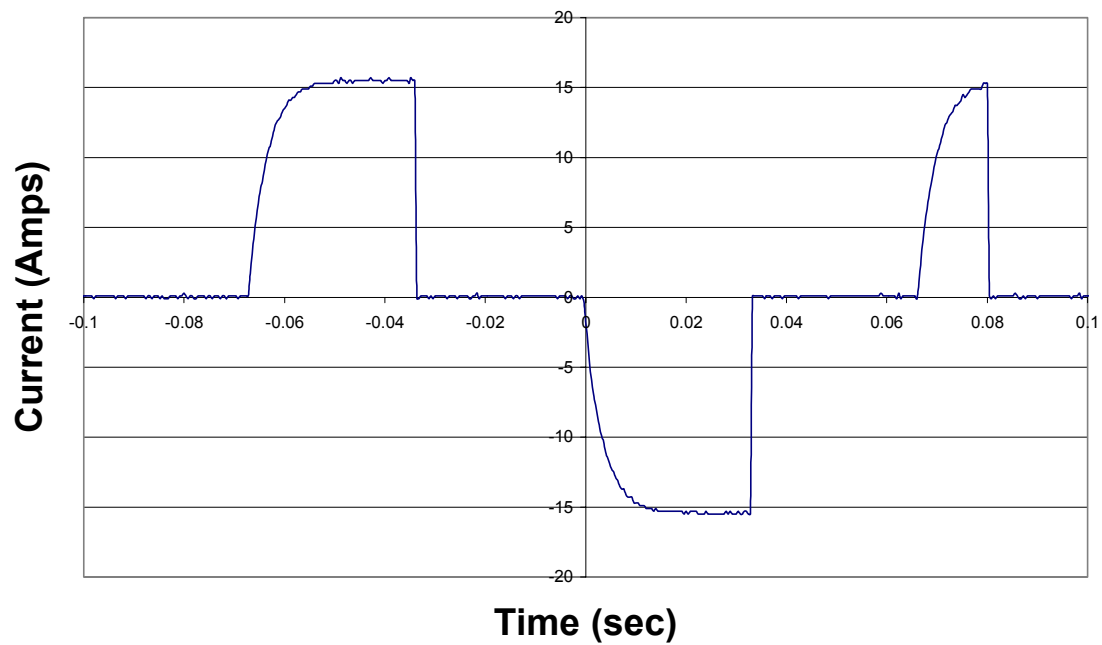


Figure 4. EM-63 Transmitter Current Waveform after Repairs. Notice the bipolar nature the waveform. Also the period of the waveform is not constant but rather is varied randomly about a mean period in order to reduce system noise.

jwL versus imaginary part of input impedance

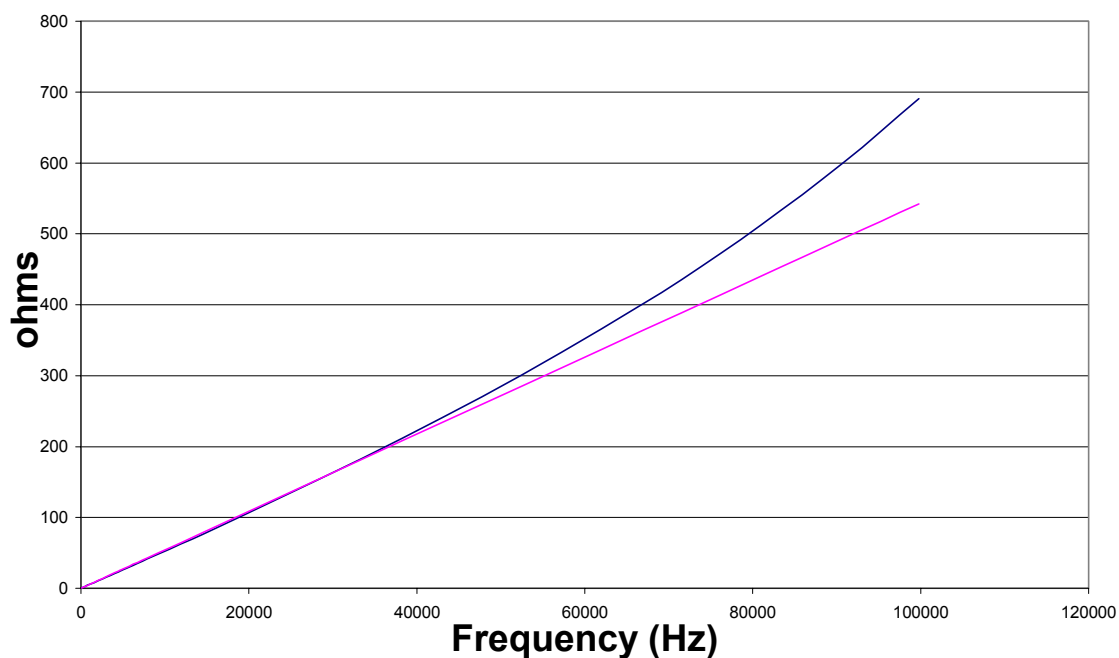


Figure 5. Imaginary part of the input impedance of the receiver coil of the EM-63. The dark line is the actual measured input impedance while the magenta line is the inductive reactance of the receiver coil assuming the coil inductance is 865 μH (independent of frequency). The curves deviate due to the parasitic capacitance of the receiver coil.



Figure 7. Preamplifier Circuit of the EM-63. Three identical circuits are used one for each of the receiver coils. The LT-1028 operational amplifier incorporated in the design has good linearity and very low DC offset. Several test points can be identified to extract raw target data.

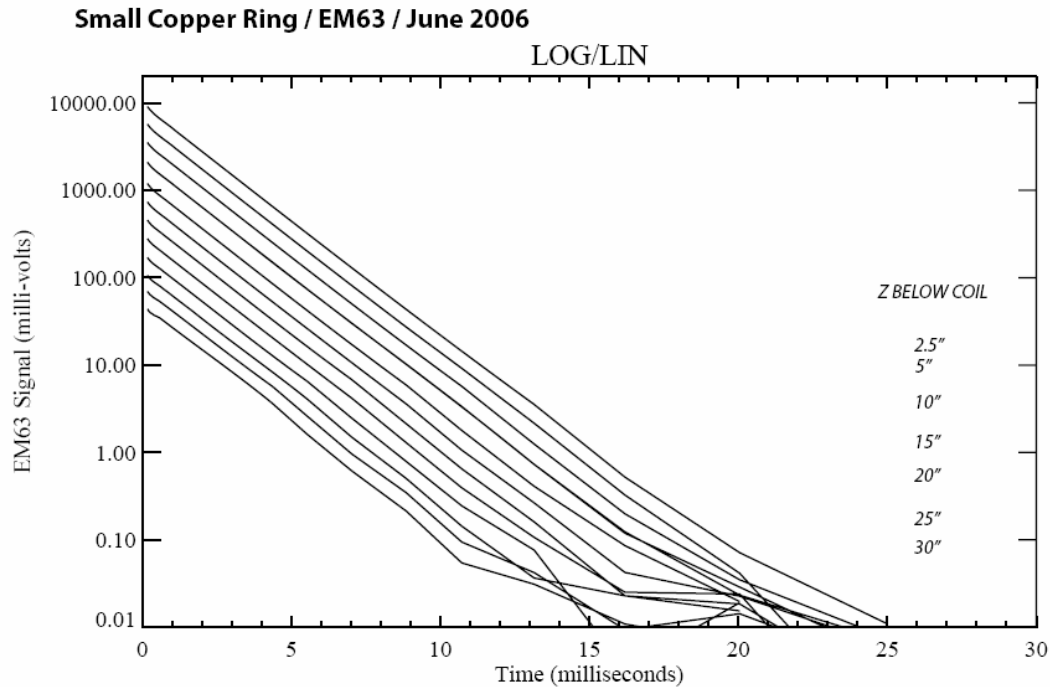


Figure 12 EM-63 response of copper wire loop for various distance from the sensor. Note that the dynamic range of the instrument extends over 6 orders of magnitude. Note the since the response of the loop is described by a single exponential the curve is linear when plotted using a logarithmic exponential.

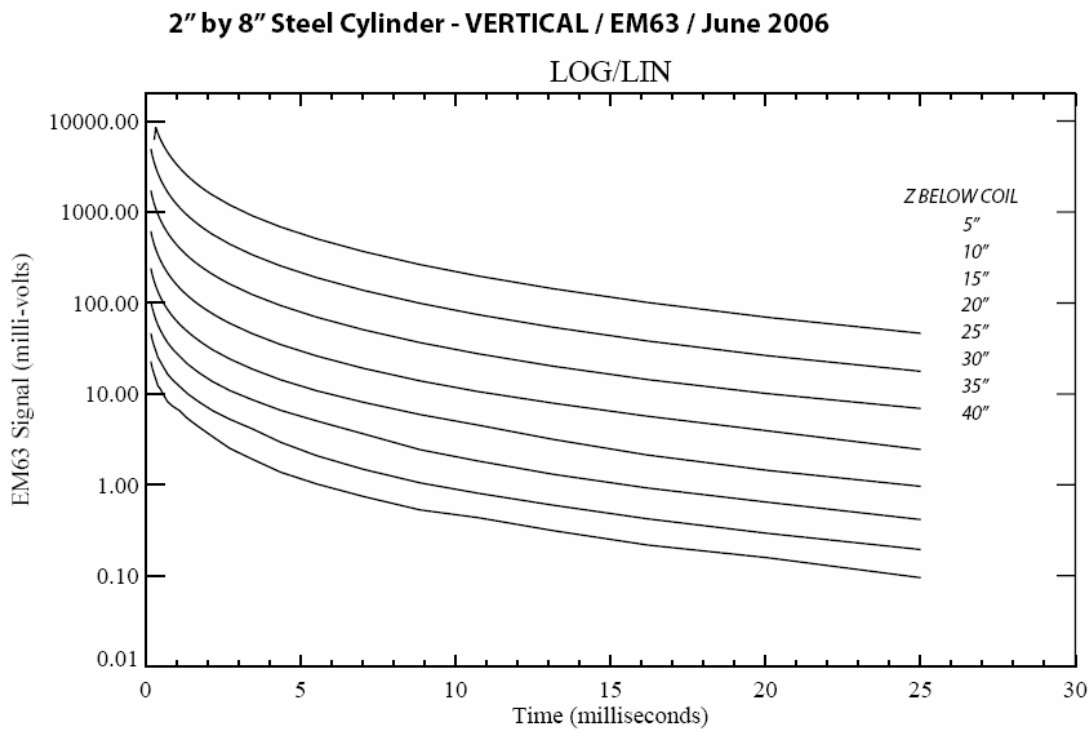


Figure 13. Response of 2" by 8" Steele Cylinder. Notice the response decays more rapidly in early time than in late time.