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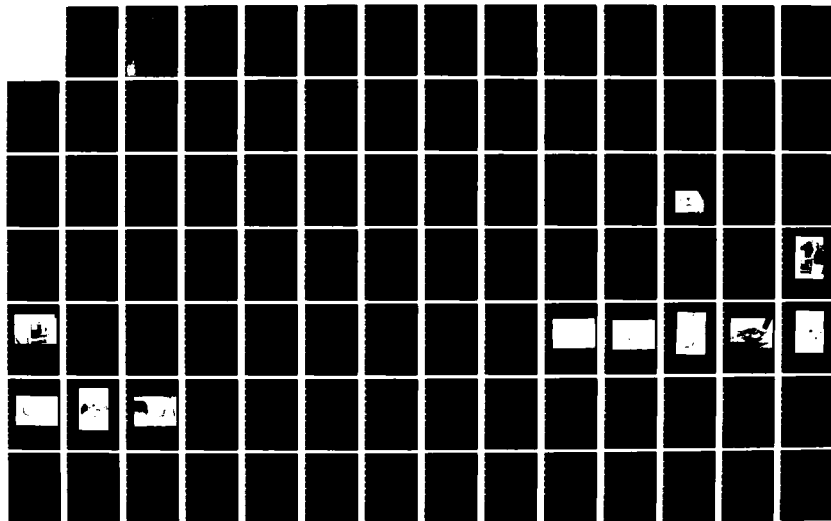
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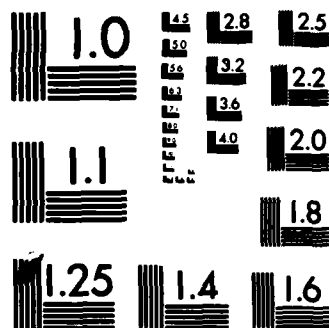
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THE APPLICATION OF A SUPERCONDUCTING
QUANTUM INTERFERENCE DEVICE SECOND-ORDER
GRADIOMETER TO MEASURE VISUAL EVOKED
RESPONSES

THESIS

AFIT/GE/EE/83D-50

ROBERT D. MURRAY
CAPT. USAF

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DEVICE SECOND-ORDER GRADIOMETER TO MEASURE VISUAL
EVOKED RESPONSES

THESIS

Presented to the Faculty of the School of Engineering
of the Air Force Institute of Technology,
Air University
in Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Electrical Engineering

by

ROBERT D. MURRAY

CAPT. USAF

Graduates Electrical Engineering
December 1983

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PREFACE

For many years, I have been fascinated with the profound, yet mysterious capabilities of the brain. This marvelous mass of tissue is able to perform complicated tasks involving the combination of sight, touch, hearing, taste, and smelling, while automatically performing life sustaining functions. Although, these tasks are often complex, many of them can be performed by young children. Yet, how the brain is able to perform these tasks is still much of a mystery.

For many years, researchers in the area of brain and central nervous system research, have used two methods to attempt to unlock the mysteries of the brain. The first method was the use of a standard electroencephalographic (EEG) machine, using scalp electrodes, to measure the gross electrical activity of the brain as measured on the surface of the scalp. The second method used to gain some insights into the operation of the brain was the meticulous, and painstaking measurements of the responses of individual brain cells to specific sensory stimulus, via the use of microelectrodes, a extremely slender glass or metal electrodes which are inserted into the individual cells.

It was late in the 1960's before advancements in cryogenics, and in the technology of superconducting semiconductor devices, brought about a new, and powerful tool to be used in the quest for understanding of the brain. This powerful tool is the Superconducting Quantum Interference Device (SQUID) Gradiometer. This device allows us for the first time to measure extremely small magnetic field, as those

associated with brain activity. I am grateful to have the opportunity to work with such a state-of-the-art research tool in my research, and at such an historical time as soon after the successful implantation of the AFIT array integrated circuit, the first cortical implant of a multiplexed multi-electrode.

I gratefully acknowledge the support of Mr. Gary Reid of the Aerospace Medical Research Laboratory in seeing that equipment was available to me as needed. Also, my thanks go to Mr. Alva Karl and the Life Science personnel of the laboratory, for the preparation and care of my canine subject, Ricky.

My sincere appreciation is extended to many people working for the Systems Research Laboratories, Inc. Some of there employees which I would like to thank especially are : Barbara McFawn for her overall support and technical advice, Karen Peio for her expert instructions in use of laboratory equipment, Donald Stafford for his advice, and maintenance of the SQUID gradiometer, Shelton Unger for his expert software support, Heather Dippel for being a willing MEG subject, Regina Palmer, Melita Ritter for their support in my data collection, and finally, David Holloway for his graphics support.

I gratefully recognize Dean L. E. Wolaver for his interest and work as a committee member, and his instruction in his interesting bioengineering class.

I would especially like to thank Dr. Matthew Kabrisky for his excellent classes on the central nervous system, and in sensory communication. These classes, along with my other

bioengineering classes motivated me to quest further knowledge in these areas. Also, I would like to thank him for support, and encouragement in my thesis effort.

Another special thanks goes to my thesis advisor, Dr. Charles P. Hatsell for his expert support, guidance, and technical advice. His expert knowledge in the areas of engineering and medicine, and his high degree of professionalism, sets a high standard for a researcher to follow.

Finally, I would like to express my sincere, and equally important gratitude to my wife, Sherry Murray, and our sons, Robert D. Jr., and John N. Murray, for their patience and understanding during the long work hours, both at home and away from home.

Robert D. Murray

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ABSTRACT

The acquisition of a Superconducting Quantum Interference Device (SQUID) gradiometer, ~~by the Air Force Aerospace Medical Research Laboratory~~, along with the previous research conducted at the Air Force Institute of Technology which led to the first cortical implant of a multiplexed multi-electrode semiconductor brain electrode, motivated the use of the SQUID second-order gradiometer to measure visual evoked responses (VER) from humans, and from the canine which had previously had the AFIT brain electrode implanted and removed. Some discussion of the current dipole model for the fields measured from the brain is presented. The human visual evoked responses picked up by gradiometer were compared to previous human electroencephalograph visual evoked responses, and were found to have similar latencies. The canine visual evoked responses which were measured by the gradiometer had similar initial waveform and latencies, but then dampen out more rapidly than the waveforms measured by the AFIT brain chip. Conclusions about the use of a SQUID gradiometer in measuring visual evoked responses, along with comparisons between the EEG and AFIT brain chip data versus the SQUID data is discussed. Recommendations for further research with the SQUID gradiometer by itself, and it in conjunction with the AFIT brain chip are discussed.

CHAPTER I

INTRODUCTION

BACKGROUND

Ever since the discovery of the electrical properties of nerves in the eighteenth century, scientists have been studying this phenomenon in the hope that with its understanding, they would be better able to understand how the central nervous system functions (Ref. 1:2). This quest to understand the central nervous system, and especially the brain, gave birth to the modern science of neurology, which is the branch of medicine which deals with the nervous system and its diseases, and to the modern science of neurophysiology, which is the branch of medicine which deals with the physiology of the nervous structure of the body. Even though, through the years, many new tools were developed for neural researchers, these tools were usually improved versions of their predecessors, rather than new innovations.

Ever since Hans Berger discovered human brain waves in 1924, after he placed small metal strips on the scalps of his subjects and ran wires from these strips to a sensitive galvanometer, the electroencephalograph (EEG) has been a major tool used by researchers to study brain activity (Ref. 1:98). Many improvements have been made to the standard electroencephalograph over the years, but still the basic concept of the EEG is measurement of electrical potentials on the subjects scalp via "gross electrodes" placed at specific locations on the scalp, and then interpreting these

measurements in the hope that detailed information about mental processes, and the mental and physiological condition of the subject might be realized. A good example of the use of the EEG as a diagnostic tool is shown in Figure 1-1, which shows an EEG record taken during a brief epileptic fit -- note the spiky waves during the attack (starting at the arrow marked a) and the return of the alpha rhythm after eye closure (arrow marked b)" (Ref. 2:148). For more background in the use of EEG, see references 3,4,5,6,7, and 8.

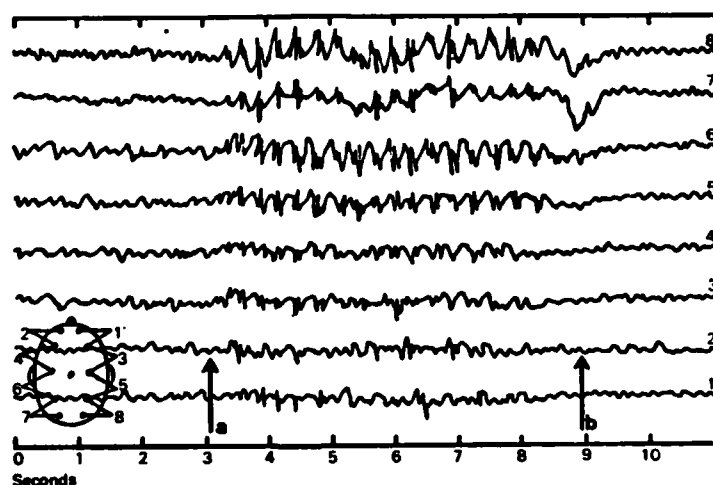


FIGURE 1-1
EEG RECORD OF BRIEF EPILEPTIC FIT
 (Ref. 2:148)

Another tool which researchers have used to study brain activity, is the microelectrode. The basic microelectrode is usually a extremely slender glass or metal electrode which is inserted into or near an individual neuron. Once again, it is electrical potentials which are measured, but this time the firing rates of action potentials of the neurons are analyzed.

This tool has been used in many, and varied research in neuron activity. Figure 1-2 shows nerve fiber activity signals which were taken by a microelectrode inserted into the hand of a subject lying at rest (Ref. 9:141).

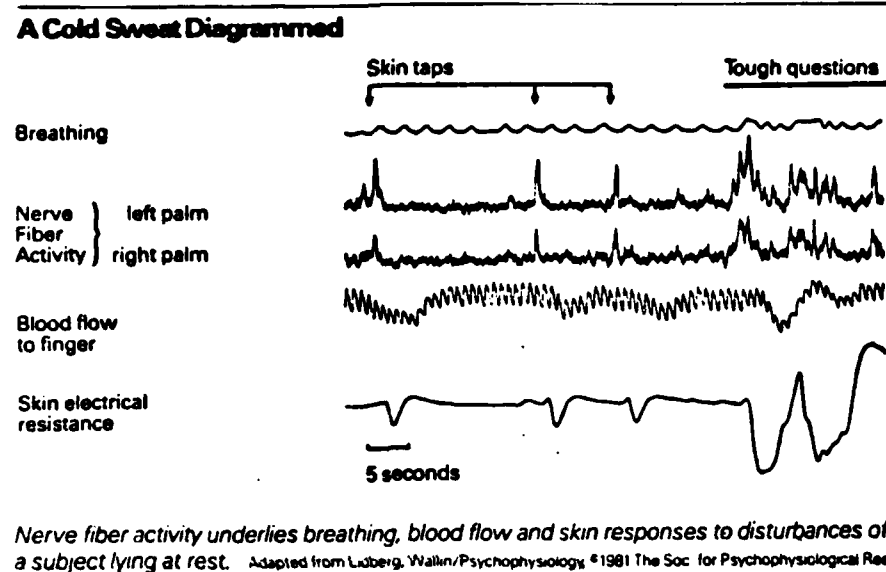


FIGURE 1-2

**EXAMPLE OF NERVE FIBER ACTIVITY
TAKEN WITH A MICROELECTRODE
(Ref. 9:141)**

For more background in the applications of microelectrodes in neural research see references 9 thru 16.

Although, both the use of the electroencephalograph and the use of the microelectrode has provided us with valuable information in the study of the central nervous system, and related electrical phenomenon, two newer innovations have provided additional understanding of neural activity. These two advance measurement devices are AFIT Cortical Implant and

the Superconducting Quantum Interference Device (SQUID) Gradiometer.

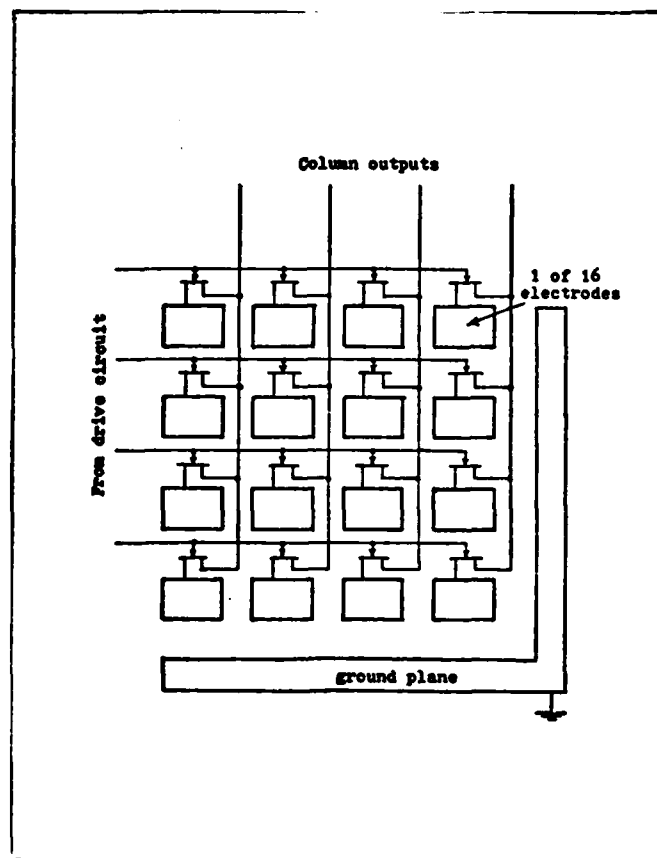


FIGURE 1-3

AFIT MULTIELECTRODE ARRAY
(REF 18:55)

In October, 1982, the first cortical implant of a multiplexed multi-electrode semiconductor brain electrode was successfully implanted on the brain of a laboratory beagle (Canis familiaris) (Ref. 17 and Ref. 18). It is an X-Y addressable, 16 electrode (4 X 4 array) multiplexed

switching electrode based on contemporary silicon computer chip technology (Ref 17). The circuit diagram for the electrode is shown in Figure 1-3.

The development of the AFIT implant is important, since it allows us to measure potentials directly from a very small area of the cortex of the brain; the electrodes were spaced 30 microns apart in one direction and 100 microns in the orthogonal direction.

Now that we have a device which can measure potentials directly from the surface of the cortex of the brain, we can look at other approaches to the measurement of brain activity. The relatively new approach to the measurement of brain activity is the use of a SQUID gradiometer to measure the magnetic fields emanating from the brain. This approach was slow in coming because we didn't have the technological advancements necessary to take these measurements until relatively recent years. These advancements were made in the fields of cryogenics, and the very low temperature superconducting semiconductor physics, which developed Josephson Junction electronic devices to be used in the Superconducting Quantum Interference Device. A discussion of the theory involved in the operation of a SQUID gradiometer will be later (Chapter 2).

Having now, both the AFIT cortical implant electrode research continuing, and research at the Air Force Aerospace Medical Research Laboratory with a second-order SQUID gradiometer, I decided to take a series of magnetic measurements with the SQUID gradiometer, and compare the results with

predicted values, and with measurements taken by the AFIT cortical implant electrode.

STATEMENT OF THE PROBLEM

The primary emphasis of this research is the comparison of measurements taken with a second-order SQUID gradiometer to waveforms either predicted mathematically, or to waveforms measured in the past with an EEG or a AFIT cortical implant electrode.

The first area of investigation was comparing the predicted mathematical magnetic and potential fields waveform emanating from a current dipole submerged in a saline solution.

Next, magnetoencephalographic visual evoked responses were measured from several human subjects, and compared with the basic EEG visual evoked response waveform.

Finally, magnetoencephalographic visual evoked responses were measured from the same laboratory beagle which had had electroencephalographic visual evoked responses measured by the AFIT cortical implant electrode.

SCOPE

When the dewar which held the liquid helium for the SQUID gradiometer failed to maintain superconducting temperatures, the ensuing downtime, along with the growing interest to measure magnetoencephalographic visual evoked responses from the same laboratory beagle which had had electroencephalographic visual evoked responses measured by the AFIT

cortical implant electrode, I decided to place my primary emphasis in taking measurements with the SQUID gradiometer. I especially placed my emphasis on measuring visual evoked responses from the laboratory beagle, instead of doing a feasibility study of simultaneous or near simultaneous electroencephalographic and magnetoencephalographic measurements from a brain.

The problem with the SQUID gradiometer downtime also reduced the amount of time I had to collect data, but sufficient data was collected to make conclusions possible.

APPROACH AND PRESENTATION

This research is presented in essentially chronological order, with each chapter representing a phase of research.

Chapter II gives a brief discussion into the theory behind the SQUID gradiometer, along with some of its proposed applications.

Chapter III gives a look at the basic current dipole model for the brain, along with the predicted and measured results for a current dipole submerged in a saline solution.

Next, Chapter IV discusses some basic theory behind visual evoked response measurements, along with human magnetoencephalographic visual evoked responses waveforms compared to the standard EEG waveform for a visual evoked response.

Chapter V details the magnetoencephalographic measurement of the laboratory beagle's visual evoked response, along with the comparison of the magnetoencephalographic visual evoked response to the electroencephalographic visual evoked

response.

Chapter VI draws conclusions about the use of the SQUID gradiometer to measure magnetoencephalographic visual evoked responses, and summarizes the results of this research.

Finally, Chapter VII makes recommendations for further experiments using the SQUID gradiometer.

CHAPTER II

SQUID GRADIOMETER THEORY

THEORY

SQUID is an acronym of "superconducting quantum interference device." In this chapter I will first discuss general SQUID theory, and then I will discuss some parameters and details of the specific SQUID gradiometer which I used in measuring the visual evoked responses.

First lets look at the SQUID gradiometer as a black box to see how it behaves when magnetic flux crosses perpendicular to the input detection coil. The input to this black box is the current which the external magnetic flux cutting the input detection coil induced into the detection loop. The output of the black box is a voltage which is proportional to the amount of magnetic flux which has perpendicularly penetrated the effective area of the input loops. So, we can say that it simply behaves like a current-to-voltage converter. It offers very high gain, extremely low noise, wide dynamic range, excellent linearity, and a wide bandwidth, extending down to dc. The current-to-voltage conversion factor for a SQUID gradiometer is usually approximately 10^7 V/A (Ref. 26:70).

Well, we see from the black box outlook, the SQUID gradiometer can give us a voltage which is proportional to a small magnetic flux detected by its input detection coil. This is an interesting conclusion, but what is the significance of the SQUID gradiometer which makes it the major tool in the area of biomagnetic measurement? It is the SQUID gradiometer's

capability to detect a magnetic field as weak as 10^{-15} Tesla which makes it so attractive in many areas of research. That weak magnetic field is over 10^{10} times smaller than the magnetic field of the earth.

Now that we have an idea of some of the capabilities of a SQUID gradiometer, let's discuss in greater detail the attributes of a SQUID gradiometer which gives it those capabilities. First, let us start by dissecting the acronym "SQUID" into its components. The "S" stands for superconducting. This device uses a special semiconductor device which operates at superconducting temperatures, that is, temperatures usually below 20° Kelvin. This special device is called a superconducting insulator-barrier junction, or more commonly as a Josephson junction, after the Noble-prize-winning English graduate student, Brian Josephson, who predicted the junction's properties in 1962 (Ref 27:42). In the literature, the Josephson junction is referred to as a "weak link" device. Josephson junctions which we find in SQUID gradiometers many times rely on the oxide at the surface of a sharp niobium point where it presses against a flat niobium surface. They are called "point contact" Josephson junctions. The superconducting transition temperature for niobium, that is, the temperature at which niobium resistance drops dramatically to approach zero resistance, is 9.2° Kelvin. The resistance of the superconducting material is not exactly zero, since you still have some molecular motion even at 9.2° Kelvin. To get zero resistance, the superconducting material must be at 0° Kelvin. Even though the resistance is not

exactly equal to zero for superconductors operating at 9.2° Kelvin, by using rings with very low inductance and a very long measurement time, together with a high sensitivity current detector, it has been possible to demonstrate that the residual resistivity of a superconductor is at least 10^{17} smaller than the resistivity of copper at room temperature. Therefore, for all practical purposes, we can consider that the superconducting material has zero resistances (Ref. 26:72). To insure that the SQUID remains superconducting, it is usually immersed in a bath of liquid helium. The 4.2 degrees Kelvin temperature of the liquid helium bath is adequate to keep the SQUID superconducting (Ref. 26:69).

But what effects of this superconducting Josephson junction allows it to be used in a SQUID gradiometer? First lets review the Meissner effect of a superconductor. Back in 1933 in Berlin, two men, Meissner and Ochsenfeld, found that the interior of a superconducting material is free of magnetic flux independent of whether the magnetic field is applied above or below T_c , the superconducting transition temperature. This property is now commonly known as the Meissner effect. In the presence of a magnetic field, a current in a very thin surface layer is generated in such a way that its field compensates the field inside. This is distinctly different than for an ideal case of Lenz's law, since the expulsion of flux from the Meissner effect occurs even in a constant field as a sample is cooled through its transition temperature. The superconductor behaves as an ideal diamagnetic material with susceptibility equal to -1 (Ref. 26:72).

The "QU" and the "I" in the acronym comes once again from the effects of a Josephson junction operating at superconducting temperatures. The "QU", as mention above, stands for quantum, and the "I" stands for interference. And finally, the "D" just stand for device. Thus the name "superconducting quantum interference device" derives from the fact that quantum interference phenomena can be observed with SQUIDS on a macroscopic scale. For example, the current through a two-junction dc-SQUID varies periodically in a manner which is analogous to the optical interference pattern from two slits. At the Josephson junction insulating barrier, the amplitude of the "wave function" describing the wavelike-properties of the superconducting electrons cannot drop abruptly to zero, because then according to quantum theory the electrons would have an enormously high kinetic energy, which is not permitted. Instead, the wave function penetrates into the wall a short distance as it decays smoothly toward zero. However, if the barrier is sufficiently thin, with superconducting electrons on both sides, the decaying wave functions from the two sides overlap appreciable, and this overlap implies that superconducting electrons can flow through the insulator without any resistance. This effect is known as tunnelling because the electrons penetrate through a potential energy barrier, where by the classical laws of physics they are forbidden to go (Ref. 26:74). But how did the electrons manage to penetrate through the potential energy barrier? Well, this phenomena can be explained by the microscopic theory of the superconducting

state which was published by Cooper and Shrieffer in 1957. The basis for this theory is the consideration that at very low temperature a weak attractive force between electrons becomes more important than the disordering effect of thermal agitation, and they bind together in pairs called Cooper pairs. It is these Cooper pairs which can tunnel through the barrier as a unit. The Cooper pairs are not scattered in a superconductor whereby wave coherence is conserved over infinitely long distances. Interference effects can thus be observed on a macroscopic scale. It can be shown that the magnetic flux Φ_j passing through the area of the weak link can be taken in account when calculating J_c , the critical current density for the junction. J_c becomes the periodic function shown in Equation 2-1.

$$J_c = J_c(0) * \frac{|\sin(\pi * \Phi_j / \Phi_0)|}{\pi * \Phi_j / \Phi_0}$$

where

J_c is the critical current density

π is 3.1415926

Φ_j is the magnetic flux passing
through the weak link

Φ_0 is the flux quantum which is equal
to $2.07 * 10^{-15}$ Weber

EQUATION 2-1

This formula has the same form as the optical Fraunhofer diffraction from a slit. Because Φ_j is much smaller than Φ , the magnetic flux threading through the superconducting loop, the interference pattern from a SQUID is modulated by "diffraction" occurring at the weak link.

If wires are connected to each side of the weak link, the voltage measured will be proportional to the externally applied magnetic flux.

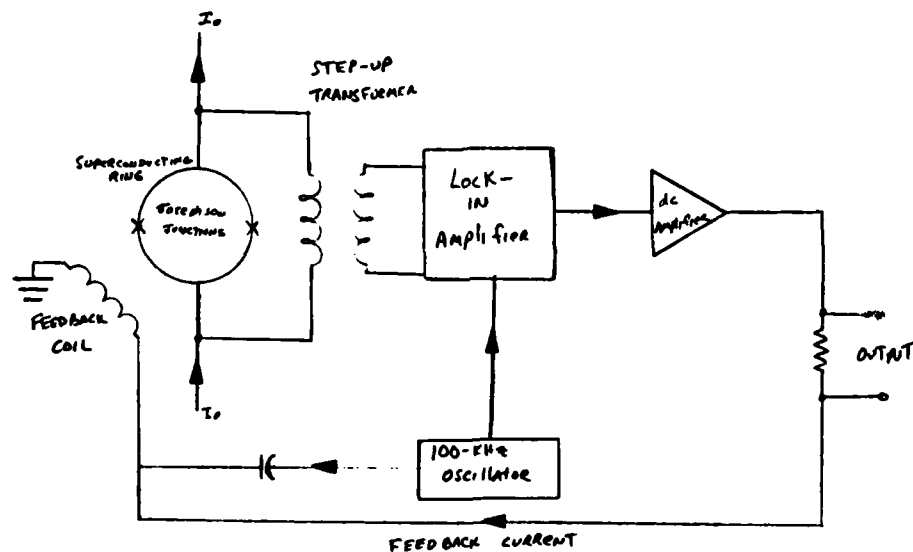


FIGURE 2-1

DC SQUID MAGNETOMETER

Now that we have discussed how a Josephson junction can be used as a weak link in a superconducting ring so as to detect small magnetic fields, let's talk about the rest of a

SQUID gradiometer. There are two types of SQUID gradiometers. The first type of SQUID gradiometer which I will discuss is the DC SQUID gradiometer. Figure 2-1 shows a diagram of a DC SQUID gradiometer.

The DC SQUID gradiometer consist of a superconducting ring interrupted by two Josephson junctions. the name follows from the fact that in operating this two-junction SQUID only a dc bias current is necessary. The voltage is taken off of the superconducting ring and passed through a step-up transformer to the lock in amplifier and then amplified by a dc amplifier. Part of the output is sent by to a feedback coil too provide the feedback necessary to allow the lock-in amplifier to maintain flux-locked mode. Flux-lock mode and the lock-in amplifier will be covered later.

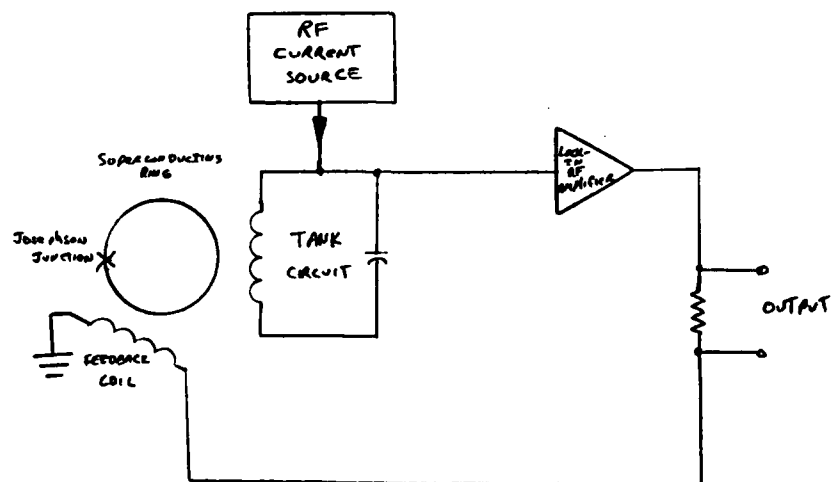


FIGURE 2-2
RF SQUID MAGNETOMETER

The second type of SQUID gradiometer is the RF SQUID gradiometer. A diagram of a RF SQUID gradiometer is shown in Figure 2-2. Once again a SQUID loop is used, but this time only one Josephson junction is used. The RF SQUID gradiometer is the type usually commercially produced. In this case, the SQUID loop is weakly coupled to a resonant tank circuit tuned to a sinusoidal pump current in the radio frequency range. The rf current source supplies a "pumping" current to a resonant tank circuit. The current flowing between the inductor and capacitor of the tank circuit exceeds the pumping current by the quality factor "Q" of the tank circuit. This circulating current generates an rf voltage across the parallel combination of the inductor and capacitor which is usually enhanced by a preamplifier, rectified by an rf detector, and then smoothed by a low-pass filter (usually a resistor and capacitor) to produce an average voltage that is proportional to the amplitude of the tank circuit's rf voltage. Note that the voltage is affected by the state of the SQUID, because the inductor of the tank circuit is magnetically coupled to the SQUID. The changing field of the inductor induces a current that flows around the SQUID loop, and this rf current is superimposed on a second current representing the input signal that results from the field applied by the input coil. In the simplest case, the non-linear response of the junction has the effect of changing the inductance of the SQUID due to the presence of this signal current. This change in SQUID inductance slightly alters the inductance in the tank circuit to which it is magnetically coupled, and thereby it affects

the tank voltage. This is a parametric effect (Ref. 26:78).

Note that the diagrams in Figure 2-1 and Figure 2-2 are magnetometers, and not gradiometers. For a magnetometer to become a gradiometer, it must have a specific coil configuration. Figure 2-3 shows four coil configurations.

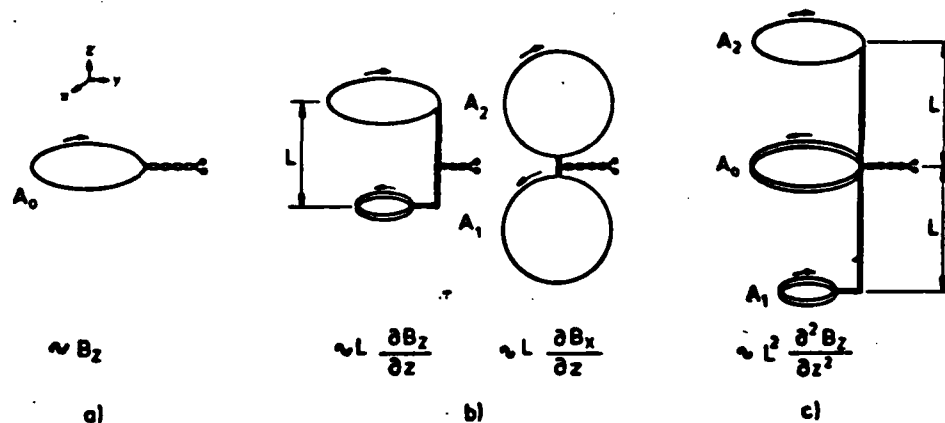


FIGURE 2-3
COIL CONFIGURATIONS

The coil in Figure 2-3(a) is a magnetometer coil for measuring the average flux density over the area of the coil. Both coils in Figure 2-3(b) are used in first order gradiometers, that is, with gradiometers which will measure flux differences of approximately one component of the field gradient. They allow measurements of local biomagnetic fields in the presence of much stronger but uniform fields from distant sources, since for distant sources the change in the

partial derivative of the magnetic field with respect to distance in the "z" direction is approximately equal to zero. The last coil configuration which is shown in Figure 2-3 is the second-order gradiometer configuration which is better suited to measure extremely small local magnetic fields while in the presence of higher noise levels, since not only are the uniform fields rejected, but also the first-order fields are rejected.

Because of its ability to select specific magnetic fields out of a noisy background, the second-order SQUID gradiometer is normally used to take biomagnetic measurements, including all the measurements reported in this report.

The second-order SQUID gradiometer can also be used to analyze heart activity by producing a magnetocardiogram (MCG), analyze muscle activity by producing a magnetomyogram (MMG), and monitoring movement of the eye by producing a magnetooculogram (MOG).

Before leaving this chapter, I will discuss the operation of the SQUID gradiometer in "Flux-lock mode", and some information on the particular SQUID gradiometer which I used to take measurements for this report. To use the SQUID in practical instruments, a linearization circuit is necessary to minimize the nonlinearity and also maximize the dynamic range by avoiding the periodicity of the SQUID response. For this reason, the SQUID normally is used as a null detector in a feedback loop. Usually, an audio frequency generator introduces a modulation flux into the SQUID. The amplitude of the modulation is approximately one-fourth of a flux quantum.

The choice of the modulation frequency depends on the desired bandwidth for a measurement, because this frequency has to be higher than the highest frequency component of the signal to be measured. Usually it is chosen to be about 50 kHz or higher. A phase-sensitive detector (PSD) extracts the portion of the SQUID electronics output at this modulation frequency and rectifies it; and this rectified output of the PSD goes to an integrator (low-pass filter). The PSD and integrator comprise what is known as a "lock-in" amplifier. Figure 2-4 shows a block diagram of a lock-in amplifier (Ref. 28:597).

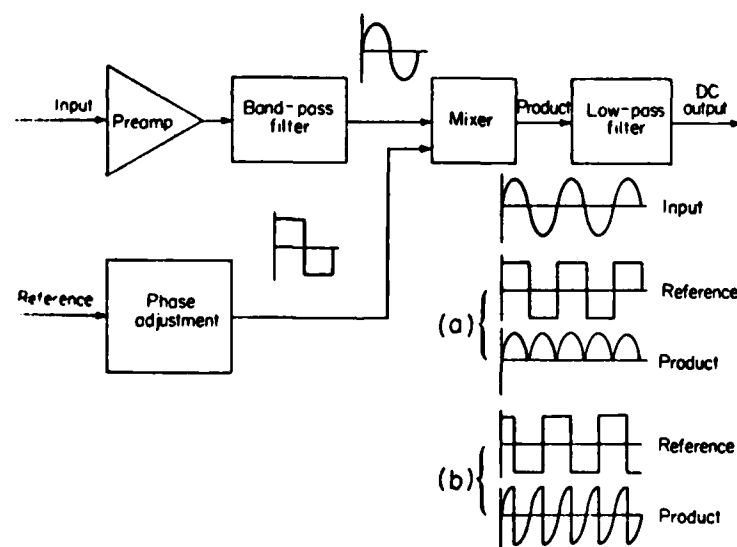


FIGURE 2-4

DIAGRAM OF A LOCK-IN AMPLIFIER

As shown in Figure 2-5, the Model 330 RF Unit uses a single weak link made from niobium. Its rf coil requires one microamp to change flux by one flux quantum. Its input coil has a current sensitivity of .1 microamp per flux quantum. It uses a RF bias frequency of 19 MHz with a 50 kHz square wave modulation. The input has an overall gain of 83 db.



Its bandwidth is plus and minus 150 kHz at carrier

frequency. The SQUID is immersed in a liquid helium bath inside of a superinsulated dewar similar to the arrangement shown in Figure 2-6.

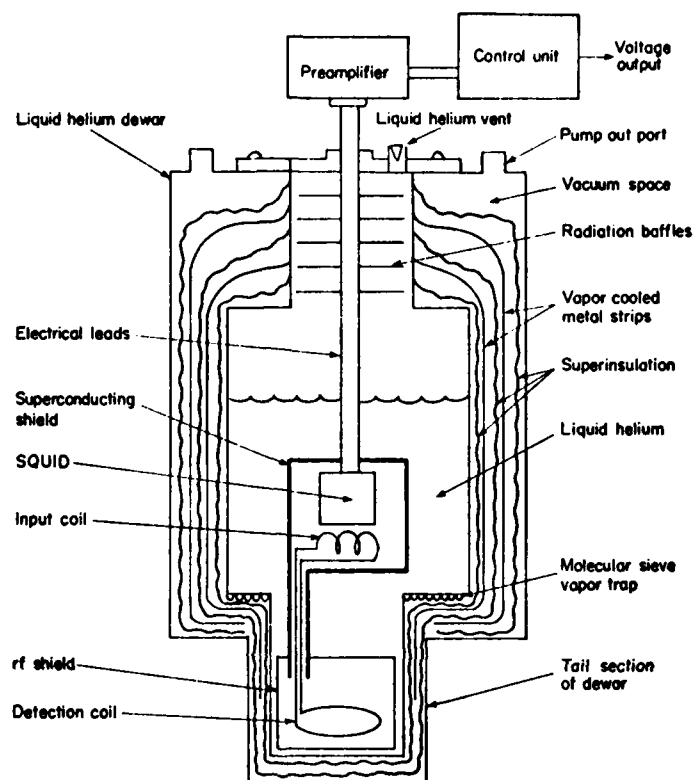


FIGURE 2-6

SQUID SYSTEM MOUNTED IN LIQUID HELIUM BATH

CHAPTER III

DIPOLE MODEL WITH TESTING

BACKGROUND

In this chapter, I will first discuss the dipole theory as the source of electrical activity in the brain. Next, I will discuss the single dipole model. In this case, it has been placed in a bowl immersed in a saline solution. The predicted values for the magnetic field emanating from the dipole are plotted, and compared with the plot of the measurements taken by the second-order SQUID gradiometer. Finally, the surface potential predicted values are plotted, and compared with the plot of the potentials measured off the surface of the saline solution, by using an oscilloscope with input differential amplifiers.

DIPOLE MODEL FOR THE BRAIN

With approximately 60 to 75 percent of cortical neurons oriented perpendicular to the cortical surface, and a large number of interconnections, it then appears that the scalp potentials are due to current dipole layers occupying various surface areas of the cortex (Ref. 5:273). For more background in reference to the dipole model for the brain see references 5,6, and 21 thru 24.

SINGLE DIPOLE

For this part of my research, I immersed a .5 cm. current dipole in a solution of .464 percent saline. Figure

3-1 shows a diagram of the current dipole experiment apparatus, while Figure 3-2 shows a picture of the apparatus. This apparatus included two 48 cm. by 31 cm. by 1 cm. pieces of plexiglas, an approximately 3 liter glass bowl, a 2 cm. by 2 cm. by 3 cm. block of lucite, and a 3 meter piece of shielded wire. I made a 1/2 cm. current dipole on one end of the wire, and connected the other end of the wire thru a 1000 ohm resistor to a BNC connector. On one of the large pieces of plexiglass I etched a 40 cm. by 25 cm. grid. This grid was graduated in 1 cm. increments. From the top left-hand corner of this grid, I marked the origin for the cartesian coordinate system to be down 12 cm. and right 20 cm. From the origin of this cartesian coordinate system, I chose the direction to the right to be the positive "y" direction, and the direction down to be the positive "x" direction. The positive "z" direction was in the direction above the apparatus. This piece of plexiglass became the bottom of my apparatus, and was used to correctly align the apparatus to the desired measurement point. For example, to align the apparatus to the "x,y" coordinate (3,-5), the point on the grid corresponding to the intersection of the "x" equal to positive 3 line and the "y" equal to negative 5 line is placed on top of a center of measurement point which was initially determined before the dipole apparatus was placed under the SQUID gradiometer. This initial center of measurement point was determined by placing the SQUID gradiometer in its vertical position and placing a mark at the point on the measurement table at which the line projecting from the center of the SQUID gradiometer detection

coil down to the table would enter the table.

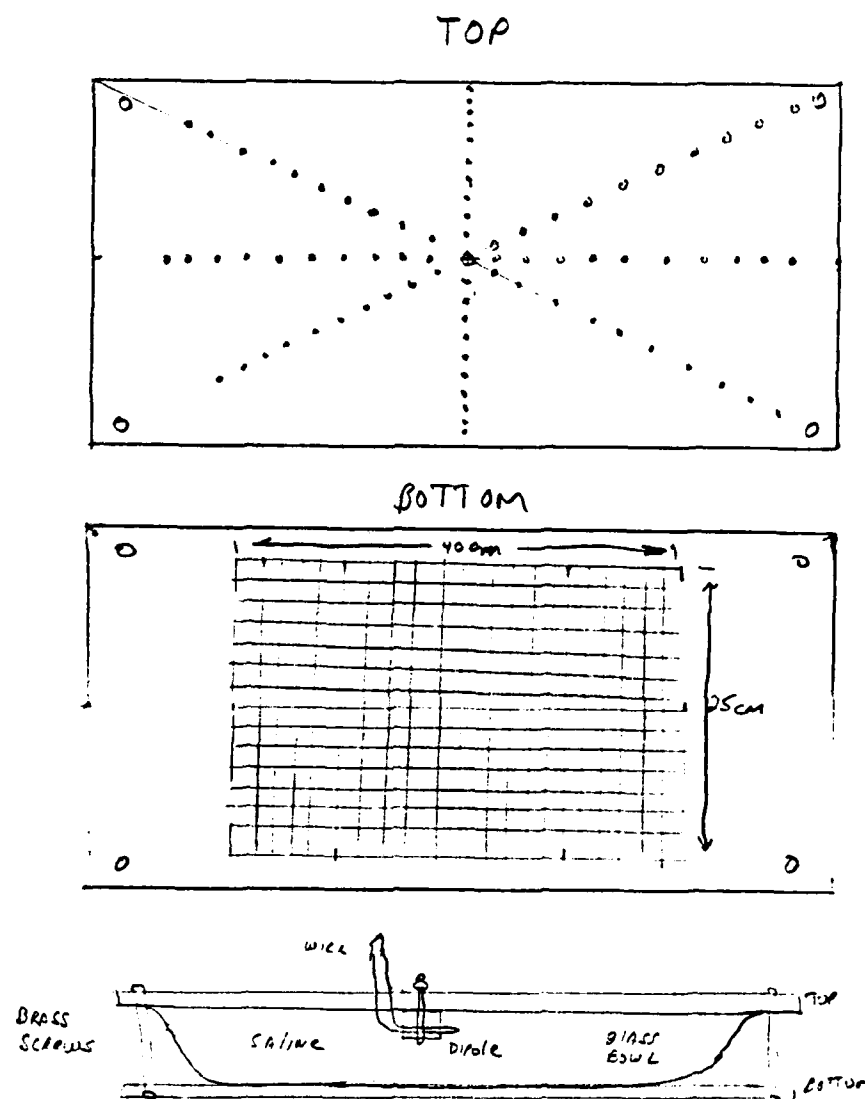


FIGURE 3-1

DIAGRAM OF DIPOLE EXPERIMENT APPARATUS

The other piece of plexiglass became the top of the apparatus, and the mount for the dipole. From the picture shown in Figure 3-2, we see that the top has a hole drilled into it at the point corresponding to the origin of the cartesian coordinate system. Also, there are ten holes drilled into the top of this apparatus in each of eight directions. These series of holes all start at the origin, and they are placed 1 cm. apart. The first direction that these holes were placed was in the positive "y" direction. The rest of the series of holes are then placed every 45°. There was also a hole drilled at the approximate "x,y" coordinate of (1,-2). This hole was used to mount the lucite block which held the dipole under the surface of the saline solution, at a position directly over the origin and pointing in the positive "y" direction.

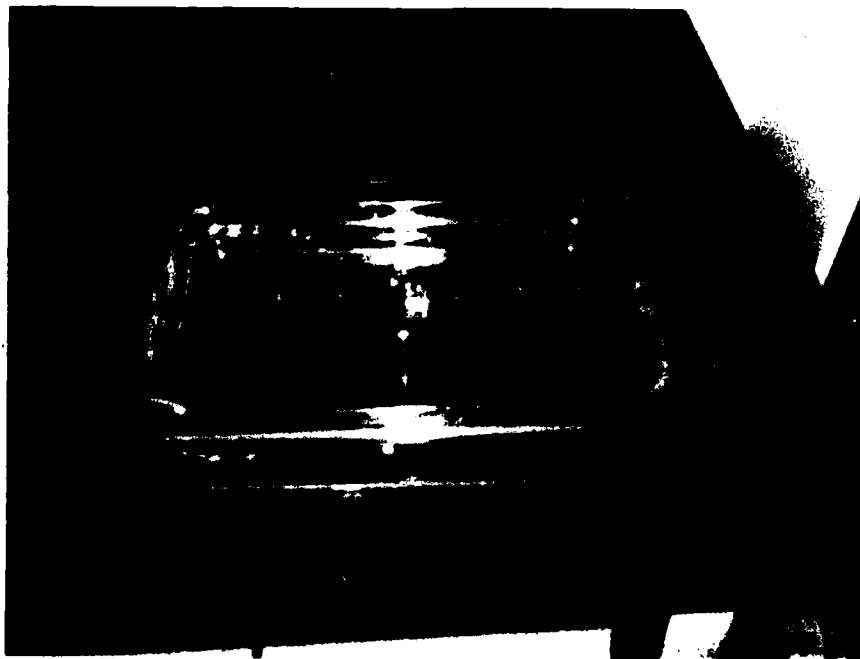


FIGURE 3-2

DIPOLE EXPERIMENT APPARATUS

The bowl was filled with the .464 percent saline solution and placed between the pieces of plexiglass. Four brass screws with wingnuts were used to fasten the bowl in place. The center of this glass bowl was determined and marked. This mark was placed on top of the origin mark on the bottom piece of plexiglas so that the dipole would be centered in the cartesian coordinate system.

Before the apparatus was completely built, I calculated mathematically the predicted values of the magnetic field strength (H) using the equation derived by Cuffin and Cohen in there paper, "Magnetic Fields of a Dipole in Special Volume Conductor Shapes. (Ref. 24:374)" Equation 3-1 shows the formula for H_z .

$$H_z = \frac{X * Py}{4 * PI * (X * X + Y * Y + (D + Z) * (D + Z))^{3/2}}$$

where

Py = dipole moment = current * dipole length

PI = 3.14159

X = distance in the X direction

Y = distance in the Y direction

Z = distance in the Z direction

D = depth dipole is below surface

EQUATION 3-1

For my experiment, $P_y = (.008)*(.005) = .00004$ and the value of D was .015 meters. To calculate the magnetic flux density (B), I used Equation 3-2.

$$B_z = \mu_o * H$$

where

B_z = magnetic flux density

$$\mu_o = 4 * \pi * 10^{-7}$$

H_z = magnetic field strength

EQUATION 3-2

The calculated magnetic flux density (B) values for the plus and minus 10 cm. grid is located in Appendix A, along with Table A-1 which shows a subset of the measurements which were taken, and their associated predicted value. As I was analyzing the calculated values versus the measured data I was looking for an isofield contour shape to correlate to each other. Figure 3-3 shows a current dipole with its associated magnetic field B and volume current density J^V . Figure 3-4 shows the plot of the calculated magnetic field for the dipole. Note that the calculated magnetic fields isofield contours forms two lobes. One lobe is pointed in the positive "x" direction, and the other lobe is pointed in the negative "x" direction.

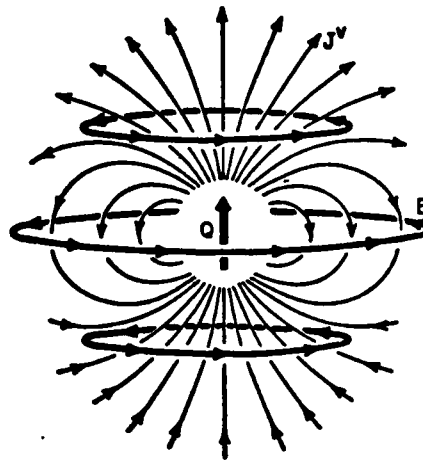


FIGURE 3-3
CURRENT DIPOLE

Also note that the positive "y" direction, that is, the direction which the dipole is pointing, is to the right, and the positive "x" direction is toward the bottom of the plot. This plot was then compared to the plot obtained by plotting the data measured by the SQUID gradiometer. This plot is shown in Figure 3-5. Although, the plot differs in absolute isofield value, and the wave shape is distorted, we can still see that it is still directly correlated to the calculated field plot. There are several factors involved in the distortion of the isofield contour lines in the measured magnetic field plot. First, we must remember that the calculated isofield contour plot did not take into account the edge effects which are introduced into the measurements since the bowl sides restricts the medium to a finite distance in the "x" and "y" directions, even though the calculations are based on an

infinite medium in the "x" and "y" directions.



CALCULATED DIPOLE MAGNETIC FIELD

PLOT NO. 4

DATE 11/10/83

TIME 20:41:44

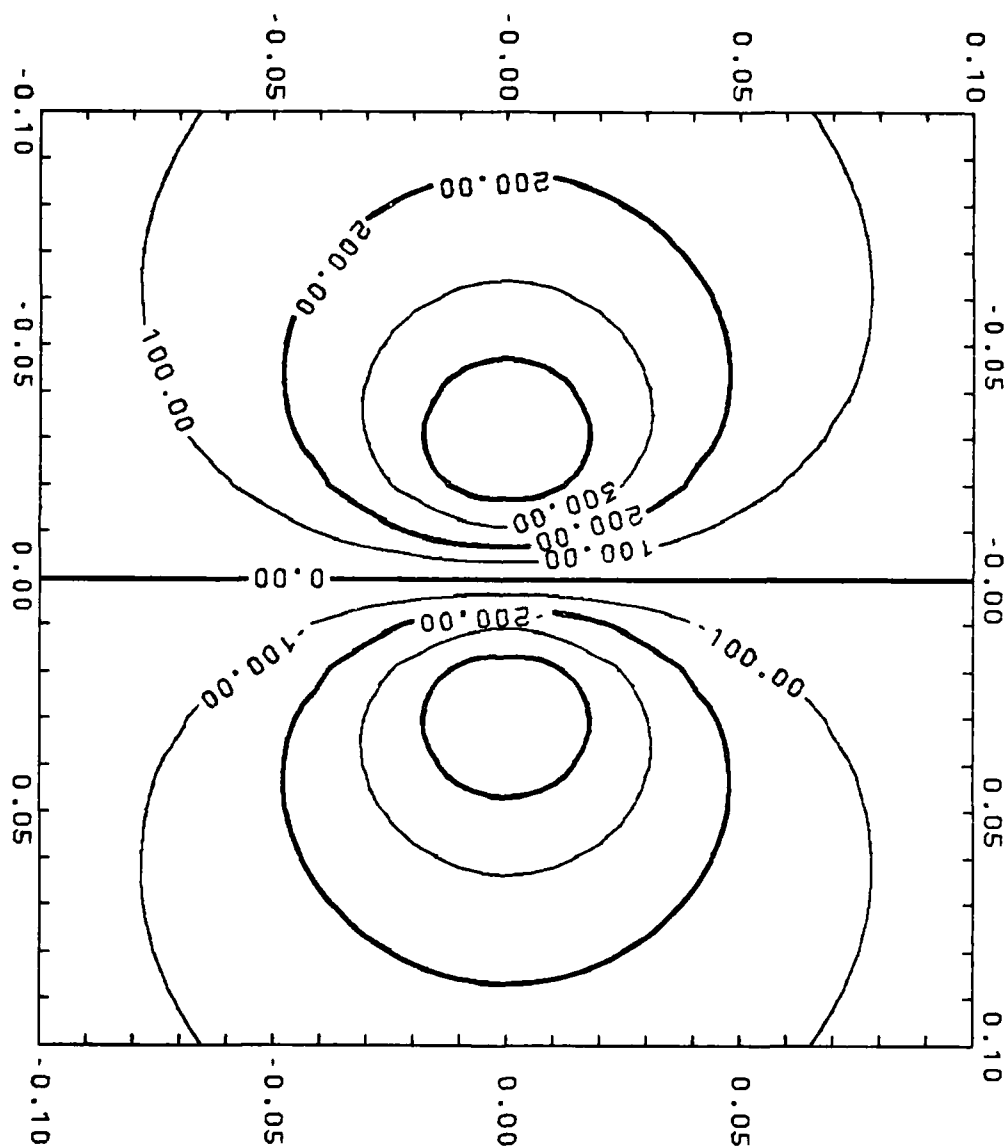


FIGURE 3-4

CALCULATED DIPOLE MAGNETIC FIELD ISOFIELDS



MEASURED DIPOLE MAGNETIC FIELD

PLOT NO. 2

DATE 11/10/83

TIME 22:13:25

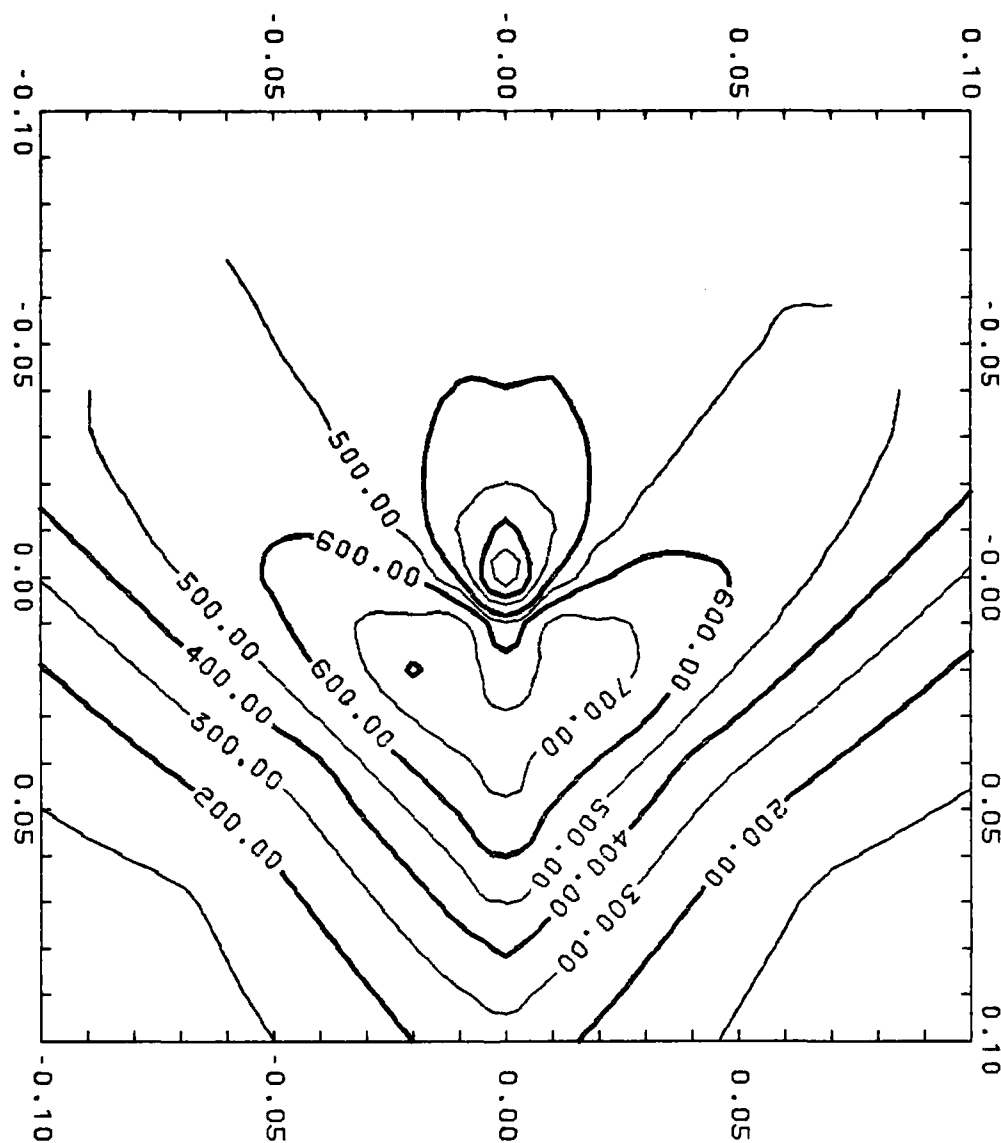


FIGURE 3-5

MEASURED DIPOLE MAGNETIC FIELD ISOFIELDS

Also, the lower lobe is greatly distorted, as expected, because of the lucite block which is used to mount the dipole is at the negative side of the dipole, so the volume are forced to go around this block and in doing so get distorted. The difference in the absolute value of the calculated magnetic field versus the measured magnetic field is partially due to the edge effects introduced into the measurements, and also the possible inaccuracies in the positioning of the apparatus with respect to the SQUID gradiometer.

Since later in this report I will be comparing magnetoencephalographic measurements of visual evoked responses to electroencephalographic measurements of visual evoked responses, my single dipole experiment would not be complete without predicting the surface electrical potential of the saline solution, and then compare the predicted values to the values I obtain from measuring the surface potential using a Tektronix 7A22 Differential Amplifier plugged into a Tektronix 7623A Oscilloscope. As for all of the experiments with the single dipole apparatus, the Textronix 503 Function Generator supplied the 8 milliamps of current to the dipole.

In order to solve for the surface potential caused by a dipole which is submerged a depth " d " below the surface of the solution, let us first consider the case shown in Figure 3-6. In Figure 3-6, you see a single dipole of length $2\ "e"$. The dipole is centered at the origin, but pointing in the " y " direction. For this case, the conductivity is the same throughout the medium. Once we choose an arbitrary point, say P , we can apply the potential function for a dipole to

determine the potential at point P due to the dipole.

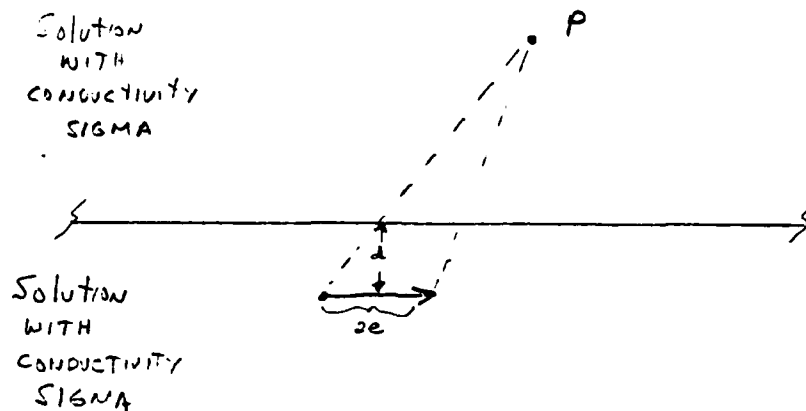


FIGURE 3-6

SINGLE DIPOLE MODEL

The potential at point P due to the dipole can be written in the form shown in Equation 3-3:

$$\Phi_d = \frac{p/e}{4 \cdot \pi \cdot \text{SIGMA}} \left[\frac{1}{R_+} - \frac{1}{R_-} \right]$$

EQUATION 3-3

where

p = dipole moment

e = half the length of the dipole

$$\text{PI} = 3.14159$$

$$R_+ = (X^2 + (Y-e)^2 + Z^2)^{1/2}$$

$$R_- = (X^2 + (Y+e)^2 + Z^2)^{1/2}$$

Φ_d = potential at point P due to the dipole

SIGMA = the conductivity of the medium

If we take the limit of the expression above as "e" goes to zero, and do some algebra, we get the expression shown below in Equation 3-4:

$$\Phi_d = \frac{2 \cdot P \cdot Y}{4 \cdot \text{PI} \cdot \text{SIGMA} \cdot R^3}$$

EQUATION 3-4

So now we have an equation for the potential at an arbitrary point P due to a single dipole in a infinite medium. Now we can use the above equation, and the superposition principle to develop the equation for the potential at an arbitrary point P due to two dipoles. Figure 3-7 shows the new problem we are working, that is, two dipoles are separated by 2 "d", but they are orientated in the same direction. Using the superposition principle, we get Equation 3-5, which is shown below, as the solution to the problem of two dipoles placed 2 "d" apart and with the same orientation.

The calculated potentials are located in Appendix B, along with Table B-1, which contains a subset of the measurements which were taken, and their associated predicted value.

$$\Phi_d = \frac{p \cdot y}{2 \cdot \pi \cdot \sigma} \left[\frac{1}{R_+} - \frac{1}{R_-} \right]$$

EQUATION 3-5

where

p = dipole moment

PI = 3.14159

$R_+ = (X^2 + Y^2 + (Z-D)^2)^{3/2}$

$R_- = (X^2 + Y^2 + (Z+D)^2)^{3/2}$

Φ_d = potential at point P due to the dipoles

SIGMA = conductivity of the medium

Once again, we will analyze the plot of the calculated dipole surface potential shown in Figure 3-8, along with the plot of the measured dipole surface potential shown in Figure 3-9. Once again, the positive "y" direction is toward the right of the plot, and the positive "x" direction is toward the bottom of the plot. In Figure 3-8, we see two lobes as we saw in the calculated magnetic field plot of Figure 3-4, but this time the lobes are pointing in the plus and minus "y" direction instead of the plus and minus "x" direction. Once again, we see that the lobe associated with the positive "y" direction is present, but that the lucite block effects is once again present.

CONDUCTIVITY
SIGMA

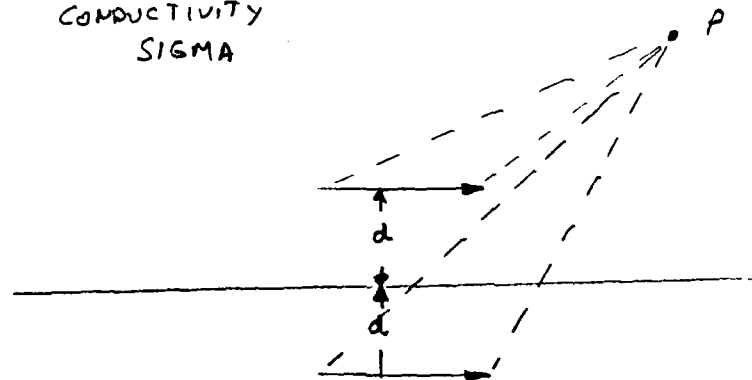


FIGURE 3-7

TWO DIPOLE MODEL



CALCULATED DIPOLE SURFACE POTENTIAL

PLOT NO. 2

DATE 11/10/83

TIME 20:21:15

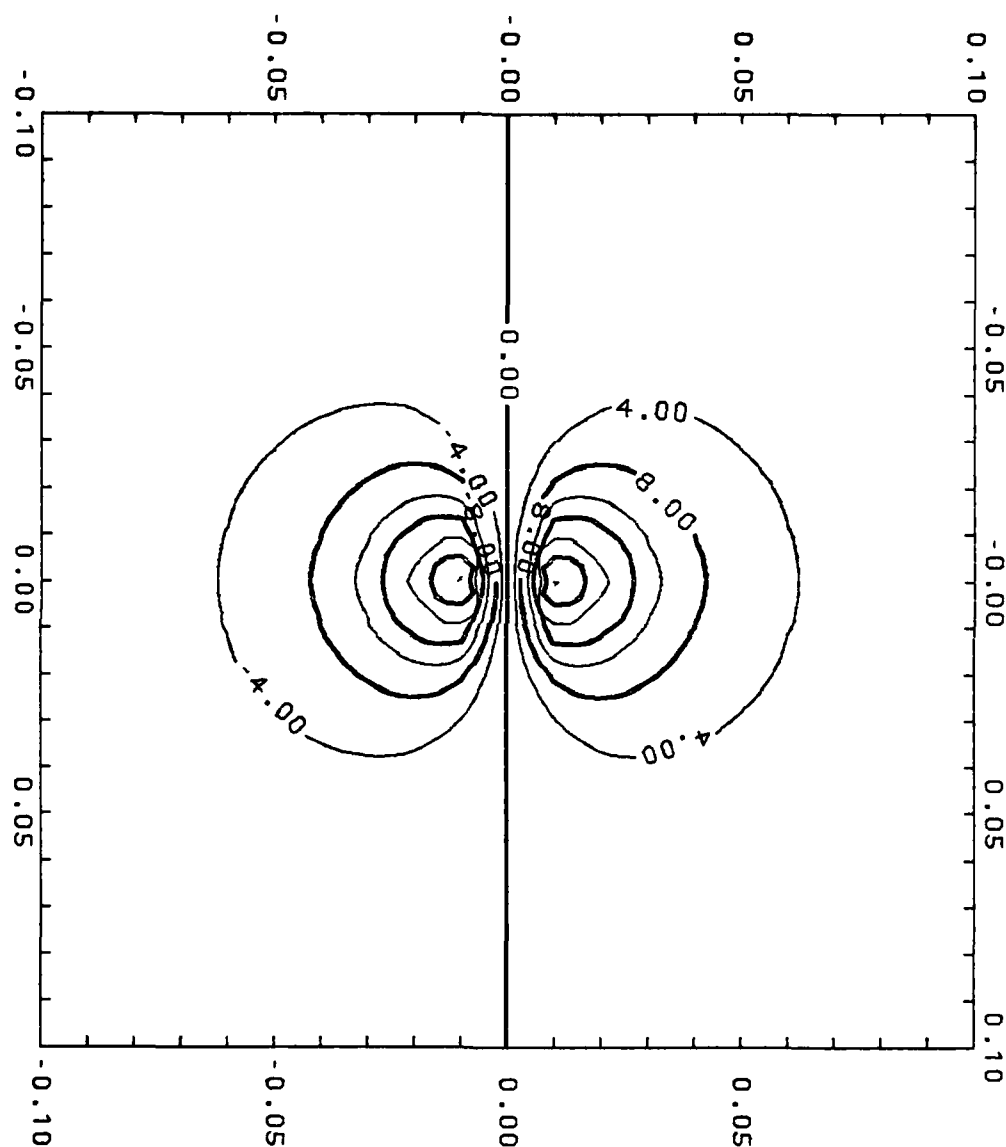


FIGURE 3-8

CALCULATED DIPOLE SURFACE POTENTIAL



MEASURED DIPOLE SURFACE POTENTIAL

PLOT NO. 4

DATE 11/10/83

TIME 19:03:39

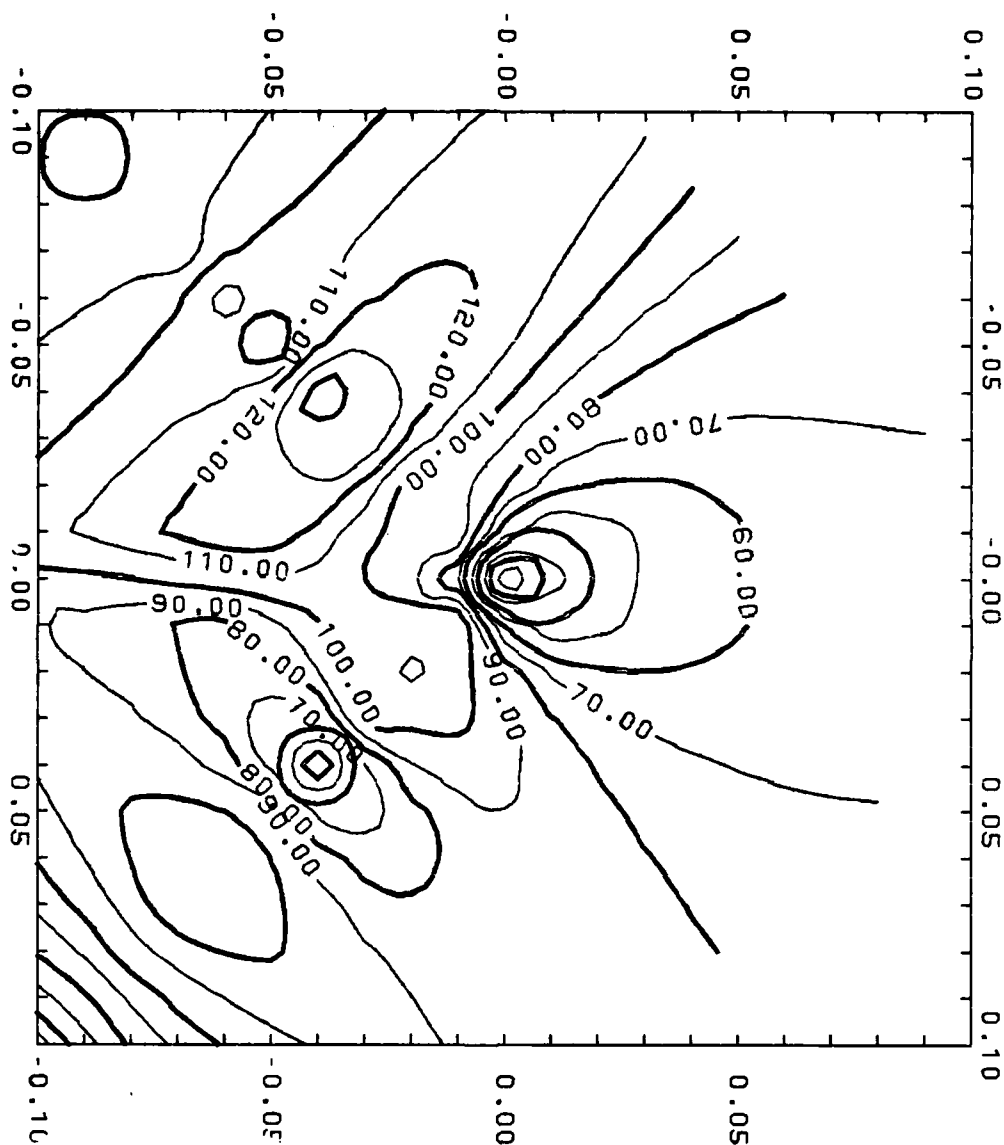


FIGURE 3-9

MEASURED DIPOLE SURFACE POTENTIAL

Some of the inaccuracies in both the wave shape and the absolute value of the measured data versus the calculated values is due to, once again, the edge effects of having a finite volume, rather than a semi-infinite volume. Also, positioning of the measurement probe may have had some affects. And finally, as shown in Equation 3-5, some inaccuracies may have been introduced by using an estimated value for SIGMA, the conductivity of the saline solution.

CHAPTER IV

HUMAN VISUAL EVOKED RESPONSE

BACKGROUND

Human brain waves were discovered in 1924 by Hans Berger of the University of Jena, Ausria (Ref. 1:98). Since then many techniques have been developed to study brain activity. One major advancement in the area of brain research was the development of the electroencephalograph. Through the years, the electroencephalograph has had many applications, including its use to measure visual evoked responses. The theory behind the technique of taking visual evoked responses, is that the chances of detecting some very small transient electromagnetic field may be enhanced by synchronizing the sample timing so that 50 to a 100 of these synchronized data sampling windows can be added together, and then averaged. Most of the noise signals when averaged will add to zero, but if there is a good signal from the brain which is hiding, it will grow bigger, since it will be synchronized.

The electroencephalograph is not the only piece of equipment which can detect visual evoked responses, SQUID gradiometer can also detect them. In this chapter, we will look at some visual evoked responses which were taken with the SQUID gradiometer, along with a comparison of some electroencephalographic visual evoked responses verses magnetoencephalographic visual evoked responses. For further research into visual evoked responses look at references 3,4,23,24, and 25.

Before continuing, lets look at the plot shown in Figure 4-1, to determine what information can be derived from its symbols and text, and then I'll talk about the experiment setup.

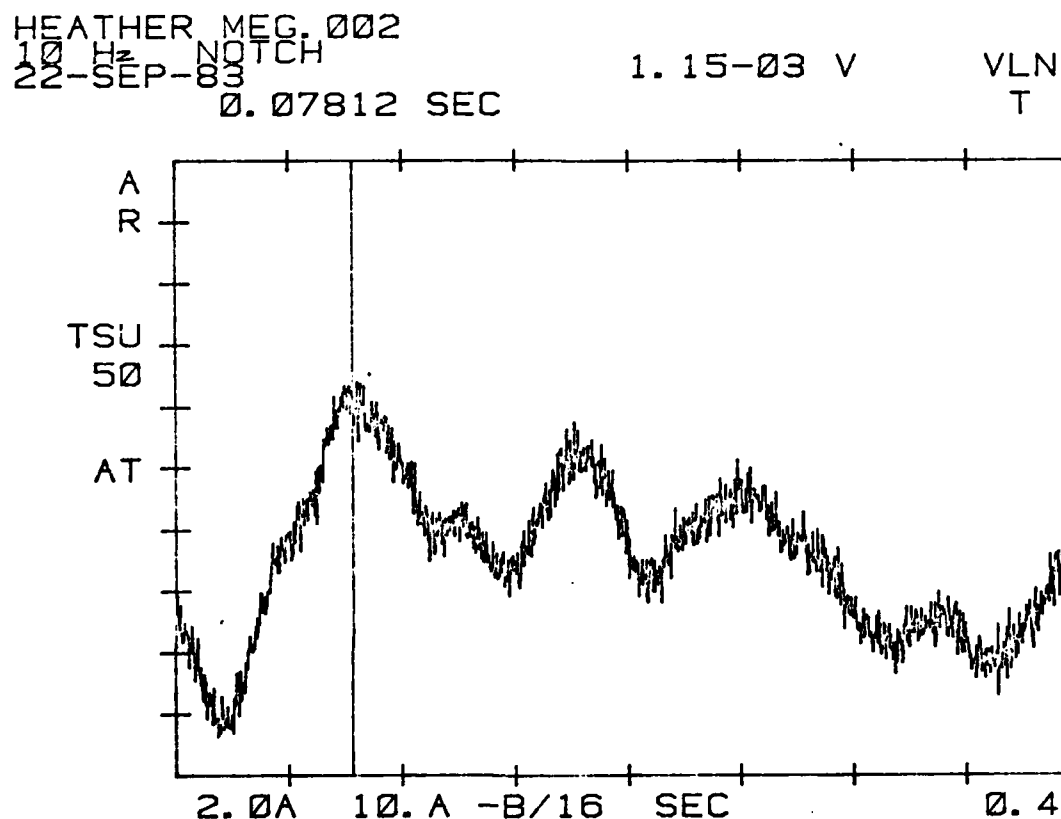


FIGURE 4-1

EXAMPLE OF A MVER

This plot was taken from the Nicolet Scientific Corporation Model 660B Dual-Channel FFT Analyzer, which is shown in Figures 4-2 and 4-3.

HEATHER is the name of the subject. MEG.002 is the name of the disk file which contains the data for this plot. To the right of the disk file name will sometimes be other information. For example, the position at which the measurement was taken and any other information about the

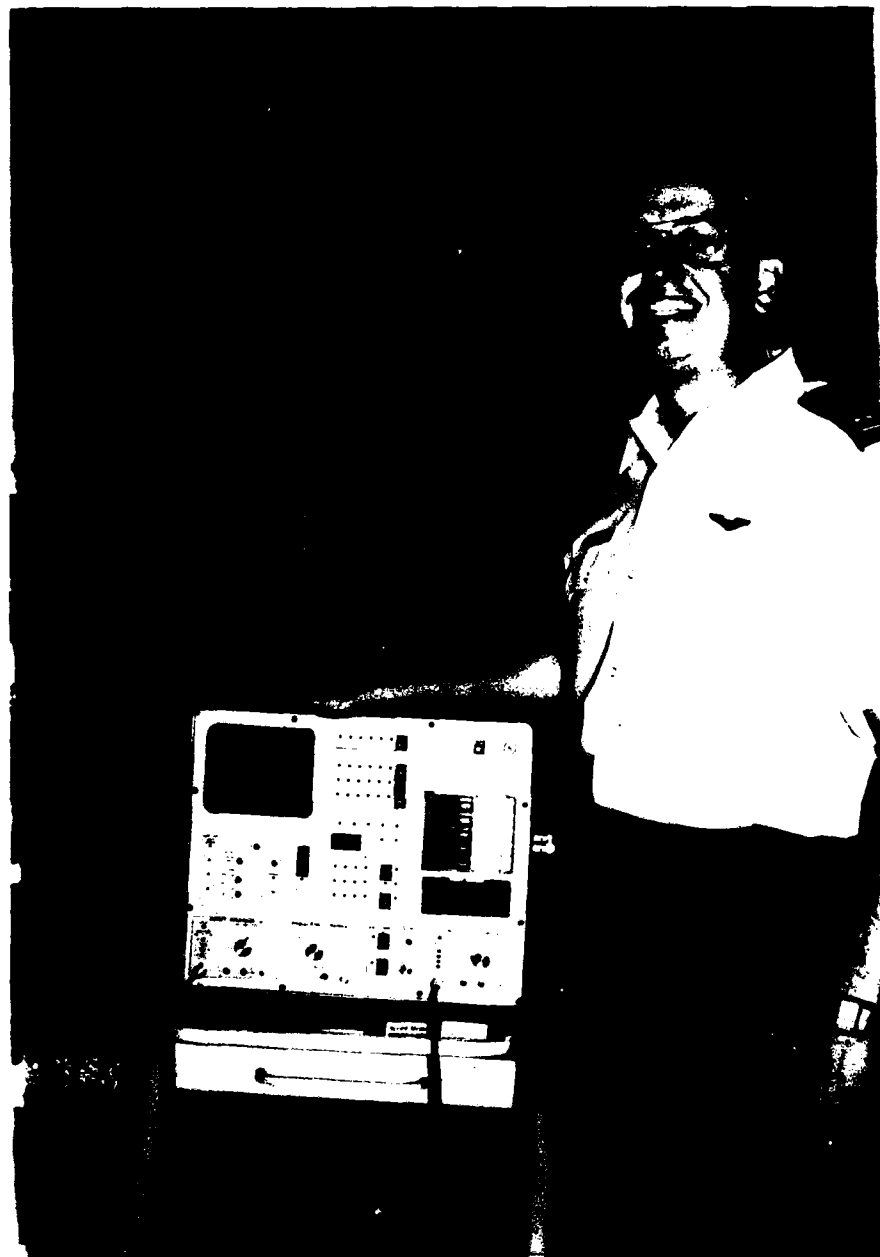


FIGURE 4-2

THE AUTHOR WITH THE FFT ANALYZER

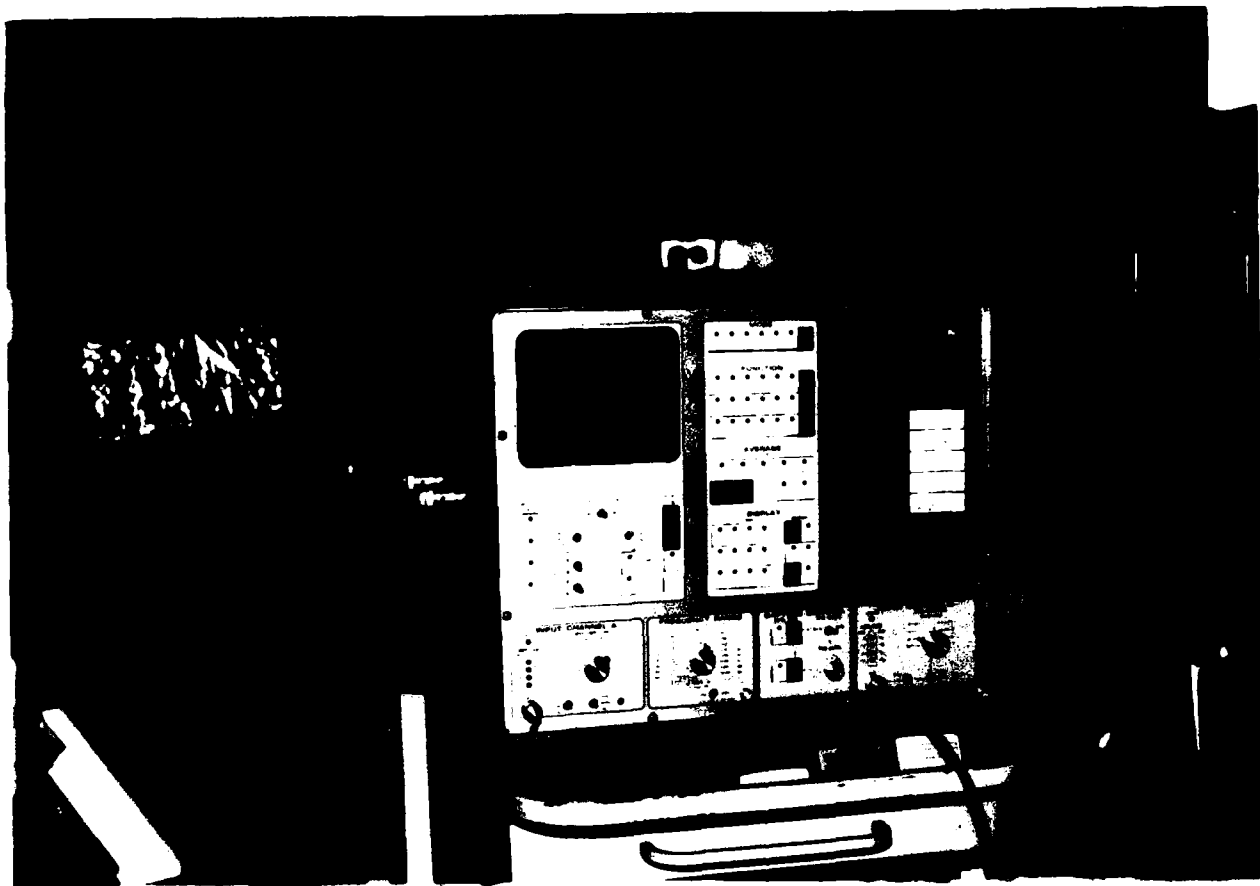


FIGURE 4-3

NICOLET MODEL 660B FFT ANALYZER

measurement environment may be there. On the second line, the 10 Hz and Notch is telling us that the 10 Hz low pass filter was used, along with the 60 Hz notch filter. Further to the right of the filter information is the value of the voltage at the cursor location. Still further to the right is the vertical scale mode. VLN stands for the vertical scale

is in linear volts, while a VLG would indicate the use of a logarithmic scale. On the third line, I have placed the date the measurement was taken. Sometimes, especially on the later plots, I entered information about the stimulus on this line and to the right of the date. Clear to the far right of the third line will be a "T" or a "C". For all of the measurements in this report, a "T" will be to the far right of the third line to indicate that the capture control setting was on transient. If I wanted to take measurements with the capture control setting in the continuous mode, a "C" would have replaced the "T". On the fourth line you will find the cursor position as determined by the horizontal scale units selected for the measurement. In this case, the cursor position is in time, that is, seconds. Now going down the left side of the plotted box, we see that the "A" tells us that the input of the top trace is was on channel A, while the "R" tells us that the format of that trace is real, versus a "P" if the format was phase, or a "M" if the format was magnitude, or "I" if the format was imaginary. The "TSU" is telling us what type of averaging, while the "50" is telling us the number of averages which were taken. In this case, the "T" stands for transient averaging, while the "SU" tells us the sum is being average. Other possible types of averaging are "PK" for peak, "EX" for exponential, "DF" for difference, and "SW" for sweep. Continuing down the left side, the "AT" tells us what function was performed. In this case, averaging by time was selected, but other types of function could have been selected. For example, a "TF" would indicate a transfer function was

selected, while a "RS" would indicate that a RMS spectrum function was selected. Two more types of functions are "COH" for coherence, and "IT" for instantaneous time. If we were using the dual trace capability of this FFT analyzer, similar information on the input channel and format of the second trace would be next to the lower left side of the box. Now, going across the bottom of the box from left to right we see the "2.0A" and the "10. A" which tells us the maximum setting for channels A and B, respectively. In this case, the maximum setting for channel A is 2 volts ac, while the maximum setting for channel B is 10 volts ac. A "D" instead of a "A" would have indicated the values were dc voltages instead of ac voltages. The "B/16" indicates that the transient trigger source is channel B, and the trigger level is set on channel B full scale divided by 16. Next, the "SEC" indicates that the horizontal scale is in time, that is, seconds. The horizontal scale may also be "HZ" if the horizontal scale is in frequency, that is, hertz. The last item at the far right of the bottom line is the horizontal full scale value. In this case, the horizontal full scale value is .4 second, or 400 milliseconds.

Now that we know how to interpret the information of the plot, let's discuss how the measurements were taken, that is, the experimental setup for the human magnetoencephalographic visual evoked response experiment. The subject sat in a wooden chair beneath the SQUID gradiometer. Pictures of the SQUID gradiometer will be shown in the next chapter. The SQUID gradiometer mount is adjusted so that the SQUID detection

coil, that is, the bottom of the dewar, is perpendicular to, and nearly touching the place on the subjects head at which the measurement is to be taken. A Grass Model PS22A Photo-stimulator was used to trigger a bright strobe light at random intervals. This flash was used as the stimulus. The signal used to fire the strobe was also used to trigger the Nicolet 660B FFT Analyzer. For the visual evoked responses measured from humans, the FFT analyzer did the time average of the sum of 50 measurements, each of a 400 millisecond window starting at the time the stimulus was triggered. The measurement stored at the end of the 50 measurements was then stored on an 8 inch disk via a Intel 80/20 computer. Later, the disk files were plotted out on a HP digital plotter.

HUMAN VER

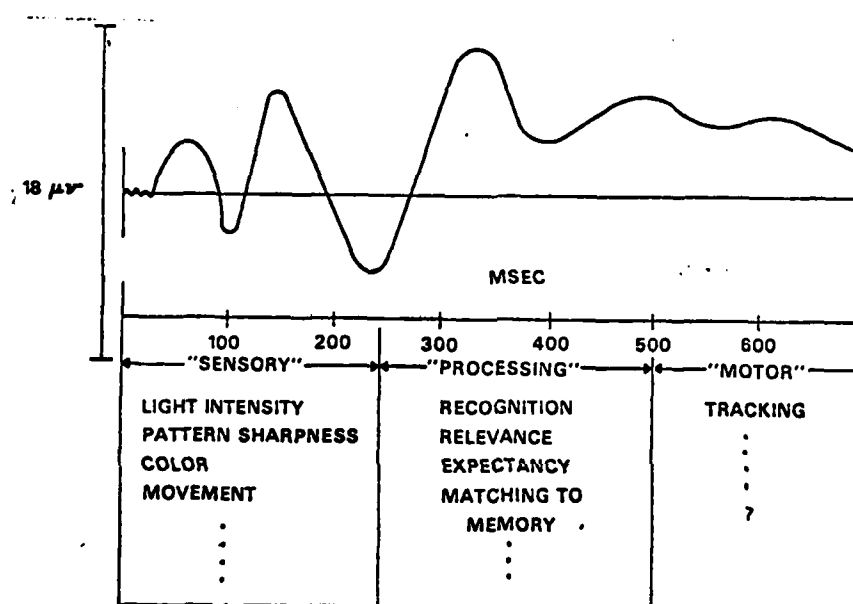
In Figure 4-1, is an example of a human visual evoked response taking with a second-order SQUID gradiometer. You will find this plot, and other human visual evoked response plots in Appendix C. This plot is a typical human magnetoencephalographic visual evoked response, since you can see a 78 millisecond peak, and 180 millisecond peak. These latencies are related to the time it takes the signals produced in the eye to be conducted via the optic nerve, pass the optic chiasm, through the lateral geniculate nucleus, and finally to the primary visual cortex.

As you look thru the five examples of human magnetoencephalographic visual evoked responses which are contained in Appendix C, note that all five different human visual

evoked response plots had an initial peak around 80 milliseconds. This component of the magnetoencephalographic visual evoked response seems to be consistent.

Figure 4-4 shows us the EEG profile of a visual evoked response.

COMPONENTS OF THE VISUAL EVOKED RESPONSE



HE-75-12-17

FIGURE 4-4

STANDARD EEG VER

Note, that the electroencephalographic visual evoked response also contains a peak with a latency off approximately 80 milliseconds, along with a peak with a latency off approximately 180 milliseconds.

CHAPTER V

DOG VISUAL EVOKED RESPONSE

BACKGROUND

During the late part of September and early part of October of this year, we got the opportunity to run some magnetoencephalographic visual evoked responses experiments on "Ricky", the laboratory beagle in which the first cortical brain chip was implanted. Appendix D has a number of plots of "Ricky's" magnetoencephalographic visual evoked response. We also had the chance to take some magnetoencephalographic auditory evoked responses from Ricky. The plots of Ricky's auditory evoked responses, along with some discussion of auditory evoked responses are contained in Appendix E.

EXPERIMENT SETUP

The experiment setup for the Ricky's magnetoencephalographic visual evoked response measurements were similar to the setup used to measure the human magnetoencephalographic visual evoked responses. For example, once again the subject is placed beneath the SQUID gradiometer, and the SQUID gradiometer mount is adjusted so that the SQUID detection coil, that is, the bottom of the dewar, is perpendicular to, and nearly touching the place on the subjects head at which the measurement is to be taken. Once again, a Grass Model PS22A Photostimulator was used to trigger a strobe light at random intervals. This flash was used as the stimulus. The signal

used to fire the strobe was once again used to trigger the FFT analyzer. Once again, the Intel 80/20 computer was used to store the average of the 50 measurements on a 8 inch disk, which was used later to recovery the data so that it could be plotted out. The major difference in the experiment setup for Ricky, versus the experiment setup for the humans is that the beagle, Ricky, was lightly anesthetized to prevent him from too much movement. Pictures of the experiment setup are shown at the end of this chapter.

VER COMPARISON

In Figures 5-1 and 5-2 are two of the magnetoencephalographic visual evoked response which were taken from the laboratory beagle, Ricky. While, Figure 5-3 is the electroencephalographic visual evoked response taken off of the visual cortex of Ricky by the AFIT Semiconductor Multielectrode Array, which was implanted on his brain. We expected to see a magnetoencephalographic visual evoked response with approximately the same latencies as the latencies measured by the AFIT array. Also, as we move the position at which the SQUID gradiometer is measuring the visual evoked response, we expected to see a phase reversal. It turns out that we did get approximately the same latencies as did the AFIT array. Also, we were able to get the phase reversal. We see that MEG.022 shown in Figure 5-1, and MEG.045 shown in Figure 5-2 could possibly be a phase reversal, but the best example of a phase reversal is from two of the plots in Appendix D. These two plots are MEG.057 and MEG.059.

RICKY MEG. 022 RT-OC LIGHTS-ON
 10CPS AND NOTCH FILTERS 12.7-03 V VLN
 26-SEP-83 0.02598 SEC T

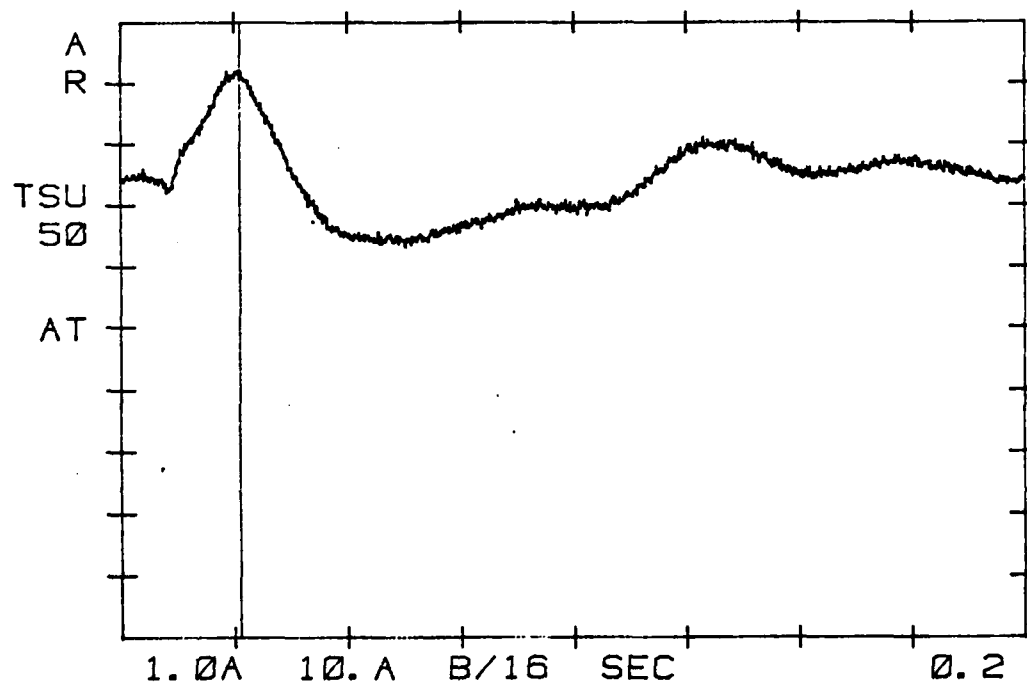


FIGURE 5-1

Ricky's VER

Figures 5-4 through Figure 5-11 shows several different pictures taken of the dog experiment.

RICKY MEG. 045 RT-OC-SAME LIGHTS-ON
 10CPS AND NOTCH FILTERS -21.4-03 V VLN
 29-SEP-83 STROBE R-N GEN T
 0.03301 SEC

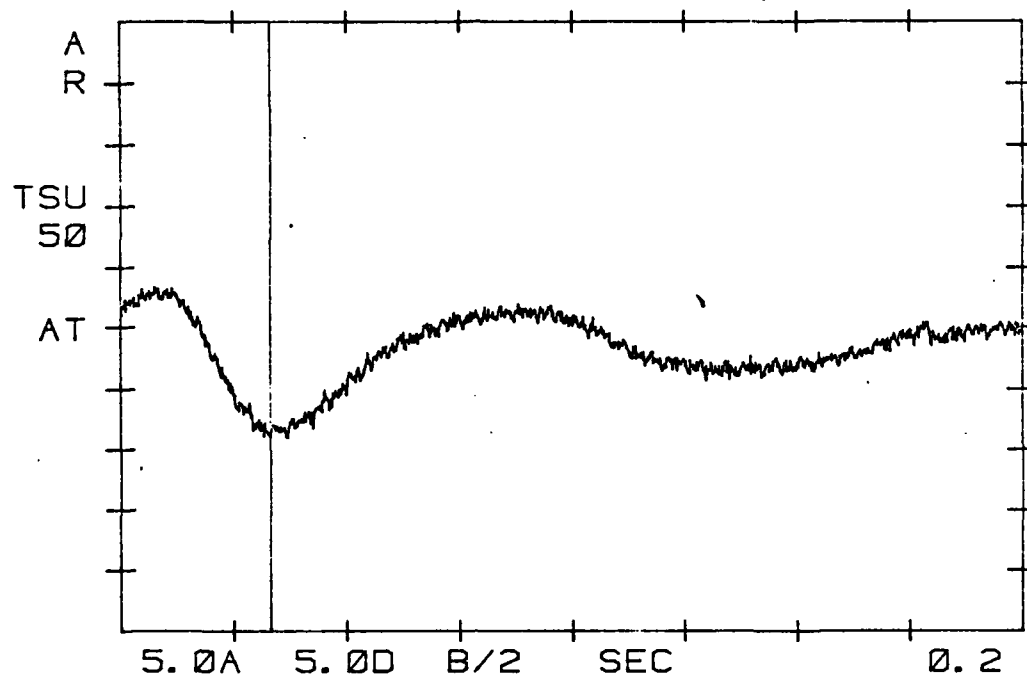


FIGURE 5-2

Ricky's VER

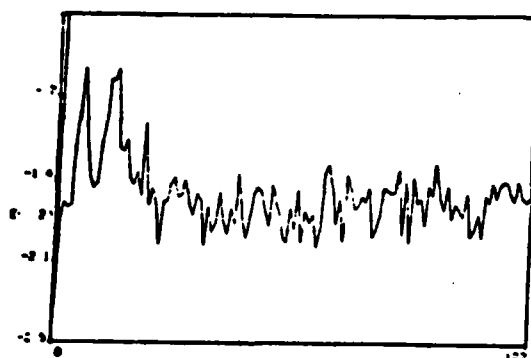


FIGURE 5-3

EEG VER

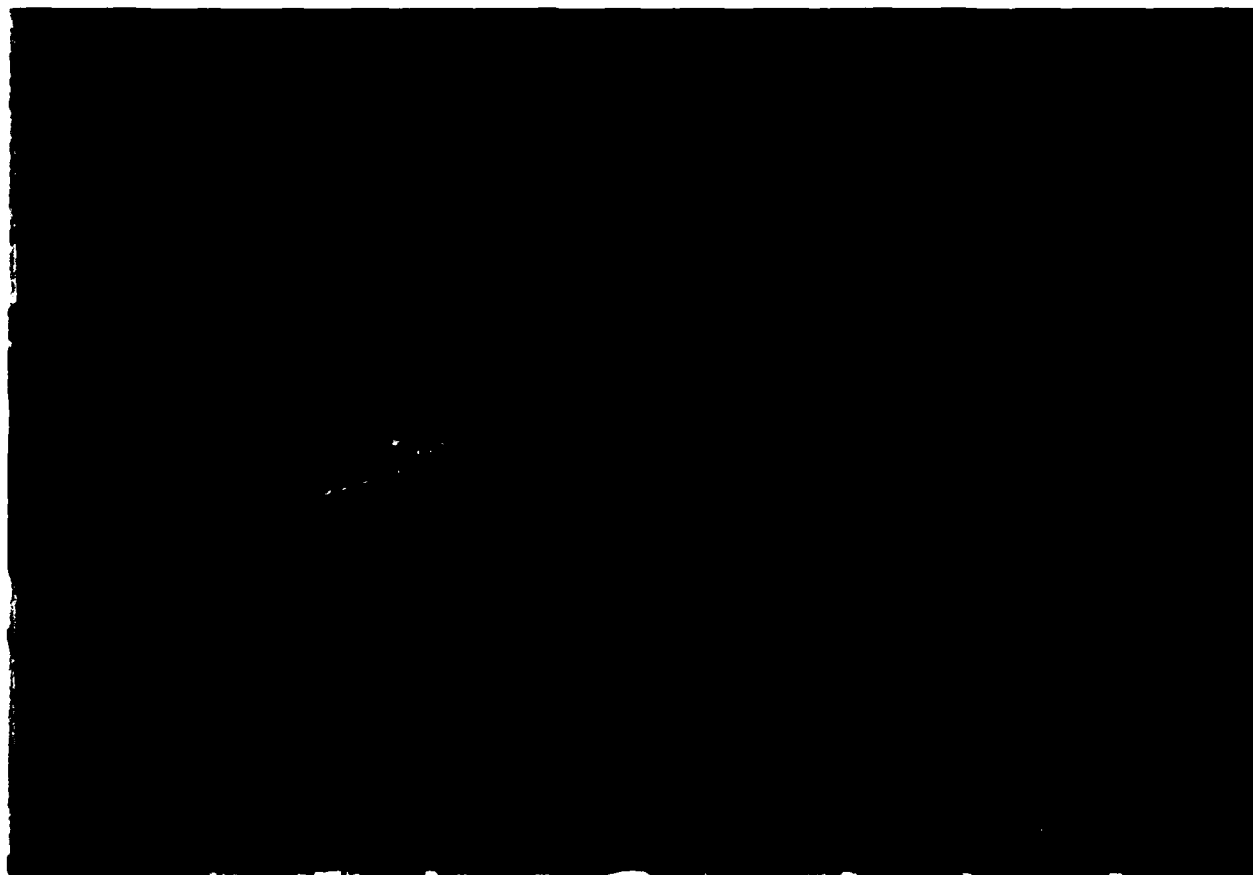


FIGURE 5-4
AUTHOR WITH EQUIPMENT



FIGURE 5-5
SQUID GRADIOMETER AND RICKY



FIGURE 5-6

SQUID, MOUNT, AND RICKY



FIGURE 5-7
SQUID POSITIONING EXAMPLE



FIGURE 5-8

BARB McPAWN WITH STROBE LIGHT



FIGURE 5-9

ALVA KARL MONITORING RICKY



FIGURE 5-10

DR. KABRISKY CHECKING A POSITION



FIGURE 5-11

DR. HATSELL POSITIONING RICKY

CHAPTER VI

CONCLUSION

DIPOLE MODEL

We saw that the predicted values in both the magnetic field and the surface potential had differences, especially in absolute value in relation to their measured values, but the wave shape of the measure magnetic field or surface potential correlated well with the calculated wave shape, except for distortions believed to be due to such factors as edge effects, the finite volume, and the lucite mounting block. Also, the conductivity of the saline solution may have been a factor in the surface potential case.

HUMAN VER

We saw some excellent plots of visual evoked responses in humans, long with some discussion into VER theory. Also, we saw that the 80 millisecond component of the visual evoked response taken by electroencephalographic means, also shows up in the magnetoencephalographic visual evoked response.

DOG VER

Once again we saw some good plots of visual evoked responses in a dog. We also conclude that the latency of the visual evoked response as measured by the AFIT implant is approximately the same as the latency measured by the SQUID gradiometer. This conclusion would tend to prove that the AFIT array seems to work.

CHAPTER VII
RECOMMENDATIONS

I recommend that further research be planned especially with a researcher looking into the feasibility of simultaneous magnetoencephalographic and electroencephalographic measurement. Also, more research be done in the area of determining means by which the SQUID gradiometer can be used as a diagnostic tool. For example, could a change in latencies of various evoked responses indicate deterioration of the visual system, or the onset of Multiple Sclerosis (MS) or Alzheimer's disease?

BIBLIOGRAPHY

1. Wooldridge, D. E. The Machinery of the Brain. New York: McGraw-Hill Book Company, 1963.
2. Lewis, P. and Rubenstein, D. The Human Body. New York: Bantam Book Company, 1971.
3. Callaway, E., Tueting, P., and Koslow, S. Event-Related Brain Potentials in Man. New York: Academic Press, Inc, 1978.
4. Regan, D. Evoked Potential in Psychology, Sensory Physiology, and Clinical Medicine. London: Chapman and Hall, LTD. 1972.
5. Nuney, P. L. "A Study of Origin of the Time Dependencies of Scalp EEG: I -- Theoretical Basis," IEEE Transaction on Biomedical Engineering, Vol. BME-28, No. 3, 271-280. March 1981.
6. Nuney, P. L. "A Study of Origin of the Time Dependencies of Scalp EEG: II -- Experimental Support of Theory" IEEE Transaction on Biomedical Engineering, Vol. BME-28, No. 3, 281-293. March 1981.
7. Guyton, A. C. Textbook of Medical Physiology (sixth edition). Philadelphia: W. B. Saunders Company. 675-683, 1981.
8. Perry, N. W., Jr. and Childers, D. G. The Human Visual Evoked Response, Springfield, Illinois: Charles C. Thomas, Publisher, 1969.
9. Miller, J. A. "Wiretap on the Nervous System," Science News, Vol 123. 140-143.
10. Ratliff, F. "Inhibitory Interaction and the Detection and Enhancement of Contours," 183-203. The Rockefeller Institute.
11. Werblin, F. S. "The Control of Sensitivity of the Retina," Scientific American. 71-79. January, 1973.
12. Lettvin, H. R. et al. "What the Frog's Eyes tells the Frog's Brain," Processings of the IRE. 1940-1951. November, 1959.
13. Lettvin, H. R. et al. "Two Remarks on the Visual System," Sensory Communication. 1962.
14. Peterson, E. L. "Visual Processing in the Leech Central Nervous System," Nature Vol 303. 240-242. 19 May 1983.

15. Maffei, L. and Fiorentini, A. "The Visual Cortex as a Spatial Frequency Analyser," Vision Res Vol 13. 1255-1267, Pergamon Press, 1973.
16. Glezer, V. D., Ivanoff, V.A., and Tscherlasch, T. A. "Investigation of Complex and Hypercomplex Receptive Fields of Visual Cortex of the Cat as Spatial Frequency Filters," Vision Res, Vol 13 1875-1904, Pergamon Press, 1973.
17. Kabrisky, M. et al "The First Cortical Implant of a Multiplexed Multi-Electrode Semiconductor Brain Electrode," AIAA (Day/Cin) 83-1. 9-4-1 -- 9-4-3.
18. Tatman, J. 1979. A Two-Dimensional Multielectrode Microprobe for the Visual Cortex, M.S.E.E. Thesis, Air Force Institute of Technology, AFIT/GE/EE/79-37, December, 1979.
19. Duzer, V. and Turner, C. Principles of Superconductive Devices and Circuits. New York: Elsevier.
20. -----."Low-Frequency Applications of Superconducting Quantum Interference Devices," Proceedings of the IEEE Vol 61, No. 1, January, 1973.
21. Heringa, A. and et al. "Solution Methods of Electrical Field Problem in Physiology," IEEE Transactions on Biomedical Engineering, Vol 29, No. 1. 34-42. January, 1982.
22. Barr, R., et al. "Determining Surfaces Potentials from Current Dipoles with Application to Electrocardiography IEEE Transaction on Biomedical Engineering, Vol BME-13 No. 2, 88-92. April, 1982.
23. Williamson, S. and Kaufman, L. "Magnetic Fields of the Cerebral Cortex," Proceedings of the Third International Workshop on Biomagnetism, Berlin (West) May 1980.
24. Cuffin, N. and Cohen, D. "Magnetic Fields of a Dipole in Special Volume Conductor Shapes," IEEE Transaction on Biomedical Engineering, Vol BME 24, No. 4, 372-381. July, 1971.
25. Cohen, D. and Cuffin, N. "Demostration of Useful Differences Between magnetoencephalogram and electroencephalogram," Electroencephalography and Clinical Neurophysiology, Vol 56, 38-51, 1983.
26. Erne, S. N. "SQUID Sensors," Biomagnetism: An Interdisciplinary Approach, New York: Plenum Press, 69-84, 1983.

27. Zimmerman, J. E. "Magnetic Quantities, Units, Materials, and Measurements," Biomagnetism: An Interdisciplinary Approach, New York: Plenum Press, 17-42, 1983.
28. Lehmann, H. P. "Signal Processing," Biomagnetism: An Interdisciplinary Approach, New York: Plenum Press, 591-624, 1983.

APPENDIX A

SINGLE DIPOLE MAGNETIC DATA

```

5 REM
10 REM  THESIS DIPOLE FIELD CALCULATION PROGRAM
20 REM  BFIELD AND VOLTAGE ( X100 )
30 REM  BY BOB MURRAY
40 REM
50 LPRINT CHR$(12)
60 INPUT "ENTER Z";Z
70 LPRINT TAB(15);"Z = ";Z
80 LPRINT TAB(15);"I = 8 MILLIAMPS"
90 LPRINT TAB(15);"L = .005 METERS":LPRINT
100 FOR I=-10 TO 10
110 FOR J=-10 TO 10
120 X=I/100
130 Y=J/100
140 T=4.D-12*X
150 F=0.0
160 B=((X[2+Y[2+(.015+Z)[2]][1.5)
170 F=-T/B
180 VF=(4.9D9)*F
190 LPRINT TAB(15);"B(";I;",";J;")=";F,TAB(15);"V(";I;",";J;")=";VF
200 NEXTJ
210 NEXTI
220 LPRINT CHR$(12)
230 INPUT"ANOTHER RUN";ANS$
240 IF(ANS$="Y") GOTO60
250 END

```

Z = .022
I = 8 MILLIAMPS
L = .005 METERS

B(-10, -10) = 1.28051E-10	V(-10, -10) = .627451
B(-10, -9) = 1.47246E-10	V(-10, -9) = .721507
B(-10, -8) = 1.68875E-10	V(-10, -8) = .827488
B(-10, -7) = 1.92761E-10	V(-10, -7) = .944528
B(-10, -6) = 2.18409E-10	V(-10, -6) = 1.0702
B(-10, -5) = 2.44902E-10	V(-10, -5) = 1.20002
B(-10, -4) = 2.70832E-10	V(-10, -4) = 1.32708
B(-10, -3) = 2.94338E-10	V(-10, -3) = 1.44226
B(-10, -2) = 3.13293E-10	V(-10, -2) = 1.53514
B(-10, -1) = 3.25665E-10	V(-10, -1) = 1.59576
B(-10, 0) = 3.29972E-10	V(-10, 0) = 1.61686
B(-10, 1) = 3.25665E-10	V(-10, 1) = 1.59576
B(-10, 2) = 3.13293E-10	V(-10, 2) = 1.53514
B(-10, 3) = 2.94338E-10	V(-10, 3) = 1.44226
B(-10, 4) = 2.70832E-10	V(-10, 4) = 1.32708
B(-10, 5) = 2.44902E-10	V(-10, 5) = 1.20002
B(-10, 6) = 2.18409E-10	V(-10, 6) = 1.0702
B(-10, 7) = 1.92761E-10	V(-10, 7) = .944528
B(-10, 8) = 1.68875E-10	V(-10, 8) = .827488
B(-10, 9) = 1.47246E-10	V(-10, 9) = .721507
B(-10, 10) = 1.28051E-10	V(-10, 10) = .627451
B(-9, -10) = 1.32522E-10	V(-9, -10) = .649356
B(-9, -9) = 1.5459E-10	V(-9, -9) = .757492
B(-9, -8) = 1.80085E-10	V(-9, -8) = .882418
B(-9, -7) = 2.09008E-10	V(-9, -7) = 1.02414
B(-9, -6) = 2.40957E-10	V(-9, -6) = 1.18069
B(-9, -5) = 2.74926E-10	V(-9, -5) = 1.34714
B(-9, -4) = 3.09129E-10	V(-9, -4) = 1.51473
B(-9, -3) = 3.40955E-10	V(-9, -3) = 1.67068
B(-9, -2) = 3.67192E-10	V(-9, -2) = 1.79924
B(-9, -1) = 3.84594E-10	V(-9, -1) = 1.88451
B(-9, 0) = 3.90703E-10	V(-9, 0) = 1.91444
B(-9, 1) = 3.84594E-10	V(-9, 1) = 1.88451
B(-9, 2) = 3.67192E-10	V(-9, 2) = 1.79924
B(-9, 3) = 3.40955E-10	V(-9, 3) = 1.67068
B(-9, 4) = 3.09129E-10	V(-9, 4) = 1.51473
B(-9, 5) = 2.74926E-10	V(-9, 5) = 1.34714
B(-9, 6) = 2.40957E-10	V(-9, 6) = 1.18069
B(-9, 7) = 2.09008E-10	V(-9, 7) = 1.02414
B(-9, 8) = 1.80085E-10	V(-9, 8) = .882418
B(-9, 9) = 1.5459E-10	V(-9, 9) = .757492
B(-9, 10) = 1.32522E-10	V(-9, 10) = .649356
B(-8, -10) = 1.351E-10	V(-8, -10) = .66199
B(-8, -9) = 1.60076E-10	V(-8, -9) = .784371
B(-8, -8) = 1.89732E-10	V(-8, -8) = .929687
B(-8, -7) = 2.24407E-10	V(-8, -7) = 1.09959
B(-8, -6) = 2.63977E-10	V(-8, -6) = 1.29349
B(-8, -5) = 3.07509E-10	V(-8, -5) = 1.50679
B(-8, -4) = 3.52866E-10	V(-8, -4) = 1.72904
B(-8, -3) = 3.96457E-10	V(-8, -3) = 1.94264
B(-8, -2) = 4.33408E-10	V(-8, -2) = 2.1237
B(-8, -1) = 4.58428E-10	V(-8, -1) = 2.2463
B(-8, 0) = 4.67307E-10	V(-8, 0) = 2.2898
B(-8, 1) = 4.58428E-10	V(-8, 1) = 2.2463
B(-8, 2) = 4.33408E-10	V(-8, 2) = 2.1237
B(-8, 3) = 3.96457E-10	V(-8, 3) = 1.94264
B(-8, 4) = 3.52866E-10	V(-8, 4) = 1.72904
B(-8, 5) = 3.07509E-10	V(-8, 5) = 1.50679
B(-8, 6) = 2.63977E-10	V(-8, 6) = 1.29349
B(-8, 7) = 2.24407E-10	V(-8, 7) = 1.09959
B(-8, 8) = 1.89732E-10	V(-8, 8) = .929687

B(-8, 9) = 1.60076E-10	V(-8, 9) = .784771
B(-8, 10) = 1.351E-10	V(-8, 10) = .66199
B(-7, -10) = 1.34933E-10	V(-7, -10) = .661169
B(-7, -9) = 1.62562E-10	V(-7, -9) = .796552
B(-7, -8) = 1.96356E-10	V(-7, -8) = .962145
B(-7, -7) = 2.37212E-10	V(-7, -7) = 1.16234
B(-7, -6) = 2.85594E-10	V(-7, -6) = 1.39941
B(-7, -5) = 3.40983E-10	V(-7, -5) = 1.67082
B(-7, -4) = 4.01124E-10	V(-7, -4) = 1.96551
B(-7, -3) = 4.61286E-10	V(-7, -3) = 2.2603
B(-7, -2) = 5.14123E-10	V(-7, -2) = 2.5192
B(-7, -1) = 5.50873E-10	V(-7, -1) = 2.69928
B(-7, 0) = 5.64106E-10	V(-7, 0) = 2.76412
B(-7, 1) = 5.50873E-10	V(-7, 1) = 2.69928
B(-7, 2) = 5.14123E-10	V(-7, 2) = 2.5192
B(-7, 3) = 4.61286E-10	V(-7, 3) = 2.2603
B(-7, 4) = 4.01124E-10	V(-7, 4) = 1.96551
B(-7, 5) = 3.40983E-10	V(-7, 5) = 1.67082
B(-7, 6) = 2.85594E-10	V(-7, 6) = 1.39941
B(-7, 7) = 2.37212E-10	V(-7, 7) = 1.16234
B(-7, 8) = 1.96356E-10	V(-7, 8) = .962145
B(-7, 9) = 1.62562E-10	V(-7, 9) = .796552
B(-7, 10) = 1.34933E-10	V(-7, 10) = .661169
B(-6, -10) = 1.31045E-10	V(-6, -10) = .642123
B(-6, -9) = 1.60638E-10	V(-6, -9) = .787125
B(-6, -8) = 1.97983E-10	V(-6, -8) = .970116
B(-6, -7) = 2.44794E-10	V(-6, -7) = 1.19949
B(-6, -6) = 3.02563E-10	V(-6, -6) = 1.48256
B(-6, -5) = 3.71807E-10	V(-6, -5) = 1.82185
B(-6, -4) = 4.50778E-10	V(-6, -4) = 2.20881
B(-6, -3) = 5.33783E-10	V(-6, -3) = 2.61554
B(-6, -2) = 6.10058E-10	V(-6, -2) = 2.98928
B(-6, -1) = 6.65009E-10	V(-6, -1) = 3.25855
B(-6, 0) = 6.85185E-10	V(-6, 0) = 3.35741
B(-6, 1) = 6.65009E-10	V(-6, 1) = 3.25855
B(-6, 2) = 6.10058E-10	V(-6, 2) = 2.98928
B(-6, 3) = 5.33783E-10	V(-6, 3) = 2.61554
B(-6, 4) = 4.50778E-10	V(-6, 4) = 2.20881
B(-6, 5) = 3.71807E-10	V(-6, 5) = 1.82185
B(-6, 6) = 3.02563E-10	V(-6, 6) = 1.48256
B(-6, 7) = 2.44794E-10	V(-6, 7) = 1.19949
B(-6, 8) = 1.97983E-10	V(-6, 8) = .970116
B(-6, 9) = 1.60638E-10	V(-6, 9) = .787125
B(-6, 10) = 1.31045E-10	V(-6, 10) = .642123
B(-5, -10) = 1.22451E-10	V(-5, -10) = .60001
B(-5, -9) = 1.52737E-10	V(-5, -9) = .748409
B(-5, -8) = 1.92193E-10	V(-5, -8) = .941746
B(-5, -7) = 2.4356E-10	V(-5, -7) = 1.19344
B(-5, -6) = 3.09839E-10	V(-5, -6) = 1.51821
B(-5, -5) = 3.9348E-10	V(-5, -5) = 1.92805
B(-5, -4) = 4.94502E-10	V(-5, -4) = 2.42306
B(-5, -3) = 6.0728E-10	V(-5, -3) = 2.97567
B(-5, -2) = 7.17036E-10	V(-5, -2) = 3.51348
B(-5, -1) = 7.9985E-10	V(-5, -1) = 3.91926
B(-5, 0) = 8.31059E-10	V(-5, 0) = 4.07219
B(-5, 1) = 7.9985E-10	V(-5, 1) = 3.91926
B(-5, 2) = 7.17036E-10	V(-5, 2) = 3.51348
B(-5, 3) = 6.0728E-10	V(-5, 3) = 2.97567
B(-5, 4) = 4.94502E-10	V(-5, 4) = 2.42306
B(-5, 5) = 3.9348E-10	V(-5, 5) = 1.92805
B(-5, 6) = 3.09839E-10	V(-5, 6) = 1.51821
B(-5, 7) = 2.4356E-10	V(-5, 7) = 1.19344
B(-5, 8) = 1.92193E-10	V(-5, 8) = .941746
B(-5, 9) = 1.52737E-10	V(-5, 9) = .748409
B(-5, 10) = 1.22451E-10	V(-5, 10) = .60001
B(-4, -10) = 1.08333E-10	V(-4, -10) = .530831

B(-4, -9) = 1.37391E-10	V(-4, -9) = .673214
B(-4, -8) = 1.76433E-10	V(-4, -8) = .864522
B(-4, -7) = 2.29214E-10	V(-4, -7) = 1.12315
B(-4, -6) = 3.00518E-10	V(-4, -6) = 1.47254
B(-4, -5) = 3.95602E-10	V(-4, -5) = 1.93845
B(-4, -4) = 5.1807E-10	V(-4, -4) = 2.53854
B(-4, -3) = 6.64847E-10	V(-4, -3) = 3.25775
B(-4, -2) = 8.18217E-10	V(-4, -2) = 4.00926
B(-4, -1) = 9.41075E-10	V(-4, -1) = 4.61127
B(-4, 0) = 9.89019E-10	V(-4, 0) = 4.84619
B(-4, 1) = 9.41075E-10	V(-4, 1) = 4.61127
B(-4, 2) = 8.18217E-10	V(-4, 2) = 4.00926
B(-4, 3) = 6.64847E-10	V(-4, 3) = 3.25775
B(-4, 4) = 5.1807E-10	V(-4, 4) = 2.53854
B(-4, 5) = 3.95602E-10	V(-4, 5) = 1.93845
B(-4, 6) = 3.00518E-10	V(-4, 6) = 1.47254
B(-4, 7) = 2.29214E-10	V(-4, 7) = 1.12315
B(-4, 8) = 1.76433E-10	V(-4, 8) = .864522
B(-4, 9) = 1.37391E-10	V(-4, 9) = .673214
B(-4, 10) = 1.08333E-10	V(-4, 10) = .530831
B(-3, -10) = 8.83014E-11	V(-3, -10) = .432677
B(-3, -9) = 1.13652E-10	V(-3, -9) = .556894
B(-3, -8) = 1.48671E-10	V(-3, -8) = .72849
B(-3, -7) = 1.97694E-10	V(-3, -7) = .968701
B(-3, -6) = 2.66892E-10	V(-3, -6) = 1.30777
B(-3, -5) = 3.64368E-10	V(-3, -5) = 1.7854
B(-3, -4) = 4.98635E-10	V(-3, -4) = 2.44331
B(-3, -3) = 6.72663E-10	V(-3, -3) = 3.29605
B(-3, -2) = 8.70279E-10	V(-3, -2) = 4.26437
B(-3, -1) = 1.04072E-09	V(-3, -1) = 5.09952
B(-3, 0) = 1.11027E-09	V(-3, 0) = 5.44033
B(-3, 1) = 1.04072E-09	V(-3, 1) = 5.09952
B(-3, 2) = 8.70279E-10	V(-3, 2) = 4.26437
B(-3, 3) = 6.72663E-10	V(-3, 3) = 3.29605
B(-3, 4) = 4.98635E-10	V(-3, 4) = 2.44331
B(-3, 5) = 3.64368E-10	V(-3, 5) = 1.7854
B(-3, 6) = 2.66892E-10	V(-3, 6) = 1.30777
B(-3, 7) = 1.97694E-10	V(-3, 7) = .968701
B(-3, 8) = 1.48671E-10	V(-3, 8) = .72849
B(-3, 9) = 1.13652E-10	V(-3, 9) = .556894
B(-3, 10) = 8.83014E-11	V(-3, 10) = .432677
B(-2, -10) = 6.26586E-11	V(-2, -10) = .307027
B(-2, -9) = 8.15981E-11	V(-2, -9) = .399831
B(-2, -8) = 1.08352E-10	V(-2, -8) = .530924
B(-2, -7) = 1.46892E-10	V(-2, -7) = .719772
B(-2, -6) = 2.03353E-10	V(-2, -6) = .996428
B(-2, -5) = 2.86814E-10	V(-2, -5) = 1.40539
B(-2, -4) = 4.09109E-10	V(-2, -4) = 2.00463
B(-2, -3) = 5.80186E-10	V(-2, -3) = 2.84291
B(-2, -2) = 7.91955E-10	V(-2, -2) = 3.88058
B(-2, -1) = 9.90093E-10	V(-2, -1) = 4.85145
B(-2, 0) = 1.07522E-09	V(-2, 0) = 5.26858
B(-2, 1) = 9.90093E-10	V(-2, 1) = 4.85145
B(-2, 2) = 7.91955E-10	V(-2, 2) = 3.88058
B(-2, 3) = 5.80186E-10	V(-2, 3) = 2.84291
B(-2, 4) = 4.09109E-10	V(-2, 4) = 2.00463
B(-2, 5) = 2.86814E-10	V(-2, 5) = 1.40539
B(-2, 6) = 2.03353E-10	V(-2, 6) = .996428
B(-2, 7) = 1.46892E-10	V(-2, 7) = .719772
B(-2, 8) = 1.08352E-10	V(-2, 8) = .530924
B(-2, 9) = 8.15981E-11	V(-2, 9) = .399831
B(-2, 10) = 6.26586E-11	V(-2, 10) = .307027
B(-1, -10) = 3.25665E-11	V(-1, -10) = .159576
B(-1, -9) = 4.27327E-11	V(-1, -9) = .20939
B(-1, -8) = 5.73035E-11	V(-1, -8) = .280787
B(-1, -7) = 7.86961E-11	V(-1, -7) = .385411

B(-1, -6) = 1.10835E-10	V(-1, -6) = .543091
B(-1, -5) = 1.5997E-10	V(-1, -5) = .783852
B(-1, -4) = 2.35269E-10	V(-1, -4) = 1.15282
B(-1, -3) = 3.46906E-10	V(-1, -3) = 1.69984
B(-1, -2) = 4.95046E-10	V(-1, -2) = 2.42573
B(-1, -1) = 6.43614E-10	V(-1, -1) = 3.15371
B(-1, 0) = 7.1044E-10	V(-1, 0) = 3.48116
B(-1, 1) = 6.43614E-10	V(-1, 1) = 3.15371
B(-1, 2) = 4.95046E-10	V(-1, 2) = 2.42573
B(-1, 3) = 3.46906E-10	V(-1, 3) = 1.69984
B(-1, 4) = 2.35269E-10	V(-1, 4) = 1.15282
B(-1, 5) = 1.5997E-10	V(-1, 5) = .783852
B(-1, 6) = 1.10835E-10	V(-1, 6) = .543091
B(-1, 7) = 7.86961E-11	V(-1, 7) = .385611
B(-1, 8) = 5.73035E-11	V(-1, 8) = .280787
B(-1, 9) = 4.27327E-11	V(-1, 9) = .20939
B(-1, 10) = 3.25665E-11	V(-1, 10) = .159576
B(0, -10) = 0	V(0, -10) = 0
B(0, -9) = 0	V(0, -9) = 0
B(0, -8) = 0	V(0, -8) = 0
B(0, -7) = 0	V(0, -7) = 0
B(0, -6) = 0	V(0, -6) = 0
B(0, -5) = 0	V(0, -5) = 0
B(0, -4) = 0	V(0, -4) = 0
B(0, -3) = 0	V(0, -3) = 0
B(0, -2) = 0	V(0, -2) = 0
B(0, -1) = 0	V(0, -1) = 0
B(0, 0) = 0	V(0, 0) = 0
B(0, 1) = 0	V(0, 1) = 0
B(0, 2) = 0	V(0, 2) = 0
B(0, 3) = 0	V(0, 3) = 0
B(0, 4) = 0	V(0, 4) = 0
B(0, 5) = 0	V(0, 5) = 0
B(0, 6) = 0	V(0, 6) = 0
B(0, 7) = 0	V(0, 7) = 0
B(0, 8) = 0	V(0, 8) = 0
B(0, 9) = 0	V(0, 9) = 0
B(0, 10) = 0	V(0, 10) = 0
B(1, -10) = -3.25665E-11	V(1, -10) = -.159576
B(1, -9) = -4.27327E-11	V(1, -9) = -.20939
B(1, -8) = -5.73035E-11	V(1, -8) = -.280787
B(1, -7) = -7.86961E-11	V(1, -7) = -.385611
B(1, -6) = -1.10835E-10	V(1, -6) = -.543091
B(1, -5) = -1.5997E-10	V(1, -5) = -.783852
B(1, -4) = -2.35269E-10	V(1, -4) = -1.15282
B(1, -3) = -3.46906E-10	V(1, -3) = -1.69984
B(1, -2) = -4.95046E-10	V(1, -2) = -2.42573
B(1, -1) = -6.43614E-10	V(1, -1) = -3.15371
B(1, 0) = -7.1044E-10	V(1, 0) = -3.48116
B(1, 1) = -6.43614E-10	V(1, 1) = -3.15371
B(1, 2) = -4.95046E-10	V(1, 2) = -2.42573
B(1, 3) = -3.46906E-10	V(1, 3) = -1.69984
B(1, 4) = -2.35269E-10	V(1, 4) = -1.15282
B(1, 5) = -1.5997E-10	V(1, 5) = -.783852
B(1, 6) = -1.10835E-10	V(1, 6) = -.543091
B(1, 7) = -7.86961E-11	V(1, 7) = -.385611
B(1, 8) = -5.73035E-11	V(1, 8) = -.280787
B(1, 9) = -4.27327E-11	V(1, 9) = -.20939
B(1, 10) = -3.25665E-11	V(1, 10) = -.159576
B(2, -10) = -6.26586E-11	V(2, -10) = -.307027
B(2, -9) = -8.15981E-11	V(2, -9) = -.399831
B(2, -8) = -1.08352E-10	V(2, -8) = -.530924
B(2, -7) = -1.46892E-10	V(2, -7) = -.719772
B(2, -6) = -2.03353E-10	V(2, -6) = -.996428
B(2, -5) = -2.86814E-10	V(2, -5) = -1.40539
B(2, -4) = -4.09109E-10	V(2, -4) = -2.00463

B(2 , -3)	=-5.80186E-10	V(2 , -3)	=-2.84291
B(2 , -2)	=-7.91955E-10	V(2 , -2)	=-3.88058
B(2 , -1)	=-9.90093E-10	V(2 , -1)	=-4.85145
B(2 , 0)	=-1.07522E-09	V(2 , 0)	=-5.26858
B(2 , 1)	=-9.90093E-10	V(2 , 1)	=-4.85145
B(2 , 2)	=-7.91955E-10	V(2 , 2)	=-3.88058
B(2 , 3)	=-5.80186E-10	V(2 , 3)	=-2.84291
B(2 , 4)	=-4.09109E-10	V(2 , 4)	=-2.00463
B(2 , 5)	=-2.86814E-10	V(2 , 5)	=-1.40539
B(2 , 6)	=-2.03353E-10	V(2 , 6)	=-.996428
B(2 , 7)	=-1.46892E-10	V(2 , 7)	=-.719772
B(2 , 8)	=-1.08352E-10	V(2 , 8)	=-.530924
B(2 , 9)	=-8.15981E-11	V(2 , 9)	=-.399831
B(2 , 10)	=-6.26586E-11	V(2 , 10)	=-.307027
B(3 , -10)	=-8.83014E-11	V(3 , -10)	=-.432677
B(3 , -9)	=-1.13652E-10	V(3 , -9)	=-.556894
B(3 , -8)	=-1.48671E-10	V(3 , -8)	=-.72849
B(3 , -7)	=-1.97694E-10	V(3 , -7)	=-.968701
B(3 , -6)	=-2.66892E-10	V(3 , -6)	=-1.30777
B(3 , -5)	=-3.64368E-10	V(3 , -5)	=-1.7854
B(3 , -4)	=-4.98635E-10	V(3 , -4)	=-2.44331
B(3 , -3)	=-6.72663E-10	V(3 , -3)	=-3.29605
B(3 , -2)	=-8.70279E-10	V(3 , -2)	=-4.26437
B(3 , -1)	=-1.04072E-09	V(3 , -1)	=-5.09952
B(3 , 0)	=-1.11027E-09	V(3 , 0)	=-5.44033
B(3 , 1)	=-1.04072E-09	V(3 , 1)	=-5.09952
B(3 , 2)	=-8.70279E-10	V(3 , 2)	=-4.26437
B(3 , 3)	=-6.72663E-10	V(3 , 3)	=-3.29605
B(3 , 4)	=-4.98635E-10	V(3 , 4)	=-2.44331
B(3 , 5)	=-3.64368E-10	V(3 , 5)	=-1.7854
B(3 , 6)	=-2.66892E-10	V(3 , 6)	=-1.30777
B(3 , 7)	=-1.97694E-10	V(3 , 7)	=-.968701
B(3 , 8)	=-1.48671E-10	V(3 , 8)	=-.72849
B(3 , 9)	=-1.13652E-10	V(3 , 9)	=-.556894
B(3 , 10)	=-8.83014E-11	V(3 , 10)	=-.432677
B(4 , -10)	=-1.08333E-10	V(4 , -10)	=-.530831
B(4 , -9)	=-1.37391E-10	V(4 , -9)	=-.673214
B(4 , -8)	=-1.76433E-10	V(4 , -8)	=-.864522
B(4 , -7)	=-2.29214E-10	V(4 , -7)	=-1.12315
B(4 , -6)	=-3.00518E-10	V(4 , -6)	=-1.47254
B(4 , -5)	=-3.95602E-10	V(4 , -5)	=-1.93845
B(4 , -4)	=-5.1807E-10	V(4 , -4)	=-2.53854
B(4 , -3)	=-6.64847E-10	V(4 , -3)	=-3.25775
B(4 , -2)	=-8.18217E-10	V(4 , -2)	=-4.00926
B(4 , -1)	=-9.41075E-10	V(4 , -1)	=-4.61127
B(4 , 0)	=-9.89019E-10	V(4 , 0)	=-4.84619
B(4 , 1)	=-9.41075E-10	V(4 , 1)	=-4.61127
B(4 , 2)	=-8.18217E-10	V(4 , 2)	=-4.00926
B(4 , 3)	=-6.64847E-10	V(4 , 3)	=-3.25775
B(4 , 4)	=-5.1807E-10	V(4 , 4)	=-2.53854
B(4 , 5)	=-3.95602E-10	V(4 , 5)	=-1.93845
B(4 , 6)	=-3.00518E-10	V(4 , 6)	=-1.47254
B(4 , 7)	=-2.29214E-10	V(4 , 7)	=-1.12315
B(4 , 8)	=-1.76433E-10	V(4 , 8)	=-.864522
B(4 , 9)	=-1.37391E-10	V(4 , 9)	=-.673214
B(4 , 10)	=-1.08333E-10	V(4 , 10)	=-.530831
B(5 , -10)	=-1.22451E-10	V(5 , -10)	=-.60001
B(5 , -9)	=-1.52737E-10	V(5 , -9)	=-.748409
B(5 , -8)	=-1.92193E-10	V(5 , -8)	=-.941746
B(5 , -7)	=-2.4356E-10	V(5 , -7)	=-1.19344
B(5 , -6)	=-3.09839E-10	V(5 , -6)	=-1.51821
B(5 , -5)	=-3.9348E-10	V(5 , -5)	=-1.92805
B(5 , -4)	=-4.94502E-10	V(5 , -4)	=-2.42306
B(5 , -3)	=-6.0728E-10	V(5 , -3)	=-2.97567
B(5 , -2)	=-7.17036E-10	V(5 , -2)	=-3.51348
B(5 , -1)	=-7.9985E-10	V(5 , -1)	=-3.91926

B(5 , 0)=-8.31059E-10
 B(5 , 1)=-7.9985E-10
 B(5 , 2)=-7.17036E-10
 B(5 , 3)=-6.0728E-10
 B(5 , 4)=-4.94502E-10
 B(5 , 5)=-3.9348E-10
 B(5 , 6)=-3.09839E-10
 B(5 , 7)=-2.4356E-10
 B(5 , 8)=-1.92193E-10
 B(5 , 9)=-1.52737E-10
 B(5 , 10)=-1.22451E-10
 B(6 , -10)=-1.31045E-10
 B(6 , -9)=-1.60638E-10
 B(6 , -8)=-1.97983E-10
 B(6 , -7)=-2.44794E-10
 B(6 , -6)=-3.02563E-10
 B(6 , -5)=-3.71807E-10
 B(6 , -4)=-4.50778E-10
 B(6 , -3)=-5.33783E-10
 B(6 , -2)=-6.10058E-10
 B(6 , -1)=-6.65009E-10
 B(6 , 0)=-6.85185E-10
 B(6 , 1)=-6.65009E-10
 B(6 , 2)=-6.10058E-10
 B(6 , 3)=-5.33783E-10
 B(6 , 4)=-4.50778E-10
 B(6 , 5)=-3.71807E-10
 B(6 , 6)=-3.02563E-10
 B(6 , 7)=-2.44794E-10
 B(6 , 8)=-1.97983E-10
 B(6 , 9)=-1.60638E-10
 B(6 , 10)=-1.31045E-10
 B(7 , -10)=-1.34933E-10
 B(7 , -9)=-1.62562E-10
 B(7 , -8)=-1.96356E-10
 B(7 , -7)=-2.37212E-10
 B(7 , -6)=-2.85594E-10
 B(7 , -5)=-3.40983E-10
 B(7 , -4)=-4.01124E-10
 B(7 , -3)=-4.61286E-10
 B(7 , -2)=-5.14123E-10
 B(7 , -1)=-5.50873E-10
 B(7 , 0)=-5.64106E-10
 B(7 , 1)=-5.50873E-10
 B(7 , 2)=-5.14123E-10
 B(7 , 3)=-4.61286E-10
 B(7 , 4)=-4.01124E-10
 B(7 , 5)=-3.40983E-10
 B(7 , 6)=-2.85594E-10
 B(7 , 7)=-2.37212E-10
 B(7 , 8)=-1.96356E-10
 B(7 , 9)=-1.62562E-10
 B(7 , 10)=-1.34933E-10
 B(8 , -10)=-1.351E-10
 B(8 , -9)=-1.60076E-10
 B(8 , -8)=-1.89732E-10
 B(8 , -7)=-2.24407E-10
 B(8 , -6)=-2.63977E-10
 B(8 , -5)=-3.07509E-10
 B(8 , -4)=-3.52866E-10
 B(8 , -3)=-3.96457E-10
 B(8 , -2)=-4.33408E-10
 B(8 , -1)=-4.58428E-10
 B(8 , 0)=-4.67307E-10
 B(8 , 1)=-4.58428E-10
 B(8 , 2)=-4.33408E-10

V(5 , 0)=-4.07219
 V(5 , 1)=-3.91926
 V(5 , 2)=-3.51348
 V(5 , 3)=-2.97567
 V(5 , 4)=-2.42306
 V(5 , 5)=-1.92805
 V(5 , 6)=-1.51821
 V(5 , 7)=-1.19344
 V(5 , 8)=-.941746
 V(5 , 9)=-.748409
 V(5 , 10)=-.60001
 V(6 , -10)=-.642123
 V(6 , -9)=-.787125
 V(6 , -8)=-.970116
 V(6 , -7)=-1.19949
 V(6 , -6)=-1.48256
 V(6 , -5)=-1.82185
 V(6 , -4)=-2.20881
 V(6 , -3)=-2.61554
 V(6 , -2)=-2.98928
 V(6 , -1)=-3.25855
 V(6 , 0)=-3.35741
 V(6 , 1)=-3.25855
 V(6 , 2)=-2.98928
 V(6 , 3)=-2.61554
 V(6 , 4)=-2.20881
 V(6 , 5)=-1.82185
 V(6 , 6)=-1.48256
 V(6 , 7)=-1.19949
 V(6 , 8)=-.970116
 V(6 , 9)=-.787125
 V(6 , 10)=-.642123
 V(7 , -10)=-.661169
 V(7 , -9)=-.796552
 V(7 , -8)=-.962145
 V(7 , -7)=-1.16234
 V(7 , -6)=-1.39941
 V(7 , -5)=-1.67082
 V(7 , -4)=-1.96551
 V(7 , -3)=-2.2603
 V(7 , -2)=-2.5192
 V(7 , -1)=-2.69928
 V(7 , 0)=-2.76412
 V(7 , 1)=-2.69928
 V(7 , 2)=-2.5192
 V(7 , 3)=-2.2603
 V(7 , 4)=-1.96551
 V(7 , 5)=-1.67082
 V(7 , 6)=-1.39941
 V(7 , 7)=-1.16234
 V(7 , 8)=-.962145
 V(7 , 9)=-.796552
 V(7 , 10)=-.661169
 V(8 , -10)=-.66199
 V(8 , -9)=-.784371
 V(8 , -8)=-.929687
 V(8 , -7)=-1.09959
 V(8 , -6)=-1.29349
 V(8 , -5)=-1.50679
 V(8 , -4)=-1.72904
 V(8 , -3)=-1.94264
 V(8 , -2)=-2.1237
 V(8 , -1)=-2.2463
 V(8 , 0)=-2.2898
 V(8 , 1)=-2.2463
 V(8 , 2)=-2.1237

B(8 , 3)=-3.96457E-10
 B(8 , 4)=-3.52866E-10
 B(8 , 5)=-3.07509E-10
 B(8 , 6)=-2.63977E-10
 B(8 , 7)=-2.24407E-10
 B(8 , 8)=-1.89732E-10
 B(8 , 9)=-1.60076E-10
 B(8 , 10)=-1.351E-10
 B(9 , -10)=-1.32522E-10
 B(9 , -9)=-1.5459E-10
 B(9 , -8)=-1.80085E-10
 B(9 , -7)=-2.09008E-10
 B(9 , -6)=-2.40957E-10
 B(9 , -5)=-2.74926E-10
 B(9 , -4)=-3.09129E-10
 B(9 , -3)=-3.40955E-10
 B(9 , -2)=-3.67192E-10
 B(9 , -1)=-3.84594E-10
 B(9 , 0)=-3.90703E-10
 B(9 , 1)=-3.84594E-10
 B(9 , 2)=-3.67192E-10
 B(9 , 3)=-3.40955E-10
 B(9 , 4)=-3.09129E-10
 B(9 , 5)=-2.74926E-10
 B(9 , 6)=-2.40957E-10
 B(9 , 7)=-2.09008E-10
 B(9 , 8)=-1.80085E-10
 B(9 , 9)=-1.5459E-10
 B(9 , 10)=-1.32522E-10
 B(10 , -10)=-1.28051E-10
 B(10 , -9)=-1.47246E-10
 B(10 , -8)=-1.68875E-10
 B(10 , -7)=-1.92761E-10
 B(10 , -6)=-2.18409E-10
 B(10 , -5)=-2.44902E-10
 B(10 , -4)=-2.70832E-10
 B(10 , -3)=-2.94338E-10
 B(10 , -2)=-3.13293E-10
 B(10 , -1)=-3.25665E-10
 B(10 , 0)=-3.29972E-10
 B(10 , 1)=-3.25665E-10
 B(10 , 2)=-3.13293E-10
 B(10 , 3)=-2.94338E-10
 B(10 , 4)=-2.70832E-10
 B(10 , 5)=-2.44902E-10
 B(10 , 6)=-2.18409E-10
 B(10 , 7)=-1.92761E-10
 B(10 , 8)=-1.68875E-10
 B(10 , 9)=-1.47246E-10
 B(10 , 10)=-1.28051E-10

V(8 , 3)=-1.94264
 V(8 , 4)=-1.72904
 V(8 , 5)=-1.50679
 V(8 , 6)=-1.29349
 V(8 , 7)=-1.09959
 V(8 , 8)=-.929687
 V(8 , 9)=-.784371
 V(8 , 10)=-.66199
 V(9 , -10)=-.649356
 V(9 , -9)=-.757492
 V(9 , -8)=-.882418
 V(9 , -7)=-1.02414
 V(9 , -6)=-1.18069
 V(9 , -5)=-1.34714
 V(9 , -4)=-1.51473
 V(9 , -3)=-1.67068
 V(9 , -2)=-1.79924
 V(9 , -1)=-1.88451
 V(9 , 0)=-1.91444
 V(9 , 1)=-1.88451
 V(9 , 2)=-1.79924
 V(9 , 3)=-1.67068
 V(9 , 4)=-1.51473
 V(9 , 5)=-1.34714
 V(9 , 6)=-1.18069
 V(9 , 7)=-1.02414
 V(9 , 8)=-.882418
 V(9 , 9)=-.757492
 V(9 , 10)=-.649356
 V(10 , -10)=-.627451
 V(10 , -9)=-.721507
 V(10 , -8)=-.827488
 V(10 , -7)=-.944528
 V(10 , -6)=-1.0702
 V(10 , -5)=-1.20002
 V(10 , -4)=-1.32708
 V(10 , -3)=-1.44226
 V(10 , -2)=-1.53514
 V(10 , -1)=-1.59576
 V(10 , 0)=-1.61686
 V(10 , 1)=-1.59576
 V(10 , 2)=-1.53514
 V(10 , 3)=-1.44226
 V(10 , 4)=-1.32708
 V(10 , 5)=-1.20002
 V(10 , 6)=-1.0702
 V(10 , 7)=-.944528
 V(10 , 8)=-.827488
 V(10 , 9)=-.721507
 V(10 , 10)=-.627451

TABLE A-1

Comparison of Predicted Versus Measured Magnetic Field

Coordinates (x,y)	Predicted mV	Measured mV	Factor
-10,-10	0.627	.042	14.9
-9,-9	0.757	.049	15.4
-8,-8	0.929	.063	14.7
-7,-7	1.162	.081	14.3
-6,-6	1.483	.126	11.8
-5,-5	1.928	.234	8.2
-4,-4	2.539	.371	6.8
-3,-3	3.296	.61	5.4
-2,-2	3.881	.788	4.9
-1,-1	3.154	.72	4.4
0,0	0.000	.4	-----
1,1	3.154-	.731	4.3
2,2	3.881-	.811	4.8
3,3	3.296-	.633	5.2
4,4	2.539-	.387	6.6
5,5	1.928-	.251	7.7
6,6	1.483-	.147	10.1
7,7	1.162-	.088	13.2
8,8	0.929-	.067	13.9
9,9	0.757	.051	14.8
10,10	0.627	.043	14.6

APPENDIX B

SINGLE DIPOLE SURFACE POTENTIAL DATA

```

10 REM
20 REM PROGRAM PHIB/BAS
30 REM CALCULATES SURFACE POTENTIAL FOR A DIPOLE
40 REM SUBMERGED IN A .464% NACL SOLUTION
50 REM I = 8 MILLIAMPS
60 REM LENGTH OF DIPOLE = .005 METERS
70 REM CAPT. ROBERT D. MURRAY
80 REM
90 P=.008*.005
100 PI=3.14159
110 D=.015
120 SIGMA=.7624
130 FOR X=-.1 TO .1 STEP .01
140 FOR Y=-.1 TO .1 STEP .01
150 R1=((X*X+Y*Y+D*D)[1.5)
160 R2=((X*X+Y*Y+D*D)[1.5)
170 K=P/(2*PI*SIGMA)
180 PHI = ((K*Y)*((1/R1)+(1/R2)))
190 LPRINT"PHI(";INT(100*(.005+X));",";INT(100*(.005+Y));") = ";PHI
200 NEXT Y
210 NEXT X

```

PHI(-10, -10) = -5.80624E-04
 PHI(-10, -9) = -6.05905E-04
 PHI(-10, -8) = -6.23268E-04
 PHI(-10, -7) = -6.28467E-04
 PHI(-10, -6) = -6.16426E-04
 PHI(-10, -5) = -5.81716E-04
 PHI(-10, -4) = -5.195E-04
 PHI(-10, -3) = -4.26971E-04
 PHI(-10, -2) = -3.04975E-04
 PHI(-10, -1) = -1.59182E-04
 PHI(-10, 0) = -2.40687E-10
 PHI(-10, 1) = 1.59181E-04
 PHI(-10, 2) = 3.04975E-04
 PHI(-10, 3) = 4.26971E-04
 PHI(-10, 4) = 5.195E-04
 PHI(-10, 5) = 5.81716E-04
 PHI(-10, 6) = 6.16426E-04
 PHI(-10, 7) = 6.28467E-04
 PHI(-10, 8) = 6.23269E-04
 PHI(-10, 9) = 6.05905E-04
 PHI(-10, 10) = 5.80623E-04
 PHI(-9, -10) = -6.73227E-04
 PHI(-9, -9) = -7.14023E-04
 PHI(-9, -8) = -7.47712E-04
 PHI(-9, -7) = -7.68656E-04
 PHI(-9, -6) = -7.69469E-04
 PHI(-9, -5) = -7.41405E-04
 PHI(-9, -4) = -6.75604E-04
 PHI(-9, -3) = -5.65457E-04
 PHI(-9, -2) = -4.09836E-04
 PHI(-9, -1) = -2.1596E-04
 PHI(-9, 0) = -3.27621E-10
 PHI(-9, 1) = 2.15959E-04
 PHI(-9, 2) = 4.09835E-04
 PHI(-9, 3) = 5.65456E-04
 PHI(-9, 4) = 6.75603E-04
 PHI(-9, 5) = 7.41405E-04
 PHI(-9, 6) = 7.69469E-04
 PHI(-9, 7) = 7.68656E-04
 PHI(-9, 8) = 7.47712E-04
 PHI(-9, 9) = 7.14023E-04
 PHI(-9, 10) = 6.73227E-04
 PHI(-8, -10) = -7.79085E-04
 PHI(-8, -9) = -8.41176E-04
 PHI(-8, -8) = -8.98774E-04
 PHI(-8, -7) = -9.44853E-04
 PHI(-8, -6) = -9.69134E-04
 PHI(-8, -5) = -9.57962E-04
 PHI(-8, -4) = -8.95537E-04
 PHI(-8, -3) = -7.67519E-04
 PHI(-8, -2) = -5.67268E-04
 PHI(-8, -1) = -3.02824E-04
 PHI(-8, 0) = -4.61497E-10
 PHI(-8, 1) = 3.02823E-04
 PHI(-8, 2) = 5.67267E-04
 PHI(-8, 3) = 7.67518E-04
 PHI(-8, 4) = 8.95537E-04
 PHI(-8, 5) = 9.57962E-04
 PHI(-8, 6) = 9.69134E-04
 PHI(-8, 7) = 9.44853E-04
 PHI(-8, 8) = 8.98775E-04
 PHI(-8, 9) = 8.41176E-04
 PHI(-8, 10) = 7.79086E-04
 PHI(-7, -10) = -8.9781E-04

PHI(-7, -9) = -9.88272E-04
 PHI(-7, -8) = -1.07983E-03
 PHI(-7, -7) = -1.16466E-03
 PHI(-7, -6) = -1.22951E-03
 PHI(-7, -5) = -1.25412E-03
 PHI(-7, -4) = -1.21129E-03
 PHI(-7, -3) = -1.07131E-03
 PHI(-7, -2) = -8.13316E-04
 PHI(-7, -1) = -4.42179E-04
 PHI(-7, 0) = -6.78276E-10
 PHI(-7, 1) = 4.42178E-04
 PHI(-7, 2) = 8.13315E-04
 PHI(-7, 3) = 1.07131E-03
 PHI(-7, 4) = 1.21129E-03
 PHI(-7, 5) = 1.25412E-03
 PHI(-7, 6) = 1.22951E-03
 PHI(-7, 7) = 1.16466E-03
 PHI(-7, 8) = 1.07983E-03
 PHI(-7, 9) = 9.88272E-04
 PHI(-7, 10) = 8.9781E-04
 PHI(-6, -10) = -1.02738E-03
 PHI(-6, -9) = -1.1542E-03
 PHI(-6, -8) = -1.29218E-03
 PHI(-6, -7) = -1.43442E-03
 PHI(-6, -6) = -1.56615E-03
 PHI(-6, -5) = -1.65999E-03
 PHI(-6, -4) = -1.67181E-03
 PHI(-6, -3) = -1.54257E-03
 PHI(-6, -2) = -1.21623E-03
 PHI(-6, -1) = -6.79155E-04
 PHI(-6, 0) = -1.05196E-09
 PHI(-6, 1) = 6.79153E-04
 PHI(-6, 2) = 1.21623E-03
 PHI(-6, 3) = 1.54257E-03
 PHI(-6, 4) = 1.67181E-03
 PHI(-6, 5) = 1.65999E-03
 PHI(-6, 6) = 1.56615E-03
 PHI(-6, 7) = 1.43442E-03
 PHI(-6, 8) = 1.29218E-03
 PHI(-6, 9) = 1.1542E-03
 PHI(-6, 10) = 1.02738E-03
 PHI(-5, -10) = -1.16343E-03
 PHI(-5, -9) = -1.33453E-03
 PHI(-5, -8) = -1.53274E-03
 PHI(-5, -7) = -1.75576E-03
 PHI(-5, -6) = -1.99199E-03
 PHI(-5, -5) = -2.21089E-03
 PHI(-5, -4) = -2.3486E-03
 PHI(-5, -3) = -2.29555E-03
 PHI(-5, -2) = -1.91198E-03
 PHI(-5, -1) = -1.11224E-03
 PHI(-5, 0) = -1.74943E-09
 PHI(-5, 1) = 1.11224E-03
 PHI(-5, 2) = 1.91198E-03
 PHI(-5, 3) = 2.29555E-03
 PHI(-5, 4) = 2.3486E-03
 PHI(-5, 5) = 2.2109E-03
 PHI(-5, 6) = 1.99199E-03
 PHI(-5, 7) = 1.75576E-03
 PHI(-5, 8) = 1.53274E-03
 PHI(-5, 9) = 1.33453E-03
 PHI(-5, 10) = 1.16343E-03
 PHI(-4, -10) = -1.29875E-03
 PHI(-4, -9) = -1.52011E-03
 PHI(-4, -8) = -1.79107E-03
 PHI(-4, -7) = -2.11976E-03

PHI(-4, -6) = -2.50772E-03
 PHI(-4, -5) = -2.93574E-03
 PHI(-4, -4) = -3.3327E-03
 PHI(-4, -3) = -3.52208E-03
 PHI(-4, -2) = -3.18245E-03
 PHI(-4, -1) = -1.97734E-03
 PHI(-4, 0) = -3.19193E-09
 PHI(-4, 1) = 1.97734E-03
 PHI(-4, 2) = 3.18245E-03
 PHI(-4, 3) = 3.52208E-03
 PHI(-4, 4) = 3.3327E-03
 PHI(-4, 5) = 2.93575E-03
 PHI(-4, 6) = 2.50772E-03
 PHI(-4, 7) = 2.11976E-03
 PHI(-4, 8) = 1.79107E-03
 PHI(-4, 9) = 1.52011E-03
 PHI(-4, 10) = 1.29875E-03
 PHI(-3, -10) = -1.42324E-03
 PHI(-3, -9) = -1.69637E-03
 PHI(-3, -8) = -2.04672E-03
 PHI(-3, -7) = -2.49971E-03
 PHI(-3, -6) = -3.08515E-03
 PHI(-3, -5) = -3.82592E-03
 PHI(-3, -4) = -4.6961E-03
 PHI(-3, -3) = -5.49808E-03
 PHI(-3, -2) = -5.60857E-03
 PHI(-3, -1) = -3.89514E-03
 PHI(-3, 0) = -6.59506E-09
 PHI(-3, 1) = 3.89514E-03
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 PHI(-3, 4) = 4.69611E-03
 PHI(-3, 5) = 3.82592E-03
 PHI(-3, 6) = 3.08515E-03
 PHI(-3, 7) = 2.49971E-03
 PHI(-3, 8) = 2.04672E-03
 PHI(-3, 9) = 1.69637E-03
 PHI(-3, 10) = 1.42324E-03
 PHI(-2, -10) = -1.52488E-03
 PHI(-2, -9) = -1.84426E-03
 PHI(-2, -8) = -2.26907E-03
 PHI(-2, -7) = -2.8466E-03
 PHI(-2, -6) = -3.6487E-03
 PHI(-2, -5) = -4.77994E-03
 PHI(-2, -4) = -6.3649E-03
 PHI(-2, -3) = -8.41286E-03
 PHI(-2, -2) = -.0101782
 PHI(-2, -1) = -8.555E-03
 PHI(-2, 0) = -1.59267E-08
 PHI(-2, 1) = 8.55499E-03
 PHI(-2, 2) = .0101782
 PHI(-2, 3) = 8.41287E-03
 PHI(-2, 4) = 6.36492E-03
 PHI(-2, 5) = 4.77994E-03
 PHI(-2, 6) = 3.64871E-03
 PHI(-2, 7) = 2.84661E-03
 PHI(-2, 8) = 2.26907E-03
 PHI(-2, 9) = 1.84426E-03
 PHI(-2, 10) = 1.52488E-03
 PHI(-1, -10) = -1.59182E-03
 PHI(-1, -9) = -1.94364E-03
 PHI(-1, -8) = -2.42259E-03
 PHI(-1, -7) = -3.09525E-03
 PHI(-1, -6) = -4.07493E-03
 PHI(-1, -5) = -5.56121E-03
 PHI(-1, -4) = -7.90935E-03

PHI(-1, -2) = -.01711
 PHI(-1, -1) = -.0190609
 PHI(-1, 0) = -4.24739E-08
 PHI(-1, 1) = .0190609
 PHI(-1, 2) = .01711
 PHI(-1, 3) = .0116854
 PHI(-1, 4) = 7.90936E-03
 PHI(-1, 5) = 5.56122E-03
 PHI(-1, 6) = 4.07492E-03
 PHI(-1, 7) = 3.09526E-03
 PHI(-1, 8) = 2.42259E-03
 PHI(-1, 9) = 1.94364E-03
 PHI(-1, 10) = 1.59182E-03
 PHI(0, -10) = -1.61522E-03
 PHI(0, -9) = -1.97876E-03
 PHI(0, -8) = -2.47764E-03
 PHI(0, -7) = -3.18629E-03
 PHI(0, -6) = -4.23576E-03
 PHI(0, -5) = -5.87013E-03
 PHI(0, -4) = -8.56826E-03
 PHI(0, -3) = -.0132776
 PHI(0, -2) = -.0213765
 PHI(0, -1) = -.0285038
 PHI(0, 0) = -7.3735E-08
 PHI(0, 1) = .0285038
 PHI(0, 2) = .0213766
 PHI(0, 3) = .0132776
 PHI(0, 4) = 8.56828E-03
 PHI(0, 5) = 5.87013E-03
 PHI(0, 6) = 4.23576E-03
 PHI(0, 7) = 3.18629E-03
 PHI(0, 8) = 2.47764E-03
 PHI(0, 9) = 1.97876E-03
 PHI(0, 10) = 1.61522E-03
 PHI(1, -10) = -1.59182E-03
 PHI(1, -9) = -1.94364E-03
 PHI(1, -8) = -2.42259E-03
 PHI(1, -7) = -3.09525E-03
 PHI(1, -6) = -4.07493E-03
 PHI(1, -5) = -5.56122E-03
 PHI(1, -4) = -7.90936E-03
 PHI(1, -3) = -.0116854
 PHI(1, -2) = -.01711
 PHI(1, -1) = -.019061
 PHI(1, 0) = -4.2474E-08
 PHI(1, 1) = .019061
 PHI(1, 2) = .01711
 PHI(1, 3) = .0116854
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 PHI(1, 5) = 5.56122E-03
 PHI(1, 6) = 4.07492E-03
 PHI(1, 7) = 3.09526E-03
 PHI(1, 8) = 2.42259E-03
 PHI(1, 9) = 1.94364E-03
 PHI(1, 10) = 1.59182E-03
 PHI(2, -10) = -1.52488E-03
 PHI(2, -9) = -1.84426E-03
 PHI(2, -8) = -2.26907E-03
 PHI(2, -7) = -2.84661E-03
 PHI(2, -6) = -3.6487E-03
 PHI(2, -5) = -4.77994E-03
 PHI(2, -4) = -6.36491E-03
 PHI(2, -3) = -8.41287E-03
 PHI(2, -2) = -.0101782
 PHI(2, -1) = -8.55503E-03

PHI(2 , 0) = -1.59268E-08
 PHI(2 , 1) = 8.55501E-03
 PHI(2 , 2) = .0101782
 PHI(2 , 3) = 8.41288E-03
 PHI(2 , 4) = 6.36492E-03
 PHI(2 , 5) = 4.77994E-03
 PHI(2 , 6) = 3.64871E-03
 PHI(2 , 7) = 2.84661E-03
 PHI(2 , 8) = 2.26907E-03
 PHI(2 , 9) = 1.84426E-03
 PHI(2 , 10) = 1.52488E-03
 PHI(3 , -10) = -1.42324E-03
 PHI(3 , -9) = -1.69637E-03
 PHI(3 , -8) = -2.04672E-03
 PHI(3 , -7) = -2.49971E-03
 PHI(3 , -6) = -3.08515E-03
 PHI(3 , -5) = -3.82592E-03
 PHI(3 , -4) = -4.69611E-03
 PHI(3 , -3) = -5.49809E-03
 PHI(3 , -2) = -5.60858E-03
 PHI(3 , -1) = -3.89515E-03
 PHI(3 , 0) = -6.59507E-09
 PHI(3 , 1) = 3.89514E-03
 PHI(3 , 2) = 5.60859E-03
 PHI(3 , 3) = 5.49809E-03
 PHI(3 , 4) = 4.69611E-03
 PHI(3 , 5) = 3.82592E-03
 PHI(3 , 6) = 3.08515E-03
 PHI(3 , 7) = 2.49971E-03
 PHI(3 , 8) = 2.04672E-03
 PHI(3 , 9) = 1.69637E-03
 PHI(3 , 10) = 1.42324E-03
 PHI(4 , -10) = -1.29875E-03
 PHI(4 , -9) = -1.52011E-03
 PHI(4 , -8) = -1.79107E-03
 PHI(4 , -7) = -2.11976E-03
 PHI(4 , -6) = -2.50772E-03
 PHI(4 , -5) = -2.93575E-03
 PHI(4 , -4) = -3.33271E-03
 PHI(4 , -3) = -3.52208E-03
 PHI(4 , -2) = -3.18246E-03
 PHI(4 , -1) = -1.97734E-03
 PHI(4 , 0) = -3.19193E-09
 PHI(4 , 1) = 1.97734E-03
 PHI(4 , 2) = 3.18246E-03
 PHI(4 , 3) = 3.52208E-03
 PHI(4 , 4) = 3.3327E-03
 PHI(4 , 5) = 2.93575E-03
 PHI(4 , 6) = 2.50772E-03
 PHI(4 , 7) = 2.11976E-03
 PHI(4 , 8) = 1.79108E-03
 PHI(4 , 9) = 1.52011E-03
 PHI(4 , 10) = 1.29875E-03
 PHI(5 , -10) = -1.16343E-03
 PHI(5 , -9) = -1.33453E-03
 PHI(5 , -8) = -1.53274E-03
 PHI(5 , -7) = -1.75576E-03
 PHI(5 , -6) = -1.99199E-03
 PHI(5 , -5) = -2.2109E-03
 PHI(5 , -4) = -2.3486E-03
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 PHI(5 , -2) = -1.91198E-03
 PHI(5 , -1) = -1.11225E-03
 PHI(5 , 0) = -1.74944E-09
 PHI(5 , 1) = 1.11224E-03
 PHI(5 , 2) = 1.91198E-03

PHI(5 , 3) = 2.29555E-03
 PHI(5 , 4) = 2.3486E-03
 PHI(5 , 5) = 2.2109E-03
 PHI(5 , 6) = 1.99199E-03
 PHI(5 , 7) = 1.75576E-03
 PHI(5 , 8) = 1.53274E-03
 PHI(5 , 9) = 1.33453E-03
 PHI(5 , 10) = 1.16343E-03
 PHI(6 , -10) = -1.02738E-03
 PHI(6 , -9) = -1.1542E-03
 PHI(6 , -8) = -1.29218E-03
 PHI(6 , -7) = -1.43442E-03
 PHI(6 , -6) = -1.56615E-03
 PHI(6 , -5) = -1.65999E-03
 PHI(6 , -4) = -1.67181E-03
 PHI(6 , -3) = -1.54258E-03
 PHI(6 , -2) = -1.21624E-03
 PHI(6 , -1) = -6.79155E-04
 PHI(6 , 0) = -1.05196E-09
 PHI(6 , 1) = 6.79153E-04
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 PHI(6 , 8) = 1.29218E-03
 PHI(6 , 9) = 1.1542E-03
 PHI(6 , 10) = 1.02738E-03
 PHI(7 , -10) = -8.9781E-04
 PHI(7 , -9) = -9.88272E-04
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 PHI(7 , -7) = -1.16466E-03
 PHI(7 , -6) = -1.22951E-03
 PHI(7 , -5) = -1.25412E-03
 PHI(7 , -4) = -1.21129E-03
 PHI(7 , -3) = -1.07131E-03
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 PHI(7 , 3) = 1.07131E-03
 PHI(7 , 4) = 1.21129E-03
 PHI(7 , 5) = 1.25412E-03
 PHI(7 , 6) = 1.22951E-03
 PHI(7 , 7) = 1.16466E-03
 PHI(7 , 8) = 1.07983E-03
 PHI(7 , 9) = 9.88272E-04
 PHI(7 , 10) = 8.9781E-04
 PHI(8 , -10) = -7.79086E-04
 PHI(8 , -9) = -8.41176E-04
 PHI(8 , -8) = -8.98775E-04
 PHI(8 , -7) = -9.44853E-04
 PHI(8 , -6) = -9.69134E-04
 PHI(8 , -5) = -9.57963E-04
 PHI(8 , -4) = -8.95538E-04
 PHI(8 , -3) = -7.67519E-04
 PHI(8 , -2) = -5.67269E-04
 PHI(8 , -1) = -3.02824E-04
 PHI(8 , 0) = -4.61497E-10
 PHI(8 , 1) = 3.02823E-04
 PHI(8 , 2) = 5.67268E-04
 PHI(8 , 3) = 7.67519E-04
 PHI(8 , 4) = 8.95538E-04
 PHI(8 , 5) = 9.57962E-04

PHI(8 , 6) = 9.69135E-04
 PHI(8 , 7) = 9.44853E-04
 PHI(8 , 8) = 8.98775E-04
 PHI(8 , 9) = 8.41177E-04
 PHI(8 , 10) = 7.79086E-04
 PHI(9 , -10) = -6.73228E-04
 PHI(9 , -9) = -7.14023E-04
 PHI(9 , -8) = -7.47712E-04
 PHI(9 , -7) = -7.68656E-04
 PHI(9 , -6) = -7.6947E-04
 PHI(9 , -5) = -7.41405E-04
 PHI(9 , -4) = -6.75604E-04
 PHI(9 , -3) = -5.65457E-04
 PHI(9 , -2) = -4.09836E-04
 PHI(9 , -1) = -2.1596E-04
 PHI(9 , 0) = -3.27621E-10
 PHI(9 , 1) = 2.1596E-04
 PHI(9 , 2) = 4.09835E-04
 PHI(9 , 3) = 5.65456E-04
 PHI(9 , 4) = 6.75604E-04
 PHI(9 , 5) = 7.41405E-04
 PHI(9 , 6) = 7.6947E-04
 PHI(9 , 7) = 7.68656E-04
 PHI(9 , 8) = 7.47713E-04
 PHI(9 , 9) = 7.14023E-04
 PHI(9 , 10) = 6.73227E-04
 PHI(10 , -10) = -5.80624E-04
 PHI(10 , -9) = -6.05905E-04
 PHI(10 , -8) = -6.23269E-04
 PHI(10 , -7) = -6.28467E-04
 PHI(10 , -6) = -6.16426E-04
 PHI(10 , -5) = -5.81716E-04
 PHI(10 , -4) = -5.19501E-04
 PHI(10 , -3) = -4.26972E-04
 PHI(10 , -2) = -3.04975E-04
 PHI(10 , -1) = -1.59182E-04
 PHI(10 , 0) = -2.40687E-10
 PHI(10 , 1) = 1.59181E-04
 PHI(10 , 2) = 3.04975E-04
 PHI(10 , 3) = 4.26971E-04
 PHI(10 , 4) = 5.195E-04
 PHI(10 , 5) = 5.81716E-04
 PHI(10 , 6) = 6.16427E-04
 PHI(10 , 7) = 6.28467E-04
 PHI(10 , 8) = 6.23269E-04
 PHI(10 , 9) = 6.05905E-04
 PHI(10 , 10) = 5.80624E-04

TABLE B-1

Comparison of Predicted Versus Measured Surface
Potential

Coordinates (x,y)	Predicted mV	Measured mV	Factor
-10,-10	0.581-	90.0	155.
-9,-9	0.714-	70.0	98.0
-8,-8	0.898-	90.0	100.
-7,-7	1.165-	84.0	72.0
-6,-6	1.566-	114.	73.0
-5,-5	2.211-	92.0	42.0
-4,-4	3.333-	144.	43.0
-3,-3	5.498-	140.	25.0
-2,-2	10.18-	94.0	9.0
-1,-1	19.06-	98.0	5.0
0,0	0.000	00.0	0.0
1,1	19.06	110.	6.0
2,2	10.18	112.	11.0
3,3	5.498	102.	19.0
4,4	3.333	29.0	9.0
5,5	2.211	96.0	43.0
6,6	1.566	110.	70.0
7,7	1.165	108.	93.0
8,8	0.898	86.0	96.0
9,9	0.714	58.0	81.0
10,10	0.581	25.0	43.0

RD-A138 407

THE APPLICATION OF A SUPERCONDUCTING QUANTUM
INTERFERENCE DEVICE SECOND-0. (U) AIR FORCE INST OF
TECH WRIGHT-PATTERSON AFB OH SCHOOL OF ENGI.
R D MURRAY DEC 83 AFIT/GE/EE/83D-50

2/2

UNCLASSIFIED

F/G 6/16

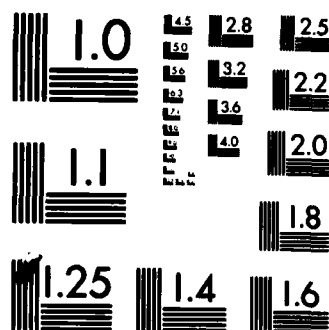
NL

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MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS-1963-A

APPENDIX C

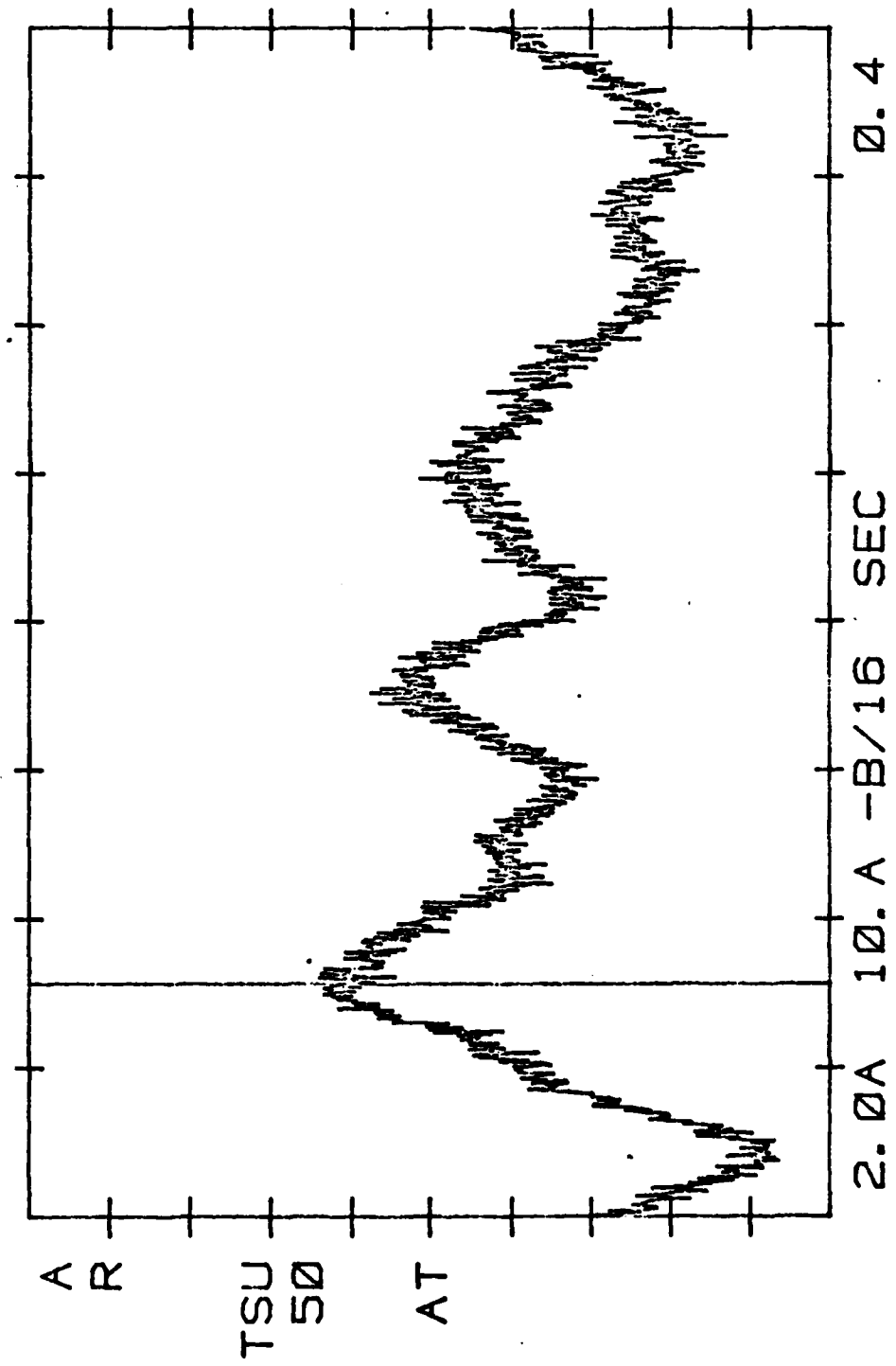
HUMAN VISUAL EVOKED RESPONSE PLOTS

HEATHER MEG. 002
10 Hz NQ TCH
22-SEP-83

0.07812 SEC

1.15-03 V

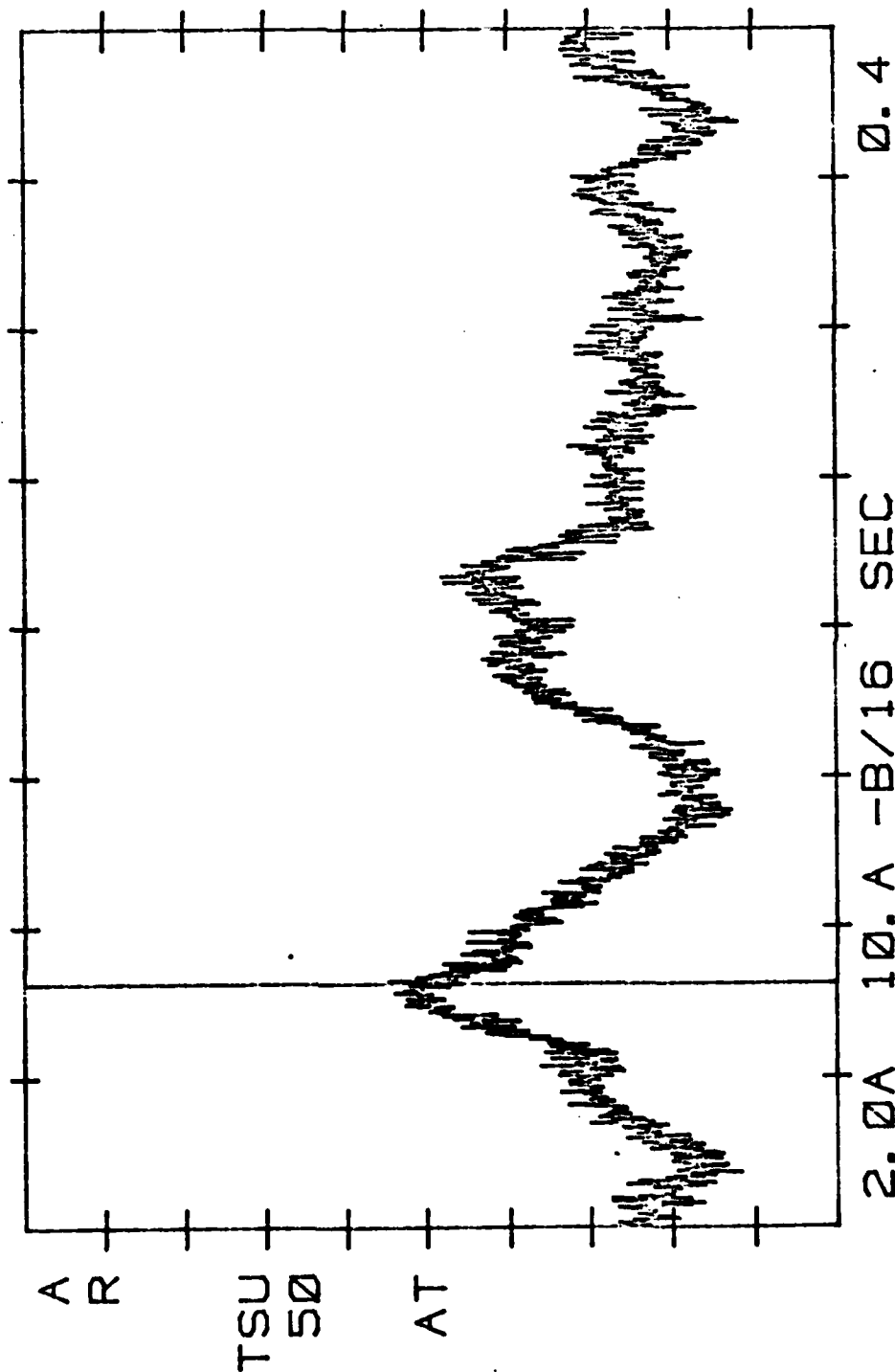
VLN
T



SHERRY MEG. 010
10 Hz NOTCH
22-SEP-83

0.08086 SEC

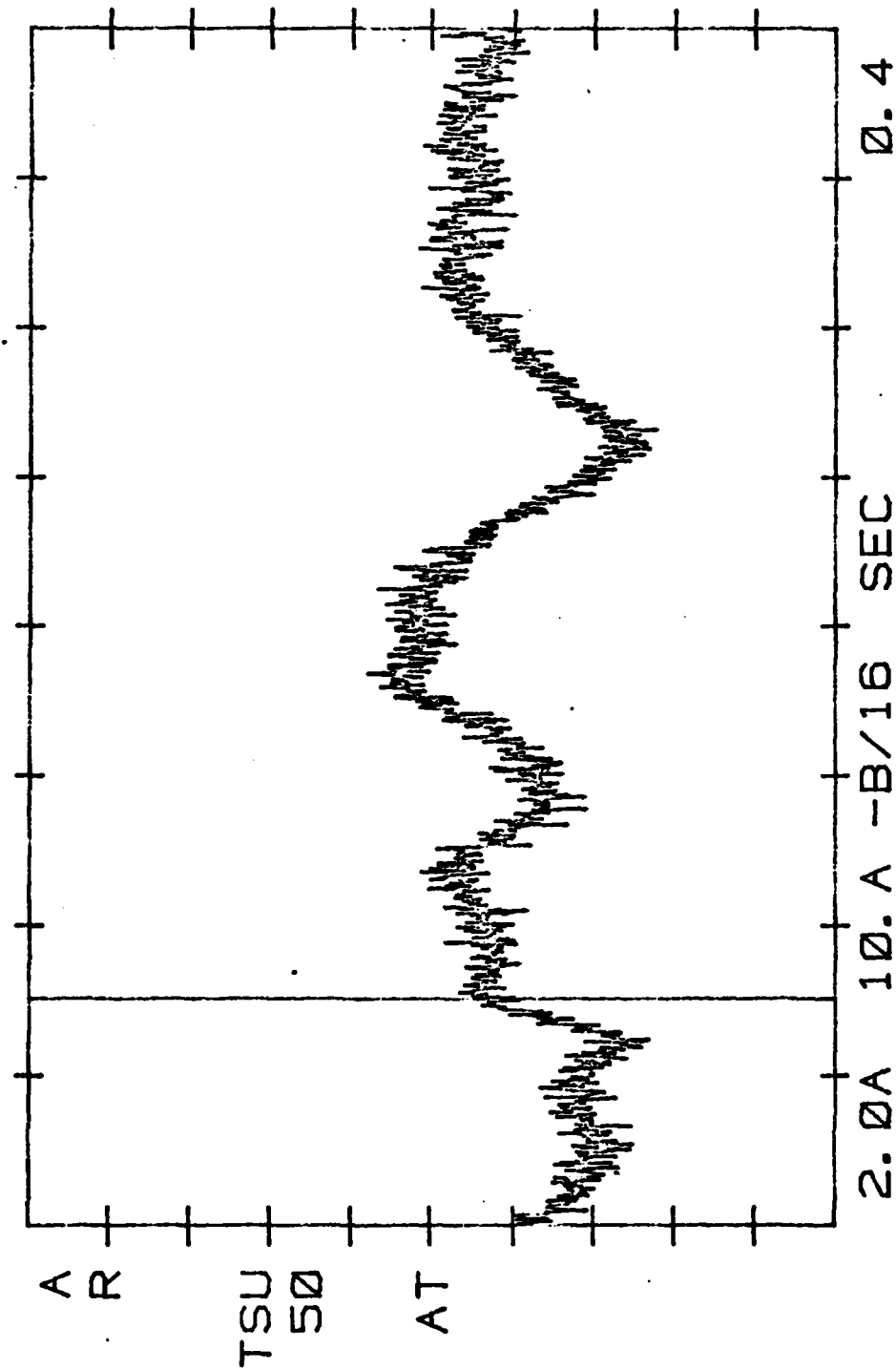
-332. -06 V
VLN
T



ROBBY MEG. Ø11
10 Hz NQ1CH

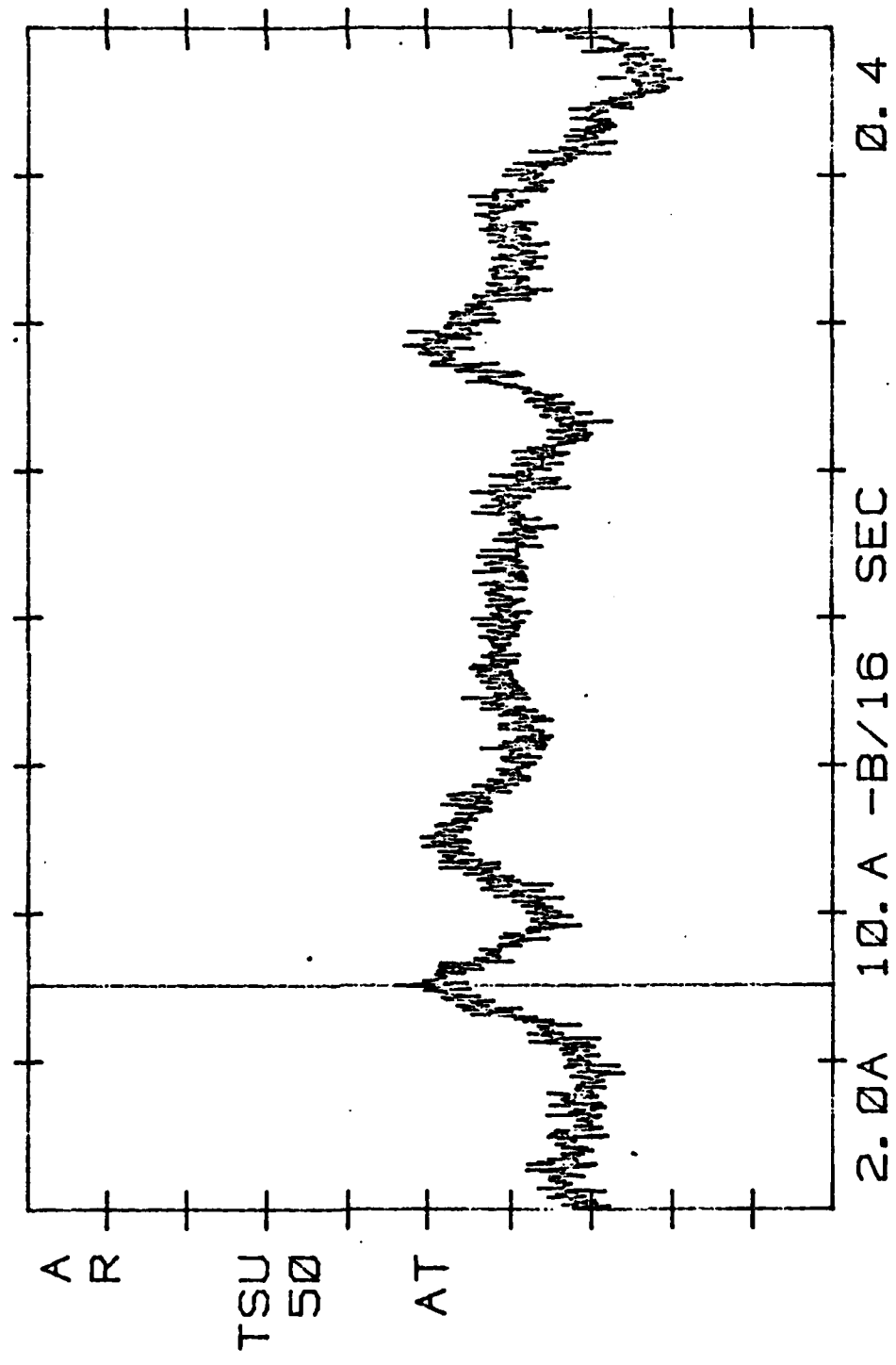
-532. -Ø6 V VLN
T

22-SEP-83 Ø. Ø7539 SEC



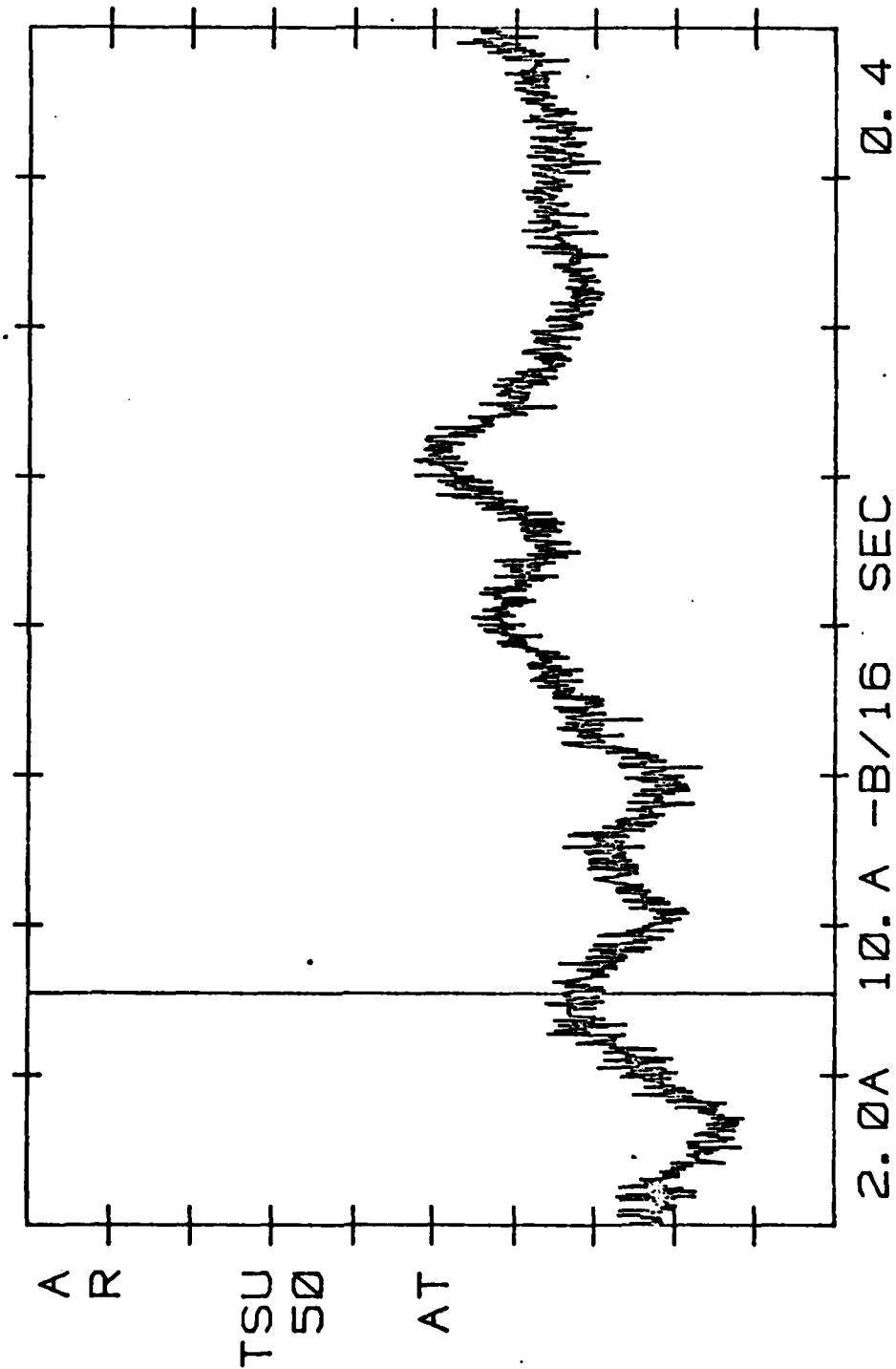
JOHN MEG. 012
 10 Hz NOTCH
 22-SEP-83 0.07539 SEC

410. -06 V VLN
 T



BOB
10 HZ
22-SEP-83
MEC. 018
NO TCH
0.07695 SEC

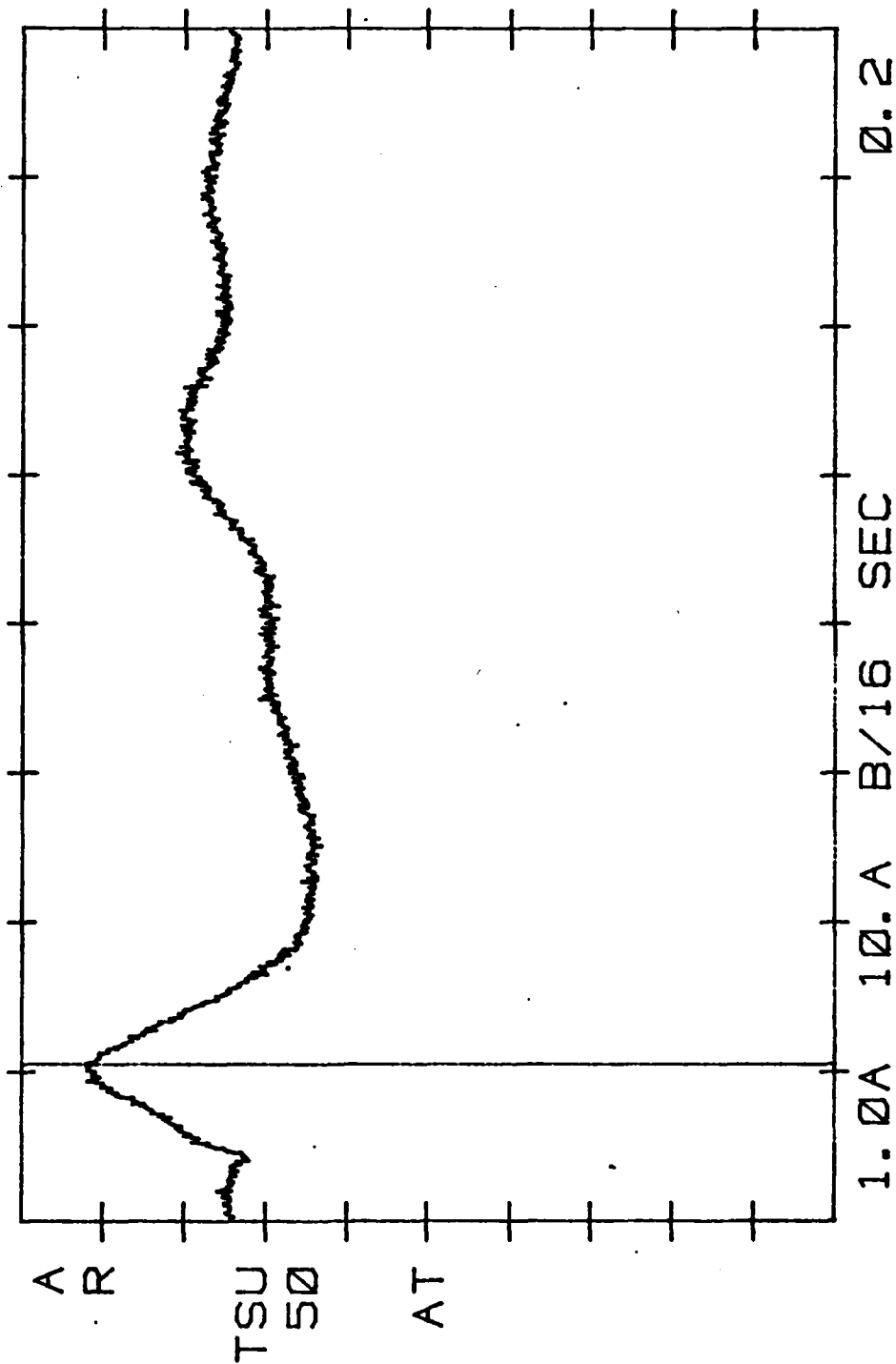
-1.60-03 V
VLN
T



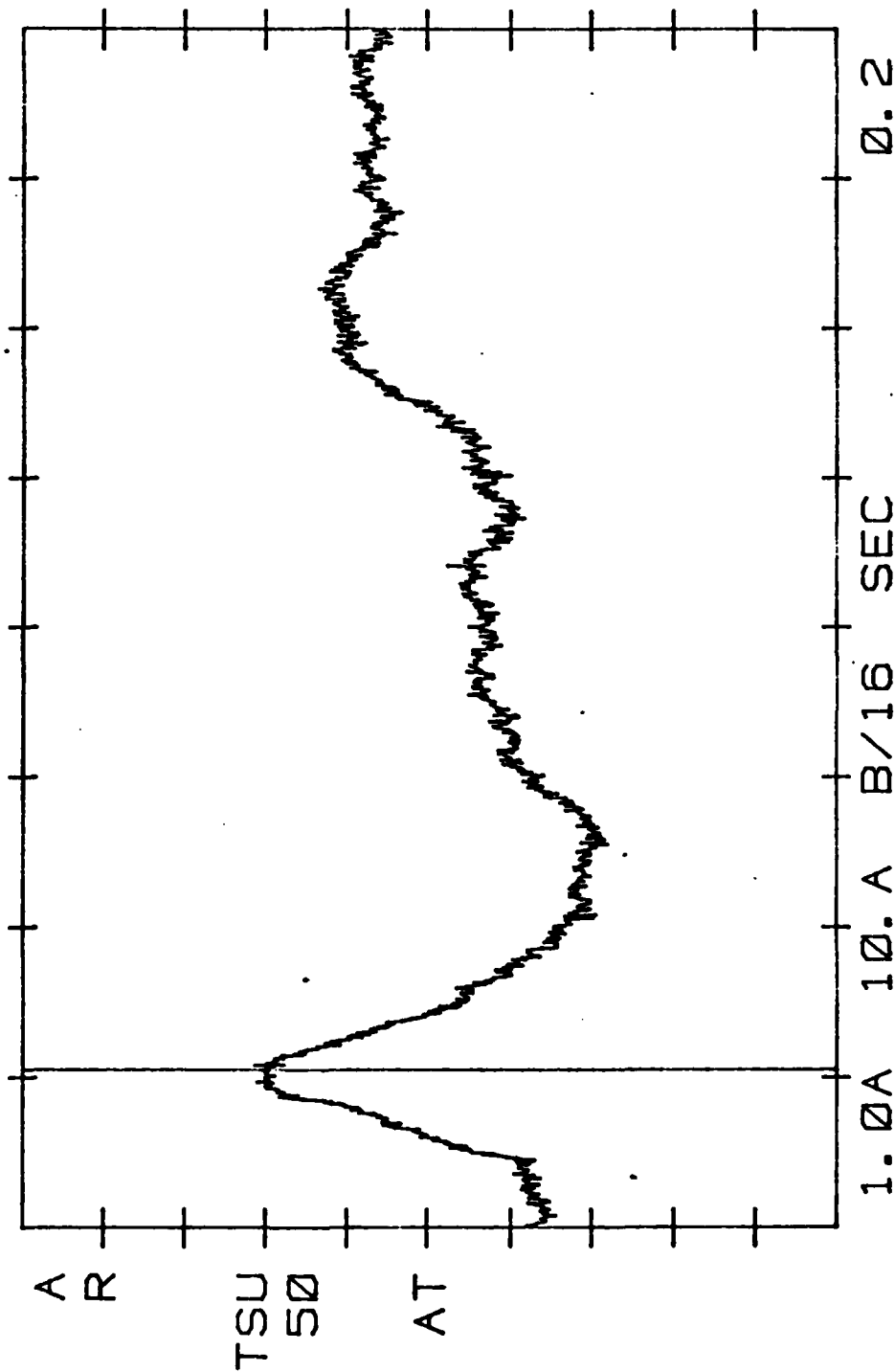
APPENDIX D

DOG VISUAL EVOKED RESPONSE PLOTS

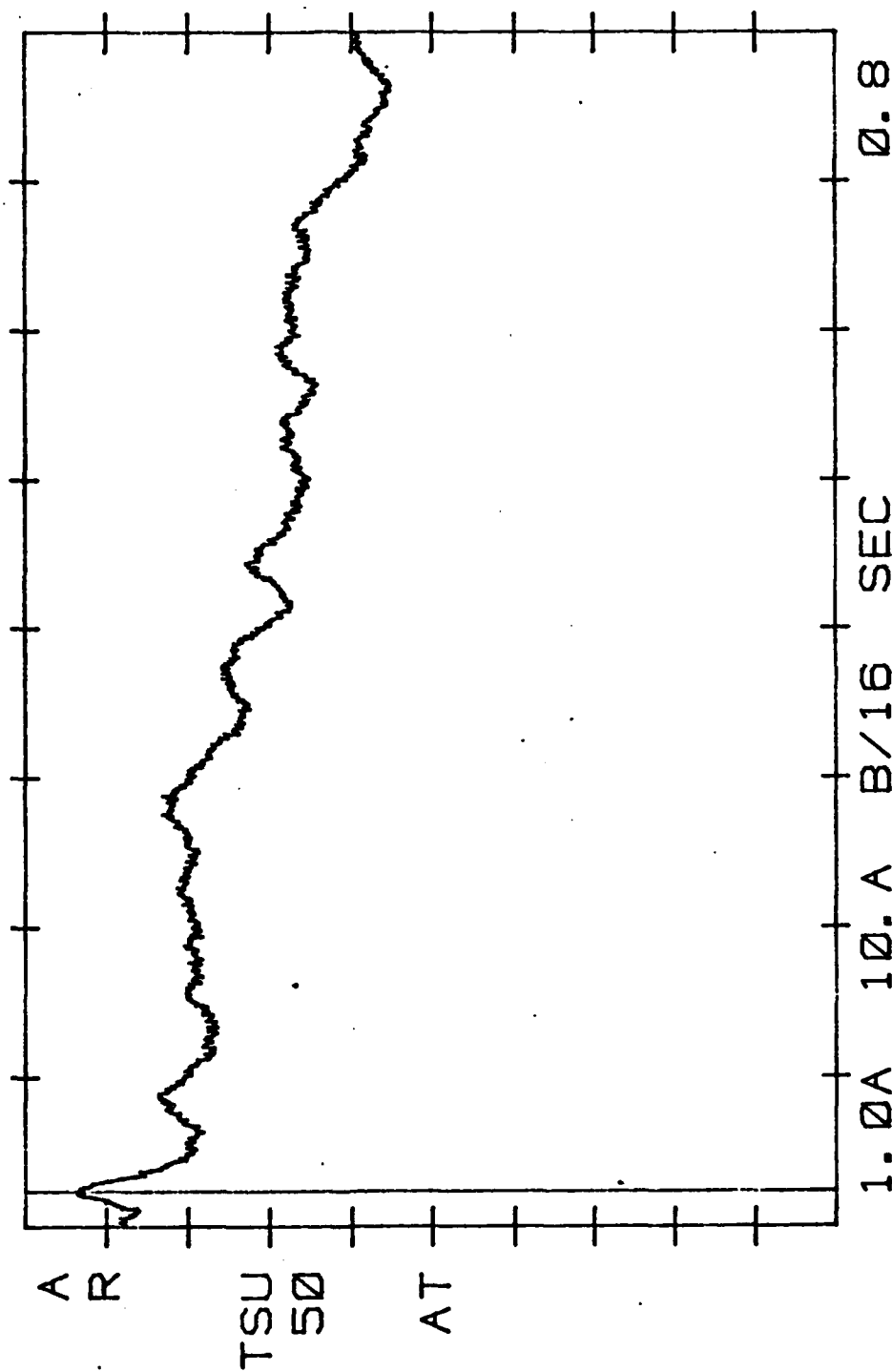
RICKY MEG-022 RI-OC LIGHTS-ON
 100 CPS AND NOTCH FILTERS 12.7-03 V VLN
 20-SEP-83 0.02598 SEC T



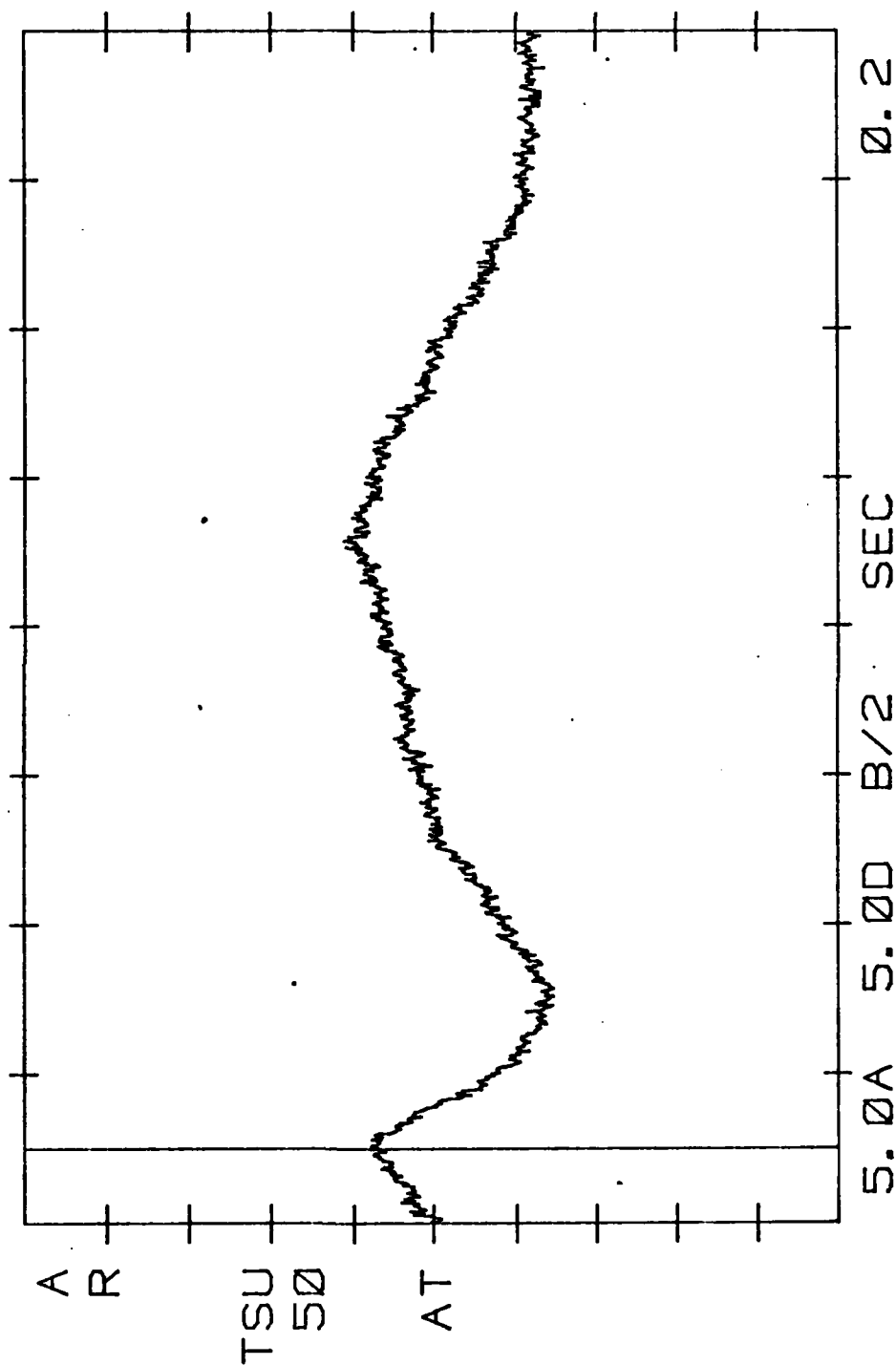
RICKY AND MEG-023 RT-OC LIGHTS-OFF
 100 CPS AND NOTCH FILTERS 3.31-03 V VLN
 26-SEP-83 0.02598 SEC T



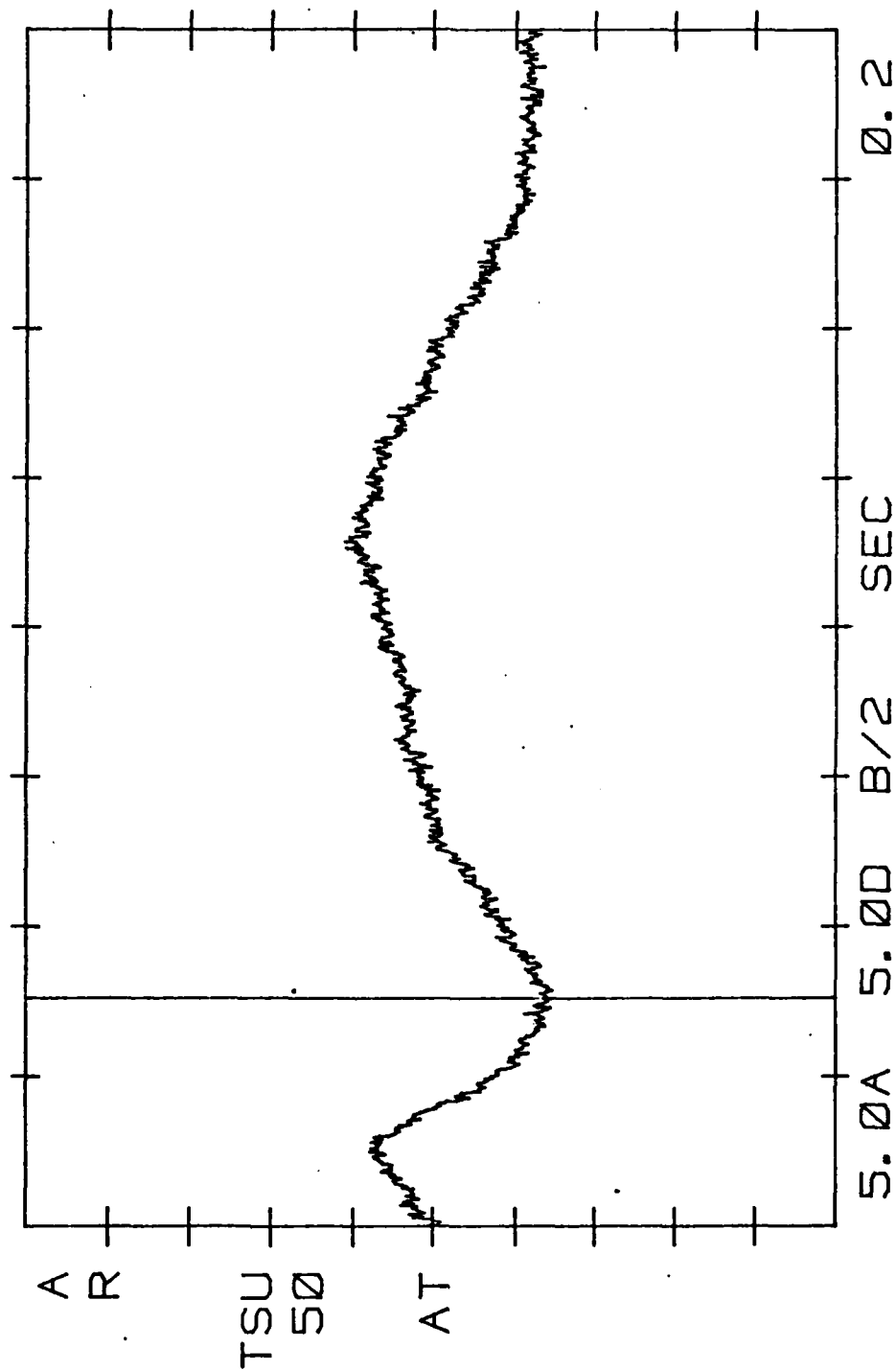
RICKY AND MEG-024 RT-OC LIGHTS-ON
 10CPS NOTCH FILTERS 13.1-03 V VLN
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 0.02344 SEC



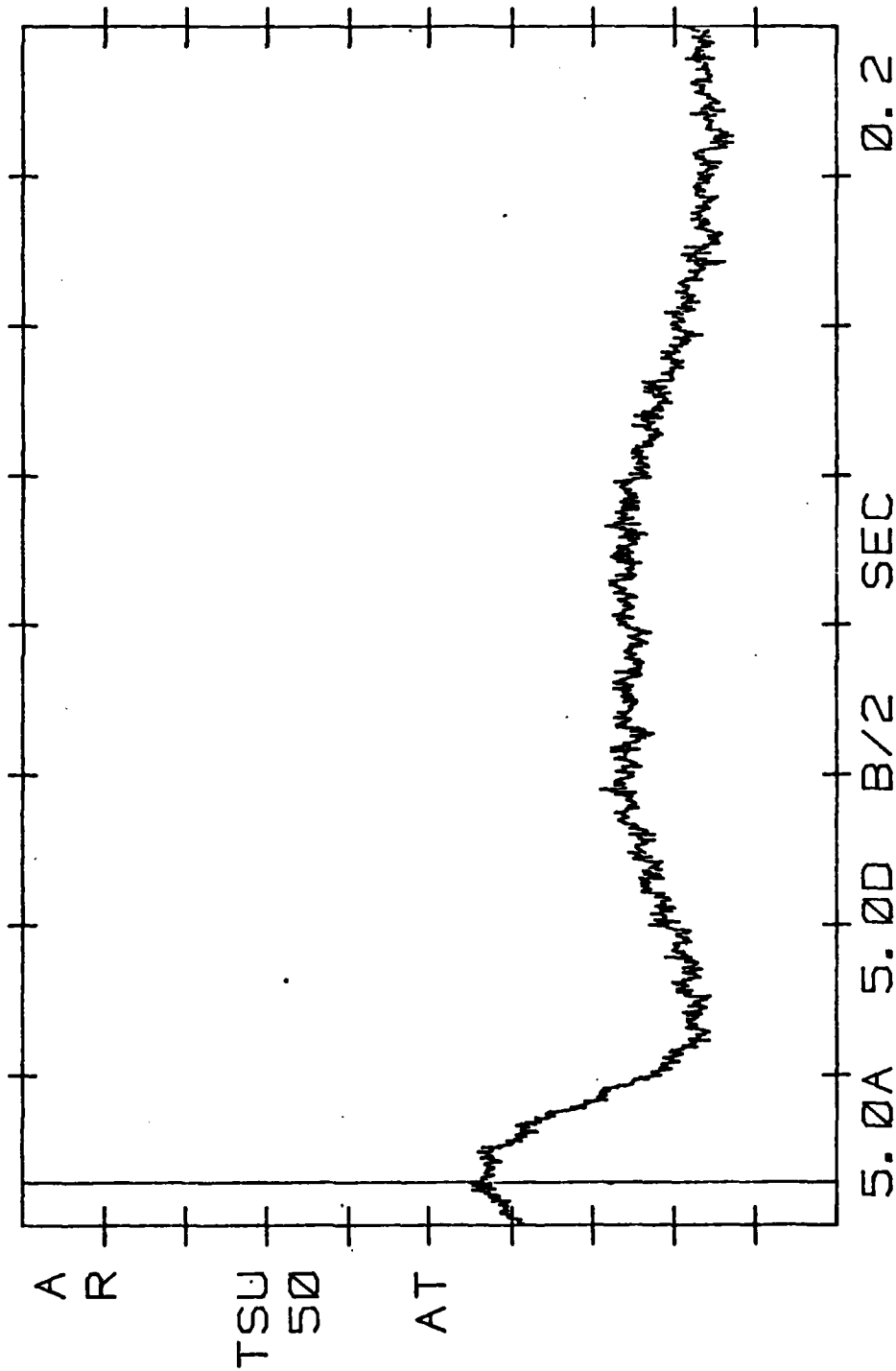
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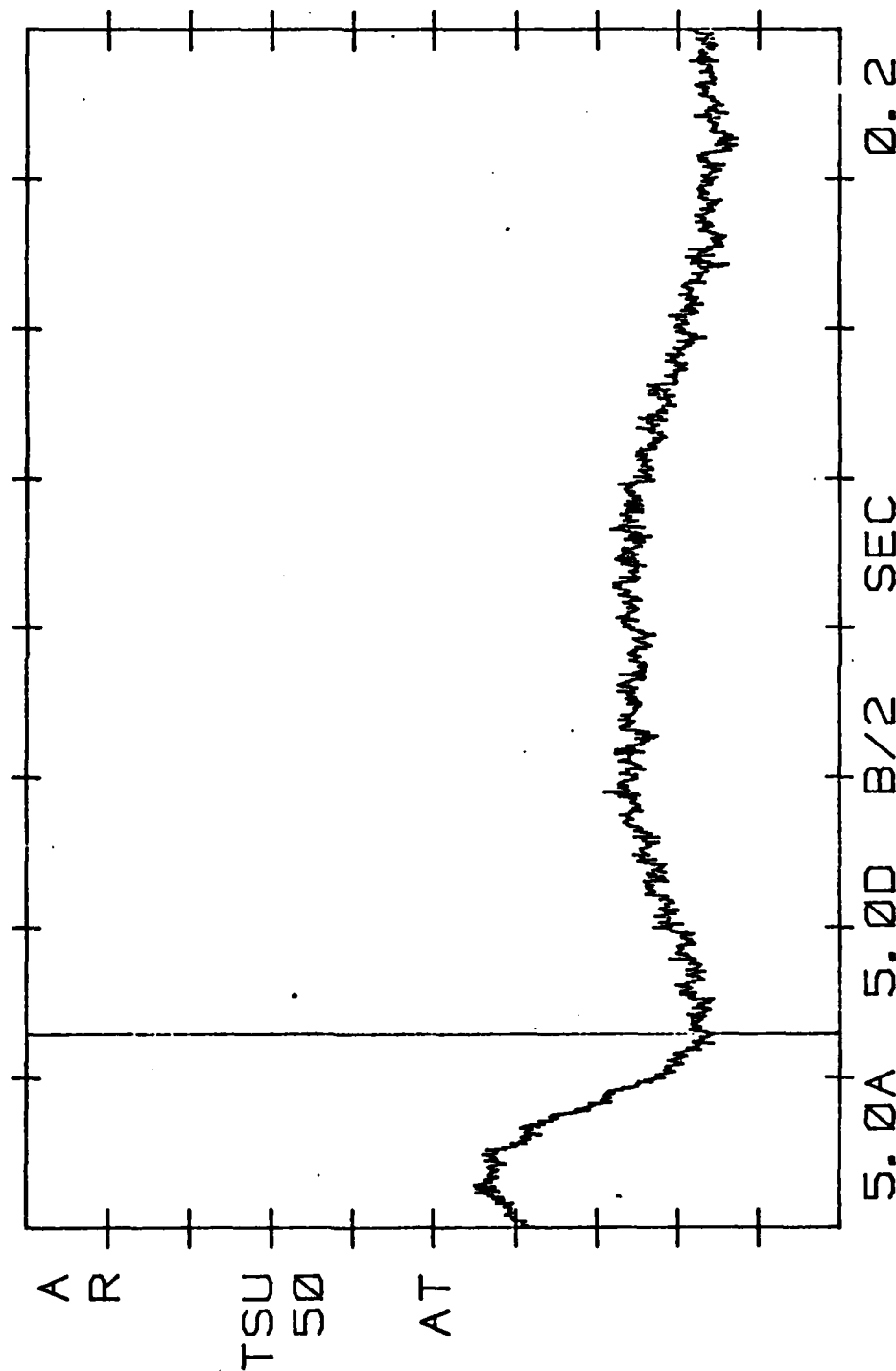
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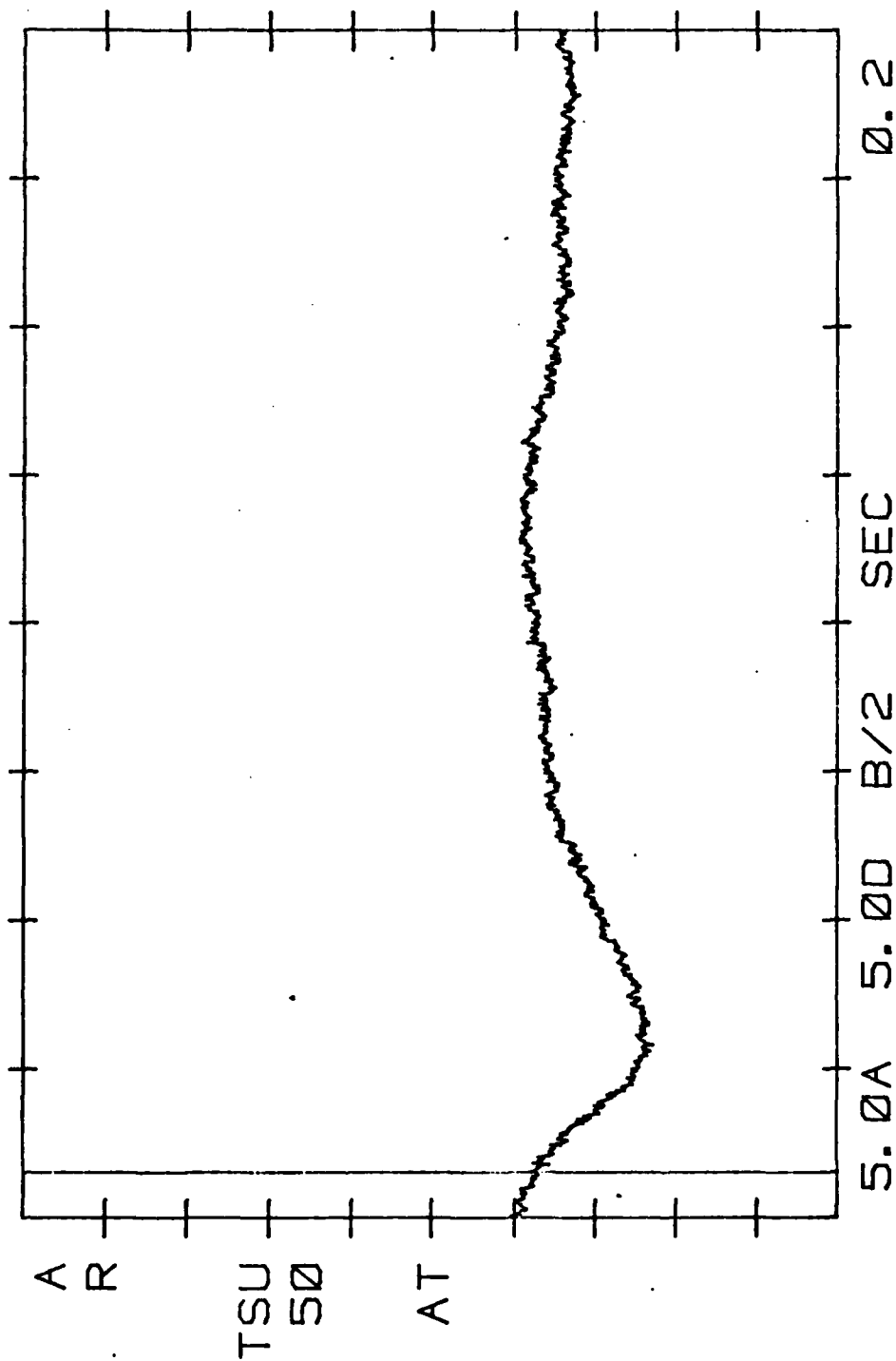
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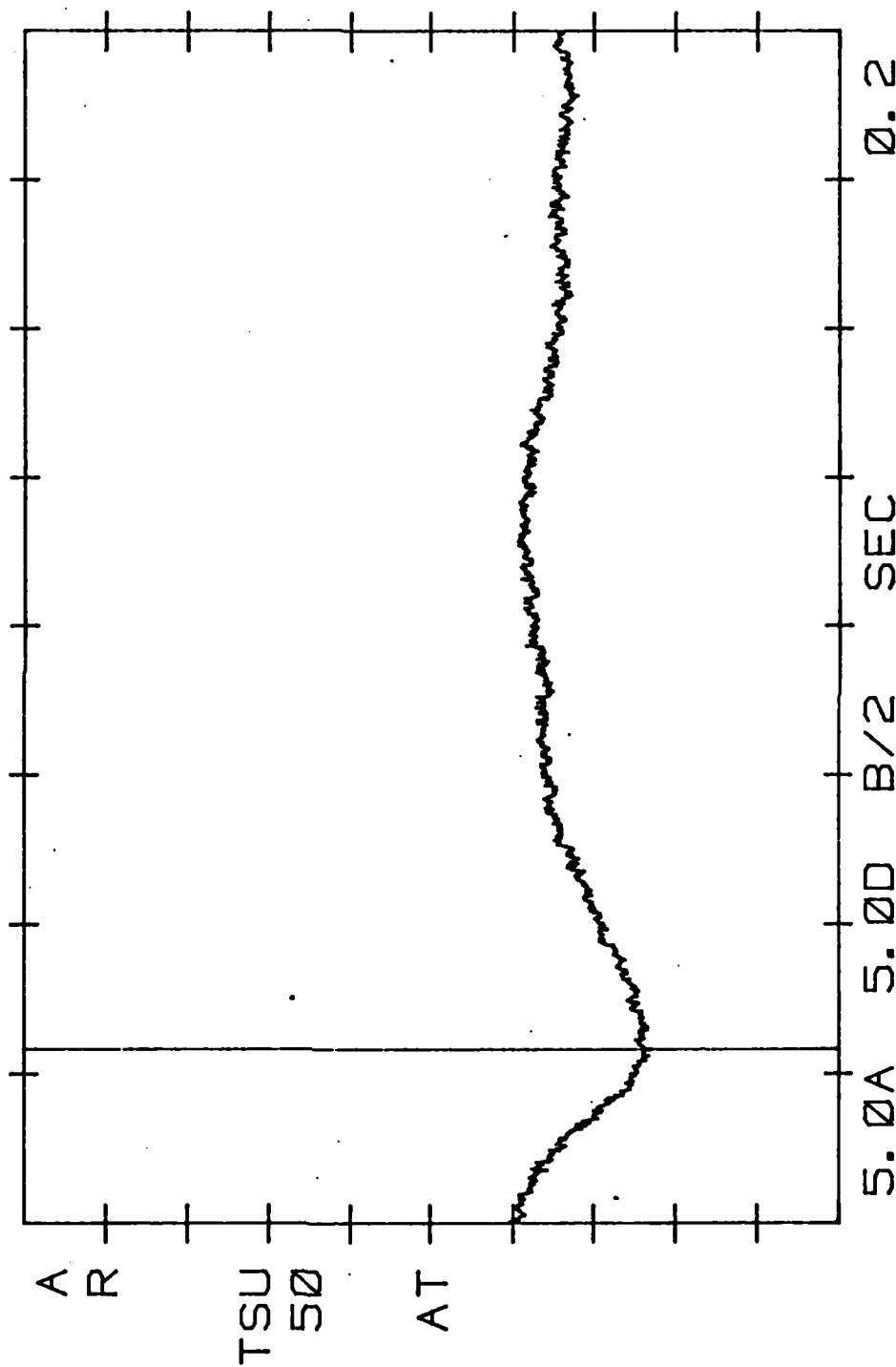
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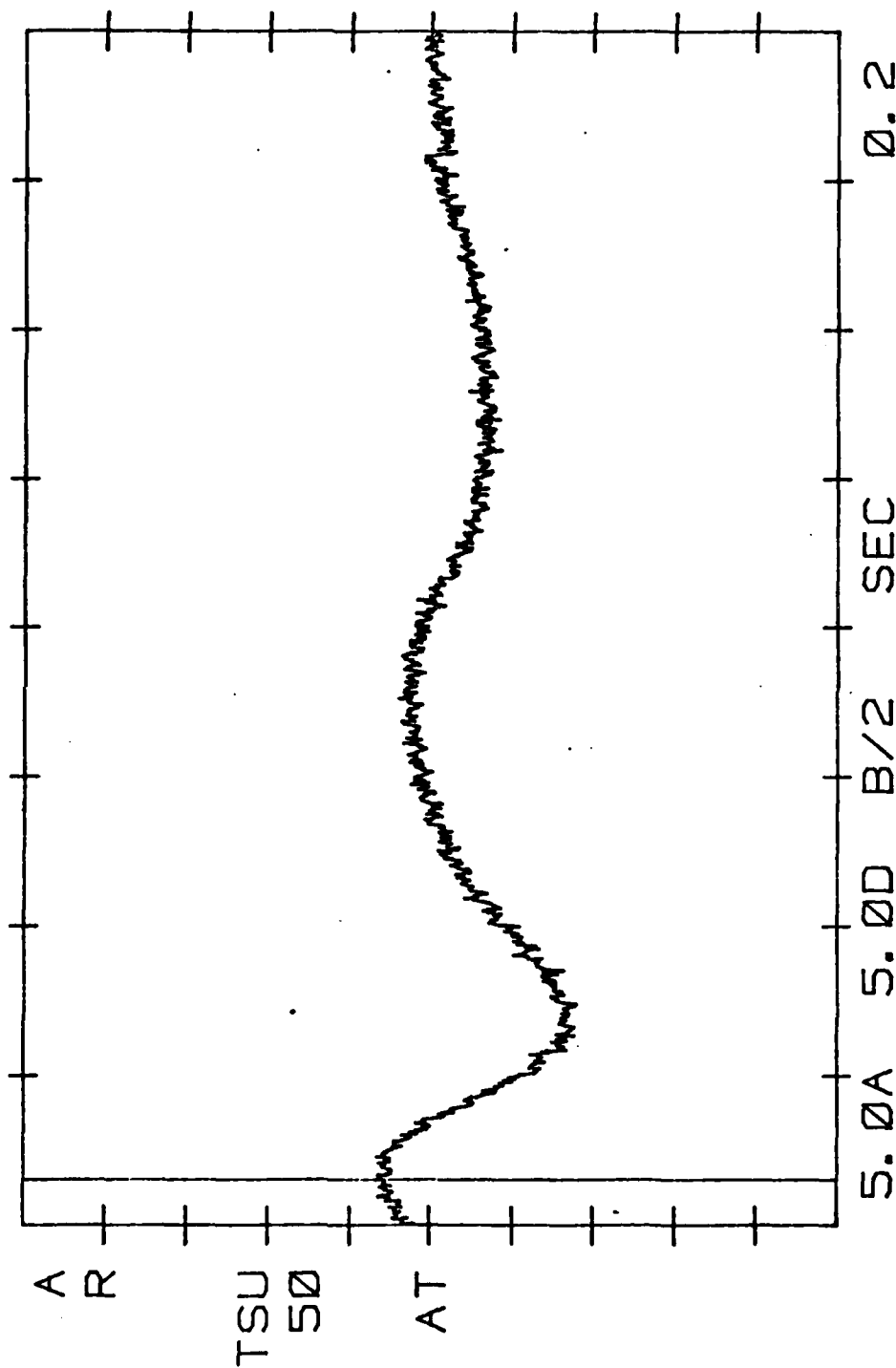
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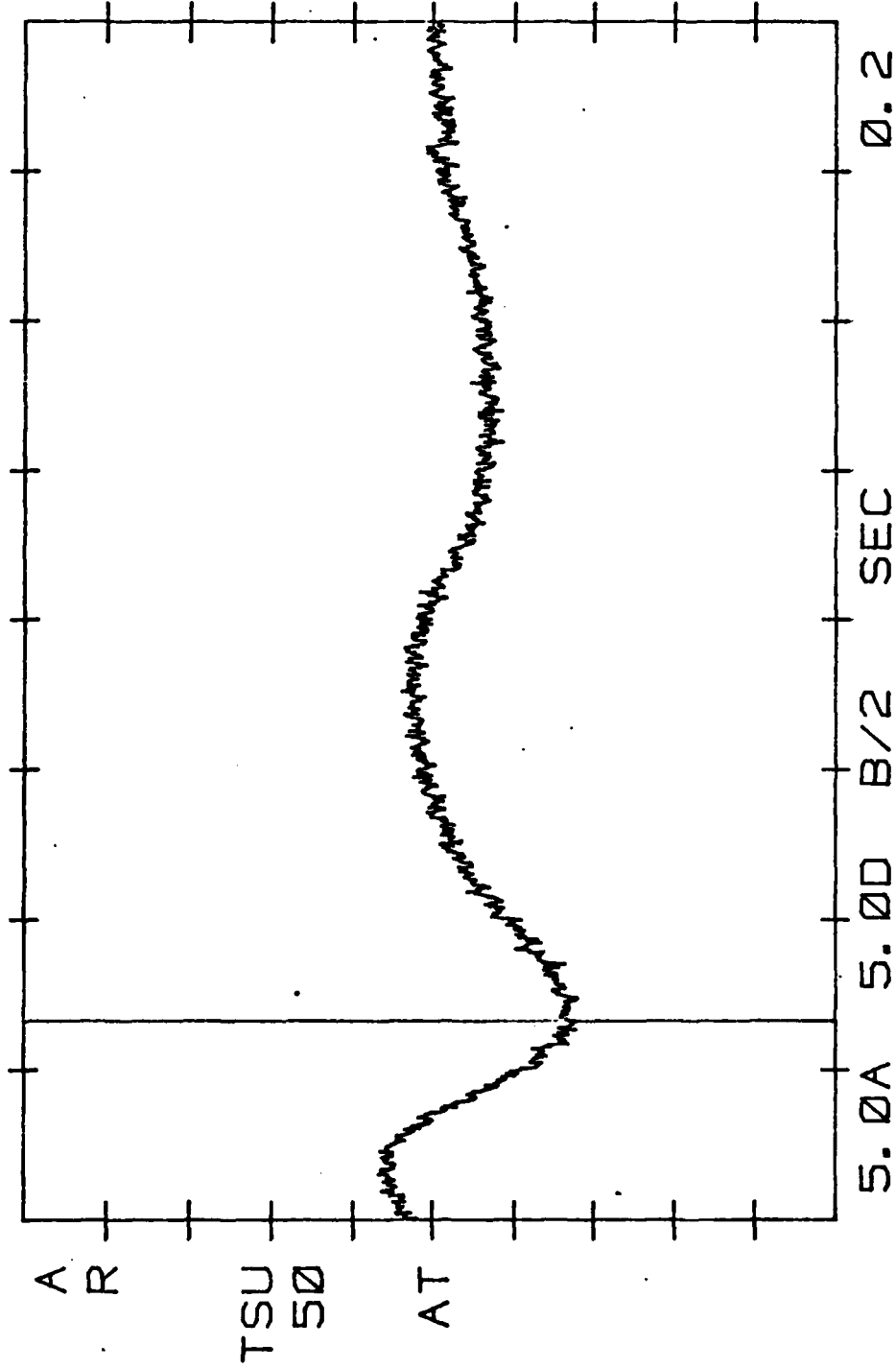
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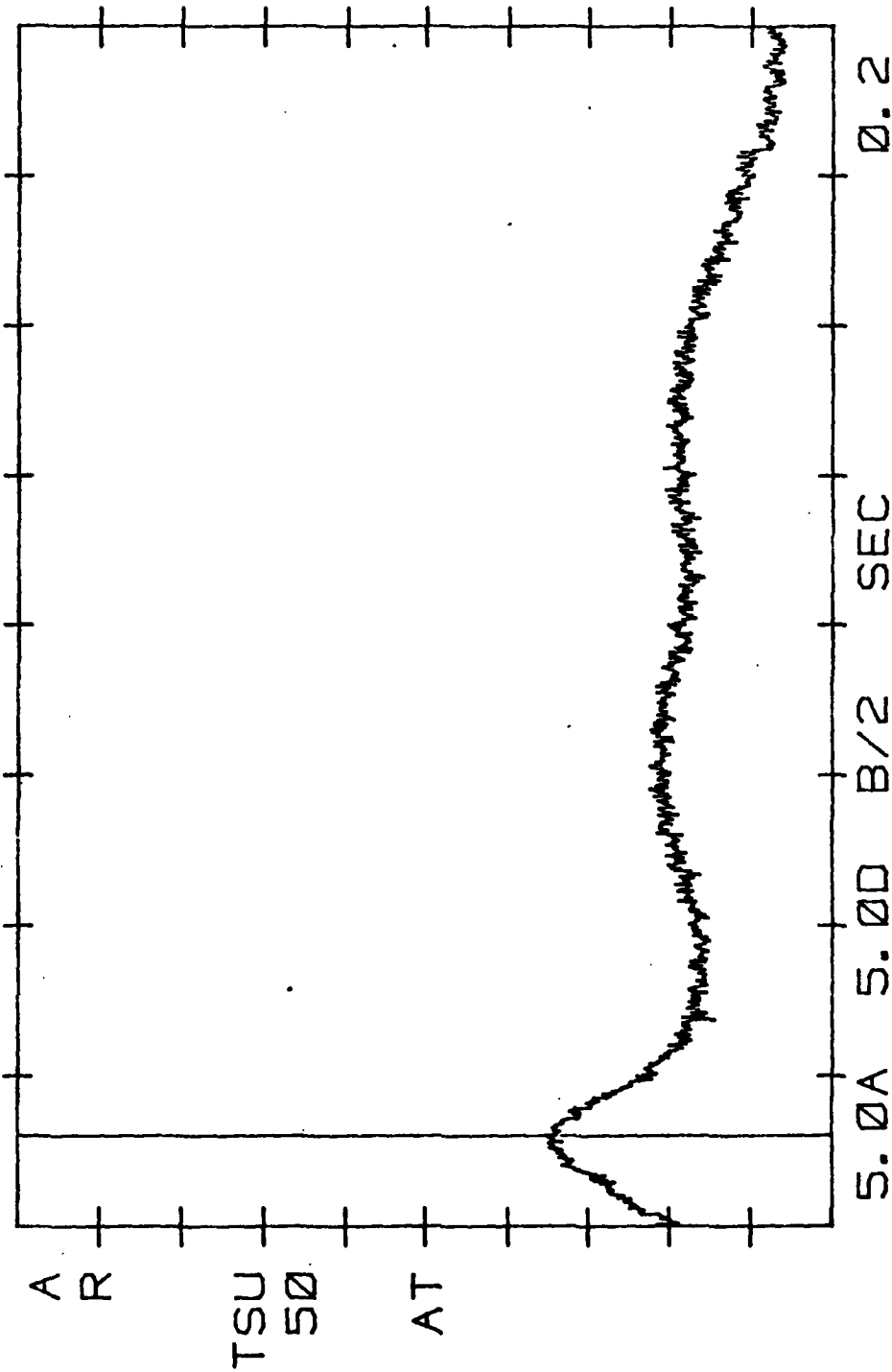
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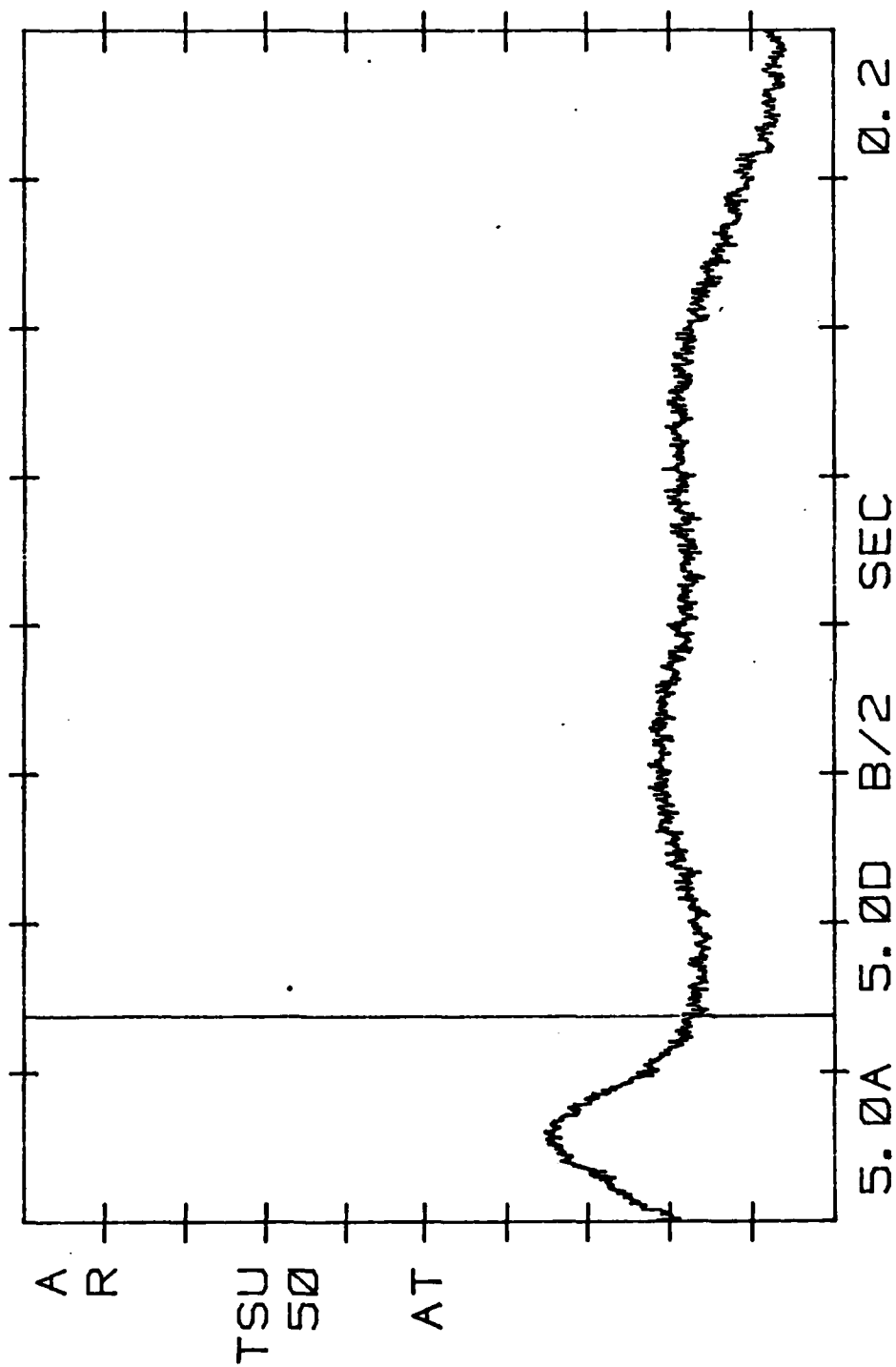
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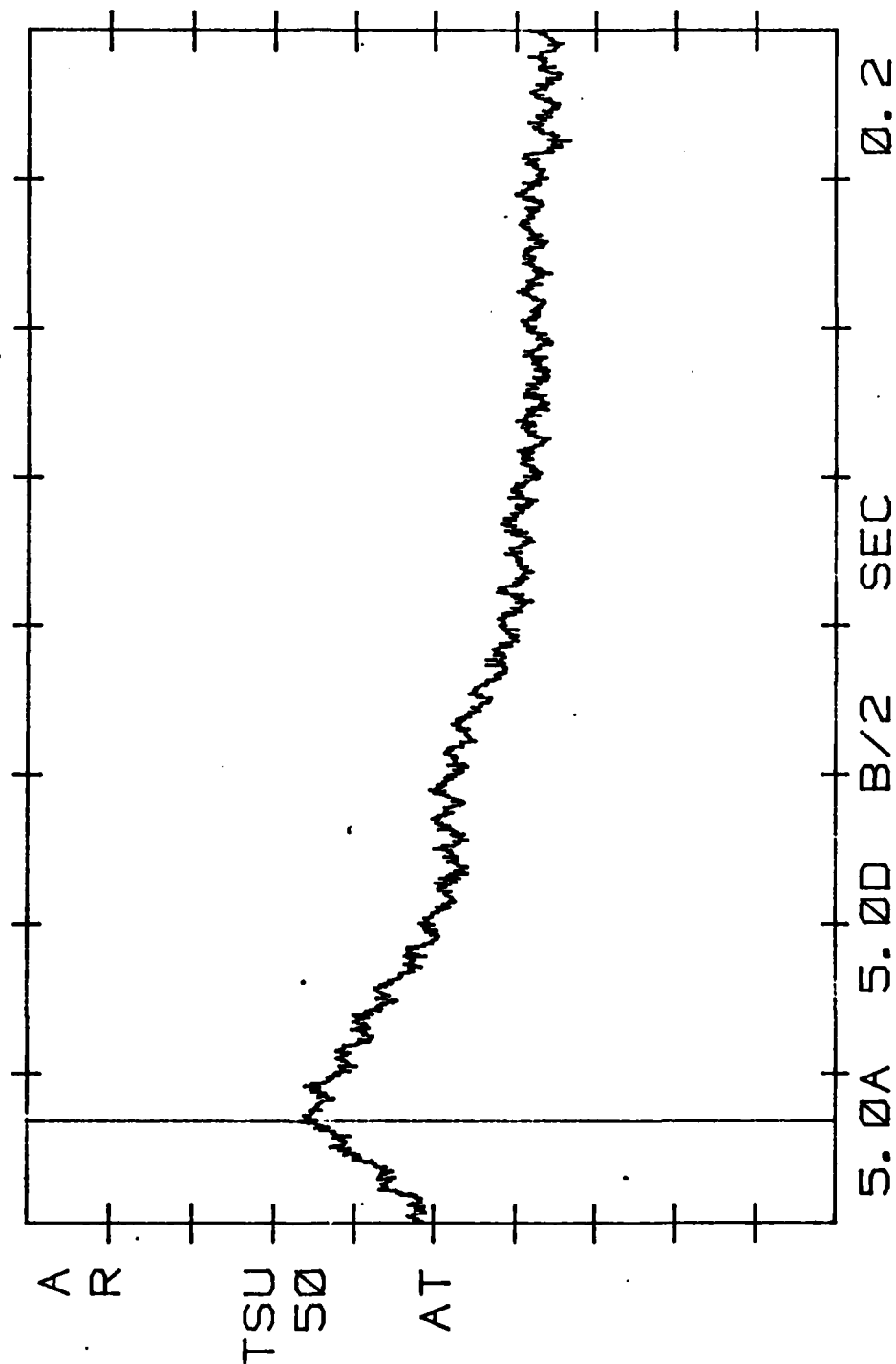
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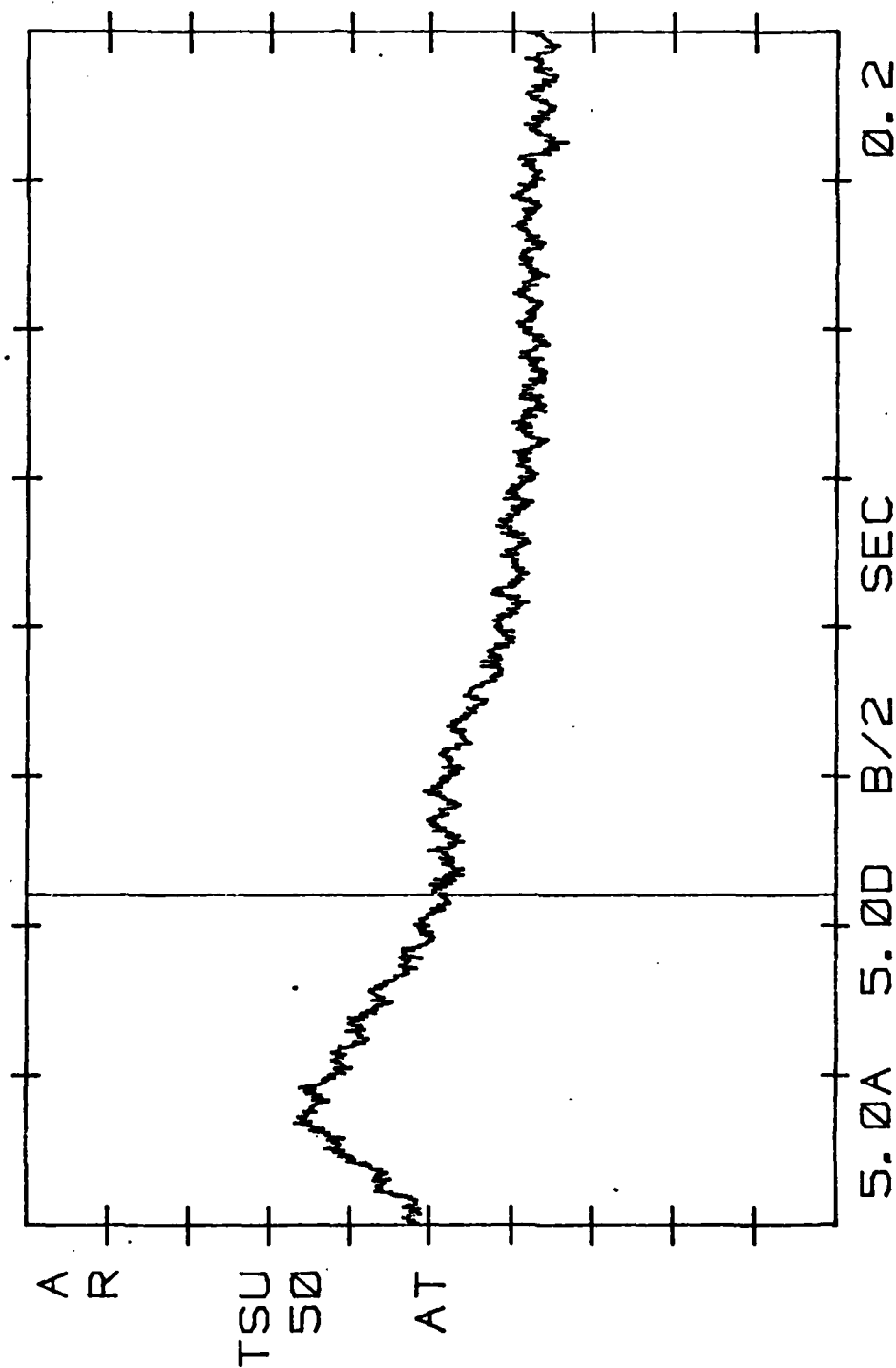
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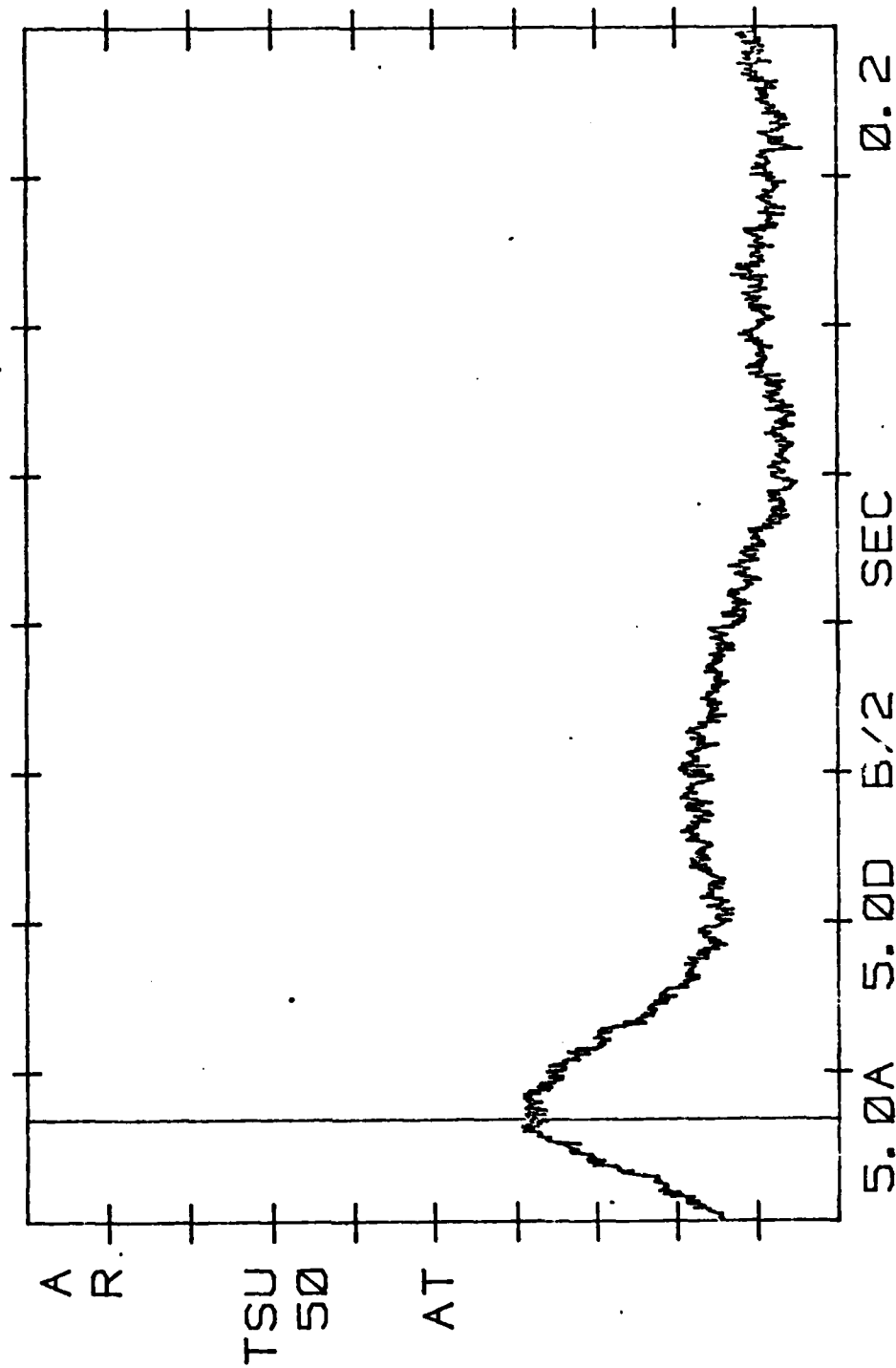
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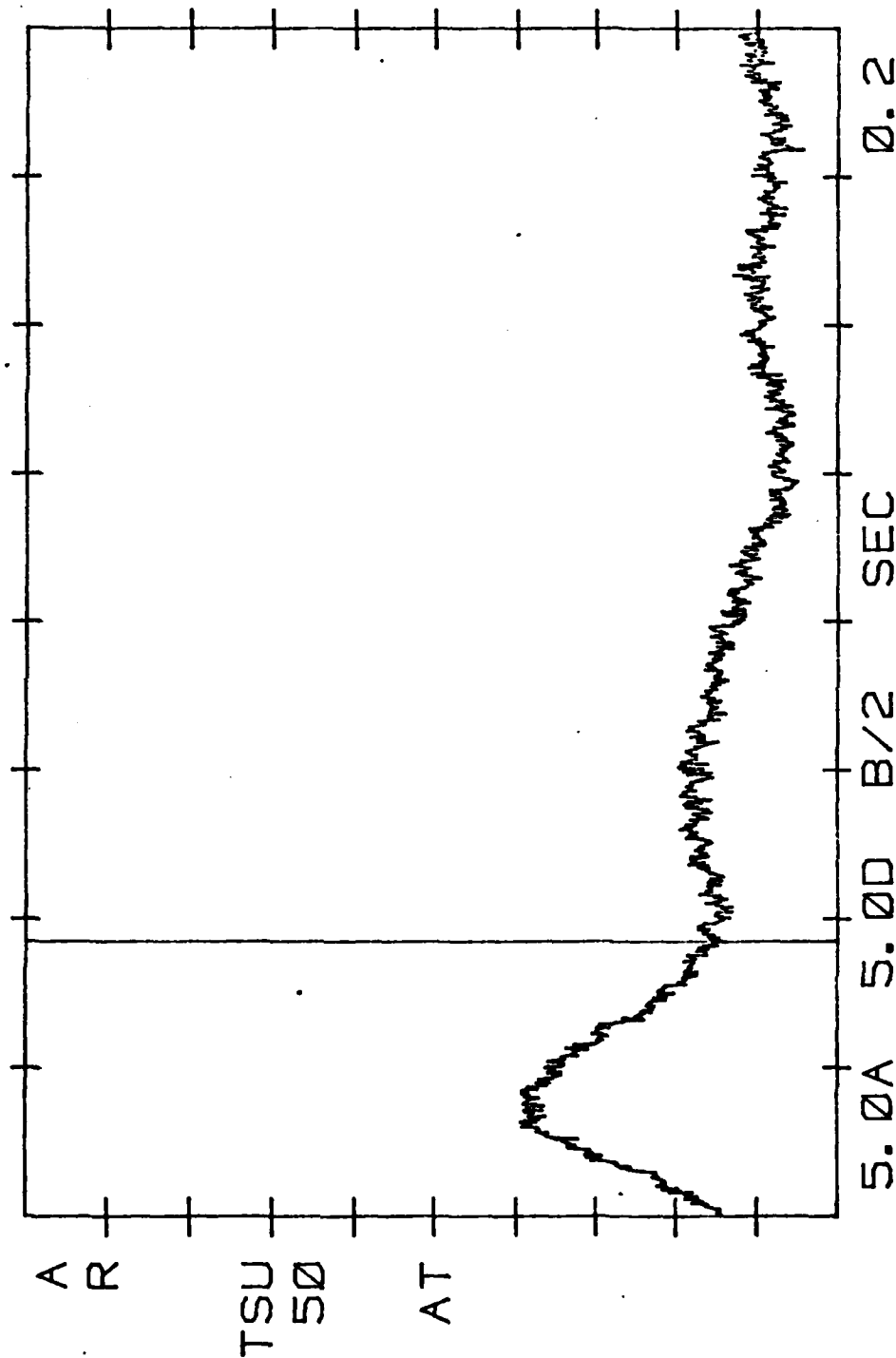
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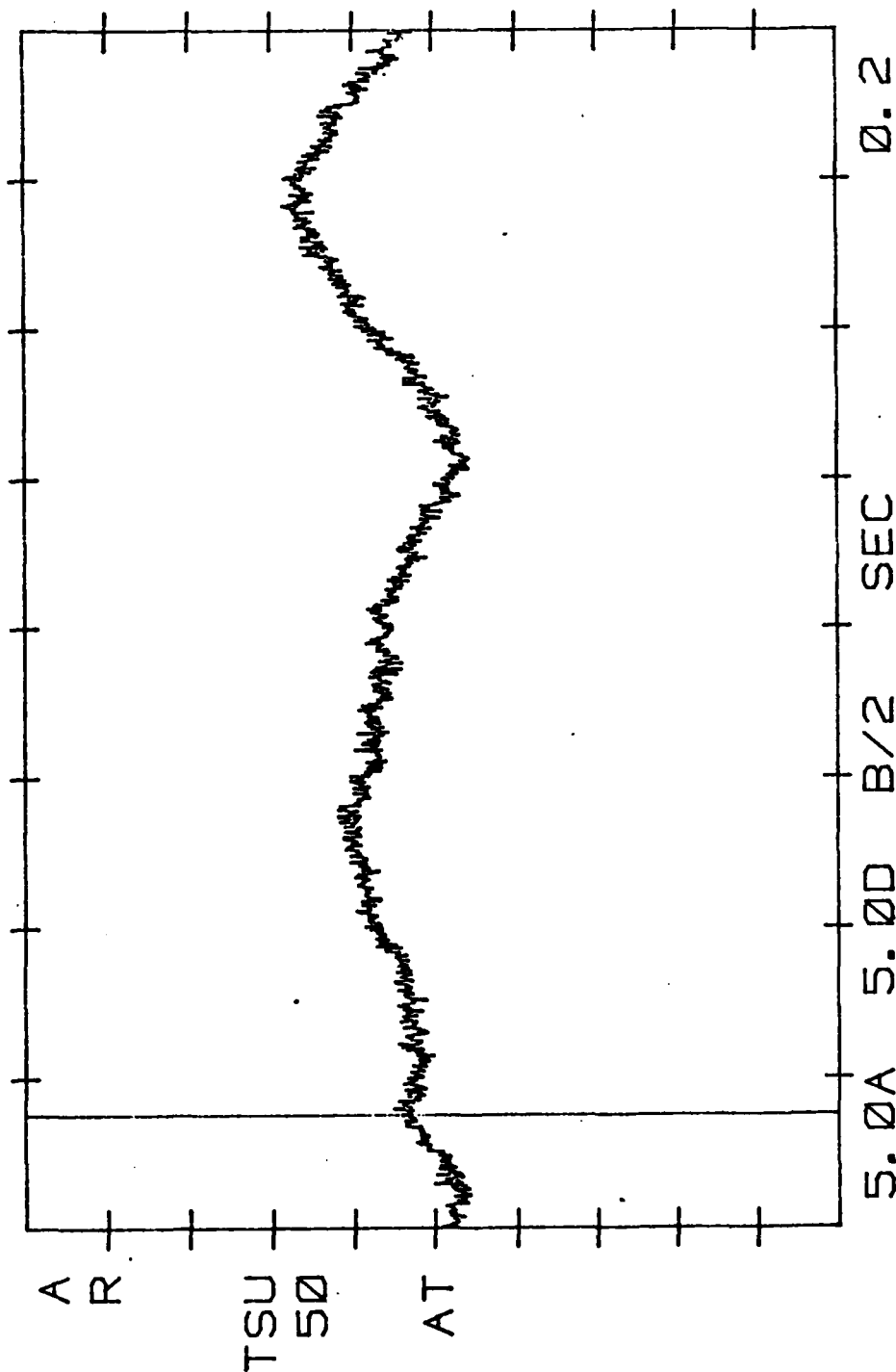
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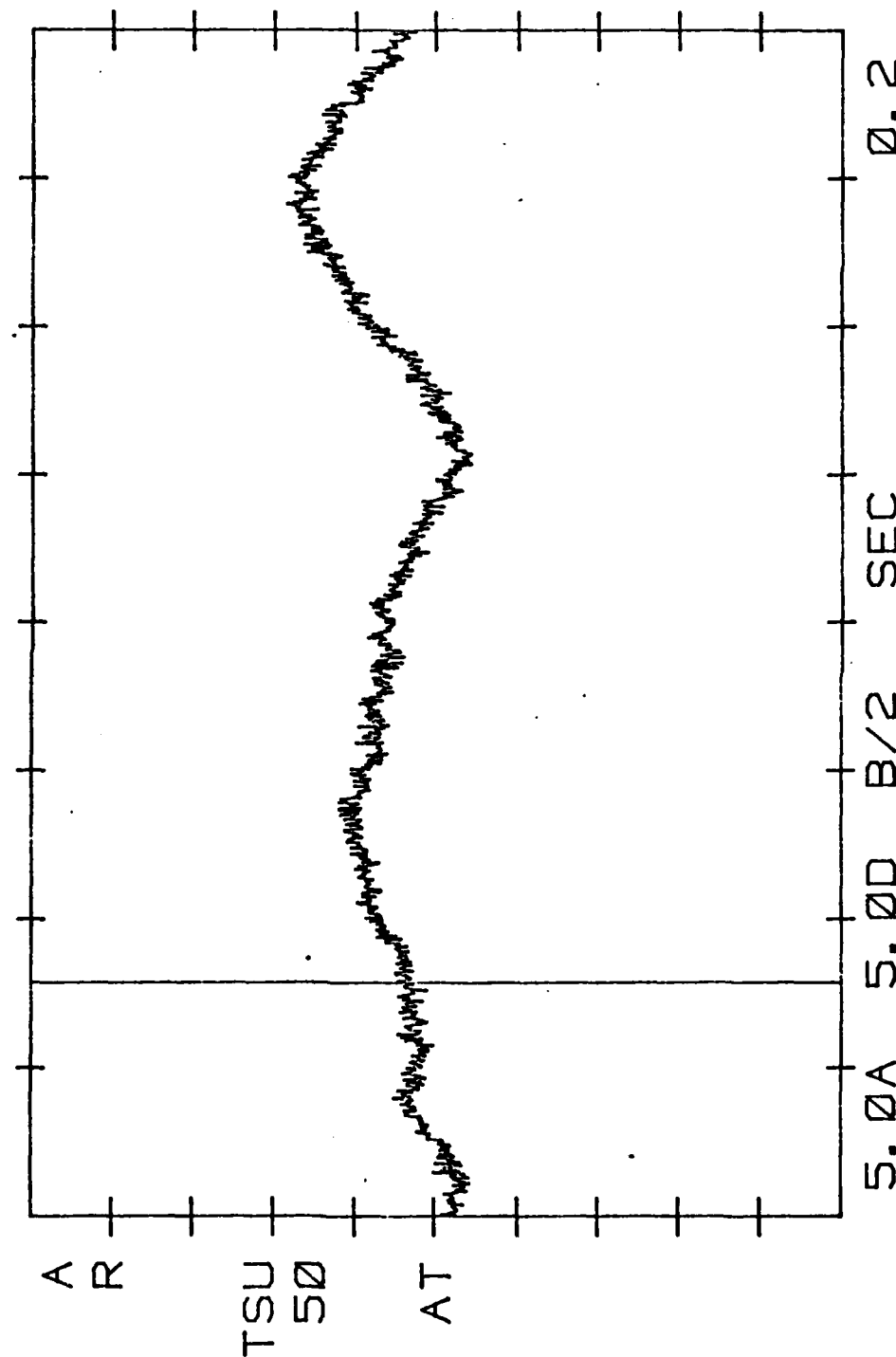
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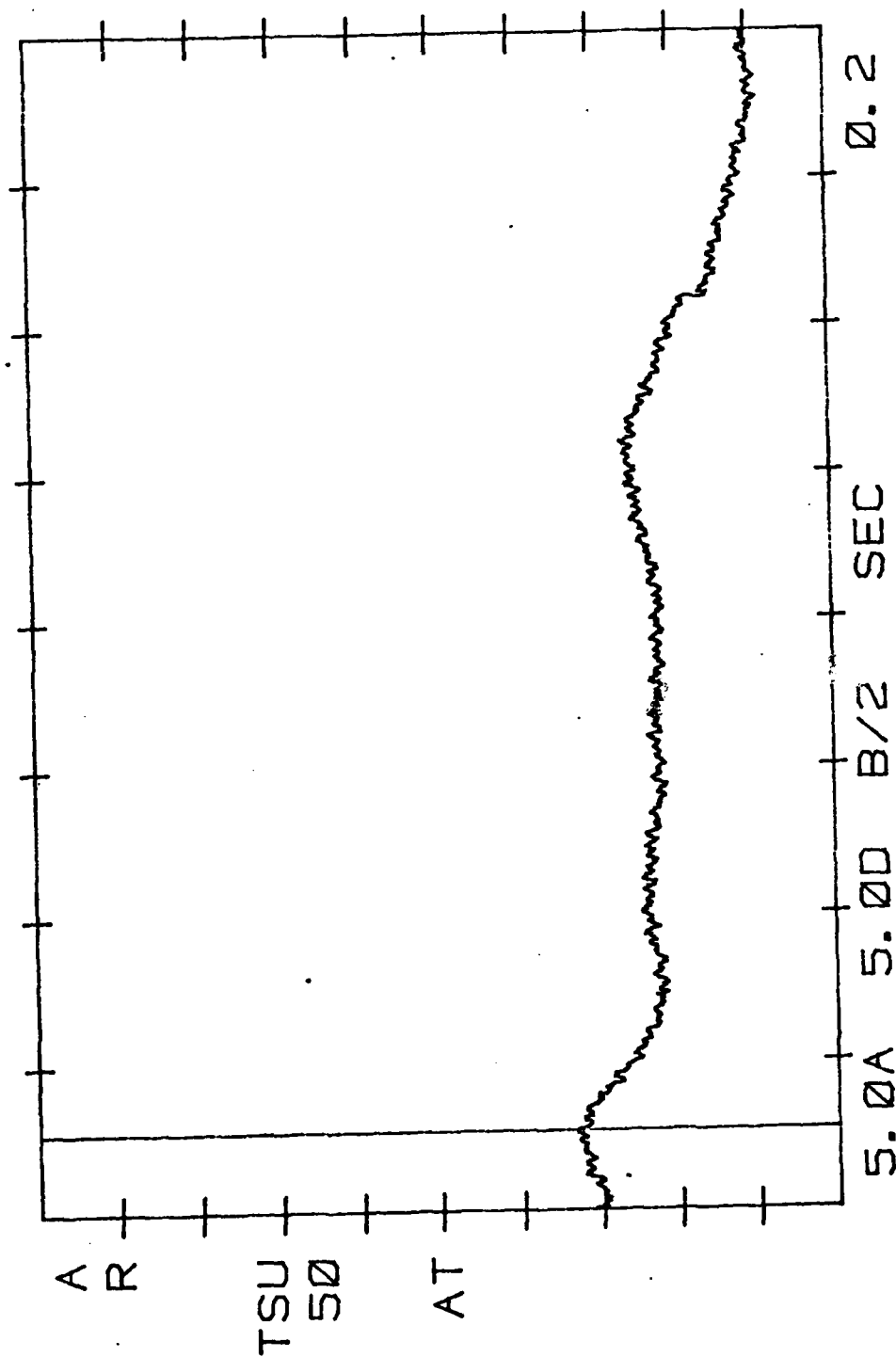
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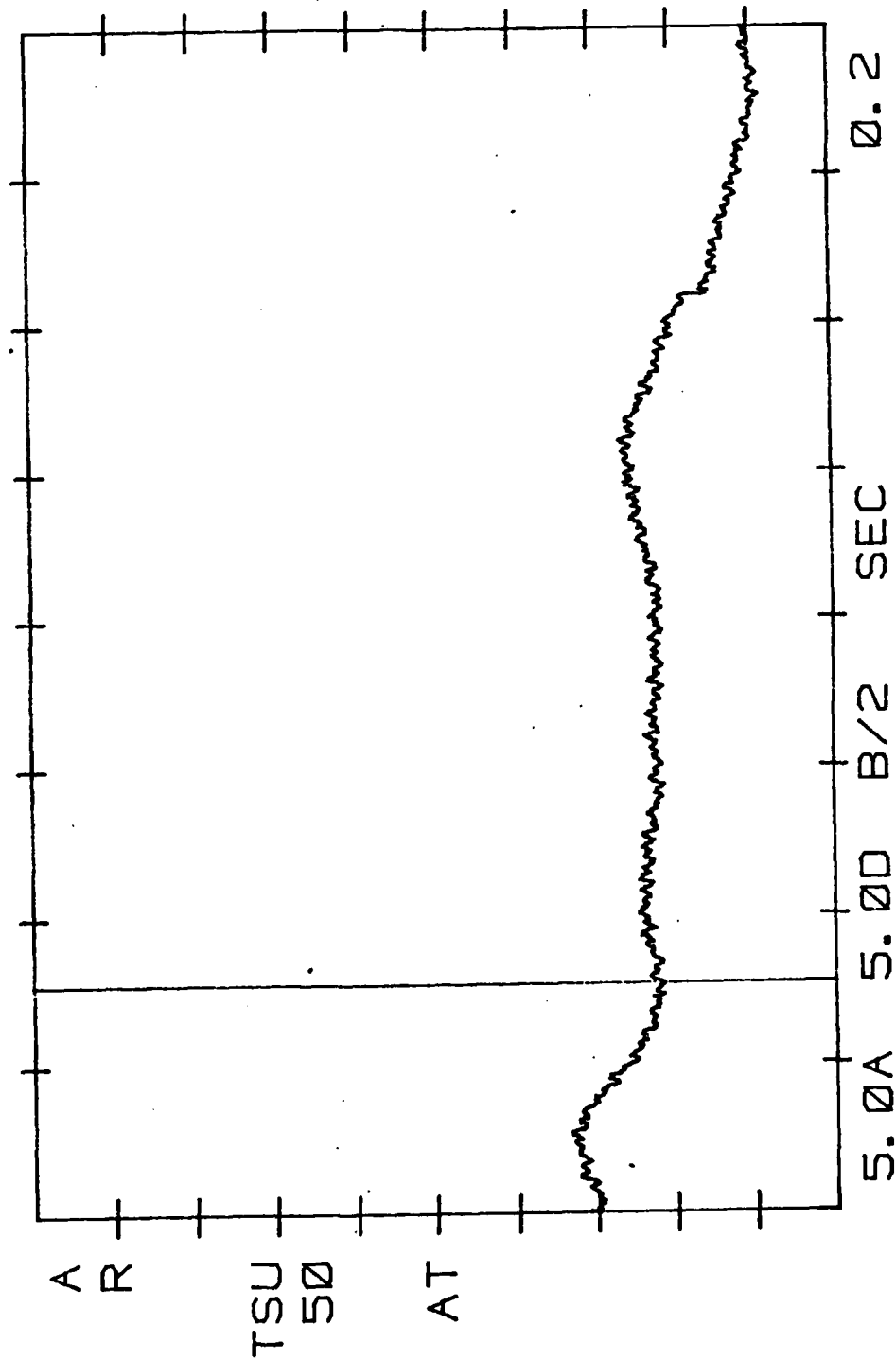
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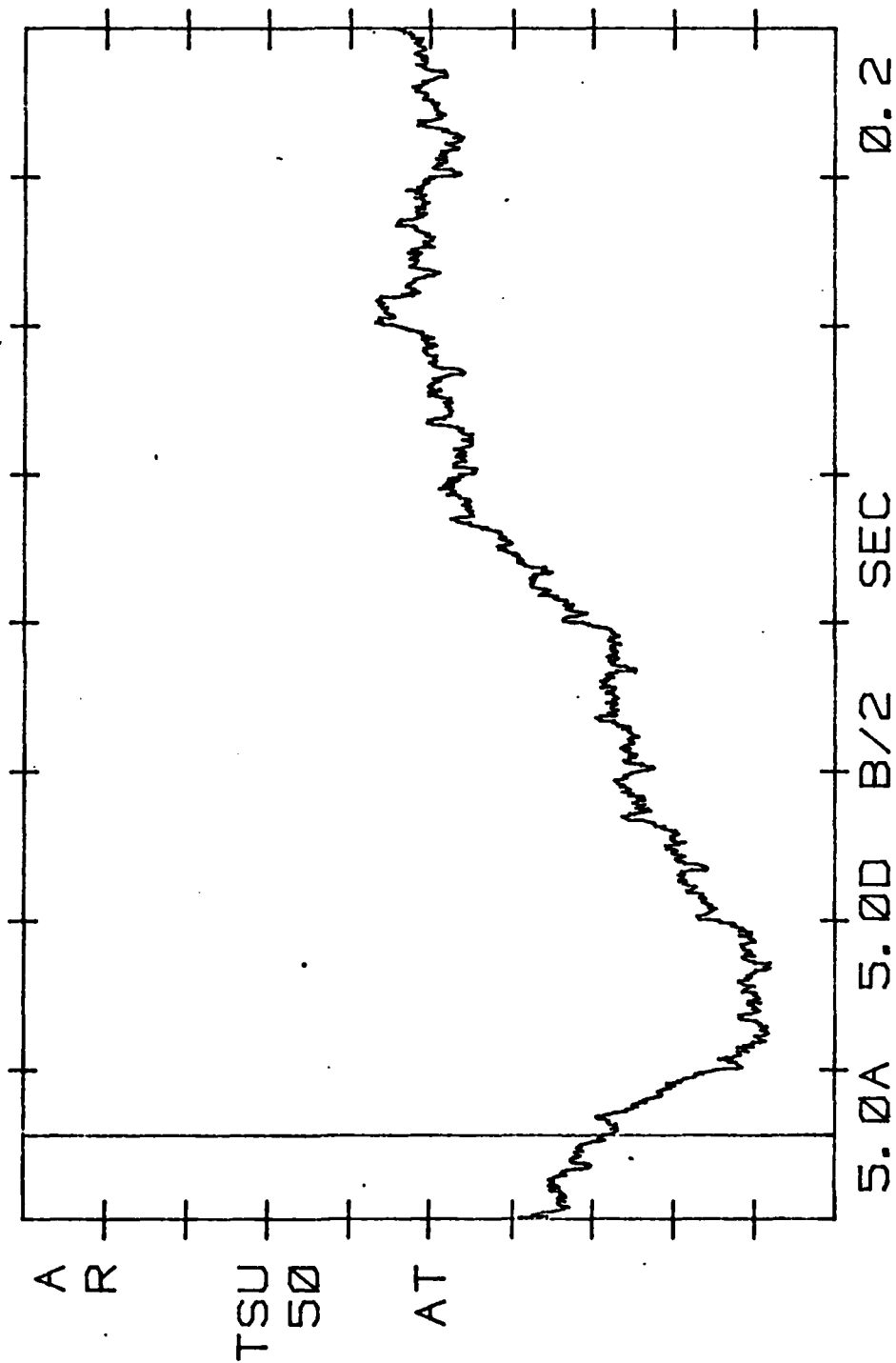
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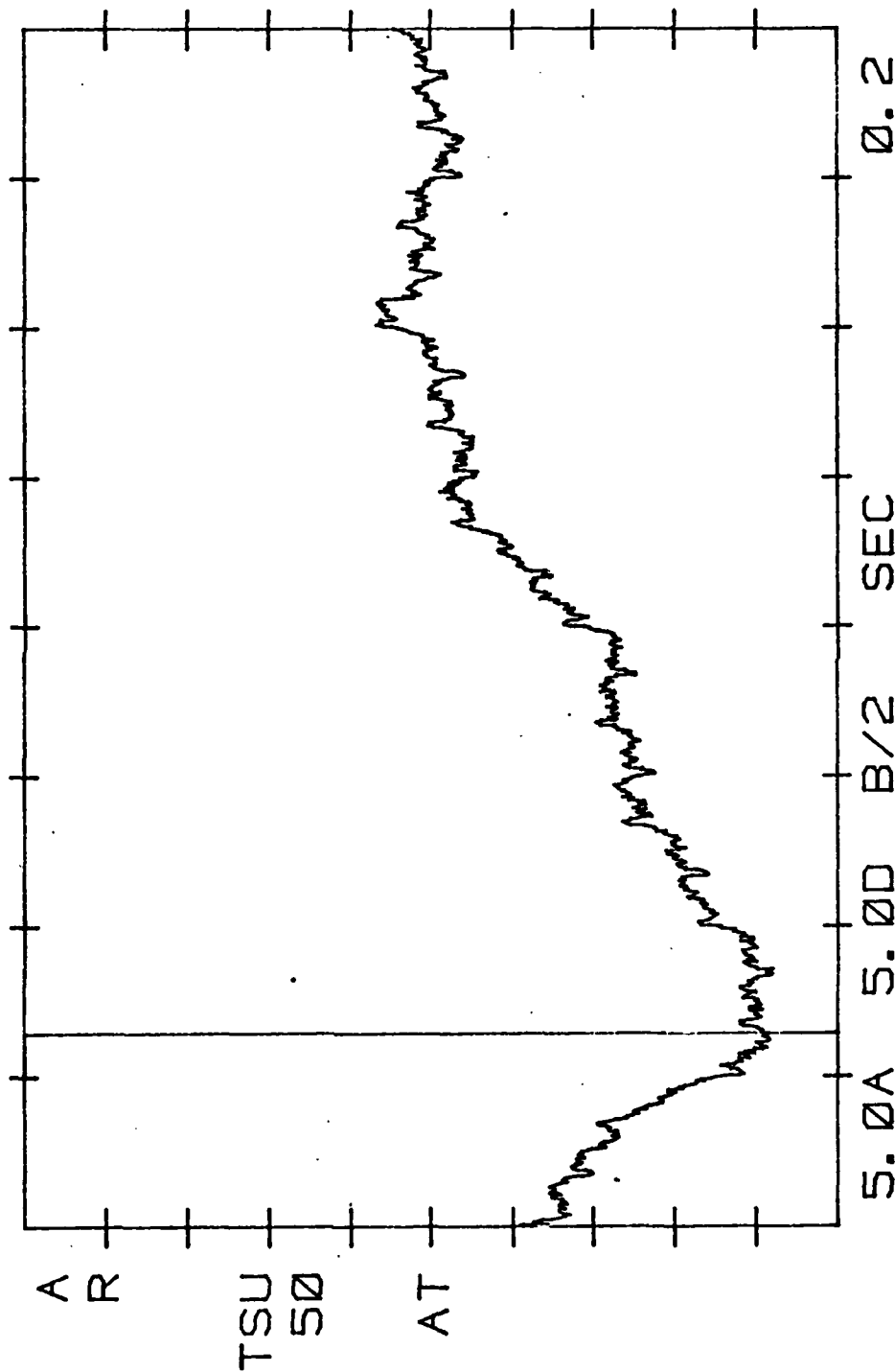
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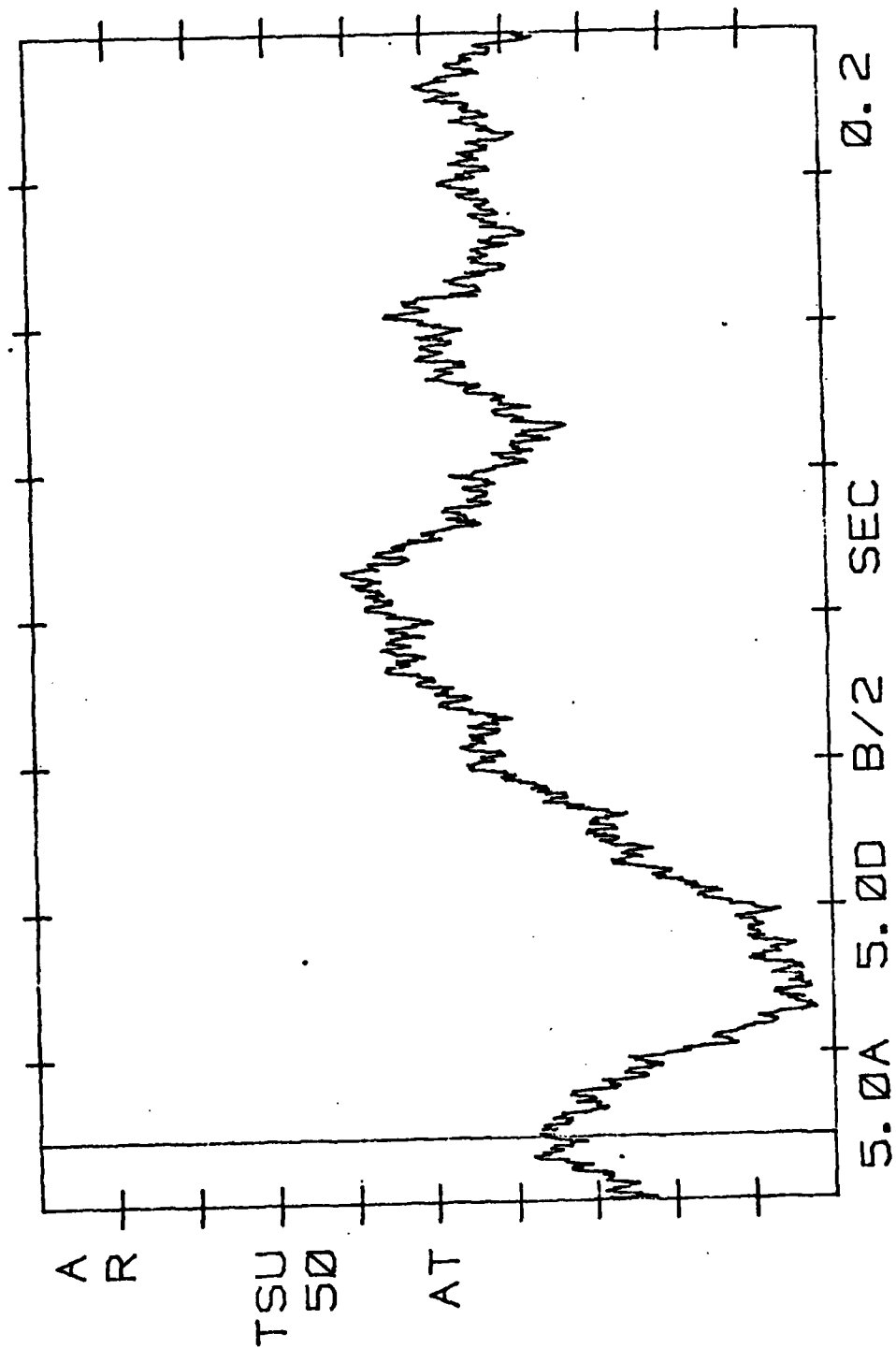
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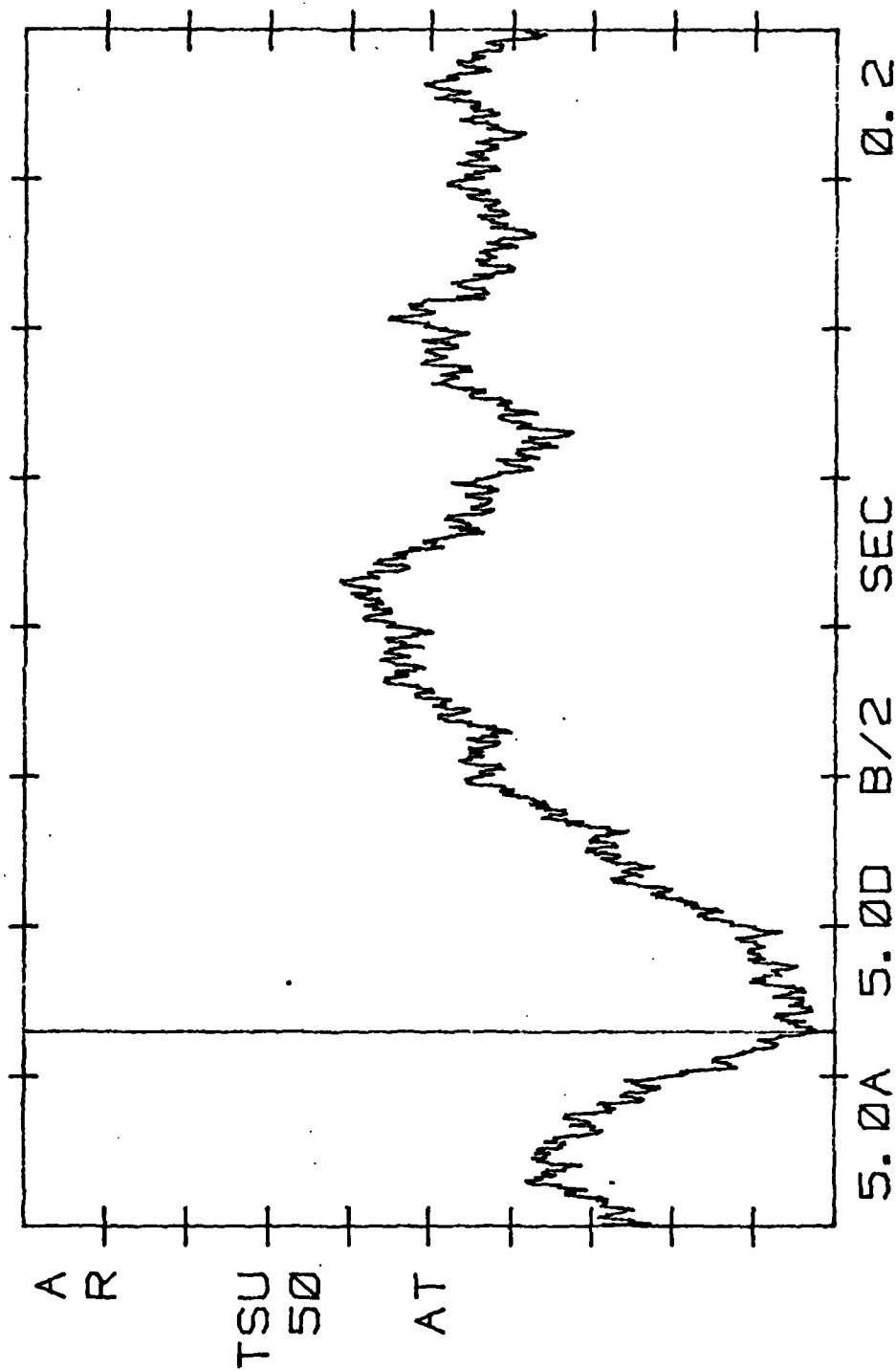
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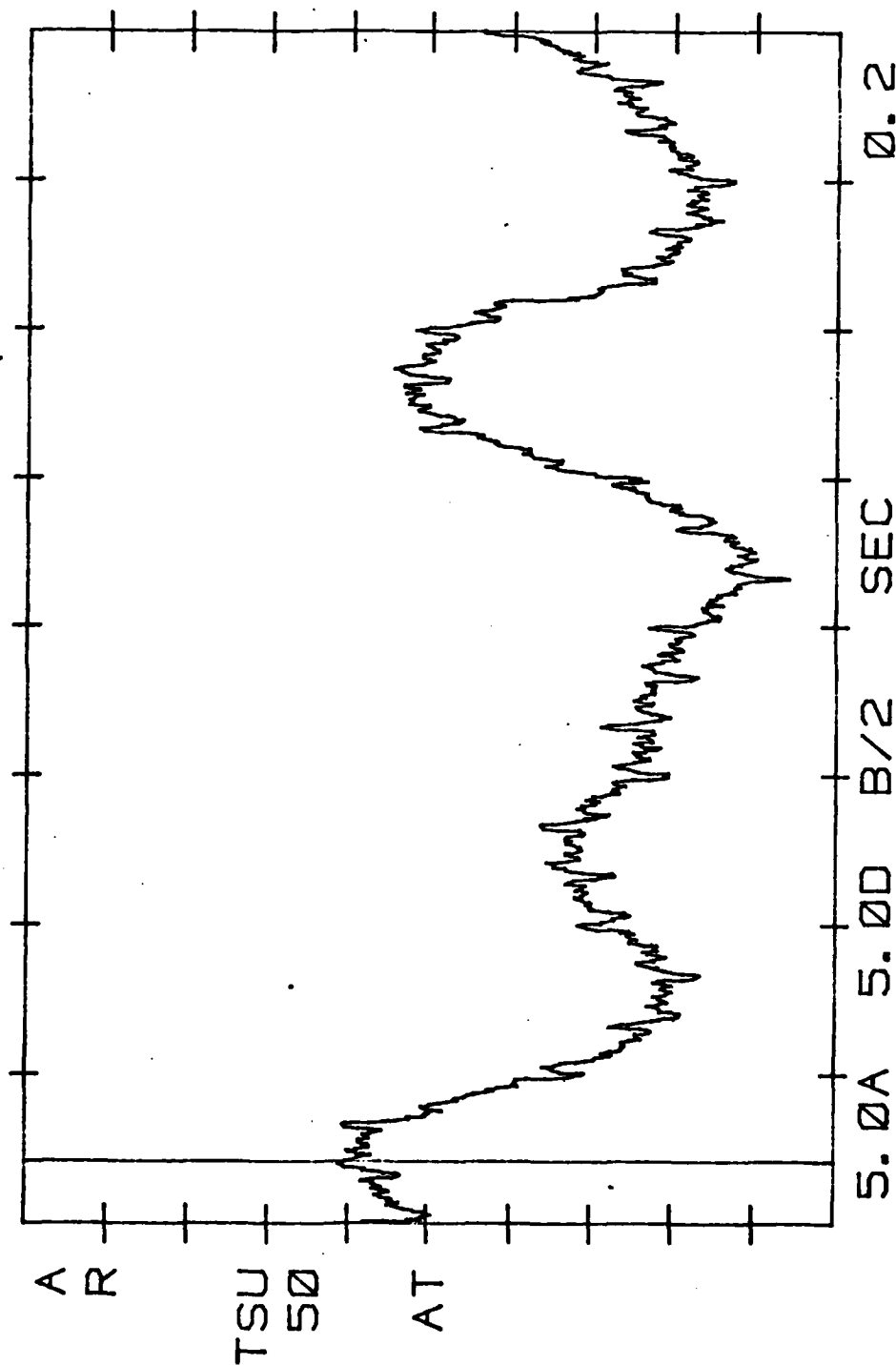
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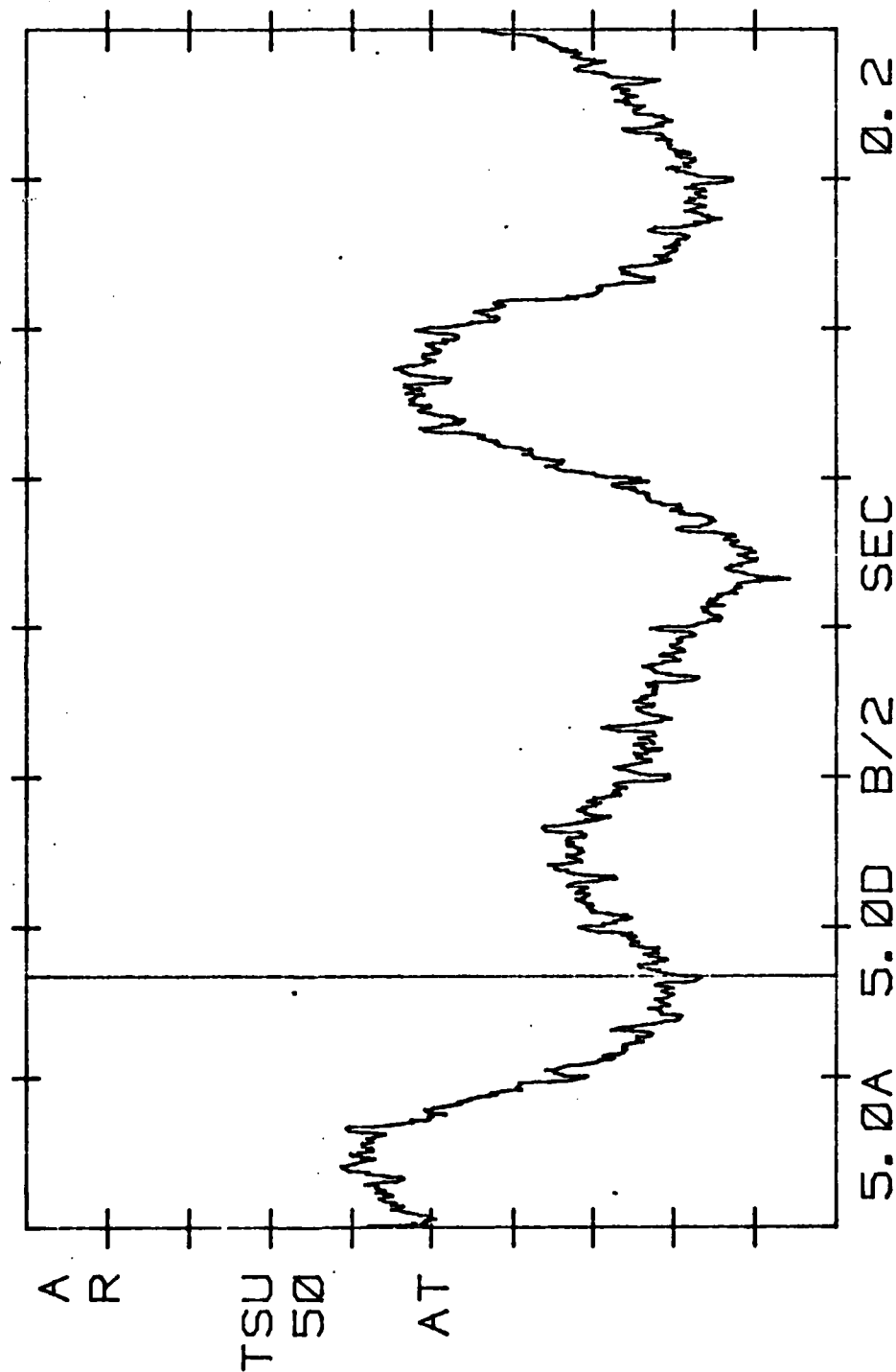
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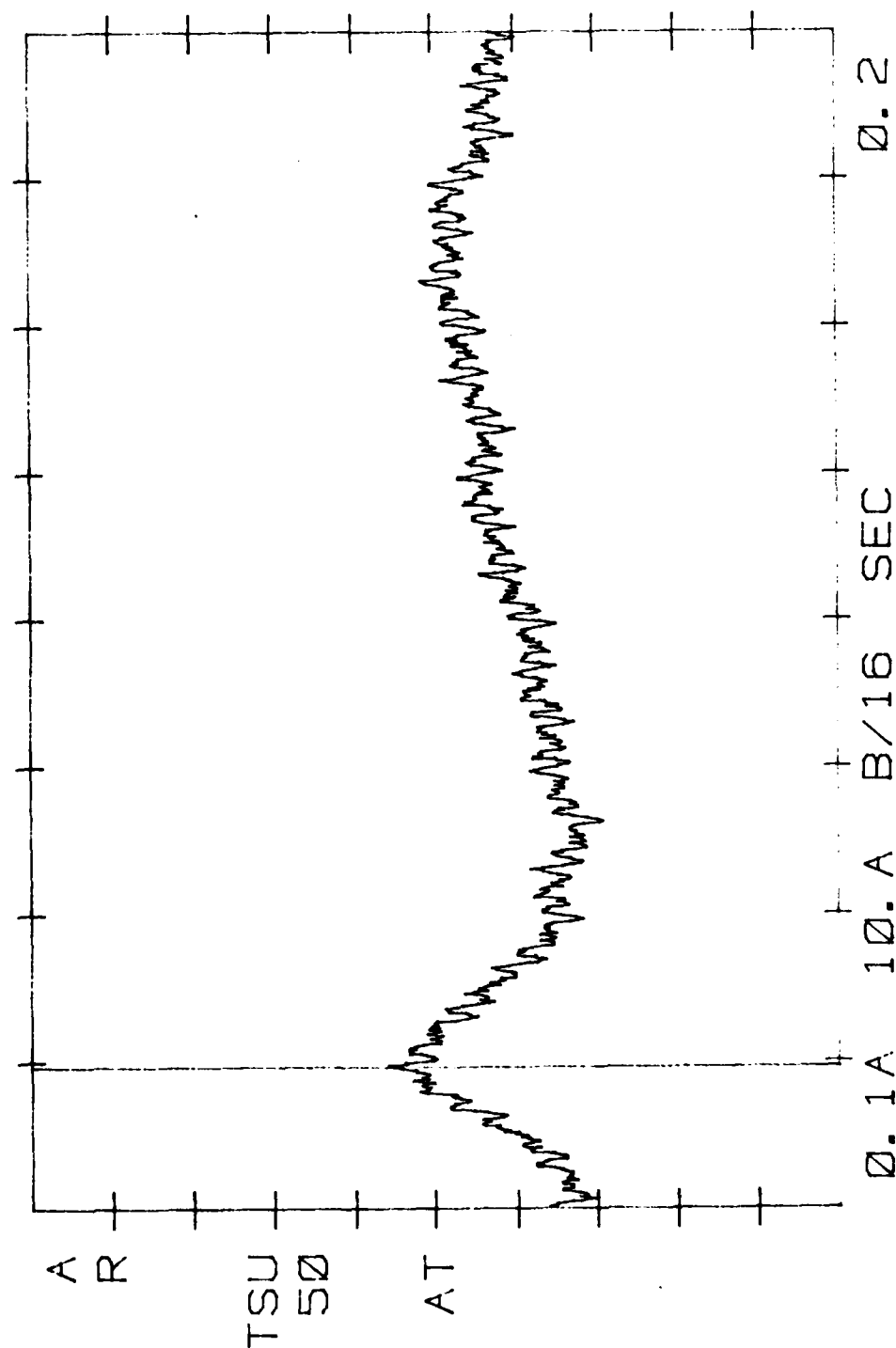
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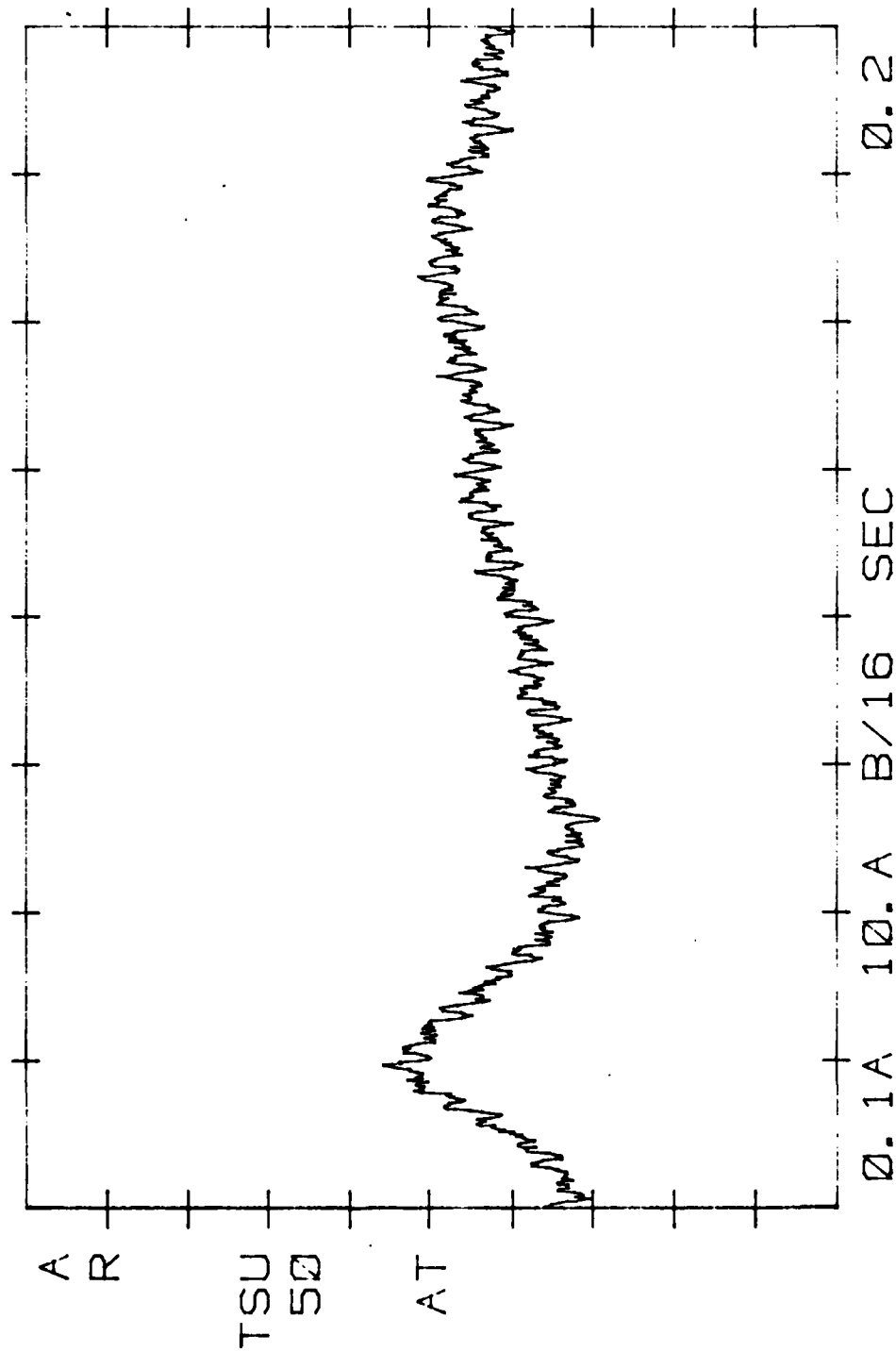
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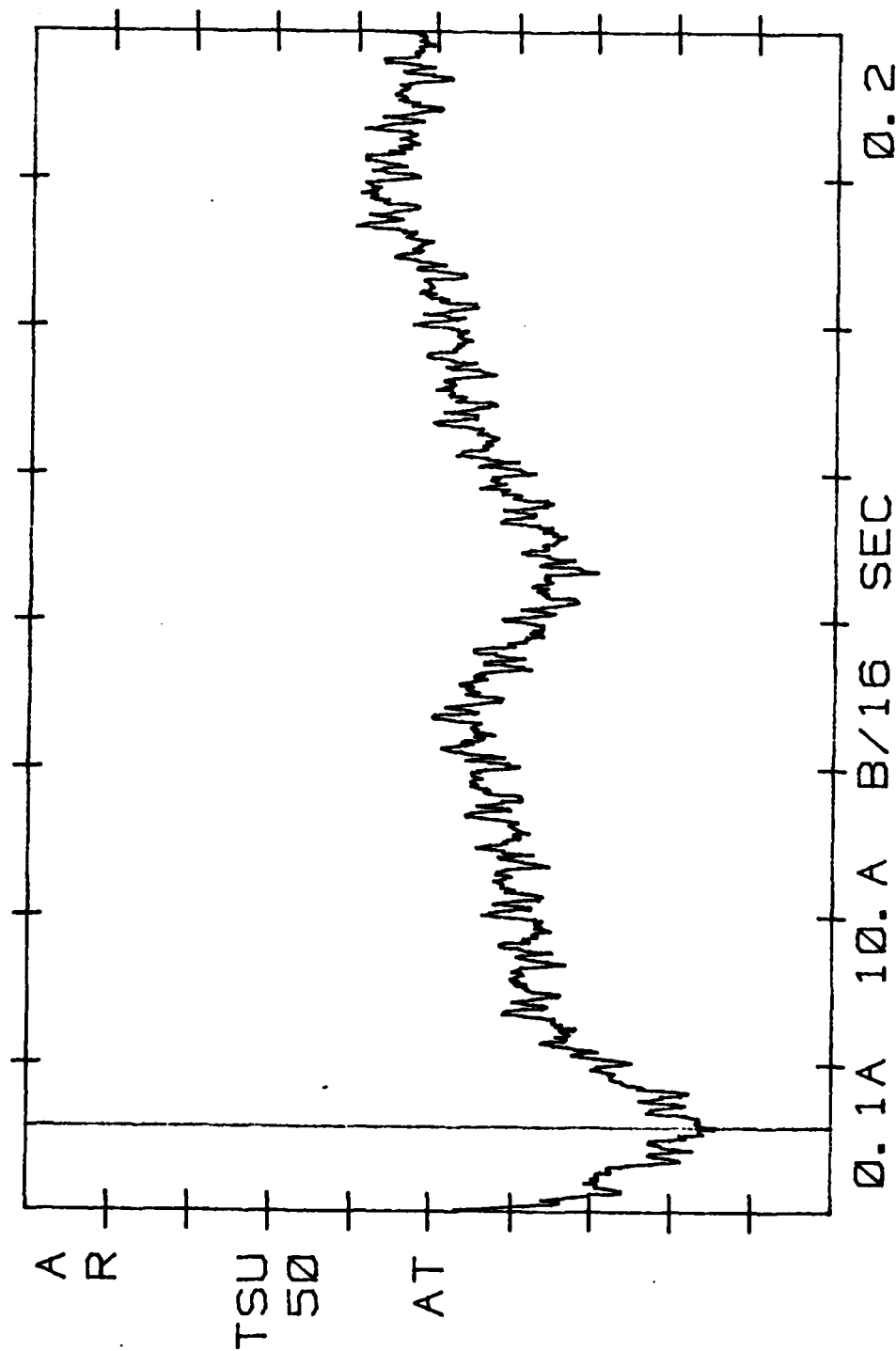
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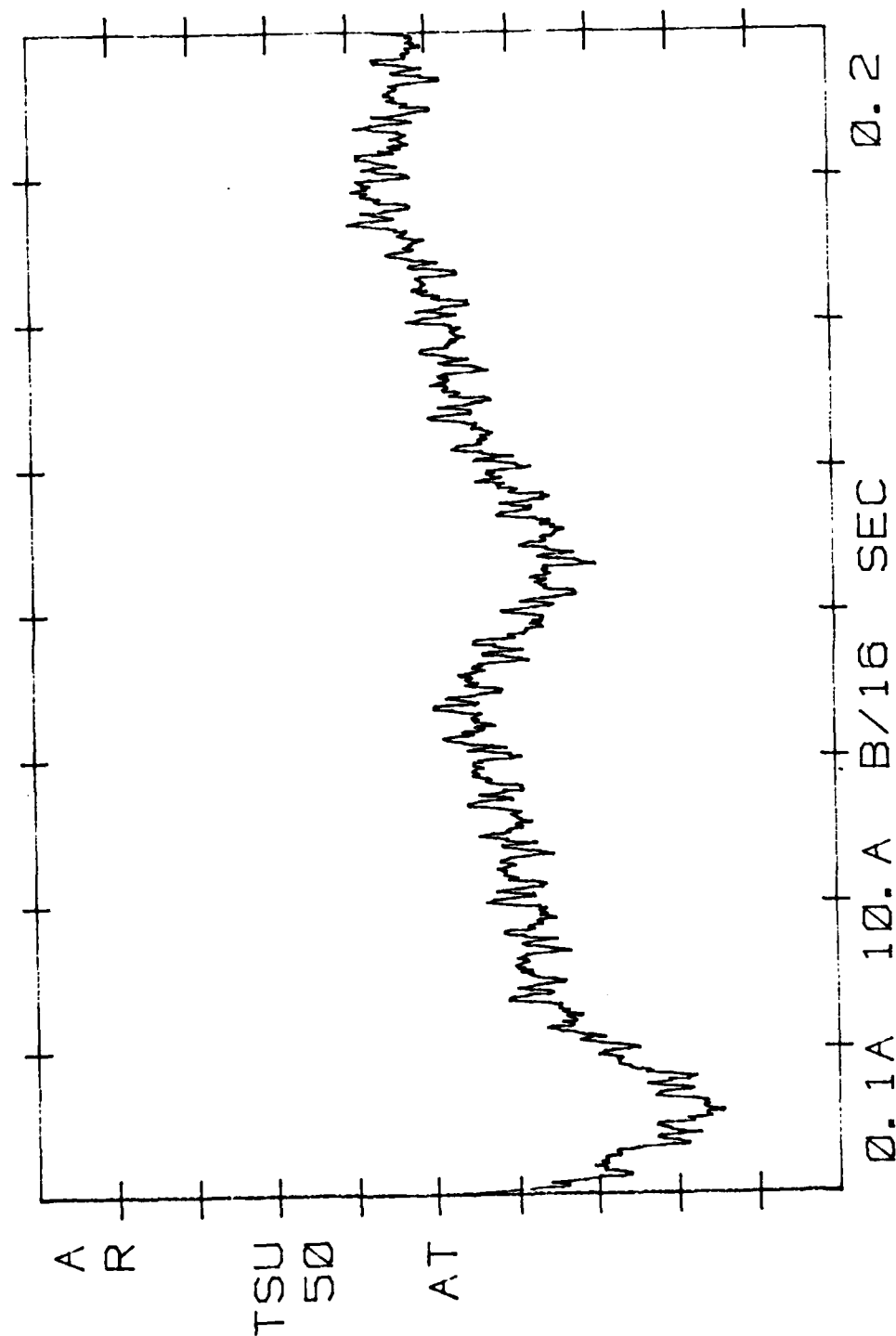
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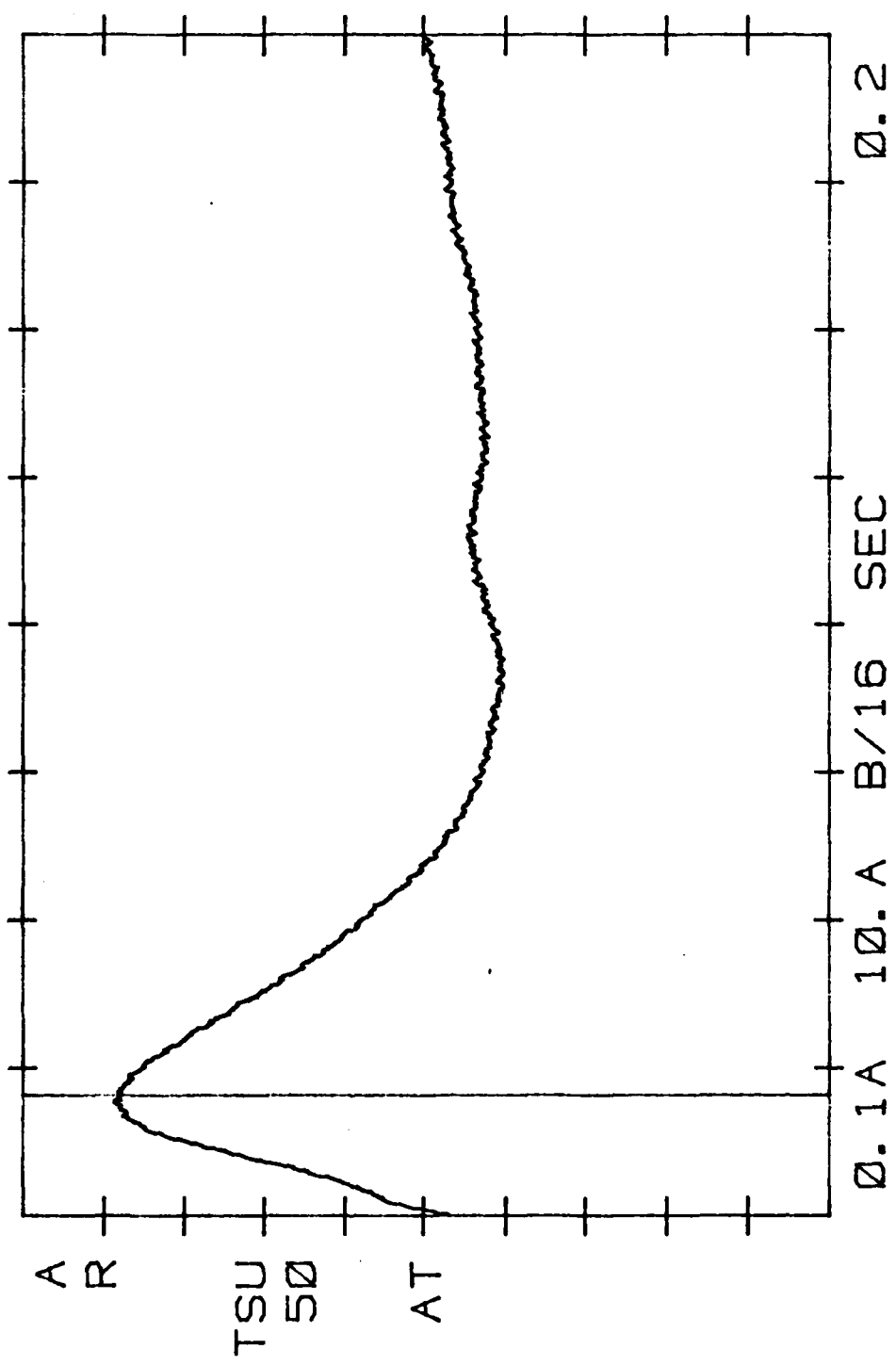
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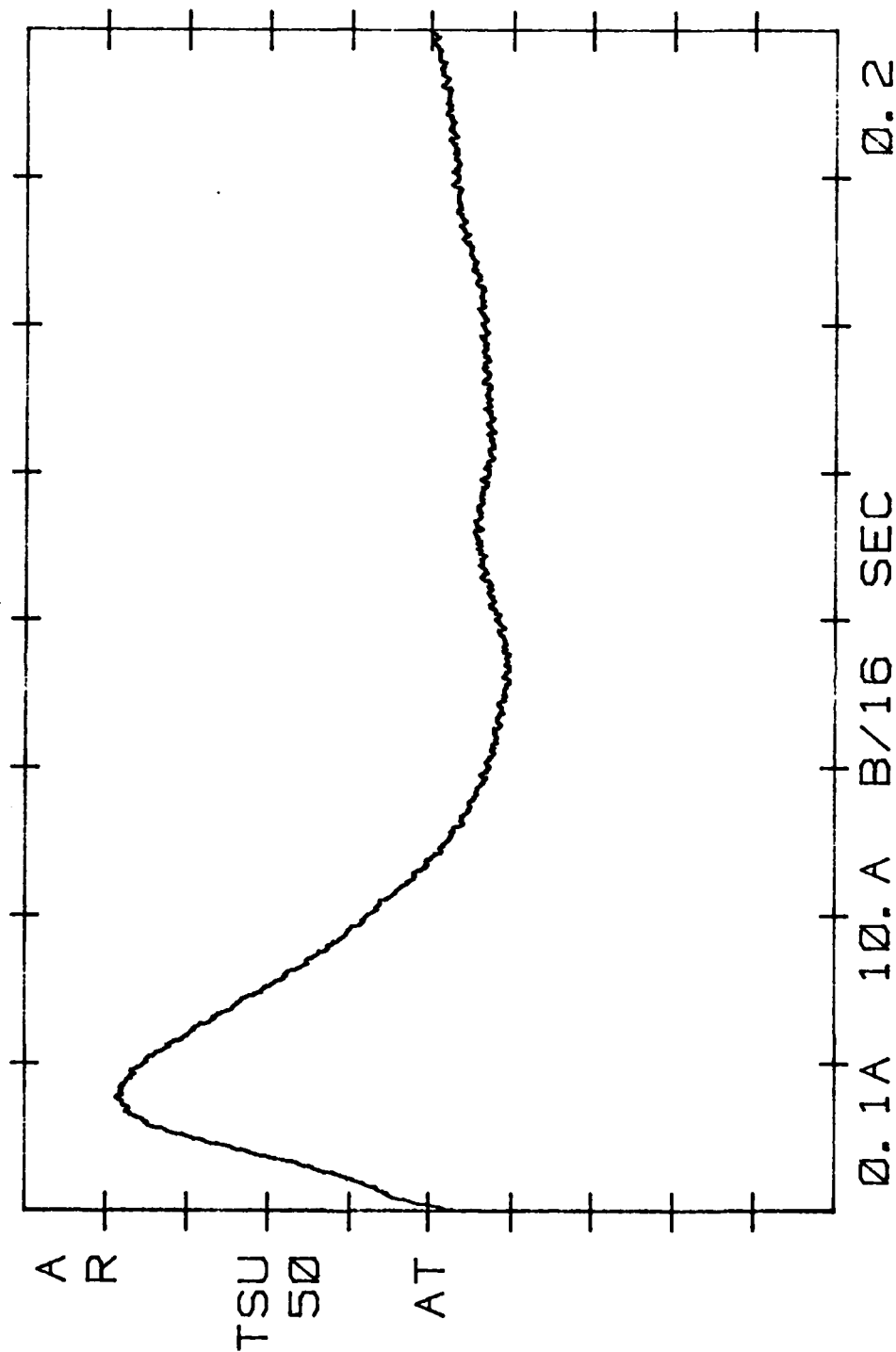
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 20-OCT-83 STROBE T
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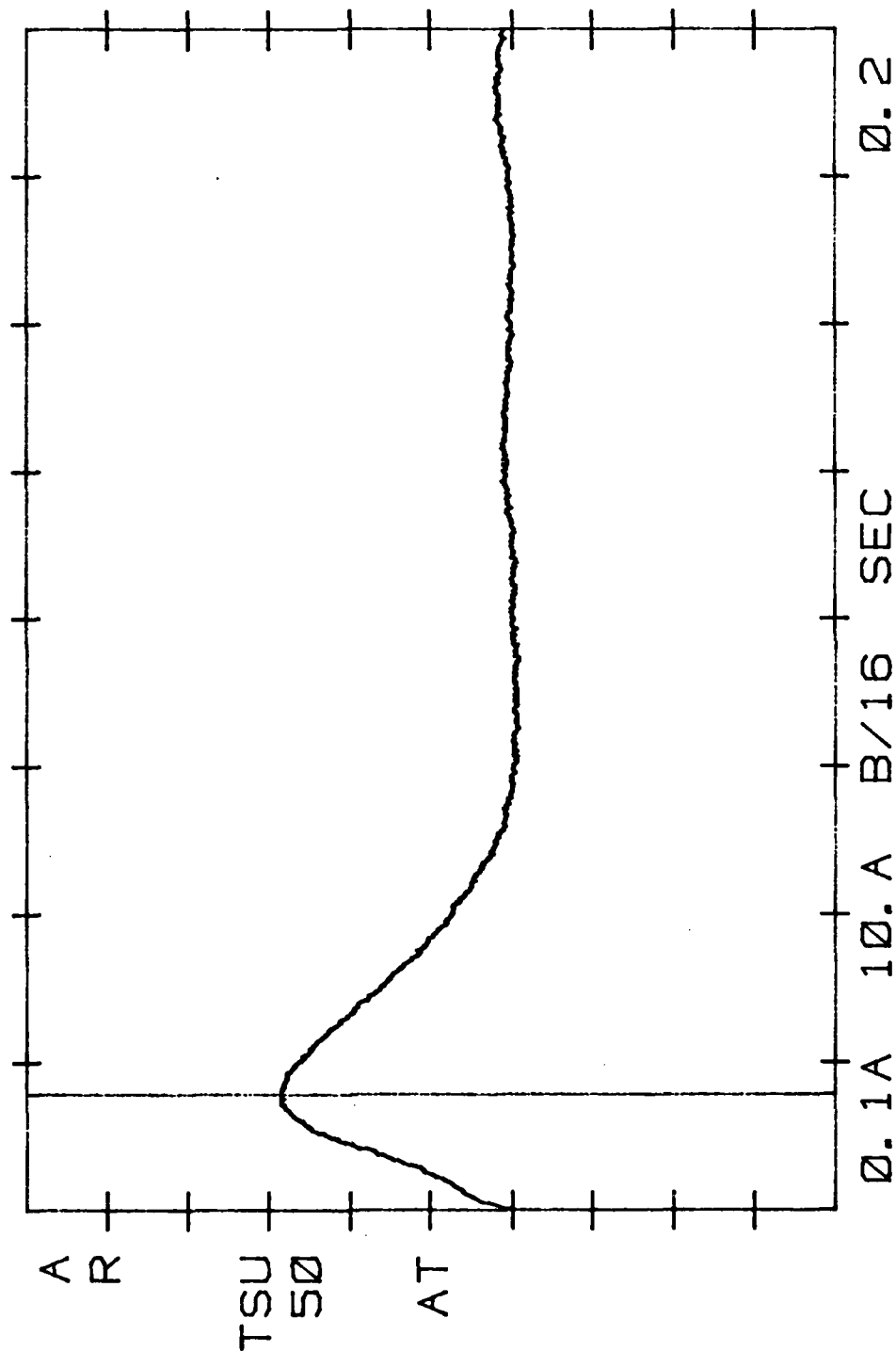
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 MEG. 056
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 7.64-03 V
 LIGHT-OFF
 VLN
 T



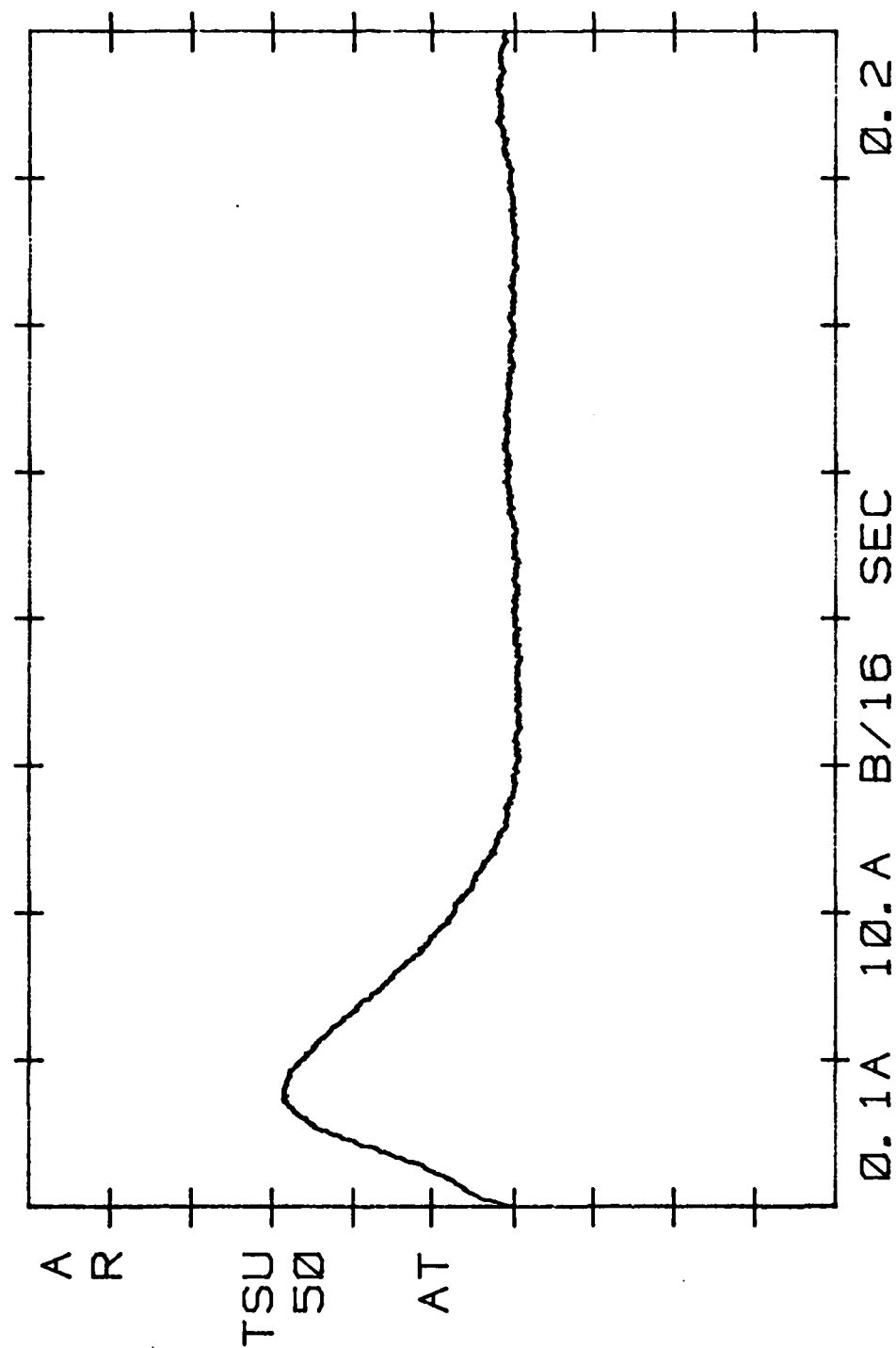
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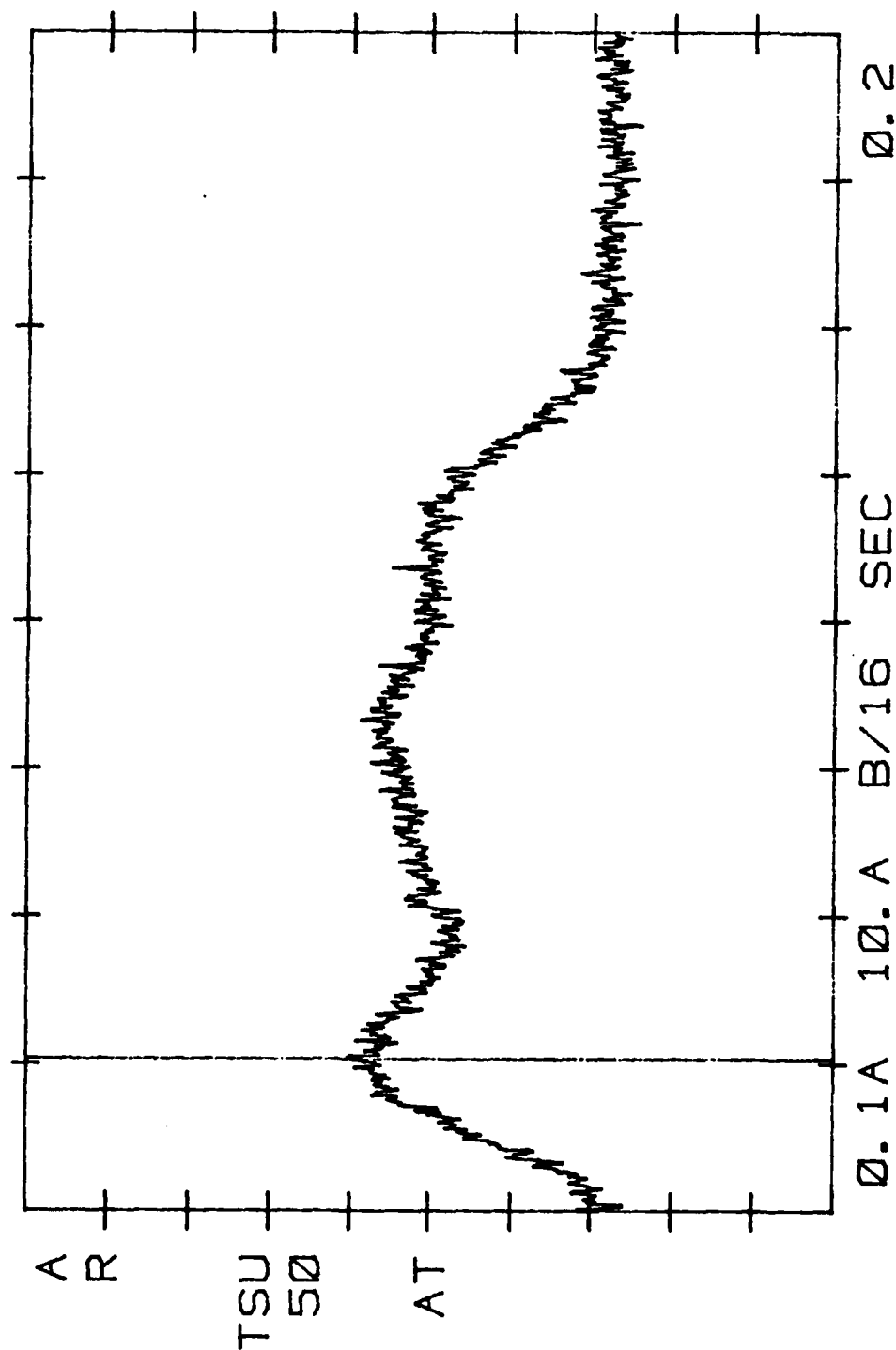
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 MEG. Ø57 NOTCH FILTERS 3.69-Ø3 V
 LIGHT-OFF VLN
 T
 Ø. Ø1953 SEC



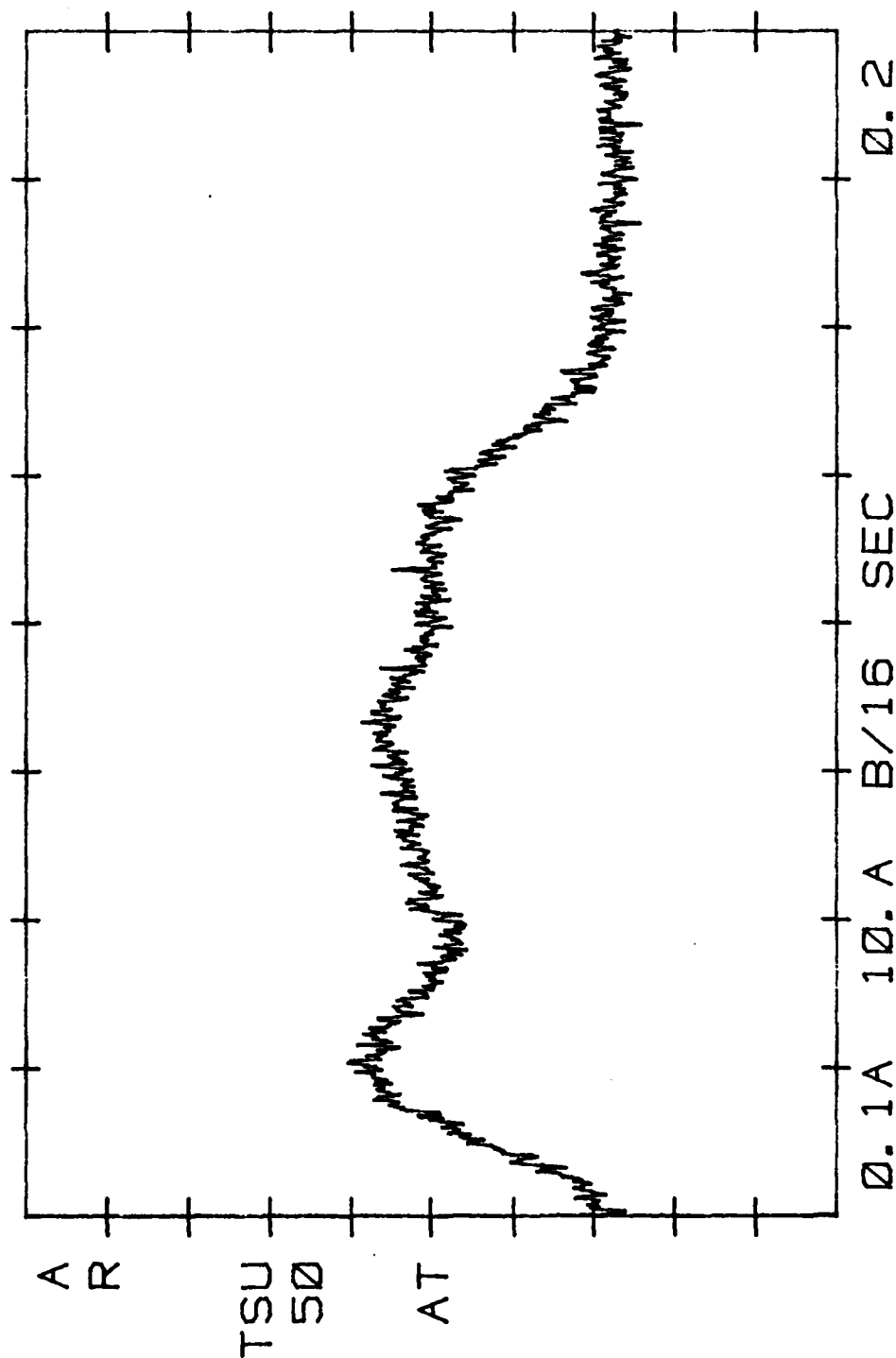
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 20-OCT-83 STROBE T
 Ø. ØØØØØ SEC



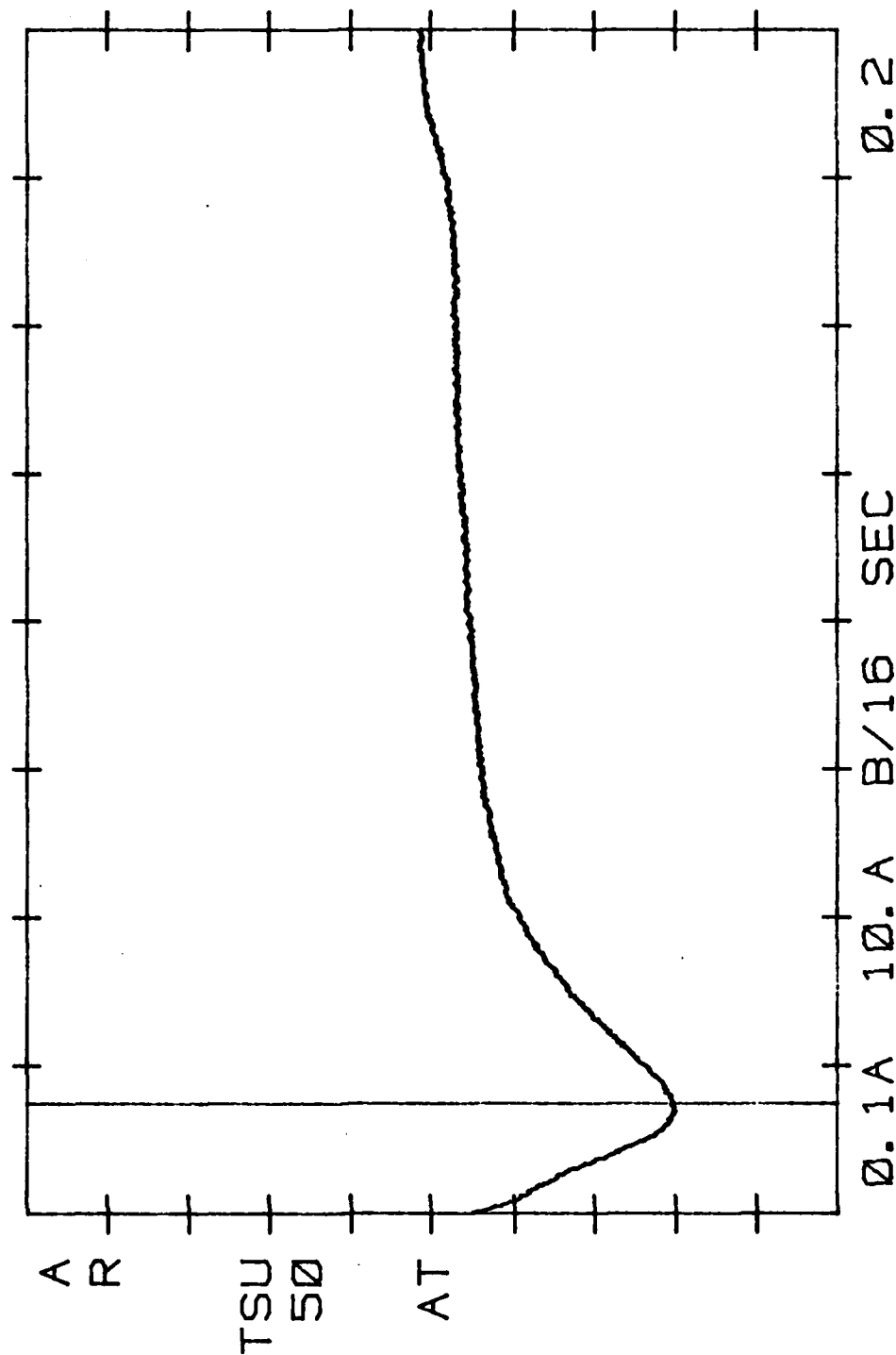
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 RT-OC-SAME
 246. -06 V
 LIGHT-OFF
 VLN
 T



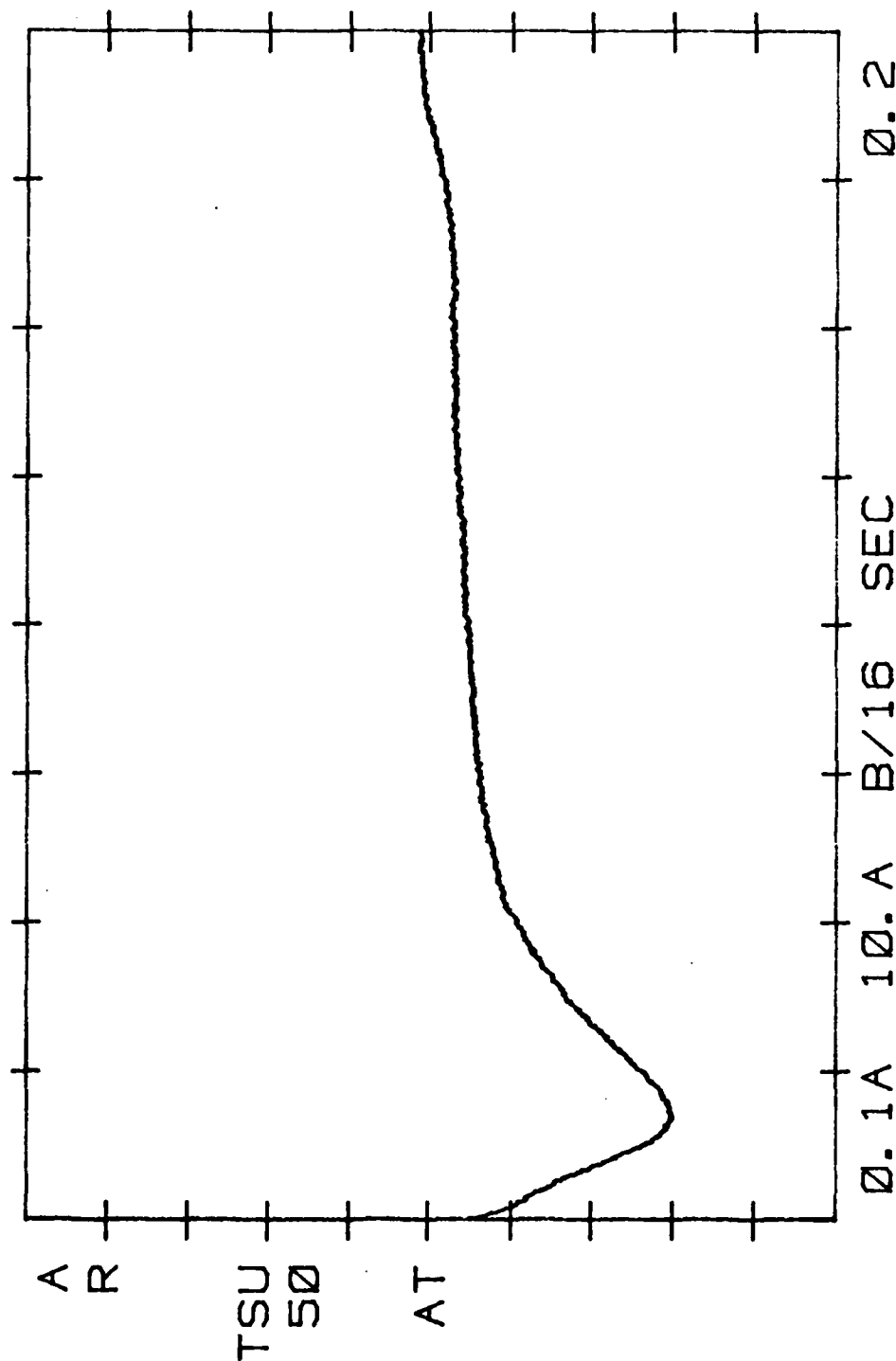
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 Ø. ØØØØØ SEC



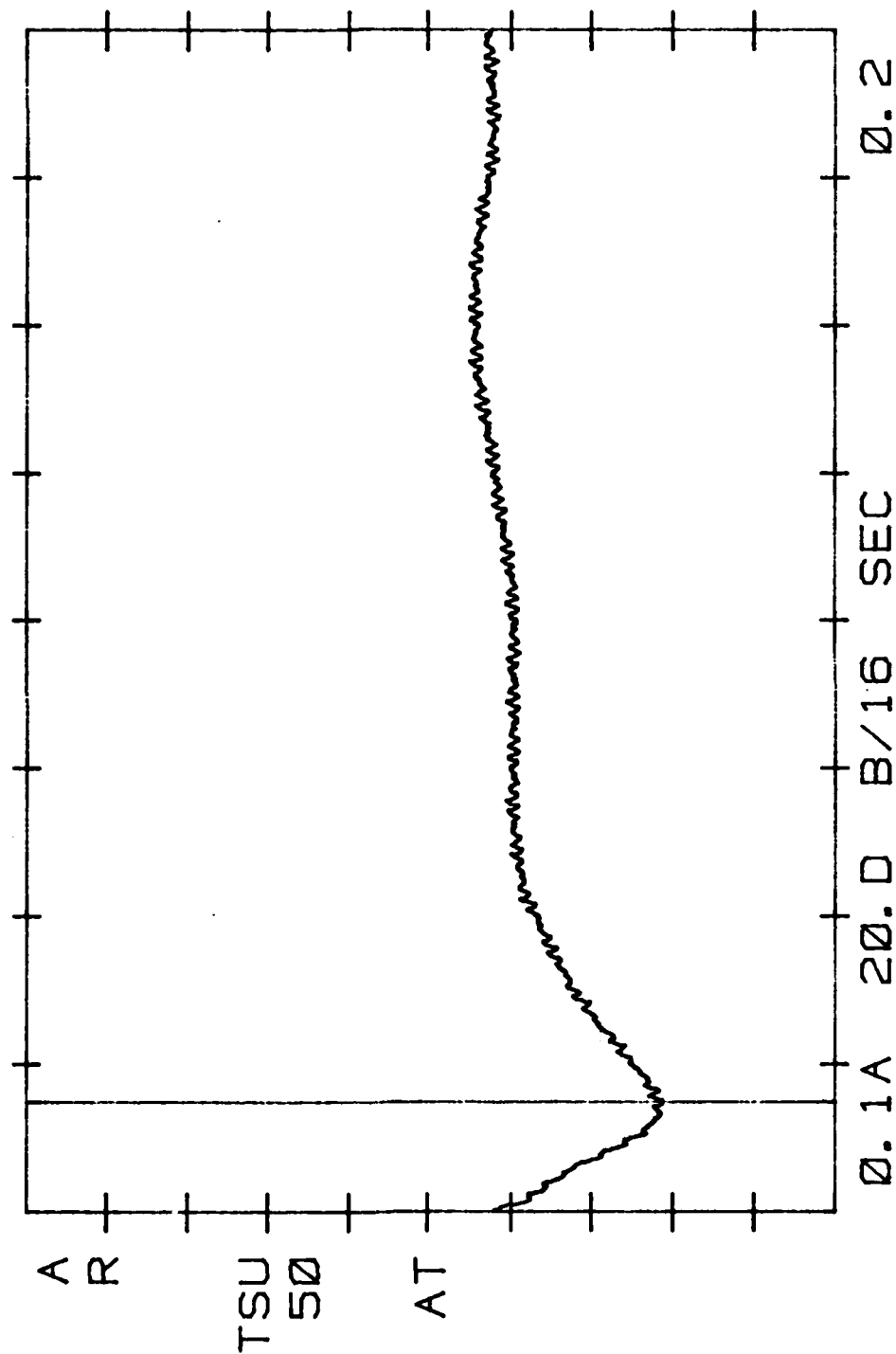
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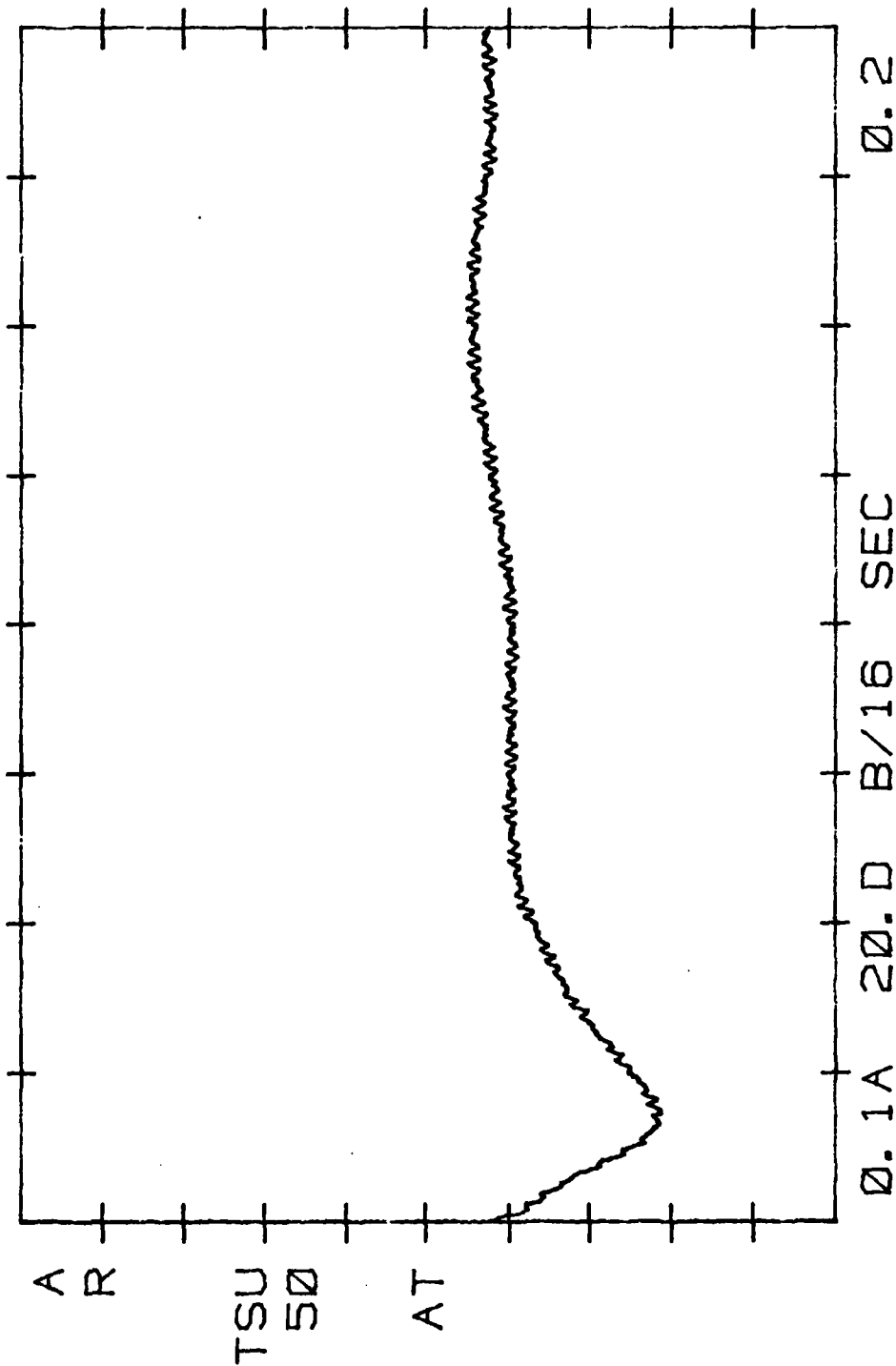
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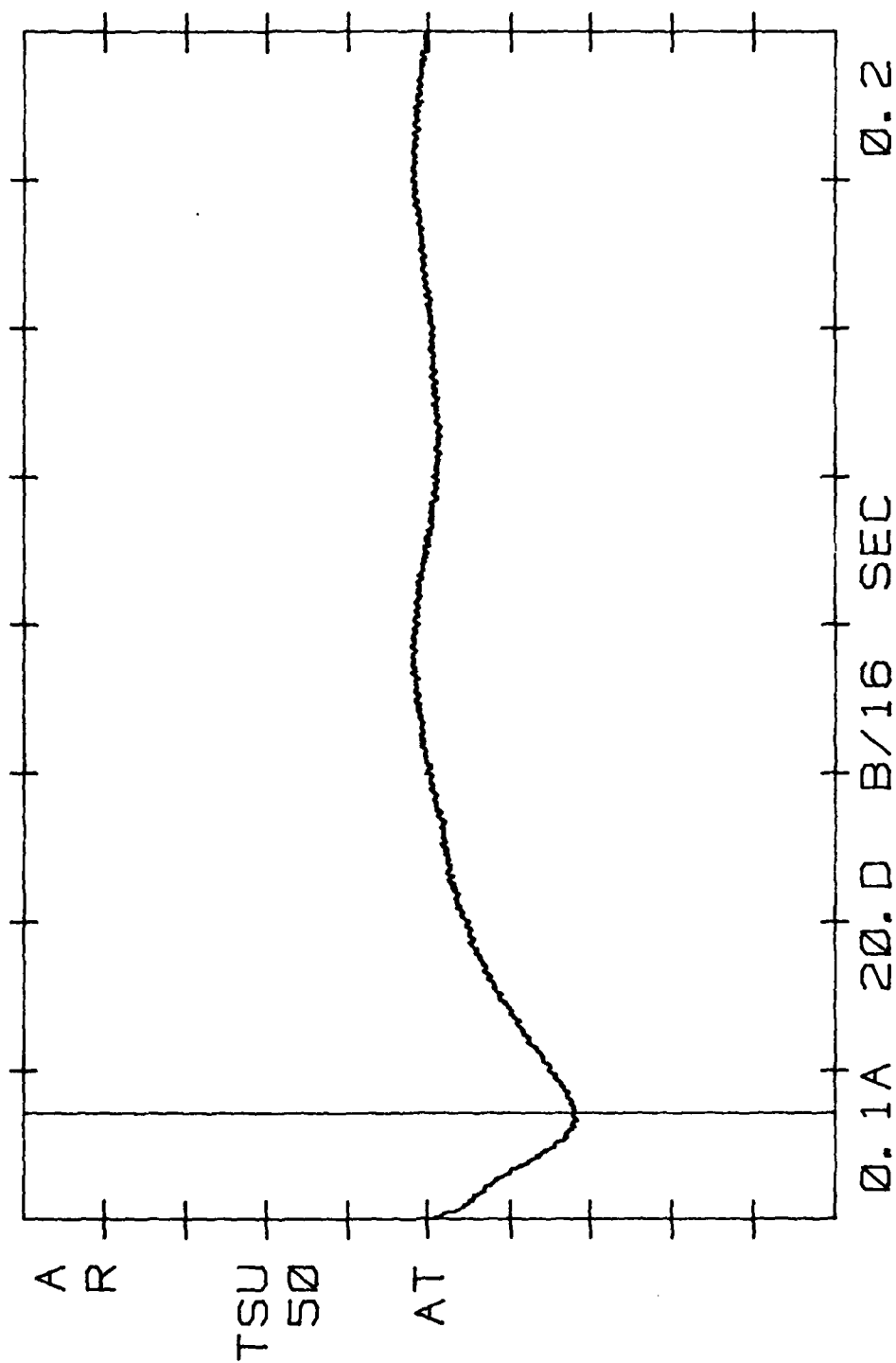
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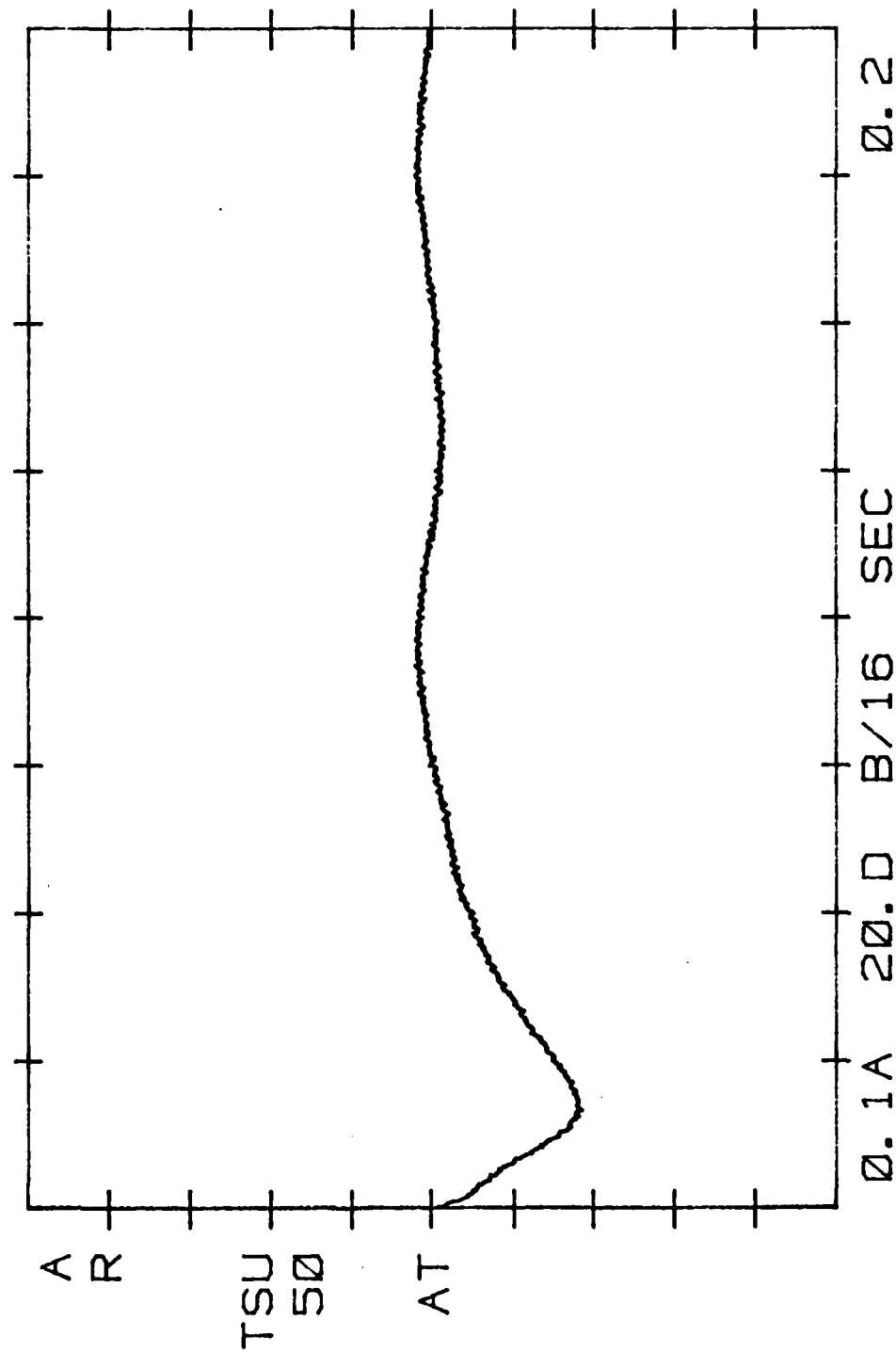
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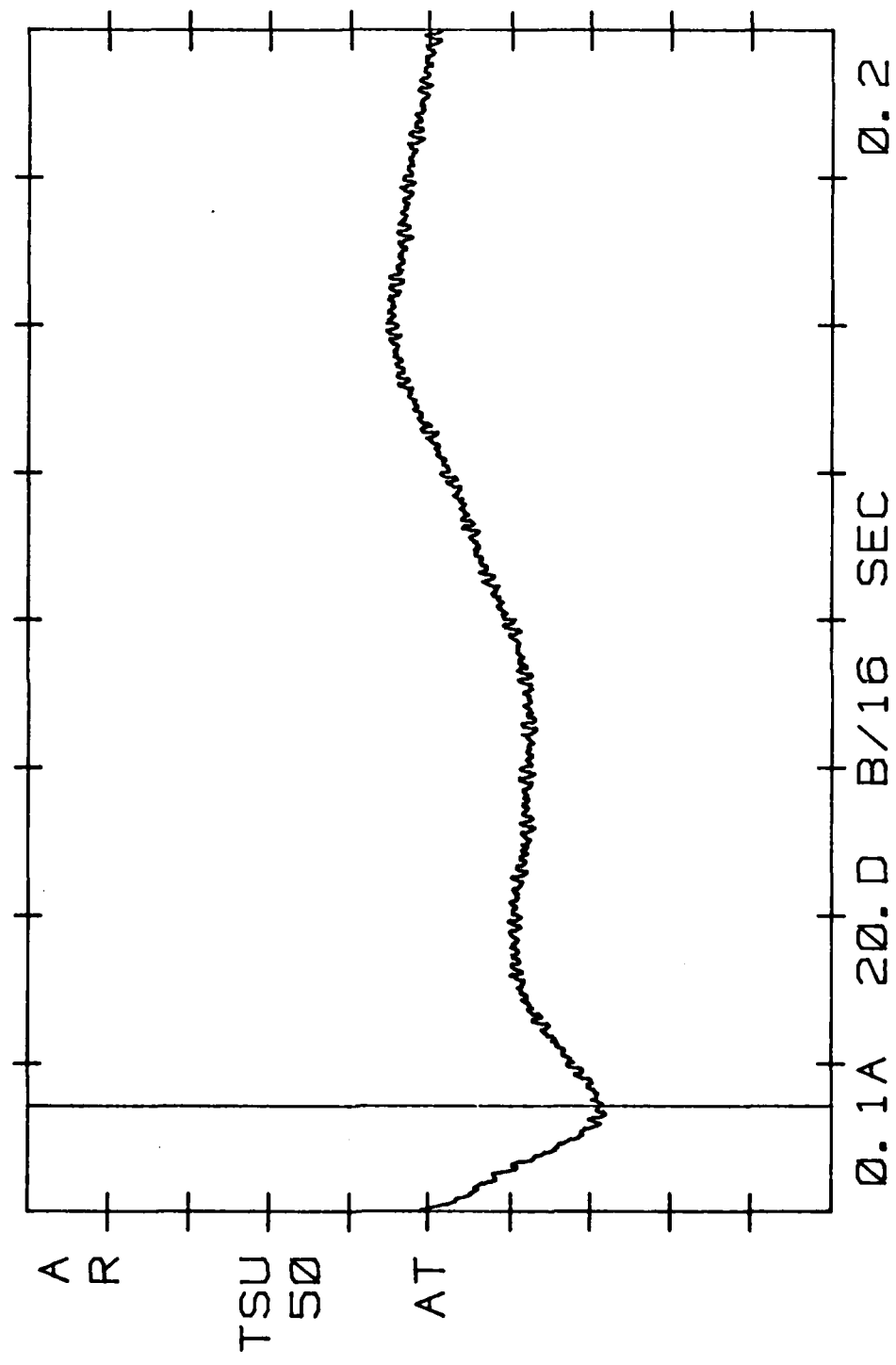
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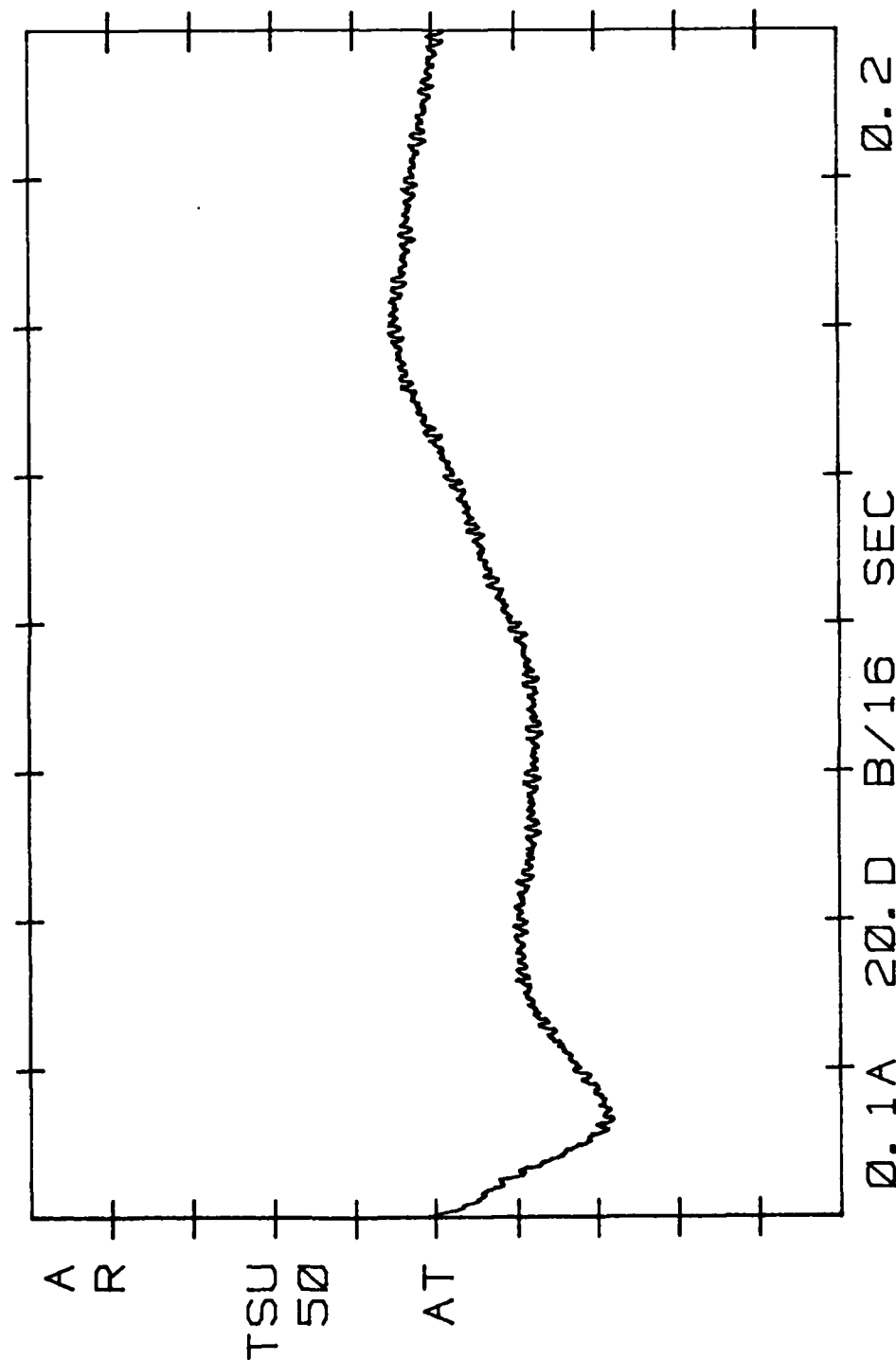
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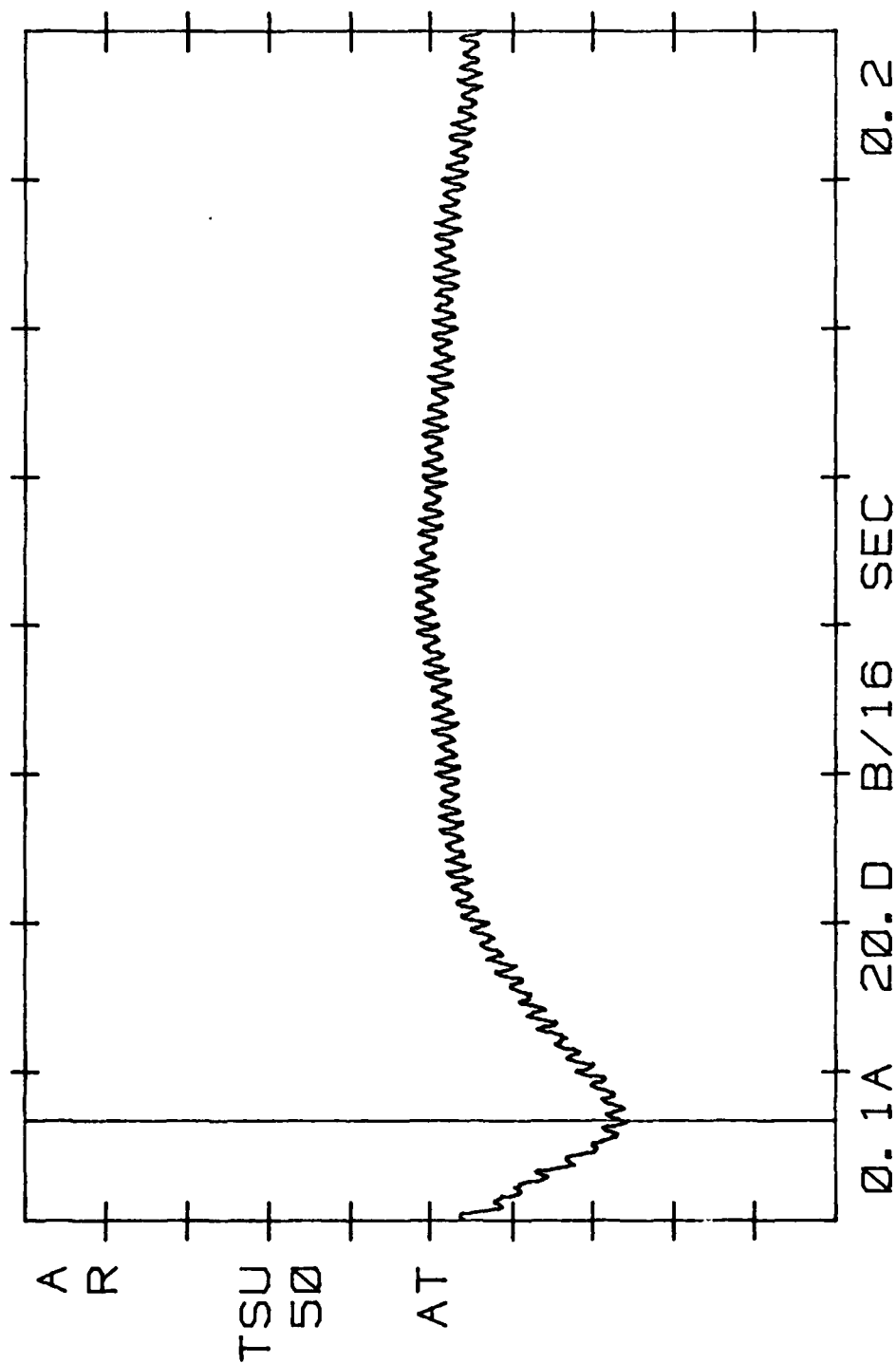
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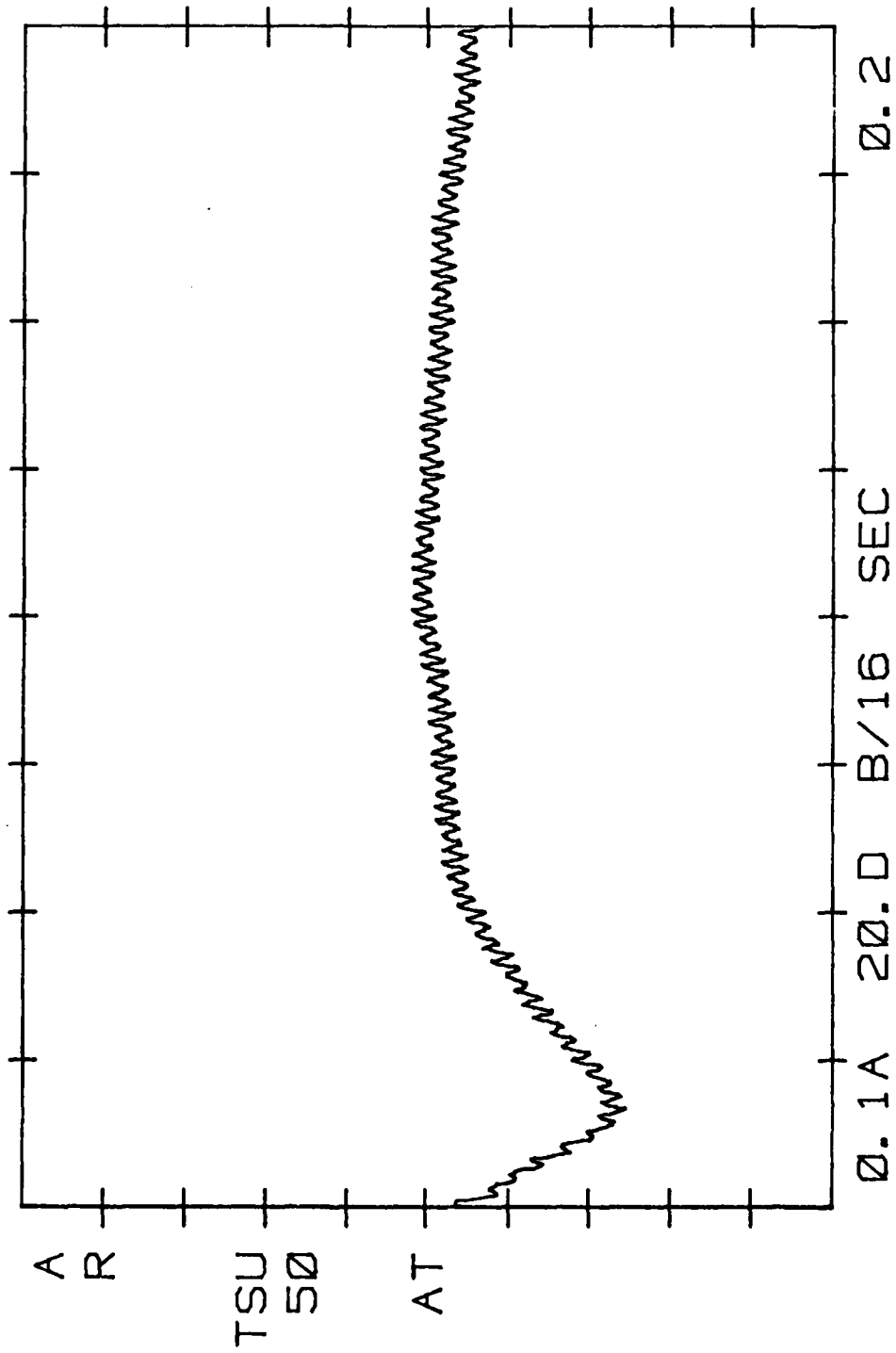
RICKY AND MEG. 062 LT-FR-NEW LIGHT-OFF
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RICKY AND MEG. 063 LT-OC-NEW LIGHT-OFF
 100 CPS AND NOTCH FILTERS-3.79-03 V VLN
 20-OCT-83 STROBE T
 0.01680 SEC



RICKY AND MEG. 063 LT-OC-NEW LIGHT-OFF
 100 CPS AND NOTCH FILTERS-626. -06 V VLN
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 0. 00000 SEC



APPENDIX E

DOG AUDITORY EVOKED RESPONSE PLOTS

APPENDIX E

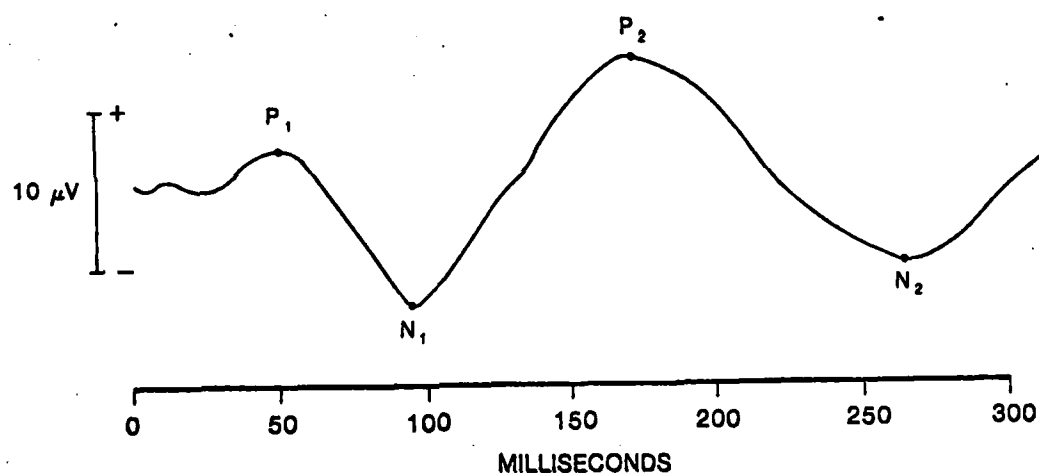
DOG AUDITORY EVOKED RESPONSES

On the last day we collected data from Ricky, the laboratory beagle, we were able to setup an auditory evoked response (AER) experiment. We used two signal generators and a pseudo-random noise generator to generate a short tone at random interstimulus intervals. This tone was coupled to the dog with air filled earphones. The rest of the setup was the same as for the visual evoked response experiment, that is, the SQUID gradiometer was positioned at different locations over the beagles head too get the best response. The output of the SQUID gradiometer was once again sent to the Nicolet 660B FFT Analyzer, so that, 50 trails could be averaged. That average was then sent out of the Nicolet 660B FFT Analyzer to an Intel 80/20 computer so that it could be stored on a 8 inch disk.

Figure E-1 shows an auditory evoked response taken from a human by electroencephalographic means, as compared to an auditory evoked response taken from a human by magnetoencephalographic means, which is shown in Figure E-2. In my literature search, I was unable to find an auditory evoked response for a dog which had been taken by electroencephalographic means, but was able to find an auditory evoked response for a cat which had been taken by electroencephalographic means. This auditory evoked response of the cat is shown in Figure E-3. The cat's brain is

physically smaller than the brain of a beagle, so I would expect the latencies measured from the cat to be shorter than the latencies we would measure from the beagle. The plots MEG.066 thru MEG.071, which are at the end of this appendix, shows the auditory evoked responses taken from the beagle by magnetoencephalographic means.

LATE AUDITORY EVOKED RESPONSE PROCESSING IN PRIMARY AUDITORY PROJECTION AREAS



FROM: BRADFORD, 1978

HE-76-2-12

FIGURE E-1
HUMAN ELECTROENCEPHALOGRAPHIC AUDITORY EVOKED RESPONSE

12 Oct 83 1600

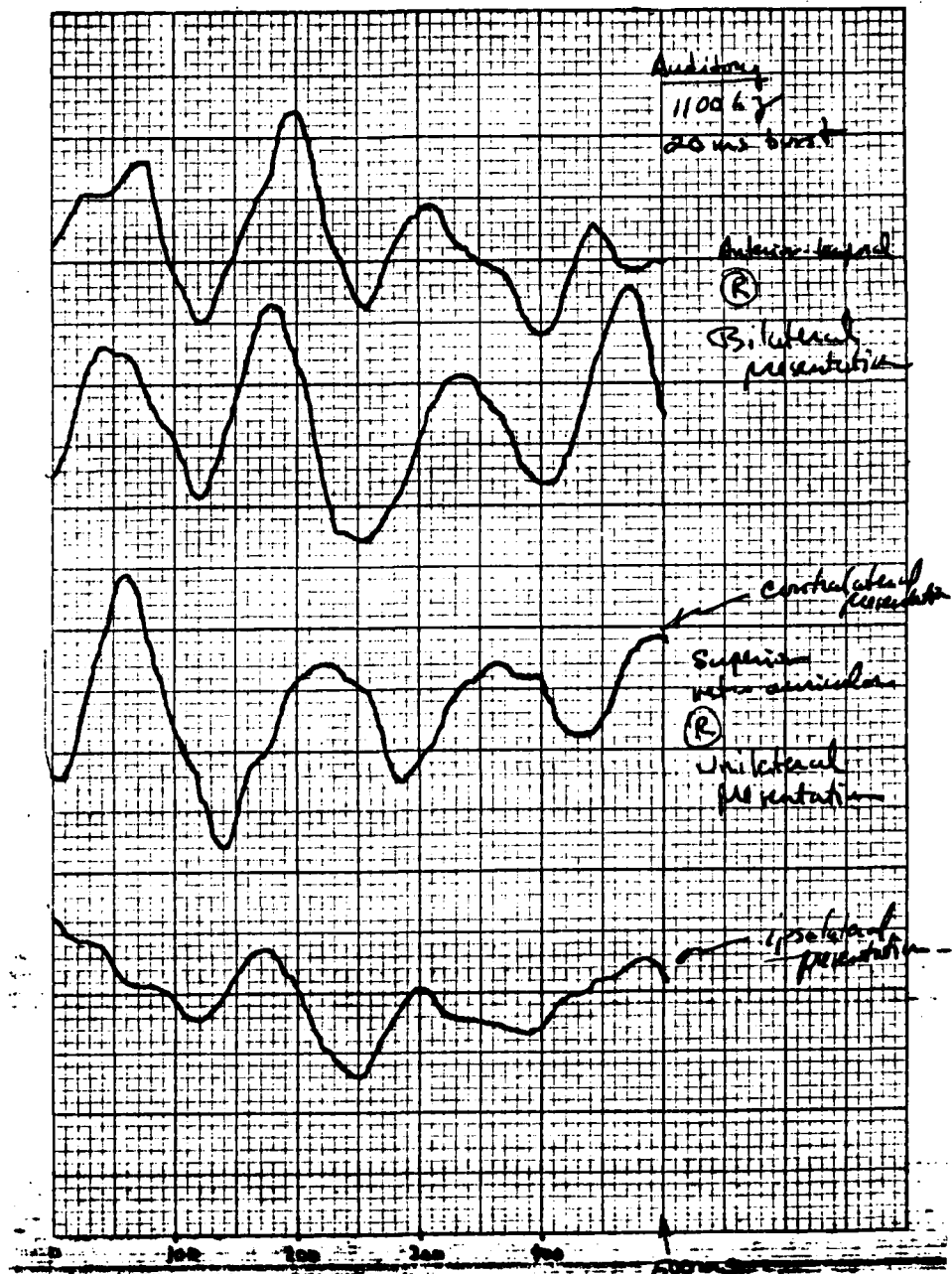


FIGURE E-2

HUMAN MAGNETOENCEPHALOGRAPHIC AUDITORY EVOKED RESPONSE

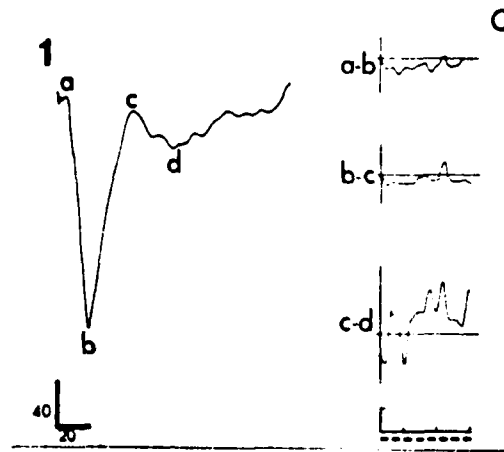


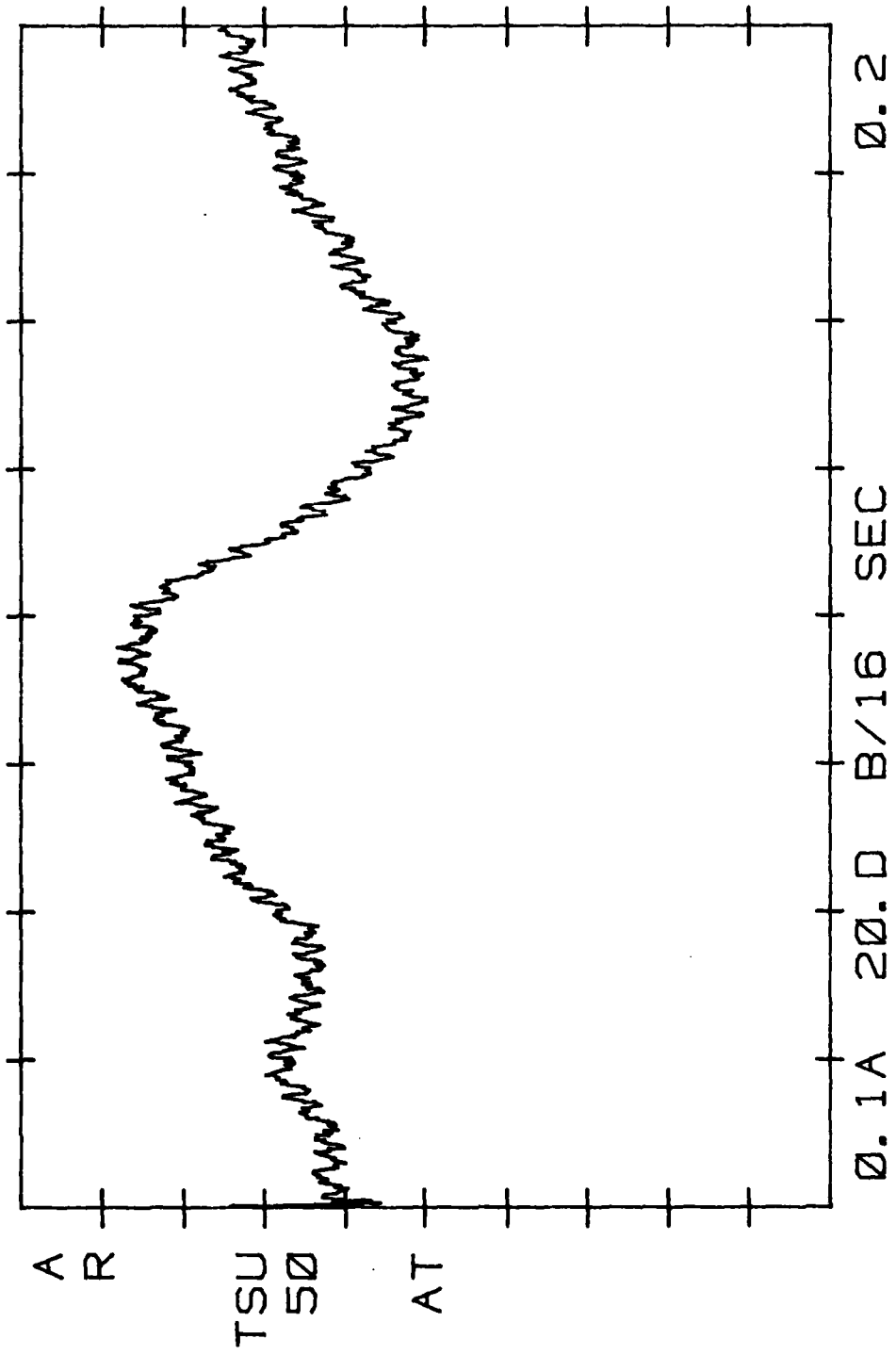
FIGURE E-3

CAT'S ELECTROENCEPHALOGRAPHIC AUDITORY EVOKED RESPONSE

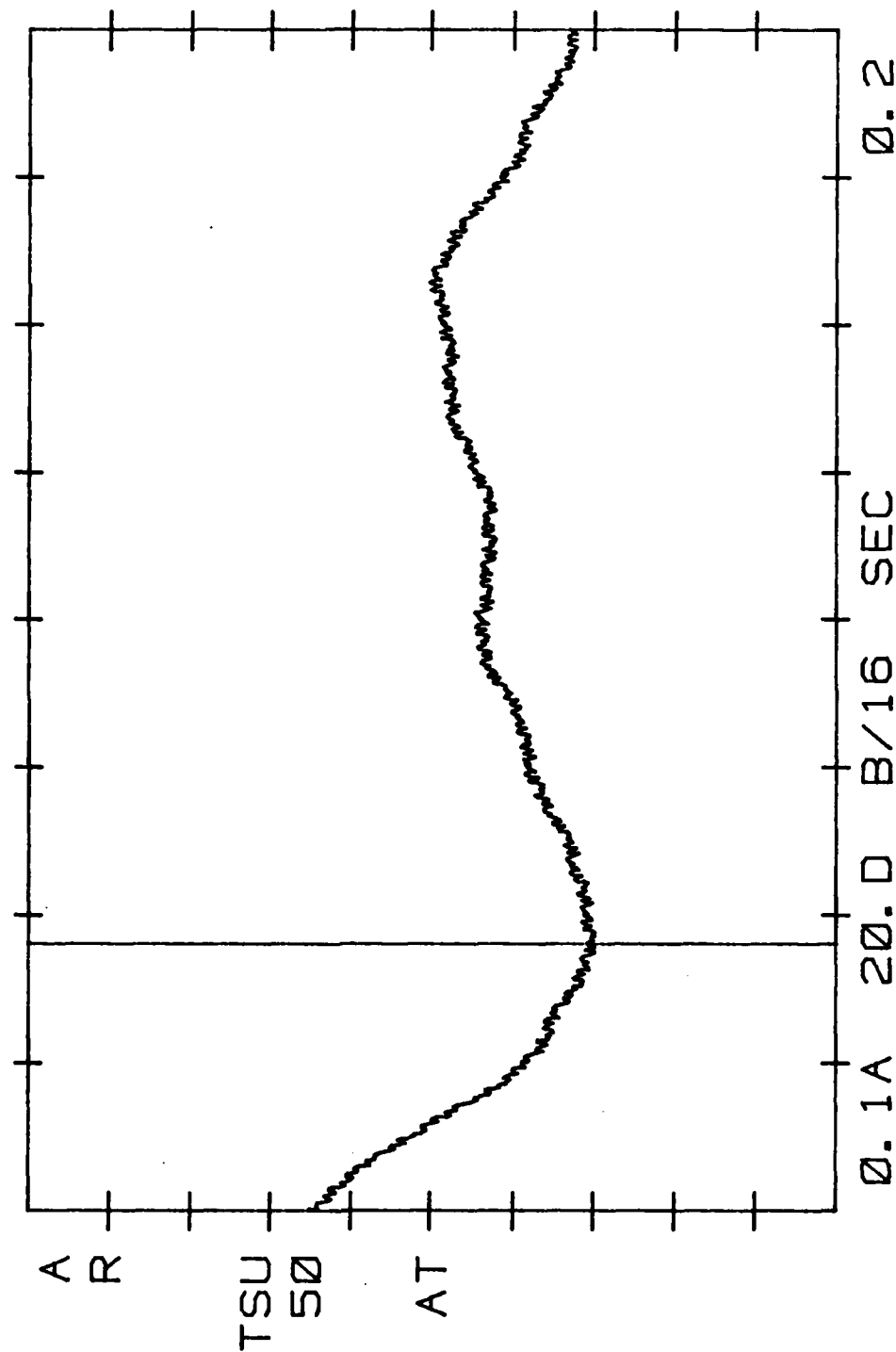
In the case of the human auditory evoked response data, we see that both the electroencephalographic auditory evoked response and the magnetoencephalographic auditory evoked response have peaks at latencies of approximately 50 milliseconds and 180 milliseconds.

For the cat versus the beagle case, we first see that the cat has a negative going waveform during the first 20 milliseconds of its response. As expected, the beagles waveform is going negative out to 40 milliseconds.

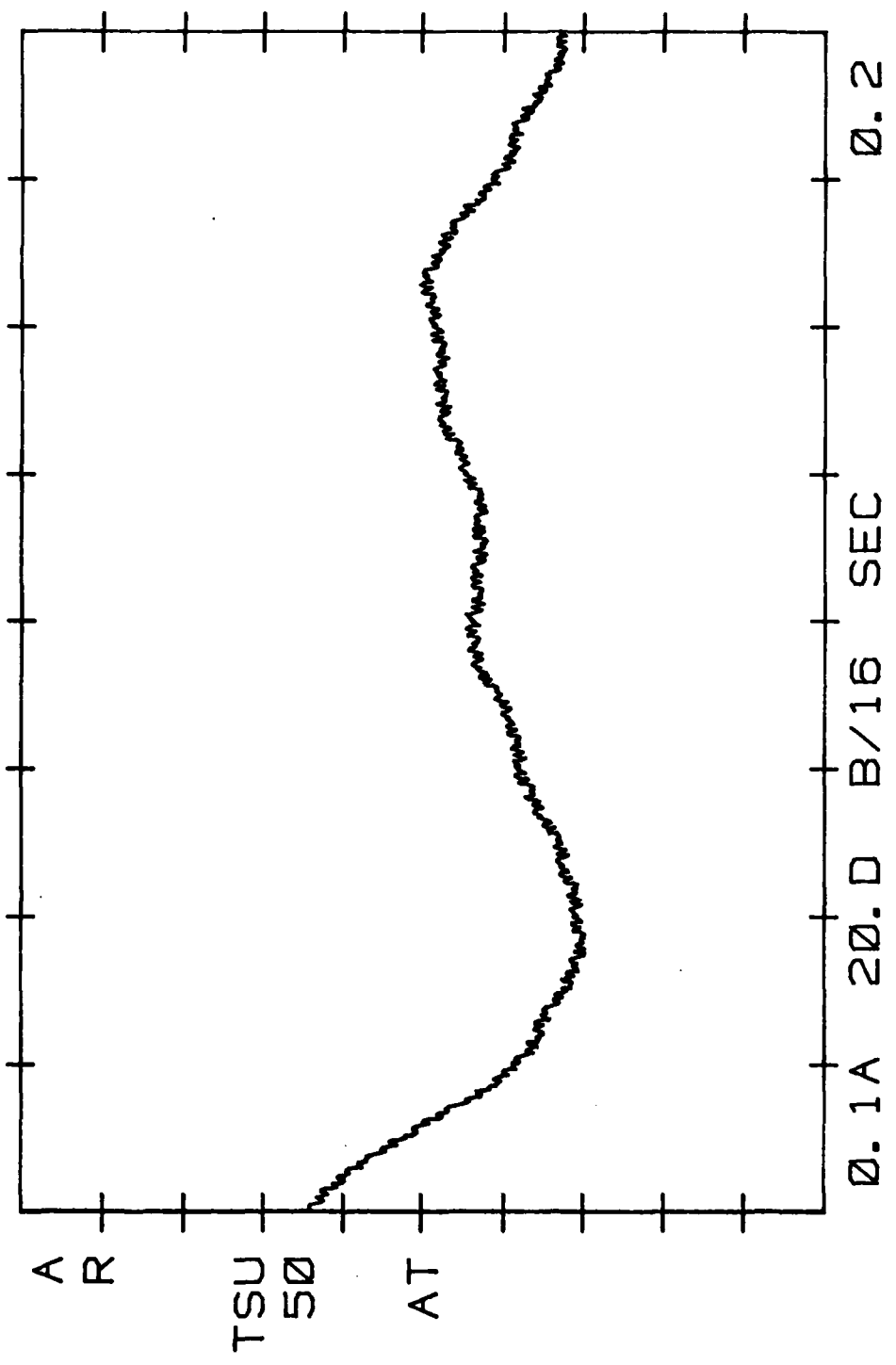
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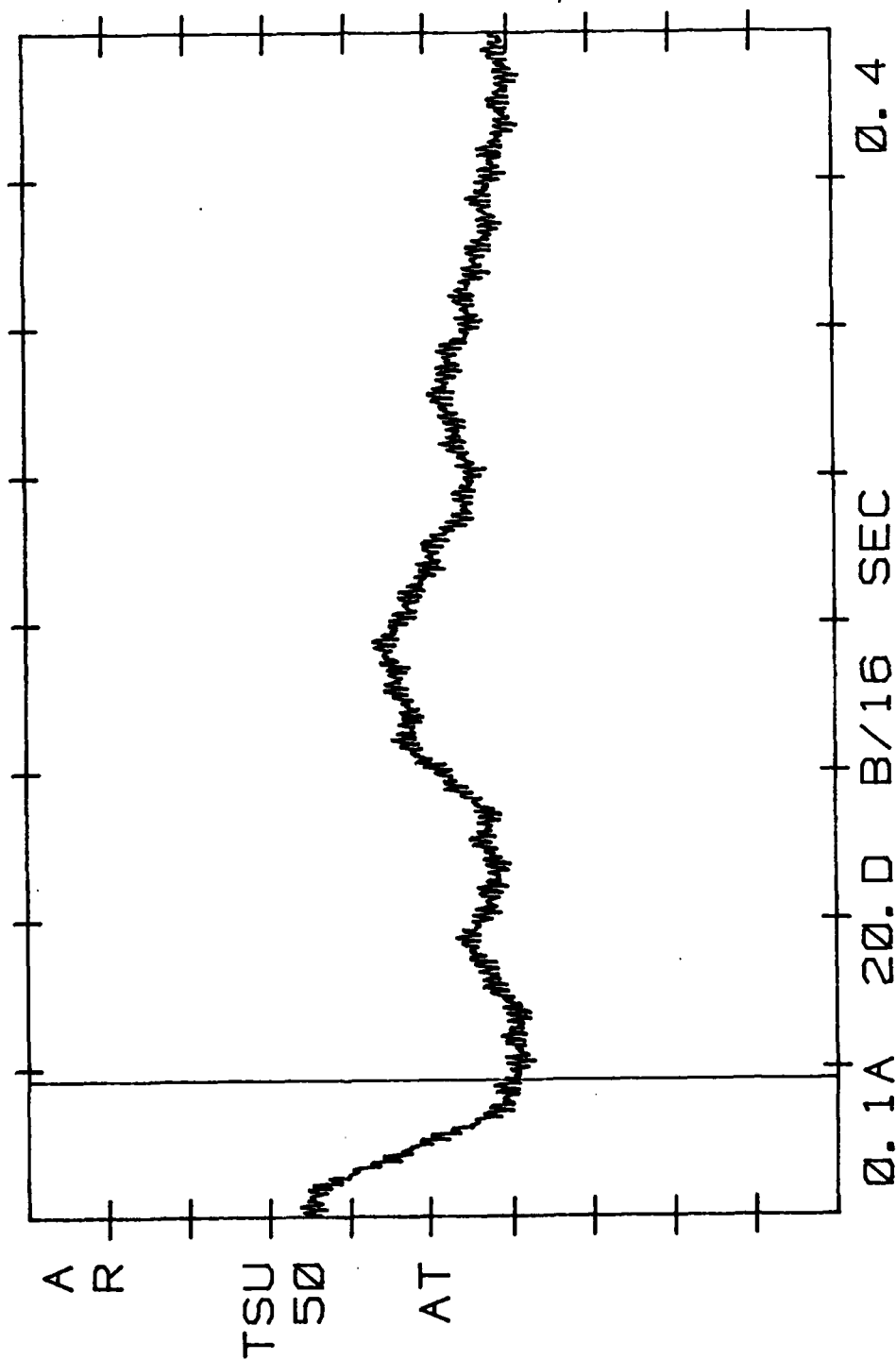
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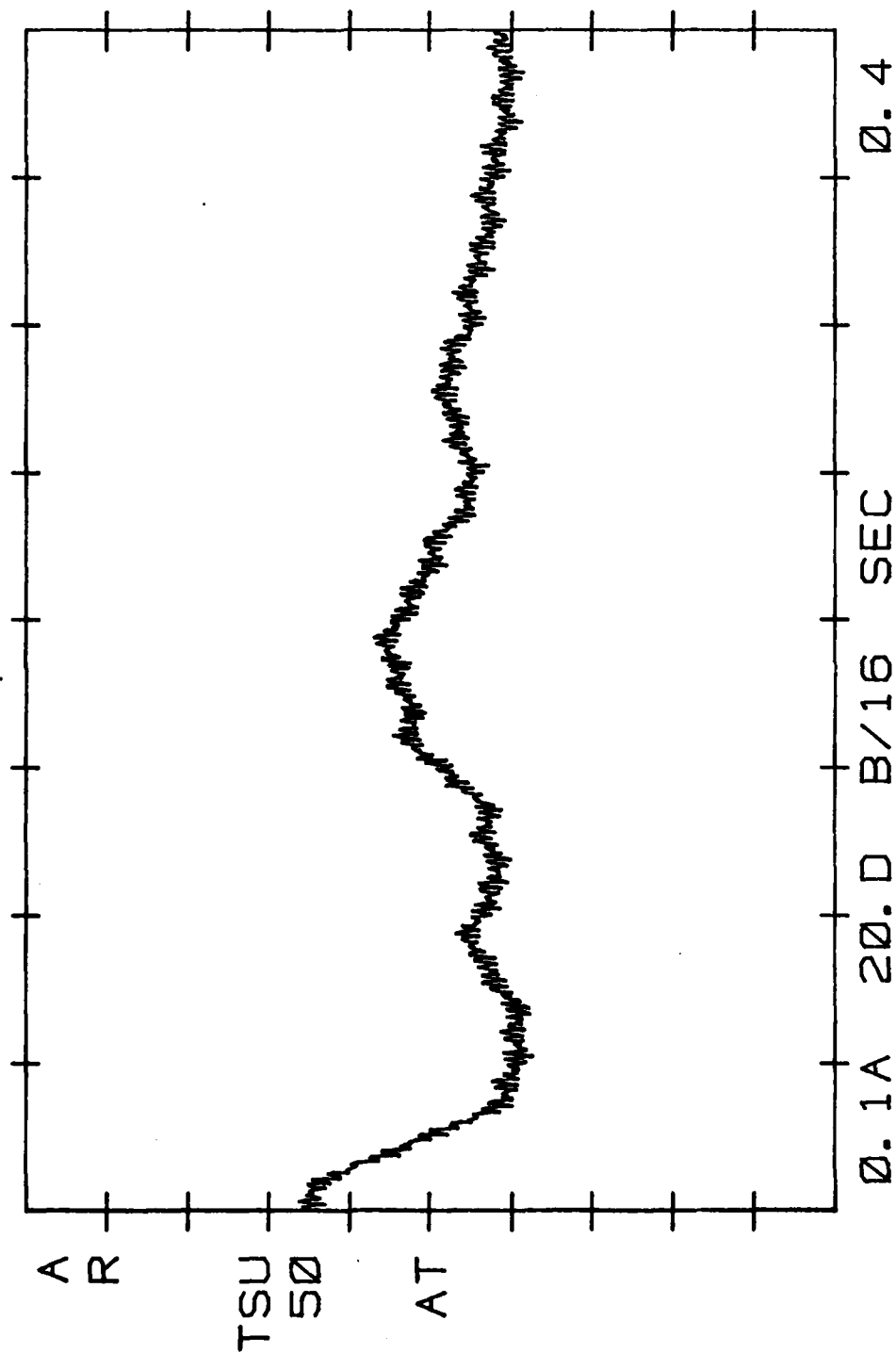
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 100CPS AND NOTCH F 1k TERS 1.81-03 V VLN
 20-OCT-83 AUDIO 2k T
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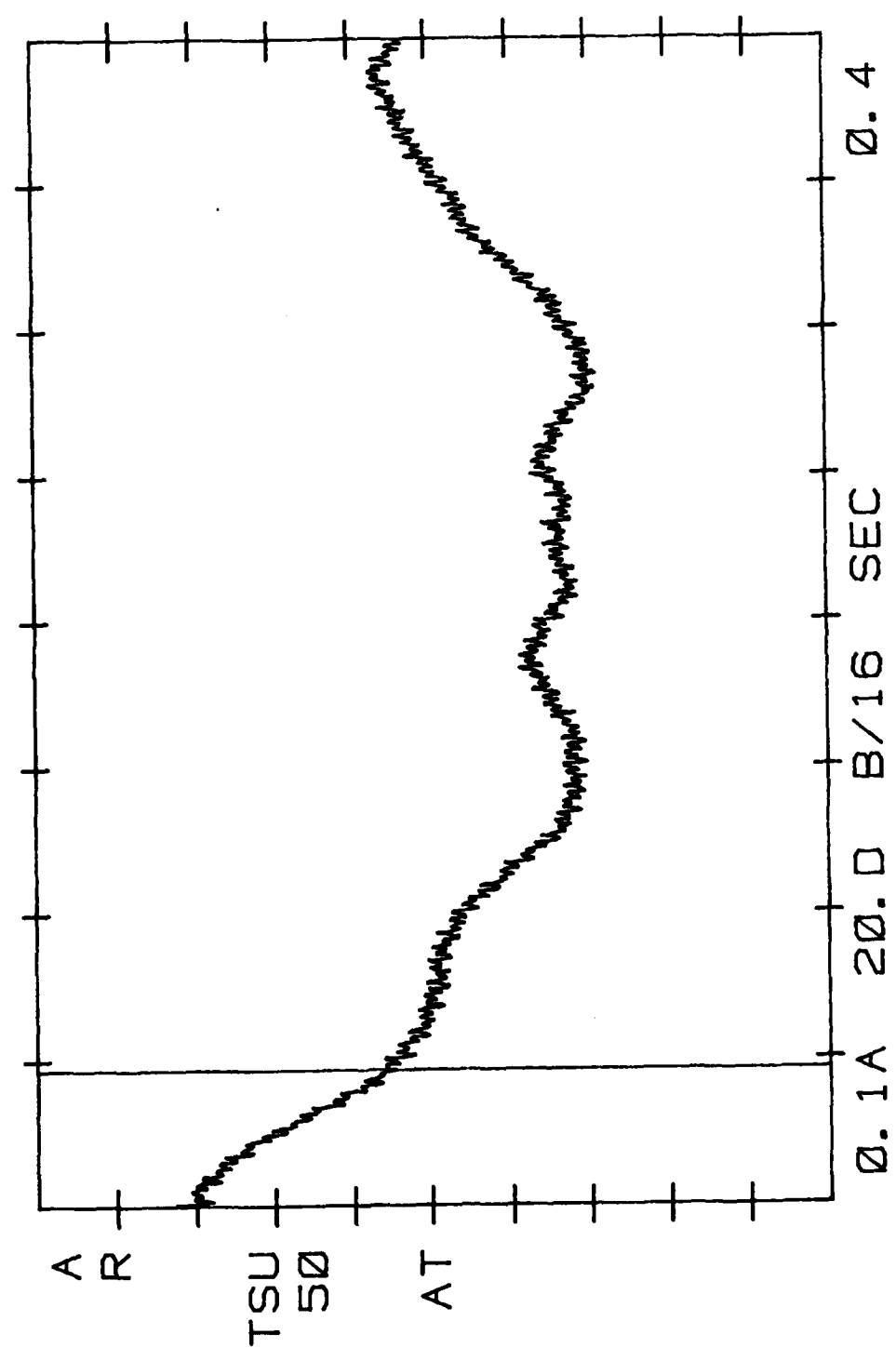
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 20-OCT-83 AUDIO 2k T
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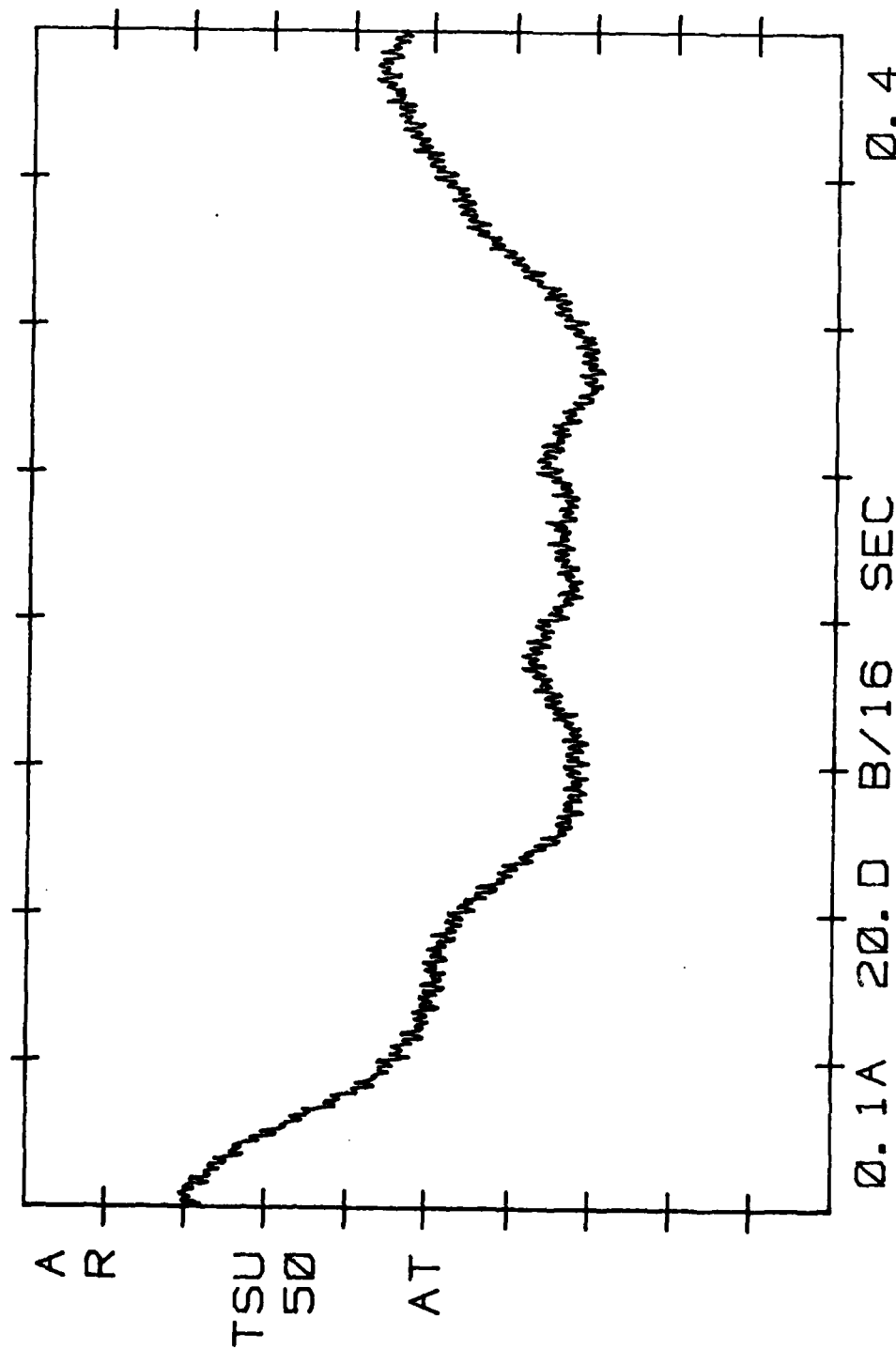
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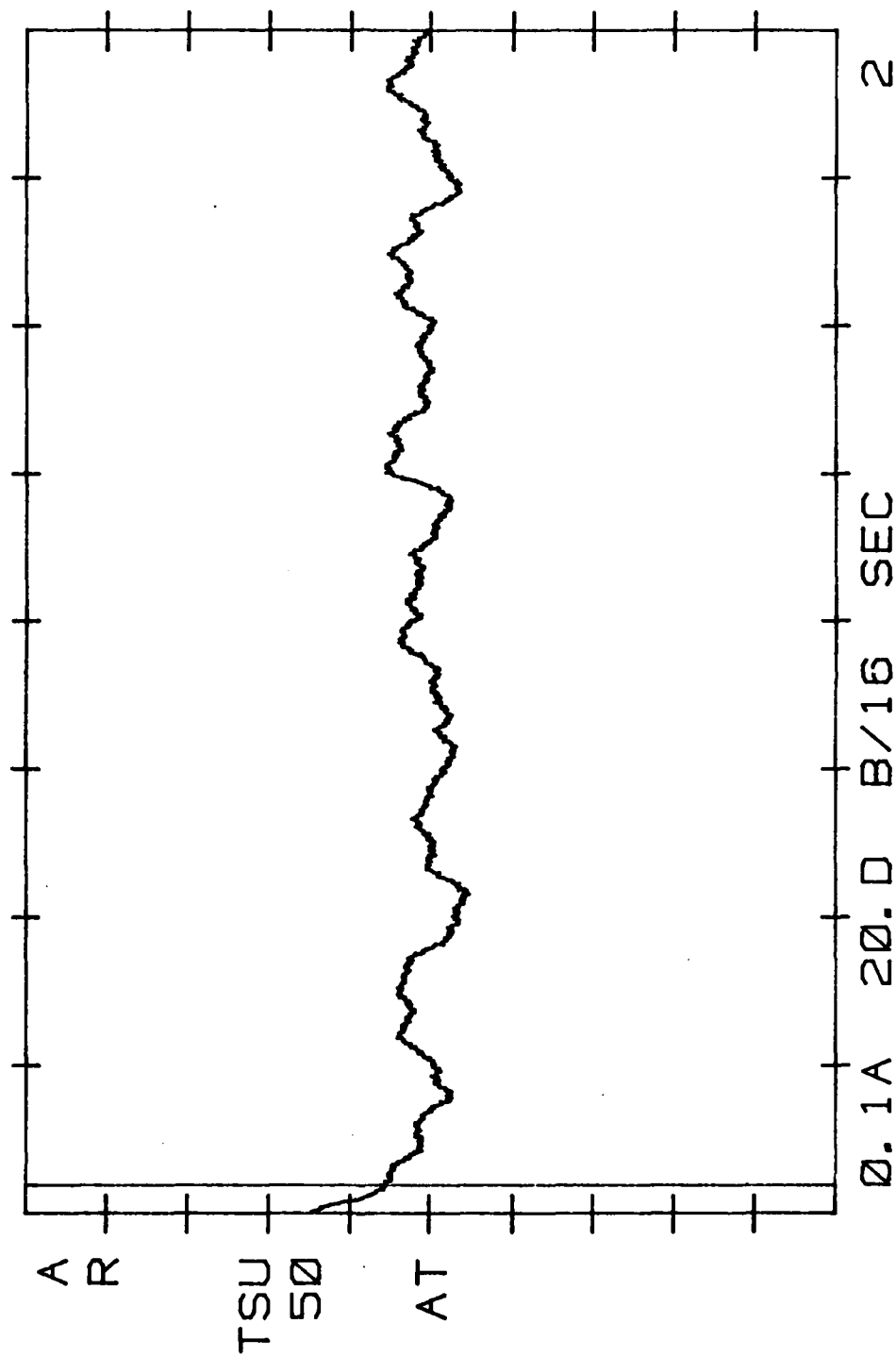
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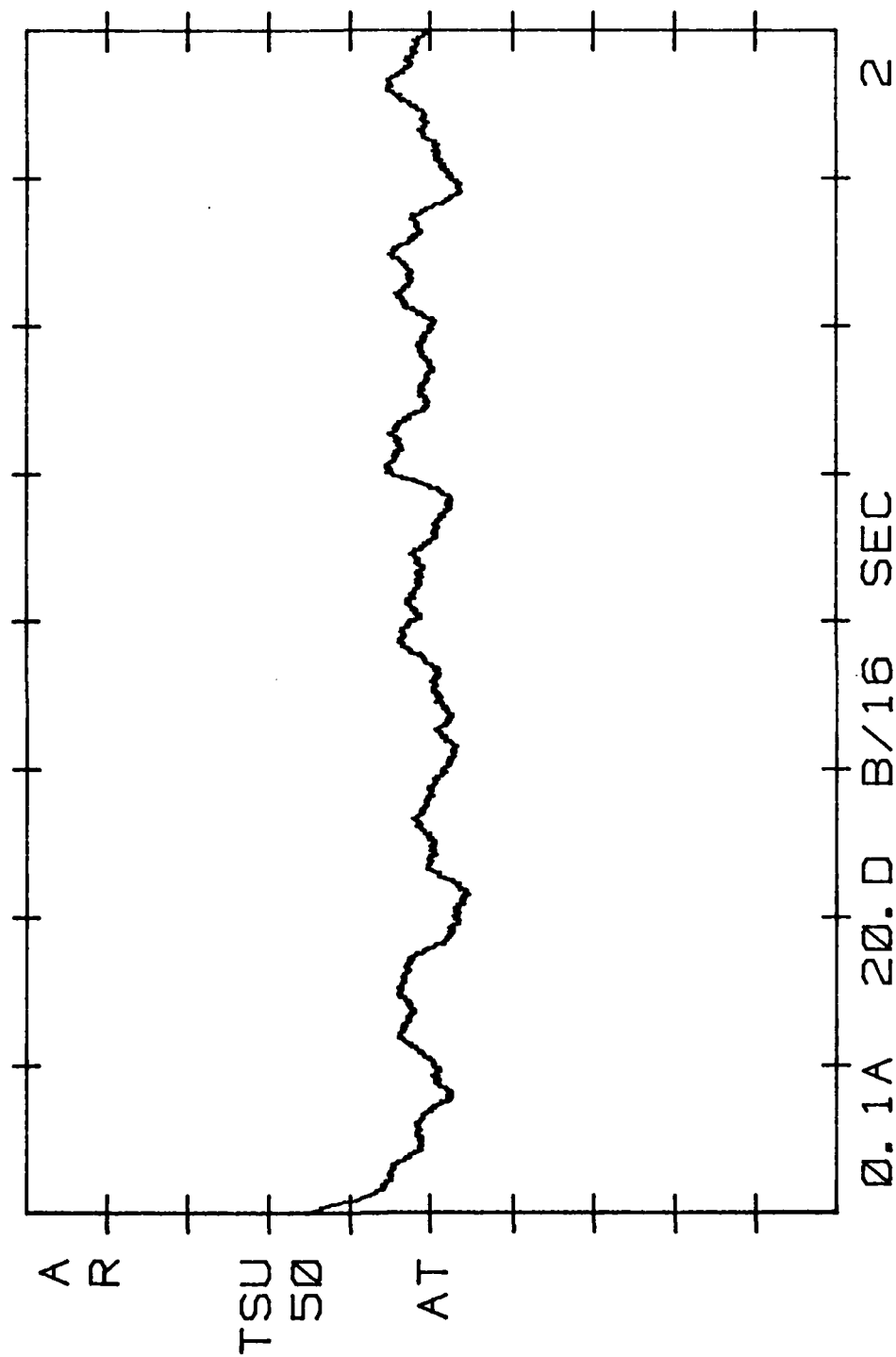
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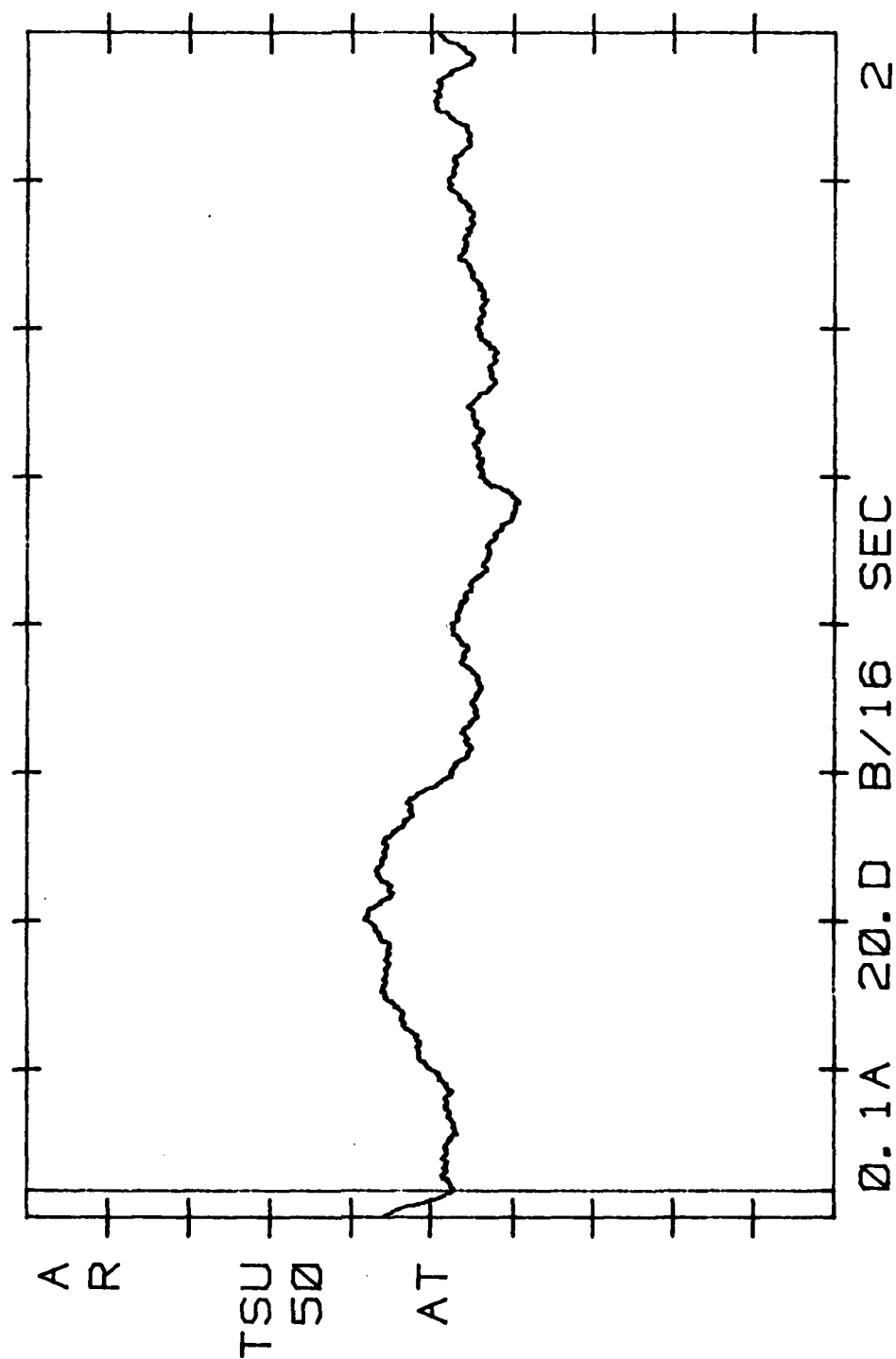
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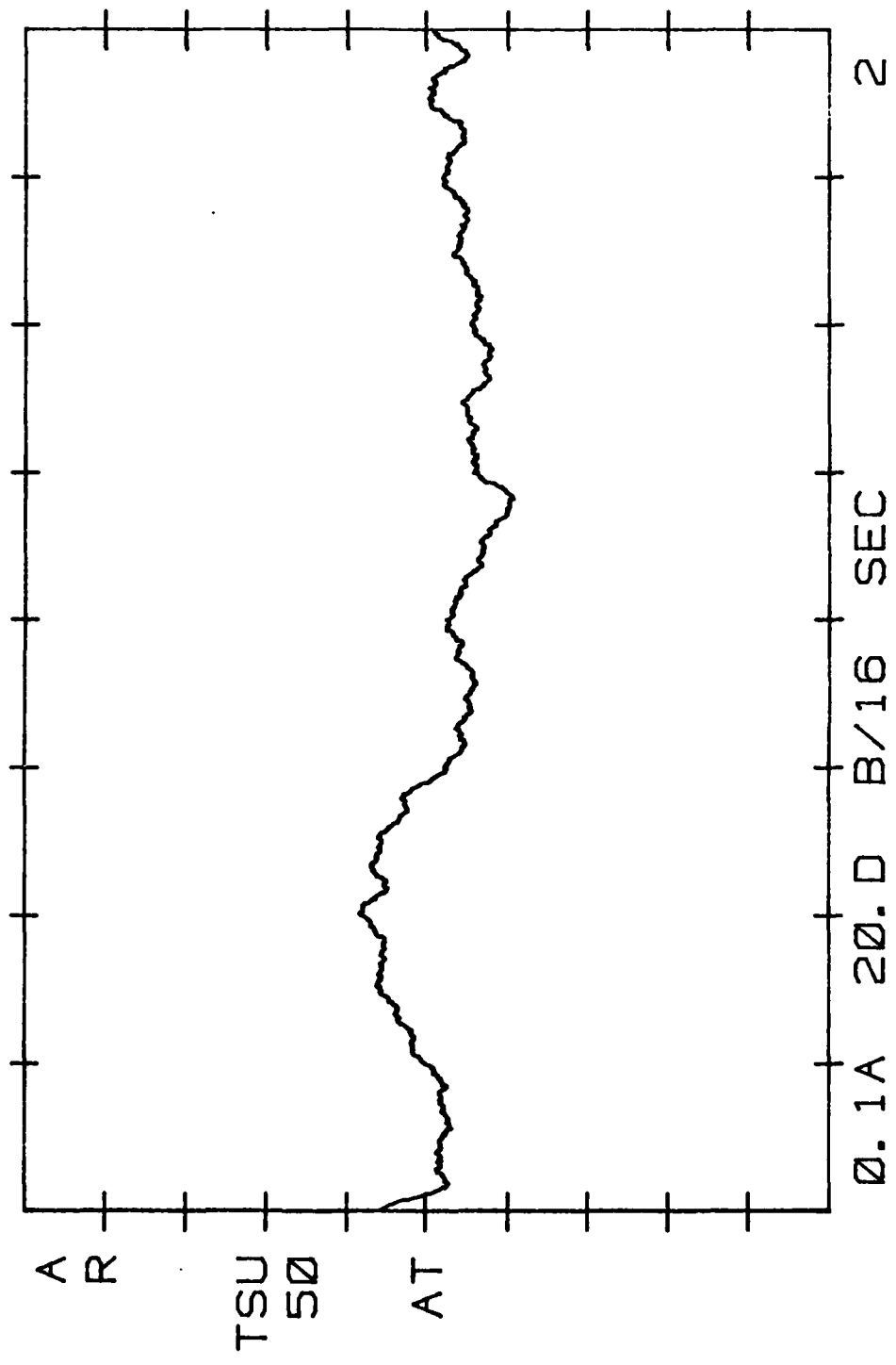
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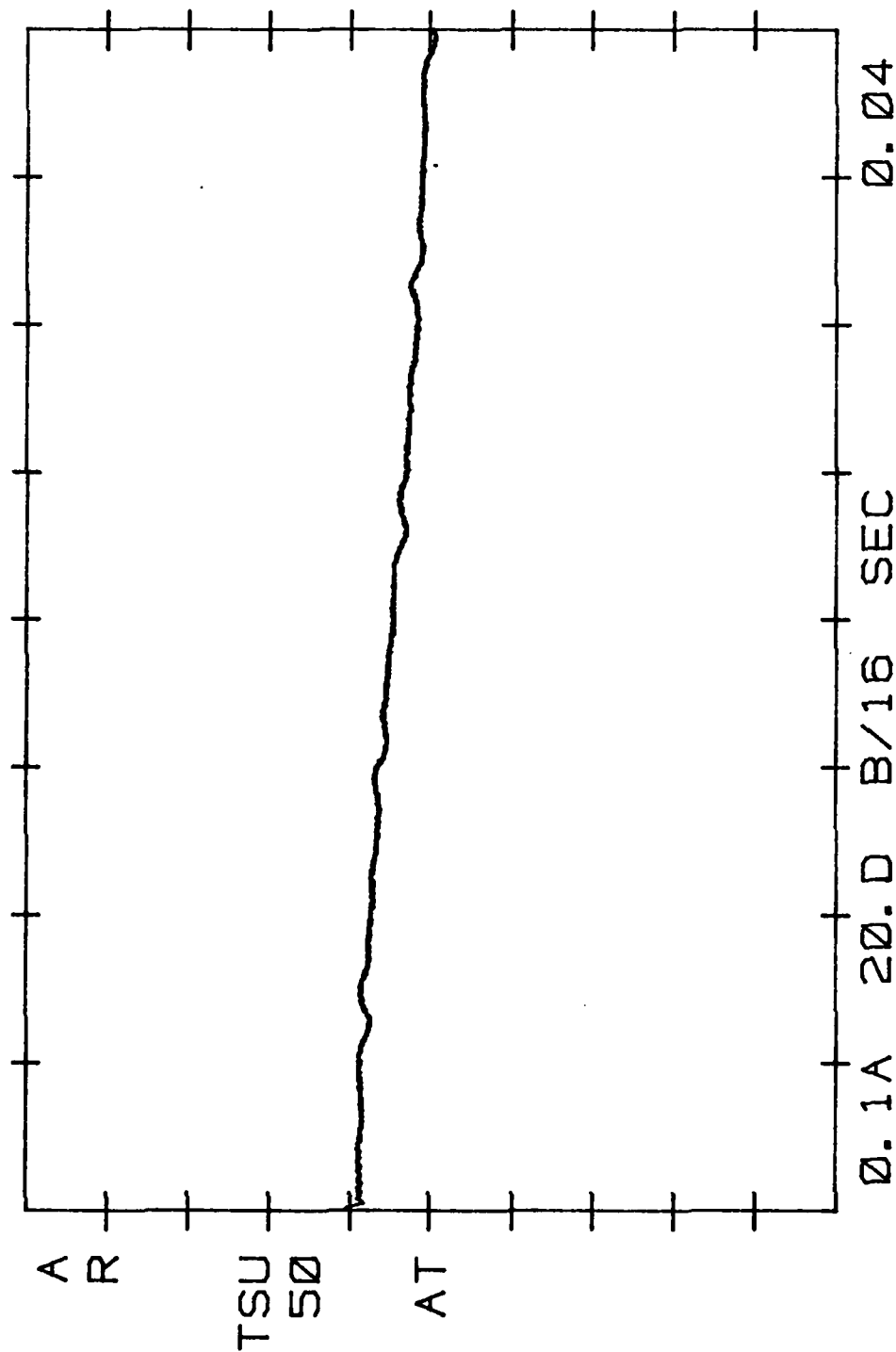
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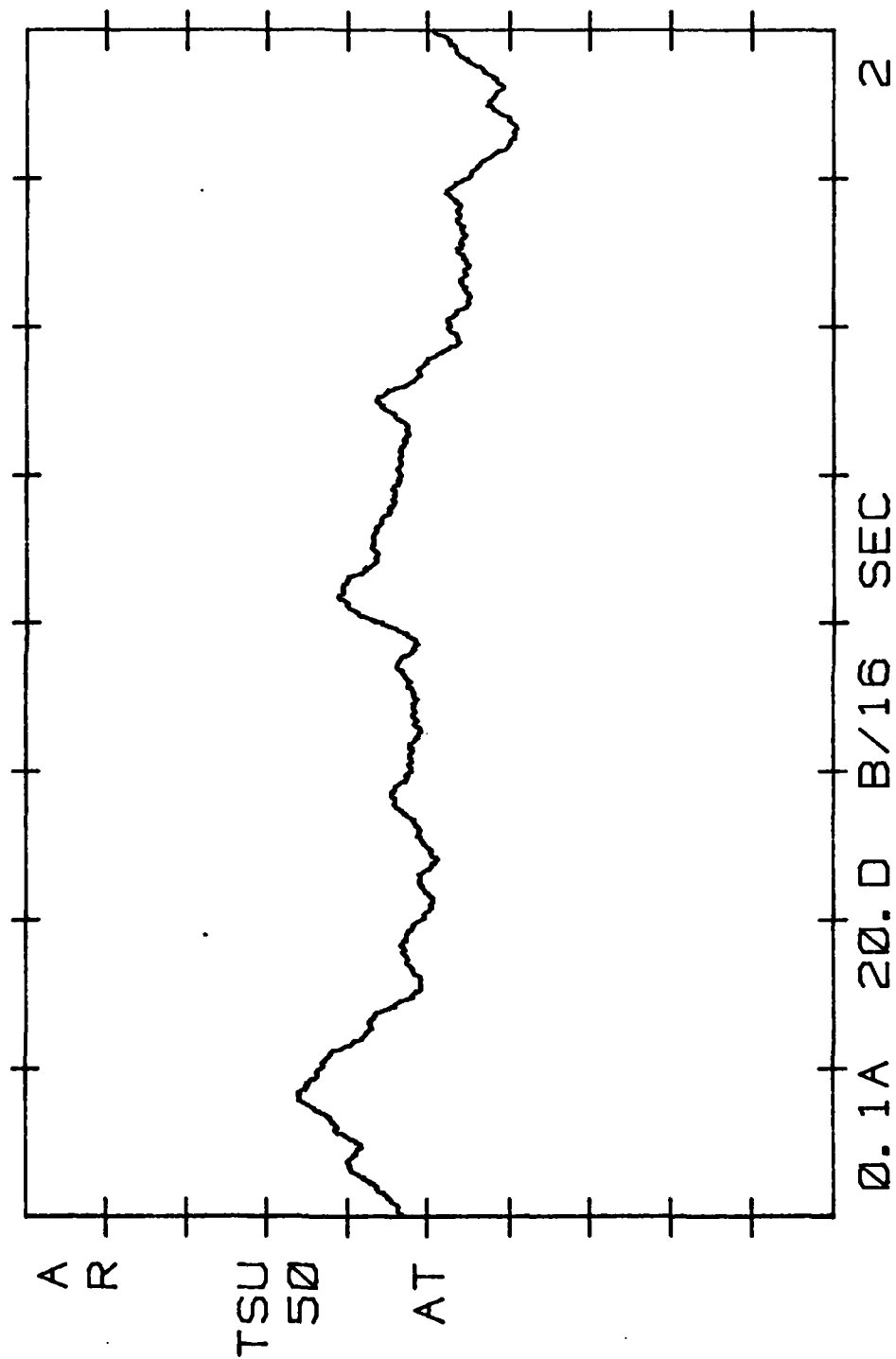
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 10 CPS AND NOTCH FILTERS 1.60-03 VLN
 20-OCT-83 AUDIO 2k T
 0.00000 SEC



VITA

Robert D. Murray was born the son of Meredith N. and Emma F. Murray on 7 June 1952 in Elyria, Ohio. He graduated from West High School in Cleveland, Ohio in 1970. After one year at Hope College in Holland, Michigan, he entered the United States Air Force. He worked as a Computer Repairman in the Combat Headquarters of NORAD in Colorado Springs, Colorado until his selection for the Airmen's Educational and Commissioning Program in 1973. He received the degree Bachelor of Science in Electrical Engineering from the University of Arizona, Tucson, Arizona in 1975. After receiving his commission from Officer Training School in April 1976, he went to Navigator School where he earned his navigator's wings in January of 1977. From Navigator School he went to Navigator Bombardier Training (NBT), still at Sacramento, California. After NBT, he went to F-4 RTU at MacDill AFB, Florida. In the next four years, he flew as a Weapons Systems Officer in F-4D and E models at Eglin AFB, Florida, Osan AB, Korea, Nellis AFB, Nevada, and Seymour-Johnson AFB, North Carolina. At Osan AB and Nellis AFB, he was Squadron Plans Officer. At Seymour-Johnson AFB, he was Assistant Chief of Squadron Computer Operations, Assistant Chief of Squadron Standardization and Evaluation Shop, and Chief of Squadron Training for the Digital Modular Avionics System (DMAS). He entered the School of Engineering, Air Force Institute of Technology in June 1982.

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The acquisition of a Superconducting Quantum Interference Device (SQUID) gradiometer by the Air Force Aerospace Medical Research Laboratory, along with the previous research conducted at the Air Force Institute of Technology which led to the first cortical implant of a multiplexed multi-electrode semiconductor brain electrode, motivated the use of the SQUID second-order gradiometer to measure visual evoked responses (VER) from humans, and from the canine which had previously had the AFIT brain electrode implanted and removed. Some discussion of the current dipole model for the fields measured from the brain is presented. The human visual evoked responses picked up by gradiometer were compared to previous human electroencephalograph visual evoked responses, and were found to have similar latencies. The canine visual evoked responses which were measured by the gradiometer had similar initial waveform and latencies, but then dampen out more rapidly than the waveforms measured by the AFIT brain chip. Conclusions about the use of a SQUID gradiometer in measuring visual evoked responses, along with comparisons between the EEG and AFIT brain chip data versus the SQUID data is discussed. Recommendations for further research with the SQUID gradiometer by itself, and in conjunction with the AFIT brain chip are discussed.

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