THE USE OF GEOPHYSICAL METHODS FOR SHALLOW PETROLEUM EXPLORATION IN SOUTHEAST KANSAS

By

Russell Roundtree

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Golden, Colorado
Date April 25th, 1983

Signed: Russell Roundtree
Russell Roundtree

Approved:
Charles H. Stoyer
Thesis Advisor

Golden, Colorado
Date April 25, 1983

George V. Keller
George V. Keller
Head of Department

ABSTRACT

Geophysical methods were employed for the search of petroleum in Woodson County, southeast Kansas, during the summer and fall of 1981. Methods selected were Radiometrics, Magnetics, and Electromagnetics because of their potential benefit and relatively low cost.

The Cherokee Group of the Pennsylvanian System is the zone of interest. Three sandstone zones, the "Squirrel", "Cattleman", and "Bartlesville", are very near shore deposits similar to the east coast of North America. The radiometric survey produced highly radioactive anomalies over known production and over one other undrilled portion of the prospect. The anomalies were not characteristic of those reported in the literature over known petroleum deposits. The Magnetic survey had good results producing a magnetic high coincident with the radiometric anomaly due to expected magnetite in the sandstone bodies. The Electromagnetic survey also yielded anomalies coincident with known production and with the undrilled area where the Radiometric and Magnetic anomalies were. An Induced Polarization response was expected but not observed. However, the data was noisy and not run in a conventional survey array.

It is recommended that Magnetic, Radiometric, and Electrical surveys be run over oil prospects in southeast

Kansas when the target is a Pennsylvanian sandstone deposit or a structural high in Mississippian aged rocks.

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CHAPTER 1

INTRODUCTION

Geophysical methods are very important in the search for petroleum. Every year new developments come about that make deeper, smaller targets resolvable. There is, however, an entire segment of the oil exploration business that does not employ geophysical methods. Shallow oil deposits with production of less than twenty barrels per day are examples of deposits that are typically explored for solely by drilling.

During the summer and fall of 1981, geophysical fieldwork was conducted in southeast Kansas to help find economic quantities of petroleum. Typical production from wells in the area is less than ten barrels of oil per day. Depth to the productive zone is 1400 to 1600 feet. The only geophysical methods commonly employed are downhole radiometric logs.

Reasons for choosing the area for exploration were: 1) its known oil bearing potential, 2) rigorous physical and economic constraints demanding an unconventional geophysical approach, 3) the opportunity to use geophysical methods not commonly used in oil exploration, as well as the opportunity to integrate these methods, and 4) most importantly, the company by which I was employed, Hasz Energy in Denver, Colorado,had several leases in the area.

Four geophysical methods were chosen based on reported successes of the methods in finding indicators associated with petroleum while staying within the economic constraints posed by the size of deposits found in eastern Kansas. A Radiometric survey was run due to its reported success at finding radioactive "halos" surrounding oil accumulations. The anomalies found in southeast Kansas were different from those reported in the literature. A magnetic survey yielded an anomaly interpreted as a Pennsylvanian sand channel. A Transient Electromagnetic survey was run to determine lateral changes in resistivity at depth. Resistivity anomalies found coincide well with known oil production. Finally, an Induced Polarization survey was run because of recent reports of chargeability contrasts over oil pools. The results from east Kansas yielded no such contrast. All four methods selected to help find oil accumulations stayed within the budget constraints and all but one method yielded positive results.

Equipment was provided by the Colorado School of Mines Geophysics Department under the specific leadership of Dr. Charles H. Stoyer. Hasz Energy provided the use of a scintillometer as well as salary support for field personnel.

The petroleum targets were stratigraphic sand channel and bar deposits of the Cherokee Group in the Pennsylvanian system. Several positive geophysical indicators were obtained, but the recent downturn in petroleum prices and demand have precluded drilling in the location of the geophysical anomalies.

A look at previous work in similar areas using similar methods is covered, then a brief review of the geology and selection of geophysical methods to be used. Finally, detailed coverage of fieldwork and interpretation of data is presented.

PREVIOUS WORK

Geophysical methods are not commonly used in southeast Kansas except for radioactive downhole logs. Some reflection seismic work has been done, with limited success, but southeast Kansas does not have reservoirs with enough oil production to warrant the cost of seismic methods. Some exploration companies have run "electrical reflection" surveys and radiometric surveys, but the results are unpublished.

At times there has been great interest in radiometric oil exploration methods. At other times, such as the present, interest has waned. During the 1950's much was published about the radiometric method, anomalies over oil accumulations, and mechanisms to generate the anomalies. Several, but certainly not all of these workers are listed in the General References section. There is still no agreement on how to emplace radioactive elements near the surface. Research is still needed to make the interpretation of radiometric data more quantitative.

Magnetic surveys are common in oil exploration, but usually for basement control of structures. This is also true in Kansas, but the author found no published indications regarding magnetics to detect primary magnetite associated with Pennsylvanian sand bars in southeast

Kansas. Several articles have been published regarding magnetic anomalies associated with petroleum emplacement. These anomalies depend on chemical alteration above the oil pool. The alteration can produce deposits of magnetite and sulphides.

In the late 1960's a considerable amount of work was published on using galvanic electrical surveys to find oil. Recently electromagnetic methods have become popular. Induced Polarization and Complex Resistivity measurements have also been used with some success to find oil. Galvanic surveys have been run in eastern Kansas but mostly to find large scale structures near the Nemaha Ridge. No published reference was found for the use of transient electromagnetic or induced polarization surveys in search of petroleum in east Kansas. Several references for electrical methods to find oil deposits in sedimentary rocks are listed in the General References section.

Although most of the methods in this thesis are not new, it is hoped that integrating these methods will produce an exploration system that will allow greater insight than any single method and that will remain economical for use in southeast Kansas petroleum deposits.

BACKGROUND INFORMATION

Field work was done on the Tipton lease, which covers one square mile. The rectangular lease is one half mile wide by two miles long, comprising the south half of sections 21 and 22, Township 25 South, Range 14 East, Woodson County, Kansas (see Figures 1 and 2). The prospect lies in the Batesville oil field about five miles west of Yates Center, Kansas. The field work was based out of Yates Center. On the prospect, the producing zone is about 1500 feet deep. The field work started in mid-June and lasted through August; however, two other prospects were also surveyed, so the data presented here took approximately one month to acquire with a three man crew.

GEOLOGY

Kansas lies on the southern extension of the Canadian Shield. The geology is common to stable craton type deposits with cyclic "layer-cake" geology and very subtle structures, with regional dip never exceeding ten degrees. Geologic units are moderately thin due to the presence of the stable craton during deposition. As Figure 3 shows, the area of interest is the Cherokee Basin, particularly

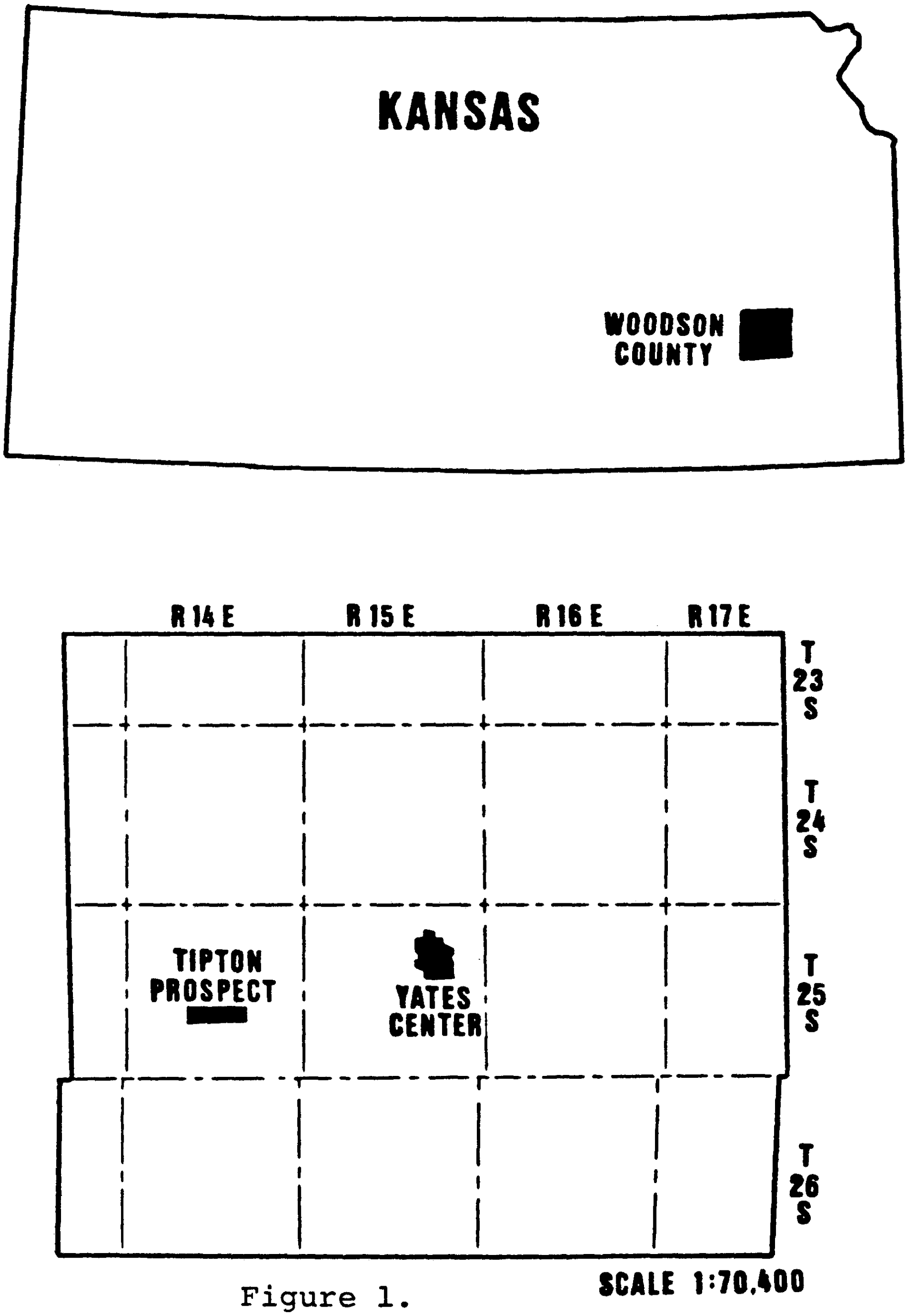

Figure 1.

Tipton lease location map

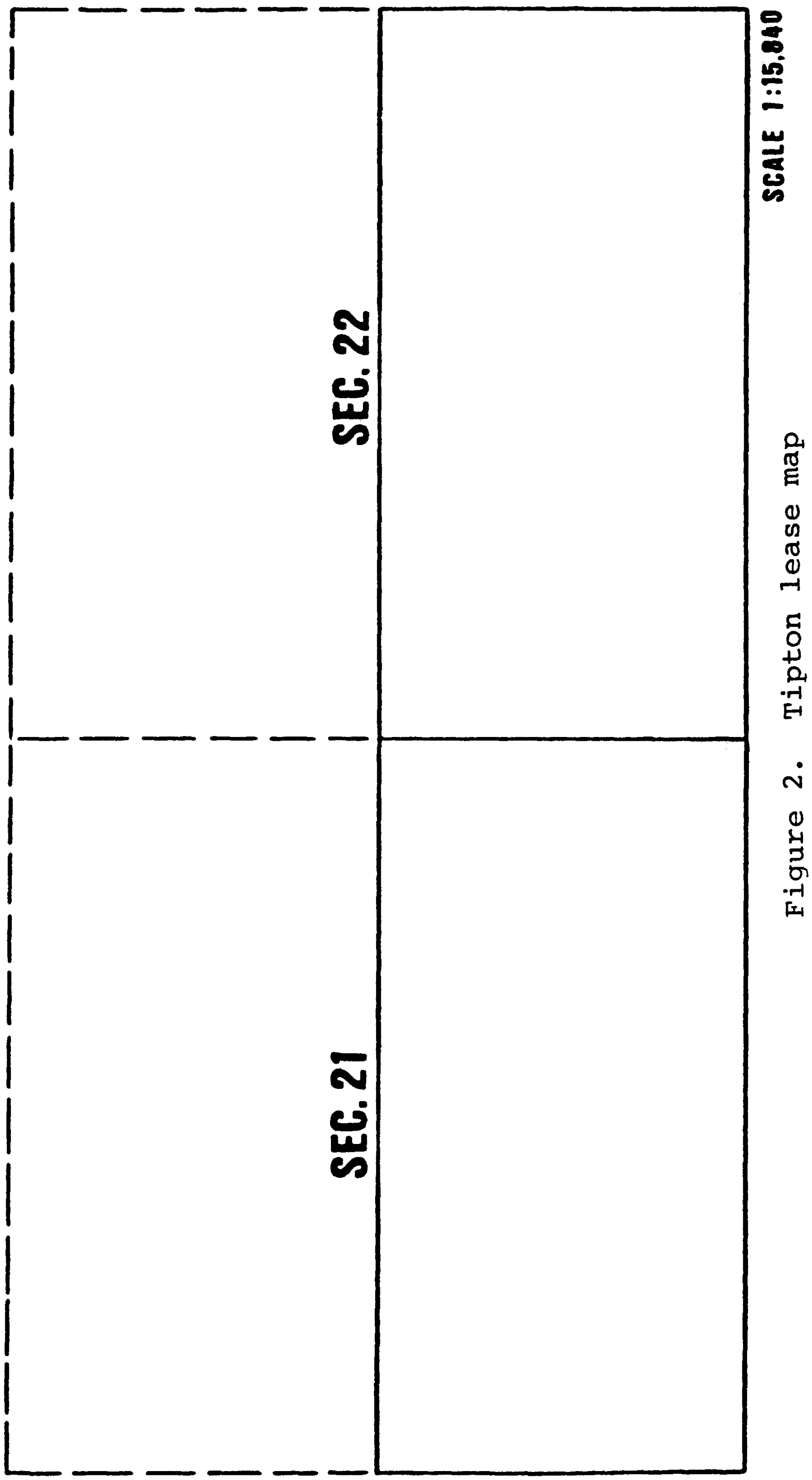

Figure 2. Tipton lease map
Lease enclosed by
solid line

Woodson and Greenwood counties. The Cherokee basin is bounded on the west by the Nemaha Anticline, a major structural feature, and by a more subtle feature to the north, the Bourbon Arch, which separates the Forest City Basin from the Cherokee Basin. While integrating geologic concepts for the area, I found the following quotation from Merriam (1963) interesting and sometimes helpful:

> Although exploration and exploitation have been conducted in eastern Kansas for almost a century, and thousands of tests have been drilled, surprisingly little information is available. Moreover, what is available is generally incomplete, inaccurate, or unreliable.

The hydrocarbon bearing rocks of interest are Pennsylvanian or older. The Permian and Pennsylvanian systems are very similar in Kansas, with slightly more clastics in the Pennsylvanian. Both systems exibit very near shore cyclic sedimentation, as shown by repetition of lithologies with intermittent coal beds. The mississippian system is domiinantly limestone, and corresponds to enclosed or restricted basin type deposition.

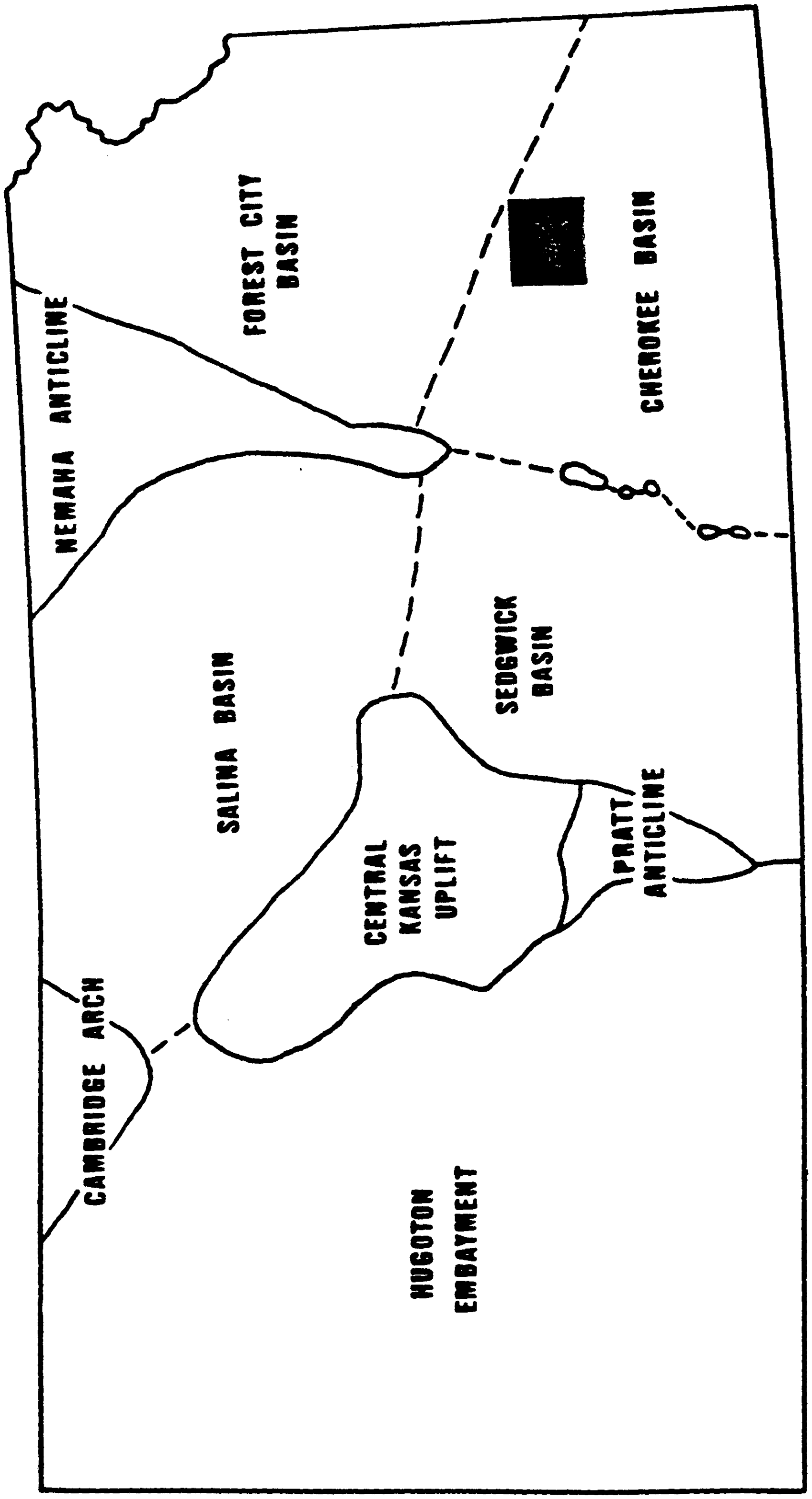

Figure 3.
Paleotectonic map of Kansas - from Merriam, 1963

STRUCTURAL HISTORY

Although several unconformities are present in Kansas, the structural history is quite simple. Any structural movements prior to Mississippian time are not very relevant for petroleum exploration. During Mississippian time the area was a downwarped restricted basin. At the end of the Mississippian system a major uplift took place in central Kansas. The unconformity at the base of the Pennsylvanian is widespread into all states adjoining Kansas.

Pre-Mississippian structural events are difficult to discern due to major tectonic activity at the end of Mississippian time. Evidence for dating this structural event is a change of lithology from a marine environment limestone to a near shore clastic deposit. Detritus came from the Nemaha uplift on the northwest side of the basin. Pennsylvanian sediments lie nonconformably on Precambrian basement over the Nemaha anticline. Minor changes in sea level during the Pennsyvanian and Permian caused the cyclic depositional patterns common to the two systems. These deposits are similar to the present day eastern coast of North America.

Most of the oil production comes from near shore sand bars created by erosion of the uplift to the northwest. The northeast trending deposits are generally parallel to the paleoshoreline and are broad, gentle sand bar deposits of low relief. The northeast trending deposits are thought to be interbar channels characterized by narrow, erratic deposits called "Shoestring Sands". Evidence suggests a link between thickening and thinning in Mississippian rocks and the location of these channel sand deposits. However, a better correlation occurs between the high percentage carbonate regions of the underlying Mississippian rocks and the location of the Pennsylvanian sand deposits (Merriam, 1963). No major structural deformation is present across the prospect. For geophysical purposes, the earth can be treated as flat lying layers with stratigraphic changes within layers.

STRATIGRAPHY

A major stratigraphic break occurs in east Kansas at the base of the Pennsylvanian system. This is due to a change in the depositional environment after the uplift in central Kansas. Pre-Pennsylvanian rocks are thick carbonate and very fine grained clastic deposits common to offshore deposition. After the uplift at the end of the Mississippian system, the depositional environment changed to very

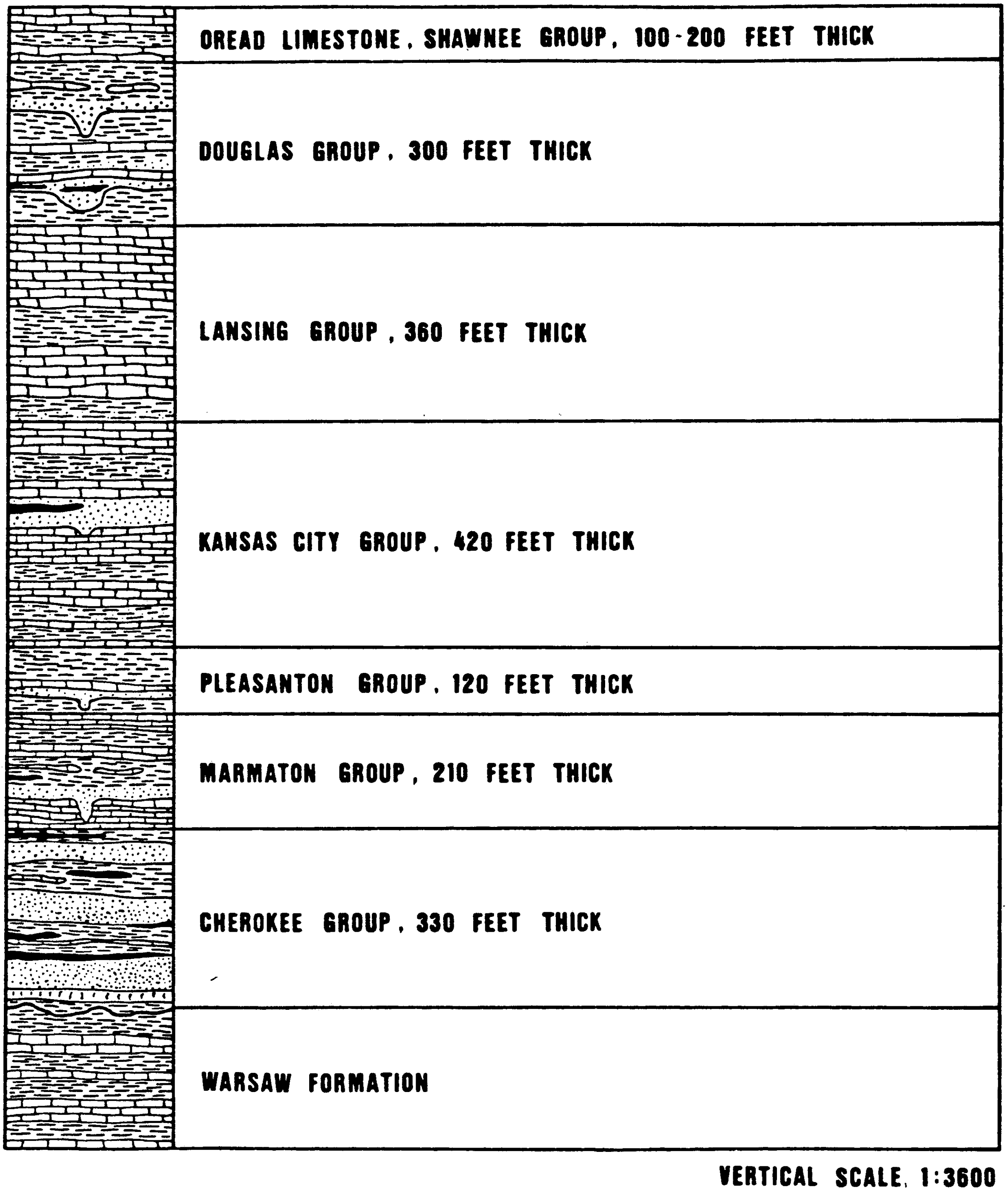

Figure 4. Stratigraphic section

near shore deposition. Hence, the Pennsylvaian system is characterized by numerous thin beds of alternating lithologies. This type of deposition is called cyclic, due to the repetitious nature of lithologies and because the numerous thin beds are caused by slight changes in sea level.

Outcropping rocks in southeast Kansas are Pennsylvanian, except for the extreme southeast corner of the state, which is Mississippian.

The geologic section presented here (see Figure 4) is covered in a cursory manner, with subdivisions of systems only to the group level. Due to the cyclic nature of sedimentation in the Pennsylvanian, many members are present in each group, but the name of these members will not be included here. The seven groups present from the outcrop down to the petroleum bearing zone are: the Shawnee, Douglas, Lansing, Kansas City, Pleasanton, Marmaton, and Cherokee Groups. The thicknesses of the groups are all derived from logs and from the literature (Jewett, 1954).

At the prospect area, the outcropping unit is the Oread limestone at the base of the Shawnee Group. The Oread limestone unit consists of four limestone members alternating with three shale members. Thickness of the remaining Oread limestone is 100 to 200 feet across the prospect due to topography. At the base of the Oread limestone of the Shawnee Group lies the Douglas Group with familiar cyclic layers consisting of three sandstones, three shales, and four limestones. The Douglas Group is about 300 feet thick. Below the douglas group is the Lansing Group, with five limestone and four shale members. The Lansing Group is about 360 feet thick. Underlying the Lansing Group is the Kansas City Group which consists of fifteen limestones, fourteen shales, and three sandstone members. The Kansas City Group is about 420 feet thick. Below the Kansas City is the Pleasanton Group which is a shale unit with a thin limestone member in the middle and a sandstone at the base. The Pleasanton is about 120 feet thick. Underlying the Pleasanton Group is the Marmaton Group which has four limestone members and four shale members, and is about 210 feet thick. Below the Marmaton is the Cherokee Group.

The Cherokee Group is the oil bearing zone of interest. It is a very near shore zone, as indicated by the numerous coal beds. Within the Cherokee are four limestone members, a dozen coal beds, and three important sandstone members. These three sandstone members have local usage names of the "Squirrel Sand", the "Cattleman Sand", and the "Bartlesville Sand" from top to bottom. The "Squirrel" and "Cattleman" are broad, gentle features usually less than fifty feet thick. The "Bartlesville" sand is a narrow channel deposit up to one hundred feet thick and is the primary oil producer. All three sandstones are oil bearing, and are the primary target of my work. The Cherokee Group is about 330 feet thick.

Below the Pennsylvaian System is the Mississippian System, which consists of relatively thick limestone, dolomite and shale units of much greater thickness. Structural highs are known to produce hydrocarbons from Mississippian aged rocks. The next oil producers in the section are the Arbuckle and Simpson Groups in the Ordivician System. Few wells have been drilled to or through Mississippian sediments.

GEOPHYSICALLY SIGNIFICANT GEOLOGIC PHENOMENA

Several geologic conditions must be present for different geophysical methods to give a response. Fortunately, different methods are sensitive to different geologic phenomena. This chapter indicates which geologic factors will pose problems and which will give a detectable response to geophysical methods. An understanding of these conditions is necessary prior to data collection and interpretation, so that methods can be optimized.

Present day dip of the rocks in southeast Kansas is a few degrees to the west-northwest. Faults, slumps, and solution features exist in the area, but the size of the structural disturbance is always very small and so for the purpose of geophysics, the geology presents no structural problems and can be treated as a plane layered earth. The cyclic nature of deposition in the upper and middle Pennsylvanian is evident, due to many thin beds of repetitious lithology sequences. This presents a problem of resolving lithologic boundaries by means of a surface geophysical method. The surface layer, being the Oread limestone, has several thin beds with expected high acoustic impedance contrasts, which may present coupling problems for a seismic surface method. Galvanic contact, however, is quite good due to the conductive surface layer.

The prospect, which is one square mile in area, has about one hundred feet of vertical relief. The area has been drilled since the early 1920's, and has many cased drill holes which can cause problems for geophysical surveys. Also, for radiometric surveys, contamination in the form of crude oil spills, artificial fertilizers, and different road surfaces can distort the data with noise.

As a result of these conditions, each method used must be carefully evaluated prior to field work and must be monitored during data acquisition. In the interpretation phase, any anomaly patterns must be cross correlated with things like drill hole locations, roads, topography, cultivated land, power lines, etc. By carefully evaluating geologic and other conditions that affect geophysics, one can remove many spurious results otherwise interpretted as anomalies.

As mentioned above, the known producers in the area are the "Squirrel", "Cattleman", and "Bartlesville" sandstones of the Cherokee Group in the Pennsylvanian System. These sandstones can appear in three different deposits: channel, lense, and sheetlike deposits. All of these are common to near shore or deltaic deposition. In Greenwood and Woodson counties, the "Squirrel" and "Cattleman" usually appear as broad, low-relief lenses, whereas the "Bartlesville" is usually a channel deposit of greater thickness but much smaller area than the other deposits. Most of the economic production in the area comes from the "Bartlesville", although hydrocarbons are often found in the two other zones.

These three sandstones have many distinguishing characteristics, some commonplace and others unique. First of all, the sandstones are shale encased, allowing the primary migration of petroleum to take place. All of the porous zones are fluid saturated and permeable. The average size of the sand bodies is ten to fifty feet thick and a few hundred feet to a half mile across. The origin of detritus for the sandstone is the Nemaha uplift to the northwest. Very high magnetite content in the sandstones indicates that the rocks being eroded on the uplift were high in magnetite (Merriam, 1963). Mississippian structures seem to parallel Precambrian basement structures; however, the issue of whether Pennsylvanian sand bar locations are related to Mississippian structures is not settled.

Of the above physical characteristics of sand bodies within the Cherokee Group, the high magnetite content certainly makes a magnetic survey of interest in the search for the sand bodies. Also, the presence of a porous, fluid satuated reservoir makes possible a resistivity anomaly. The change in lithology from shale to sandstone also indicates a possible acoustic impedance contrast. The presence of radioactive elements in most hydrocarbons indicates that a radioactivity survey is warranted to detect the presence of the hydrocarbons. Finally, sand bodies in a flat layered geologic sequence may have a detectable density contrast. The analysis and utility of each of these geophysical methods will be discussed in detail later.

ECONOMICS

The shallow depth and other distinguishing physical properties of the oil bearing rocks would indicate that an exploration program incorporating geophysics would be wise; however, this is historically not true. Only recently have several geophysical methods attained the ability to resolve such subtle targets. Along with increased complexity and sophistication has come increased cost. Economics plays an important role in all oil exploration, but in southeast Kansas the economics severly constrain the geophysical methods used, as well as constraining the field procedures involved in data acquisition. With the exception of down-hole techniques, geophysical methods are not commonly used among oil explorationists in southeast Kansas.

Several factors contribute to the lack of geophysical exploration in southeast Kansas. Low production, shallow drilling depths, small leases, and high wildcat success ratios have deterred the use of geophysics. The wildcat success ratio in southeast Kansas is about one in three (Hasz, personal communication, 1981) without geophysics, which is twice the industry standard using geophysics. The problem in southeast Kansas is that a well producing one hundred barrels of oil per day is quite uncommon and the average well produces about seven barrels per day. The recent downturn in oil prices has rendered many of these marginal "stripper" wells uneconomic. The reason for incorporating geophysics in southeast Kansas exploration is to increase the wildcat ratio to about one in two, but more importantly, to find the higher production areas.

Average drilling costs in the area are about six dollars per foot, so dry hole costs run about ten thousand dollars. Completion costs will add another thirty to forty thousand dollars. If a hole is logged, it is usually limited to radioactive logs. With the high water saturations and very gentle structures encountered there are often problems with water in the wells. Secondary flooding techniques are common in the larger bars and channels. Some tertiary recovery projects have also been undertaken, using everything including fireflood techniques.

FEASIBLE GEOPHYSICAL METHODS

Because of the physical and economic constraints, it was necessary to evaluate the utility and effectiveness of several geophysical methods. Once the promising geophysical methods were selected, a search for available instrumentation was made.

Seismic methods, both reflection and refraction, were unsuitable for use in the survey area for several reasons: 1) the small area to be surveyed renders seismic crew mobilization costs prohibitavely expensive, 2) the dimensions of the sand bodies are virtually at the limit of seismic resolving capabilities, and would require nonroutine field procedures and instrumentation, 3) the many thin layers of alternating limestones and shales would make energy penetration quite difficult. For these reasons, the seismic method was ruled out for use in finding Cherokee sand deposits.

A gravimetric survey was also ruled out because Mississippian and Precambrian structures are not well known and any small perturbation in subsurface structure could totally overwhelm the effect of the sand body.

A magnetic survey was conducted for several reasons: 1) the low cost of survey data, 2) the reported high magnetite content in Pennsylvanian sand deposits, and 3) the reported existence of magnetic anomalies associated with petroleum accumulations (Campbell, 1979). Some special considerations were to have a high spatial sampling rate along profile lines and, in the interpretation of the data, to expect anomalous shapes due to the remanent component associated with sedimentary deposition of magnetite grains.

Electrical methods were determined to be the best. Transient Electrmagnetics was the method with which the most time was spent and possibly from which the most fruitful data were obtained. The method was chosen for several reasons: 1) the equipment was available, 2) the transient method has very good resolving capabilities as well as good random noise rejection via stacking the data, and 3) the flexibility of the system. Its very limited use in oil exploration at the time put the project at the forefront of technology. Problems with the transient method were: high geologic noise associated with very conductive overburden, and poor coherent noise rejection due to the broad band recording system.

Initially Induced Polarization seemed to be the most powerful electrical method for oil exploration. However, after the results of the IP survey were obtained, the data did not contain all the information hoped for. The literahas purported IP anomalies related to hydrocarbon deposits (Snyder, 1981) and I hoped to confirm the responses reported in the literature, but the results were not positive. Problems encountered during data acquisition may have caused the poor results.

A Magnetotelluric survey was not conducted, due to the unavailability of equipment and the poor resolving capabilities for the dimensions of the sand bodies.

A Radiometric survey was conducted over the prospect because of the low survey cost and because of the anomaly patterns associated with hydrocarbon deposits reported in the literature (Sikka, 1962). A spectrographic survey would have been preferable, but the only equipment available was a total count scintillometer, which was used instead. Expected problems with the radiometric survey were the general lack of scientific basis for the existence of empirical anomalies.

To summarize, seismic was prohibitively expensive. Gravity, magnetotellurics, and seismic did not have sufficient resolution for the problem, or simply would not have a perceptable response associated with the Cherokee sandstones. The electrical methods were the mainstream exploration tool, but magnetics and radiometrics were done because of low cost and successes reported in the literature.

CHAPTER 2

FIELD WORK

Field work was done on the Tipton prospect, which encompasses an area of one square mile (see Figure 2). The prospect is the south half of sections 21 and 22, Township 25 South, Range 14 East, Woodson County, Kansas. The prospect lies in the Batesville oil field, which lies on the north edge of the Quincy oil field (Jewett, 1954). The Quincy oil pool is a large Bartlesville shoestring sand deposit. It trends northwest-southeast through Greenwood county into Woodson county. The Batesville oil field is probably an associated deposit with scattered production mainly in the Squirrel and Cattleman zones.

In the 1920's and 1930's the area was drilled for gas with some oil production. Today very few gas caps are found which introduces problems in production due to the reduced reservoir pressures, and also changes the expected resistivity model somewhat. There are two producing wells on the prospect in the south half of the southwest quarter of section 21. Production from these wells is between five and ten barrels of oil per day. There are two injection wells in the north half of the southeast quarter of section 21. Another well was drilled in the fall of 1981 on a geologic

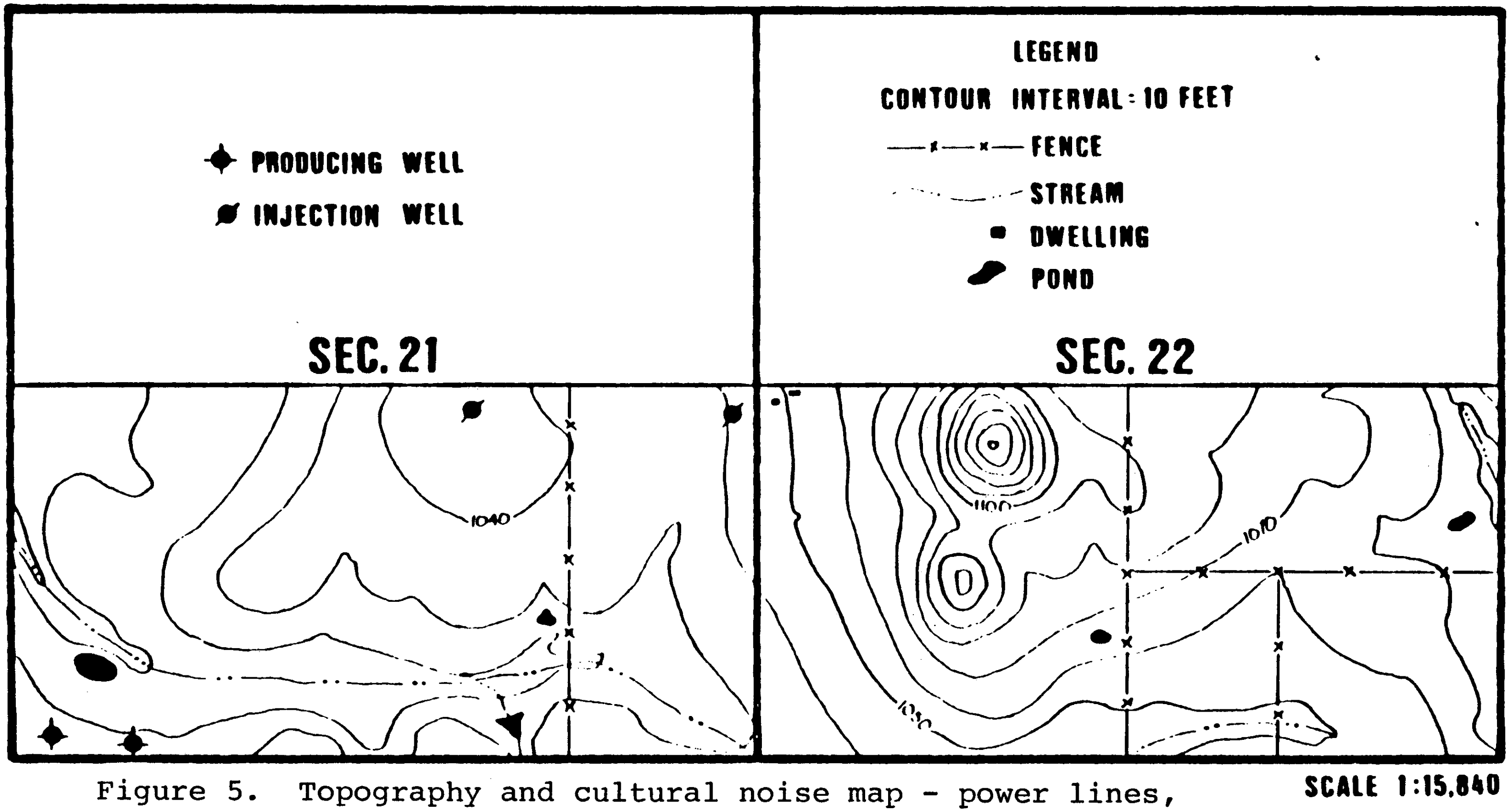

Figure 5. Topography and cultural noise map - power lines, telephone lines, and fences along perimeter of prospect and along section lines

target in the northeast quarter of the southwest quarter of section 22 (see Figure 5). Intermittent production coupled with completion problems have plagued this well.

The prospect is relatively flat, with the exception of two hills in the southwest quarter of section 22. Vertical relief of the hills is about 100 feet. The area is mostly covered with tall grass, except for a cultivated bean field in the southeast quarter of section 22 and a corn field in the southwest quarter of section 22 and southeast quarter of section 21. Gravel roads run along all section lines bordering the prospect. Power and telephone lines run along most roads. Dwellings are located in the northwest corner of the southwest quarter of section 22. A lake is located due south of the southwest quarter of section 22, with its output drainage trending westerly across the south half of section 21. There are several other small ponds on the prospect (see Figure 5).

During the summer of 1981, when most of the data was collected, the humidity was is the high nineties and the temperature was usually over one hundred degrees. These conditions, as well as high electromagnetic noise levels during the day,caused the data collection to be done at night. This slowed production somewhat, but resulted in higher data quality which later proved to be marginal any-way. The first data collected in the area was from the radiometric survey. During the rest of the summer, transient electromagnetic data were taken on the Tipton prospect as well as on other prospects in southeast Kansas. In the late fall, a magnetic survey was run over the prospect, concluding the data acquisition over the prospect.

RADIOMETRIC SURVEY

The radiometric survey was run with a Royal scintillometer provided by Hasz Energy, Denver, Co. Approximately eight miles of carborne scintillometer data were collected on the prospect (see Figure 6). The crystal detector of the instrument was fitted with a two-pi lead shield to reduce above-ground noise sources. Sample interval between data points was approximately 260 feet. Values taken on different road bases were corrected to a datum removing the effects of different roadway materials.

Much empirical success has been reported in the literature on finding petroleum deposits with radiometric surveys (Sikka, 1962). The mechanism by which these anomalies are produced is still a hotly debated issue. The intent here is not to propose a new mechanism, but only to invest-

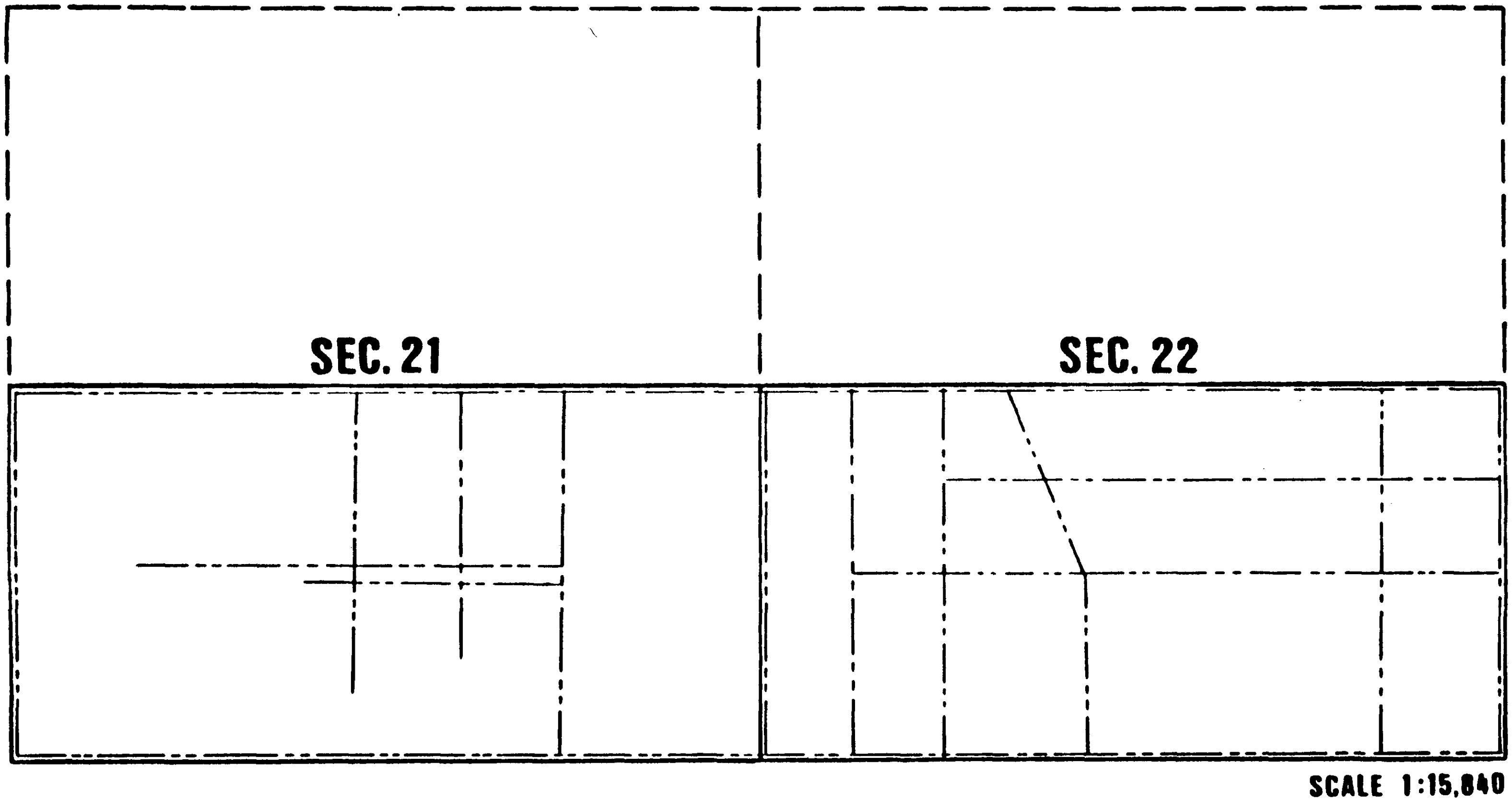

Figure 6. Radiometric survey - data coverage

—-- —---Radiometric data

igate those in the literature and apply the predictions to the data set collected in southeast Kansas.

The background of radiometric surveys started with surface evidence of reservoirs at depth. Initially this was as simple as looking for oil seeps. Soon all the oil seeps were discovered, and workers found high concentrations of hydrocarbon gases over oil fields. This soon led to radiometric surveys, which were much faster and more economical. Several workers have reported "halos" of high radioactivity surrounding oil fields. The radioactive anomalies are due to radioactive elements at or near the reservoir being transported to the surface.

Classical theory postulated the continual upward movement of radon gas. This theory had problems with the vertical migration of the gas because the maximum permeability path was never exactly vertical. Also, the primary radioactive source in sedimentary rocks is potassium-40.

The second mechanism for radioactive elements emplaced near the surface depends on the upward migration of natural gas from the reservoir. This upward movement of gas causes the displacement of ground waters to the surface. After the gas has essentially boiled off the ground waters, capillary attraction causes upward movement of water in or near the reservoir, which contains soluble radioactive elements.

When the waters reach the surface they evaporate, leaving the radioactive residue to accumulate in the near surface (Merritt, 1952).

Some interesting work was done by Miller (1958) in which samples of gas were taken along traverse lines over known oil fields and the samples were analyzed for molecular content. Surprisingly, methane is most common directly over the petroleum deposit. Ethane and higher hydrocarbons were most common in halo patterns about the edges of the field. The oil water interface is where soluble radioactive elements from the oil dissolve in the water. Hence the radioactive anomalies emanate around the edges of the oil field. In lieu of these principles, if the oil deposit is the only source of gas, then, depending on what predominant molecule makes up most of the gas, a radioactive anomaly should be present overlying a petroleum deposit. On this basis, a radioactive anomaly was expected over the known producing area of the prospect.

The data collected was corrected for any man-made deposits such as road beds and was then convolved with a digital smoothing filter with coefficients of .05, .25, .4, .25, .05. The data were then converted to percent anomaly based on the maximum difference in millirad per hour values across the prospect. The data were then plotted in profiles

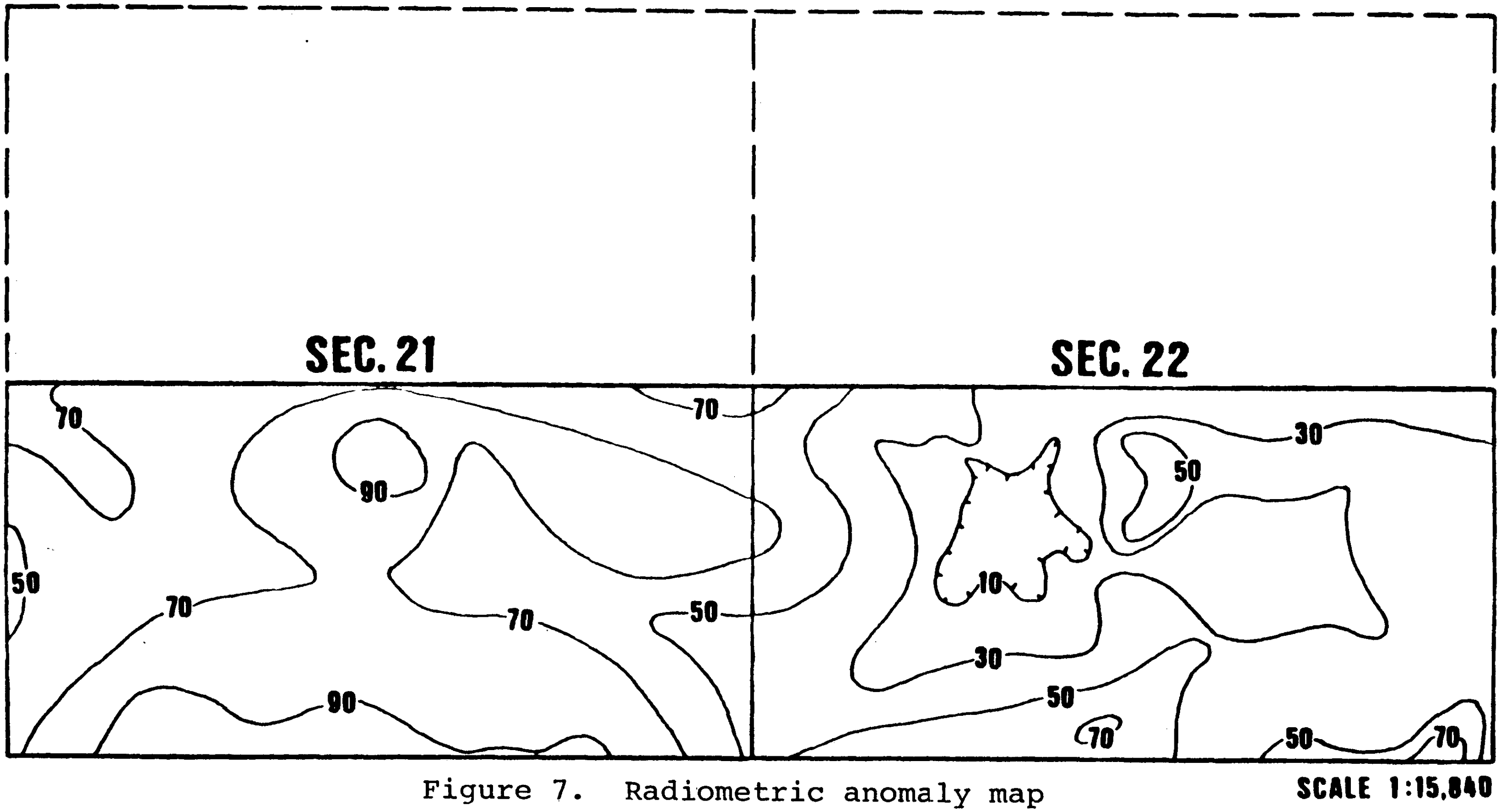

Figure 7. Radiometric anomaly map
percent anomaly contoured with 20 percent contour interval

and contoured (see Figure 7). As seen in the data, radioactive highs are present overlying the known production as well as an area in the southeast corner of section 22. It will be shown later that the anomaly in the southeast corner of the prospect is coincident with a magnetic high and a high conductivity region at depth.

The presence of a radiometric high directly over the producing area, instead of a halo around the production, indicates that methane was the primary gas migrating upward. However, petroleum is known to have many gases and on this basis alone, the anomaly is unexplained. As mentioned earlier, the reservoirs in the area were largely degassed in the 1920's and 1930's, which would certainly allow enough time for rainfall to dissolve the radioactive elements, deposited prior to 1920, to be removed and transported elsewhere. On this premise, no radioactive anomaly should exist. The Cherokee Group has several coal beds, and these coal beds produce moderate amounts of methane. Perhaps methane gas migration takes place all over the prospect and is responsible for the transport of radioactive elements associated with the petroleum accumulation. Where there is no oil, the methane migration continues but does not cause any radioactive elements to migrate to the surface.

The results of the radiometric survey are qualitative, but do seem to indicate high radioactivity areas possibly associated with petroleum accumulations. The cost of the radiometric survey was quite low and should be run on all prospects if only to amass a large data base so that responses can be empirically determined for a specific oil province. Much work needs to be done on this fast, inexpensive, but potentially powerful geophysical method. Regarding the equipment used, a spectrometer would yield data that would be much easier to interpret and probably aid in deciphering the mechanism by which radioactive elements are being transported.

MAGNETIC SURVEY

The November 1981 magnetic survey consisting of four east-west lines across the prospect and four north-south lines in section 22 (see Figure 8). Unfortunately, data could not be collected on adjoining property, and the magnetic anomaly found does not return to background level at the Tipton lease boundary. Ten miles of magnetic data were taken at a spatial sampling interval of thirty feet. The instrument used was a McPhar, one gamma sensitivity, proton precession magnetometer provided by the Colorado School of Mines Geophysics Department under the authorization of Dr. Maurice Major. The data were corrected for linear drift, then convolved with a five point digital smoothing filter with coefficients of .1, .2, .4, .2, .1, and plotted in profiles as well as contoured (see Figures 9 and 10).

The data quality is very good with very little drift during acquisition and good tie points where lines cross. Known sources of error were edited from the data set and usually occurred at fences, metal buildings, cased drill holes, power lines, and trash piles. The data set is relatively flat, with a plateau in the southeast corner of section 22. Depth to the causative body is difficult estimate because the data set is limited to the boundaries of the lease, and the data values do not get down to a background level. Hence a depth was estimated using a half width approach and finding the width of the anomaly by doubling the distance from peak to background. This estimated depth to the body is within the zone of interest for petroleum.

Another problem is that the profiles do not show a negative lobe associated with the peak, which is explained by the expected presence of a remanent component of the magnetic field due to sedimentary deposition of the magnetite grains. Unfortunately, no quantitative measurements of

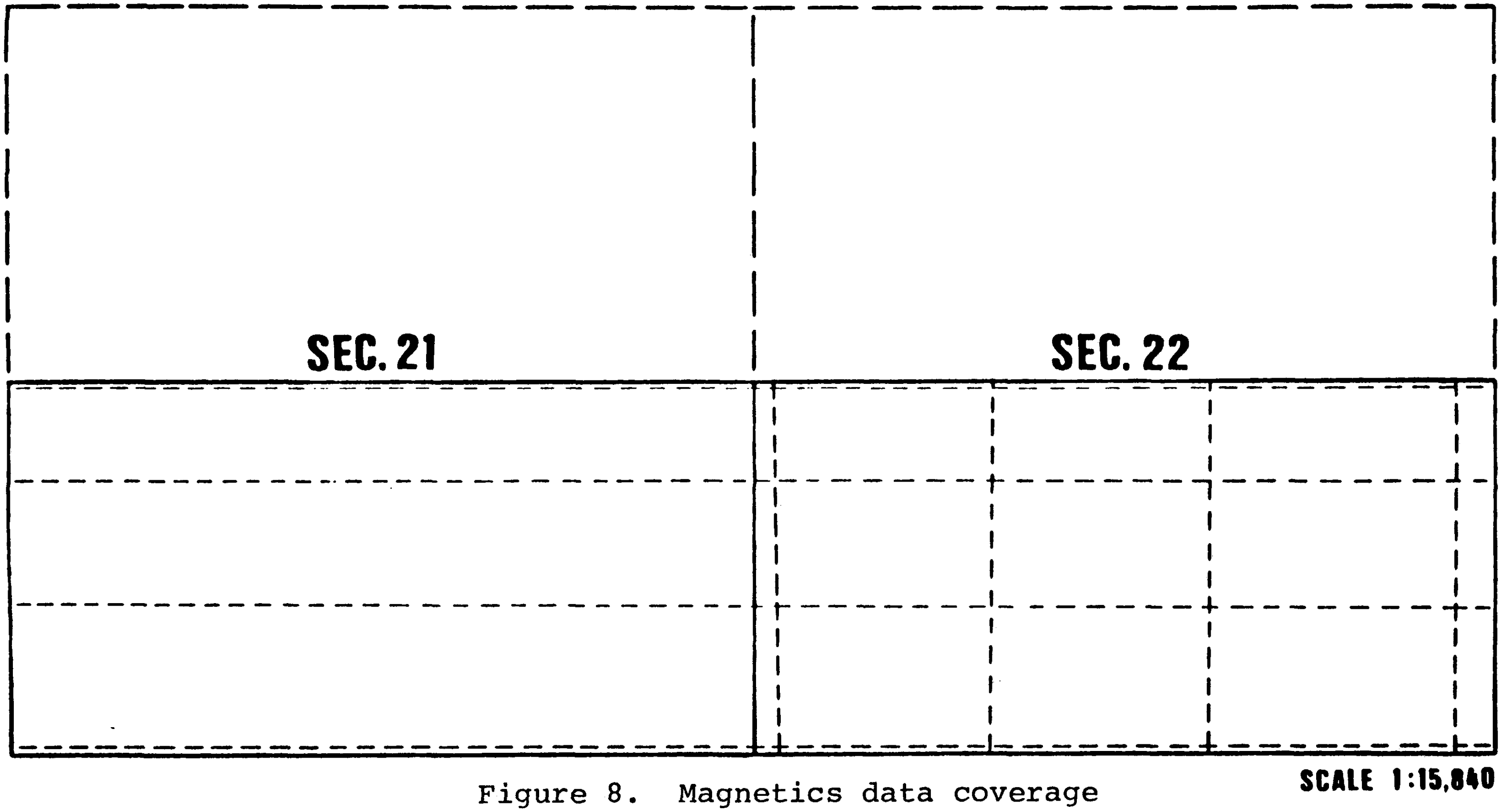

Figure 8. Magnetics data coverage

------ Magnetics data

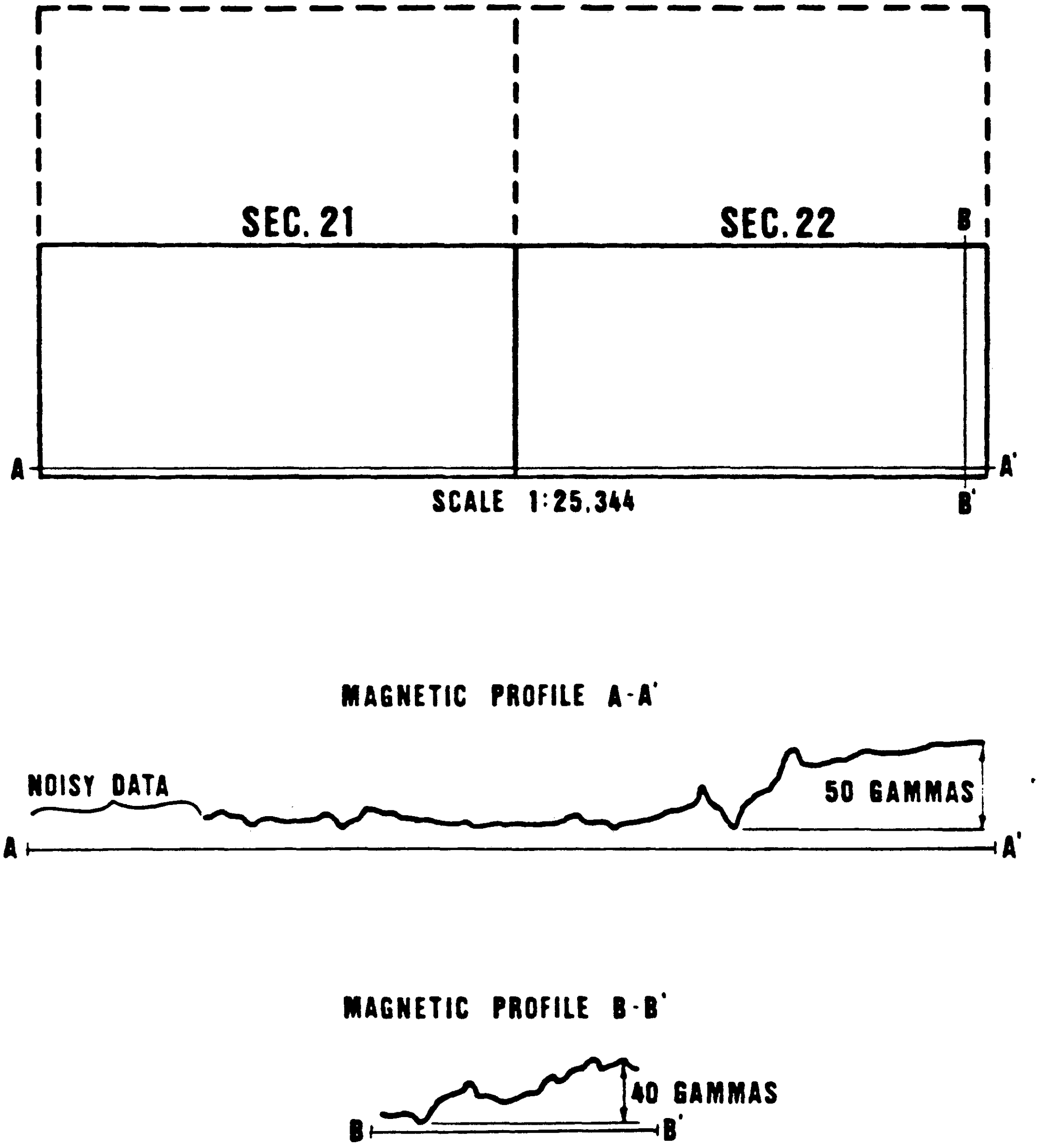

Figure 9. Magnetic profiles

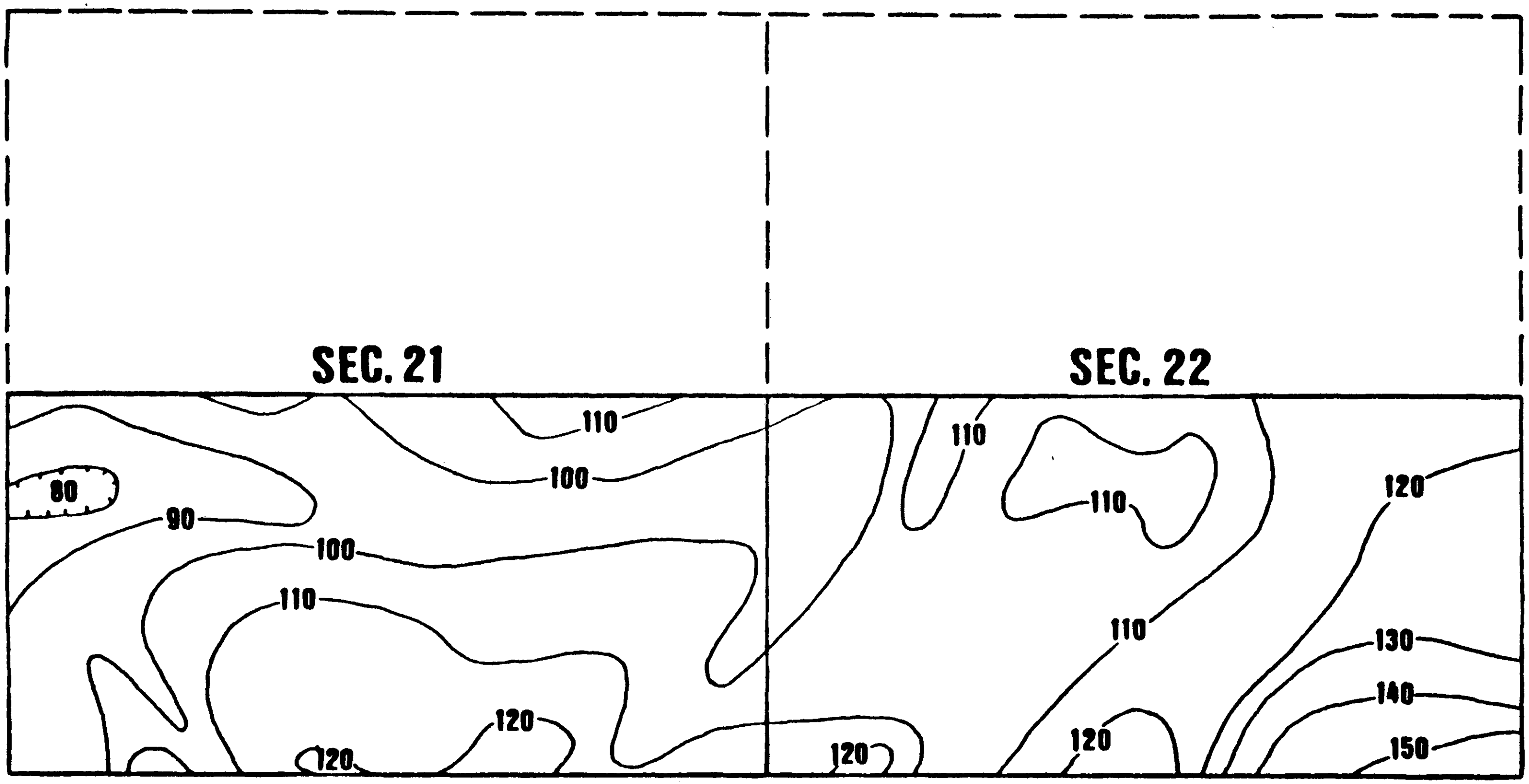

Figure 10. Contoured magnetics data
contour interval of 10 gammas, plotted to datum of 55,000 gammas

moment orientation or susceptibility values are available. However, the literature reports up to eight percent magnetite by weight in Pennsylvanian and Permian sandstones in east Kansas (Merriam, 1963).

With the problems of anomaly width and uncharacteristic shape pushed aside, one can see from the data set (see Figure 7) that a definite anomaly exists in the southeast quarter of section 22. If we assume that the anomaly is symmetrical, a depth estimate of about 1200 feet puts the magnetic body near the top of the Cherokee Group. If indeed the anomaly seen in the southeast corner of the prospect indicates Cherokee sand deposits, then why is not a similar anomaly seen in the south half of the southwest quarter of section 21? There may well be a similar anomaly there but the data collected over the area was extremely erratic, indicating many near surface magnetic sources of noise.

Such was the case; there lies a trash dump with many rusted tin cans, four large storage tanks, two cased wells with electric pump jacks on them, and numerous pieces of iron and wire laying around. Even after smoothing the data it was useless, due to 1000 gamma spikes over distances of 100 feet.

Magnetic anomalies may also indicate oil bearing Mississippian rocks. Precambrian basement structural highs are often associated with Mississippian structural highs, due to post Mississippian structural movement. These Mississippian highs are often oil bearing and hence the magnetics, by finding the basement highs, would be useful in finding petroleum accumulations in Mississippian rocks as well.

In conclusion, the results of the survey were quite positve, and magnetics should probably be run over all prospects in southeast Kansas due to the potential of finding Pennsylvanian sand deposits and the low cost of running such a survey. The results on the Tipton prospect showed a magnetic high consistent with a radiometric high in the southeast corner of the prospect. This could not be related to the known production on the prospect though, because the data over the known production were too noisy. It is unfortunate that more data were not collected, especially off the prospect, but that is a common problem in the interpretation of all geophysical methods.

ELECTRICAL SURVEY

Eighty percent of the field time was used taking electrical data on the Tipton prospect as well as other prospects in southeast Kansas. The electrical survey was run using the TDEM (time domain electromagnetics) truck provided by the Colorado School of Mines Geophysics Department under the authorization and guidance of Dr. Charles H. Stoyer. The system is quite advanced and is very flexible. The field configuration used was two orthogonal grounded wire dipoles with a fixed transmitter location. The receiver was then moved to various locations on the prospect and data were collected at those points. Data collected were the electromagnetic force (EMF) from the time varying vertical magnetic field, and the voltage from four orthogonal dipoles with a common centerpoint (see Figure 11).

The transmitter consists of a twenty five kilowatt generator producing 220 volt, three phase power, which is then switched on and off with Cutler Hammer switches, which can then be boosted through a transformer to 440 or 880 volts, and finally rectified. The output of the transmitter is a square wave with no dead time. The frequency of the square wave is controlled with a synchronized clock identical to the one in the receiver. On the Tipton lease, peak-to-peak currents were about 100 amperes. The dipole length was 200 meters for both dipoles.

The receiver is mounted in a Ford van and controlled by a digital MINC-11 computer. The source of the magnetic field EMF is a twenty six turn loop with an equivalent area

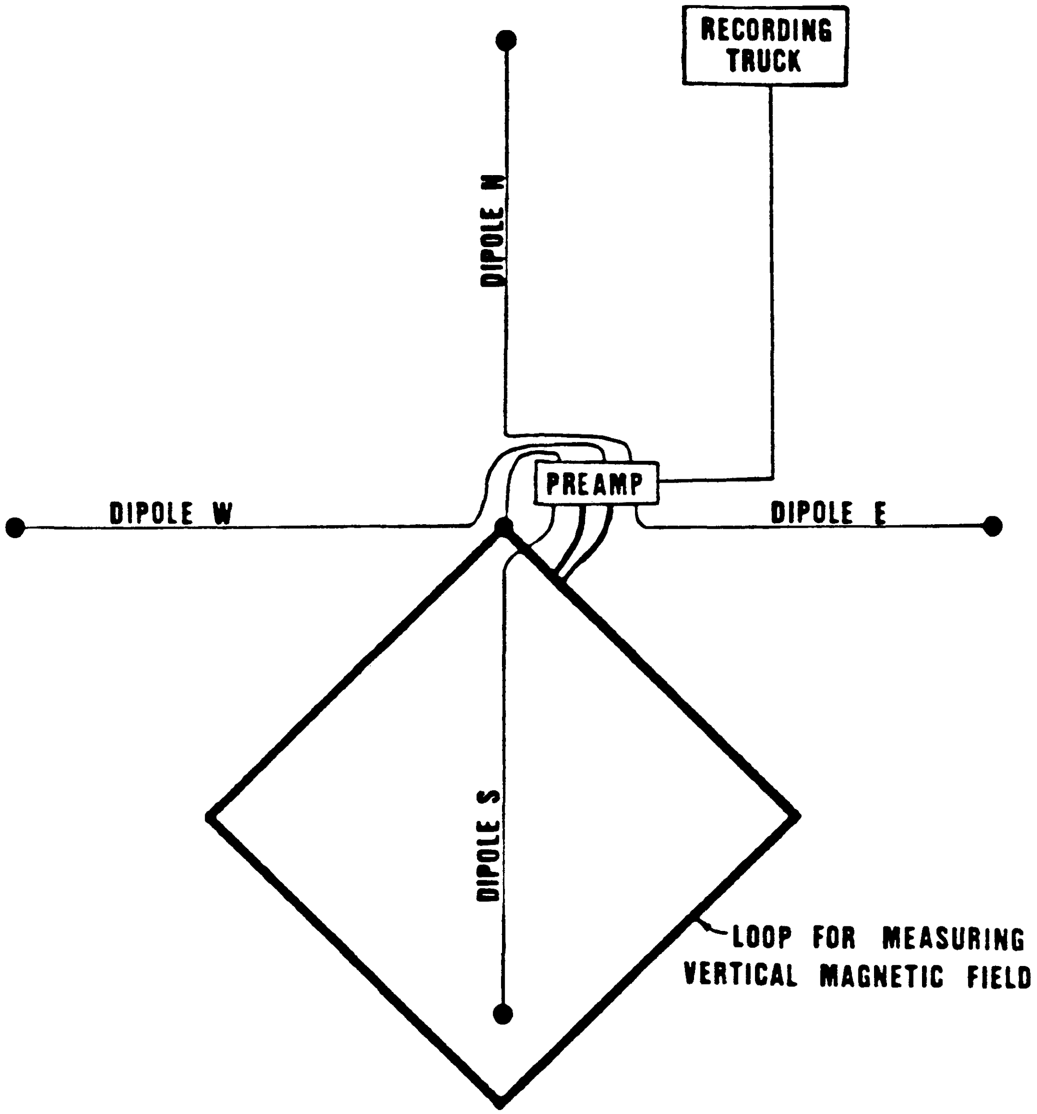

Figure 11. Electrical field recording array

of 149,000 square meters. The source of the electric field potential was a fifty meter long wire with porous pot coupling to the earth.

Four potentials were recorded in the north, south, east, and west directions from the center point. Each voltage measured went into a preamplifier with gain control, 60 hertz notch filter, and spontaneous potential bucking. The signal was then run down a 100 meter length of shielded cable to the recording truck. It was then fed into another gain change amplifier and low pass filtered. Then it was digitized with a twelve bit A/D converter, sent to a storage oscilloscope and put in the operators control. From there the operator has capabilities to continue stacking the transients, take only selected transients, or let the computer set a coherence window to accept only certain transients.

Nine sets of data were taken at each point: four electrical transients from dipole one, four electrical transients from dipole two, and one magnetic transient from one of the dipoles depending on source-receiver orientation. The field procedure was to record five transients from one dipole and then record the remaining four transients after switching to the other transmitter dipole. Nineteen stations were occupied on the prospect (see Figure 12).

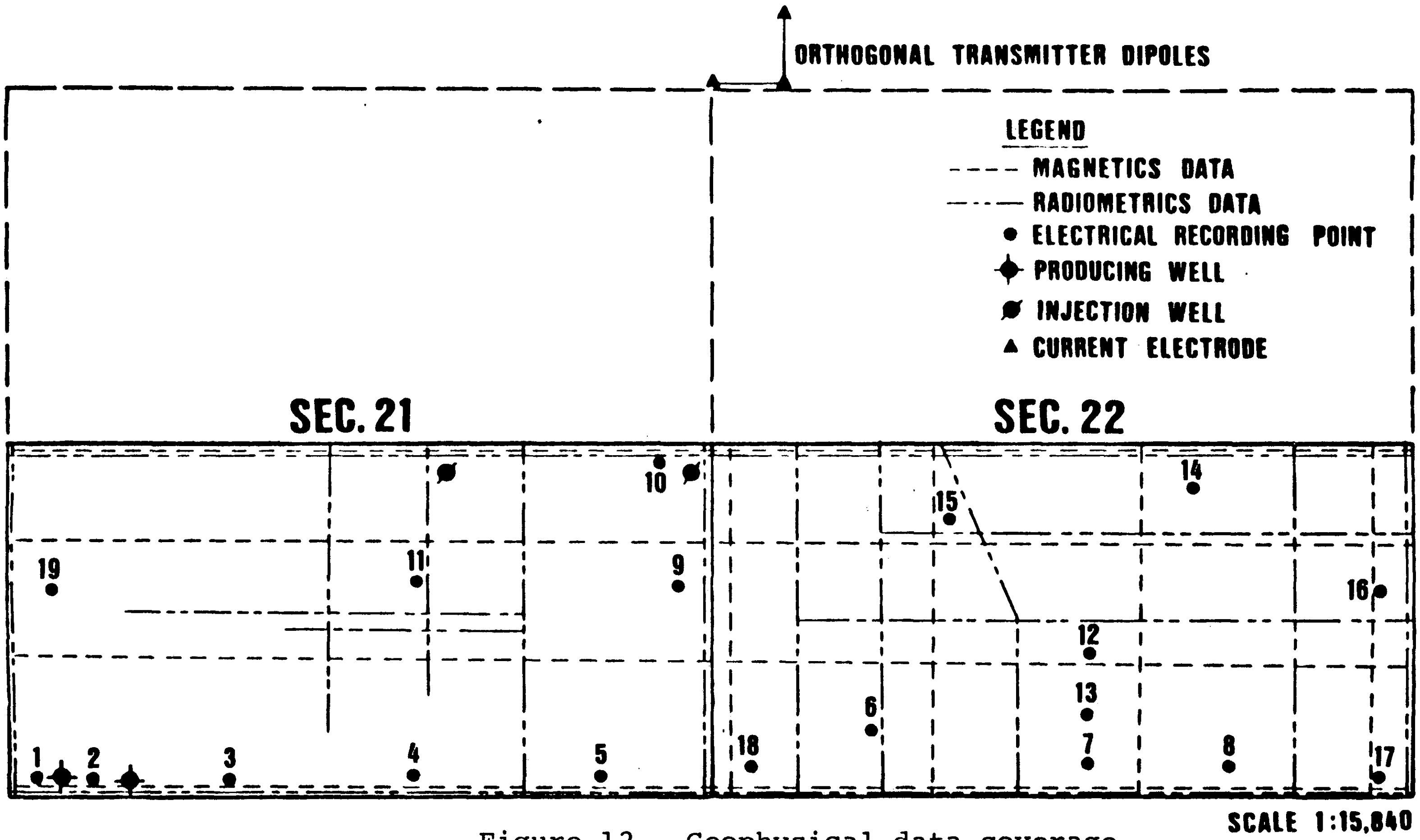

Figure 12. Geophysical data coverage station locations numbered as shown

Results expected from the electromagnetic survey were to find a high resistivty area occupied by the hydrocarbons, as well as a reduced resistivity overburden overlying the oil pool (Snyder, 1981). The transient electric field was expected to show some very long, slow decays overlying the petroleum accumulation, indicating a large chargeability contrast due to postulated sulphides overlying an oil pool (Snyder, 1981).

The digital processing of the data was very powerful and flexible in getting the data into an interpretable form. The computer system has many available options, of which the following is only a typical processing sequence. Two analog inputs are fed into the digital processing sequence, one is the recorded transient, and the other is the step response of the system (filters etc.). Ideally one wants the impulse response of the system, but physically producing an impulse is difficult, so a step function is fed into the system and the recorded response is differentiated, producing the impulse response. The impulse is then deconvolved with the recorded data, and theoretically the data are free of influence from the system.

Other preliminary operations performed on the data are: low pass filtering, smoothing, windowing the useful portion of the transient, and finally computing the early

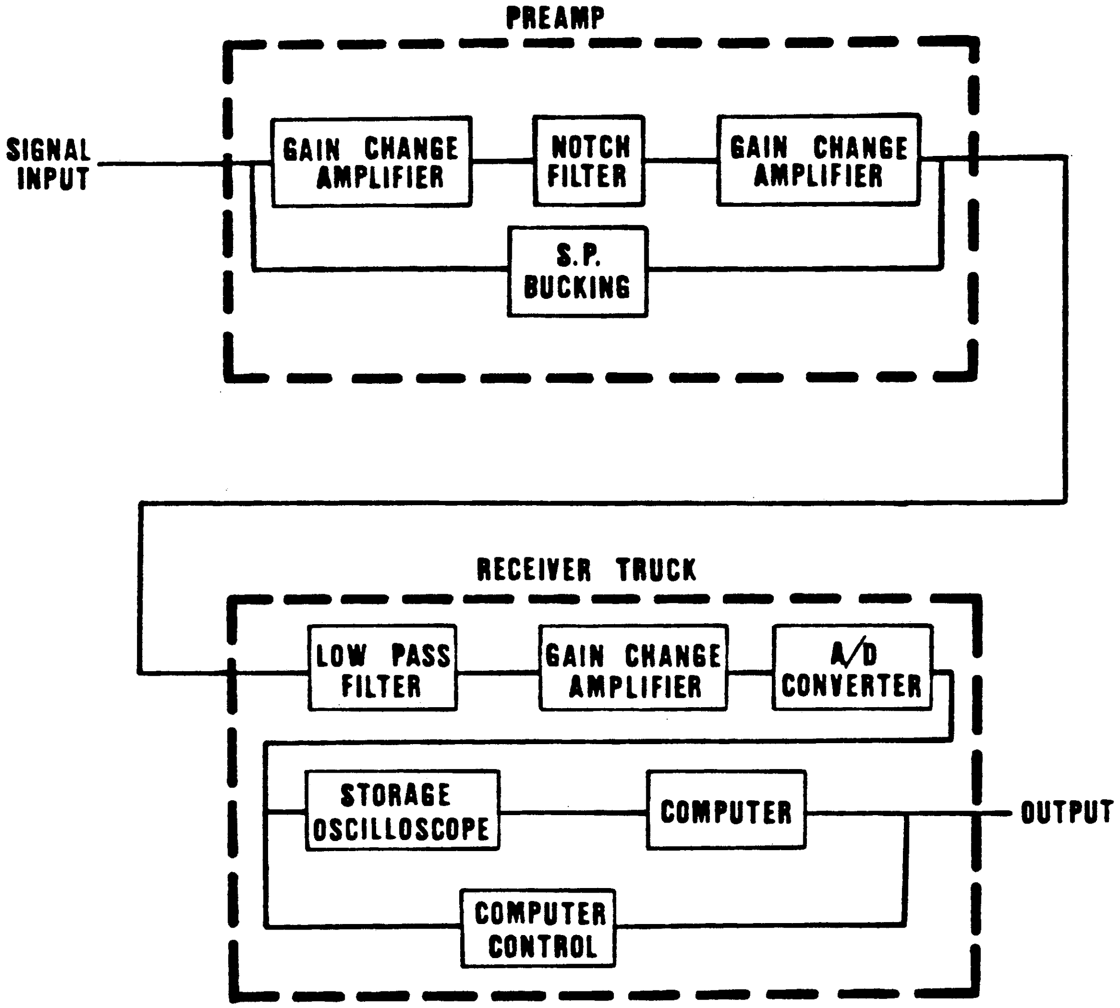

Figure 13. Analog processing sequence

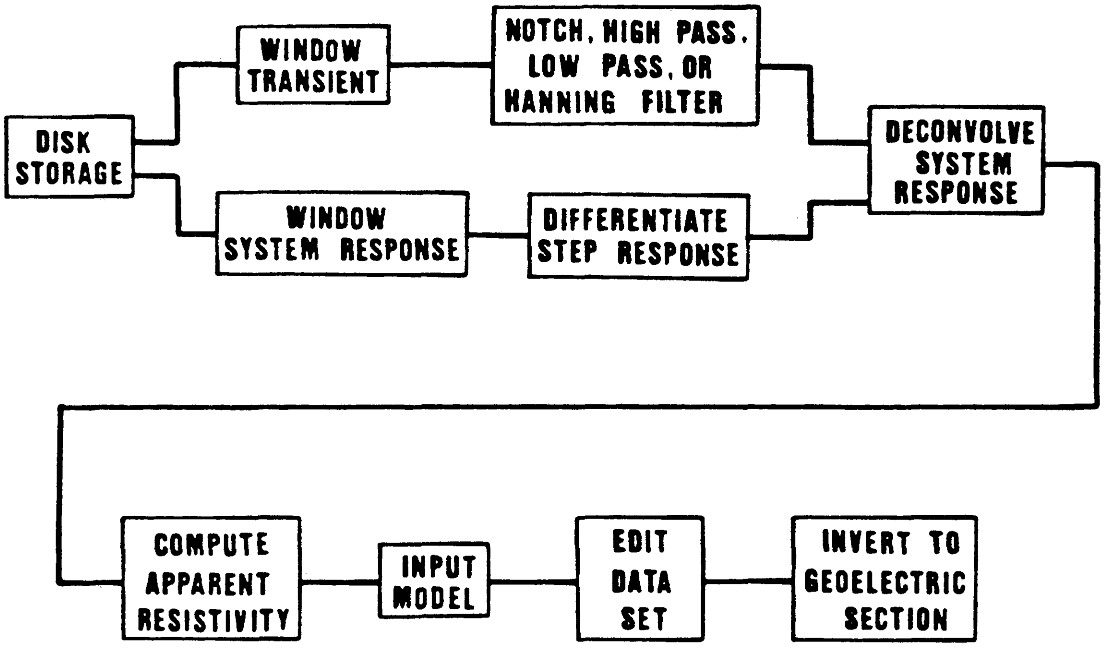

Figure 14. Digital processing sequence

and late time apparent resistivity versus time plots. All of these manipulations are performed by the program called TDEM created by Dr. Charles H. Stoyer. Diagrams of the analog and digital portions of the Colorado School of Mines TDEM recording system are provided in Figures 13 and 14 respectively.

Another of Dr. Stoyer's programs called SATI (semi-automatic transient inversion) will perform one dimensional inversion given an apparent resistivity versus time plot and a first guess geoelectric section model. All of the curves on the prospect were inverted via this program, and several interpretation schemes were used to present the output of the SATI program. Of the methods used to present the data, the procedure that yielded the best results was to use a model with fixed thicknesses of layers and optimize the resistivity of those layers. Then a contour map showing lateral changes in resistivity was made for the layers in the geoelectric section. The thicknesses were chosen to match known lithologic boundaries.

The resistivity contour map for the interval corresponding to the Cherokee Group is shown in Figure 15. As seen in the figure, there are two regions of high conductivity at the depth of the suspected oil producer. The highest conductivity region corresponds with the radiometric and magnetic anomalies. The other region corresponds with the known producing area. The correlation of anomalies with petroleum production was good, except that the producing areas were expected to have a high resistivity instead of a high conductivity, due to the emplacement of resistive hydrocarbons.

The increase in pore space in the sandstones relative to the encasing shales and overlying carbonates allows much more fluid to be present. The Cherokee Group, like almost all oil producing formations, is below the water table, and the waters at a depth of 500 feet or more are saline. Water has a greater capillary attraction to a sand grain than does oil, and hence even in an oil saturated reservoir, with very few exceptions, at least ten percent of the pore volume will be filled with saline pellical waters (Baars, personal communication, 1982). The important thing is that the water is spread across each grain surface, and hence provides a continuous current path across the reservoir.

A high resistivity anomaly would be present if the hydrocarbons were present in the form of gases, for they would totally displace the pellical waters. As mentioned earlier, the gas caps were bled off in the 1920's and 30's, so now the reservoir fluid is almost totally liquid. With a saline water film to provide a current path, one would

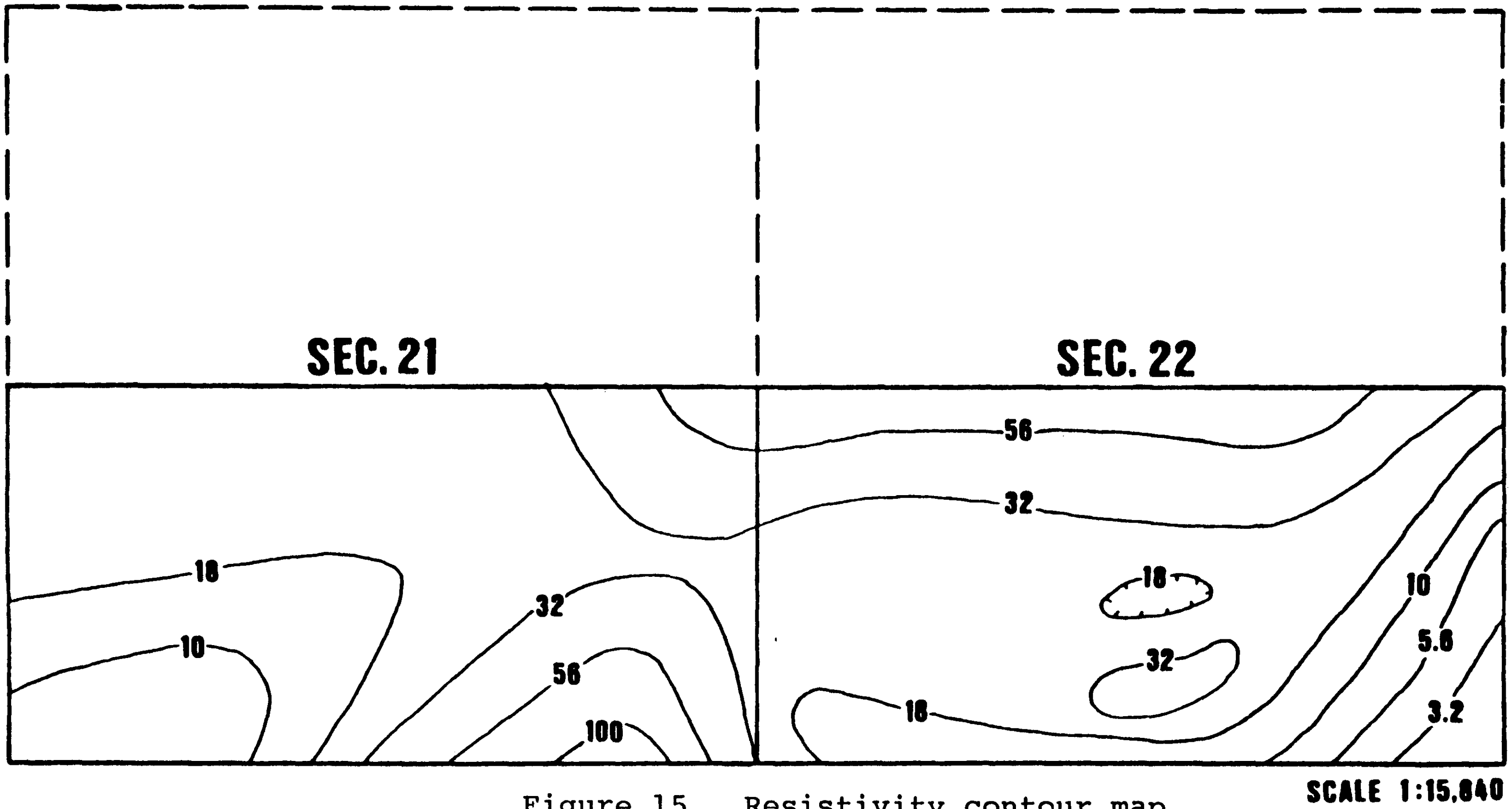

Figure 15. Resistivity contour map
logarithmic contour interval expressed in ohm-meters
depth = 1400 feet

expect a high conductivity anomaly over the producing area in the absence of a gas cap (Keller, personal communication, 1982). The interpretation of the transient magnetic field yielded a large, high conductivity region superimposed on the magnetic anomaly in the southeast corner of section 22, indicating a porous sandstone providing a good current path across it. The producing area also had a similar anomaly, but with a smaller conductivity contrast.

The results of the transient magnetic field survey were quite good; the survey was probably the most definitive of the geophysical methods used. It was also by far the most expensive survey to run, due to high noise levels that rendered many nights of recording useless. Even with large currents and small offsets, the noise would start and the data would be overwhelmed. Limitations on the system, then, are its capability to remove or reject noise of all types, its expense to run in the field, and the much more difficult processing and interpretation procedure involved. Even though the system may be able to find porous sand bars at depth, just like magnetics, transient EM data can not tell if there is oil in the rock. Overall the transient EM data provded the best indicator for finding the Cherokee sand deposits.

The transient electric field was measured at each station as described above. Four components of the electric field were measured so that the first and second vertical derivatives of the electrical field with depth could be computed. The reason for the two orthogonal current dipoles was twofold: 1) the entire prospect could be surveyed without getting on line with a dipole while measuring the vertical component of the transient magnetic field and, 2) the electric dipoles could be mathematically rotated to get the maximum and minimum values of the resistivity ellipse (Doicin, 1976).

In recording the decay of the electric field, the direct current value prior to the decay is also recorded. The direct current survey did not prove to be very useful, because with only nineteen data points, each at a different distance from the source, an adequate resistivity map could not be generated for the zone of interest. The averaging of the resistivity between source and receiver, common to DC surveys, reduced resolution to an unacceptable level. DC surveys would be potentially useful if soundings were made or if profiling was done at several a-spacings. The benefits of using a DC survey in the area are: 1) low data acquisition cost and simple instrumentation required, 2) very good galvanic contact to the ground, 3) mathematical ease in data manipulation and interpretation, and 4) the very high sensitivity of DC surveys to a very conductive layer at depth.

As stated earlier, four components of the electric field were measured such that derivatives of the vertical electric field could be computed. Unfortunately, the noise levels so high and the dipole lengths so short (50 meters) that, instead of computing a derivative, the summing of the transient decays left the value of the derivative far subdued by the noise level. No consistent results could be obtained for the derivative, but all was not lost. Often one dipole would be very noisy and its conjugate dipole could be inverted and used because they were quite similar, with only a 50 meter dipole length.

The primary goal of recording the transient E-field was to get the induced polarization response. Recent success has been claimed in the literature for finding hydrocarbons with induced polarization or complex resistivity measurements (Snyder, 1981). Hence, the expected result was to find a rise in the voltage at some time after the EM effects subsided (Bode, personal communication, 1981). This bump in the transient would be attributed to a chargeability phenomenon. The IP response is caused by a "sulphide plume" above the oil accumulation. Certainly most crude oils contain some sulpher and, if this sulpher can be removed and transported upward into reducing conditions, the sulphides can and do form.

California, West Texas, and the Rocky Mountains are regions where high sulpher oils are common (Levorsen, 1954). These areas are also relatively arid compared to east Kansas. Figure 16 illustrates a typical transient E-field from the prospect. As seen from the decay, there is no indication of an induced polarization response. The justification for no IP response is that the oil is relatively low sulpher in the first place, and if a "sulphide plume" was ever present, the high rate of rainfall has moved enough oxygen rich groundwater to oxidize those sulphides deposited.

Processing of the transient E-field data included smoothing the decay using the smoothing filter in the TDEM program. Then the curve was integrated, and the values of the integrations over different windows for all components of the E-field were plotted at the station locations. The results, again, were dominated by noise, and did not correlate to the other anomalies. This is due to the very small or nonexistent IP response. Instrumentation and field procedures were not optimum however, which could partially explain the poor results.

The preamplifiers used were the same as those used to

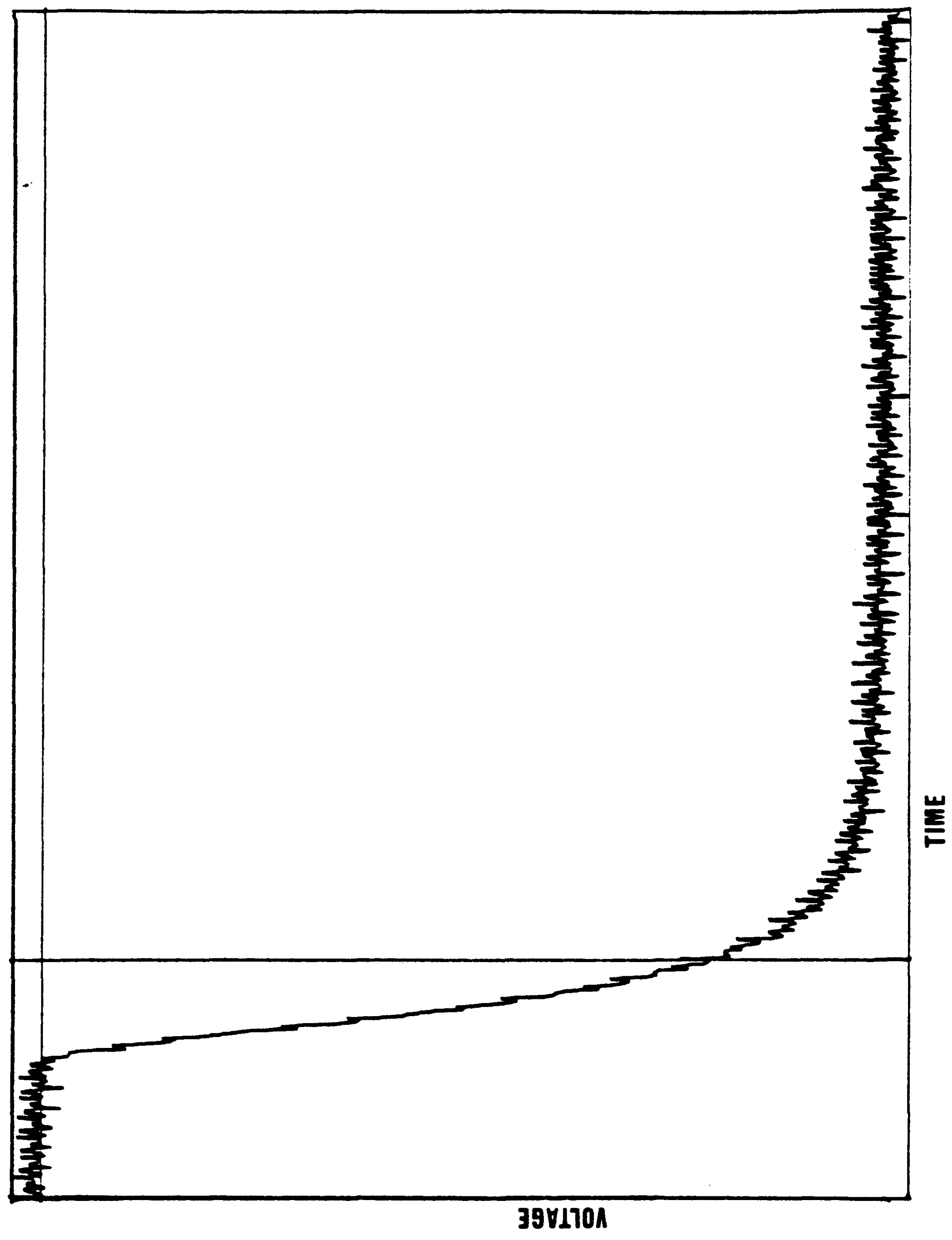

Figure 16. Example E-field decay

record the transient magnetic field; however, the source impedance of the loop was much lower than that of the galvanic contact to the ground, which caused common mode and isolation problems. Results of the survey were degraded by all of the above problems, and I feel that these problems must be eliminated before there can be any analytic or scientific predictions about such a new and difficult problem. Recommendations for the future are: 1) Stick with a conventional array so that the results can be compared to those of other workers in the field, and so there will be one less variable parameter and, 2) In galvanic surveys the input impedance of the preamplifier must be quite high and preferably isolated, to prevent common mode voltage problems.

CHAPTER 3

SUMMARY OF RESULTS

The radiometric survey was fast and easy to run, but the anomaly pattern associated with known petroleum production was uncharacteristic. The literature reports finding radiation "halos" or high radioactivity regions surrounding an oil pool. The radiometric anomaly on the Tipton prospect is a high radioactivity level directly over the petroleum with no apparent halos. This is explained by the following: 1) the reservoirs have been degassed, 2) methane produced from coal beds is probably the primary source of gas to cause radioactive elements to migrate to the surface, and 3) high rates of rainfall and groundwater movement have caused any "halos" present prior to 1920 to be dissolved and transported away.

Due to the low cost, ease of acquisition and interpretation , and the potential benefits of this powerful geophysical method, a radiometric survey is recommended on all petroleum prospects in southeast Kansas.

The magnetic survey was economical, fast, easy to interpret, and yielded very significant results. The presence of magnetite in Pennsylvanian sand channel deposits is truely a blessing to the oil explorationist in southeast

Kansas. Problems encountered with the magnetic survey were: 1) an incomplete data set, 2) no knowledge about the magnetic susceptibility of the Cherokee sandstone deposits, and 3) no information about the magnitude or direction of the suspected remanent component.

Although the magnetic survey was not free of problems, it did indicate a sandstone deposit in the southeast corner of section 22 where other anomalies also coincide. A magnetic survey should be run over all prospects in southeast Kansas where the target is a Pennsylvanian sandstone or a structural upwarp in the Mississippian aged rocks.

The electrical survey was quite complicated and costly but yielded the most definitive results. The vertical component of the magnetic field was recorded, processed, and inverted to give a geoelectric section. A contour map of resistivity was generated at the depth coinciding with the Cherokee Group sandstones. Two anomalies appear from the map, one low resistivity section where oil is currently being produced and the other in the same location as the radiometric and magnetic anomalies in the southeast corner of section 22. The transient E-field was expected to yield a large IP response over the oil field because of sulphide deposits reported in the literature over such oil pools. Very little or no IP response was seen in the survey.

Several things could have caused this lack of an IP response: 1) a lack of sulphides deposited over the oil pool or the oxidation of them after they were deposited, 2) noise levels greater than the IP response, or 3) unconventional survey procedure.

A composite map of the three data sets, radiometrics, magnetics, and electromagnetics, that yielded consistent anomalies, is shown in Figure 17. The data is viewed from the north looking south for purposes of illustration. The electrical data were plotted as conductivity so that all anomalies will be consistent. The two producing wells are shown in the right hand corner of the plots. The proposed drill hole location is shown on the left side of the plot. As seen from the data the oil producing regions have high radioactivity, high magnetic fields and, high conductivity.

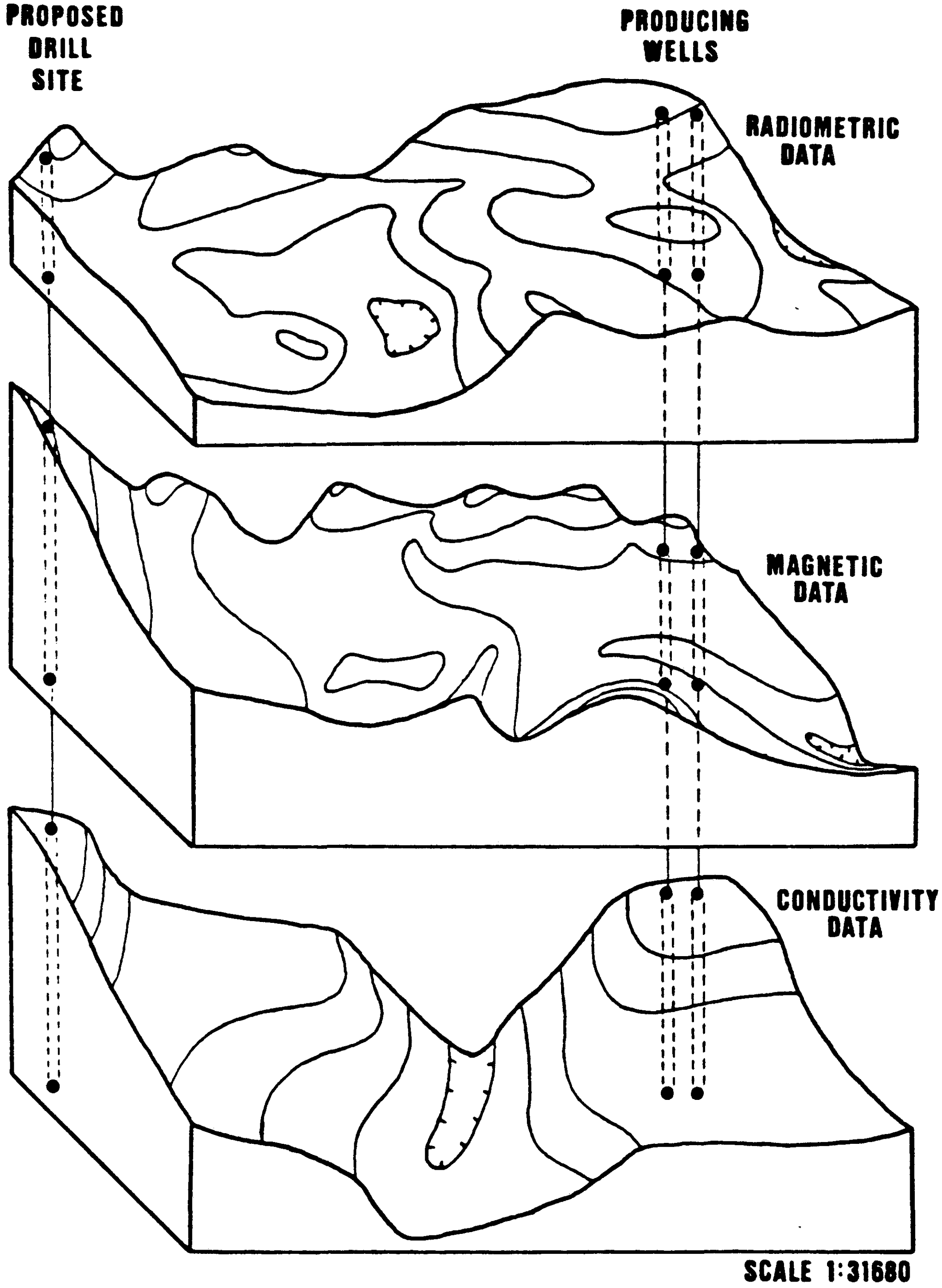

Figure 17. Composite anomaly map view looking south for illustration

CHAPTER 4

CONCLUSION

Geophysical methods are useful for oil exploration in southeast Kansas. Methods and field procedures must be unconventional and closely monitored to be economically feasible.

Resistivity, magnetic, and possibly radiometric anomalies indicate the presence of Pennsylvanian sandstone deposits. The data acquisition, processing and interpretation of both the radiometric and magnetic surveys is easy and inexpensive. The electrical survey data are more complex and expensive to process but provide the best tool to find porous conductive zones associated with oil reservoirs.

Induced Polarization phenomena reported in the literature was not present in the data collected. Several problems existed in methodology, instrumentation, and noise reduction; hence, it is not claimed than sulphides do not exist above oil pools but only that their effect is not seen in southeast Kansas. High groundwater flow rates may have oxidized any suphides deposited above the oil pools.

Due to the limited scope of this project the work presented here by no means exhausts the topic or even this data set. Multidimensional inversion of the EM data would surely produce more information. The other data sets could too have been investigated more thoroughly but the limits of time and funding have only advanced the project to its present state. However, significant results were obtained.

A memo was prepared for Hasz Energy recommending a drill site in the southeast corner of section 22, T25S, R14E, Woodson County, Kansas. The downturn in petroleum prices have delayed the drilling of the anomalies on the prospect, so no field check of the interpretation has been made to date.

Due to the lack of geophysical data in southeast Kansas, it is recommended that a radiometric and magnetic survey be run over all petroleum prospects in the area. An electrical survey should also be run if equipment and qualified personnel are available to acquire, process, and interpret the data.

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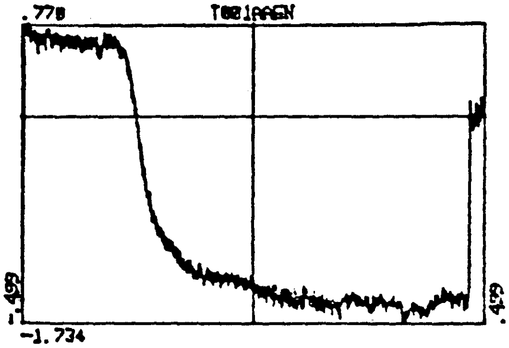
APPENDIX A

Contained within are displays of all raw electrical field decays. The curves are plotted voltage versus time. All curves are one second in length. The curves are title as follows:

Tnnnxxyz

where T = Tipton Prospect
nnn = number of station occupied
xx = AA or AB depending on source orientation
y = E for electrical field
z = N, S, E, or W for orientation of receiving dipole.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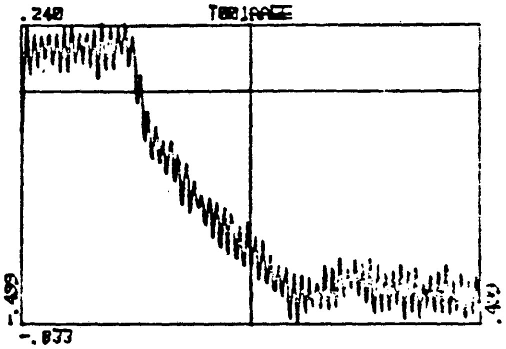
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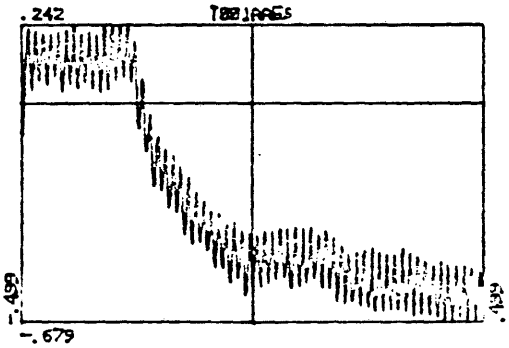
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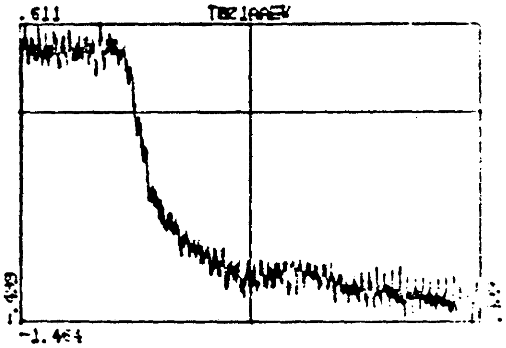
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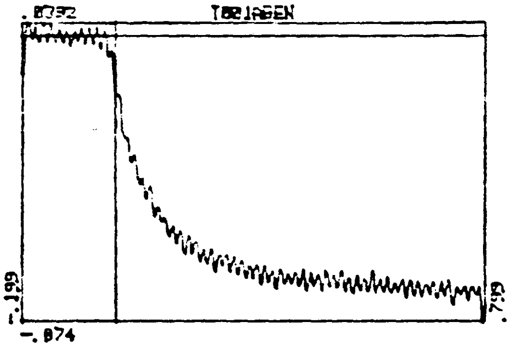
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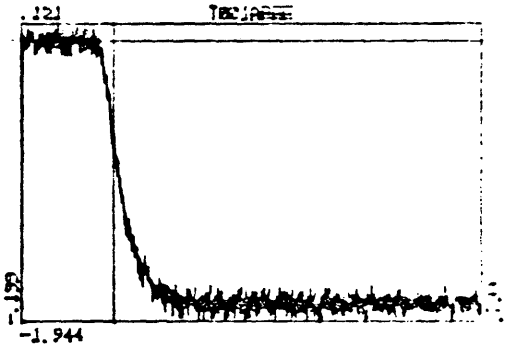
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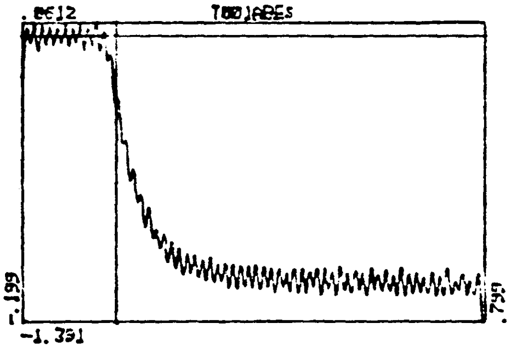
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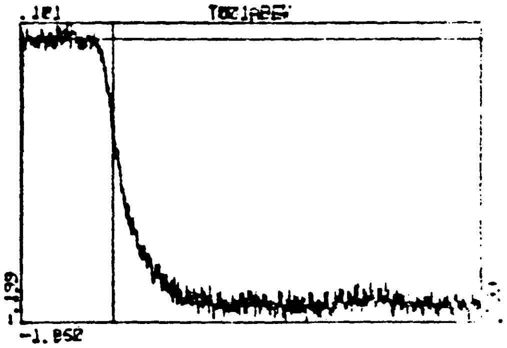
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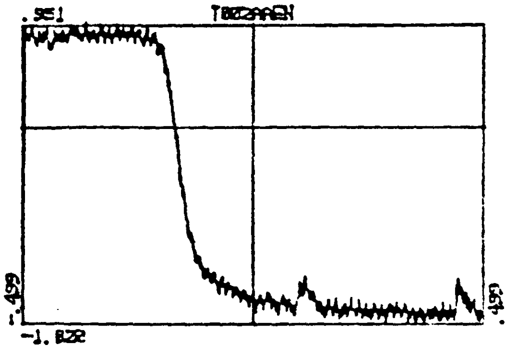
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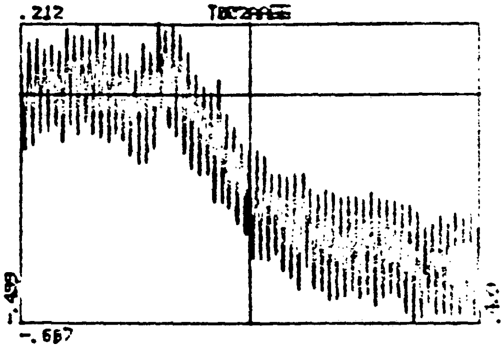
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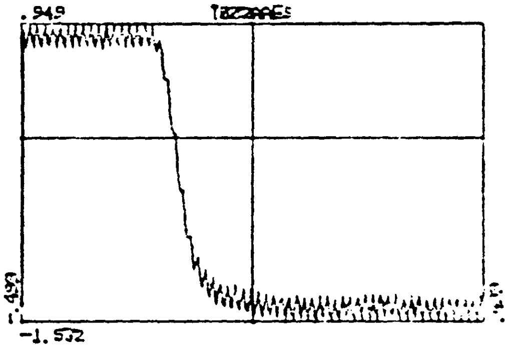
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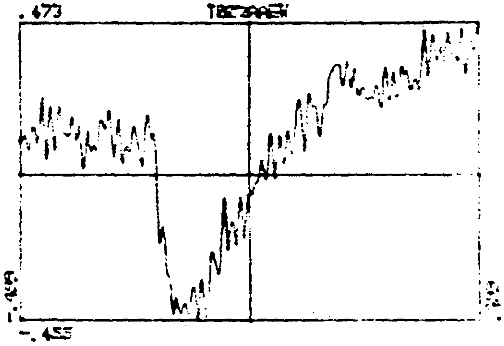
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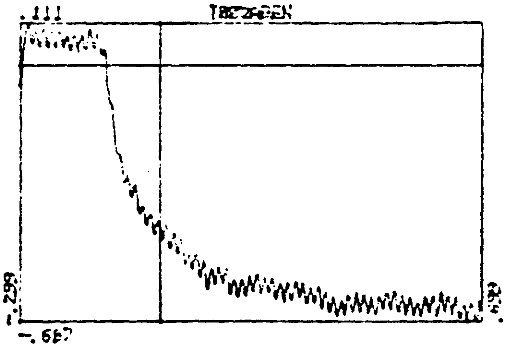
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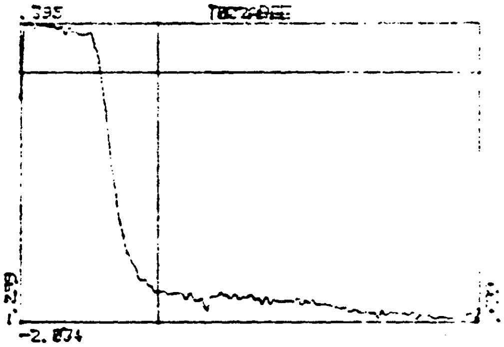
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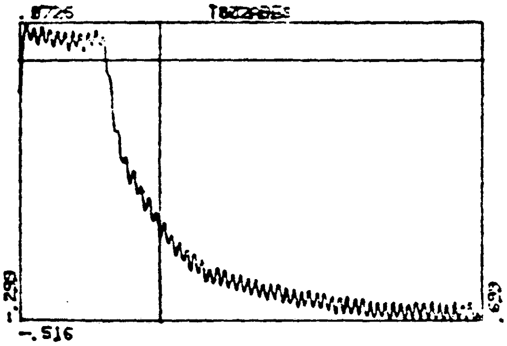
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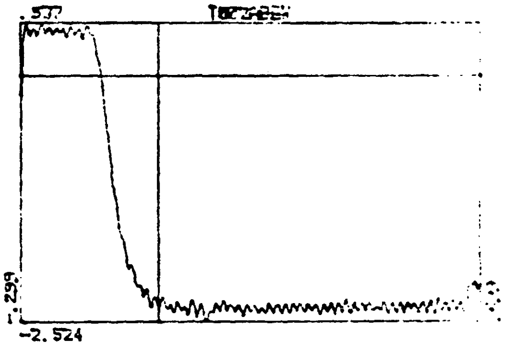
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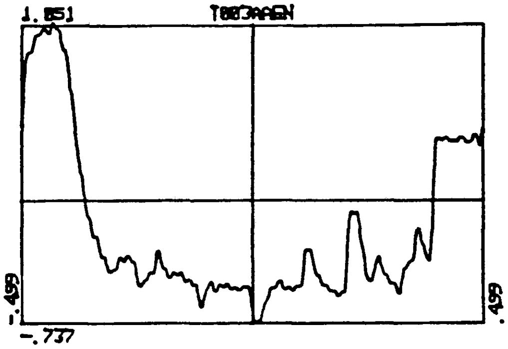
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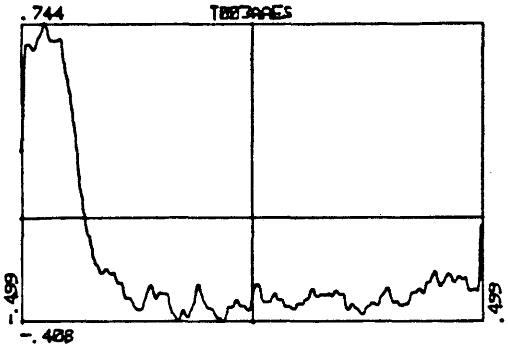
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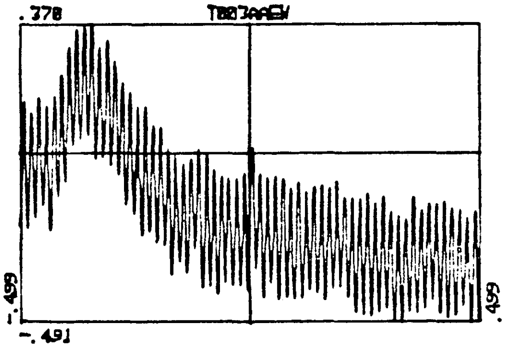
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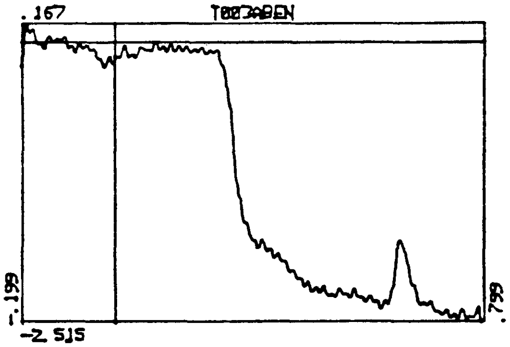
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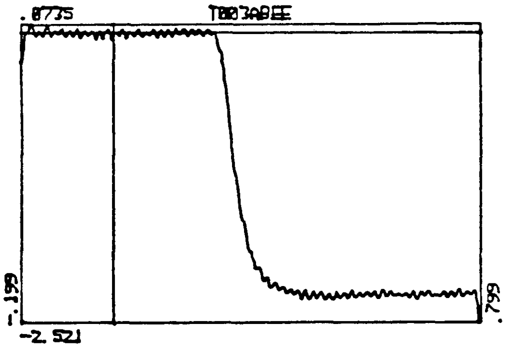
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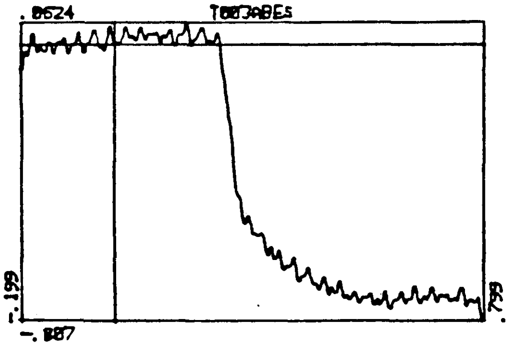
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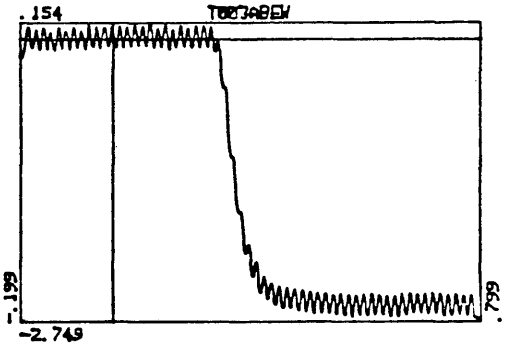
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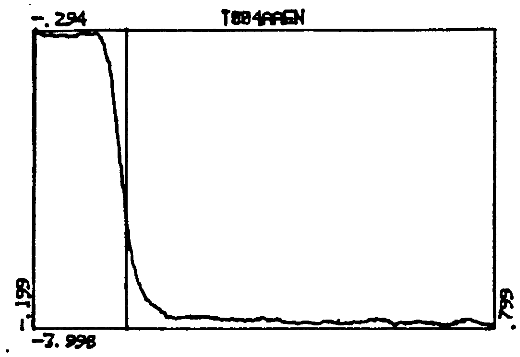
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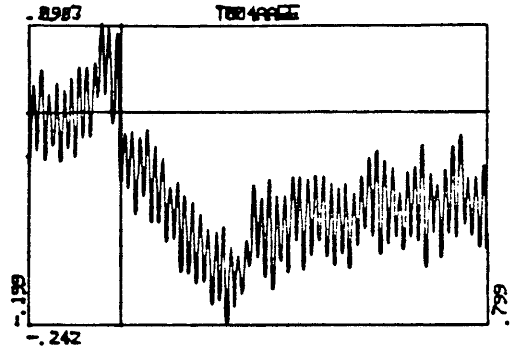
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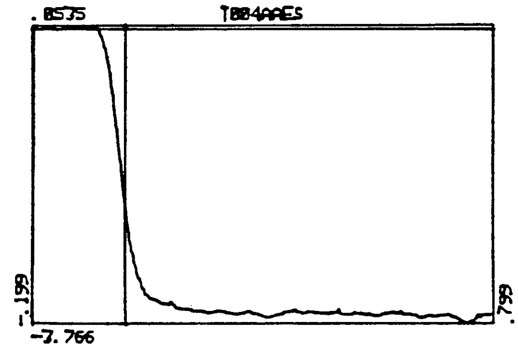
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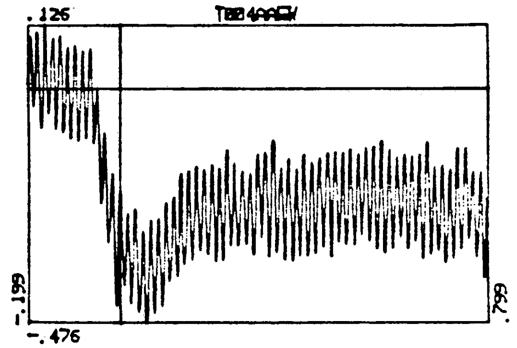
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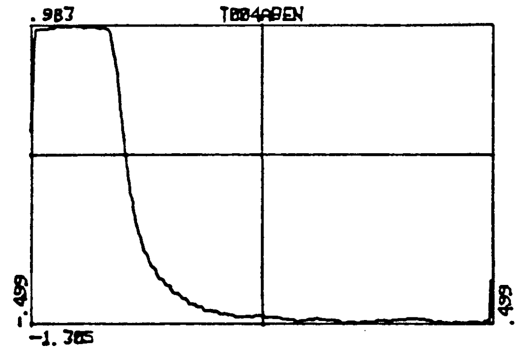
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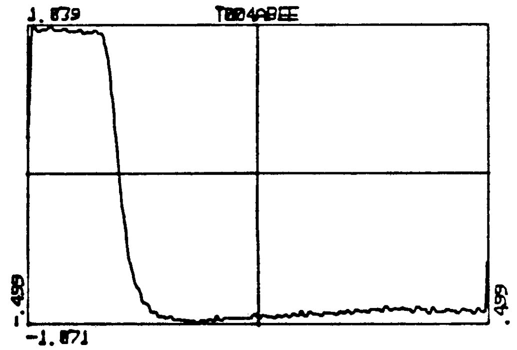
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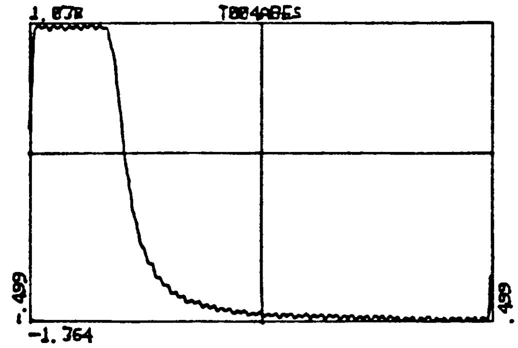
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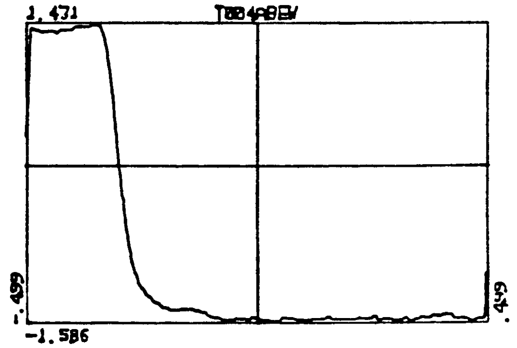
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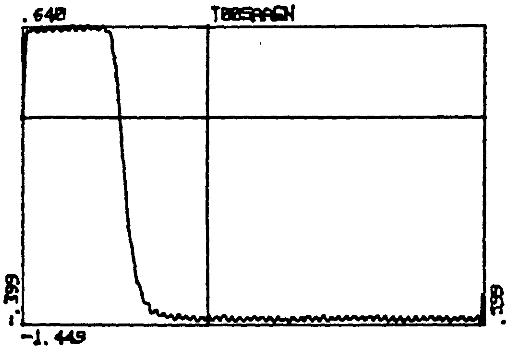
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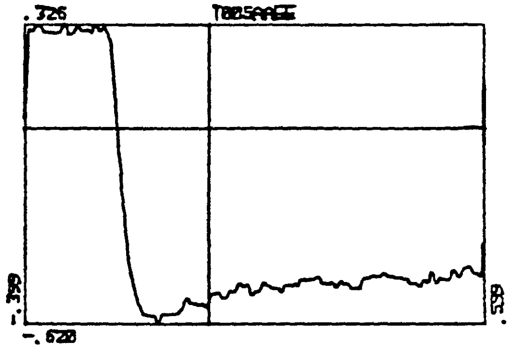
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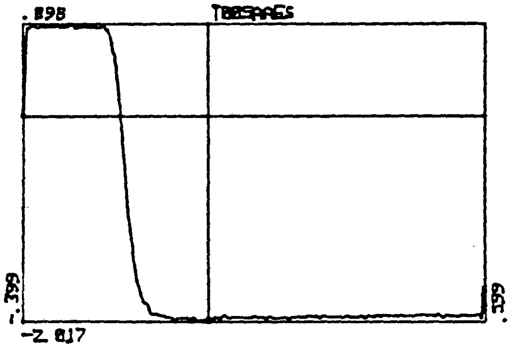
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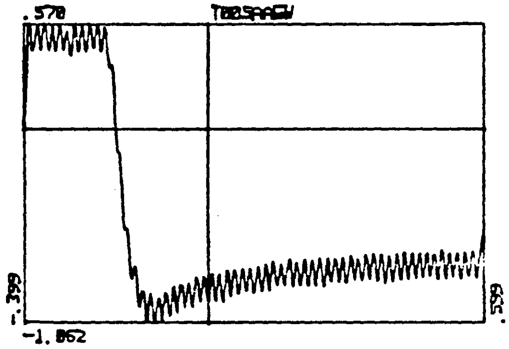
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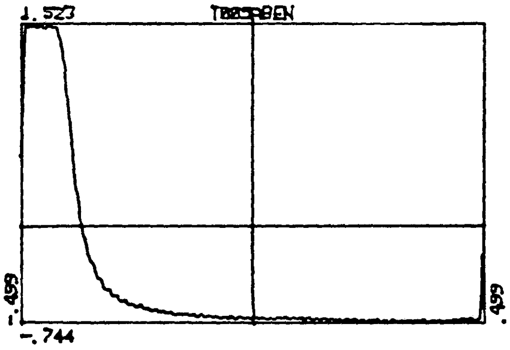
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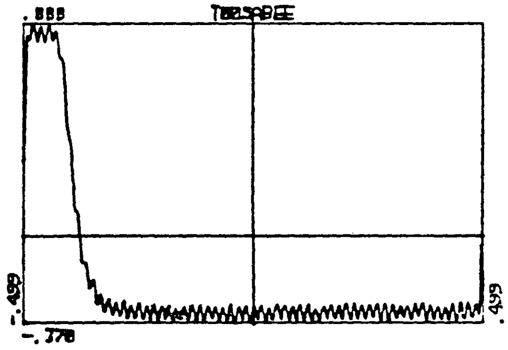
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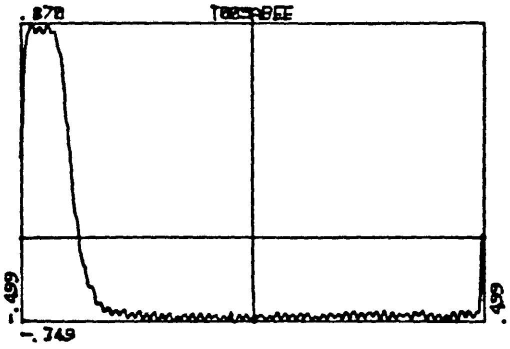
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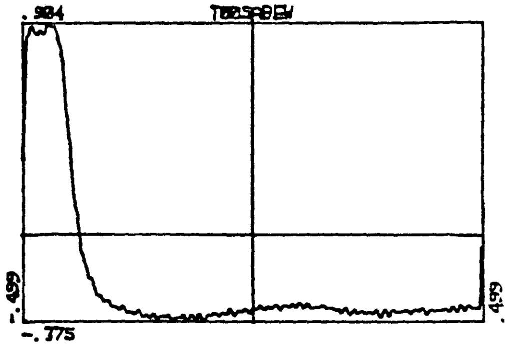
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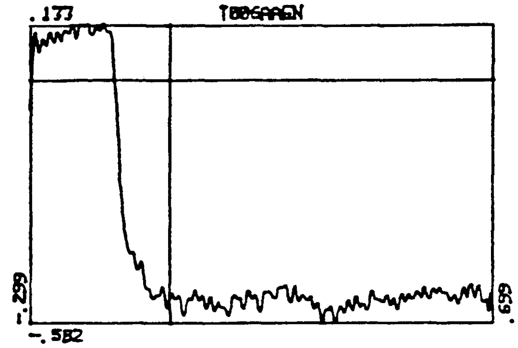
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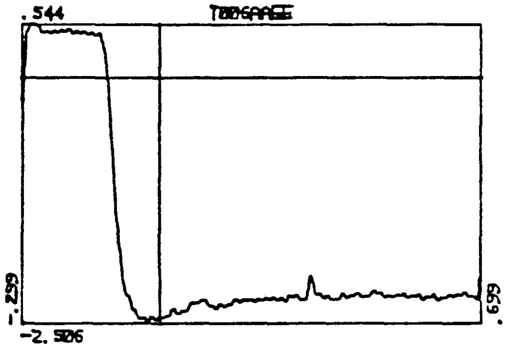
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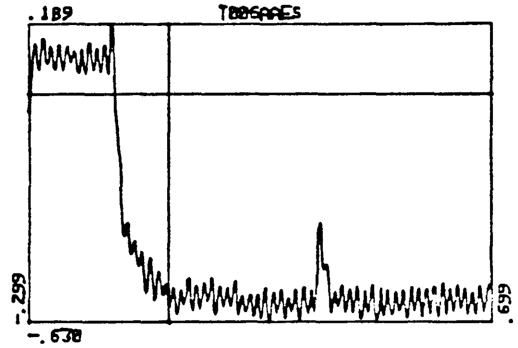
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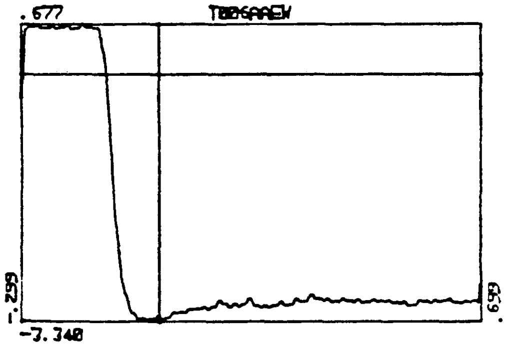
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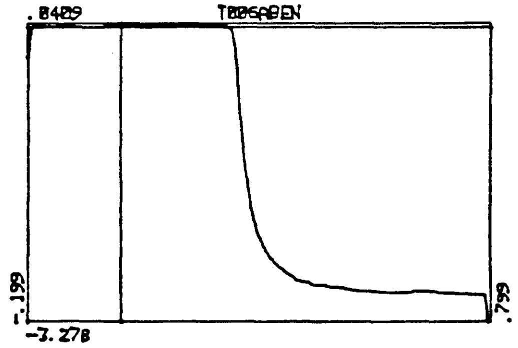
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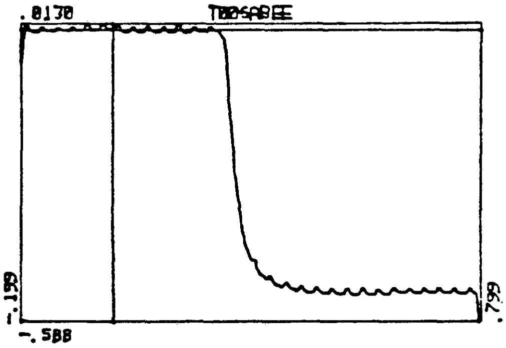
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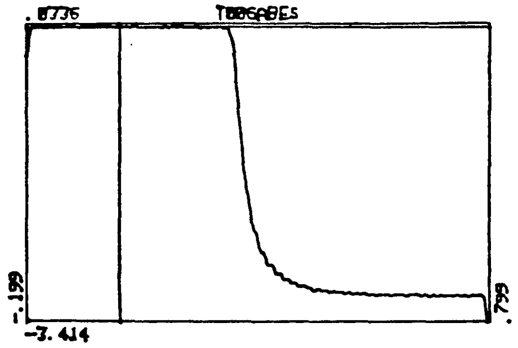
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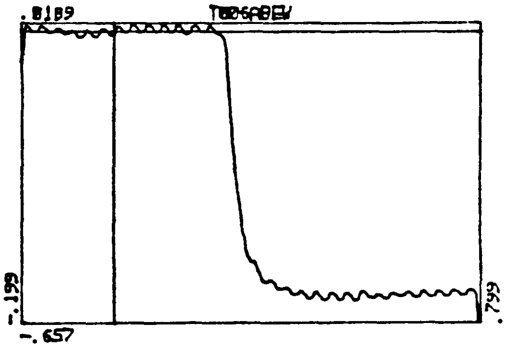
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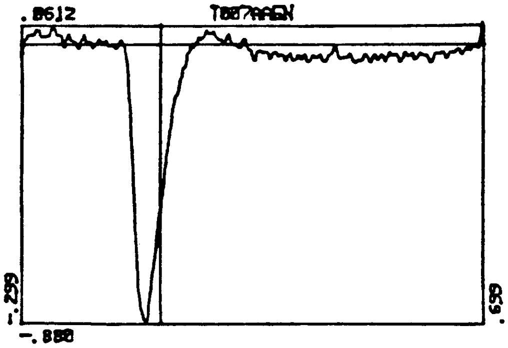
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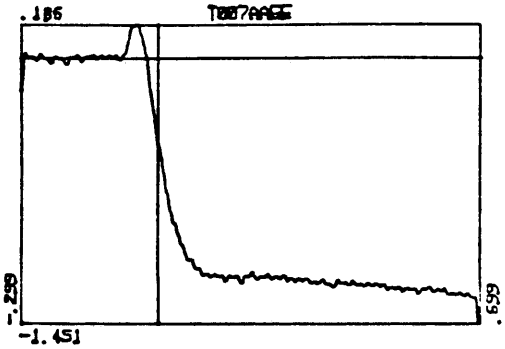
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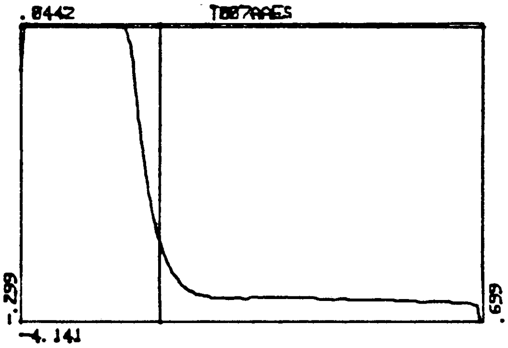
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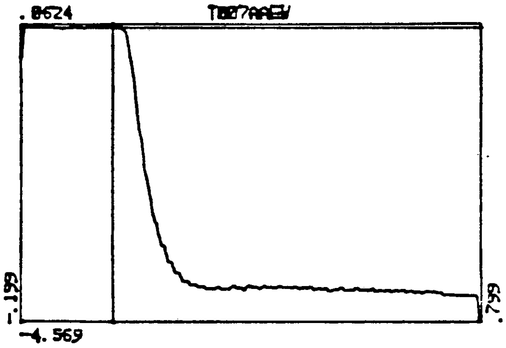
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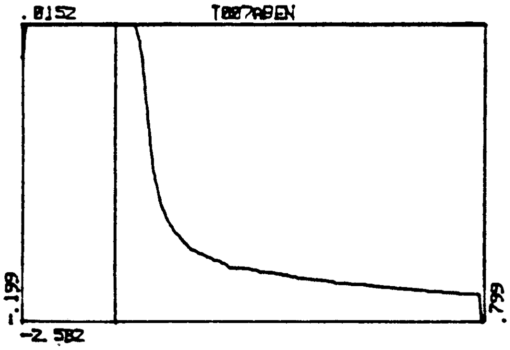
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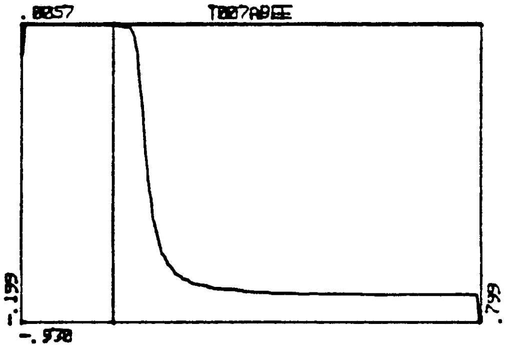
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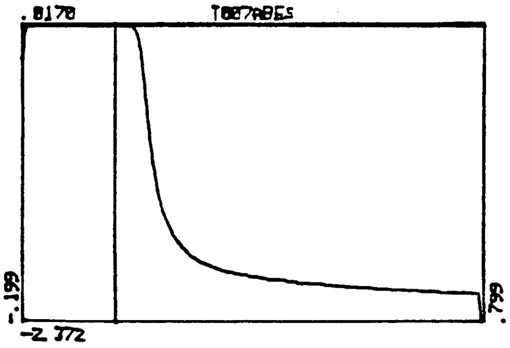
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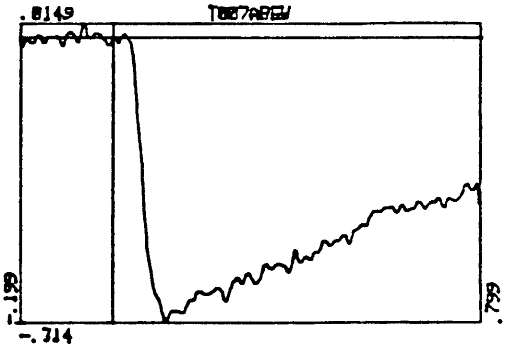
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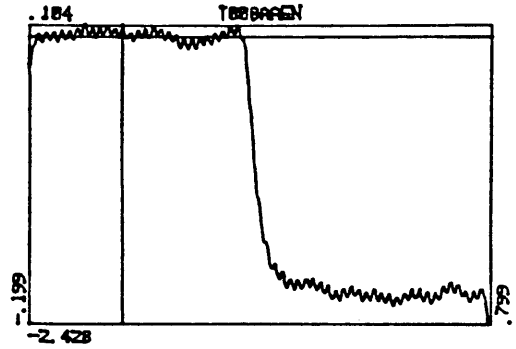
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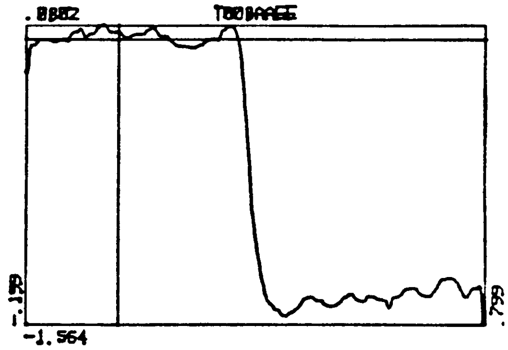
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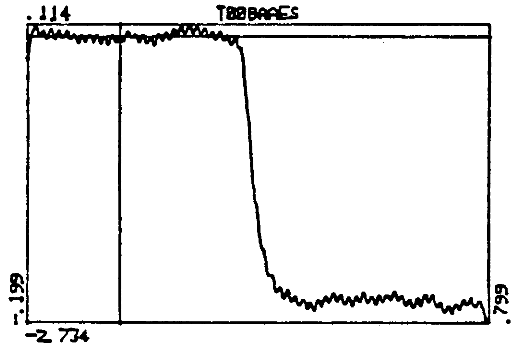
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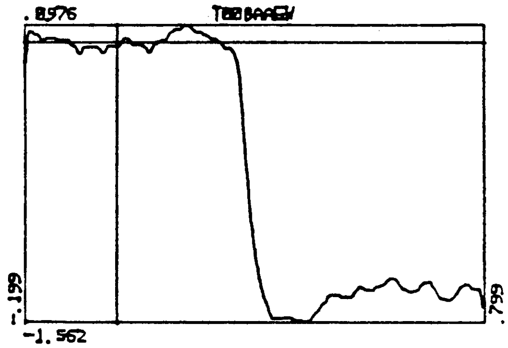
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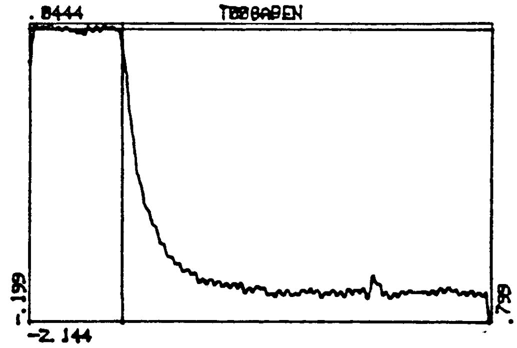
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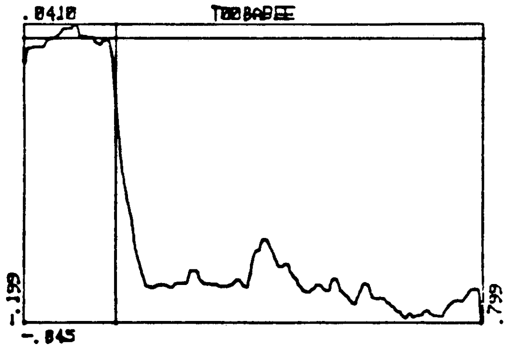
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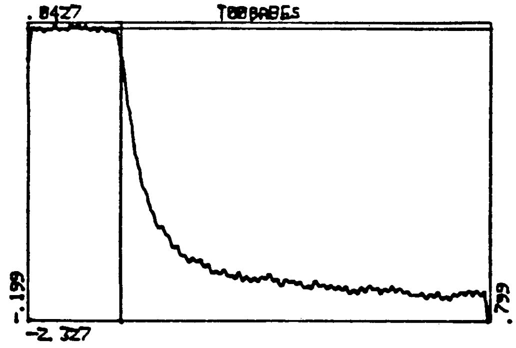
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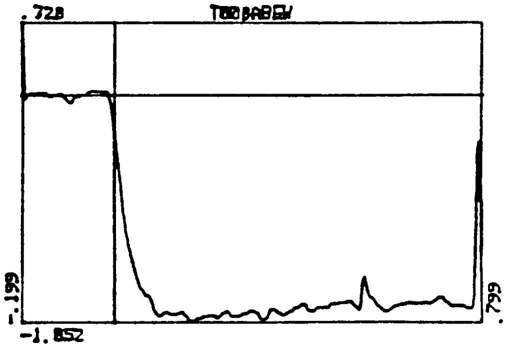
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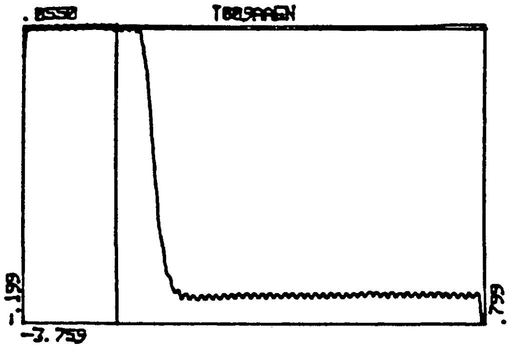
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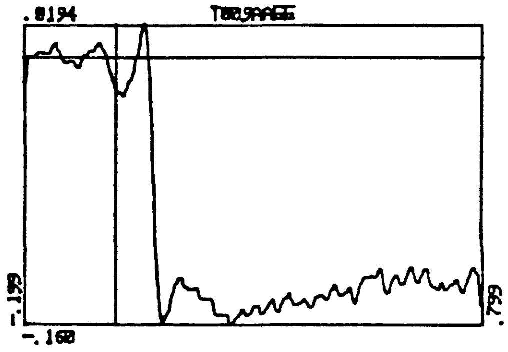
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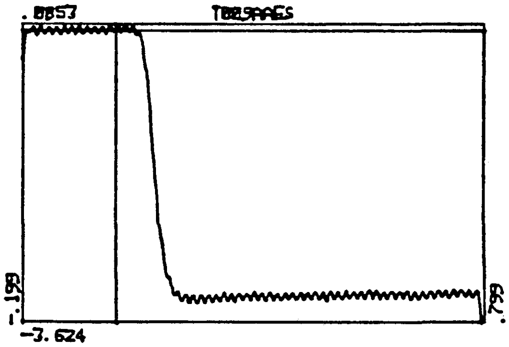
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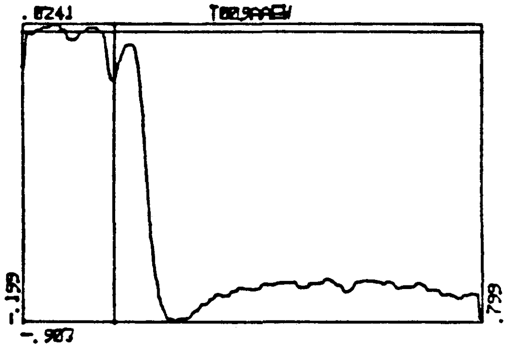
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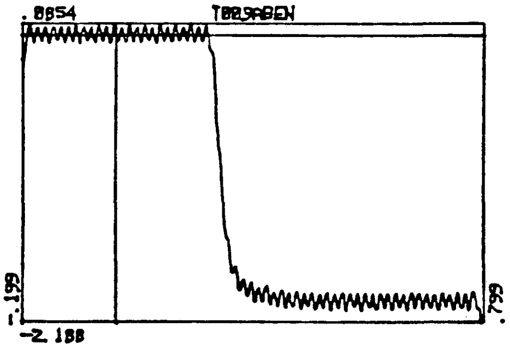
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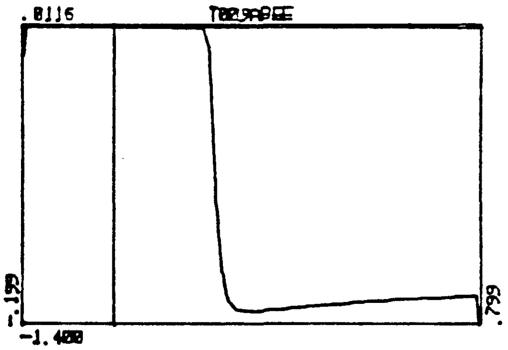
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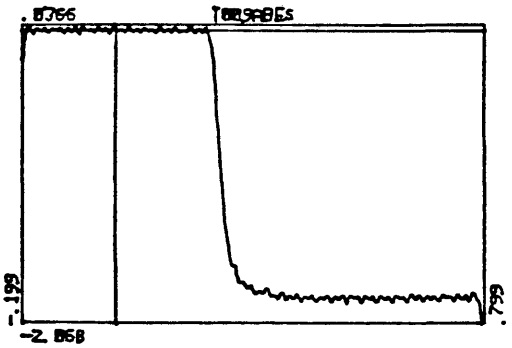
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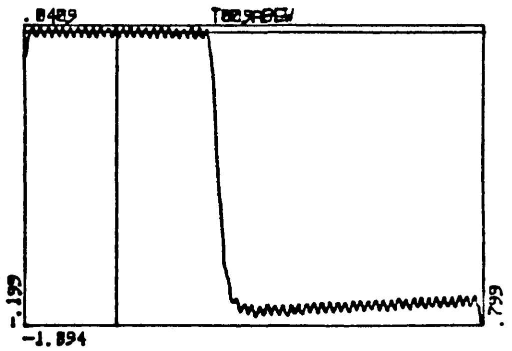
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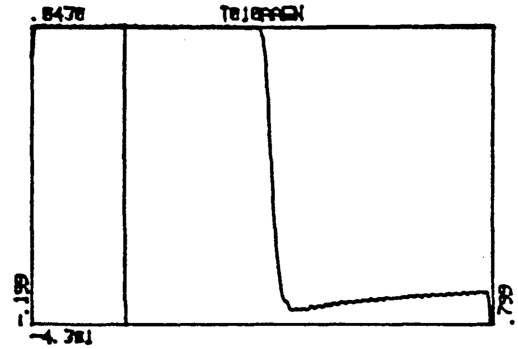
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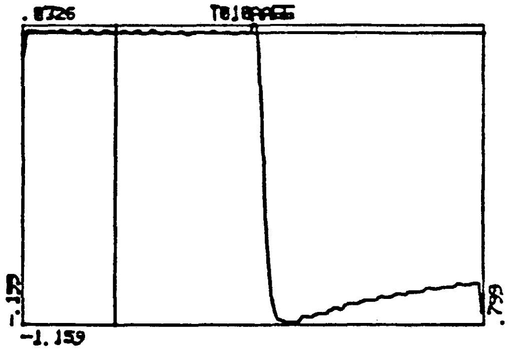
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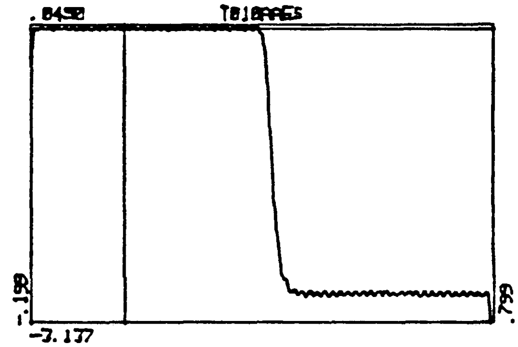
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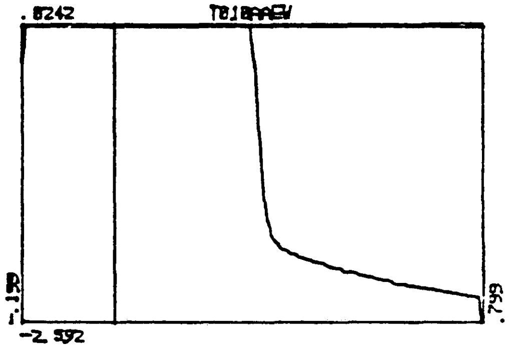
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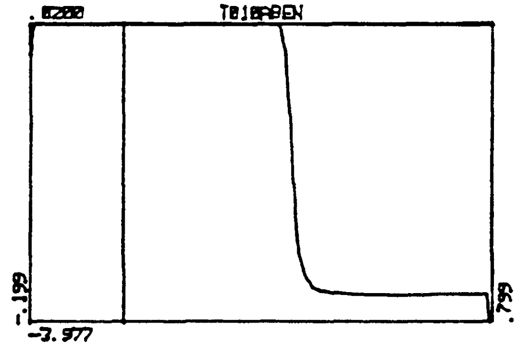
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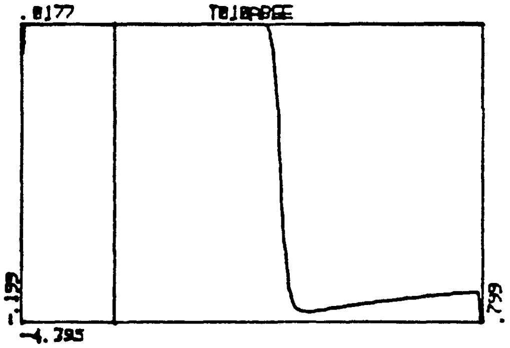
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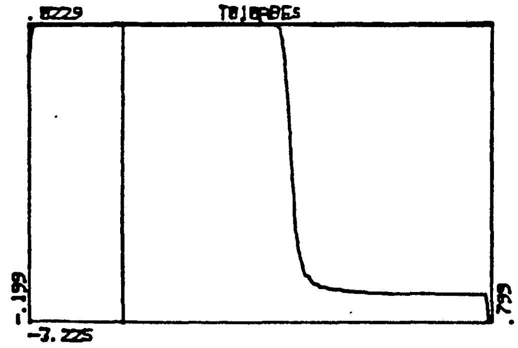
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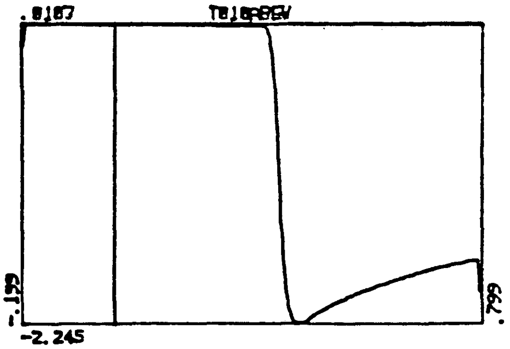
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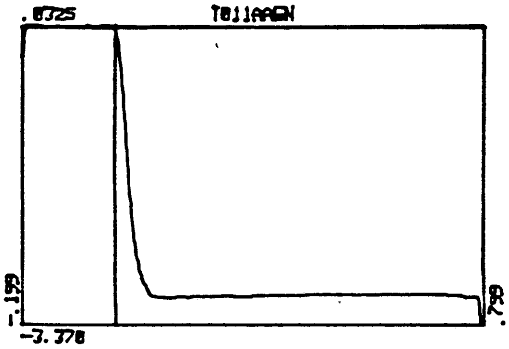
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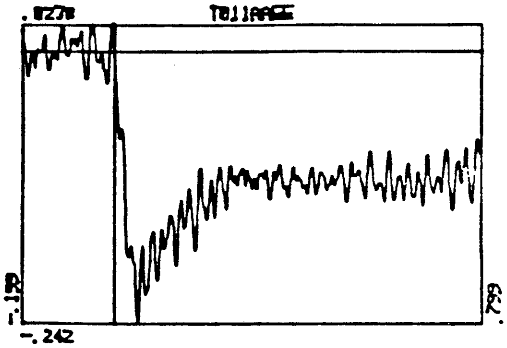
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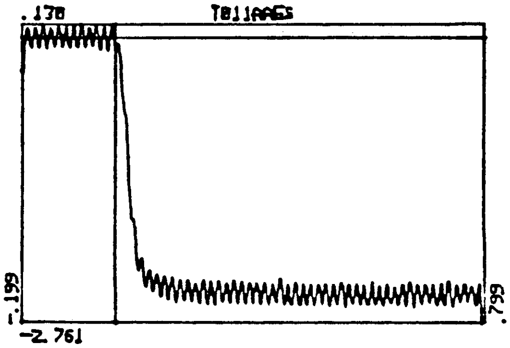
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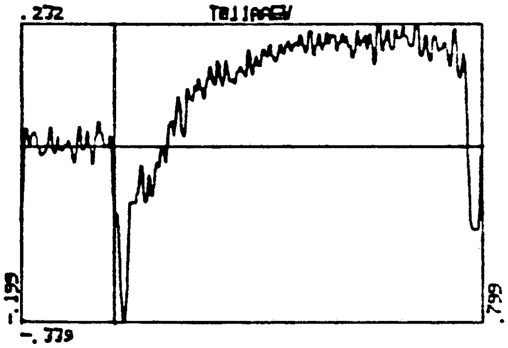
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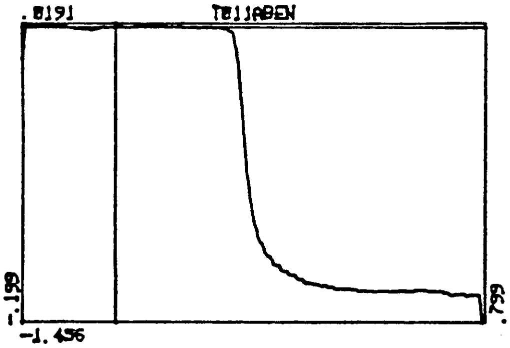
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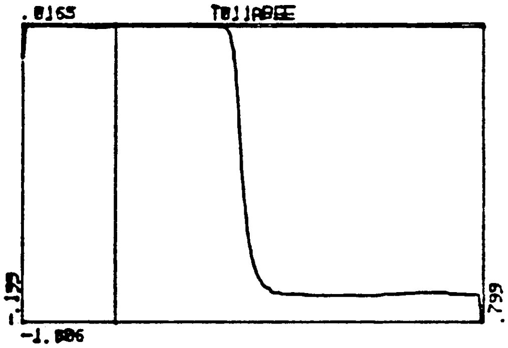
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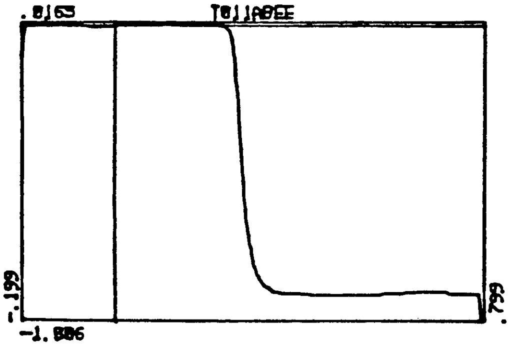
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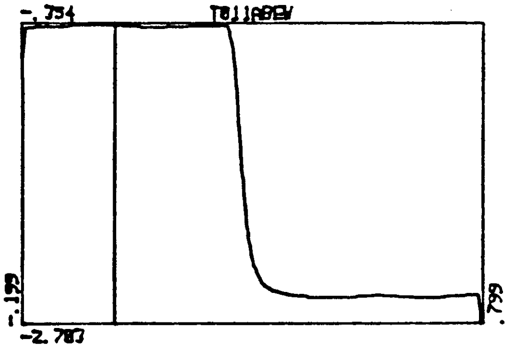
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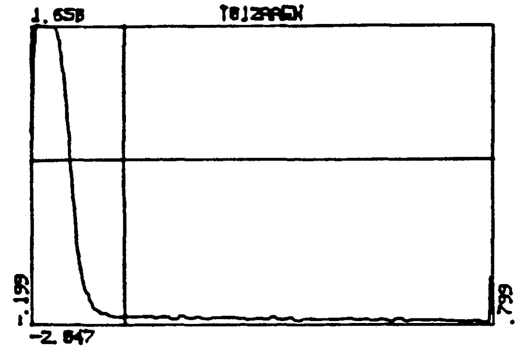
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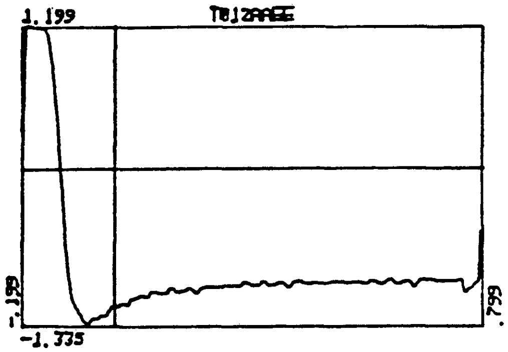
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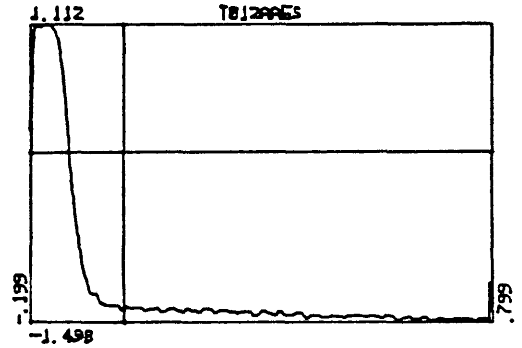
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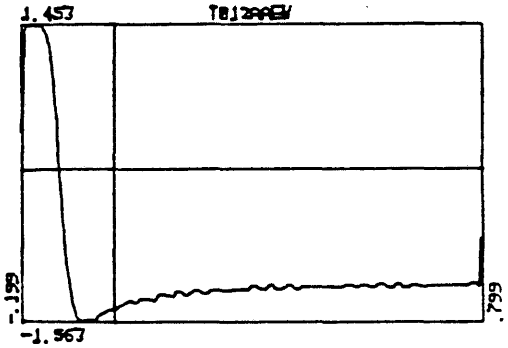
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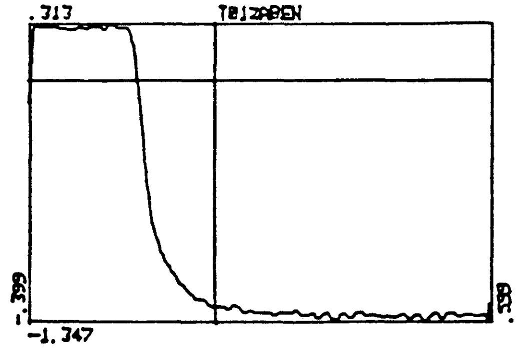
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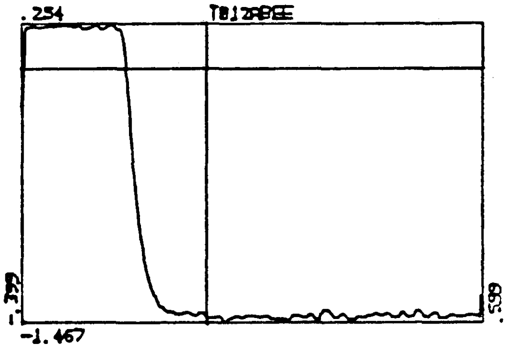
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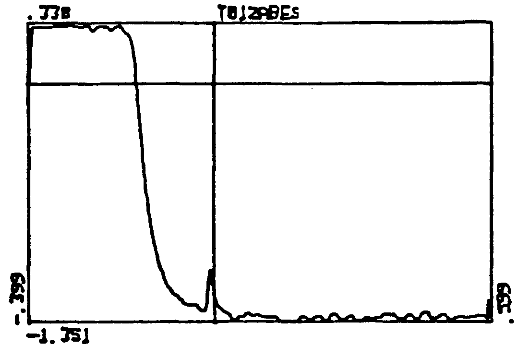
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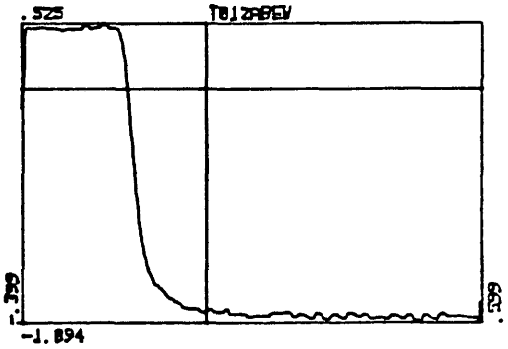
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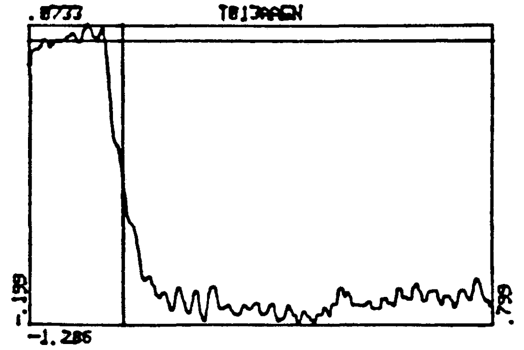
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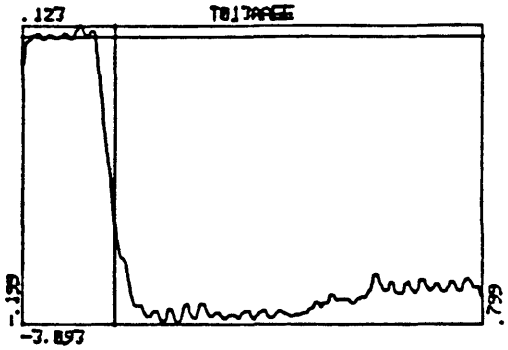
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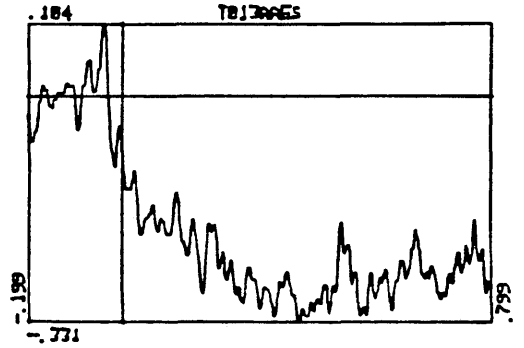
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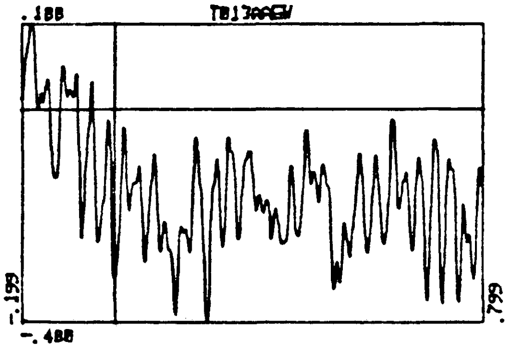
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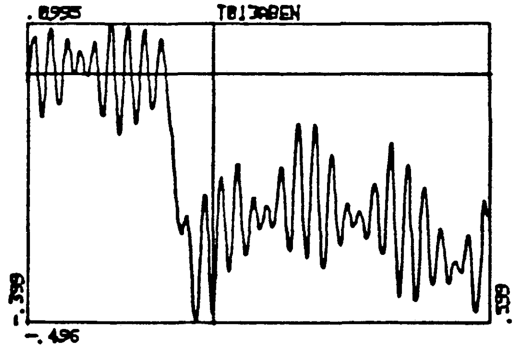
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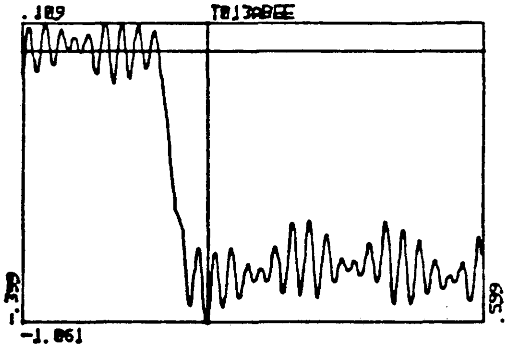
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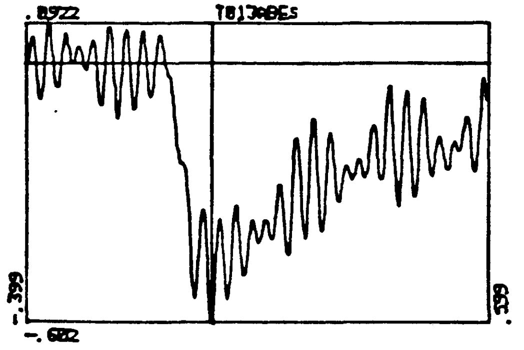
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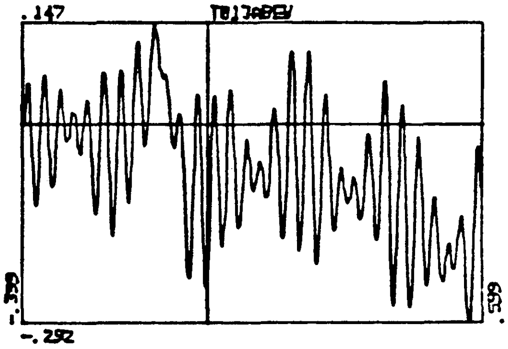
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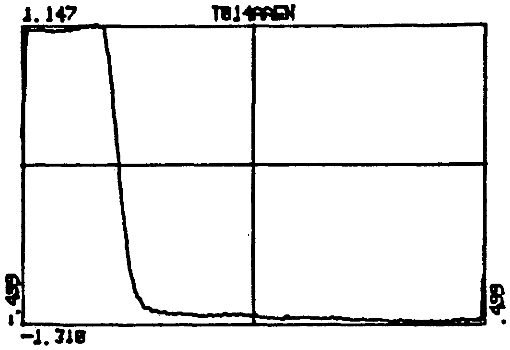
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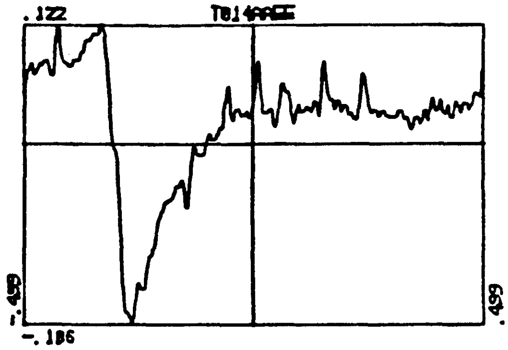
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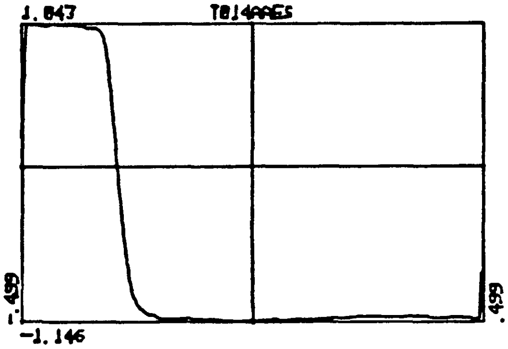
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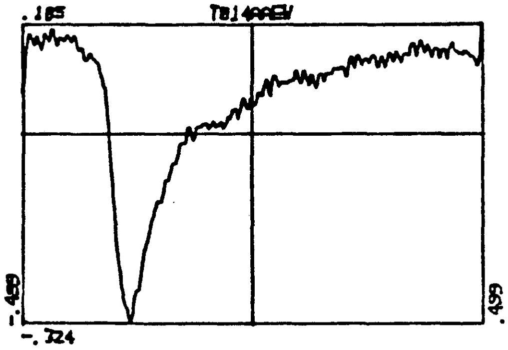
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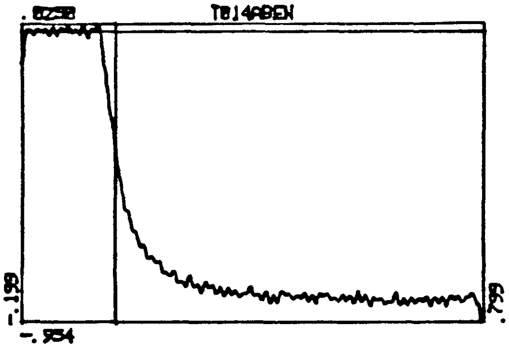
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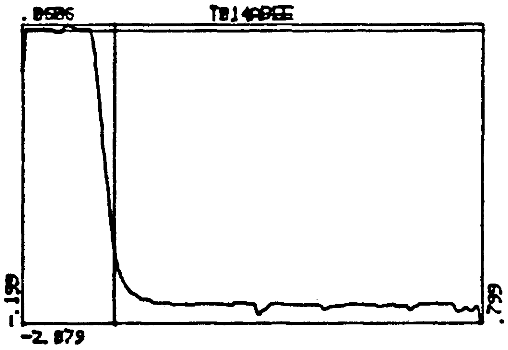
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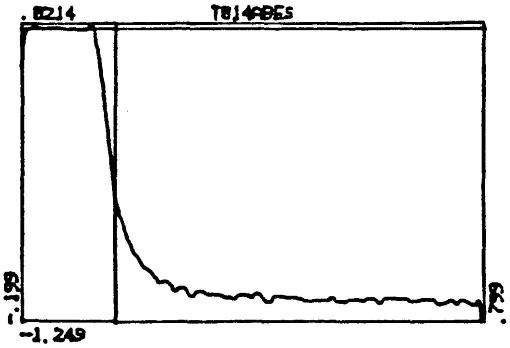
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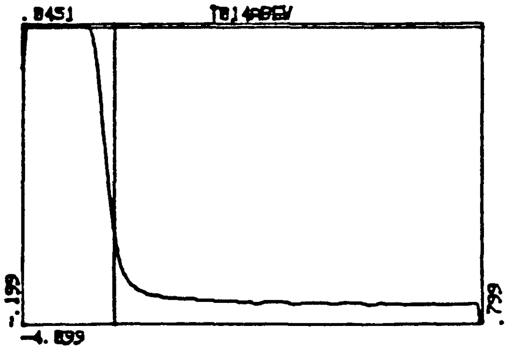
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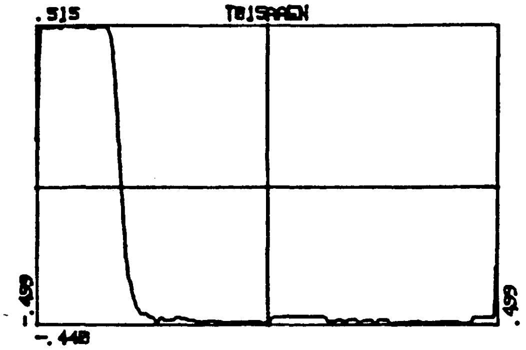
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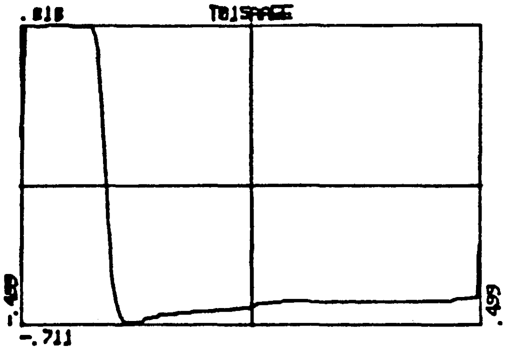
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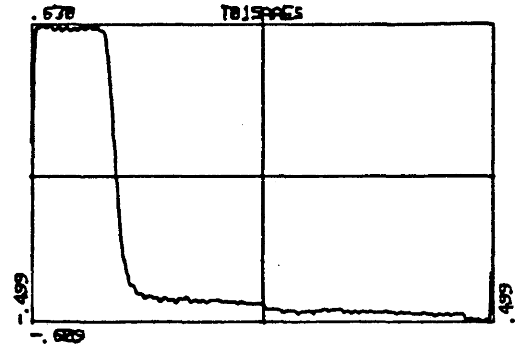
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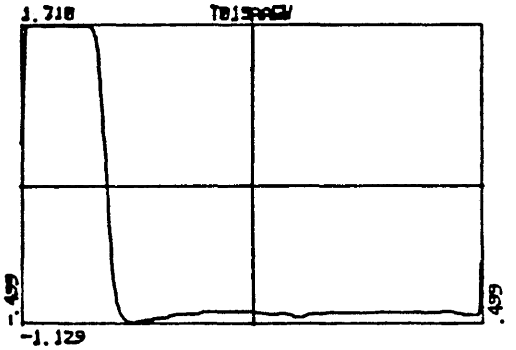
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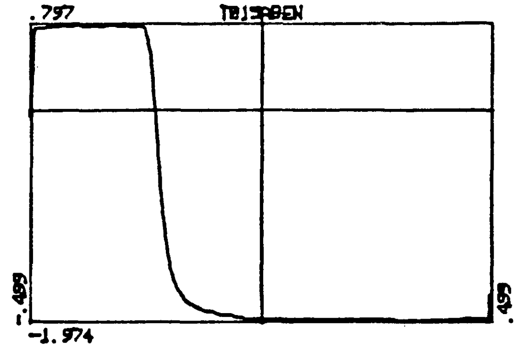
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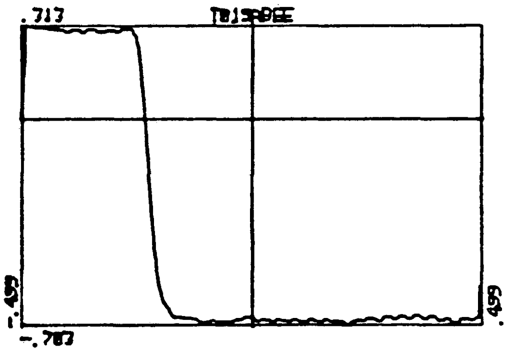
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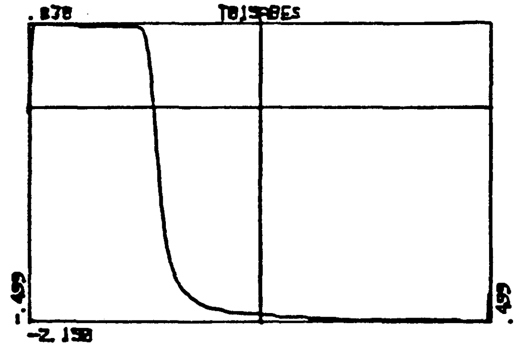
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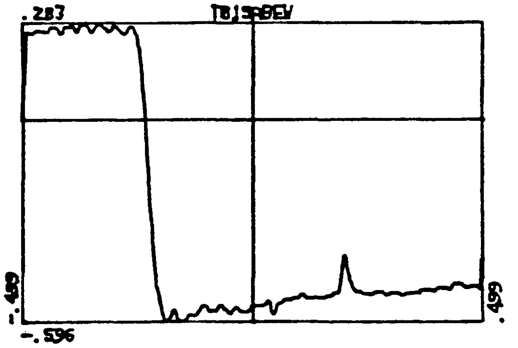
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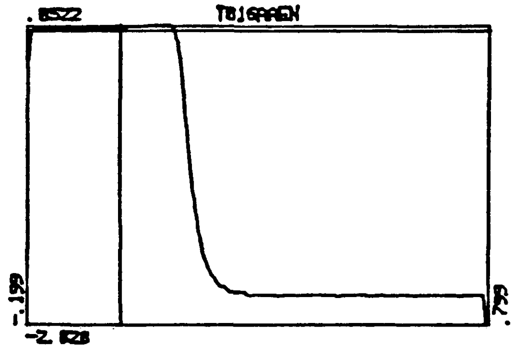
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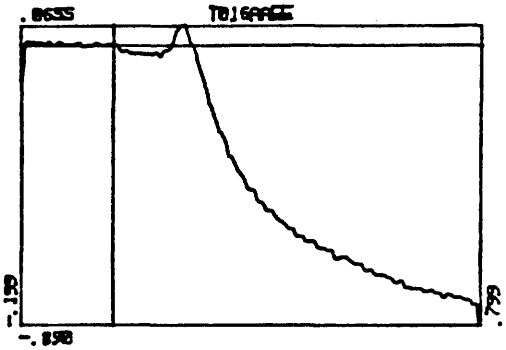
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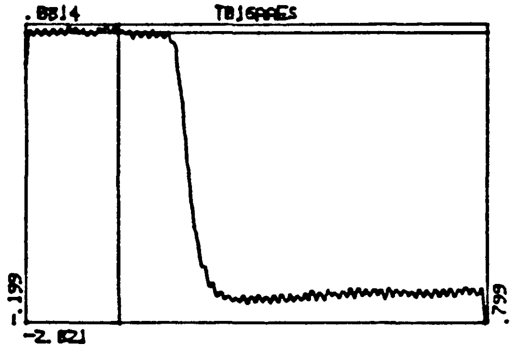
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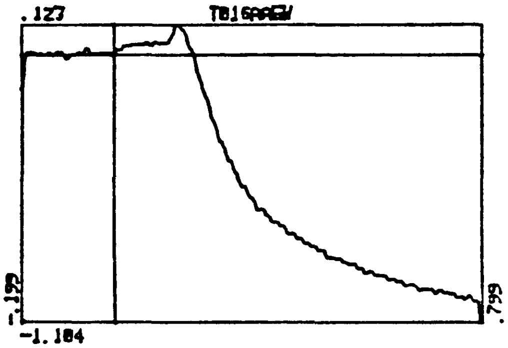
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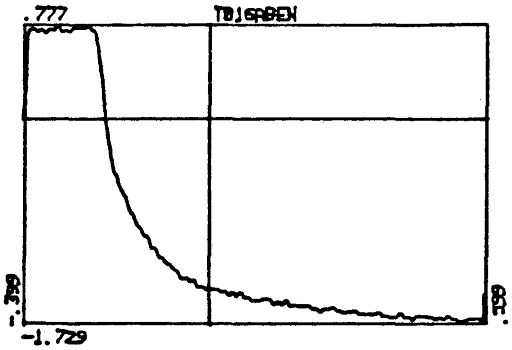
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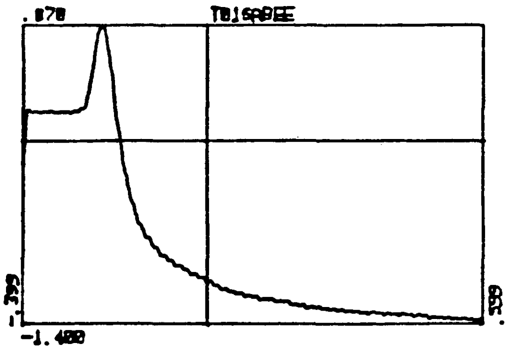
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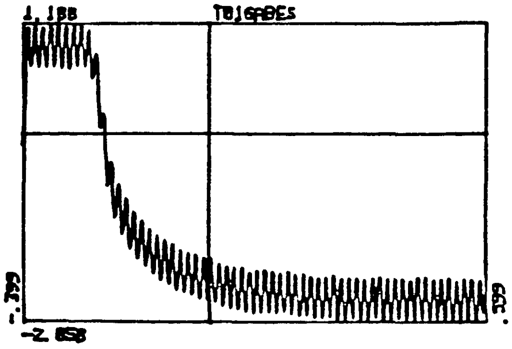
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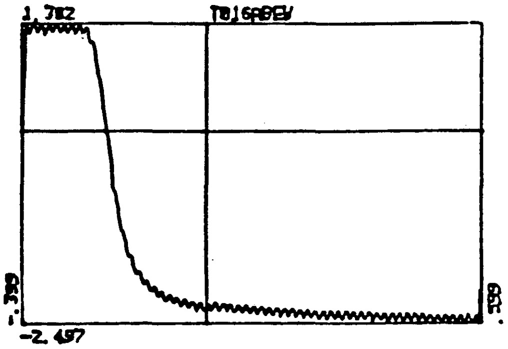
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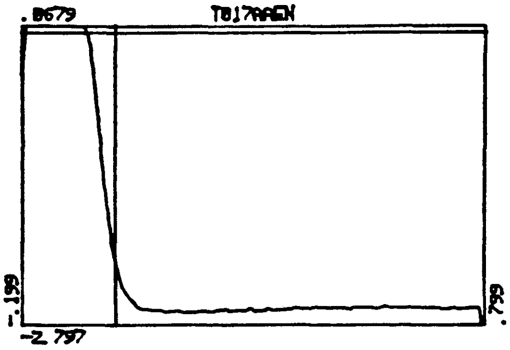
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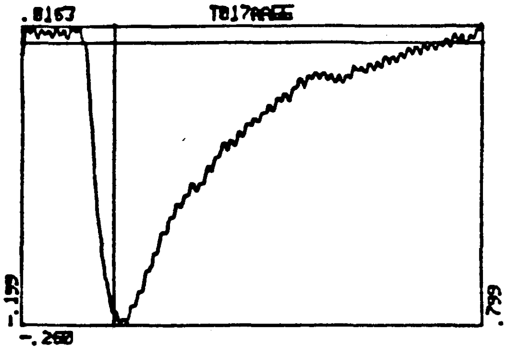
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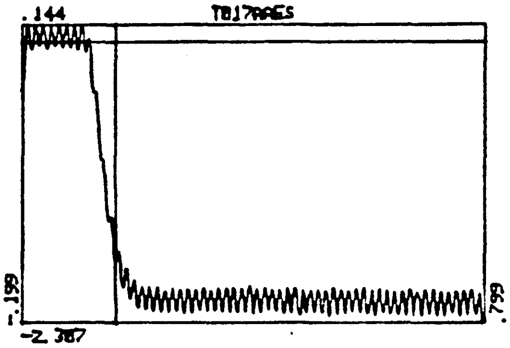
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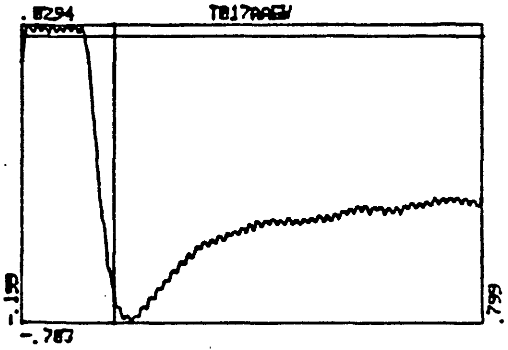
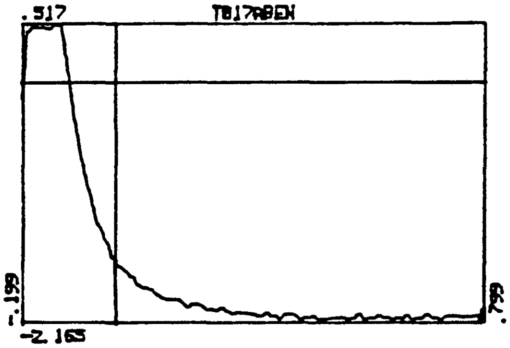
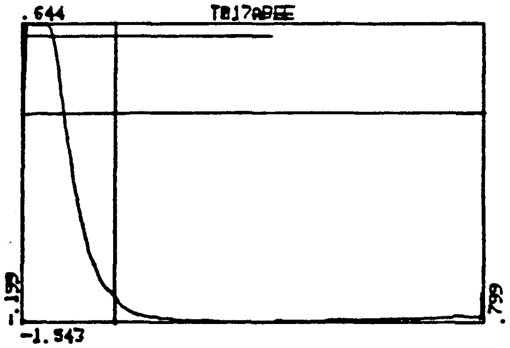
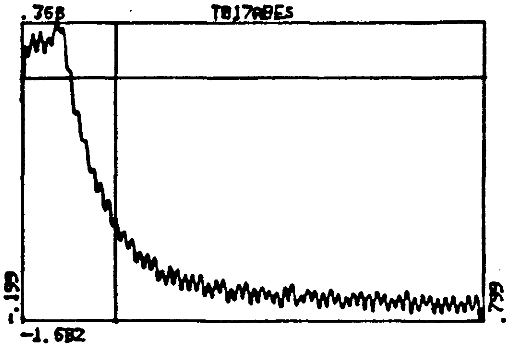
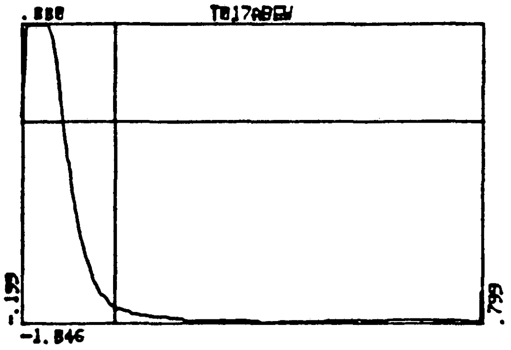
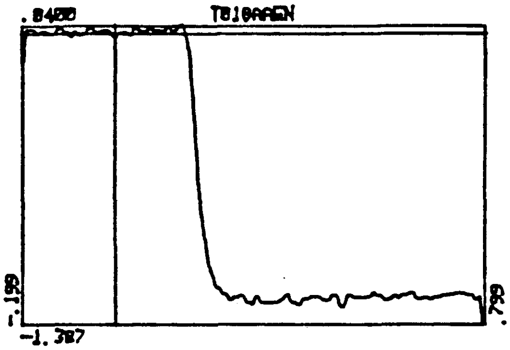

.0294
TB17AAEW
-.199
.799
-.783

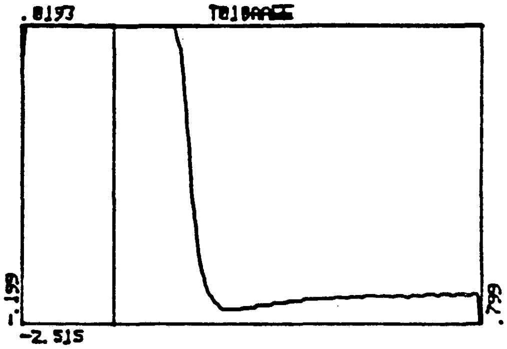

.517
TB17ABEN
-.199
.799
-2.165

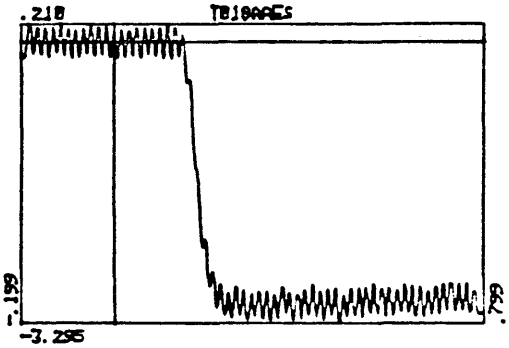

.644
TB17ABEE
-.199
.799
-1.543

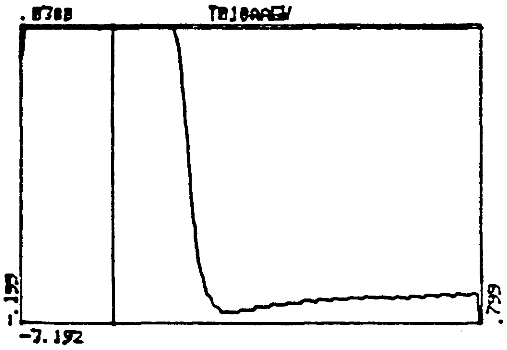

.368
TB17ABES
-.199
.799
-1.682

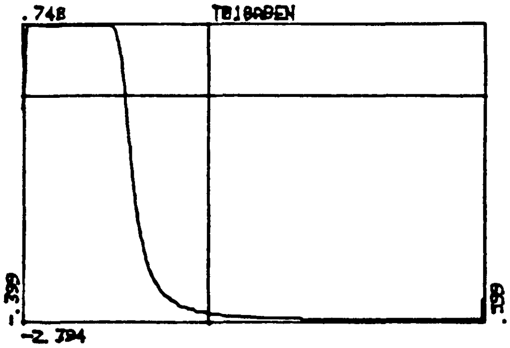

.888
TB17ABEW
-.199
.799
-1.846

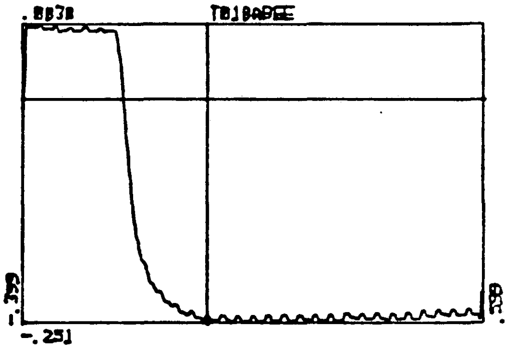

.8400
TB18AAEN
-.199
-1.387
.799

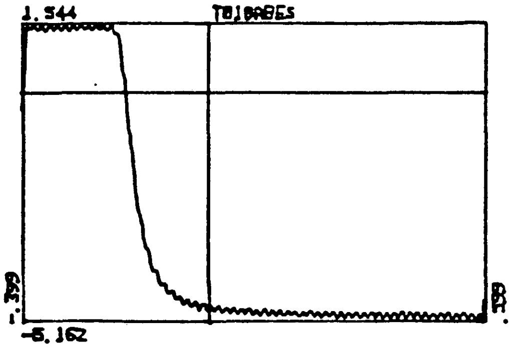

.8193
TB18AAEE
-.199
-2.515
.799

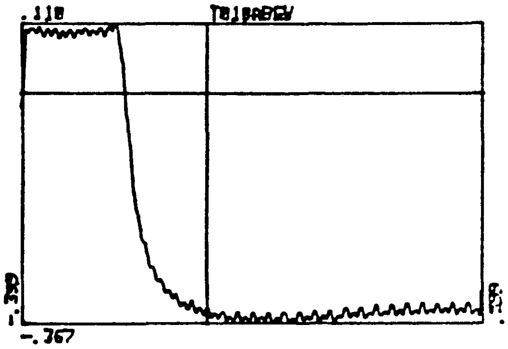

.218
TB18AAES
-.199
-3.295
.799

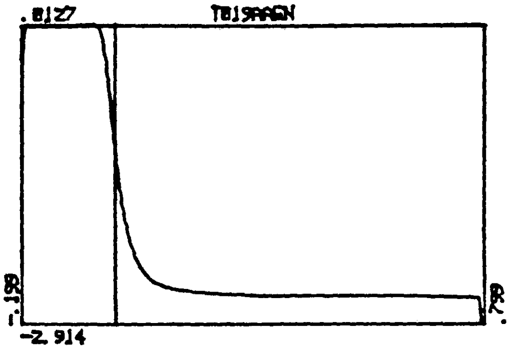

.8788
TB18AAEW
-.199
-7.192
.799

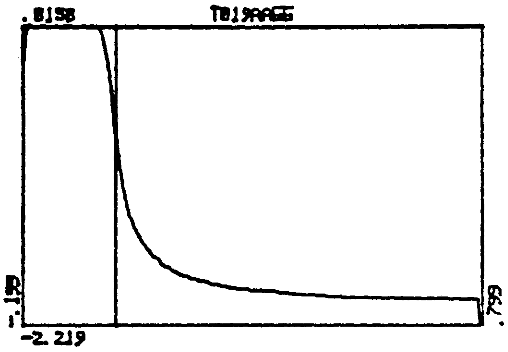

.748
TB18ABEN
-.399
-2.394
.399

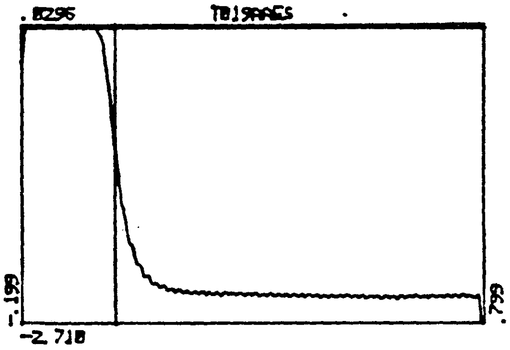

.8838
TB18ABEE
-.399
-.251
.399

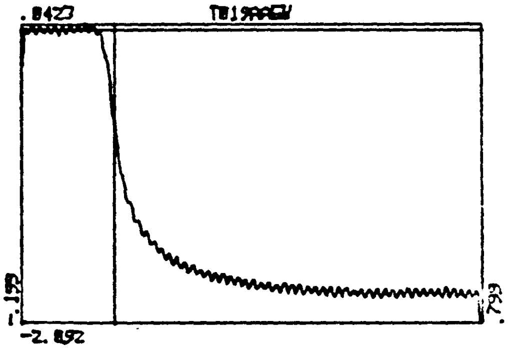

1.544
TB18ABES
-.399
-5.162
.399

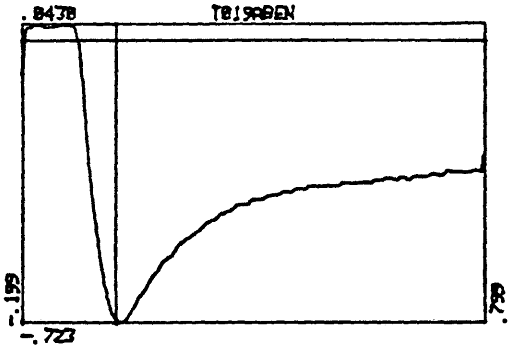

.118
TB18ABEW
-.399
-.367
.399

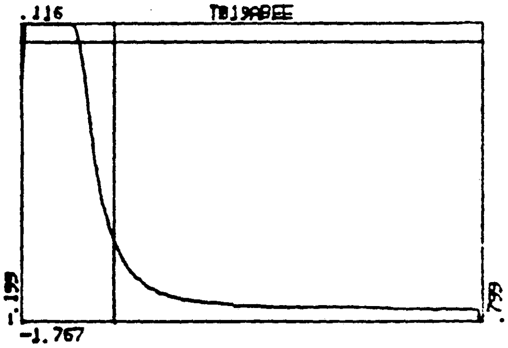

.8127
TB19AAEN
-.199
.799
-2.914

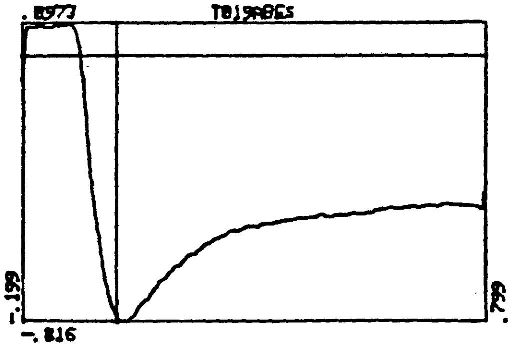

.8158
TB19AAEE
-.199
.799
-2.219

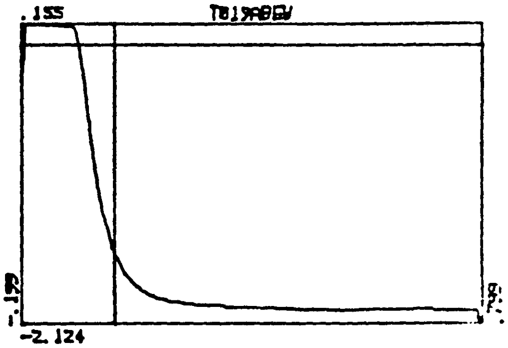

.8296
TB19AAES
-.199
.799
-2.718


.8423
TB19AAEW
-.199
.793
-2.892


.8438
TB19ABEN
-.199
.790
-.723


.116
TB19ABEE
-.199
.799
-1.767


.8973
TB19ABES
-.199
.799
-.816

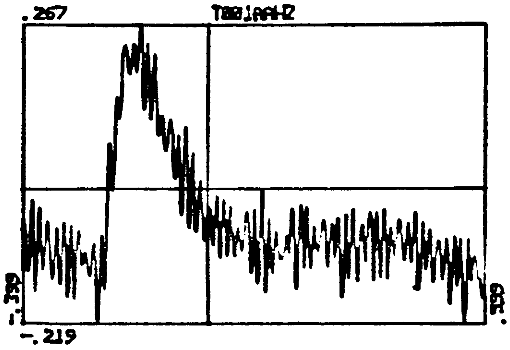

.155
TB19ABEW
-.199
.799
-2.124

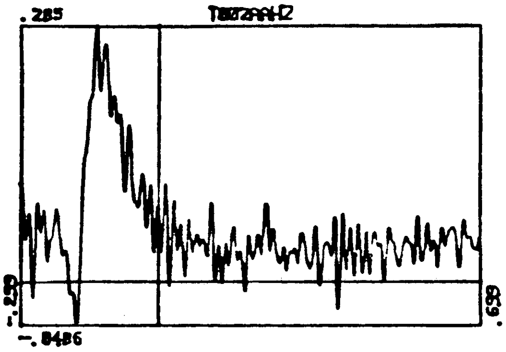
APPENDIX B

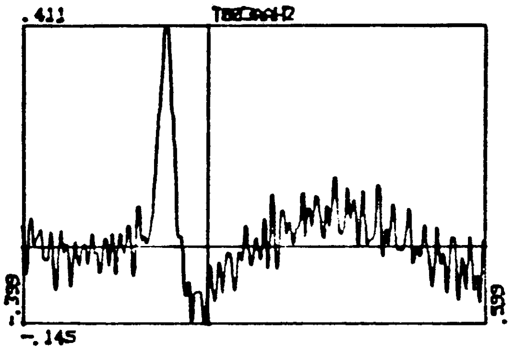
Contained within are displays of all the raw magnetic field transient decays. The curves are plotted EMF versus time. All curves are exactly one second in length. The curves are titled as follows:

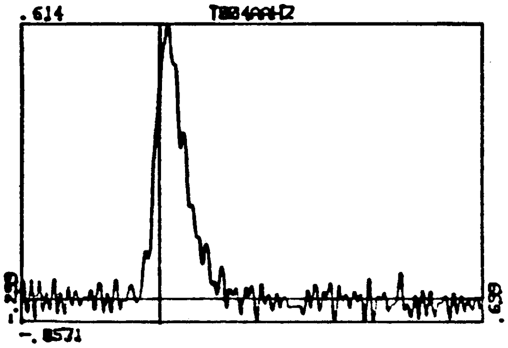
Tnnnxxyy

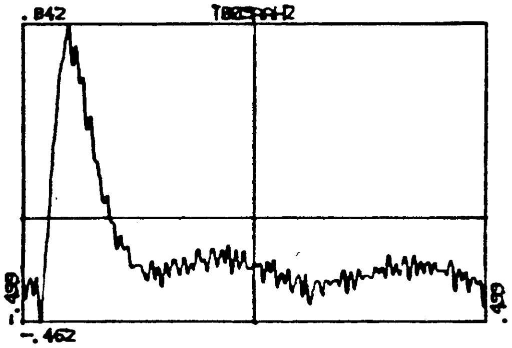
where T = Tipton Prospect
nnn = number of station occupied
xx = AA or AB depending on source orientation
yy = HZ for vertical component of the magnetic field

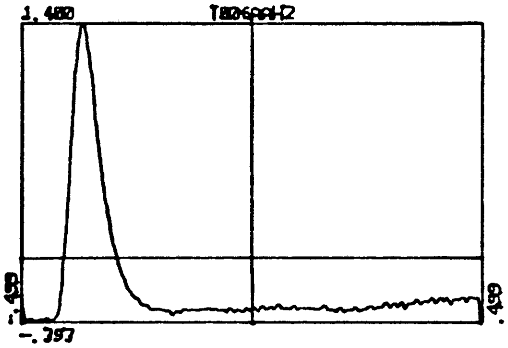

.267
T801AAHZ
-.399
-.219
.599

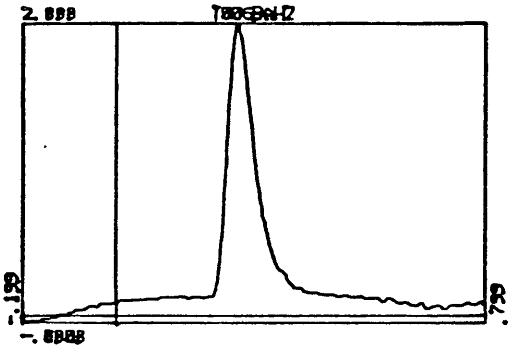

.285
T802AAHZ
-.259
-.0486
.699

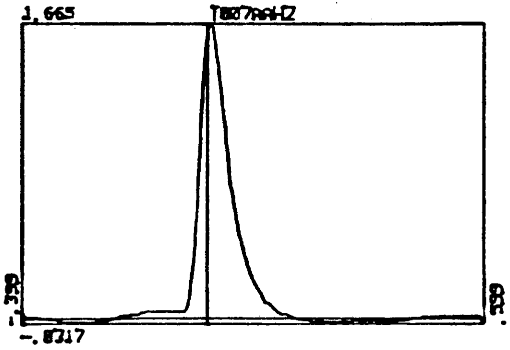

.411
T803AAHZ
-.399
-.145
.599

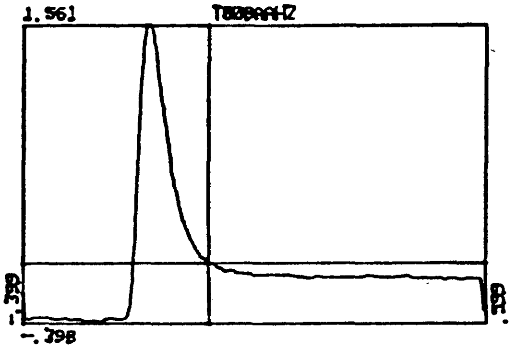

.614
T804AAHZ
-.259
-.0571
.699

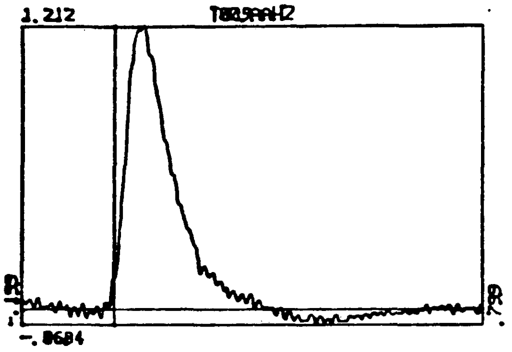

.042
T805AAHZ
-.499
-.462
.499

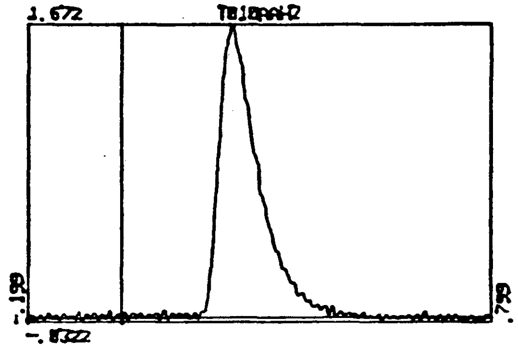

1.480
T806AAHZ
-.499
-.397
.499

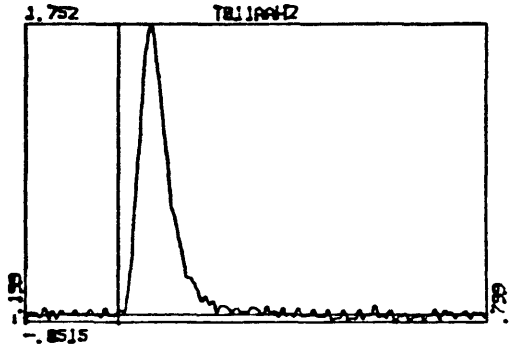

2.000
T806BAHZ
-.199
-.0000
.799

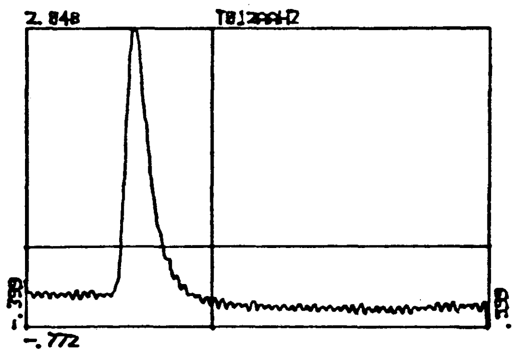

1.665
T807AAHZ
-.399
-.0717
.599

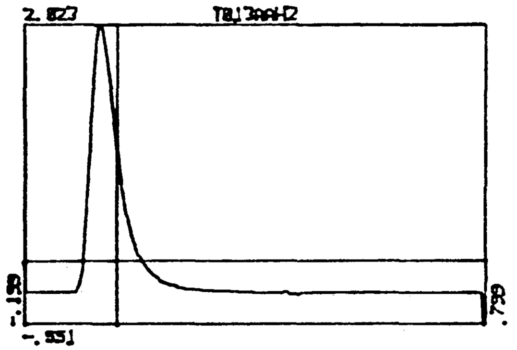

1.561
TB08AAHZ
-.398

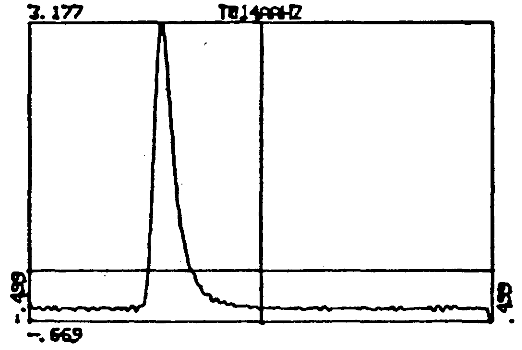

1.212
TB09AAHZ
-.0684

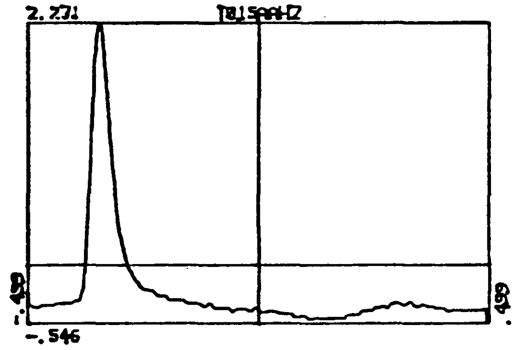

1.672
TB10AAHZ
-.0322

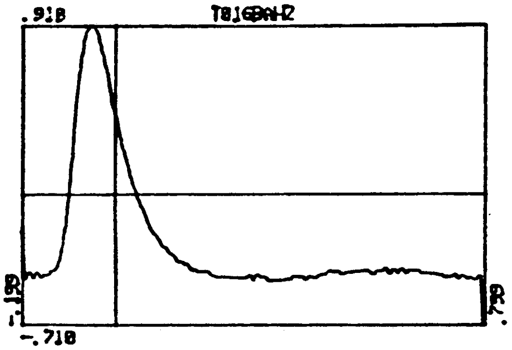

1.752
TB11AAHZ
-.0515

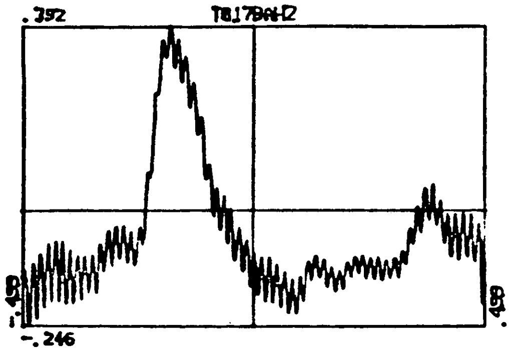

2.848
TB12AAHZ
-.772

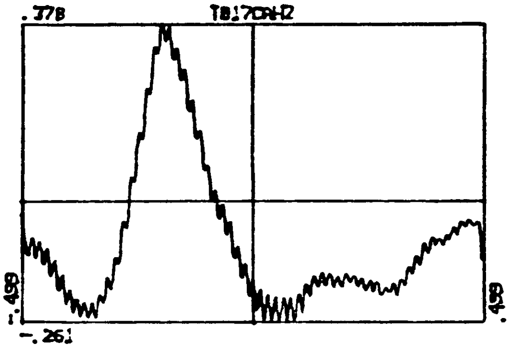

2.827
TB13AAHZ
-.551

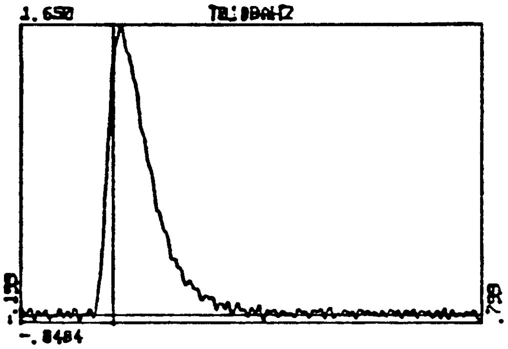

3.177
TB14AAHZ
-.669

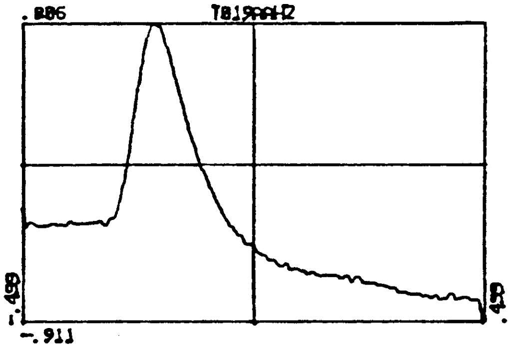

2.271
TB15AAHZ
-.546


.918
T816BAHZ
1.190
.790
-.718


.392
T817BAHZ
1.490
.490
-.246


.378
T817CAHZ
1.490
.490
-.261


1.650
T818BAHZ
1.190
.790
-.8484


.886
T819AAHZ
1.490
.490
-.911

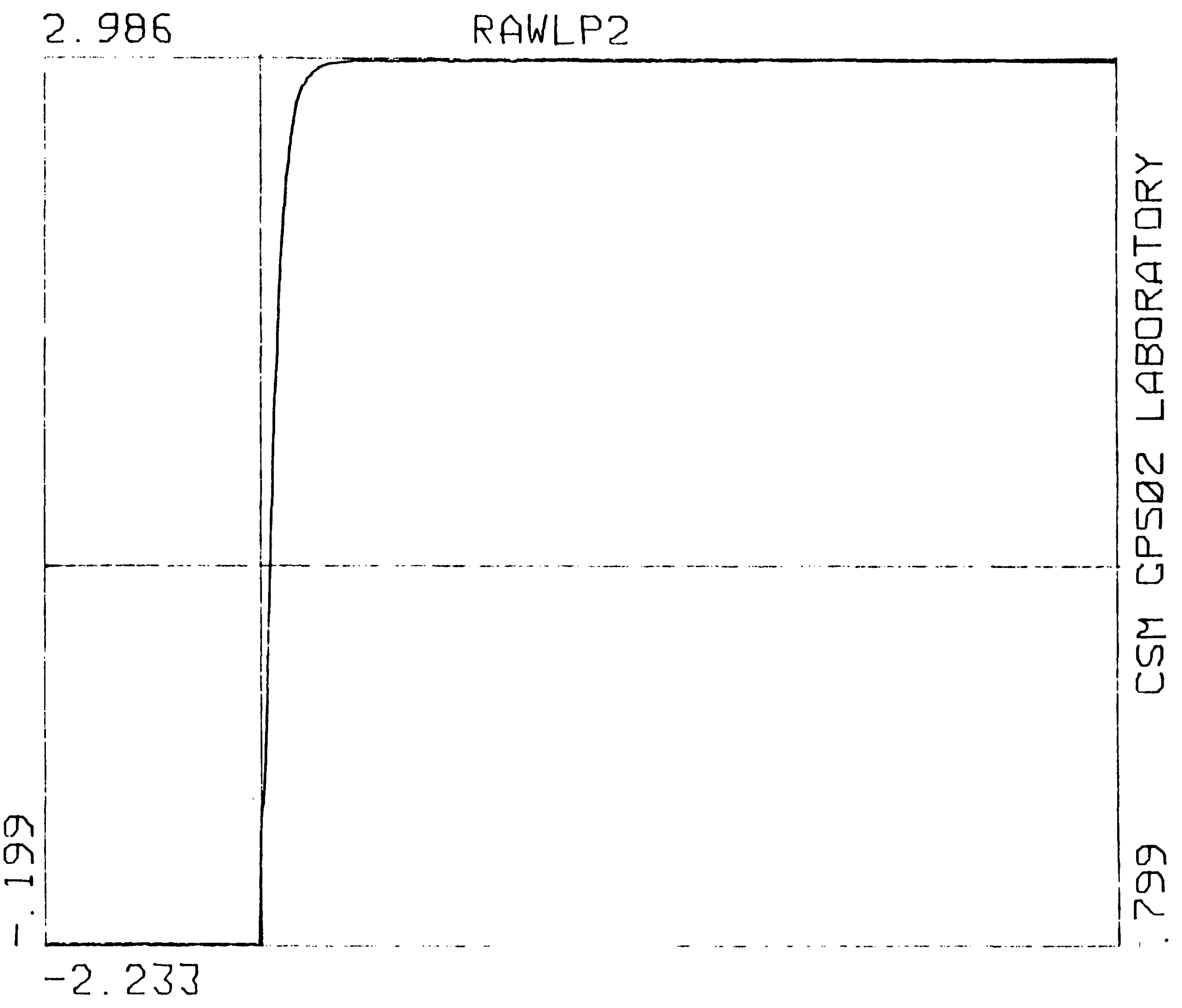
APPENDIX C

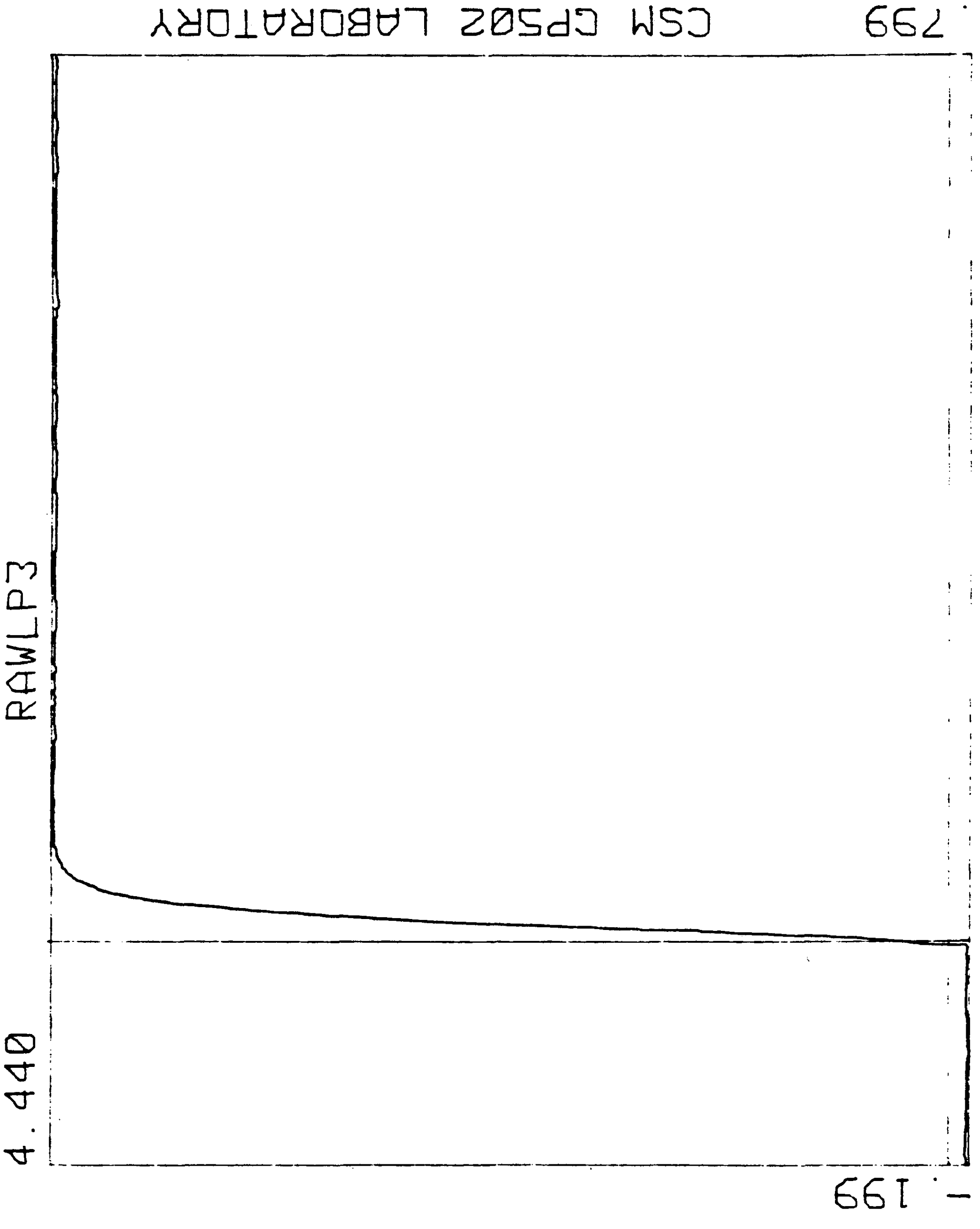
Contained within are displays of the step and impulse response of the three low pass analog filter settings used in data acquisition. LP4 was rarely used and only in very noisy conditions. Curves are plotted voltage versus time. All curves are one second in length. Curves are titled as follows:

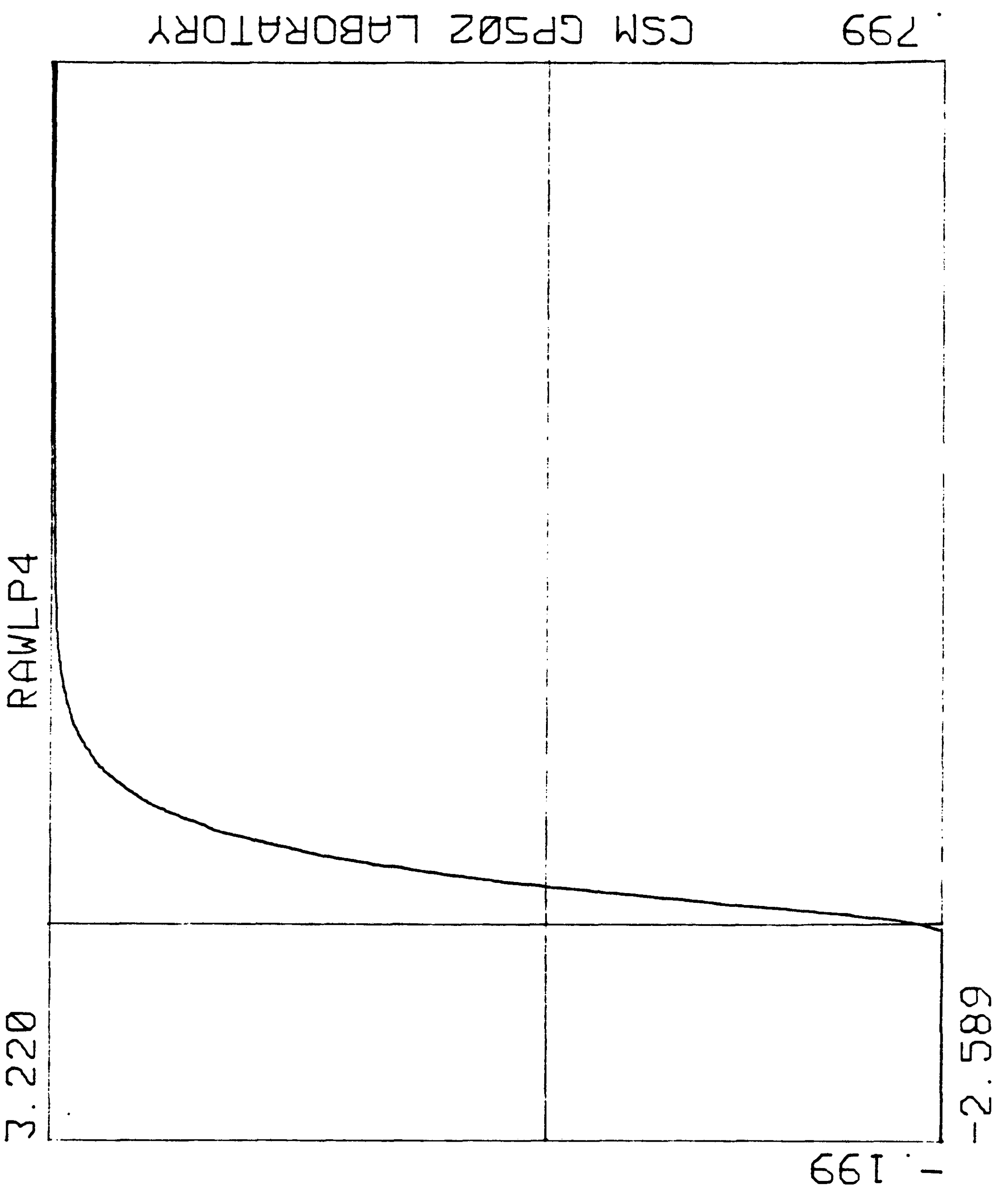
RAWLPn

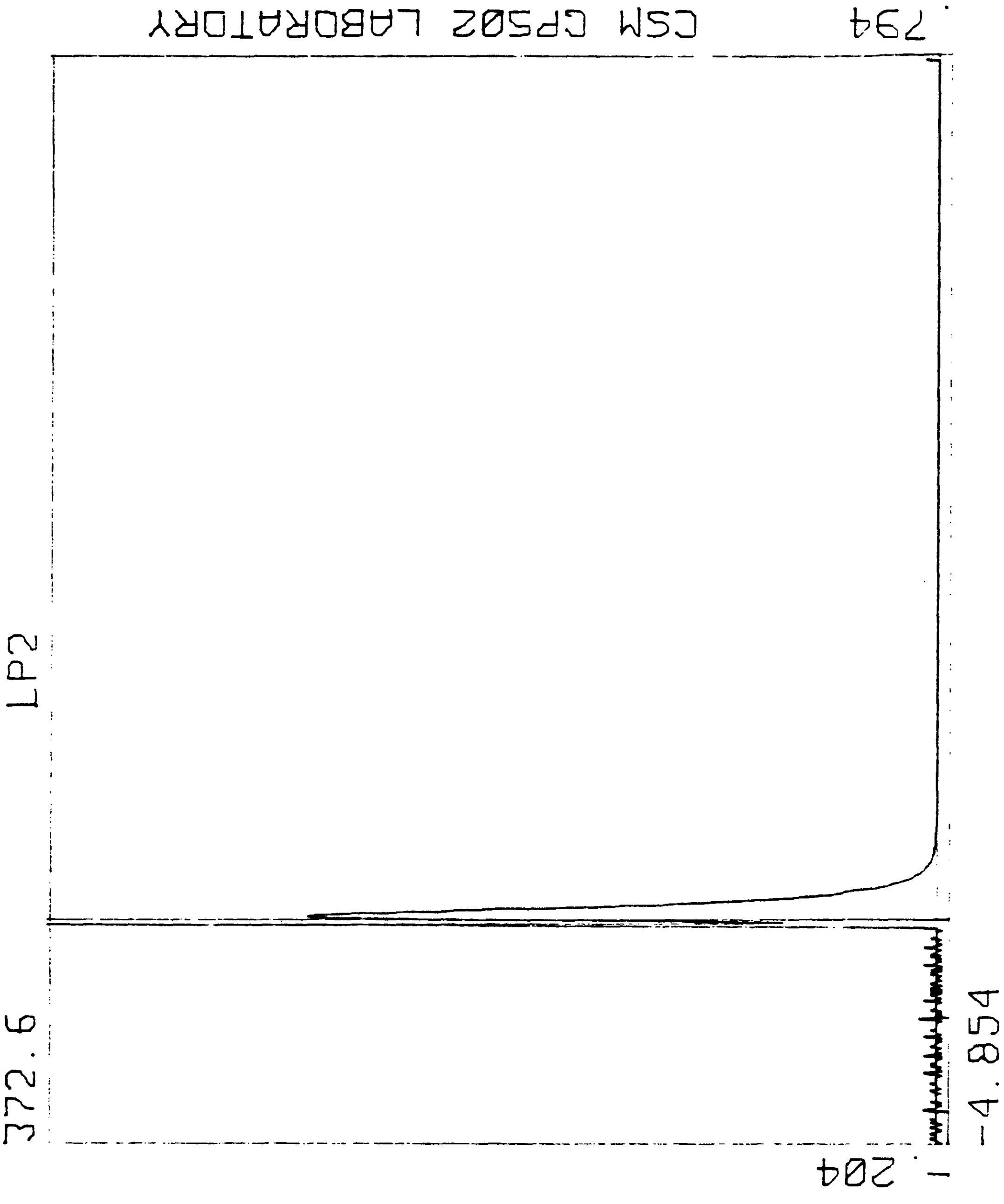
where n = number of low pass filter setting
and RAWLP is the step response

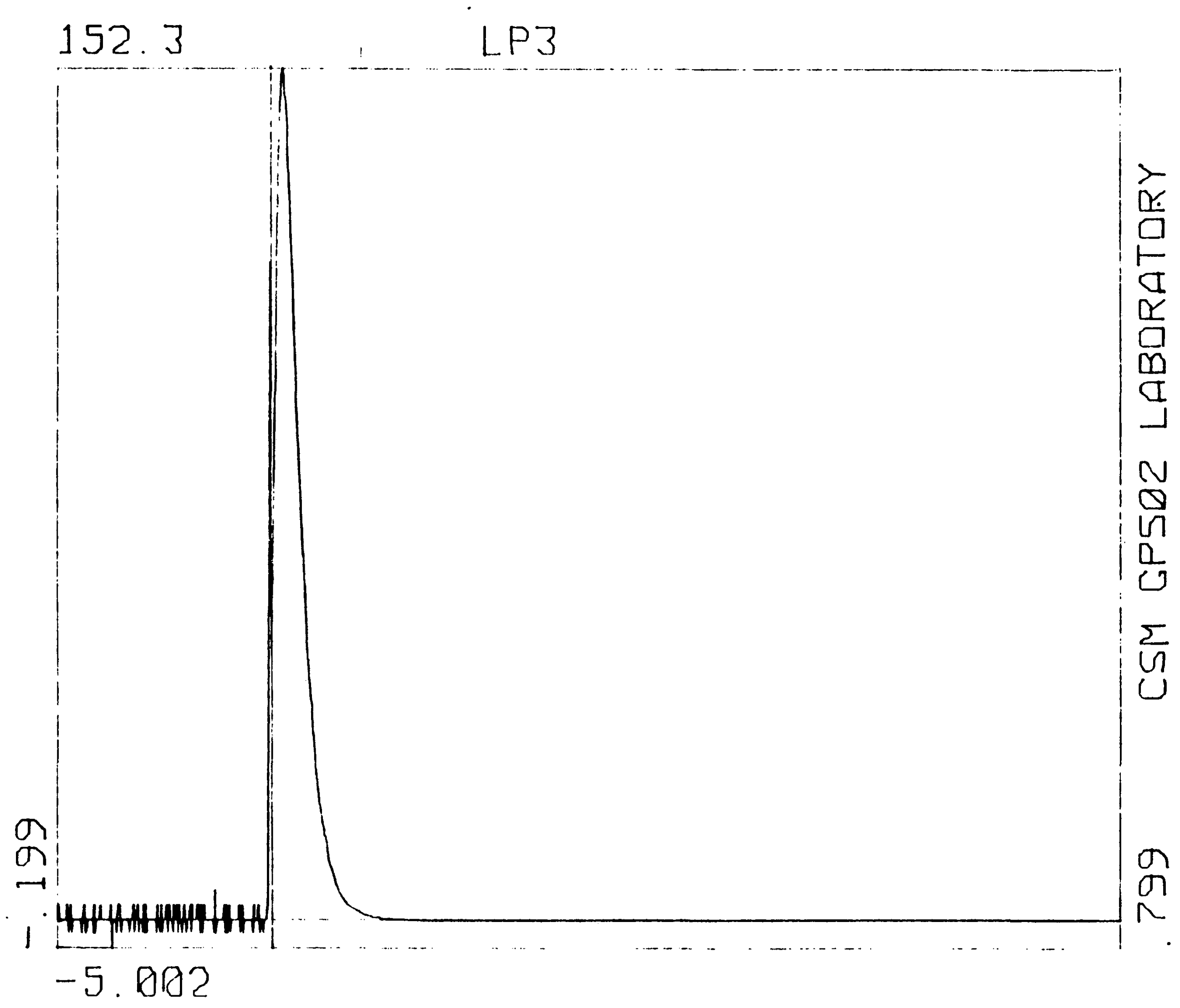
or LPn
where n = number of low pass filter setting
and LP is the impulse response

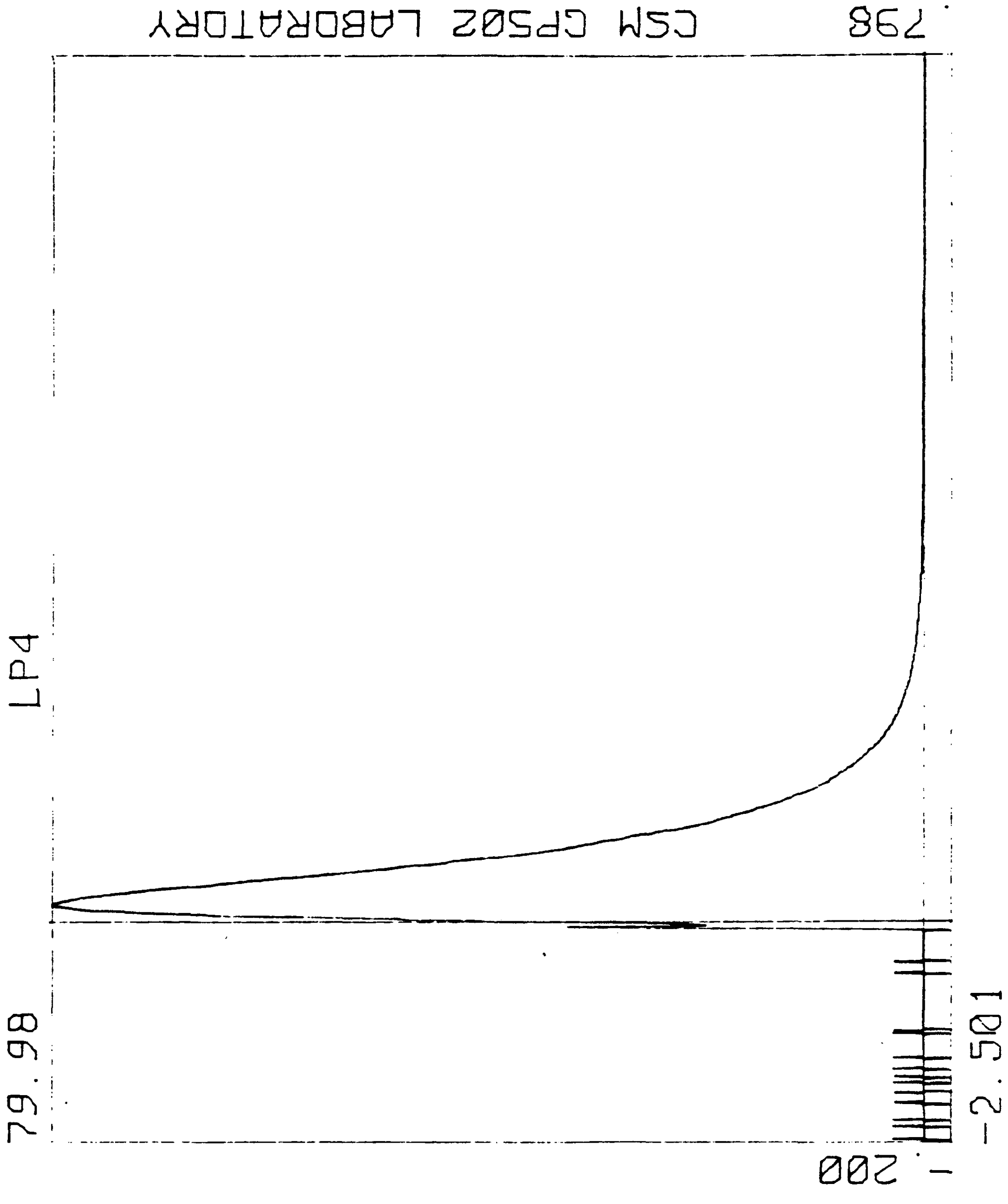

2.986
RAWLP2
CSM CP502 LABORATORY
-.199
-2.233
.799


CSM CP502 LABORATORY
799
RAWLP3
4.440
-.101
-199


CSM CP502 LABORATORY
.799
RAWLP4
3.220
-2.589
-.199


CSM CP502 LABORATORY
794
LP2
372.6
-4.854
204


152.3
LP3
CSM GP502 LABORATORY
199
799
-5.002

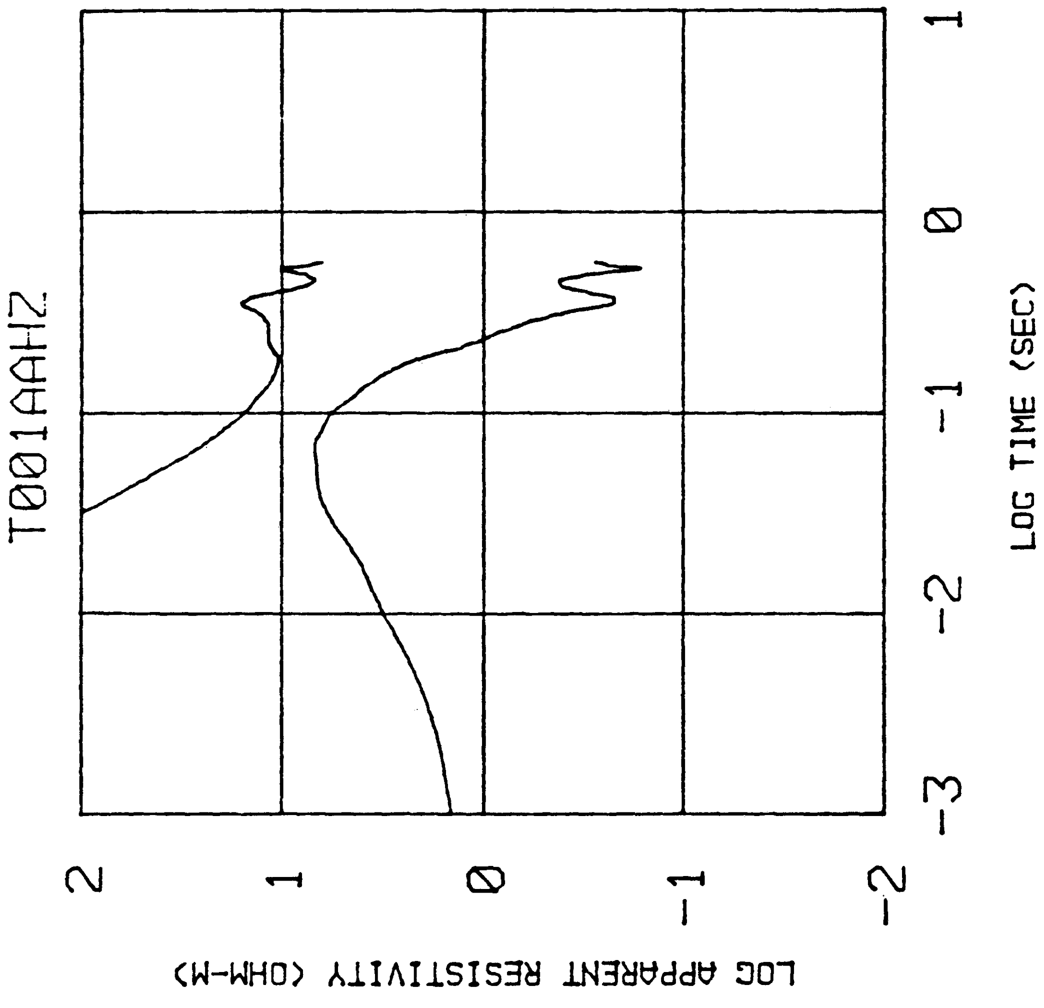

CSM GP502 LABORATORY
798
LP4
79.98
-2.501
200
1

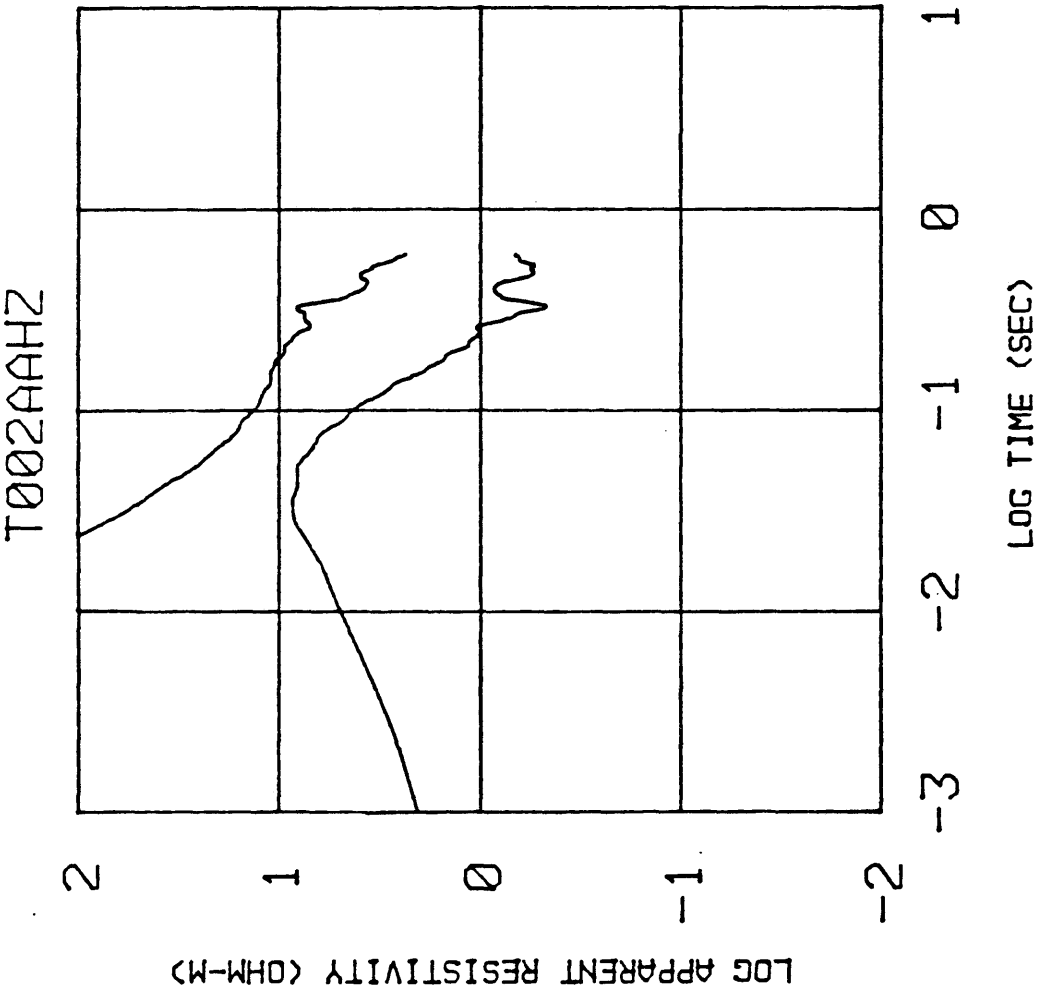
APPENDIX D

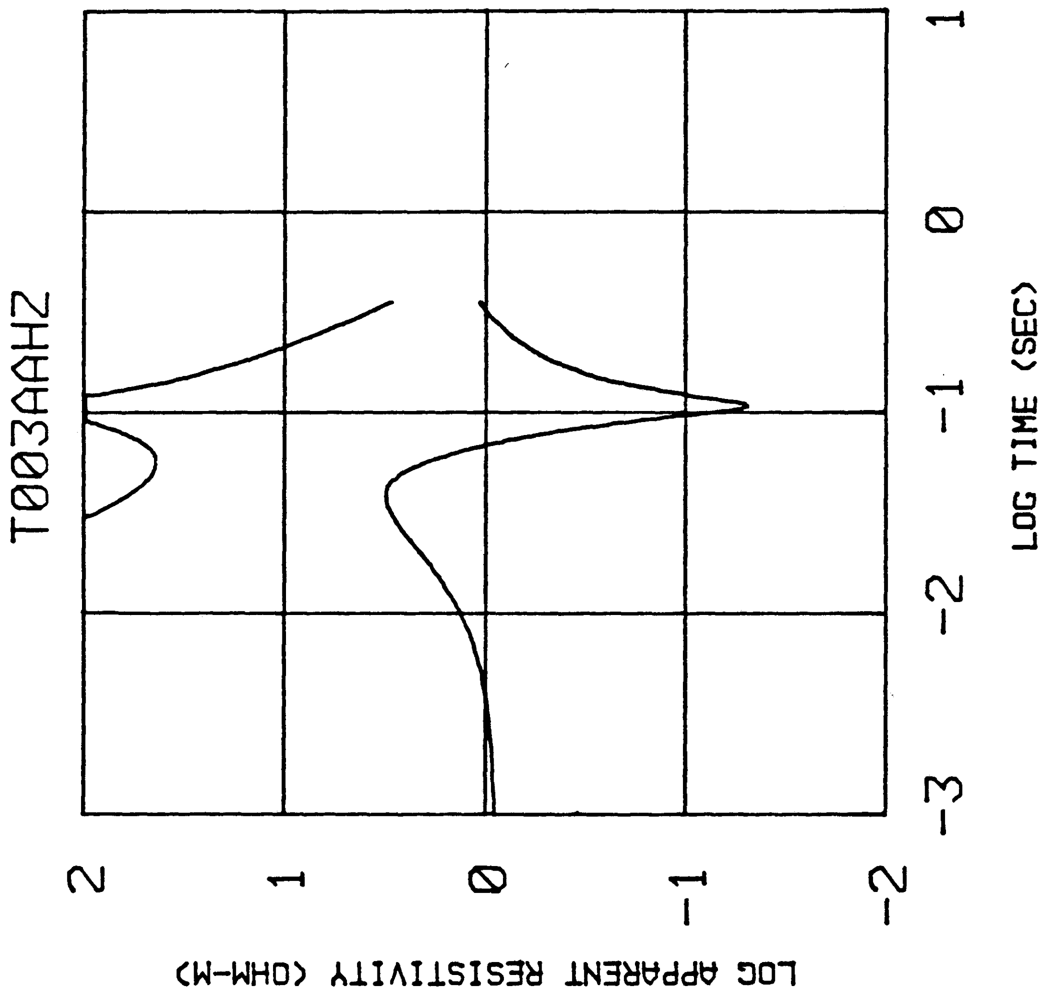
Contained within are plots of apparent resistivity versus time. The curves are represented as early and late time plots where the upper curve is the late time and the lower curves is the early time resistivity. The plots are titled as follows:

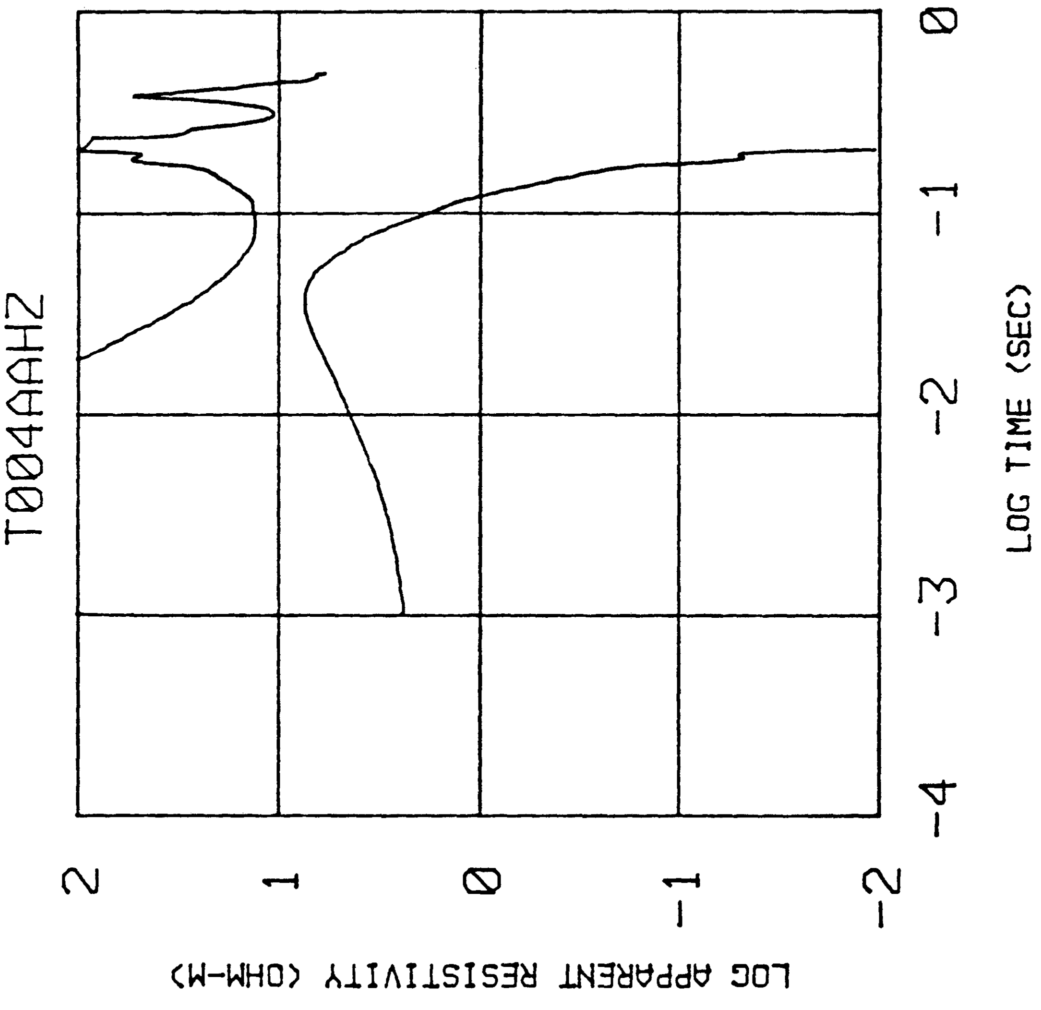
Tnnnxxyy

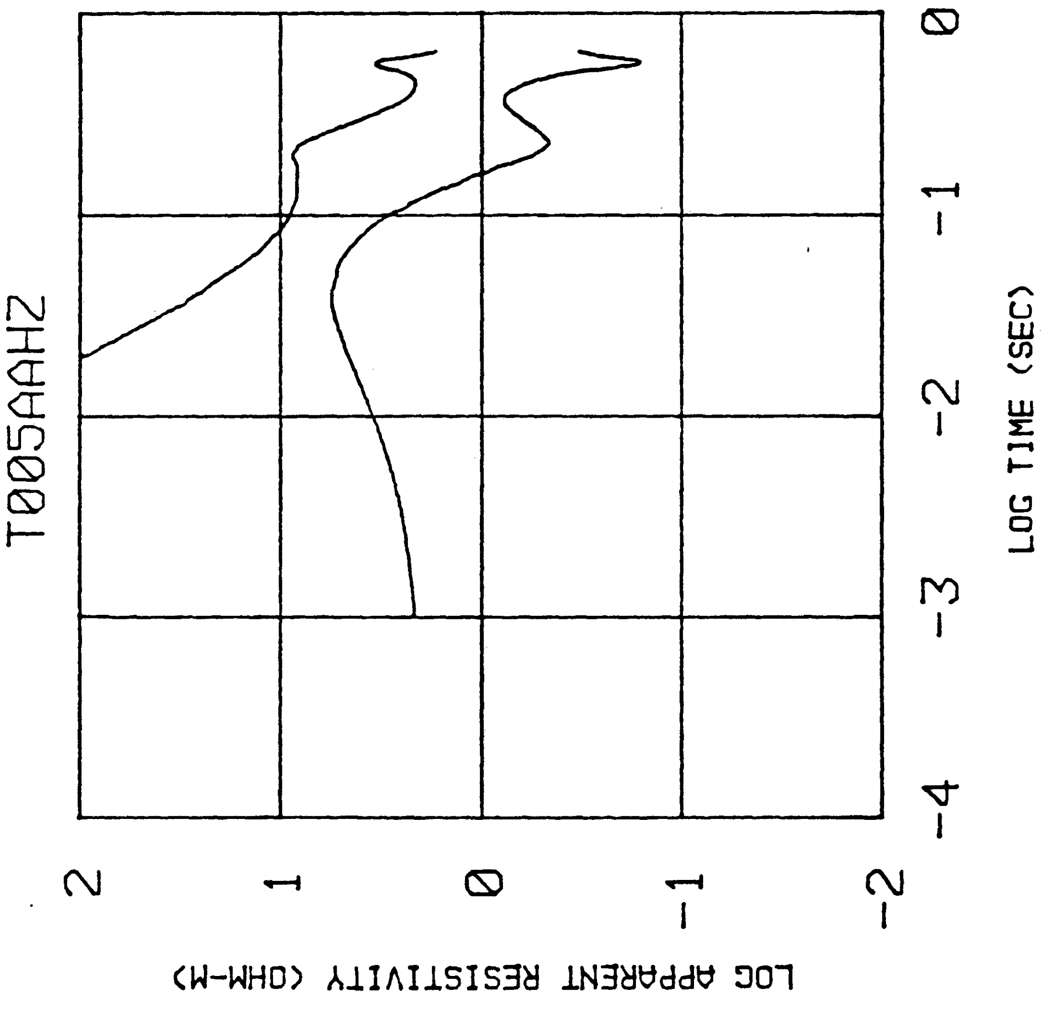
where T = Tipton Prospect
nnn = station number occupied
xx = AA or AB depending on source orientation
yy = HZ for the vertical component of the magnetic field

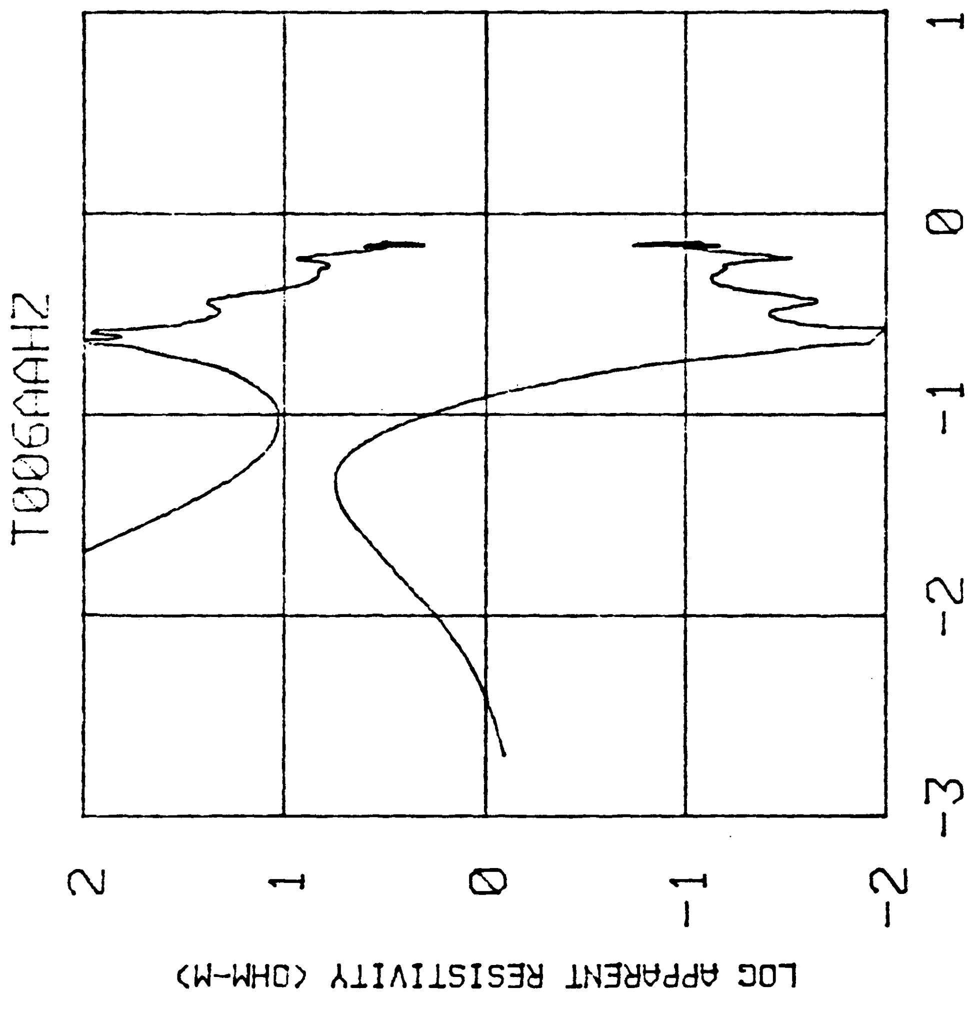

T001AAHZ
LOG TIME (SEC)
-3
-2
-1
0
1
LOG APPARENT RESISTIVITY (OHM-M)
2
1
0
-1
-2

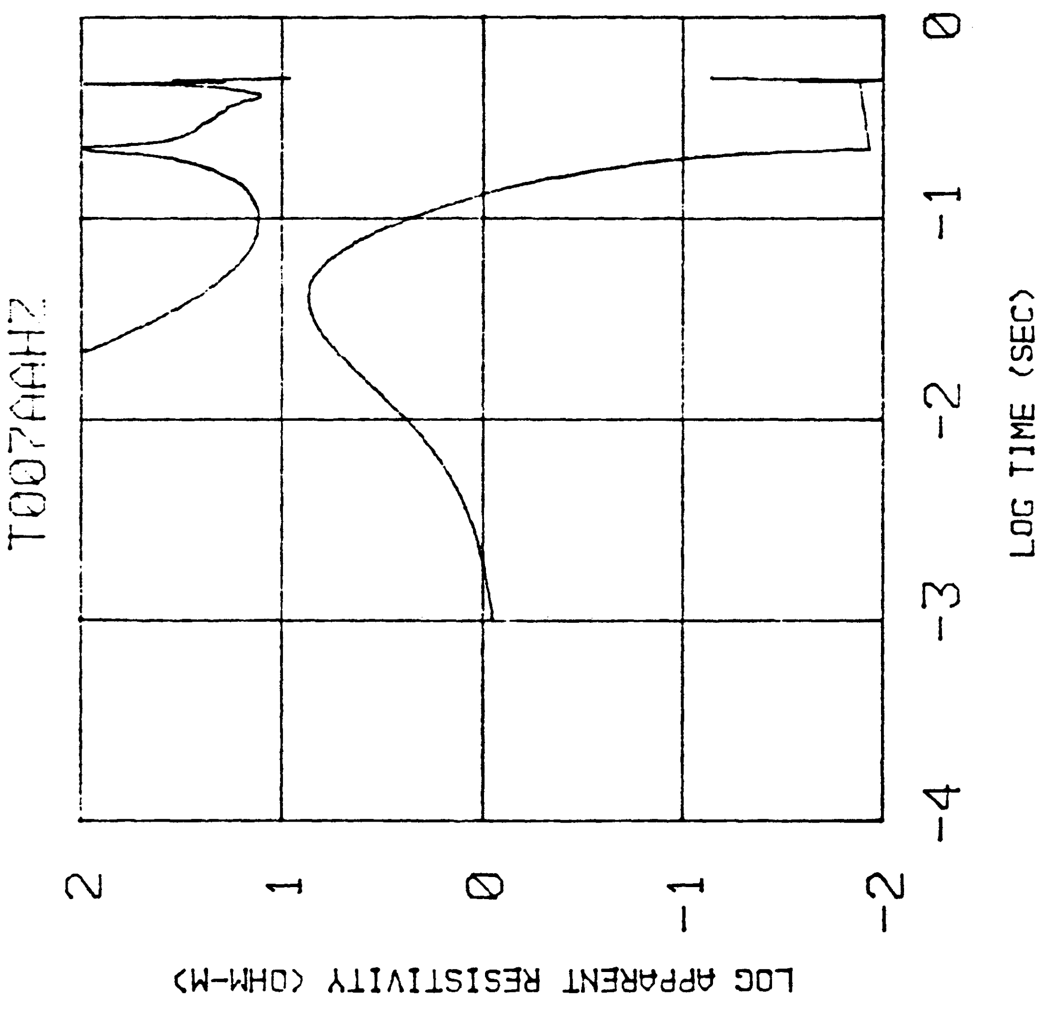

T002AAHZ
LOG TIME (SEC)
LOG APPARENT RESISTIVITY (OHM-M)
-3
-2
-1
0
1
2
1
0
-1
-2

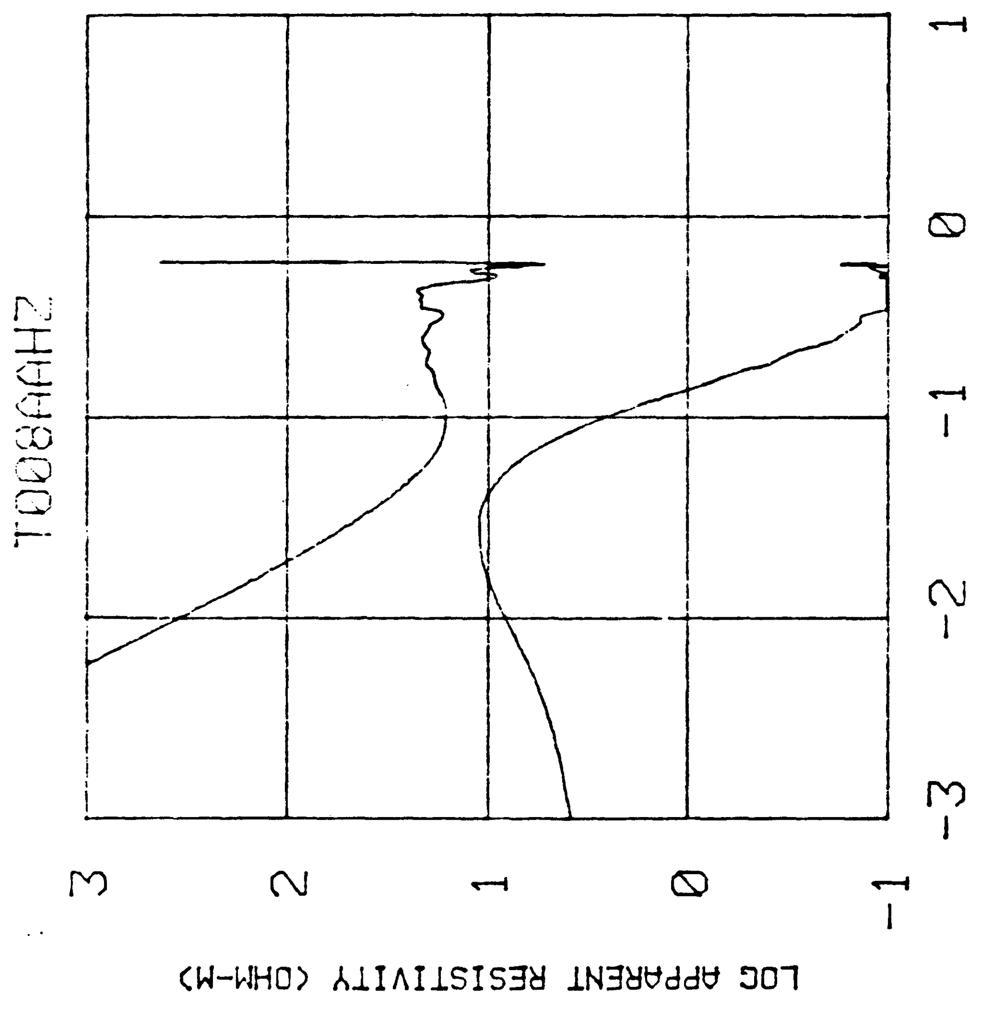

T003AAHZ
LOG TIME (SEC)
-3
-2
-1
0
1
LOG APPARENT RESISTIVITY (OHM-M)
2
1
0
-1
-2

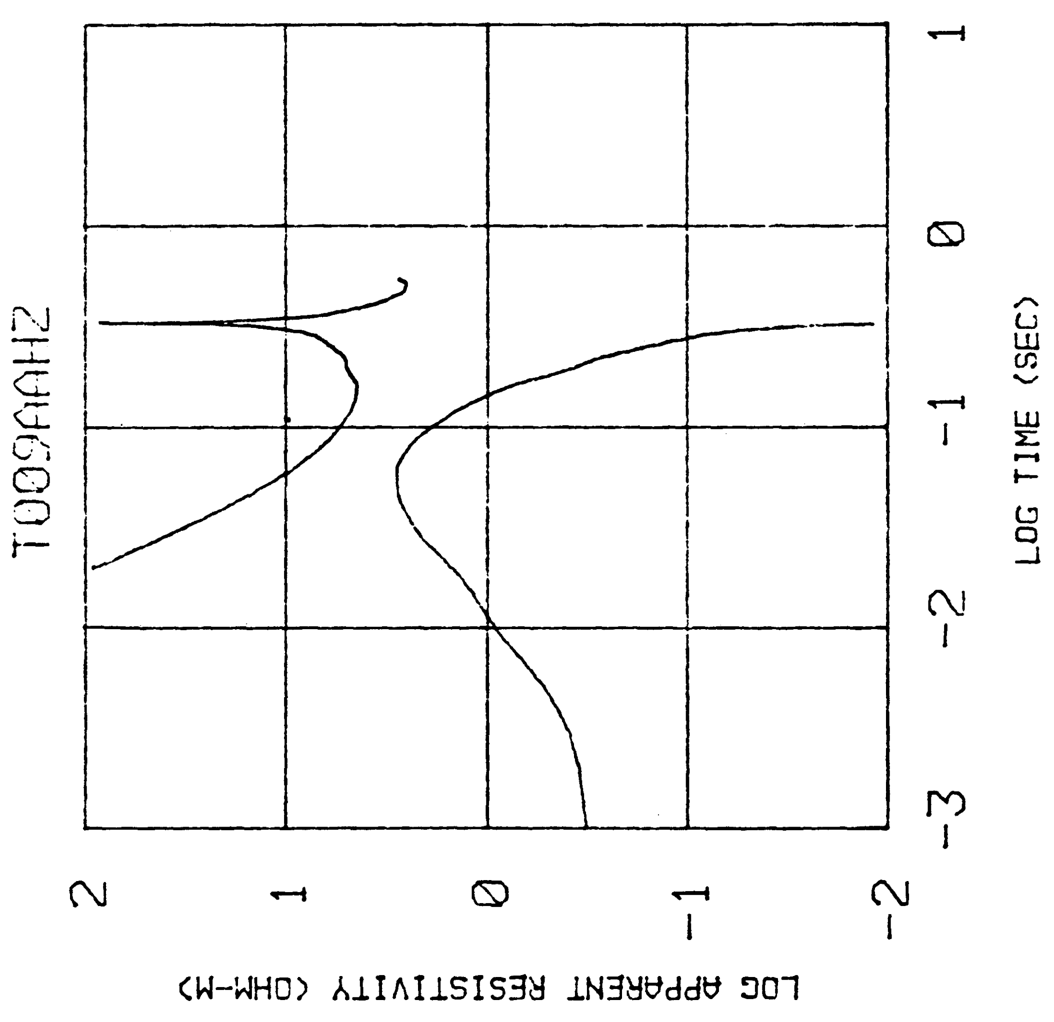

T004AAHZ
LOG TIME (SEC)
0
-1
-2
-3
-4
LOG APPARENT RESISTIVITY (OHM-M)
2
1
0
-1
-2

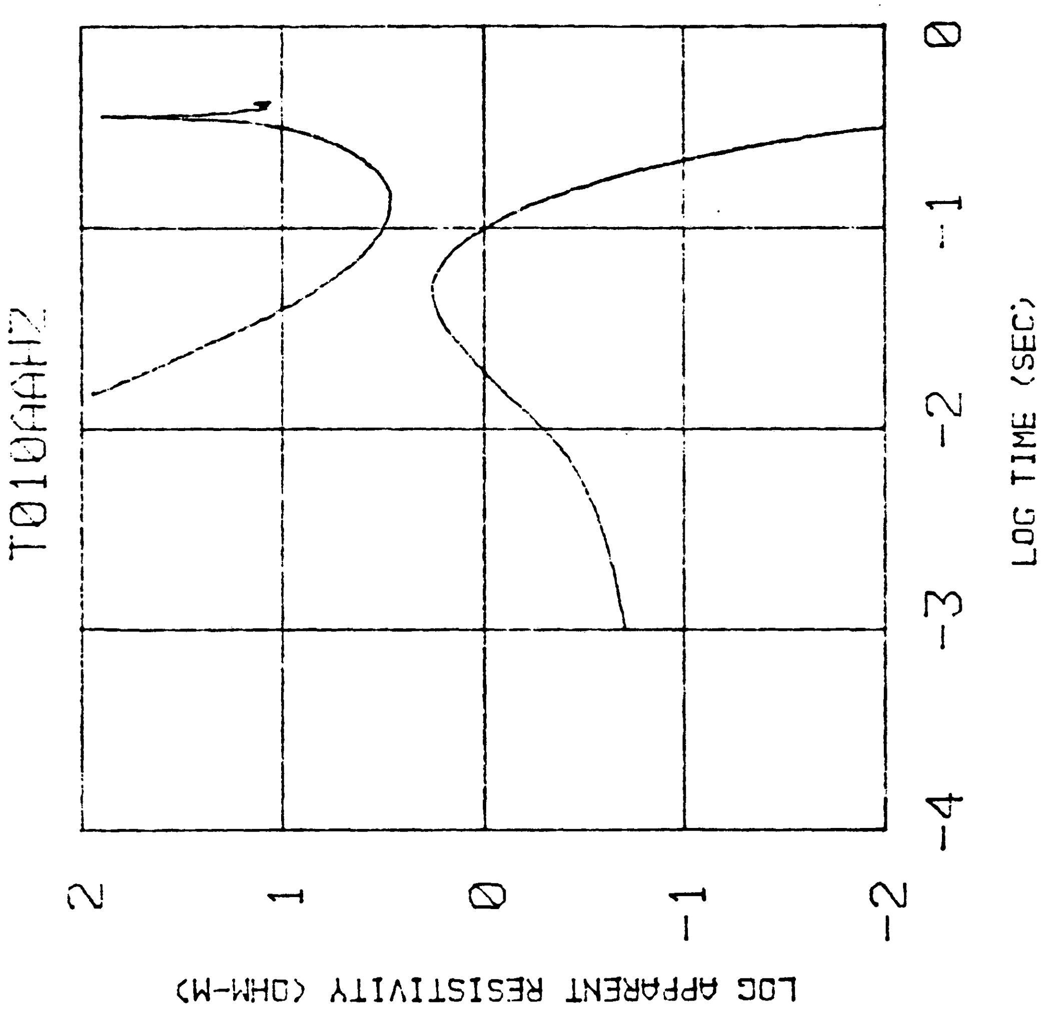

T005AAHZ
LOG APPARENT RESISTIVITY (OHM-M)
2
1
0
-1
-2
LOG TIME (SEC)
-4
-3
-2
-1
0


T006AAH2
LOG TIME (SEC)
-3
-2
-1
0
1
LOG APPARENT RESISTIVITY (OHM-M)
2
1
0
-1
-2


T007AAHZ
LOG APPARENT RESISTIVITY (OHM-M)
LOG TIME (SEC)
2
1
0
-1
-2
-4
-3
-2
-1
0


T008AAHZ
LOG APPARENT RESISTIVITY (OHM-M)
3
2
1
0
-1
LOG TIME (SEC)
-3
-2
-1
0
1


T009AAHZ
LOG APPARENT RESISTIVITY (OHM-M)
2
1
0
-1
-2
LOG TIME (SEC)
-3
-2
-1
0
1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-2
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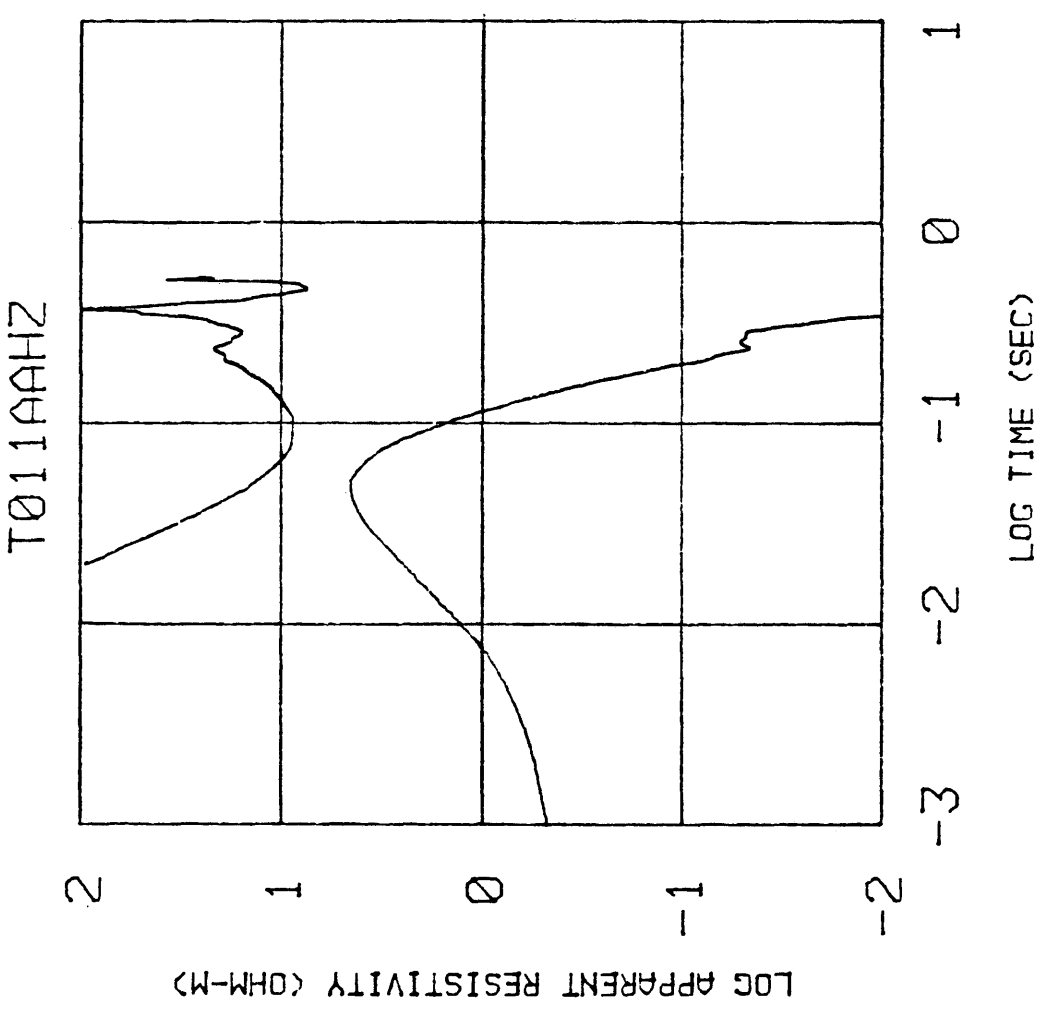
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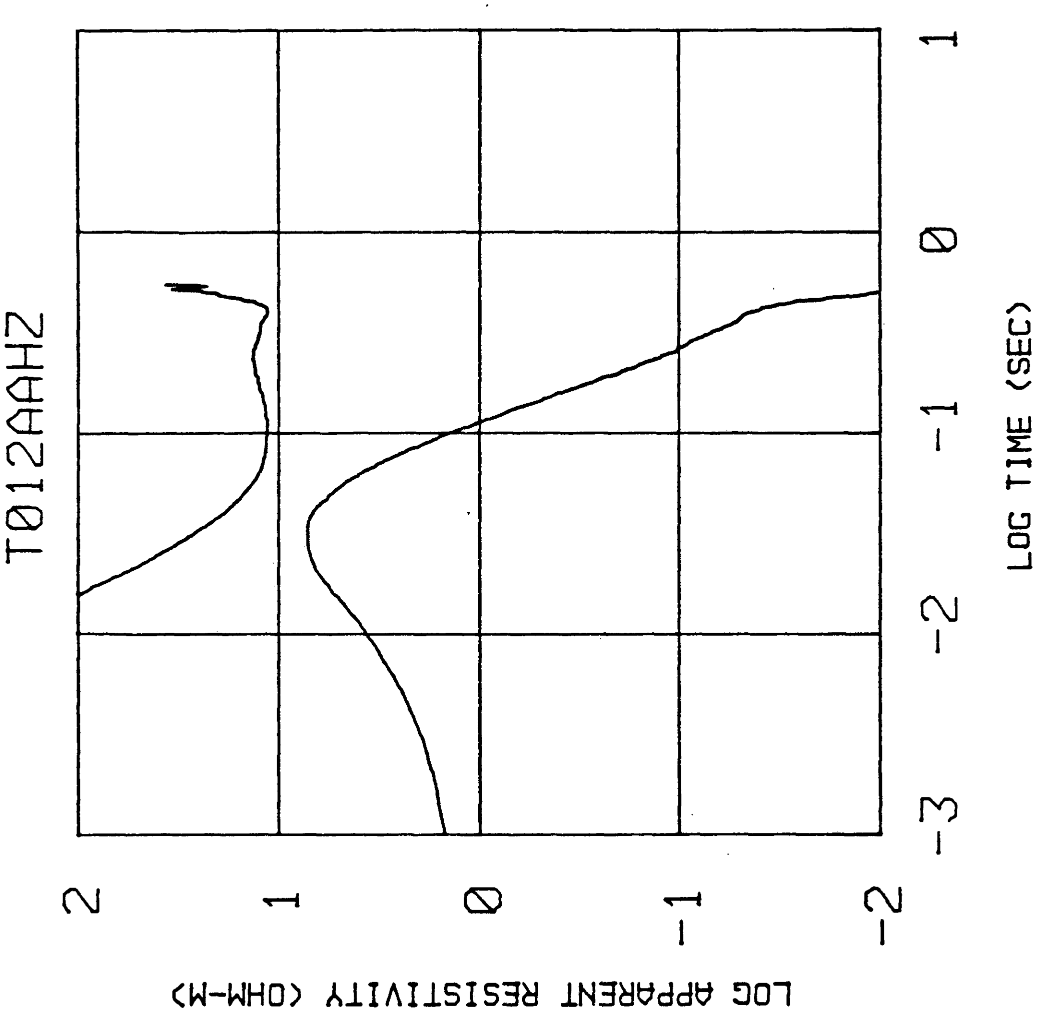
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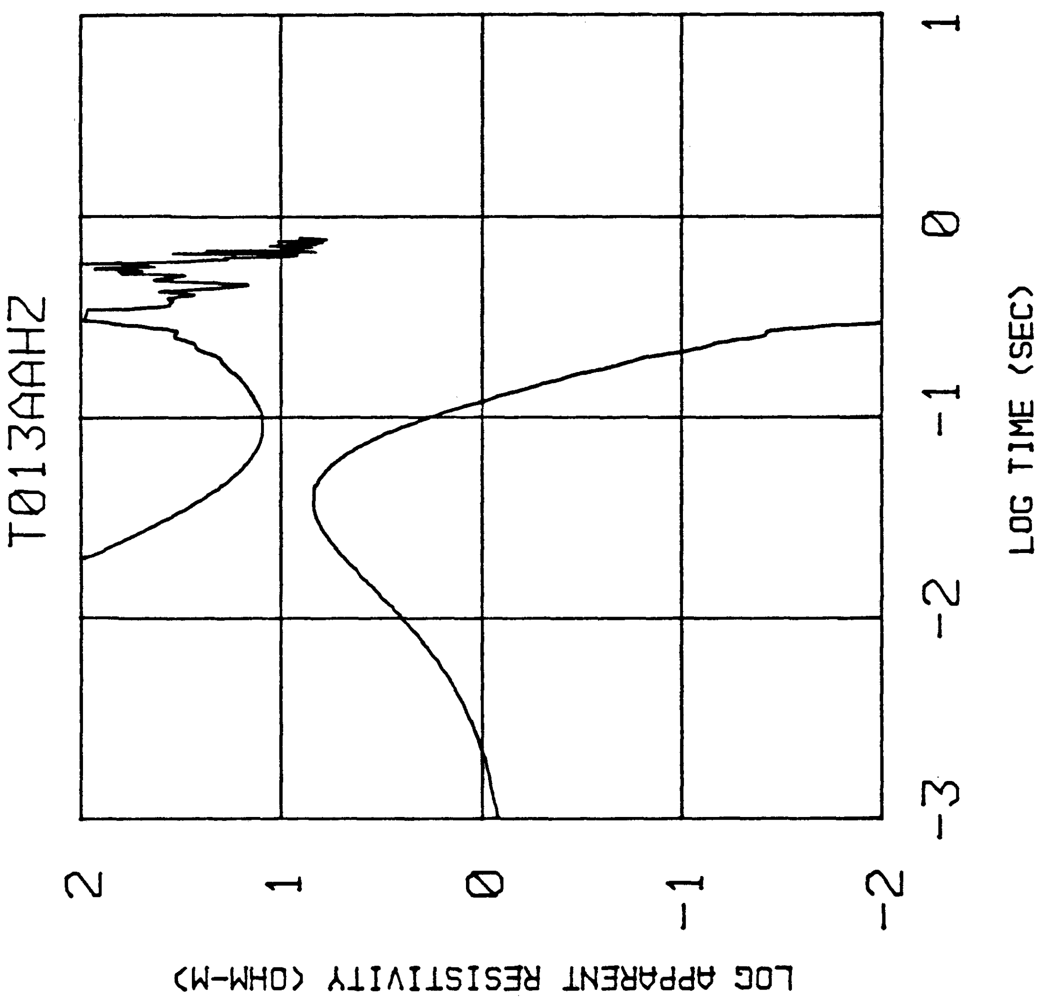
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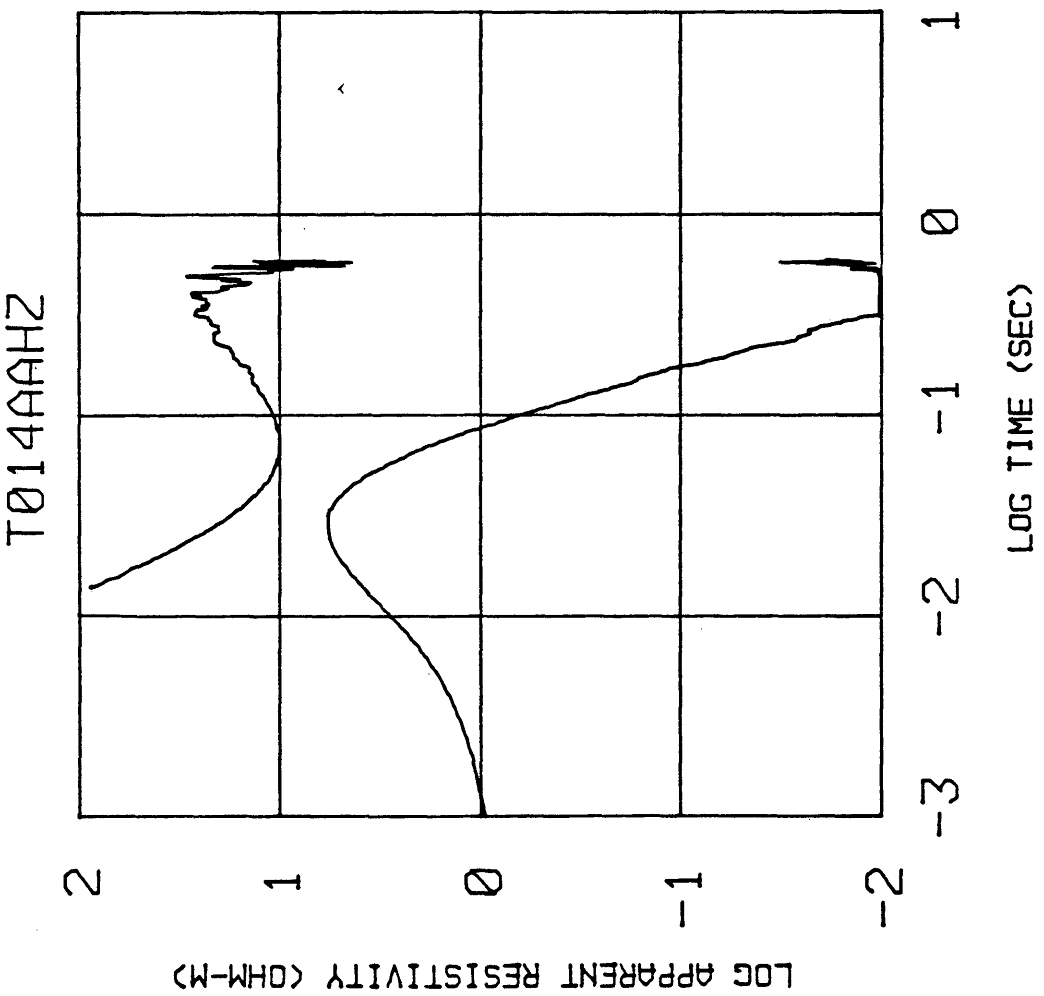
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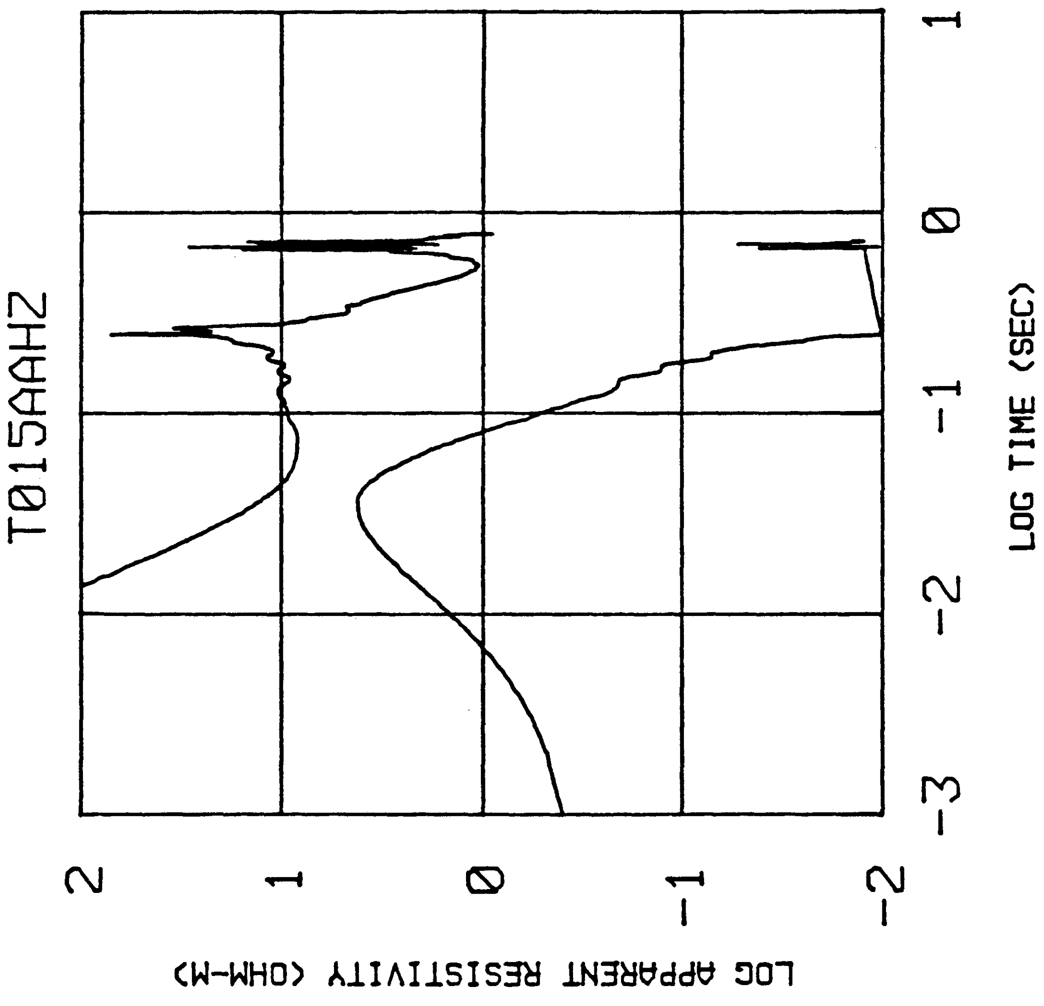
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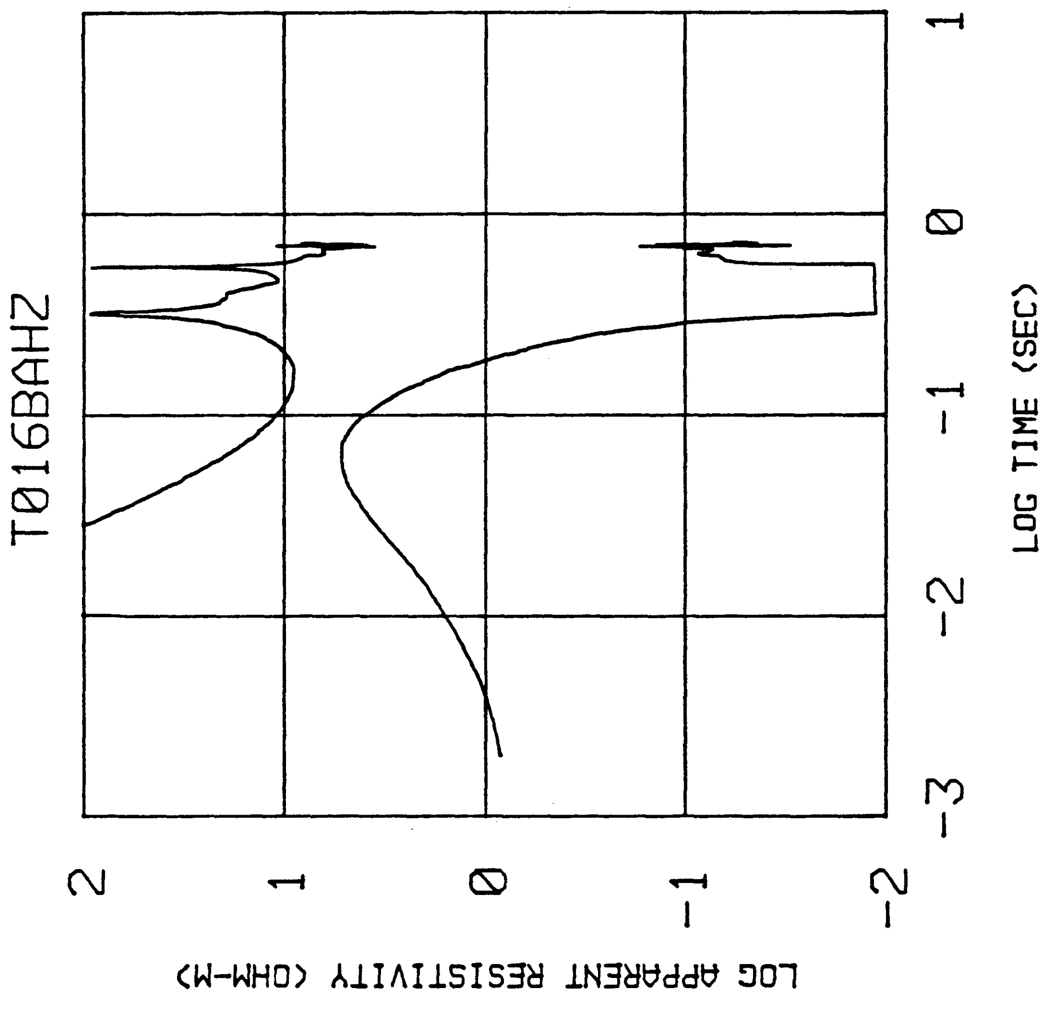
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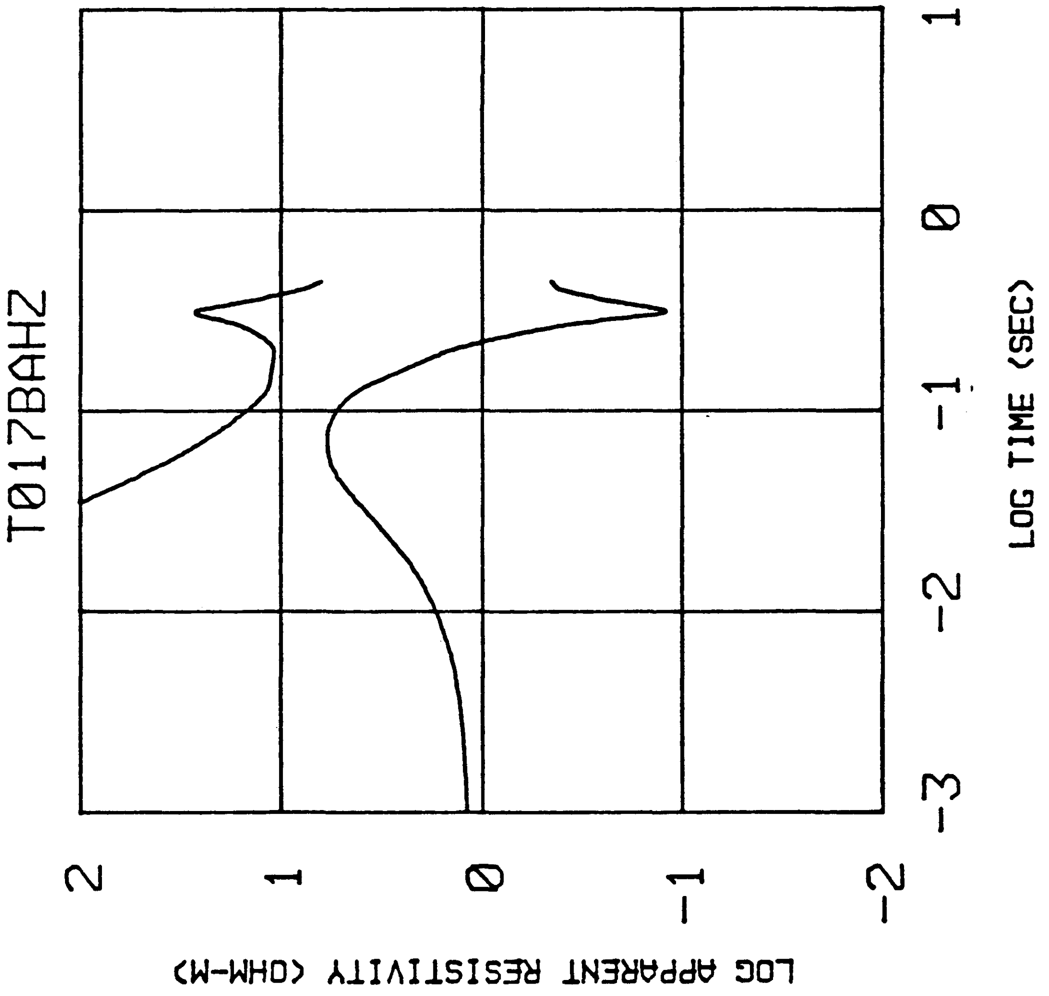
-2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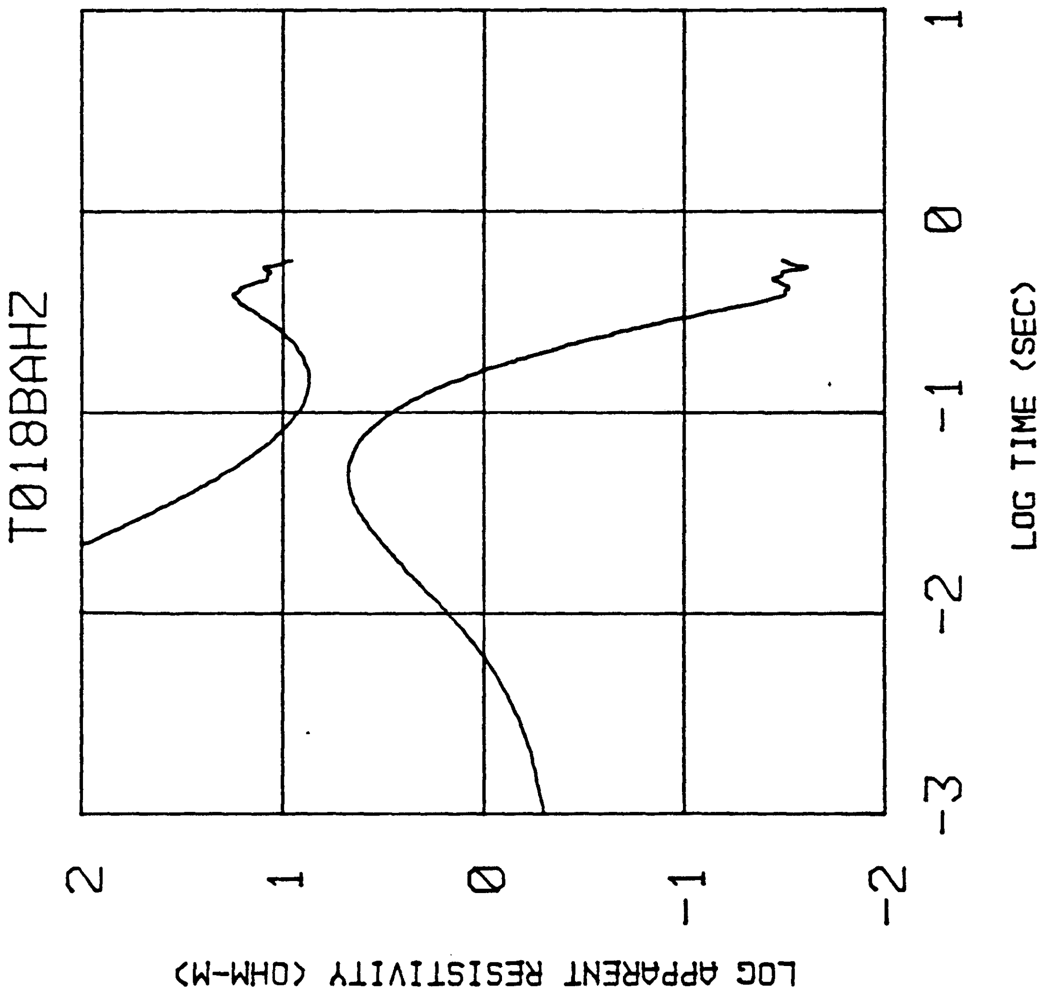
-2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-2
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-2
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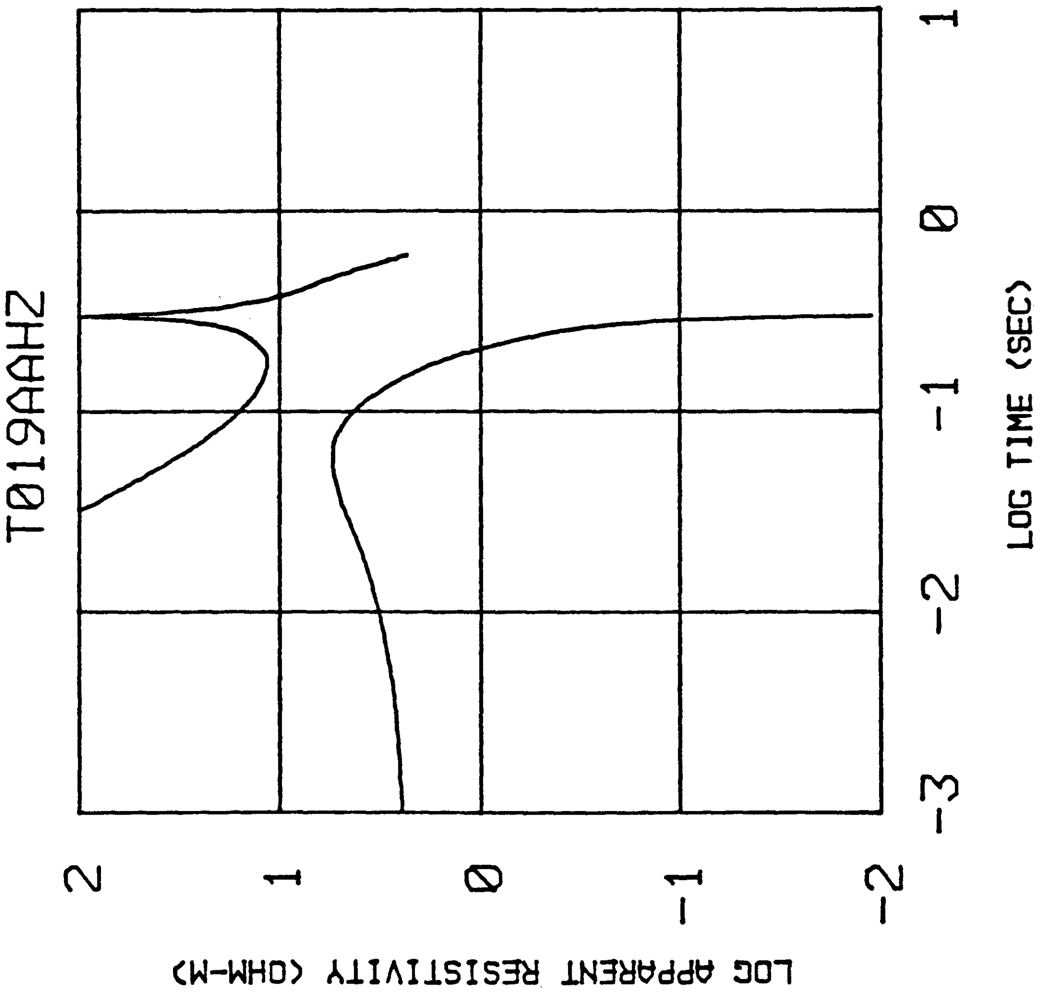
1
LOG TIME (SEC)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LOG APPARENT RESISTIVITY (OHM-M)
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-2

APPENDIX E

Contained within are the results of inverting the transient magnetic field data to a resistivity versus depth section. Three and four layer inversions were done as shown.

R1, R2, R3, and R4 are the resistivities of the first, second, third, and fourth layers respectively.

H1, H2, and H3 are the thicknesses in meters of the first, second, and third layers respectively.

The error between the model and the actual data is also given in percent.

THREE LAYER INVERSIONS

Station Occupied	R1	R2	R3	H1	H2	Percent Error
1	74	59	6.6	105	247	33
2	83	4.1	16	101	136	30
3	95	6.4	17	45	93	36
4	88	4.7	13	45	120	27
5	12	23	14	31	116	14
6	26	1.3	107	85	68	16
7	34	3.1	82	57	138	18
8	180	7.2	24	104	227	43
9	19	17	3.9	53	122	29
10	6.8	3.1	1.6	113	461	20
11	39	1.2	34	30	62	35
12	12	5.1	16	115	240	17
13	70	3.3	31	40	123	32
14	4.7	3.6	15	44	150	13
15	5.3	3.0	28	66	164	15
16	16	22	6.4	52	110	29
17	22	34	1.1	52	164	39
18	29	32	6.8	54	181	23
19	15	1.8	16	136	123	32

FOUR LAYER INVERSIONS

Station Occupied	R1	R2	R3	R4	H1	H2	H3	Percent Error
1	74	74	4.2	12.5	103	296	259	34
2	101	8.7	4.7	8.6	45	84	266	44
3	122	5.6	4.4	36	17	51	67	36
4	95	2.6	5.5	89	104	88	84	27
5	56	107	29	2.2	71	388	95	24
6	31	2.8	12	17	37	92	259	20
7	36	4.2	13	15	43	106	306	19
8	166	52	4.0	49	141	148	184	42
9	22	50	1.7	31	83	129	136	22
10	10	876	1.9	57	62	80	132	15
11	36	2.0	6.4	20	28	73	144	36
12	11	11	5.6	14	48	91	240	15
13	68	2.3	9.0	35	68	84	75	33
14	3.7	27	1.4	67	25	155	62	9
15	4.1	4.4	3.0	15	47	80	87	12
16	27	77	3.9	21	61	218	218	21
17	50	47	2.5	15	103	203	157	41
18	33	27	11	11	60	123	299	23
19	90	86	18	2.5	99	296	80	48