1990

Magnetic fields associated with sixty hertz power systems

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Magnetic fields associated with sixty hertz power systems

by

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A Thesis Submitted to the

Graduate Faculty in Partial Fulfillment of the

Requirements for the Degree of

MASTER OF SCIENCE

Department: Electrical Engineering and Computer Engineering
Major: Electrical Engineering

Approved:

Signatures redacted for privacy.

Iowa State University
Ames, Iowa

1990

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1. INTRODUCTION

Electric and magnetic fields have become a very controversial topic in the last few years. Epidemiologists have inferred these fields cause cancer in humans, primarily leukemia in young children. At the cellular level, researchers have yet to find the mechanism of interaction between the fields and cells. They have found cell reactions, but have not determined how it affects the organism as a whole. The human body has many counteractions to specific occurrences, and in many cases, effects at the cellular level are compensated by some other factor in the body. Another factor that seems to add to the controversy is the matter of dose response relationship. In most cases of harmful effects, more is worse (i.e., radiation, asbestos, poisoning, etc.). Magnetic fields do not seem to follow this relationship, either by the amount, the length, or the frequency of exposure. At this time, researchers have not established what type of exposure is harmful, if any.

It is the intent of this thesis to discuss what has been done at Iowa State University concerning the subject of magnetic fields. This discussion will cover a review of the literature, the measurement device used to gather data, some of the measurement activities that have been done, and software that exists to perform theoretical field calculations. The materials in this thesis are the thoughts of the author on the work that he has completed with the help of others. The acronyms that are commonly used in this thesis are summarized in Appendix A.

1.1 General Background

Magnetic and electric fields are two separate entities, but generally are mentioned together. One can exist without the other. Both types of fields exist wherever electricity is present, whether it be large transmission lines, or small appliances. Electric fields are created whenever there is a pair of charges and those charges are separated. Magnetic fields, on the other hand, are created whenever those charges are moving. On the power system, electric fields are created whenever a line is energized, even if no current is flowing in it. Magnetic fields, however, are created only when there is current flowing in the line. Similarly, an appliance has an electric field associated with it whenever it is plugged in, but has a magnetic field associated with it only when the appliance is turned on. Units that are used to measure electric fields are volts/meter, or around transmission lines, kilovolts/meter (1000 volts/meter). Magnetic fields are measured in units of gauss, or milligauss (1/1000th of a gauss). Electric fields are generally many times higher near transmission lines than are the electric fields found around the home. Magnetic fields, on the other hand, are much higher in close proximity to operating appliances in the home, than are magnetic fields found near transmission lines.

The electric and magnetic fields that are associated with the electrical system in the United States fit in the category of extremely low frequency (ELF) fields, specifically sixty hertz fields. Sixty hertz means that the currents flowing in the lines change direction one hundred twenty times a second, or sixty complete cycles a second. Figure 1.1 contains a picture of the path that electricity typically follows from generation to its end use in the home.

The earth has a magnetic and electric field associated with it, but it is a direct current field – it is constant in one direction always. The earth's electric field averages one hundred thirty volts/meter and the earth's magnetic field averages five hundred milligauss. It must be remembered that these fields are direct current, and

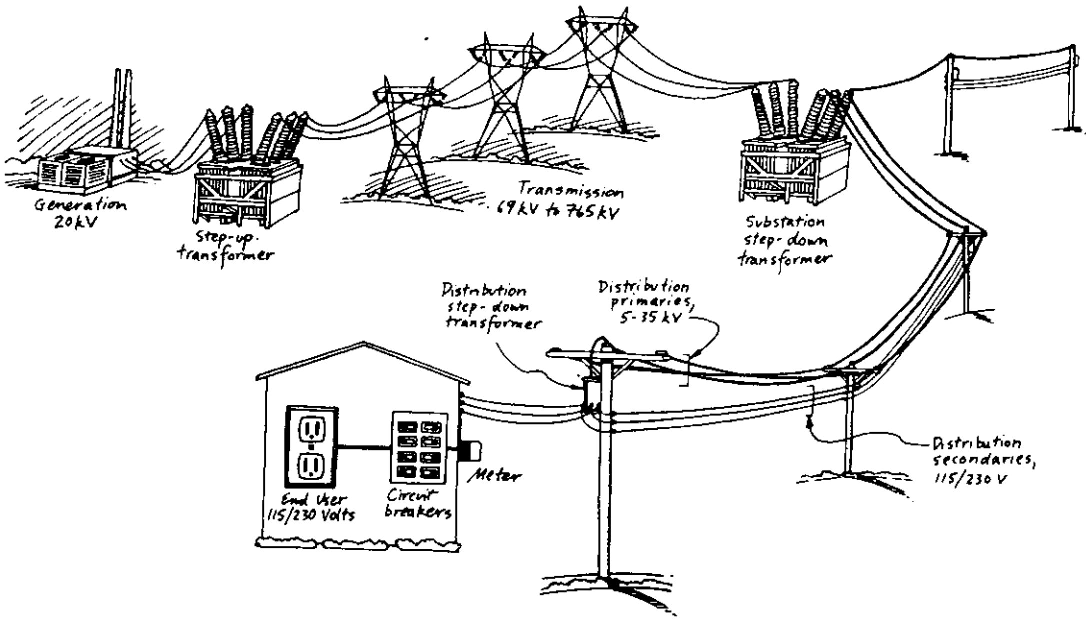


Figure 1.1. The electric power system [1]

therefore are quite different from the alternating sixty hertz fields that are of interest in this paper.

There is one major difference between electric and magnetic fields. Magnetic fields can penetrate most substances and are unperturbed when they encounter objects or biological materials. Electric fields are perturbed or changed when they encounter objects or biological materials. This makes magnetic fields much easier to measure than electric fields. When a human is brought into a room that has a magnetic field associated with it, the magnetic field remains the same within the room. However, when a human is brought into a room that has an electric field associated with it, the electric field changes everywhere in the room. The electric field level at the person's head may increase to as many as fifteen or twenty times greater than before the person entered the electric field. The electric field is perturbed by objects, and this perturbation is dependent on the shape, size, and orientation of the object in the field.

Magnetic fields that are in the home environment are of interest because of the very long periods of time people are exposed to them. Recently, these fields have been measured by many different people and results vary depending on instrumentation, methodology, and interpretation. Generally, levels from one to five milligauss are considered as being in the range of ordinary background measurements found in the home.

The EPA just recently (mid–June, 1990) released a statement concerning their position in the magnetic field controversy. Their statement is based on a two years analysis of research conducted in all areas of interest, whether it be the cellular level, animal level, human level, epidemiologic level, or the engineering level. Their findings on the connection between ELF magnetic and electric fields was "a consistent pattern of response which suggests, but does not prove a causal link". Their final report has not been issued, but is being reviewed at the time of this thesis.

Several states have set limits for electric fields at the edges of electrical right–of-ways, and currently only Florida has both electric and magnetic field limits (Table 1.1). The state of New York is proposing to be the second state to limit magnetic fields emanating from transmission lines. New York state regulators are proposing to enforce the idea that magnetic fields at the edge of right–of–ways shall not exceed the levels that are currently found near existing 345 kV lines. This is to be an interim standard, not intended to indicate either safe or unsafe levels, merely to guarantee that in the future, no one will be exposed to higher levels of fields at the edge of right–of–ways than those that already exist today. This policy is the one that many utility companies already endorse, support, and follow. Based on data collected in the state of New York, the edge of right–of–way limit will be set at 200 milligauss where a right-of-way currently exists. Where no right-of-way exists, the levels are to be less than 200 milligauss seventy-five feet away from 345 kV lines, and less than 200 milligauss fifty feet away from lines smaller than 345 kV. In comparison to these limits, data that has been collected in the past for New York showed that levels are less than 30 milligauss fifty percent of the time at the edge of

Table 1.1. State regulations limiting field strengths on transmission line right–of–ways [1]

State	Field Limit
Montana	1 kV/m at edge of ROW in residential area
Minnesota	8 kV/m maximum in ROW
New Jersey	3 kV/m at edge of ROW
New York	1.6 kV/m at edge of ROW
North Dakota	9 kV/m maximum in ROW
Oregon	9 kV/m maximum in ROW
Florida	10 kV/m (for 500 kV), 8 kV/m (for 230 kV) maximum in ROW 2 kV/m at edge of ROW all new lines 200 mG (for 500 kV single circuit), 250 mG (for 500 kV double circuit), 150 mG (for 230 kV) maximum at edge of ROW

the right–of–ways. These proposed levels may be exceeded for period of less than fifteen minutes only in the case of emergency conditions.

1.2 Historical Background

The original concern of the adverse health effects of electric and magnetic fields (EMF) dates back to the mid–1960s with a group of Soviet high voltage switchyard workers. They complained of general malaise, headaches, insomnia, fatigue, loss of libido, and general disorders of the cardiovascular system. There were several other studies done in Europe to try to replicate the Soviet results, but none were successful. The general concern at this time was that of the adverse health effects because of electric fields. Intensive study in the next decade seemed to clear electric fields from the concern list. It was found that the only danger from electric fields was receiving shocks from induced voltages on objects under high voltage lines, and this risk could be eliminated if proper grounding practices were used. Thus electric fields will not be discussed in the remainder of this document. It wasn't until the late 1970s when an article was published in the *American Journal of Epidemiology* [2] that the health effects of magnetic fields were first being questioned.

1.3 Nancy Wertheimer and the Denver Study

It was Nancy Wertheimer and Ed Leeper who first published this report that linked "high current configurations" and childhood cancer in the Denver area. Nancy Wertheimer is an epidemiologist. An epidemiologist is a person who conducts observational studies rather than experimental studies. Ed Leeper is a physicist friend of Mrs. Wertheimer. It was their report which made the United States, and possibly the whole world, think that there may be some possible link between magnetic fields and adverse health effects.

Nancy Wertheimer was studying childhood leukemia incidence in the Denver area. She had obtained a list of every child and their birthplace in a four county area who had died of leukemia between 1950 and 1969. She also received a matched list of children who had not died of leukemia to serve as a control group. She then set out to visit these homes to see if there was some type of commonality that linked all of the leukemia deaths. After visiting many of these homes and not finding any connection between the deaths, she did notice a pole top transformer located in the back yard of one of the houses. She recalled seeing many of them recently. She originally didn't think much of the incident until she remembered reading an article which contained a picture where a fluorescent tube had been placed under a high voltage transmission line, causing the tube to glow. With these two thoughts, she began to think that maybe overhead transmission lines were the cause of the leukemia incidence she was studying.

A paragraph must be added here to explain a little about the type of distribution systems that were around the homes Nancy Wertheimer was observing. Each pole top transformer she found served many homes. These pole top transformers stepped down the voltage from 13,000 volts down to 120/240 volts, which is the voltage residential customers use. After the distribution transformer, the current is carried along alleys in distribution lines called secondaries, until it finally branches off into customers' homes. If you are the last person on the secondary, your electricity has traveled by everyone else's home on the way to yours. If you are the second to last person on the secondary, your electricity has traveled by everyone else's home on the way to yours except the last one, etc. This continues on so all the current traveling on the secondary goes by the first house, and generally the second house, before branching into other homes to reduce the loading on the secondary.

Nancy Wertheimer started retracing her steps and found that there was a much greater chance of finding a home with leukemia in the first or second house away from the pole top transformer. After the second house, the rate of leukemia dropped off significantly. She began talking about her results to her friend, Ed Leeper, and it was he who ruled out the electric field because the electric field would be constant under all the secondary lines. He proposed that the problem was with the magnetic fields because they were dependent on the current in the line. He made a crude gauss meter which had a speaker that would hum in the presence of magnetic fields. The higher the field, the louder the hum. Nancy Wertheimer took this device to homes she had studied, and as she passed from the second house to the third house, the hum dropped off. She believed to have discovered something. Hence, the beginning of the magnetic field concern in the United States.

Early on, sixty hertz magnetic fields were dismissed as a cancer causing agent because the fields do not possess enough energy to cause cell damage. It is this cell damage, growing out of control, which causes cancer. The argument of lack of energy was used for quite some time by many people until the medical profession's knowledge of cancer grew. Cancer is now viewed as a two stage process. The first stage is initiation, or the initial cell damage; the second stage is promotion, or cell growth and replication. Initial cell damage occurs when the DNA, which carries cell information, somehow is damaged. This damage may exist for years before some kind of promotion causes this damaged cell to begin to multiply out of control. Either process alone will not cause cancer. If magnetic fields are found to be a cancer causing agent, it is hypothesized to be in the stage of cancer promotion.

1.4 Media Coverage

Much of the concern of the possible health effects has been brought about by the media and its increased coverage of the topic. Examples are magazine articles in *The New Yorker* [3–6], *Family Circle* [7], and *Newsweek* [8], numerous newspaper stories similar to the story appearing in the *Des Moines Register* [9]; and television talk shows such as Good Morning America [10], and Nightline [11]. Paul Brodeur, author of *The New Yorker* articles, has recently written a book entitled *Currents of Death* [12] leaving no question to the reader as to his view on the subject.

What many people do not realize is that the verdict on the health effects of magnetic fields is not in yet. Some scientific studies indicate that magnetic fields have adverse effects, while others indicate there are no effects. The scientific profession must determine what levels of field exposure currently exist in our environment, and then the medical profession must determine what, if any health effects result from exposure to magnetic fields. Only then may practical exposure limits be set, if required.

In addition, many people are unaware that utility transmission lines, distribution lines, and transformers are not the only sources of magnetic fields. Some household appliances and electrical devices found in the home produce levels of magnetic fields that are in many cases hundreds of times higher than those levels found near utility equipment.

1.5 Research at Iowa State University

It is the goal of this document to present what research has been done at Iowa State University in the past, and what is planned to be done in the near future. The research activities have centered mostly around characterizing magnetic fields strengths that exist in our environment. This has been done by taking measurements or using programs that compute the strengths of the fields that exist. This data has provided information that has been used in responding to public concerns and determining what may be done to limit exposure.

The collection of data, the hardware and software used to collect data, the software used in modeling exposure, and other related activities are all reported in the following sections. It is the hope of this document to clarify what is known and what is not known currently concerning the subject of magnetic fields.

2. LITERATURE REVIEW

2.1 Introduction

A complete literature review on the topic of magnetic and electric fields would be an immense task because of the popularity of the topic and the increasing amount of recent media coverage. Although many newspaper and magazine articles were found covering many aspects of the subject, very few are listed in this review. This literature review was conducted with emphasis in two areas, the first area consists of some of the more famous articles and papers that have been written, and the second area consists of technical papers that this engineer/author has found beneficial in his studies of the subject. The material is presented under the following categories: general, medical, epidemiologic, and engineering.

2.2 General

Included in the general section of the literature review is a variety of material, much of which can be considered background material. Materials that are good for the first time reader and answer common questions are [1,13–18]. This material is general in nature and does not get too specific about any one topic, and thus is a good overview of the problem.

A good monthly publication is written by Robert S. Banks, a consultant who keeps track of all the latest happenings in the magnetic and electric field controversy. This publication entitled "Transmission/Distribution Health and Safety Report – A monthly review of research and regulatory developments" [19], contains a variety of up to date information.

A review of literature would not be complete without covering the author, Mr. Paul Brodeur. Mr. Brodeur is a well known author advocating that magnetic and electric fields are harmful. A writer for the *New Yorker*, he has had four lengthy articles published in it [3–6]. In these articles, he accuses the government and utilities of covering up the biggest health menace since asbestos, magnetic fields from electrical lines. Mr. Brodeur prides himself in being the first to publish material about the dangers of asbestos. Mr. Brodeur also has written a book entitled *Currents of Death* [12], leaving no doubt on his views of the controversial subject of the health effects of magnetic fields. Also appearing recently in *MacWorld* is an article by Mr. Brodeur on the dangers of computer terminals [20]. Mr. Brodeur does do a good job of presenting evidence and everything he writes is well documented. What Mr. Brodeur fails to do is present the other side of the story. He also has a tendency to include material that sounds damaging, but is totally unrelated. Mr. Brodeur's material is a must to read, because this is the type of material that is read by a majority of the public.

2.3 Medical

The area of medical studies concerning health effects of magnetic and electric fields is always changing, therefore only recent papers are of any use since earlier hypothesis are either thrown out or are being studied further. This is an area in which the author has limited knowledge. It is important, however, to get a feeling of what research has been and continues to be conducted. Included in this section are some papers that instill a feeling of how the problem has evolved.

Several papers have been published that are a literature review themselves that cover specifically health effects [13,14,21,22]. These are extremely helpful because they generally summarize the results of each individual paper contained in the review. This type of material usually gives the author enough information on the ongoing research in the medical field to keep him up to date.

A conference that was found extremely useful was one sponsored by EPRI in 1989 in Delevan, Wisconsin, which was entitled Power–Frequency Electric and Magnetic Field Laboratory Research [23]. This three–day conference was made up of medical professionals presenting current knowledge to a non–technical audience.

Other types of materials containing medical information presented in a non–technical format are [24–26]. The best of these is probably [24] which is a Background Paper done by Carnegie Mellon University for the United States Office of Technology Assessment.

A recently released paper, Immunological and Biochemical Effects of 60–Hz Electric and Magnetic Fields [27], was done for the U.S. Department of Energy by the Midwest Research Institute, and is probably one of the more recent papers published.

2.4 Epidemiologic

Epidemiologic studies have gotten a lot of publicity since the publication of the most important driving force for the further study of magnetic and electric fields by Nancy Wertheimer and Ed Leeper [2]. Their paper was the first published in the United States and created a tremendous controversy when their study linked childhood leukemia and the presence of distribution lines. A second study they published, Adult Cancer Related to Electrical Wires Near the Home [28], was seen as an improved study which found a weaker correlation.

Many other epidemiologic type studies have been conducted, some which find a statistical correlation, others that do not. David A. Savitz is probably the best known and respected epidemiologist today. David Savitz, et al. [29] recently released a paper that studied the incidence of childhood cancer and magnetic field exposure from electric applications and found no obvious connection. Another recent paper studied the use of electric blankets and incidence of testicular cancer [30].

2.5 Engineering

The literature review of technical material is quite extensive, since engineering is the main thrust of this thesis. A variety of topics can be studied when considering engineering topics, and a few papers for each category have been listed.

The first general topic is the study of fields resulting from electrical transmission and distribution equipment. A variety of papers indicate how to measure these types of fields [31–36]. Other studies and papers were done on how to minimize these types of fields by proper operation and design of the electrical system [37–39].

A second general topic is the study of fields and measurements resulting from things other than electrical transmission and distribution equipment. These cover a variety of topics ranging from appliances [40–42] to computer display terminals [43]. Low frequency fields from naval communication facilities were studied in [44].

Another topic that received some study was how to shield magnetic fields. This literature consisted of a set of handbooks with two books that were extremely useful [45–46]. Also found was a paper that presented material on how to shield a room [47].

Last, was some literature that fell into the category of measuring devices and tools which include computational techniques. Those concerning measuring devices were [48–52] where [52] gives an evaluation of many different devices. Programs that are used in the calculation of magnetic and electric fields are the TLWorkstation [53] and EXPOCALC [54].

3. MEASUREMENT DEVICE

3.1 Introduction

Chapter 3 describes the EMDEX unit, the instrument that is used at Iowa State University to collect magnetic field data. Included with this discussion of the EMDEX unit is a discussion of the software used in communicating with it, accessories that are used with the EMDEX, and a couple of the studies sponsored by EPRI for which the EMDEX was originally developed.

3.2 EMDEX

The term EMDEX stands for Electric and Magnetic Field Digital Exposure. It is a name given to the device that does just that, it measures electric and magnetic field exposure. It was originally developed by General Electric staff for an EPRI study [48,49] that consisted of fifty–five utilities working in a coordinated effort to study the exposure of utility employees in various work environments. The study came about because of epidemiologic studies such as Nancy Wertheimer's that suggested a link between exposure to magnetic fields and cancer, but where actual magnetic field measurements were not taken. The total EMDEX system consists of the hardware, software, and methodology used in conducting the study.

The EMDEX unit is a remarkable self–contained portable device that measures 2 x 6 x 4.5 inches (Figure 3.1). It contains four coils, each with ten thousand turns of a find copper wire. Three of these coils are used to sense power-frequency magnetic fields in each of three orthogonal axis, the fourth is used to sense the earth's geomagnetic field in order to detect motion. To measure electric

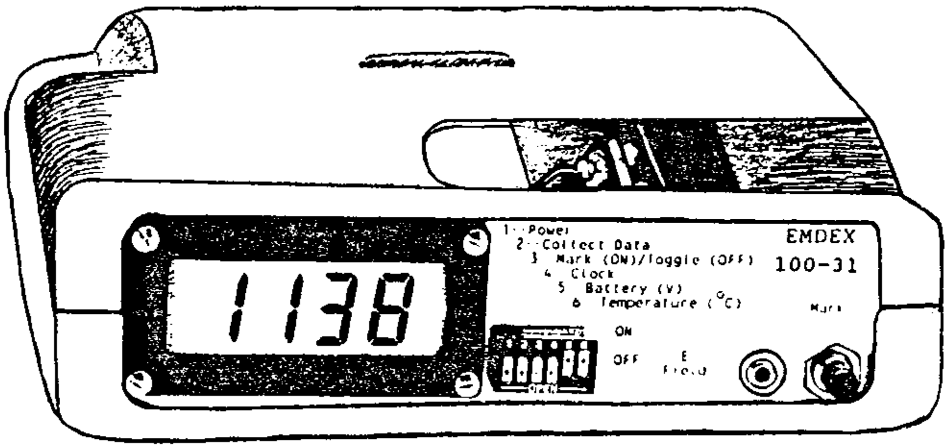


Figure 3.1. EPRI EMDEX unit

Table 3.1. Specifications for original EMDEX

	Magnetic Field Range (mG)			
	0	1	2	3
Full Scale:	0–25	0–250	0–2500	0–25000
Resolution:	0.1	1	10	100
Offset:	±.5	±5.0	±50	±500
Accuracy:	Range 0–2: ±5% of full scale reading Range 3: –20% of full scale reading			
Frequency Response:	–3dB from 15 Hz to 80 Hz			
	Electric Field Range (kV/m)			
	0	1	2	3
Full Scale:	0–0.556	0–5.56	0–55.6	0–556
Resolution:	0.0022	0.022	0.22	2.2
Offset:	±.011	±.11	±1.1	±11
Accuracy:	Range 0–2: ±5% of full scale reading Range 3: +0%, –12% of full scale reading			
Frequency Response:	–3dB from 35 Hz to 300 Hz			

fields, an electric field sensor can be connected to the unit, either a sash that can be worn, or a sock that can be slipped around the outside of the EMDEX unit. When the unit is operating and collecting data versus time, it stores magnetic field data, electric field data, field motion indicator data, and the time that those measurements are taken on an on–board microcomputer. Specifications are shown in Table 3.1.

The software used with the EMDEX was developed by Enertech, and was created so the EMDEX could be run from an IBM–PC or compatible computer. The PC can communicate with the EMDEX through a serial connection cable that connects between the EMDEX and the PC. The software is used in initializing the EMDEX unit with various types of information, such as how frequently to take measurements, the time, the date, and the program which to use as the operating system in the EMDEX unit. The unit can then be disconnected from the PC and carried around, totally portable, relying only on its nine–volt battery for power. Once the data has been collected, the EMDEX is returned to the PC and re-connected so the software package can transfer the data that had been collected back to the PC. The software of the PC then can analyze, as well as prepare tables and graphs of the data.

As mentioned earlier, the EMDEX unit was originally constructed for use in an EPRI project. This project was called EMDEX Phase I and ended in Spring of 1989. The methodology of the study for the project was developed by Dan Bracken and Associates. The methodology told how data was to be collected and what to do with the data that had been collected. EPRI is still compiling the data, however, a report is to be released near the time of the completion of this thesis.

The main objective of EMDEX Phase I was to characterize magnetic field exposure among utility workers. A very broad range of utility workers was selected for the project and consisted of everyone from linemen, to management, to office staff, to engineers. Employees were encouraged to volunteer for the project. From the list of volunteers, individuals were selected to fill quotas of the different types of workers that were required. The people selected to participate in the project were sub–divided into the three groups of subjects based on the time period they were to wear the EMDEX unit: (1) subjects who were to only wear the unit during working hours, (2) twenty–four hour subjects who would not only wear the unit at work, but would also wear it at home, (3) weekend subjects who would wear the unit over the weekend, whether working or not. The employees would be instructed in the use of the EMDEX unit and what was expected of them while wearing the unit, which was basically to do their job as normal and record in a logbook any change of environment. Examples of this are: going to and from lunch, changing from traveling to working on an energized line, or going home for the day. Examples of the types of data that were collected in Phase I of the EMDEX project are included in Figures 3.2–3.13. Each plot contains eight hours of a typical day for the employee. The horizontal axis is time and the vertical axis is the magnitude of the measurement, with a maximum of either 10 mG, 50 mG, or 500 mG.

Iowa State's role in the EMDEX Phase I project was to act as a coordinator for four Iowa utilities (Iowa Electric Light and Power, Iowa Power and Light Company, Iowa Public Service, and Iowa Southern Utilities) participating in the project. Iowa State University representative attended all of the preliminary meetings for the EMDEX Phase I and brought the information back to the

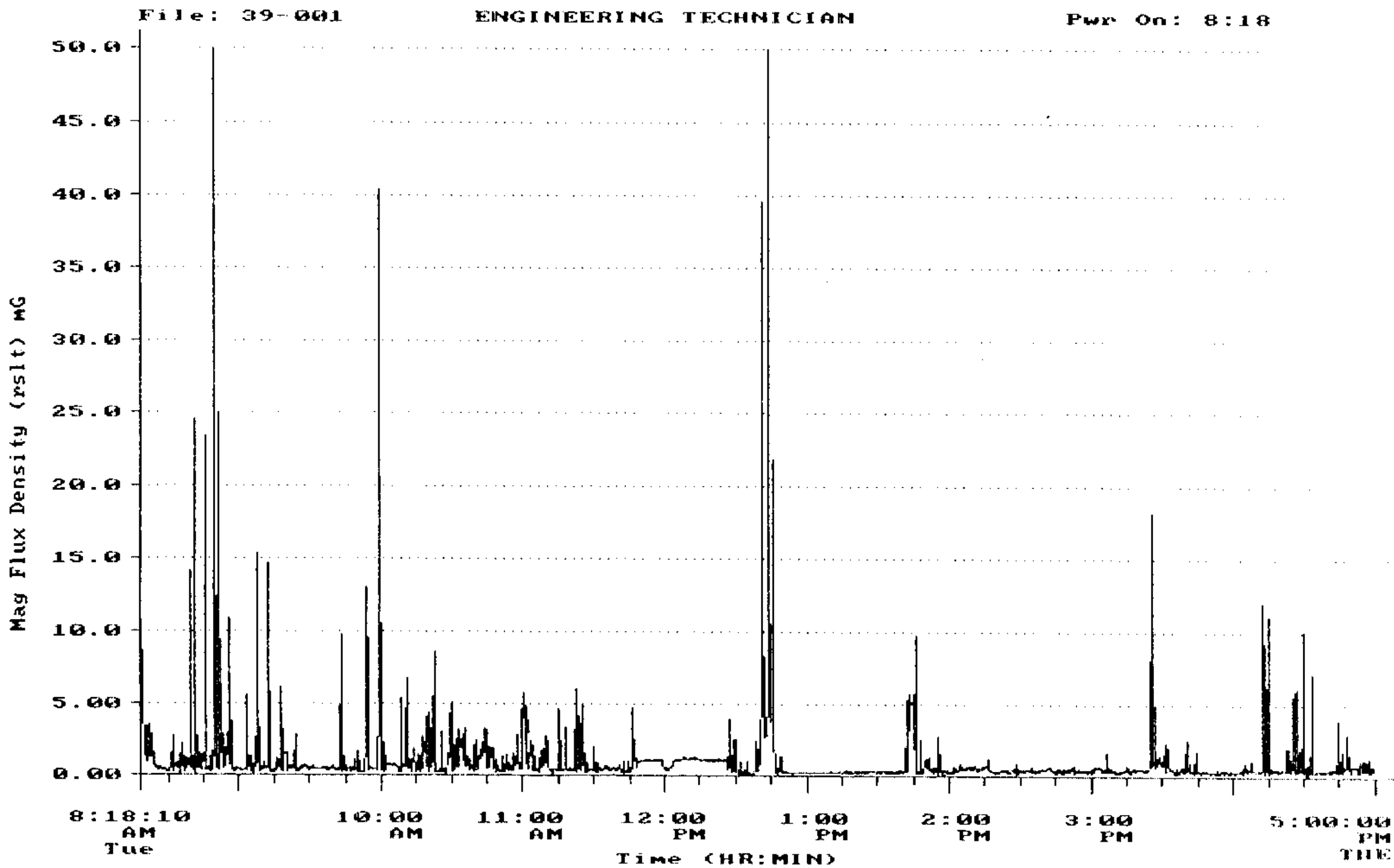


Figure 3.2. Phase I EMDEX project data

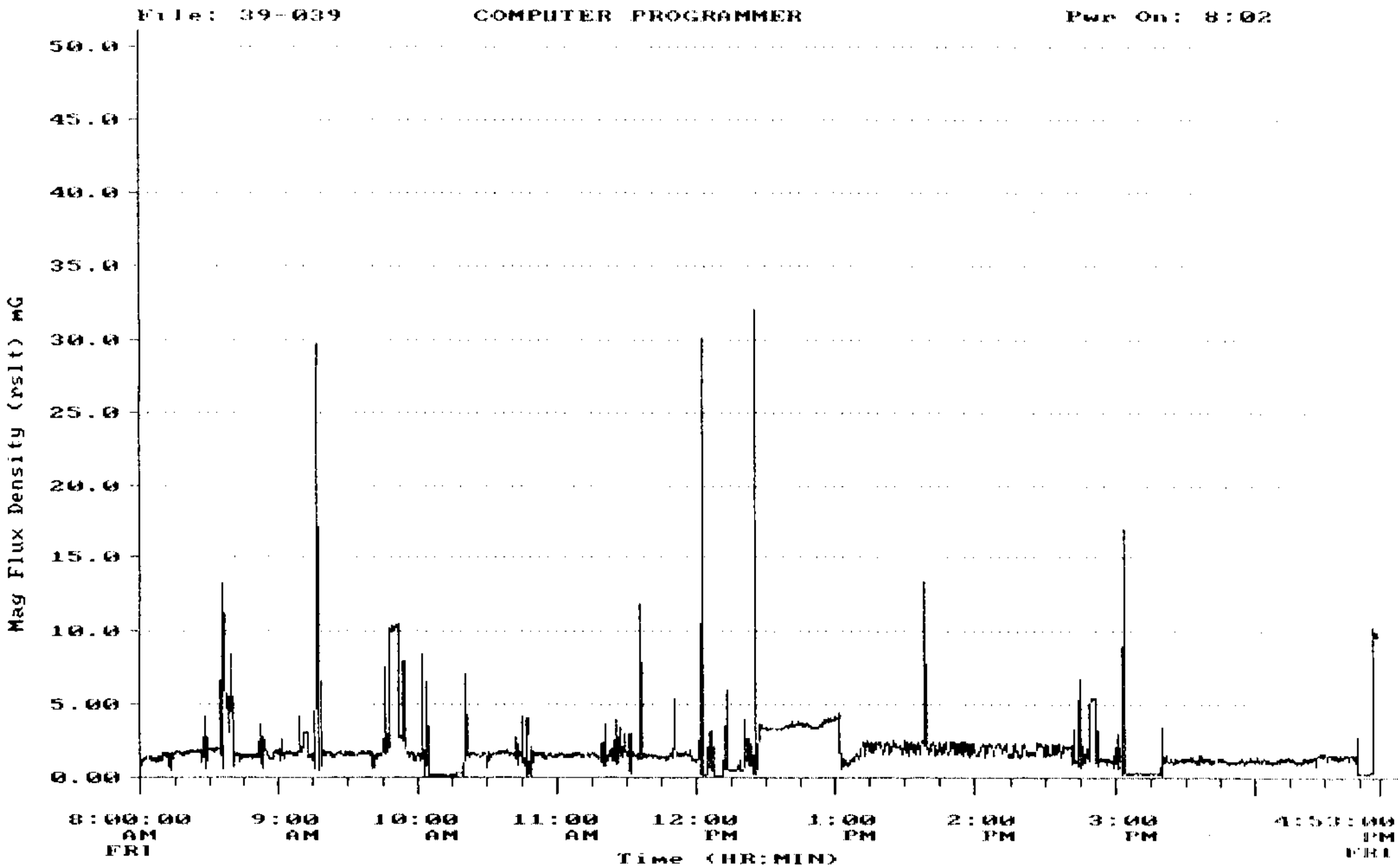


Figure 3.3. Phase I EMDEX project data

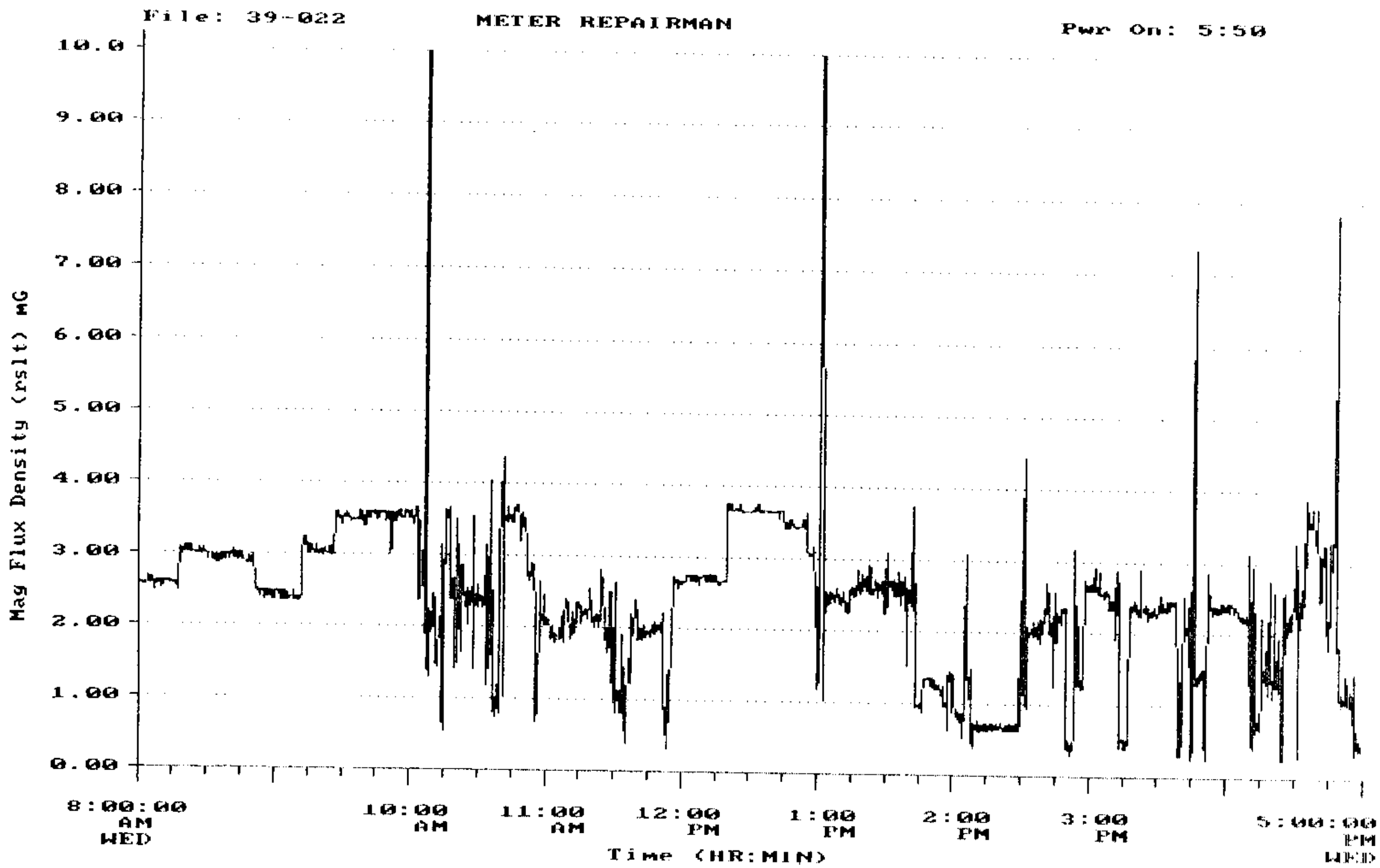
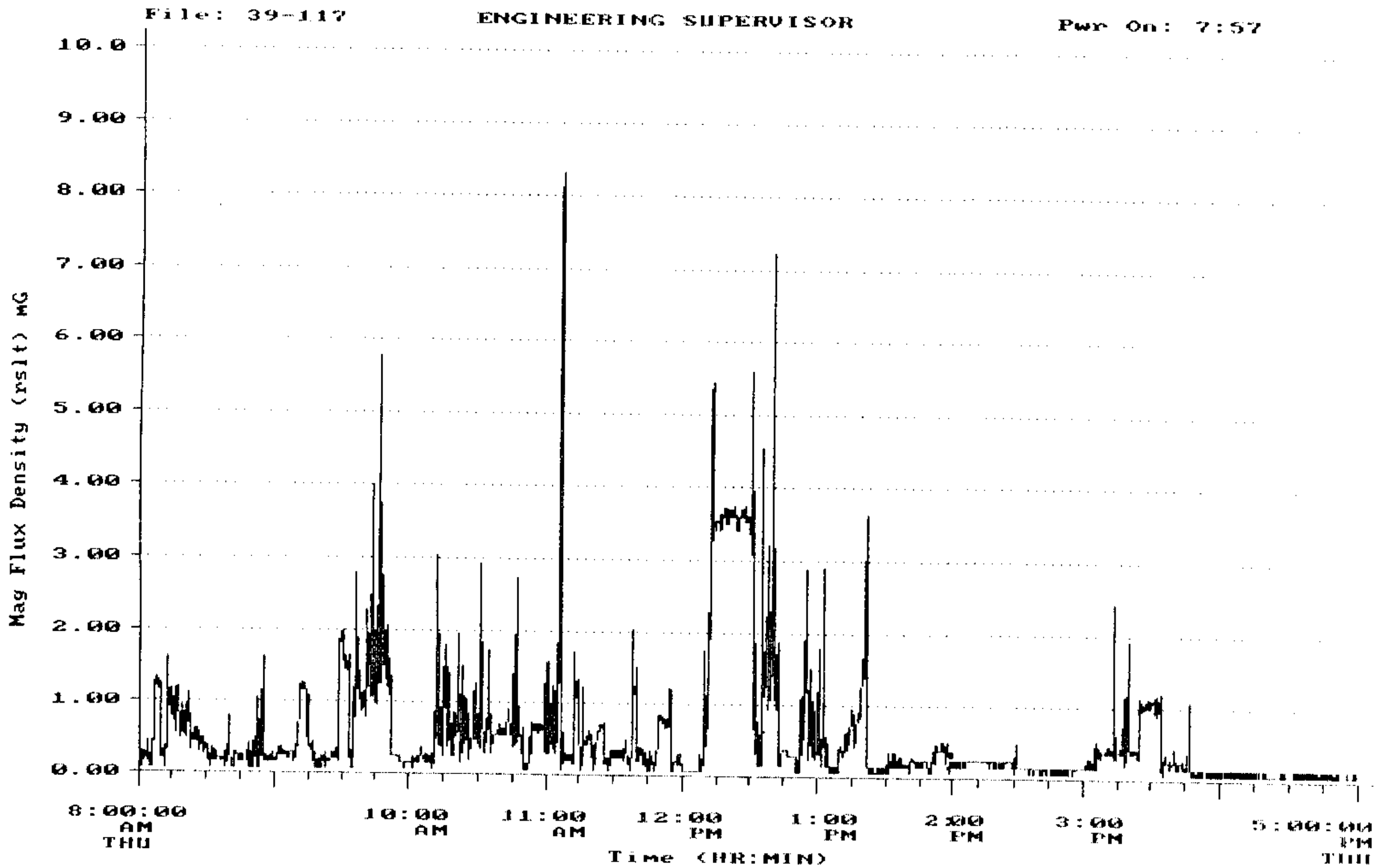


Figure 3.4. Phase I EMDEX project data



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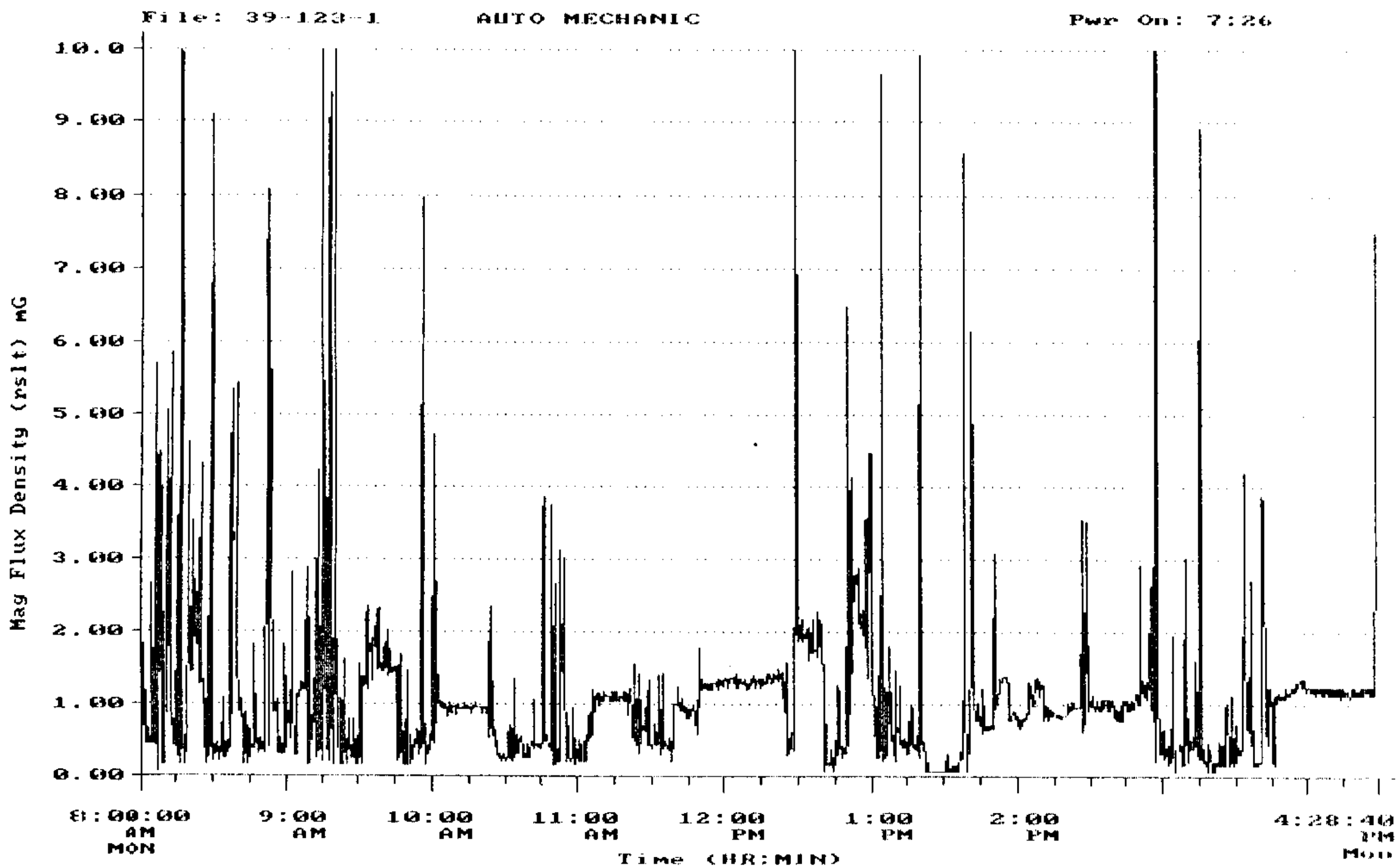


Figure 3.6. Phase I EMDEX project data

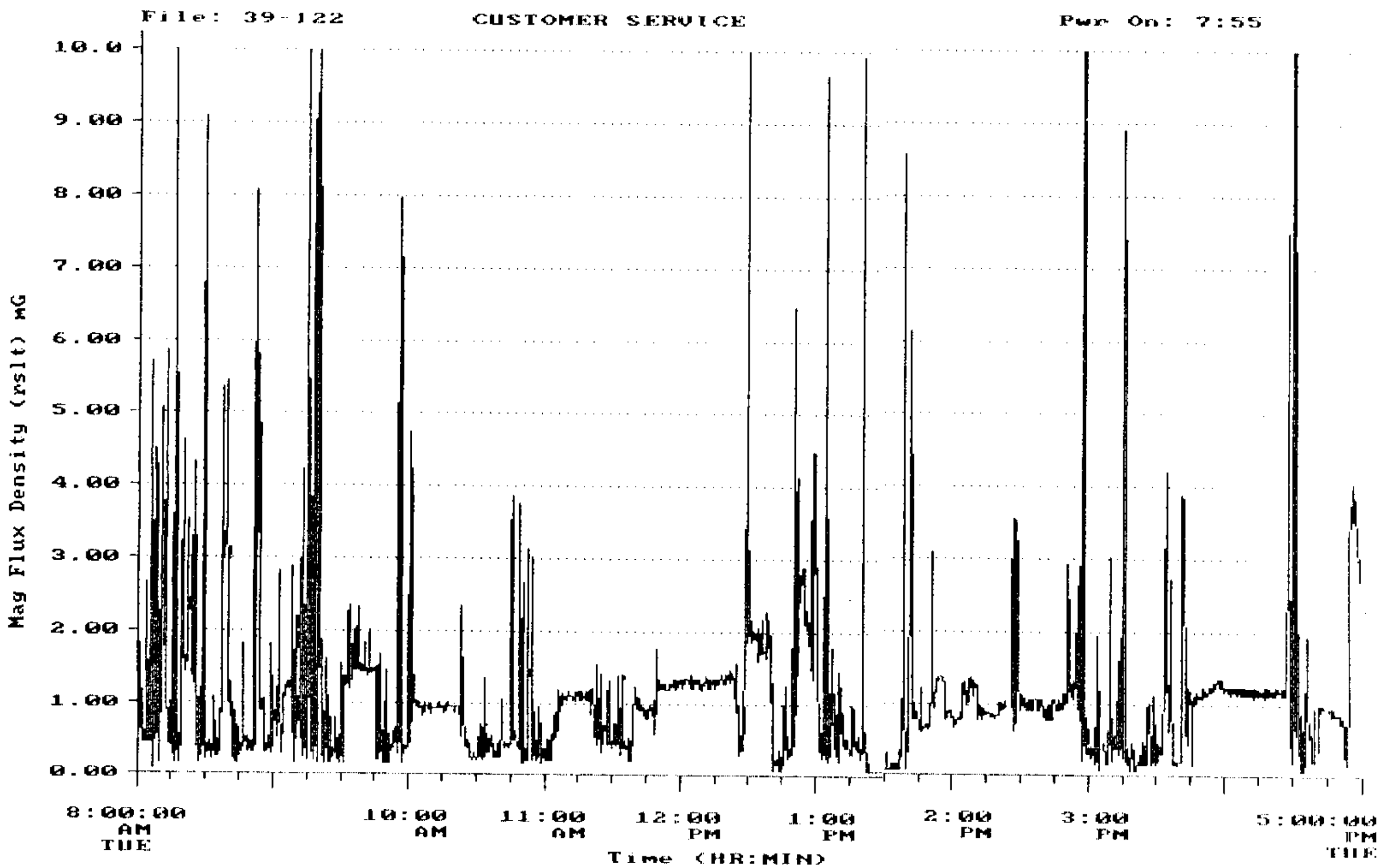


Figure 3.7. Phase I EMDEX project data

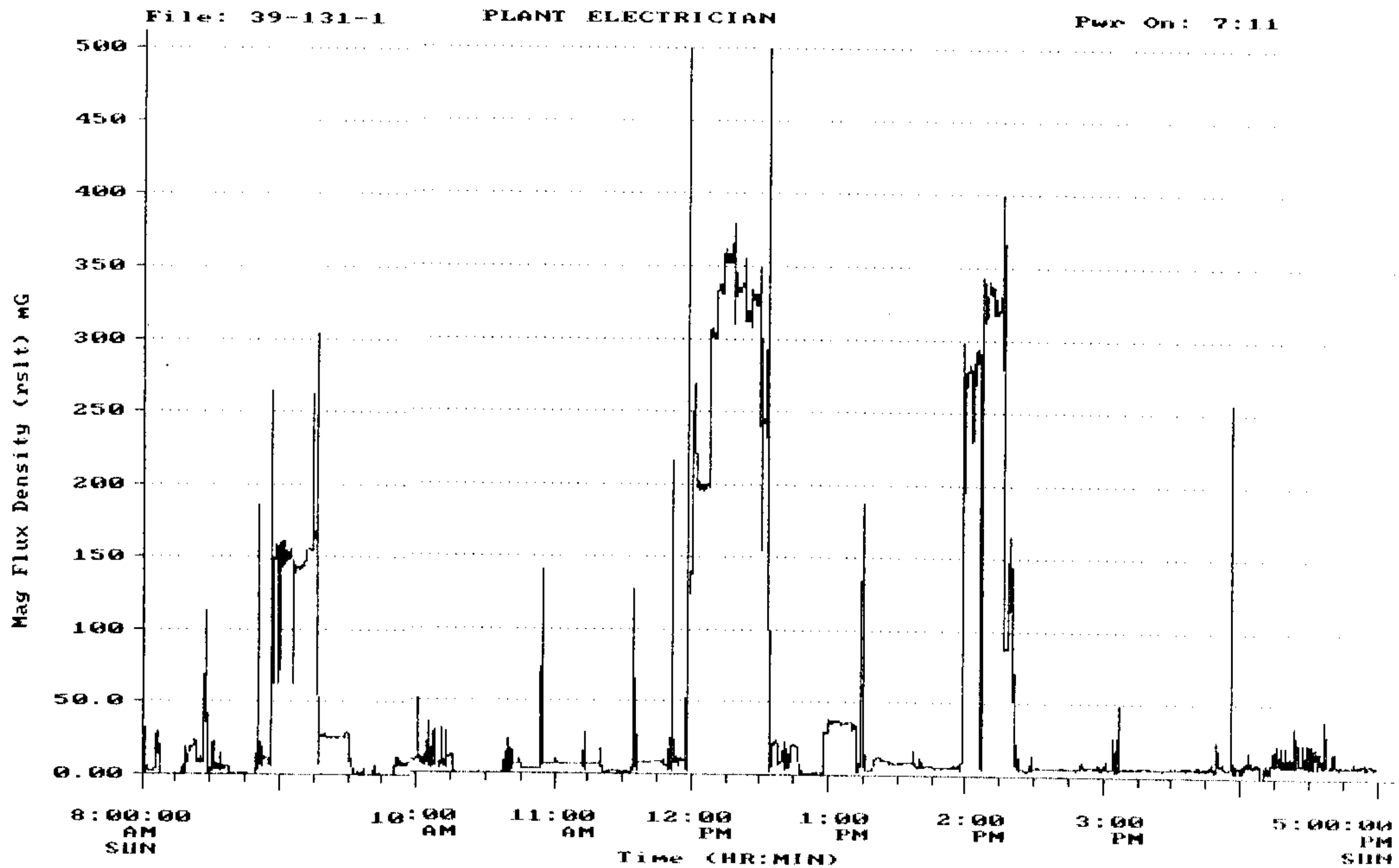


Figure 3.8. Phase I EMDEX project data

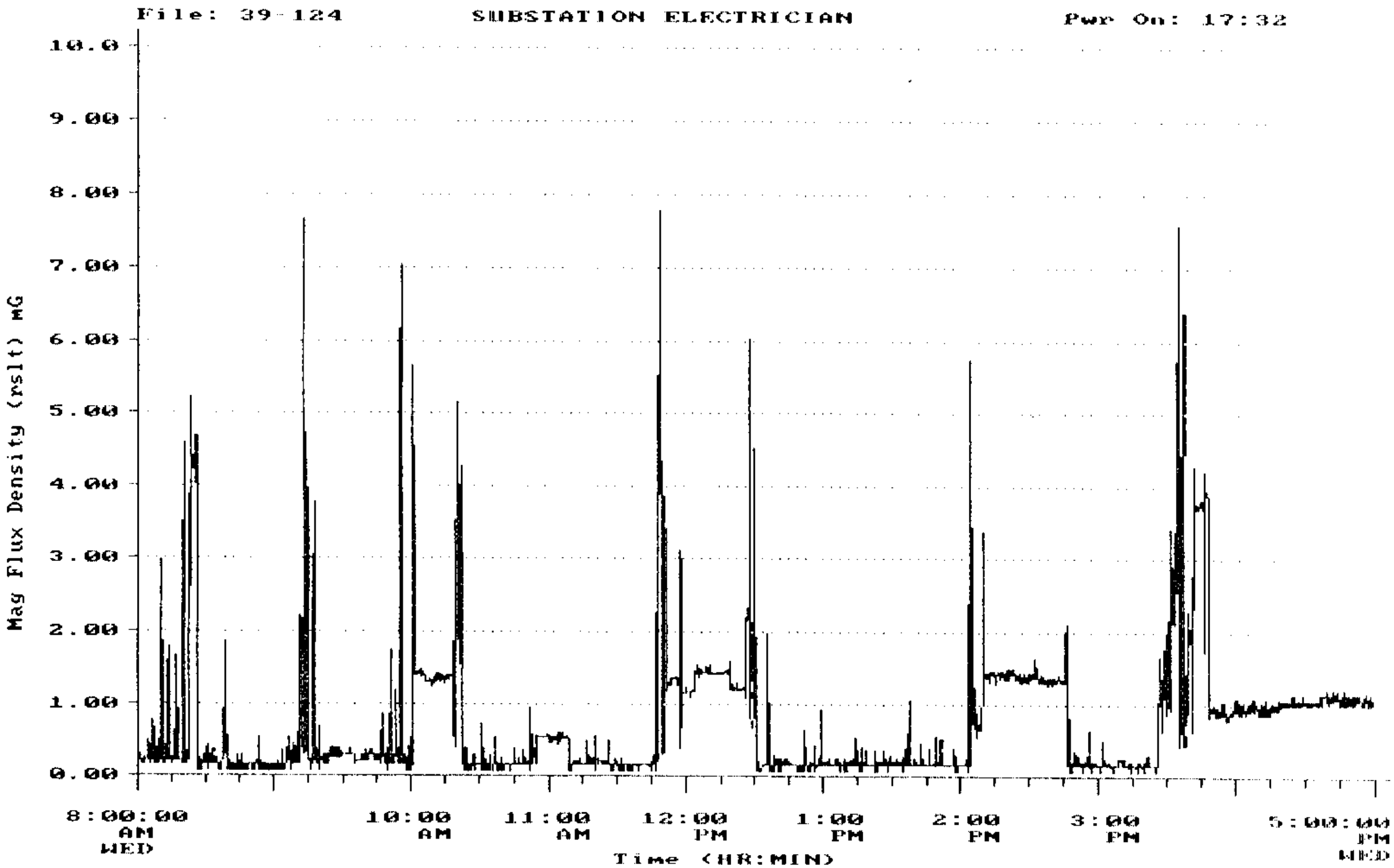


Figure 3.9. Phase I EMDEX project data

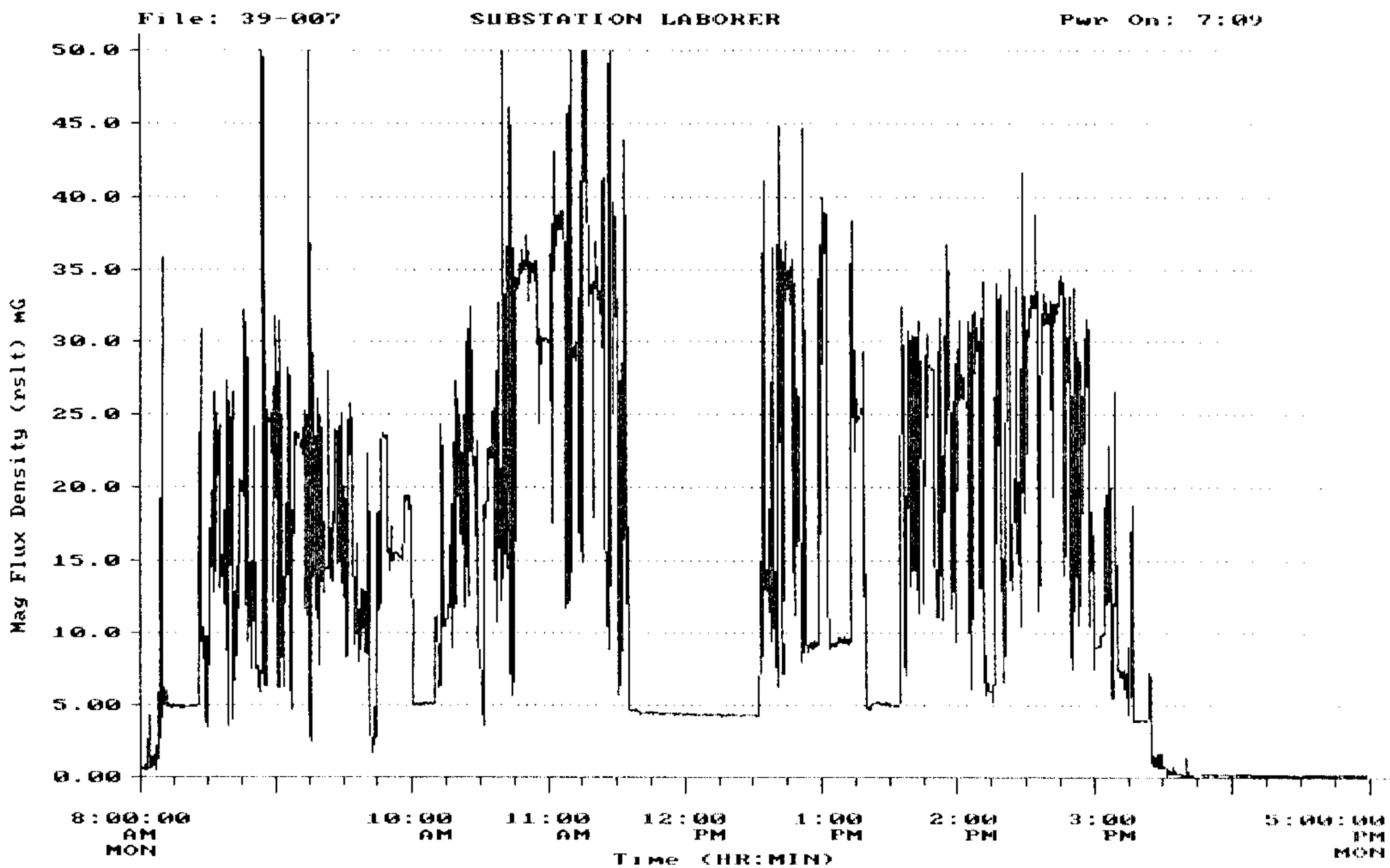


Figure 3.10. Phase I EMDEX project data

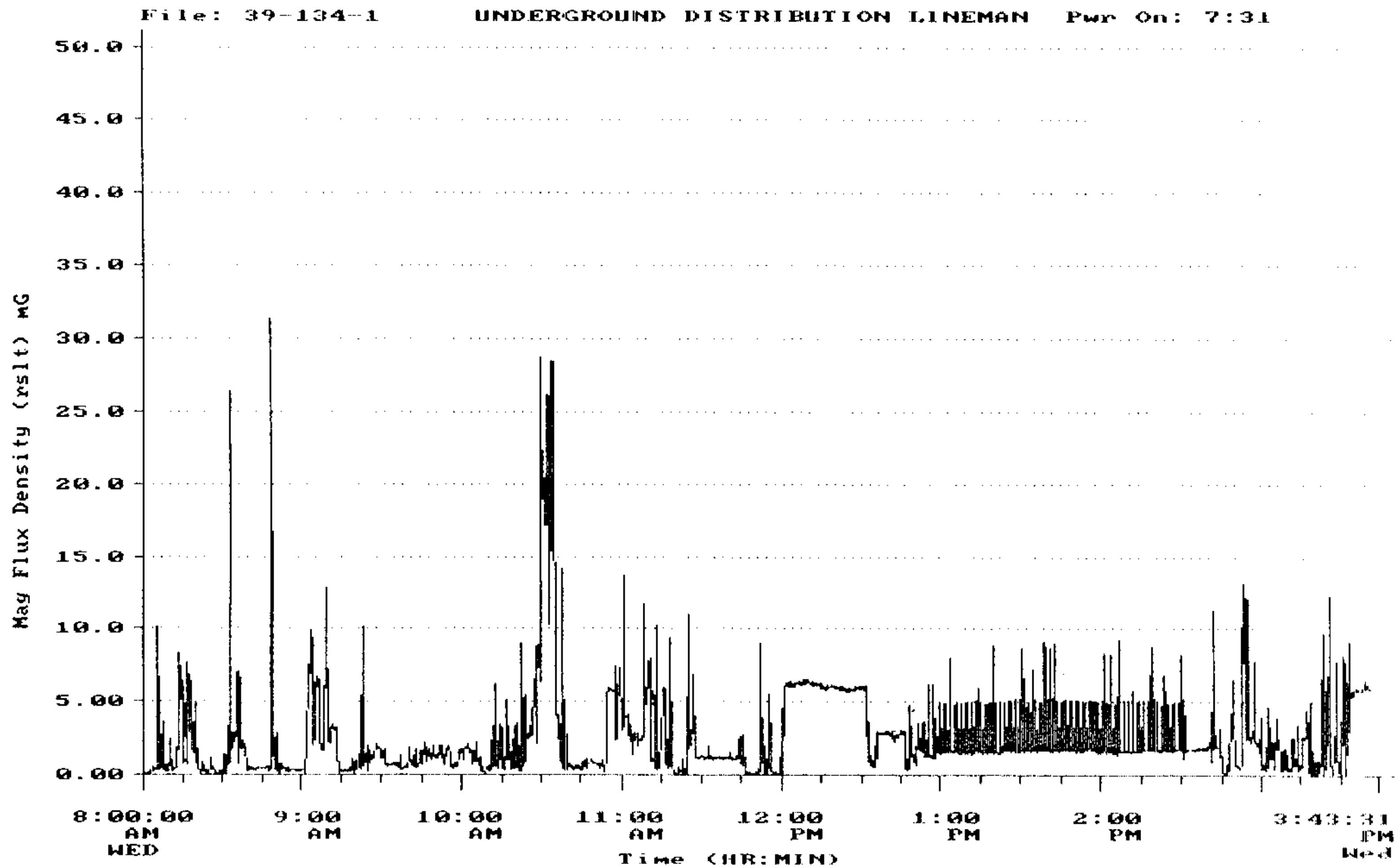


Figure 3.11. Phase I EMDEX project data

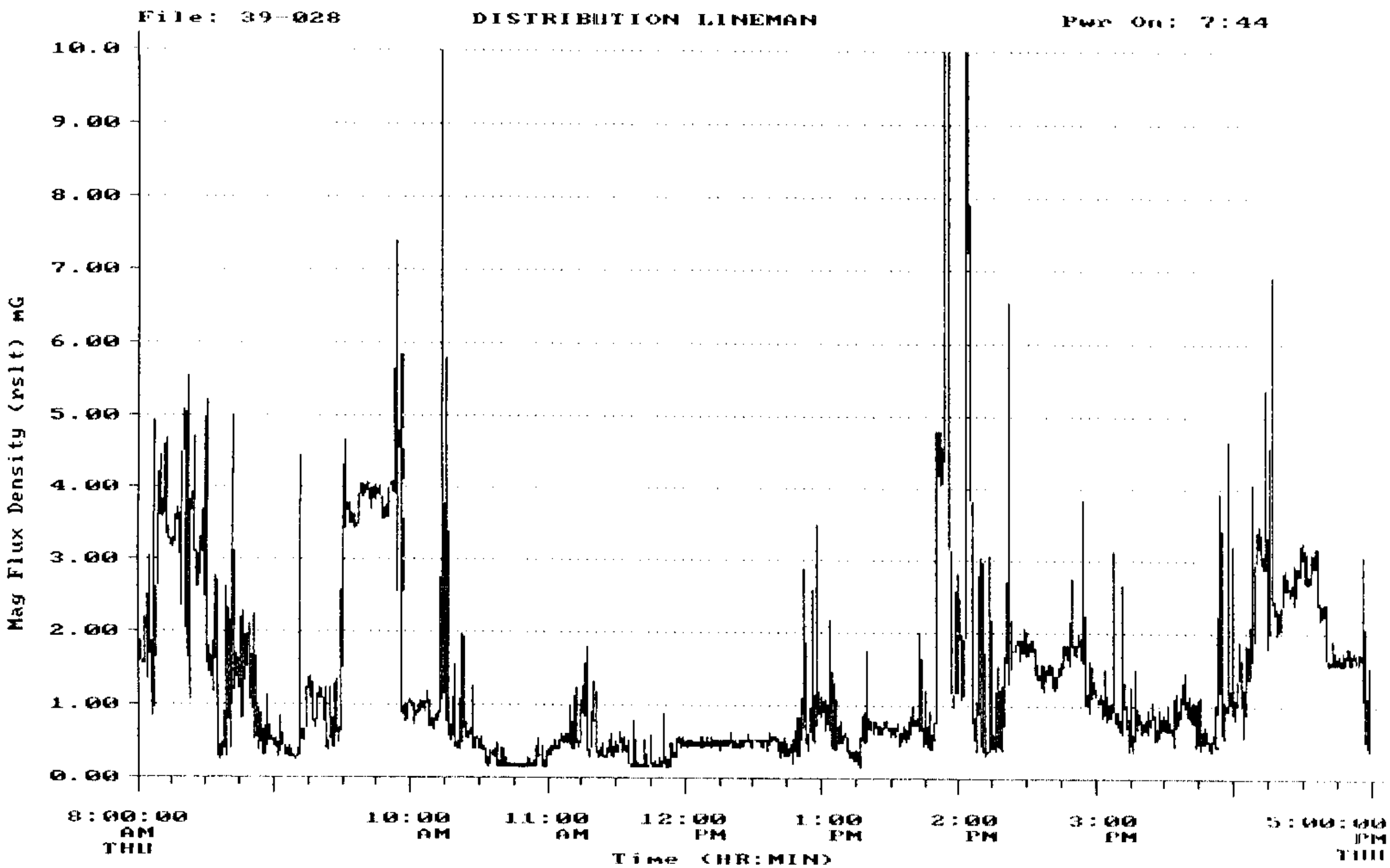


Figure 3.12. Phase I EMDEX project data

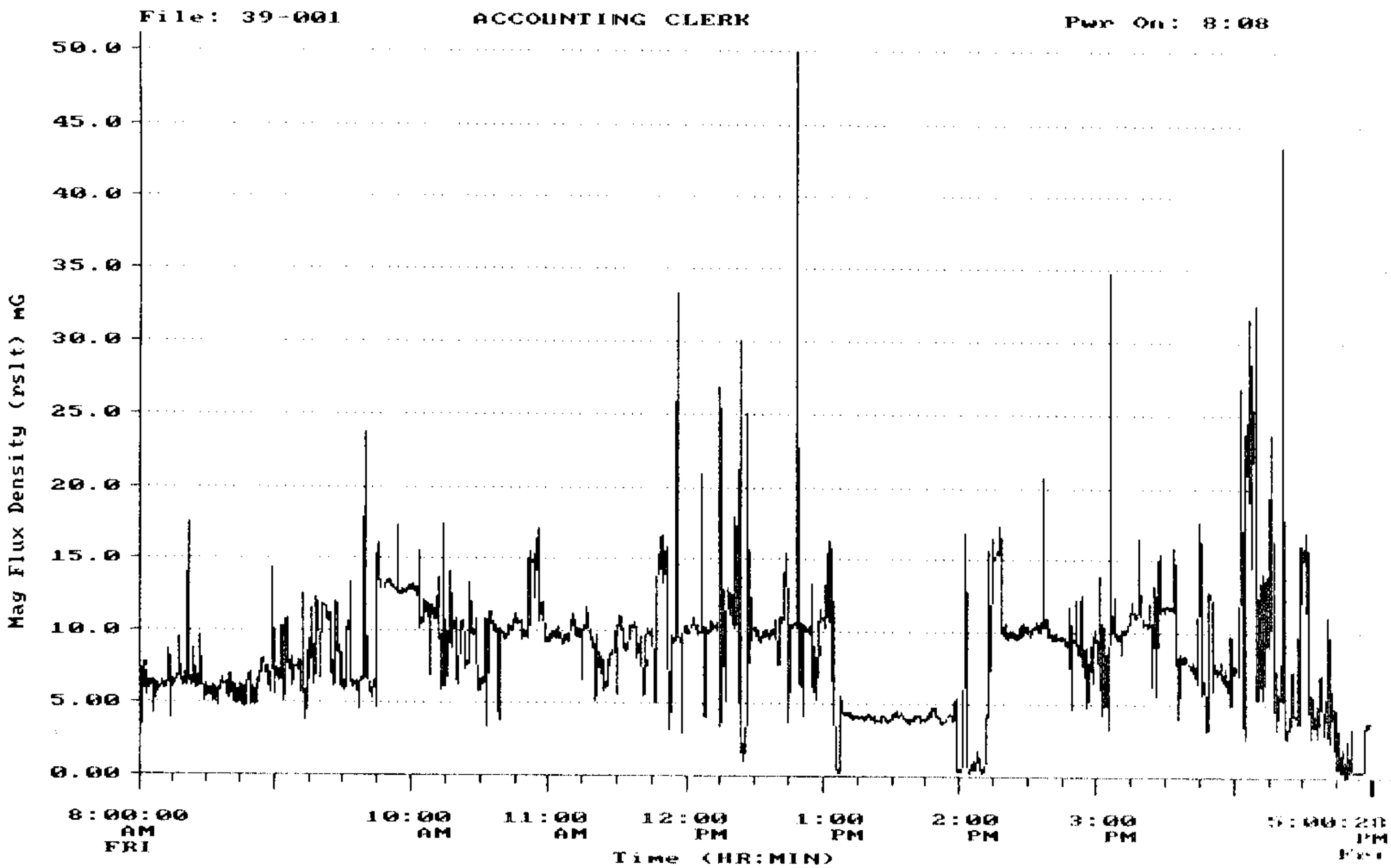


Figure 3.13. Phase I EMDEX project data

participating utilities. The State of Iowa was acting as one utility in the project through the coordination of Iowa State University.

The second phase of the EMDEX Project, EMDEX Phase II, began in late July of 1990. Whereas the first project was to find magnetic field exposure of utility workers, the second phase of the project is to characterize the magnetic field exposure found in homes. Also under study is the electrical system that is located within one hundred fifty feet of each home. After studying the electrical system within the area, and consulting with utility system maps and utility employees, if needed, the house is classified in a wire–coding category, dependent on the type of the line, the size of wires, and the proximity of the lines to the house. Lines fell into one of five categories: (1) very high current configuration, (2) ordinary high current configuration, (3) ordinary low current configuration, (4) very low current configuration, or (5) underground (see Table 3.2). It is the goal of the project to prove or disprove the methods used by epidemiological studies that used wire coding as a surrogate for magnetic fields measurements.

In this project, the same four utilities that participated in the Phase I project are again participating. Iowa State University is again acting as coordinator for the Phase II project, but is also participating in the project. Each utility, including Iowa State University, is required to wire code and select twelve homes, with a goal to find three homes in each wire code category, which leaves two homes that the site coordinator can select independently. Magnetic field measurements are to be taken in each home for three days at a time, for three different times of the year – summer, fall or spring, and winter. Figures 3.14–3.16 are examples of approx-

Table 3.2. Distance criteria for wire code categories in feet

	Transmission	Primary Distribution			Secondary Distribution	
Category	Transmission Line	6 Phase	Thick 3 Phase	Thin 3 Phase	First Span	Other Span
1) VHCC	<50	<50	<50	<25		
2) OHCC	<130	<130	<130	<64	<50	
3) OLCC				<130	<130	<130
4) VLCC	None of the above and the secondary is overhead.					
5) Underground	None of the above and the secondary is underground.					

imately three day periods of magnetic field measurements that have been collected by Iowa State University as part of their participation in Phase II.

3.3 EMDEXC

A few comments must be made about the progress of the EMDEX unit. After the completion of the EMDEX Phase I project, the EMDEX units were released commercially by Electric Field Measurements [50]. The released version of the EMDEX, called the EMDEXC (Figure 3.17), had many improvements and used a totally different software package with which to initialize the unit and analyze the data. The Iowa Test and Evaluation Facility (ITEF) purchased six of these EMDEXC units so that Iowa State University and ITEF's member utilities could use them in data collection projects.

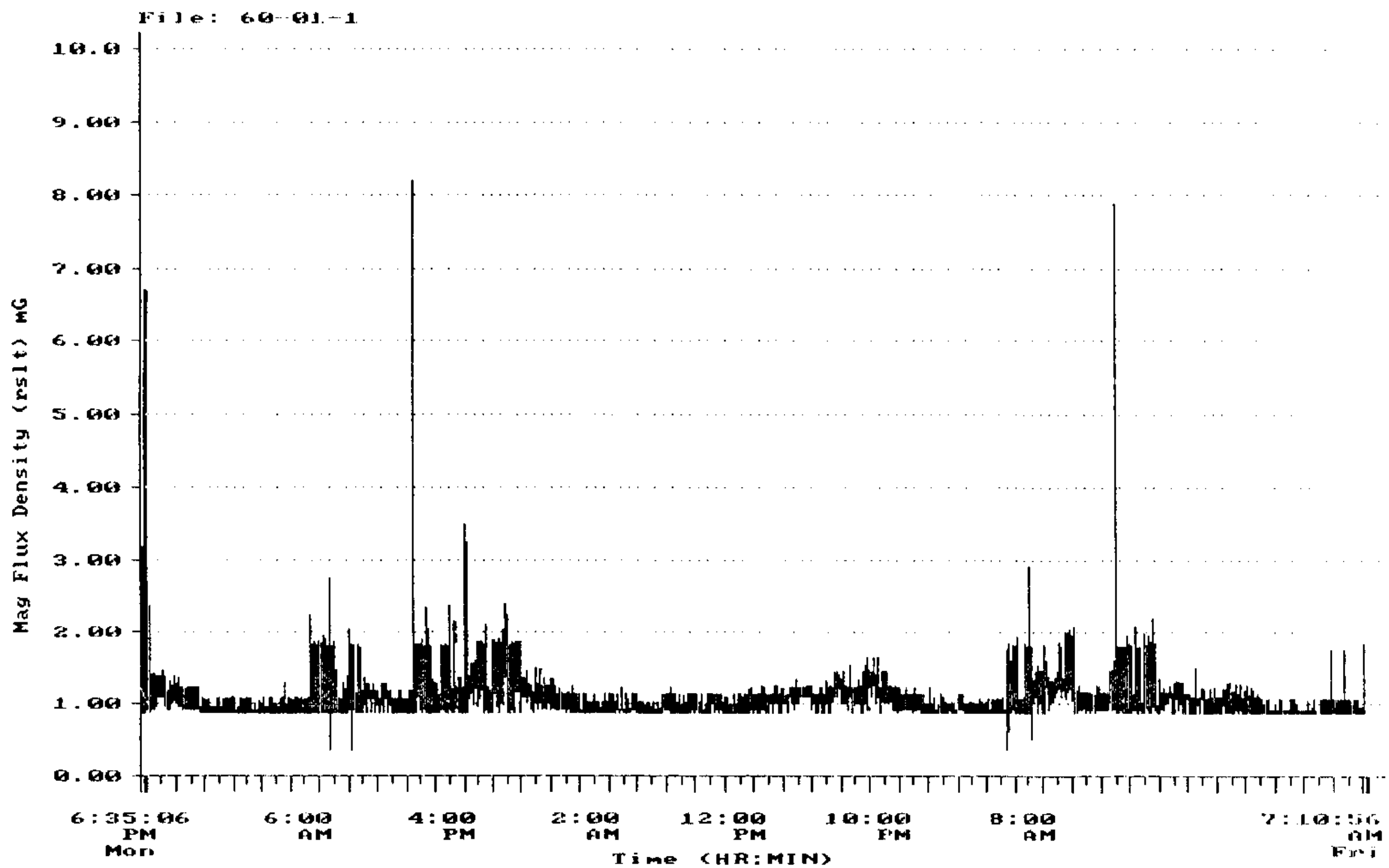


Figure 3.14. Phase II EMDEX project data

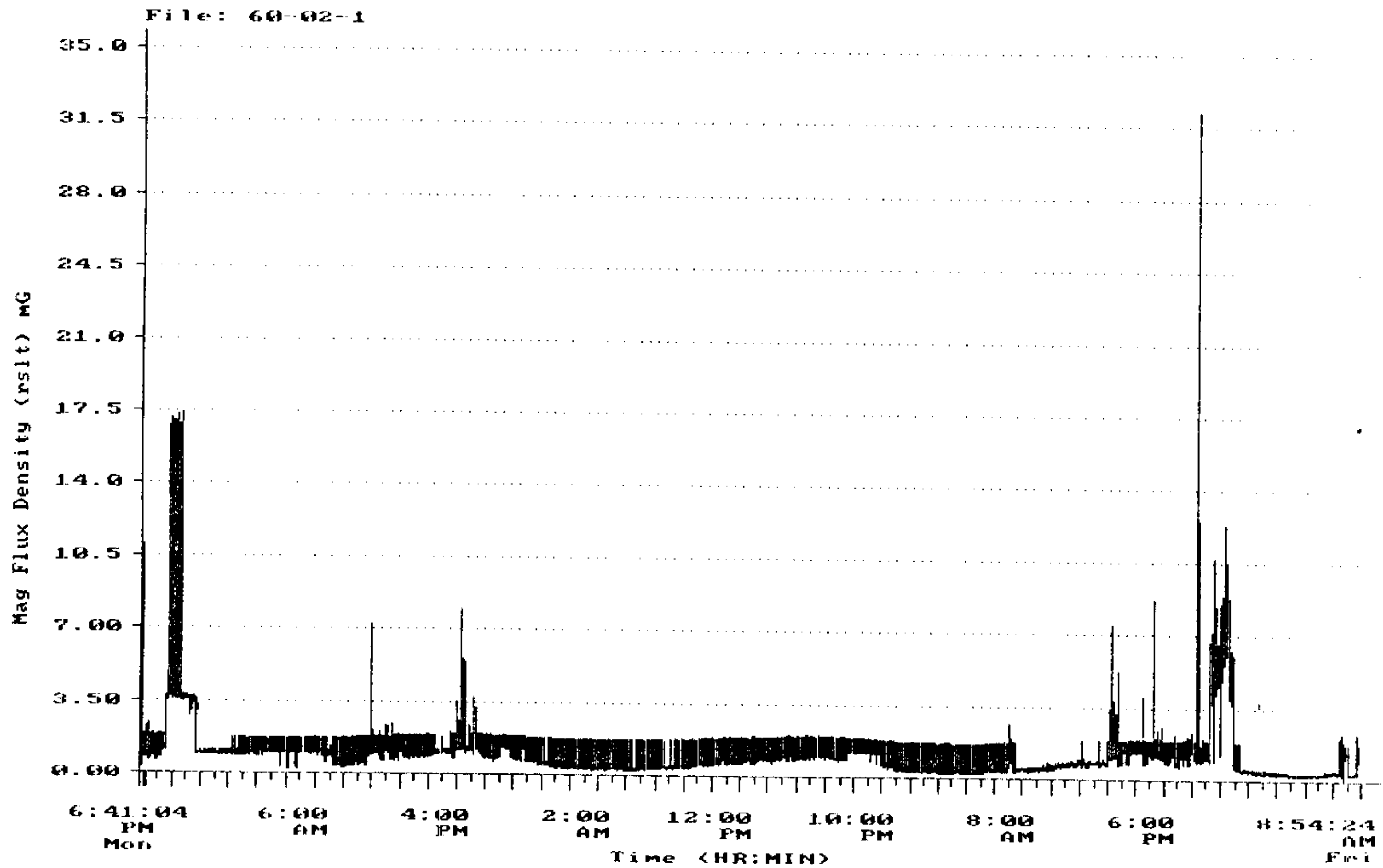


Figure 3.15. Phase II EMDEX project data

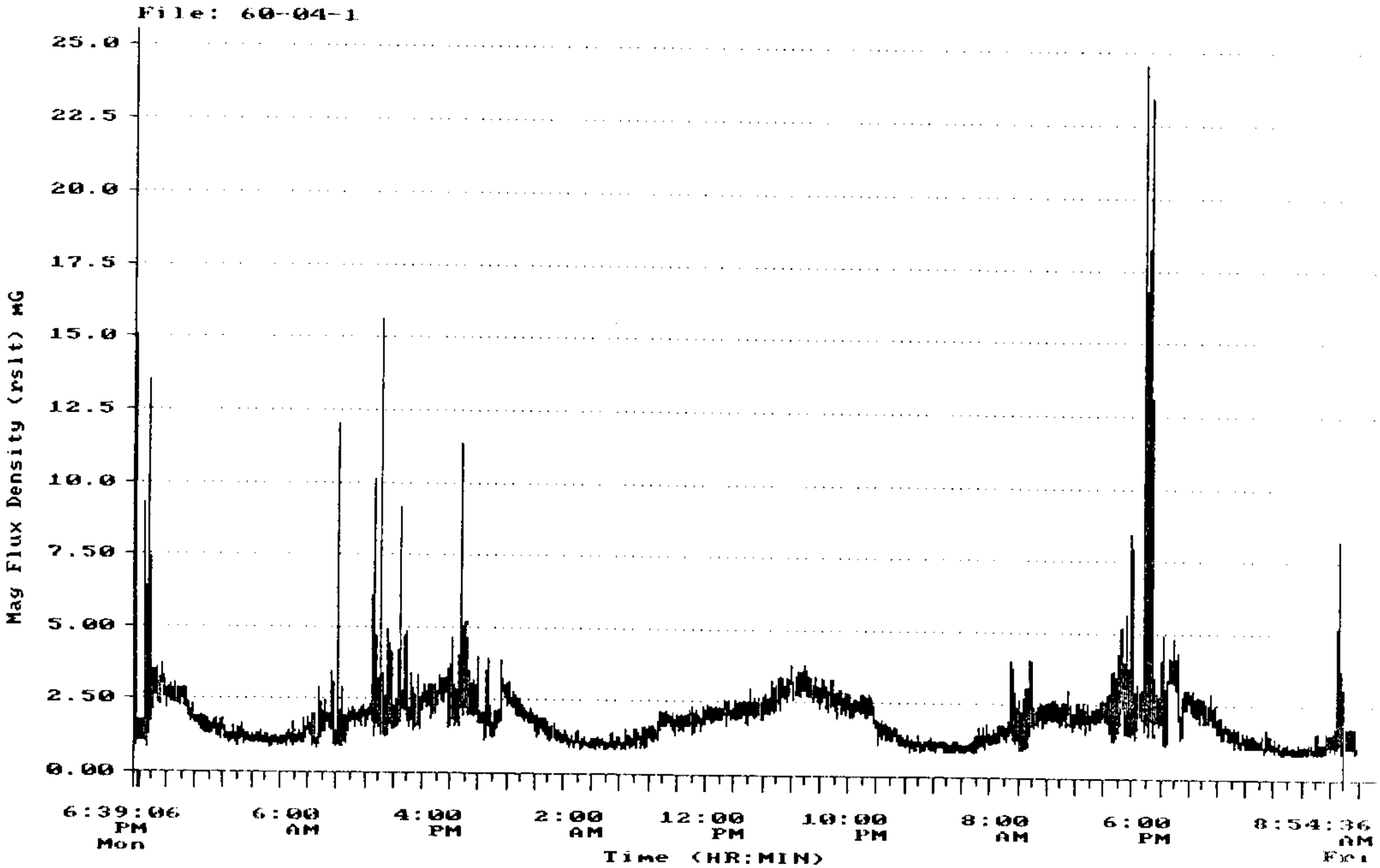


Figure 3.16. Phase II EMDEX project data

Improvements of the commercial EMDEXC over the original EMDEX include the following:

1. Data acquisition may be initiated in independent sequences.
2. Data may be taken at regular time intervals, or regular distance intervals with the use of a distance triggering enhancement such as the one presented in Section 3.4, or by manually pushing a button.
3. A text file of arbitrary length may be loaded on the EMDEXC unit when initializing to document what data is intended to be recorded.
4. Increased versatility when handling data through the use of macros.

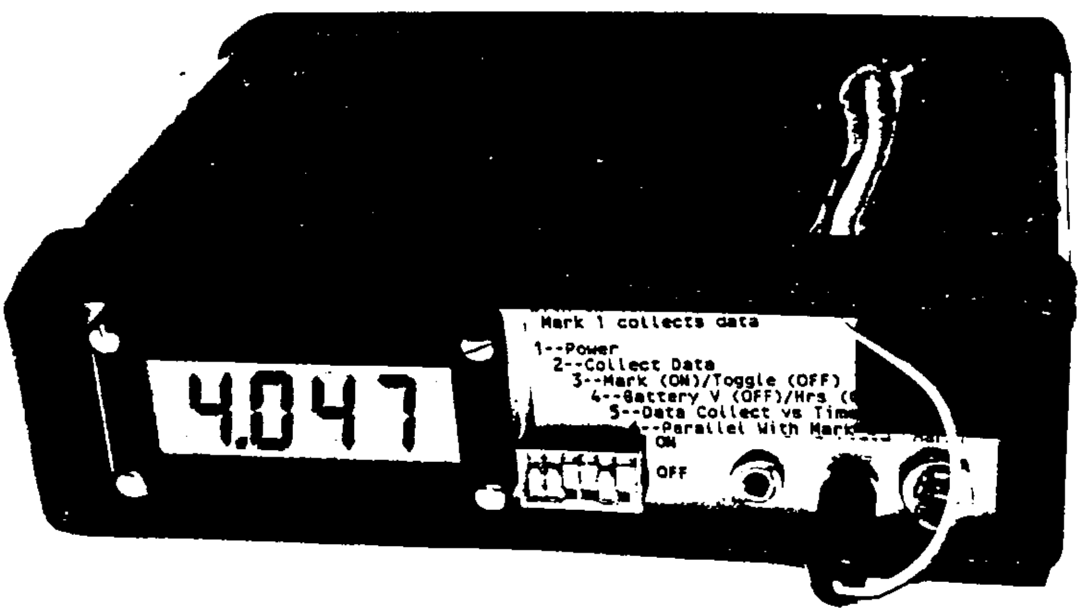


Figure 3.17. The EMDEXC

The biggest improvement is that data acquisition can be now initiated at periodic intervals. No longer does the EMDEX unit need to be on until the data that have been collected are downloaded. The unit can now be initialized and shut off until data are to be next collected, or until the unit is to be downloaded. This new feature allows battery power to be conserved and extends the period of time that measurements can be collected.

The second biggest improvement is that data acquisition can be triggered externally. This means measurements can be taken by the push of a button on the EMDEXC or by a triggering device mounted on a measuring wheel which is plugged into the EMDEXC, allowing to take measurements versus distance. A device to take measurements versus distance was developed at Iowa State University and is explained later in this chapter.

The software program used with the EMDEXC is also called EMDEXC. Its main advantage is its versatility. The Datacalc software developed for the original EPRI studies is definitely more user friendly, but does not easily allow for handling large blocks of data. Also included with the EMDEXC distribution package is a video tape that helps the user get acquainted with the uses of the software.

Also obtained by ITEF with the six EMDEXCs were two devices that can be used in calibrating both the EMDEXCs and the original EMDEX units. It consists of a rectangular coil that is two feet by three feet and contains five hundred turns of copper wire. This calibration unit is plugged into the wall and the field created by the coiled wire can then be controlled by a potentiometer. The calibration device also has a connection so that a digital ammeter can be connected, and the magnetic field can be calculated by measuring the current in the coil and multiplying by a coefficient. One problem that was found is that one must be careful when selecting the calibration location. Care must be taken to avoid any large magnetic fields that may be nearby, and also to avoid any nearby large metal objects that may concentrate the field. The only time a problem was encountered when calibrating an EMDEXC unit was when a metal desk top was being used as the surface on which to calibrate. The metal on the desk top concentrated the lines of flux, not allowing for the correct calibration of the unit. In the one and one–half years that the EMDEXC units have been used at Iowa State University, no EMDEXC unit has required recalibration. Had this been necessary, it would have been shipped to the manufacturer for recalibration.

3.4 Measuring Wheel

After ITEF acquired the six EMDEXCs, it was possible to take measurements by externally triggering the units. No longer is the EMDEXC limited to taking only measurements versus time. All that is required is to short a connection that plugs into the EMDEXC. The manufacturer of the EMDEXC, Electric Field Measurements, has available a measuring wheel package that could be used to externally trigger the EMDEXC versus distance. This package was too costly for Iowa State University, especially since multiple wheels were required because Iowa State University now had six measuring devices. A new and cheaper method to take measurements versus distance was set as a goal.

The first step to achieve this goal was to determine what was required to trigger the EMDEXC to take measurements. The manufacturer's user manual provided no information, so various ideas were tried, not necessarily in the most logical order. The first was to build a pulse generator, thinking a pulse was what was required to trigger the EMDEXC to take measurements. This was tried with a variety of pulse sizes and durations to no avail. Once when we were trying to get one of the pulse generators to work, we accidentally got the EMDEXC to gather data. The astounding thing about this is that the pulse generator wasn't even on. It was by chance that two wires were accidentally shorted. It was then that we discovered that all that was needed to take a measurement was to electrically complete a circuit. After this discovery, we set out to develop a set of mechanical contacts that could be mounted on a typical measuring wheel.

We tried a variety of mechanical contacts, with little satisfaction. It was then we discovered a magnetic reed switch that consisted of two parts, each about the size of a pencil eraser. The first part consisted of a switch that when acted on by an external constant magnetic field, would complete a circuit connected to the EMDEXC. The second part was simply an ordinary magnet. The switch was mounted on the frame of the measuring wheel, with the small magnet place on the rim of the wheel. Now, when the wheel turned, a data frame was taken every revolution of the wheel, or every four feet (the circumference of the wheel). With the addition of another magnet on the opposite side of the wheel, a data frame could be taken with every half of a revolution, or every two feet. Collection of data much faster than this was difficult because of the constraint of the EMDEXC to collect data no more than one data frame per second. A slow walk is approximately two feet per second.

After receiving the measuring wheel back from the welder with a few modifications, we were able to test our new data collection technique. The only additional modification made was to glue the magnets on the measuring wheel, because when data was gathered in high grass, magnets were subject to being knocked off. Our modified measuring wheel was built at about one–fifth the cost of the commercial product.

4. MEASUREMENT ACTIVITIES

4.1 Introduction

Chapter 4 is a review of some of the measurement activities that have been performed by researchers at Iowa State University. These activities include a variety of measurement locations, but in each case it is the sixty hertz magnetic fields that are of interest. Discussed first is a study of magnetic fields created by distribution lines. Second is a study of a pad–mount transformer and the fields that are caused by its presence in a back yard. Next is a study of an office space located above a transformer vault in a multi–story building. Another project is a joint project between the College of Veterinary Medicine and the Electrical Engineering department, both of Iowa State University. Two studies that measured magnetic fields in the home are also included. The first studied background magnetic fields, the second studied magnetic fields around various electrical devices.

4.2 City of Ames

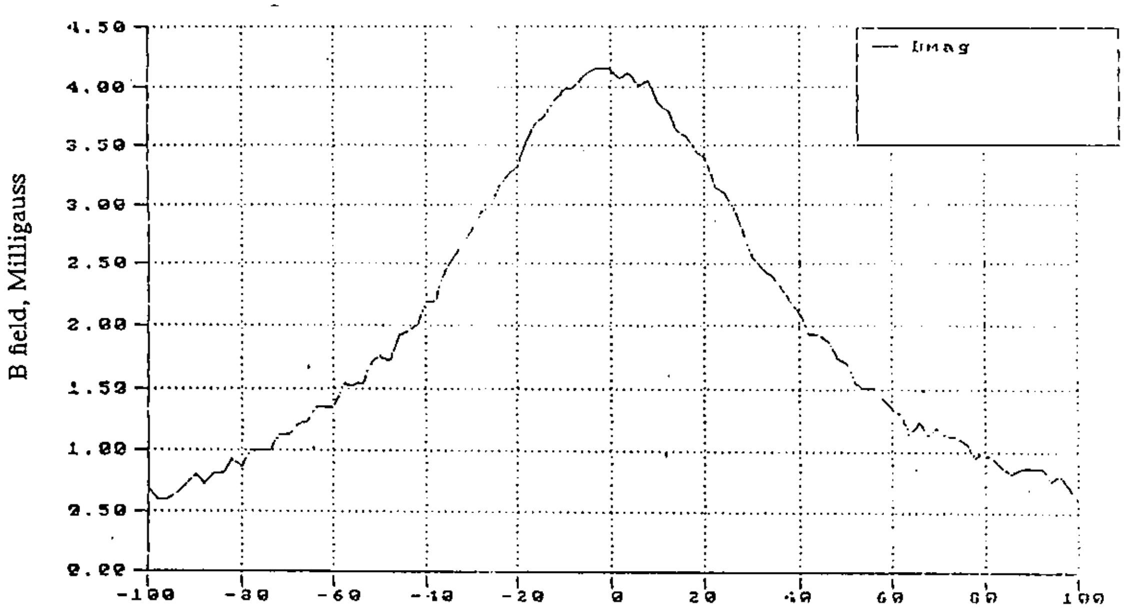
The City of Ames' study is an examination of magnetic fields caused by distribution systems. The Ames Municipal Electric System had been contacted by a number of customers who were concerned about the magnetic fields they were being exposed to by the electrical equipment that was located in the vicinity of their homes. The City of Ames then contacted Iowa State University in search of pertinent information. Since we had not studied any distribution systems, a joint project was proposed and carried out. The City of Ames' role was to provide system maps and loading information; Iowa State University was to provide the equipment and manpower to measure the magnetic fields.

The measurements were taken at two different times. The first set of measurements gathered distribution structure and magnetic field data at various sites. Both underground and overhead data were collected. Overhead lines that were measured consisted of 69 kV, 13.8 kV, and 4 kV lines. Underground measurements that were collected consisted of the same 13.8 kV and 4 kV lines. Also measured was a 208 V underground service drop. For each line, an estimate of the loading on the line at the time of data collection was made. The magnetic field profiles obtained are shown in Figures 4.1–4.6.

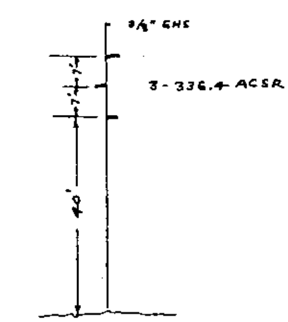
The second set of measurements consisted of analyzing an entire customers' lot to see how each part of the distribution equipment (i.e., primary, secondary, distribution transformer, and service drop) contributed to the background magnetic fields in the vicinity of each home. Measurements of various types were collected outside six homes within the City of Ames' service territory. Data were also gathered inside two of these homes. Again, at each of these locations it was noted what type of electrical lines existed in the area of their home and an estimate of the loading on these lines at the time of measurement. The six homes where data were gathered are illustrated in Figure 4.7. The addresses of these homes are:

1010 Curtis
1106 Curtis
1518 Carroll
120 O'Neil
1618 Top–O–Hollow
2226 Donald

69 kV Overhead



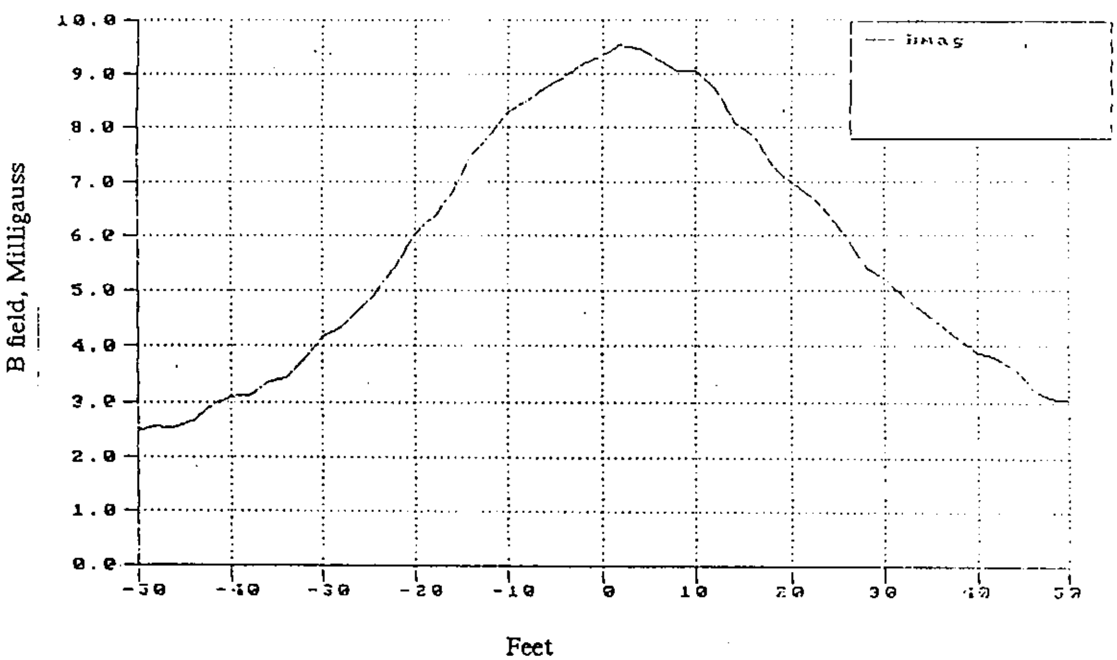
Feet

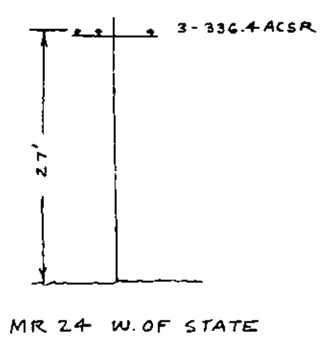


Line Loading - 69 kV - 78.9 A

Figure 4.1. City of Ames distribution line data

13.8 kV Overhead





Line Loading - 13.8 kV - 88.3 A

Figure 4.2. City of Ames distribution line data

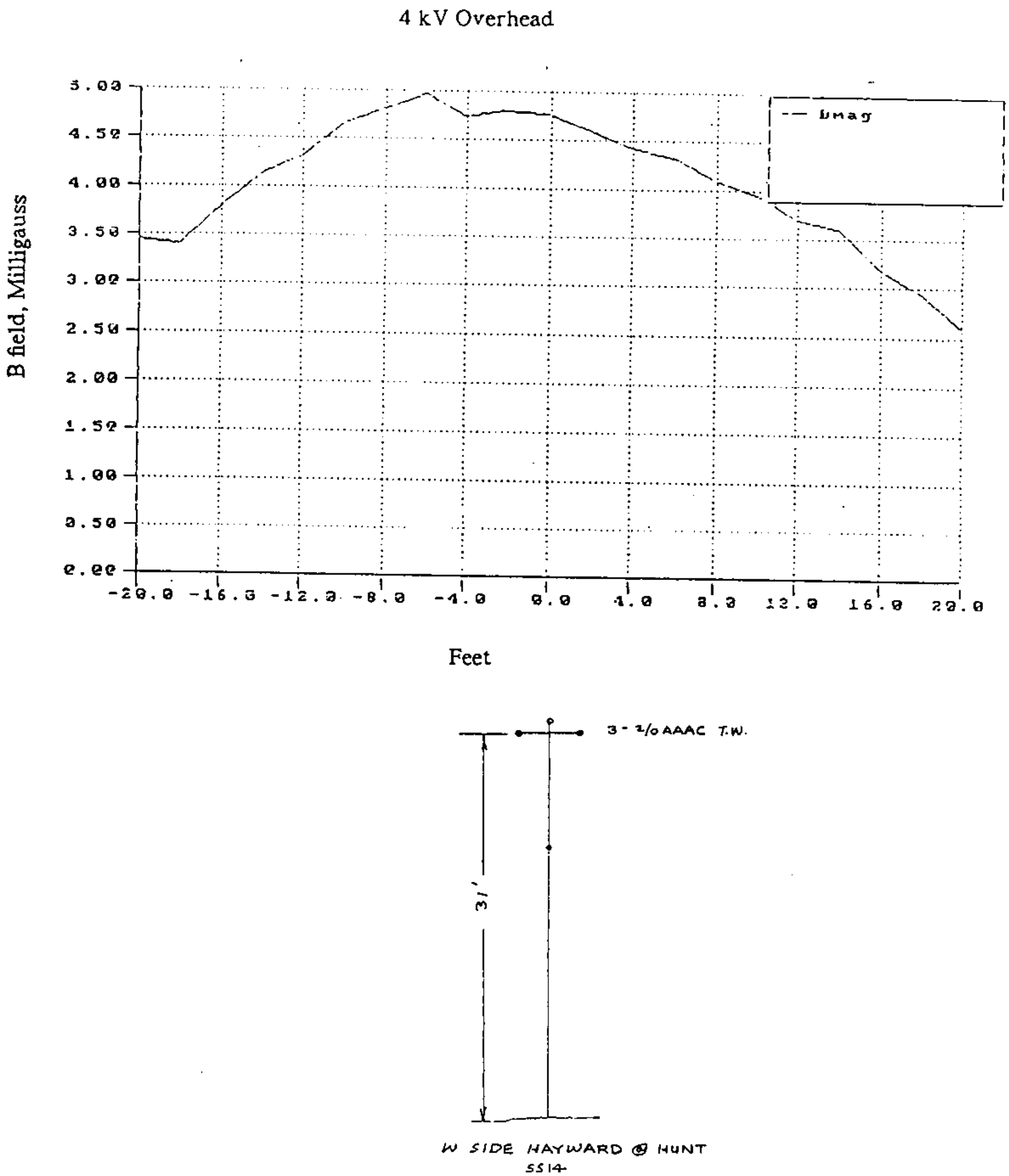
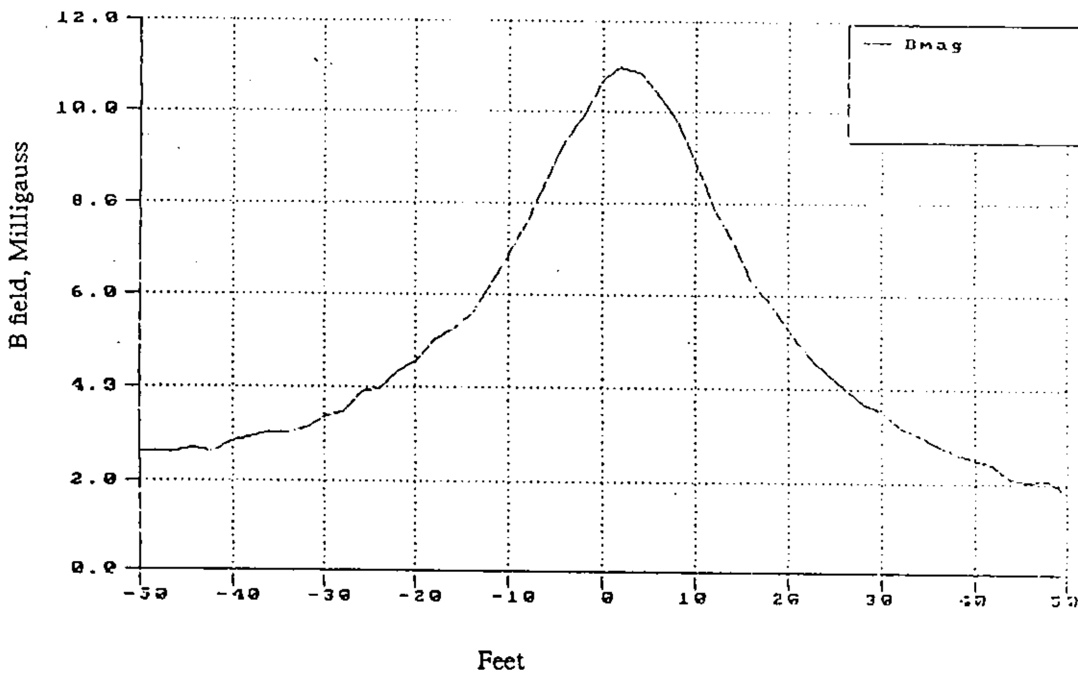
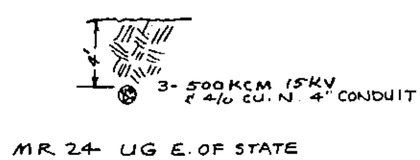


Figure 4.3. City of Ames distribution line data

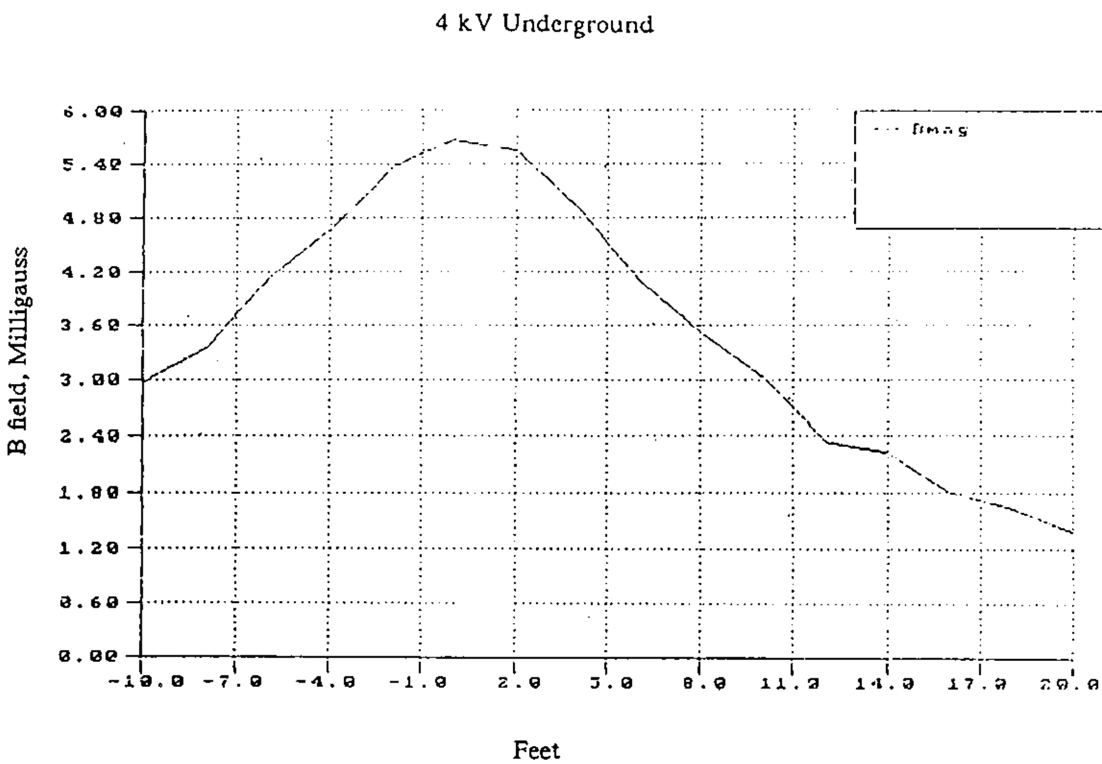
13.8 kV Underground





Line Loading - 13.8 kV - 88.3 A

Figure 4.4. City of Ames distribution line data



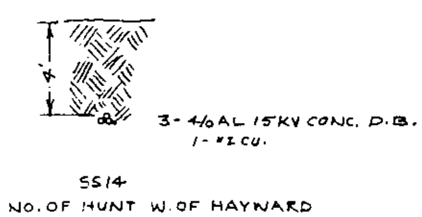
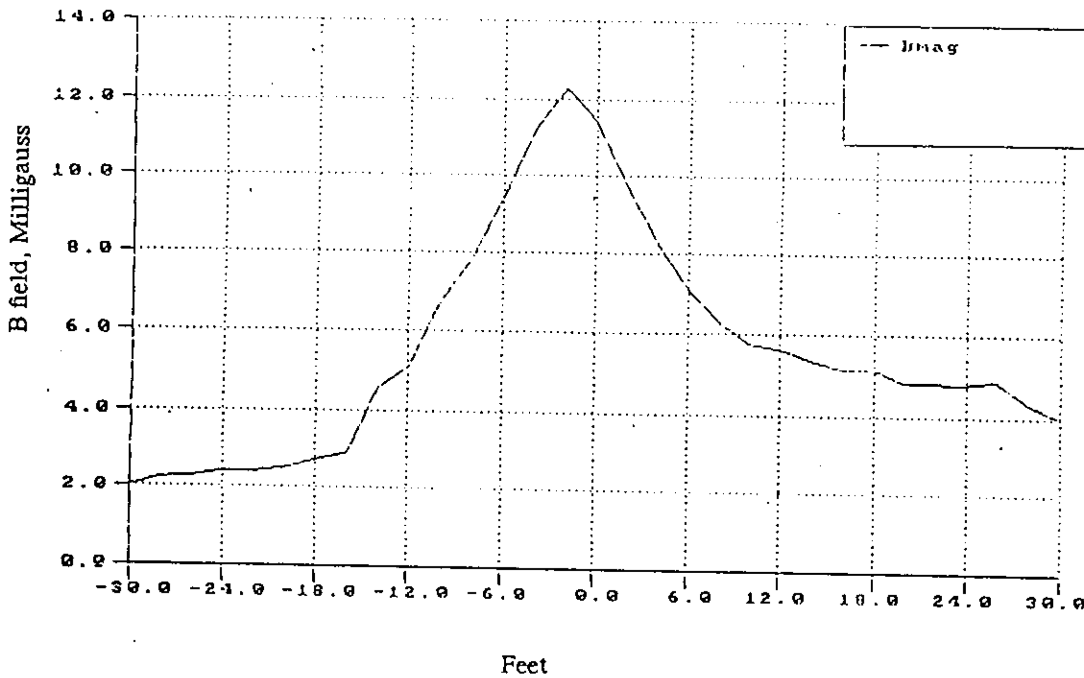
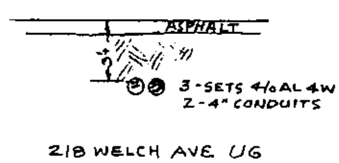


Figure 4.5. City of Ames distribution line data

208 V Underground Service Drop





Line Loading - 208 V - 43 kW

Figure 4.6. City of Ames distribution line data

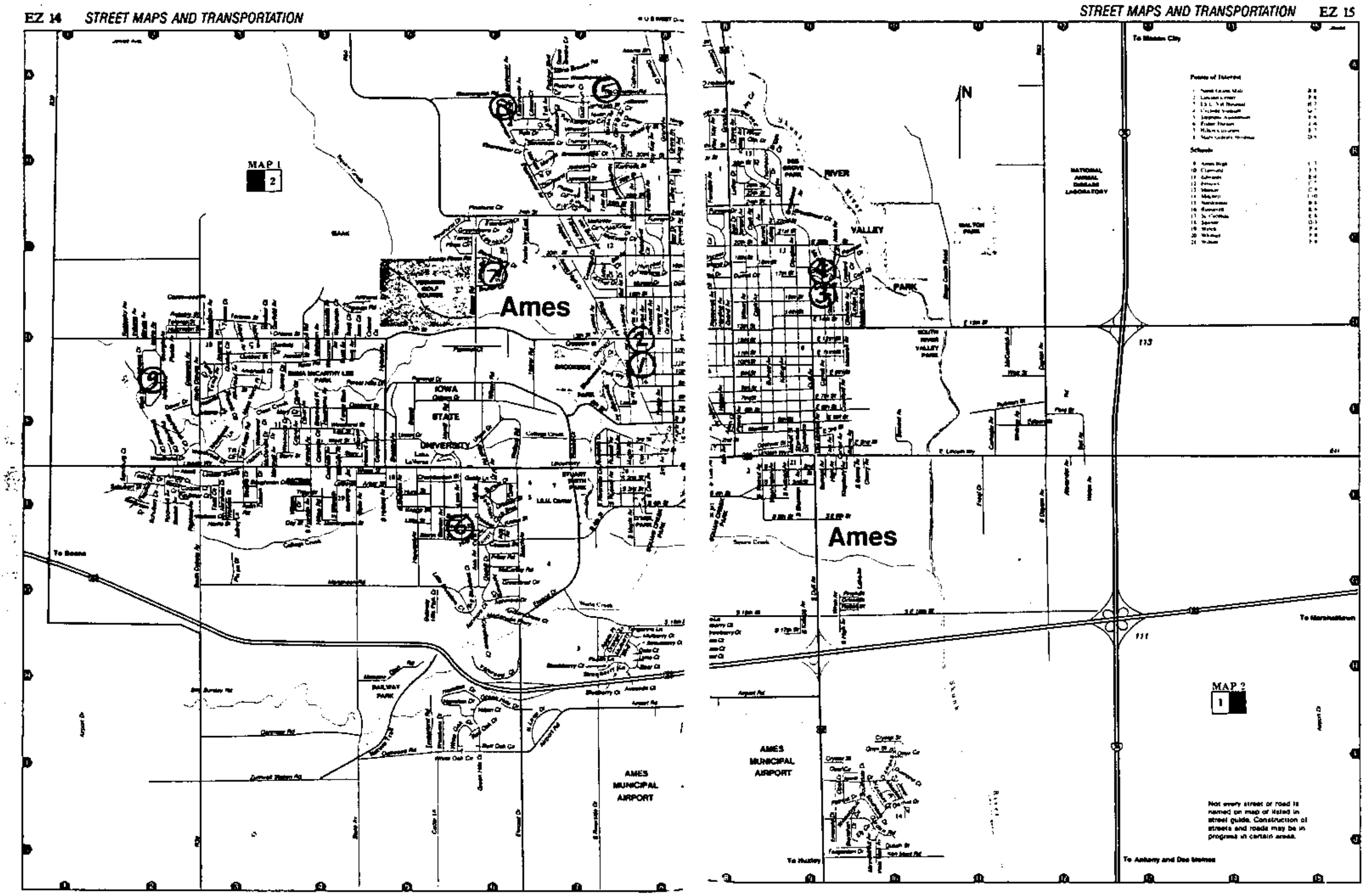


Figure 4.7. Map of the City of Ames

A map of the lot, explanations of what data were gathered, and the data gathered at each home are provided in Figures 4.8–4.43. When possible, data were taken perpendicular and parallel to the electrical lines. Superimposed on the lot diagrams are lines with arrows, which show the path where measurements were taken. The numbers on the arrowed lines correspond to the profile graph showing the data that were collected.

It can be seen that the distribution system contributes very insignificantly to the overall magnetic field level in the six homes that were studied. The only fields that were found to contribute were the service drops. Since electricity must reach the house, very little can be done to avoid the fields created by the service drop.

4.3 Pad–Mount Transformer

The pad–mount transformer study was a study conducted by Iowa State University researchers of the magnetic fields that exist in the back yard of a home where a fifty kVA pad–mount transformer is located. The purpose of this study was to determine the typical strengths of magnetic fields that exist in an area around a pad–mount transformer. Iowa State University conducted the study after being contacted by Iowa Power and Light Company in Des Moines, Iowa.

On August 4, 1989, representatives of Iowa State University visited the site in order to gather data. Measurements were taken in the middle of the afternoon when temperatures reached the upper 90s. This situation was ideal, since the site was in a residential area and many homes were running their air conditioners. This increase in electricity usage (i.e., an increase in line current) maximizes the fields that were measured since magnetic fields are proportional to the currents on the lines.

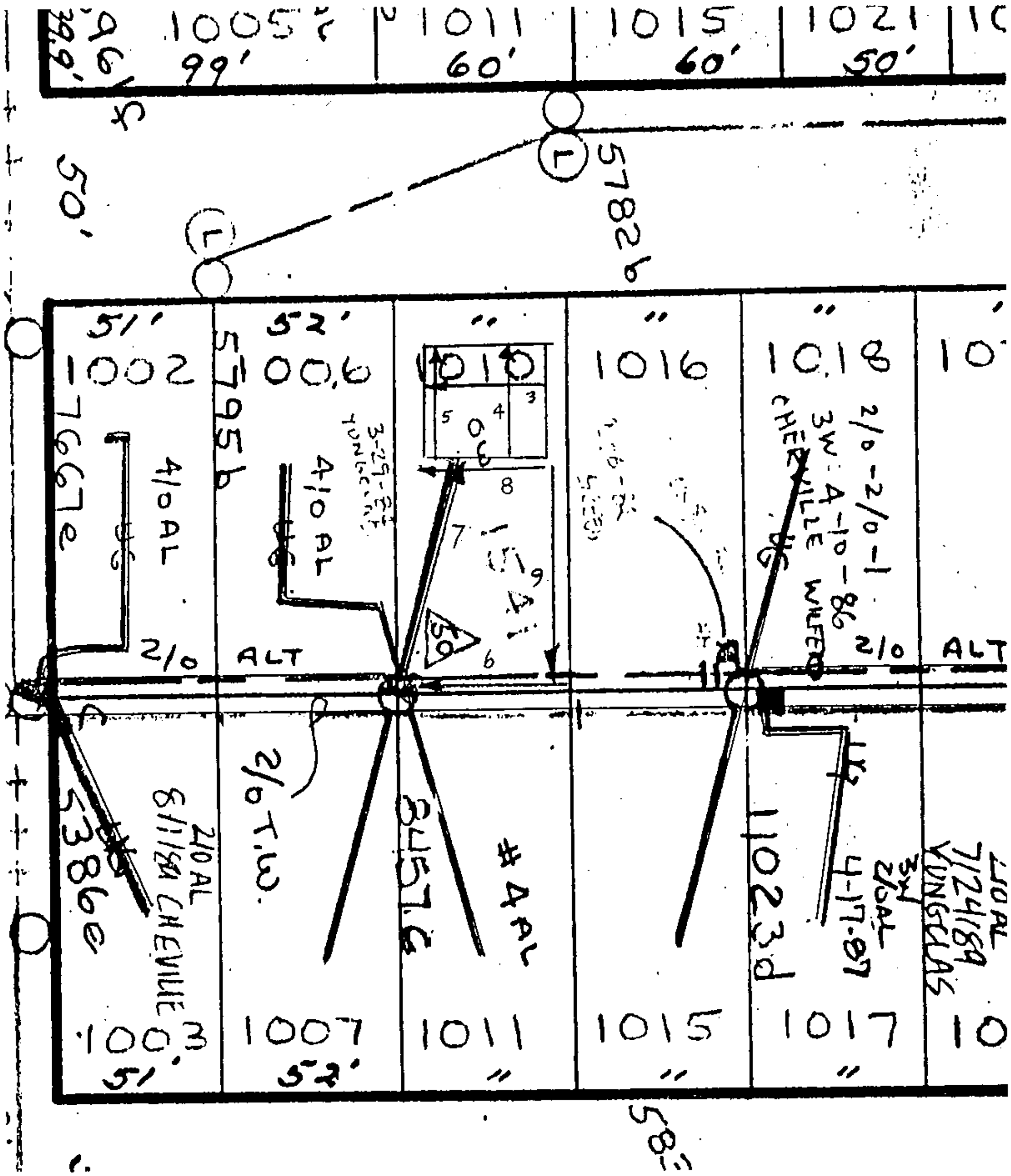


Figure 4.8. Lot at 1010 Curtis

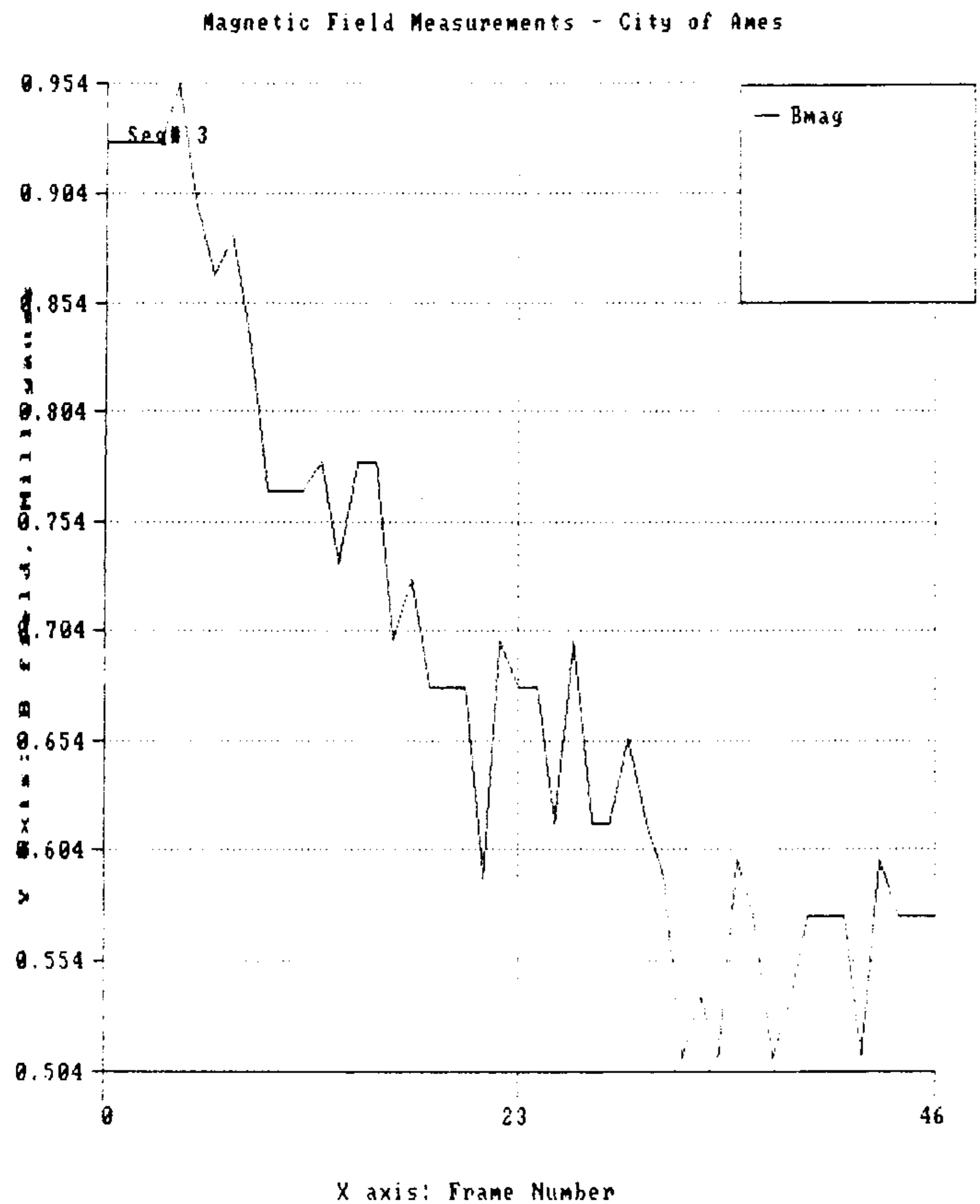


Figure 4.9. Magnetic field measurement #3

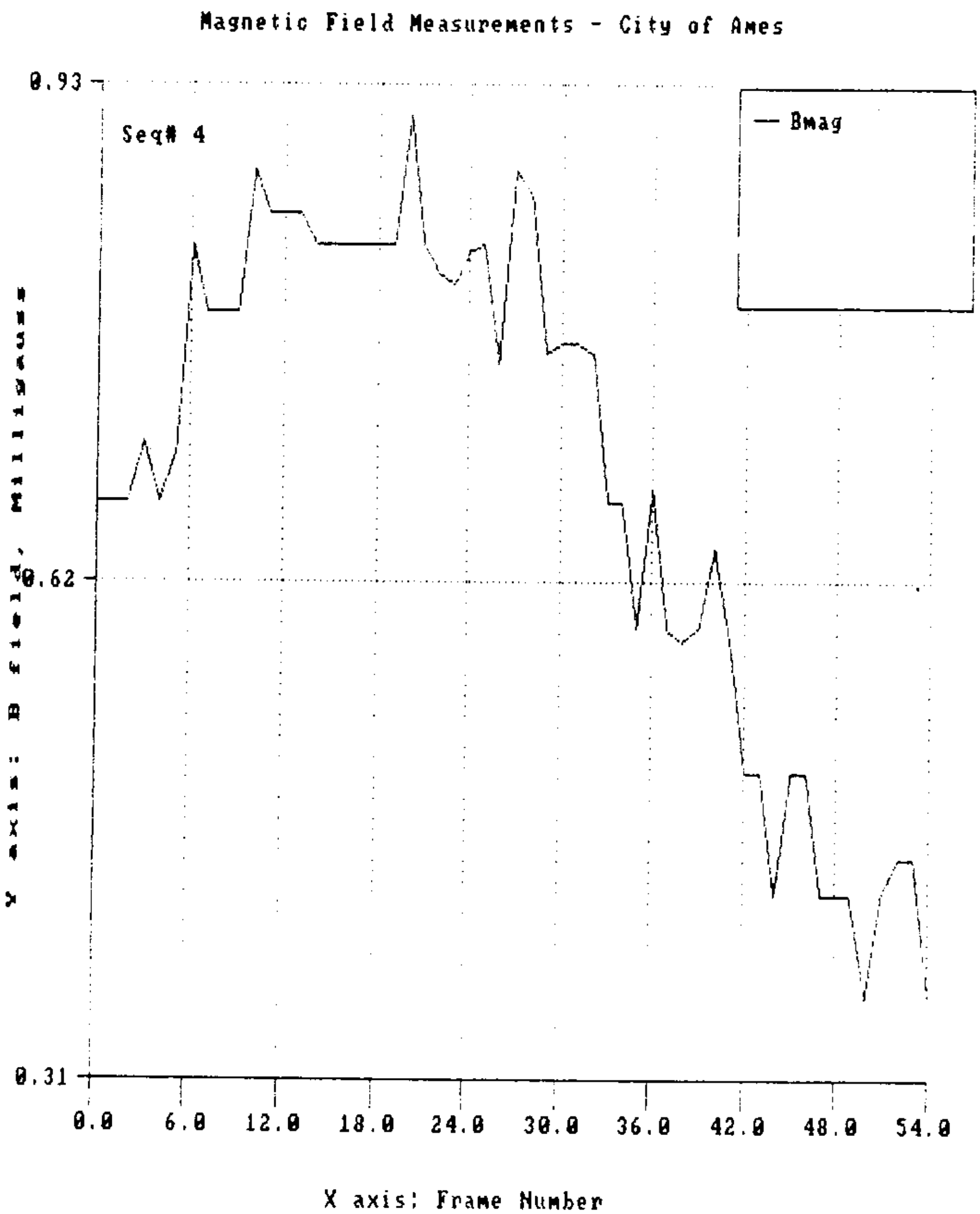


Figure 4.10. Magnetic field measurement #4

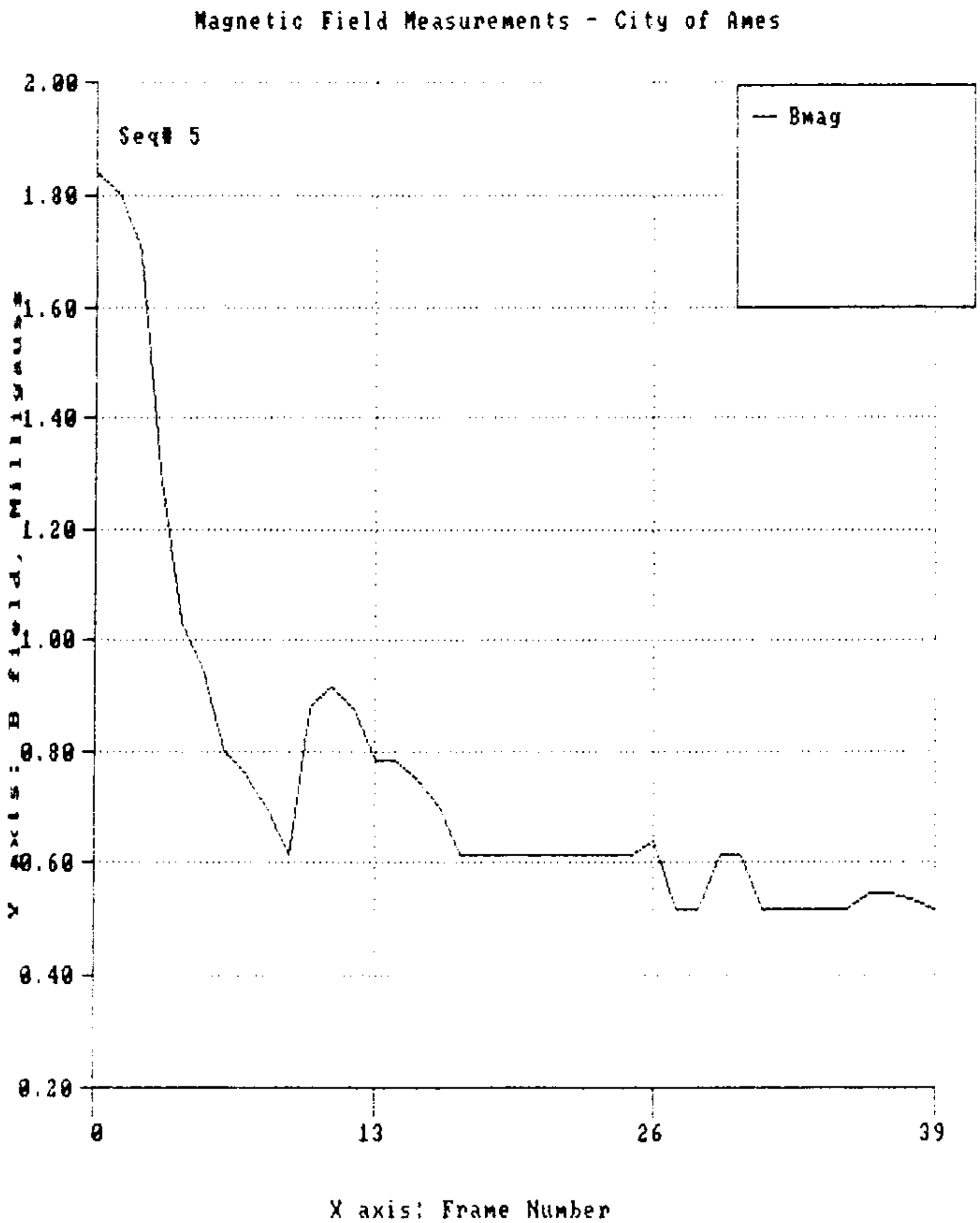


Figure 4.11. Magnetic field measurement #5

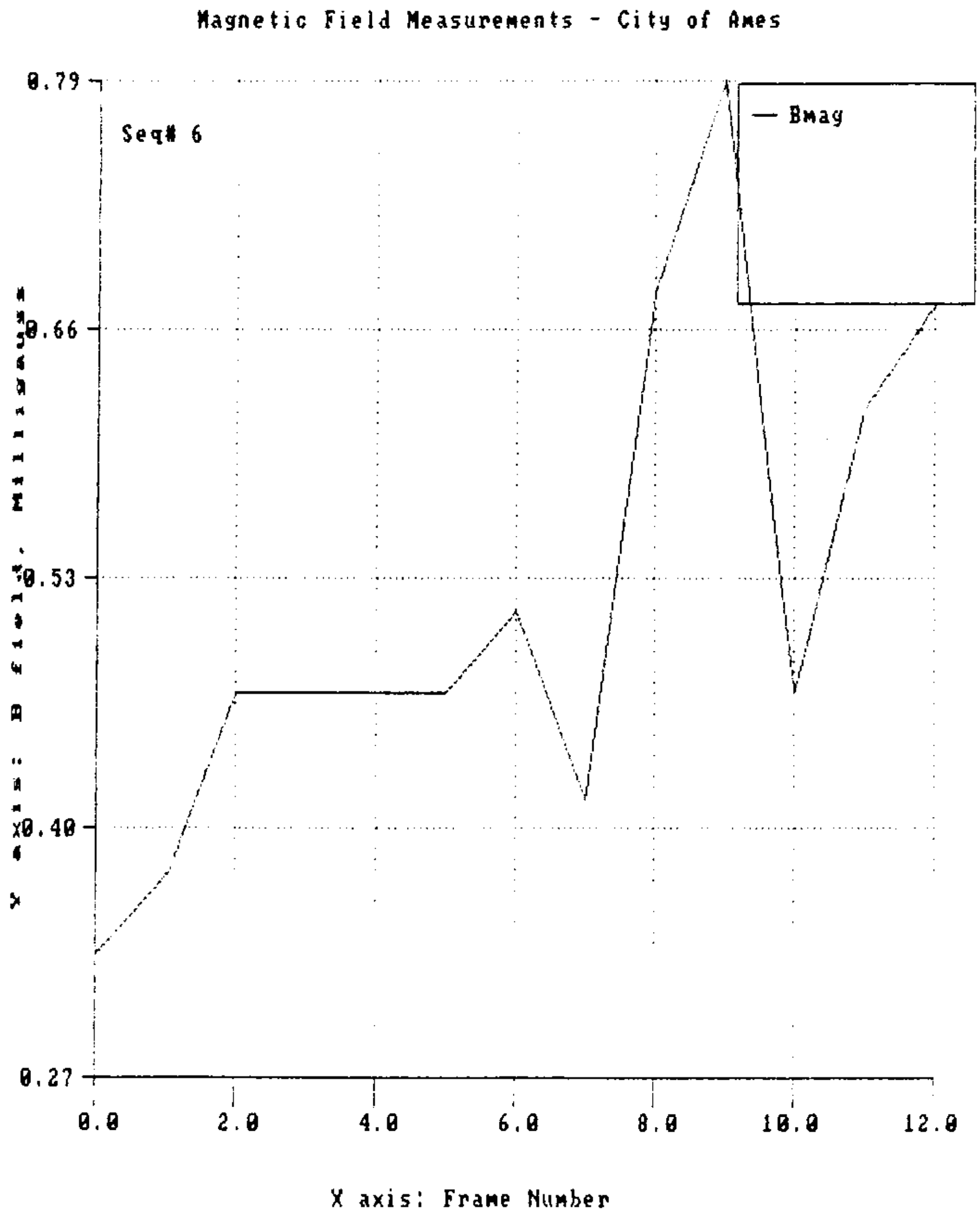


Figure 4.12. Magnetic field measurement #6

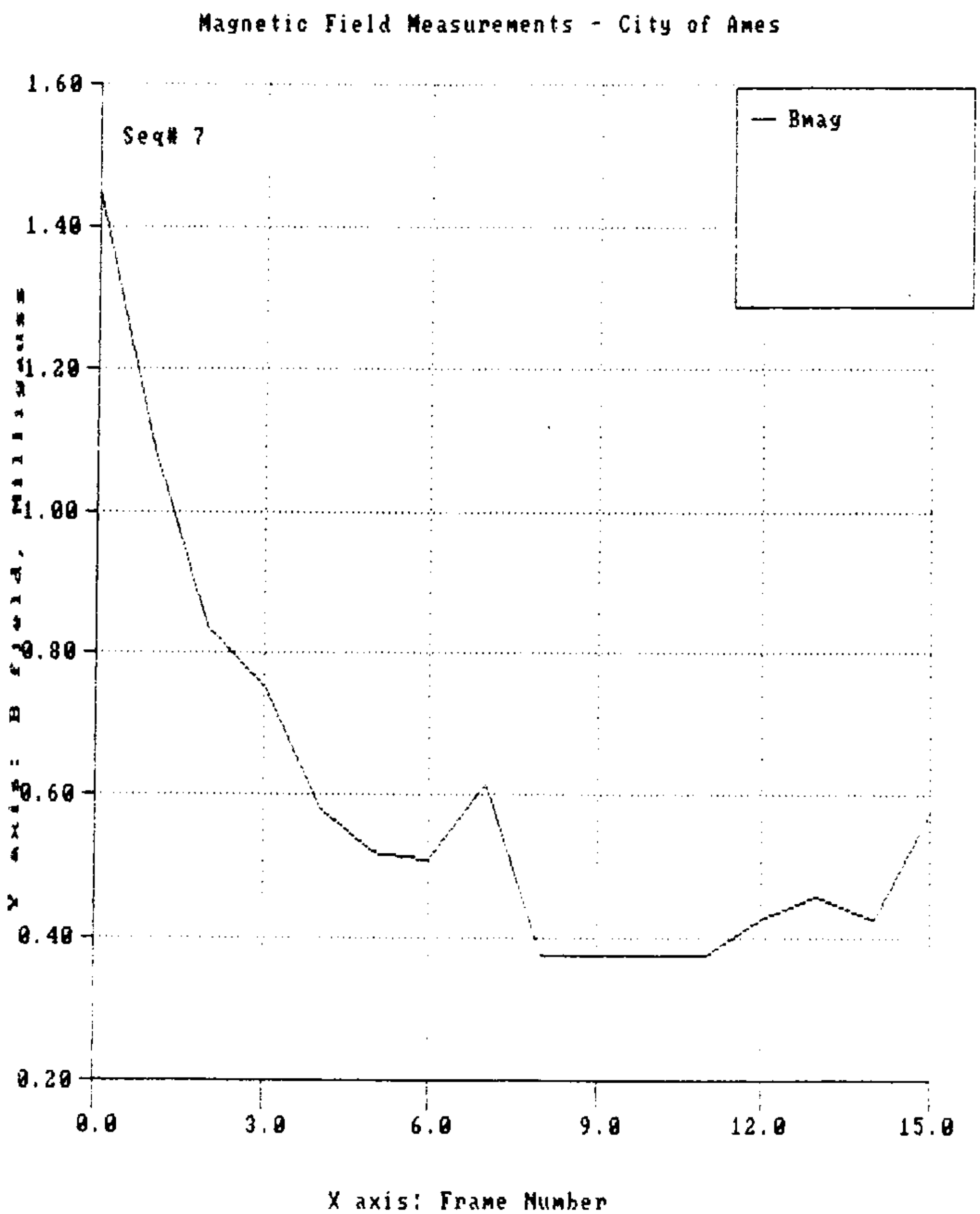


Figure 4.13. Magnetic field measurement #7

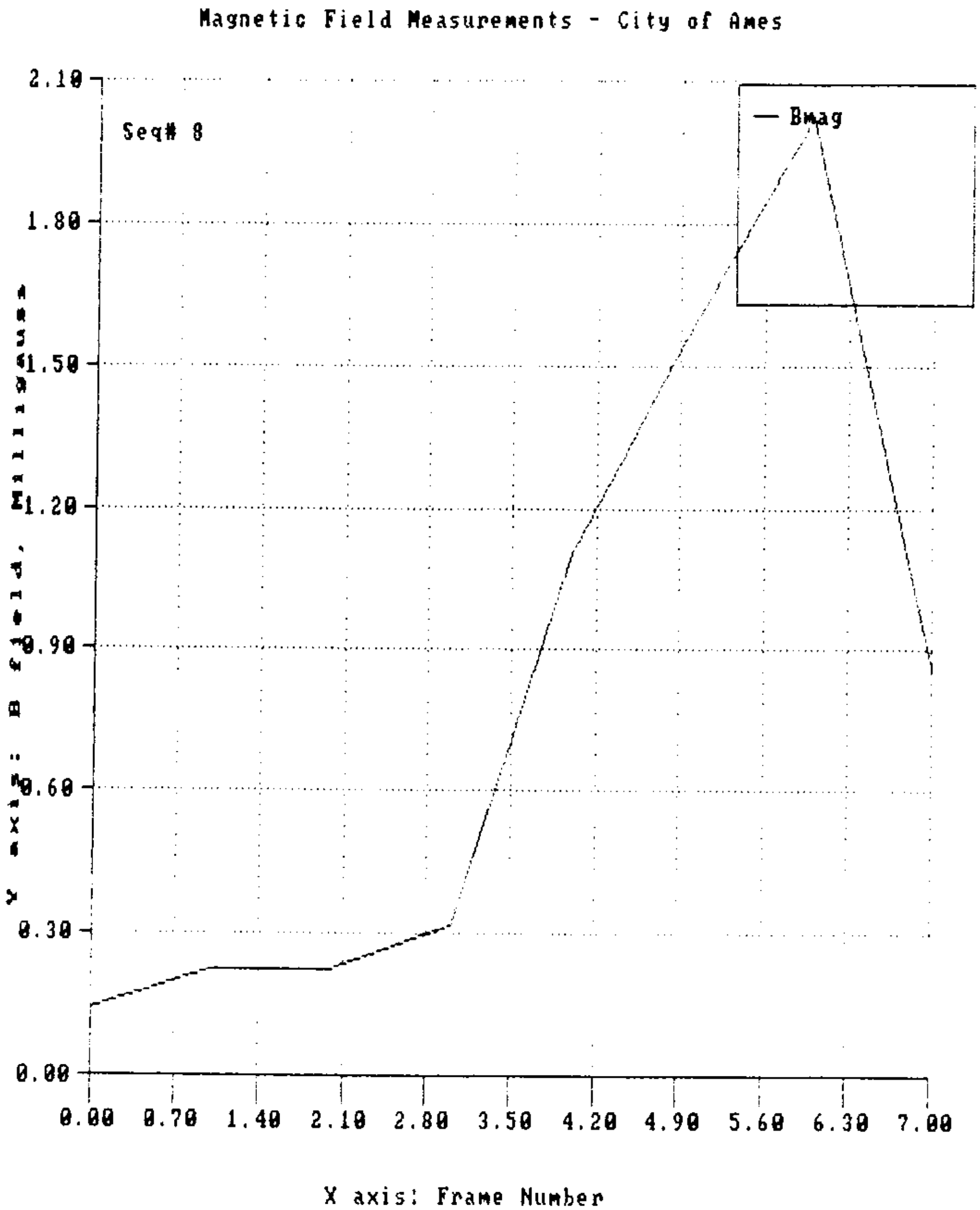


Figure 4.14. Magnetic field measurement #8

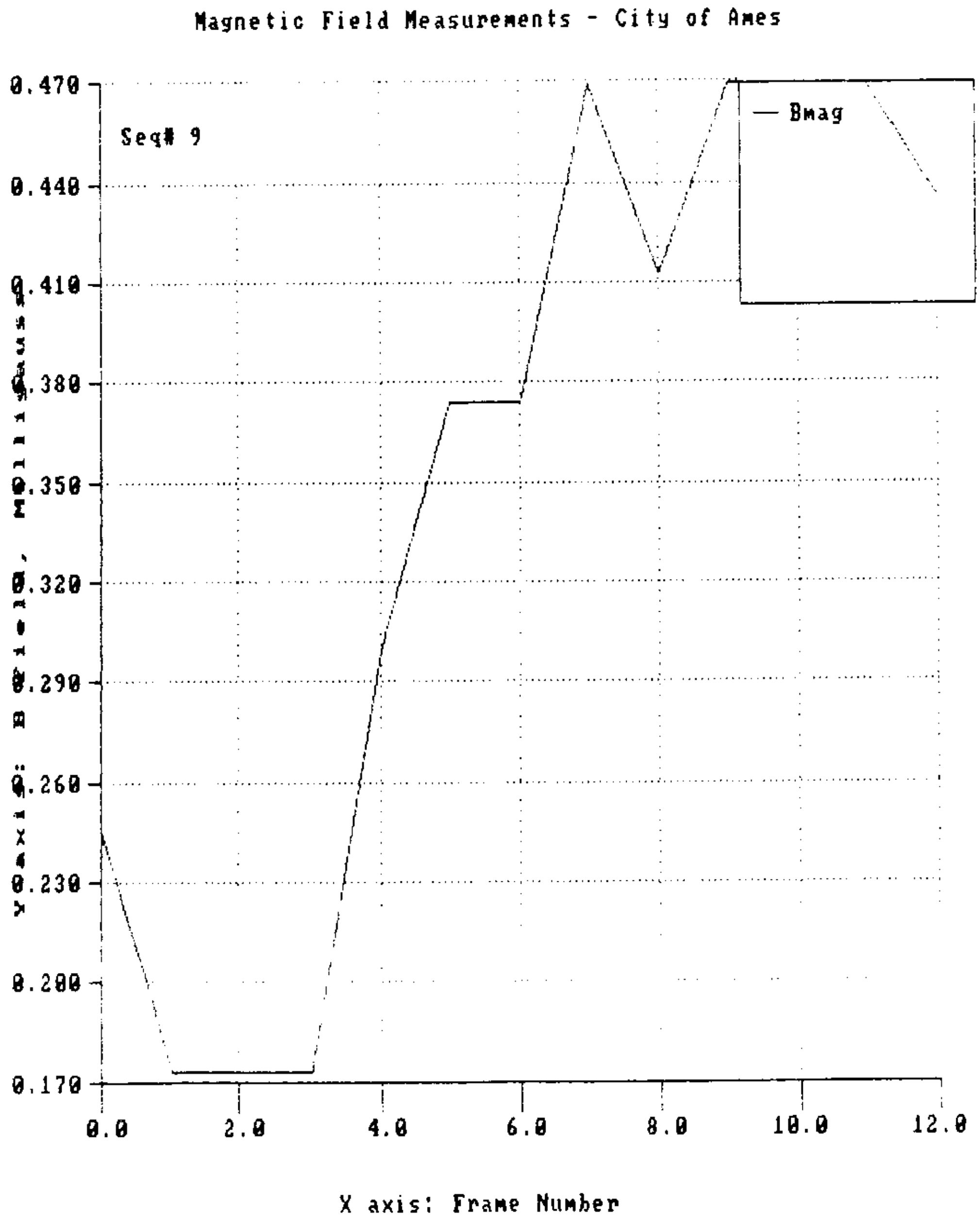


Figure 4.15. Magnetic field measurement #9

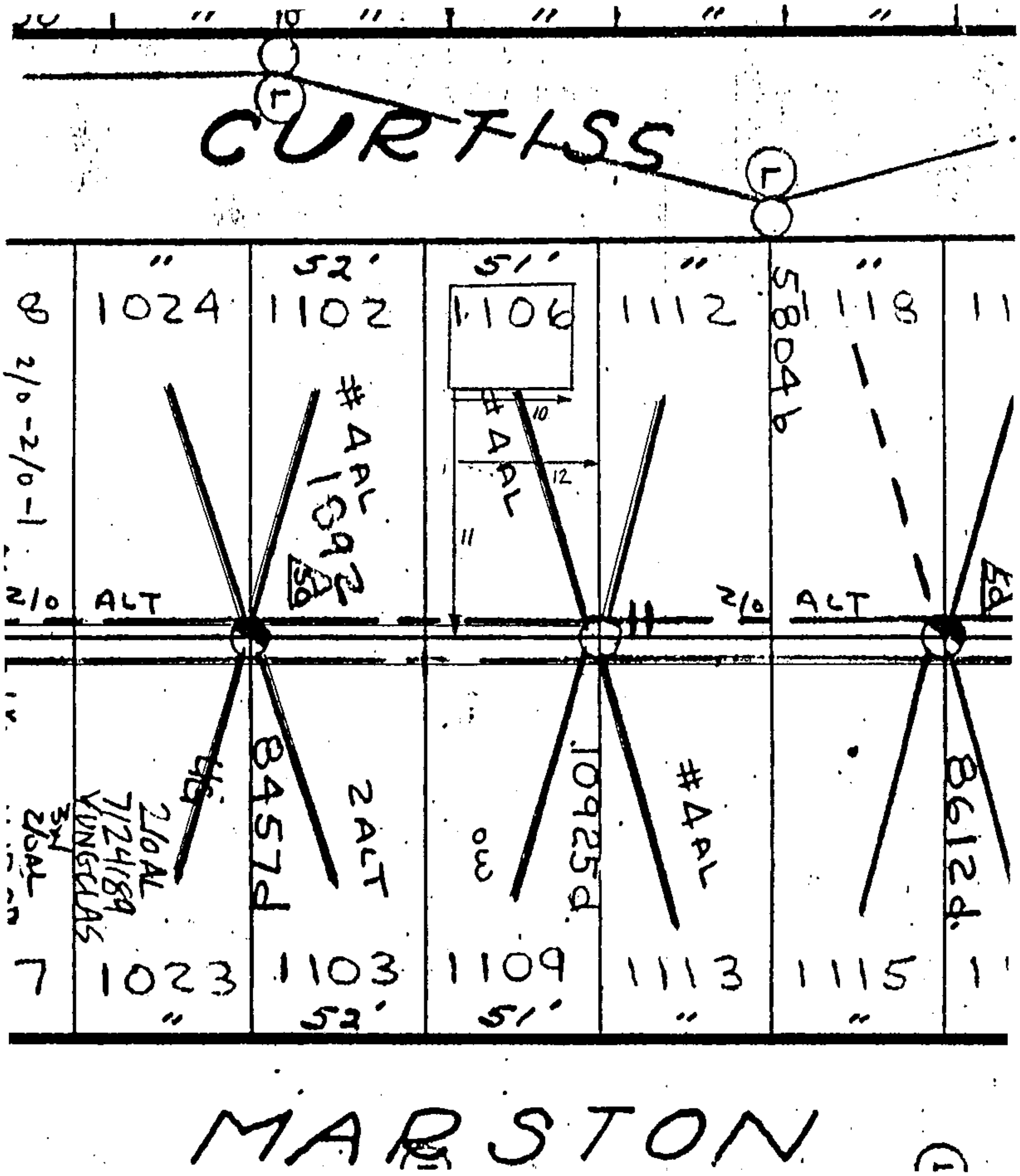


Figure 4.16. Lot at 1106 Curtis

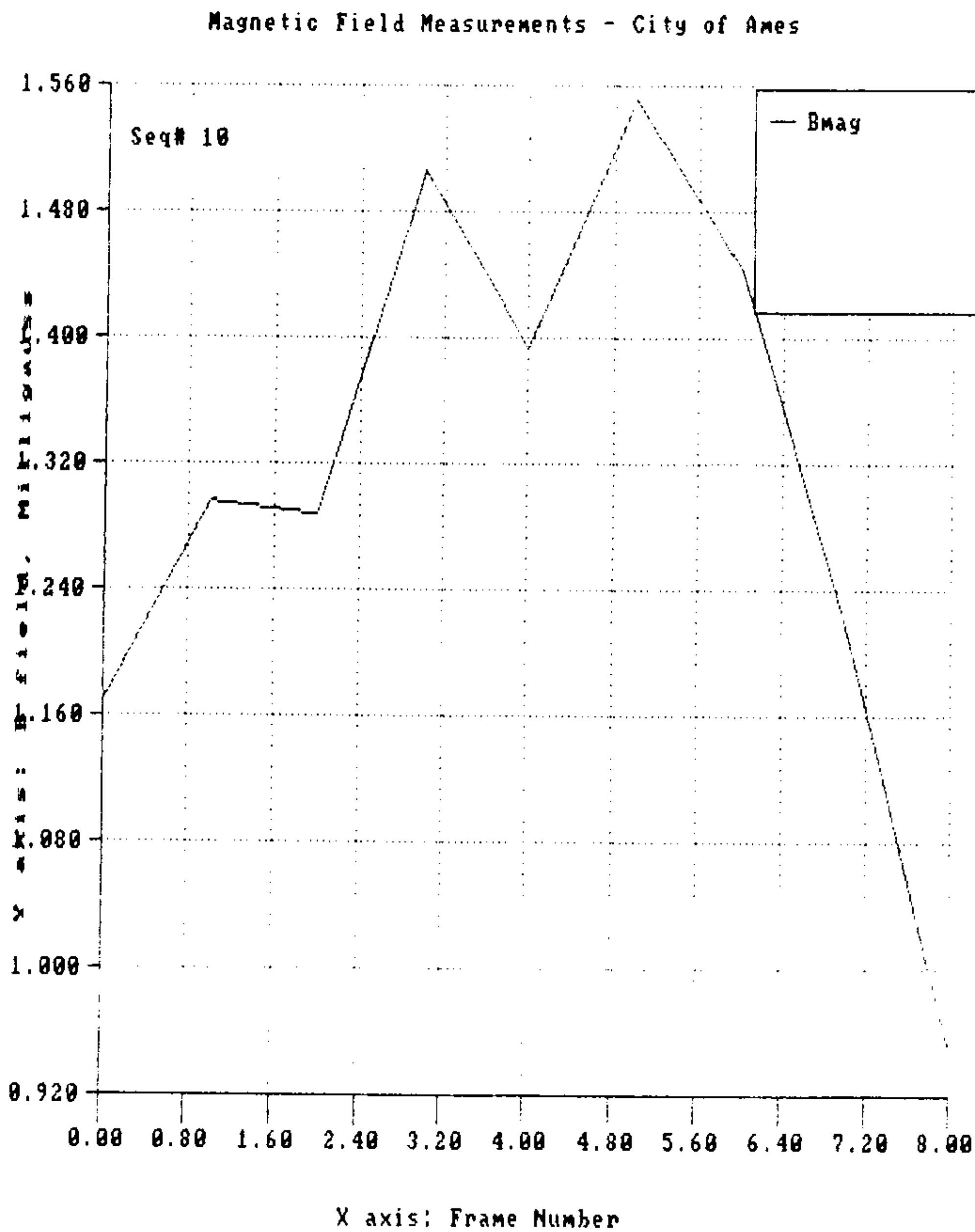


Figure 4.17. Magnetic field measurement #10

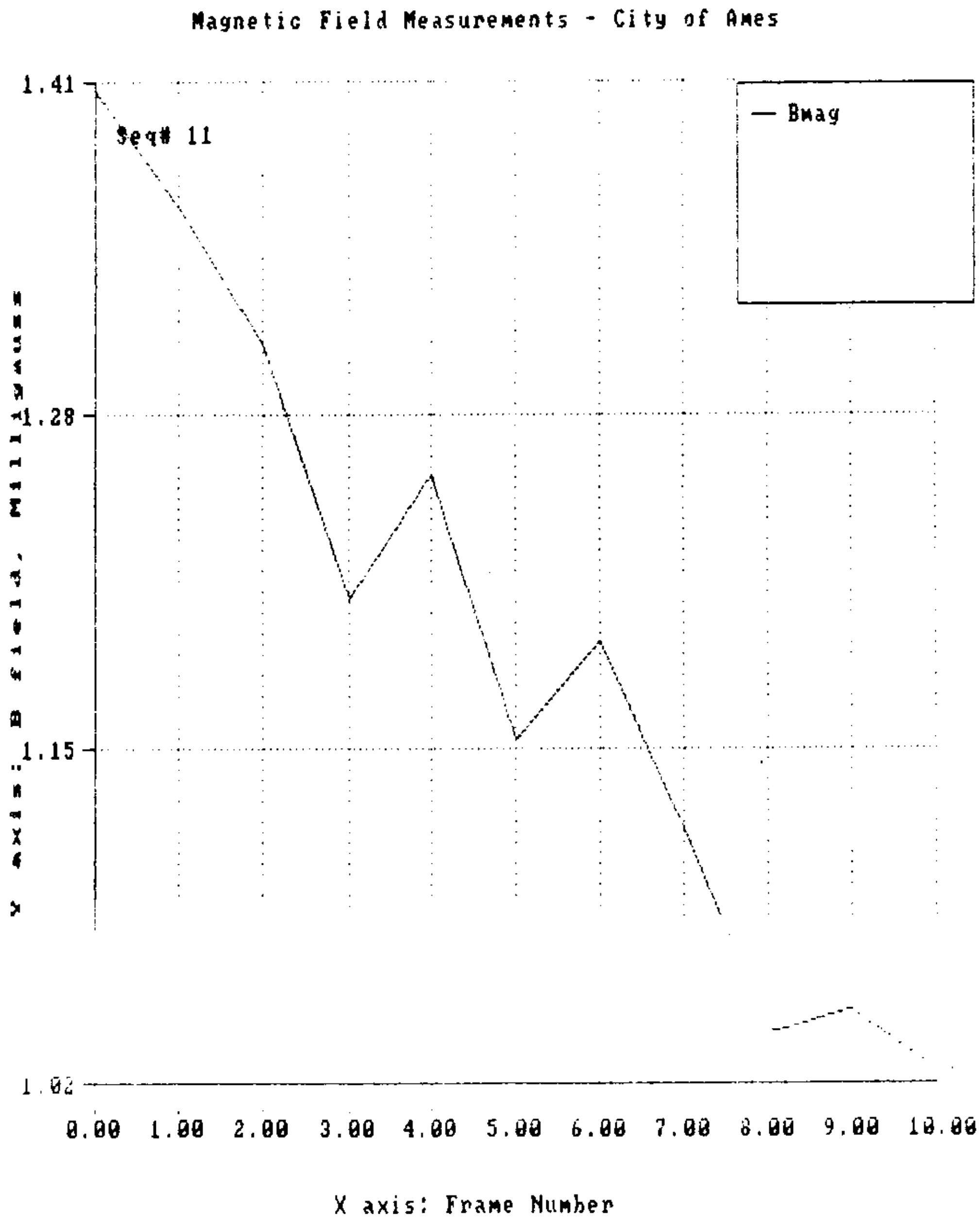


Figure 4.18. Magnetic field measurement #11

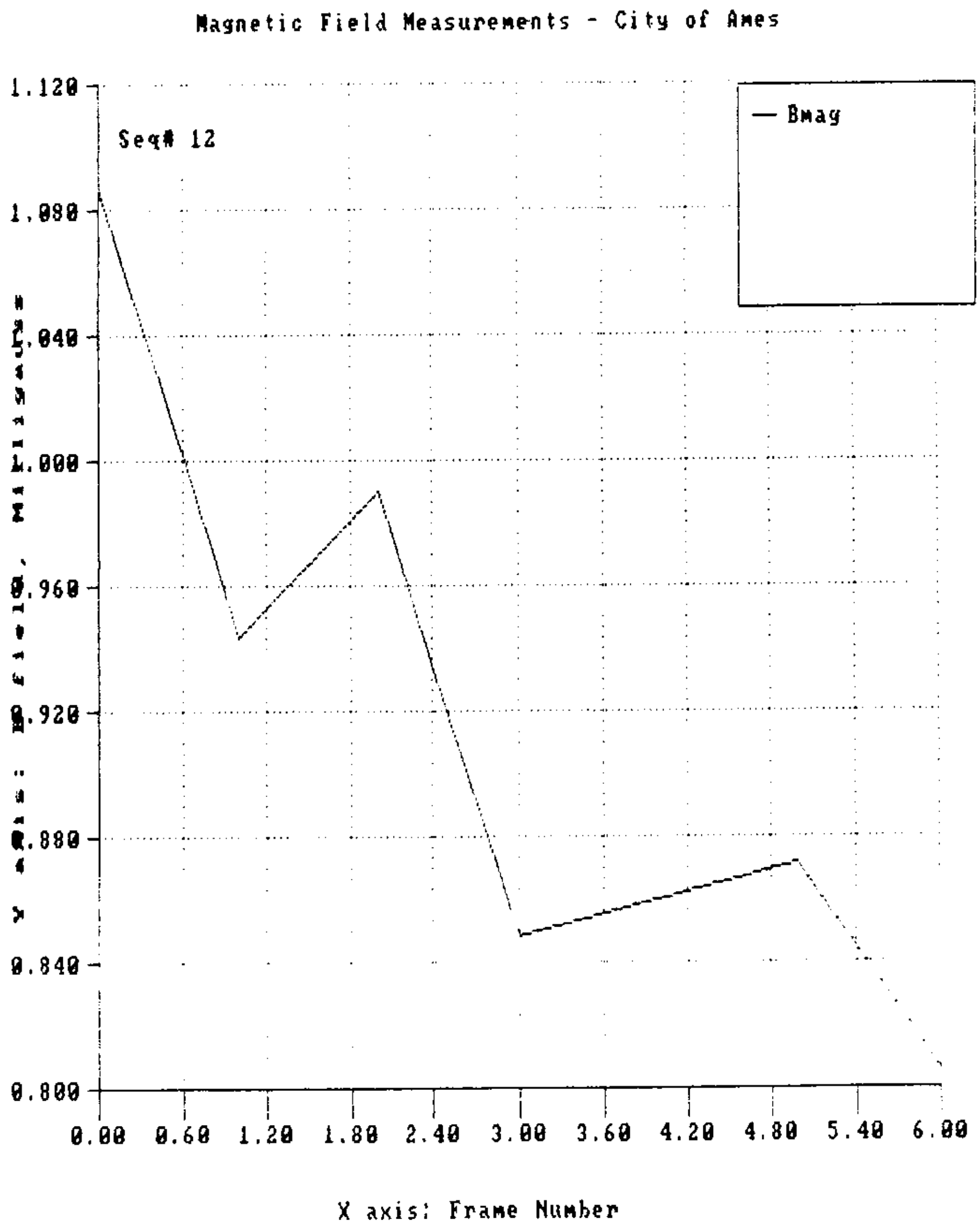


Figure 4.19. Magnetic field measurement #12

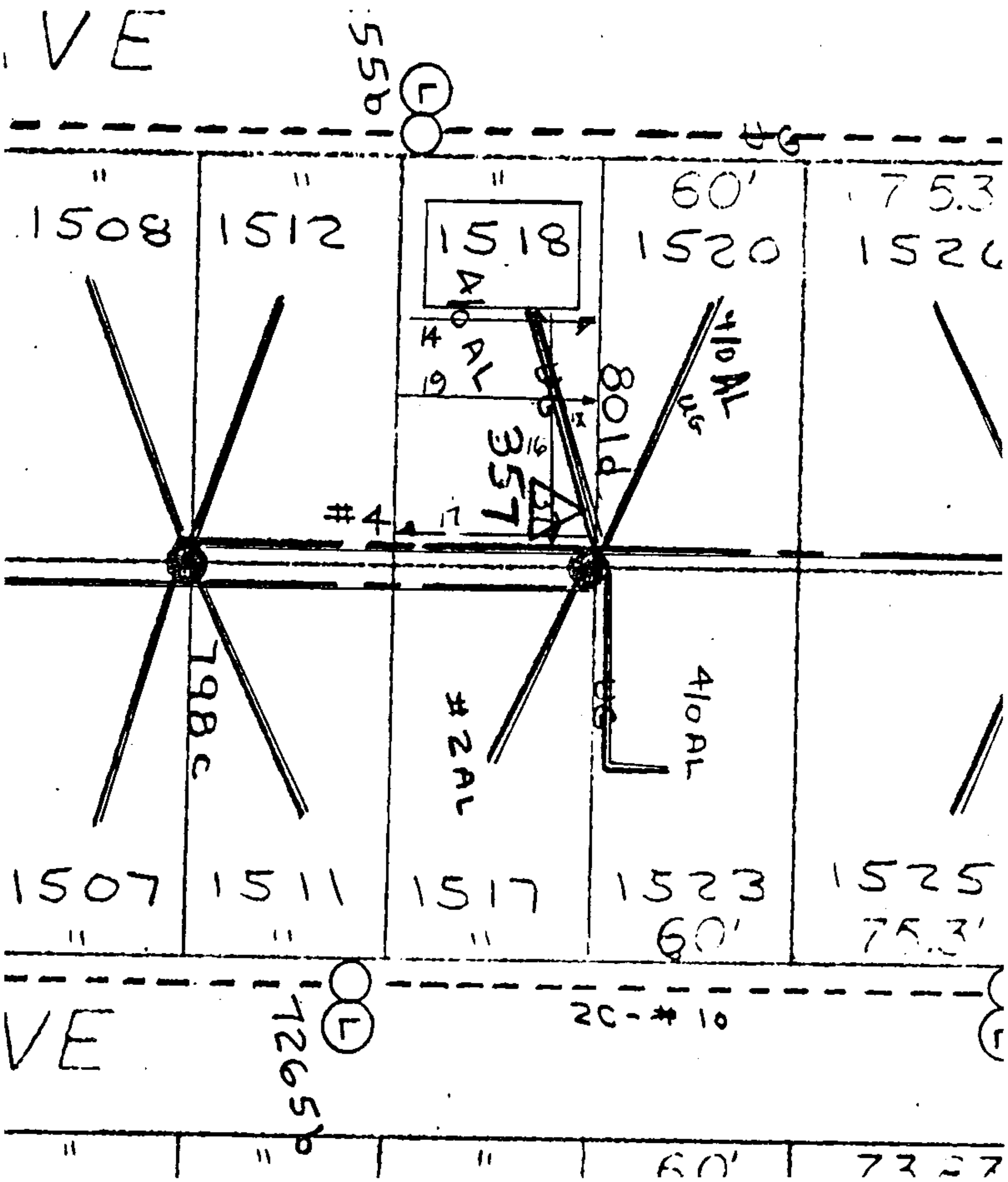


Figure 4.20. Lot at 1518 Carroll

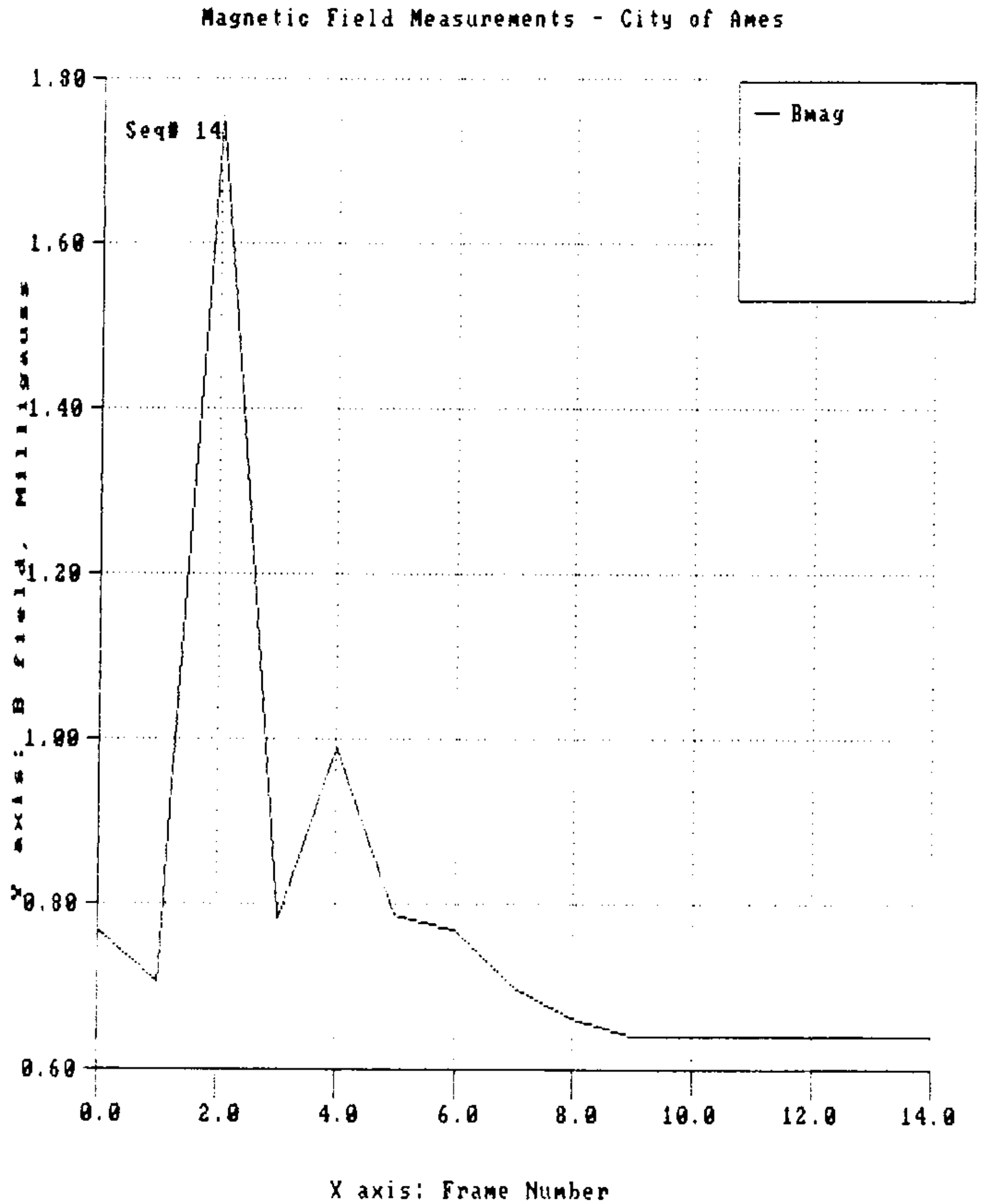


Figure 4.21. Magnetic field measurement #14

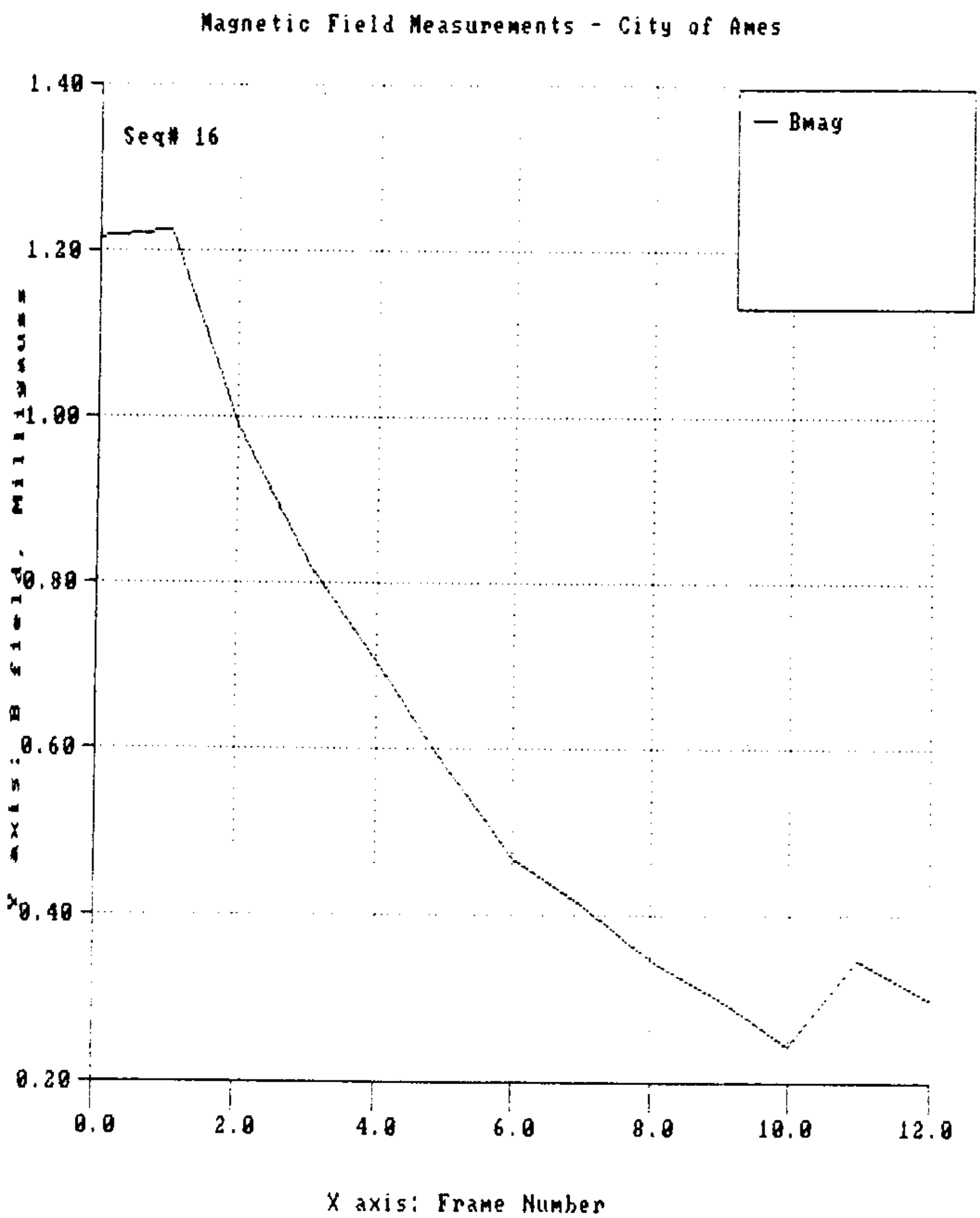


Figure 4.22. Magnetic field measurement #16

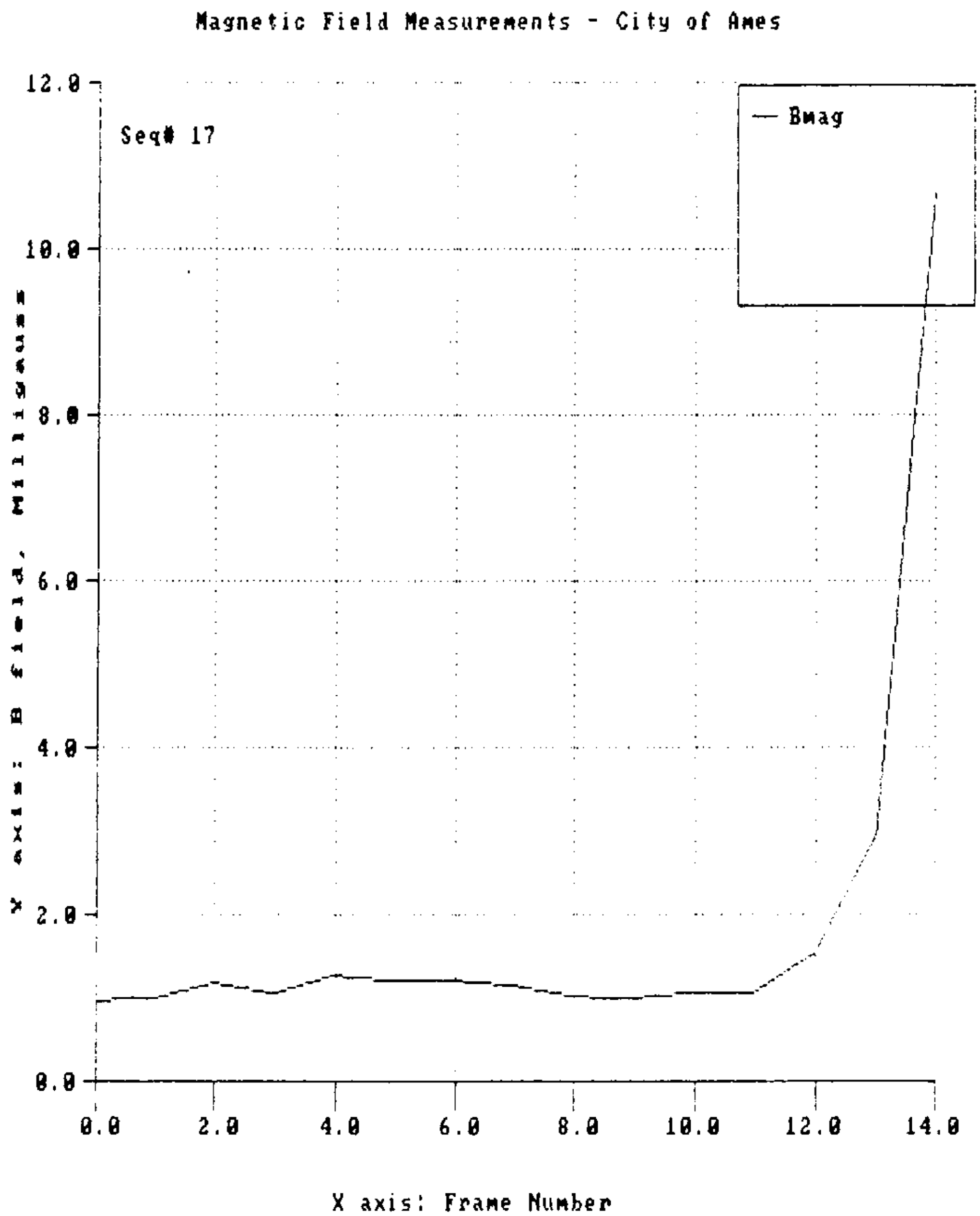


Figure 4.23. Magnetic field measurement #17

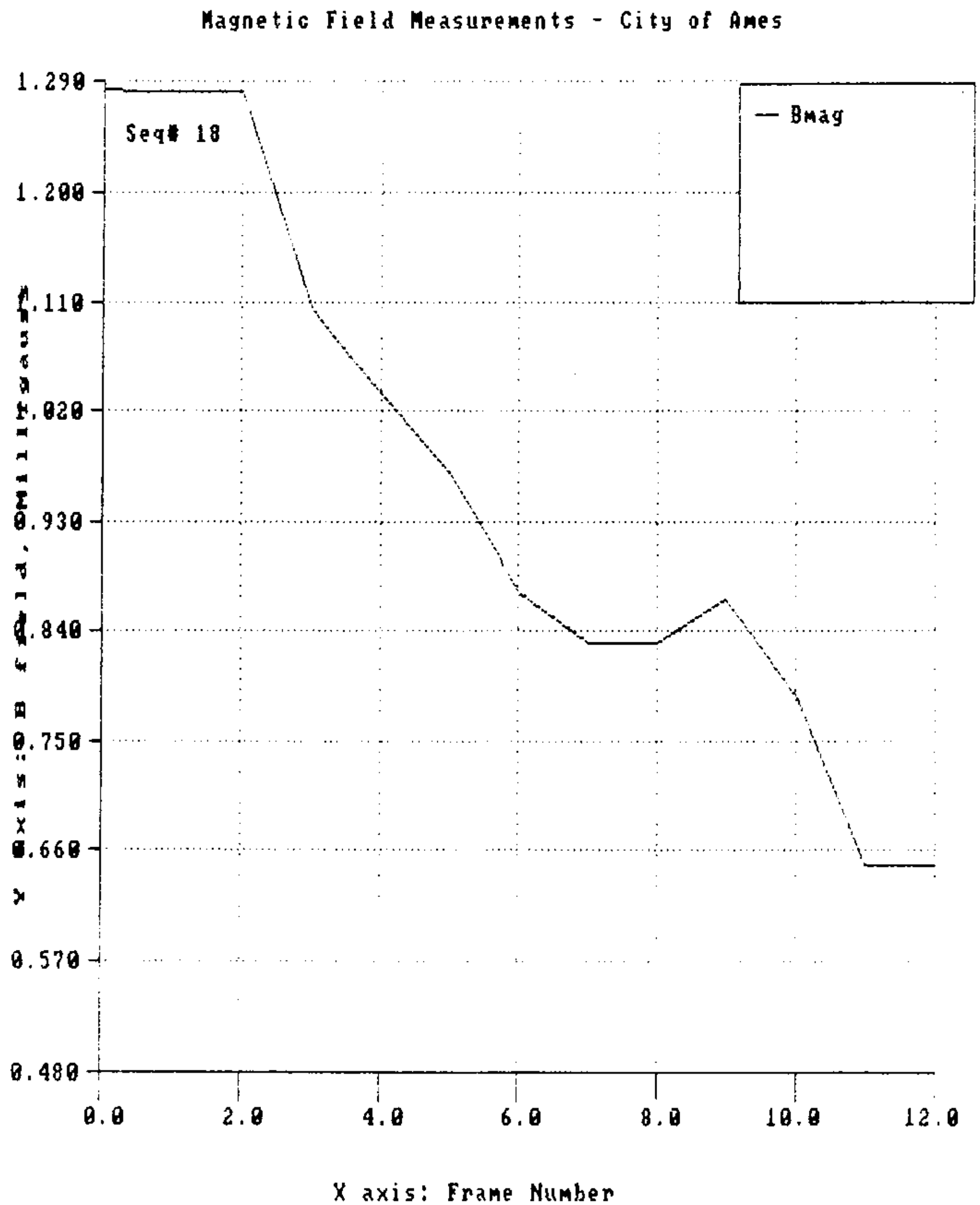


Figure 4.24. Magnetic field measurement #18

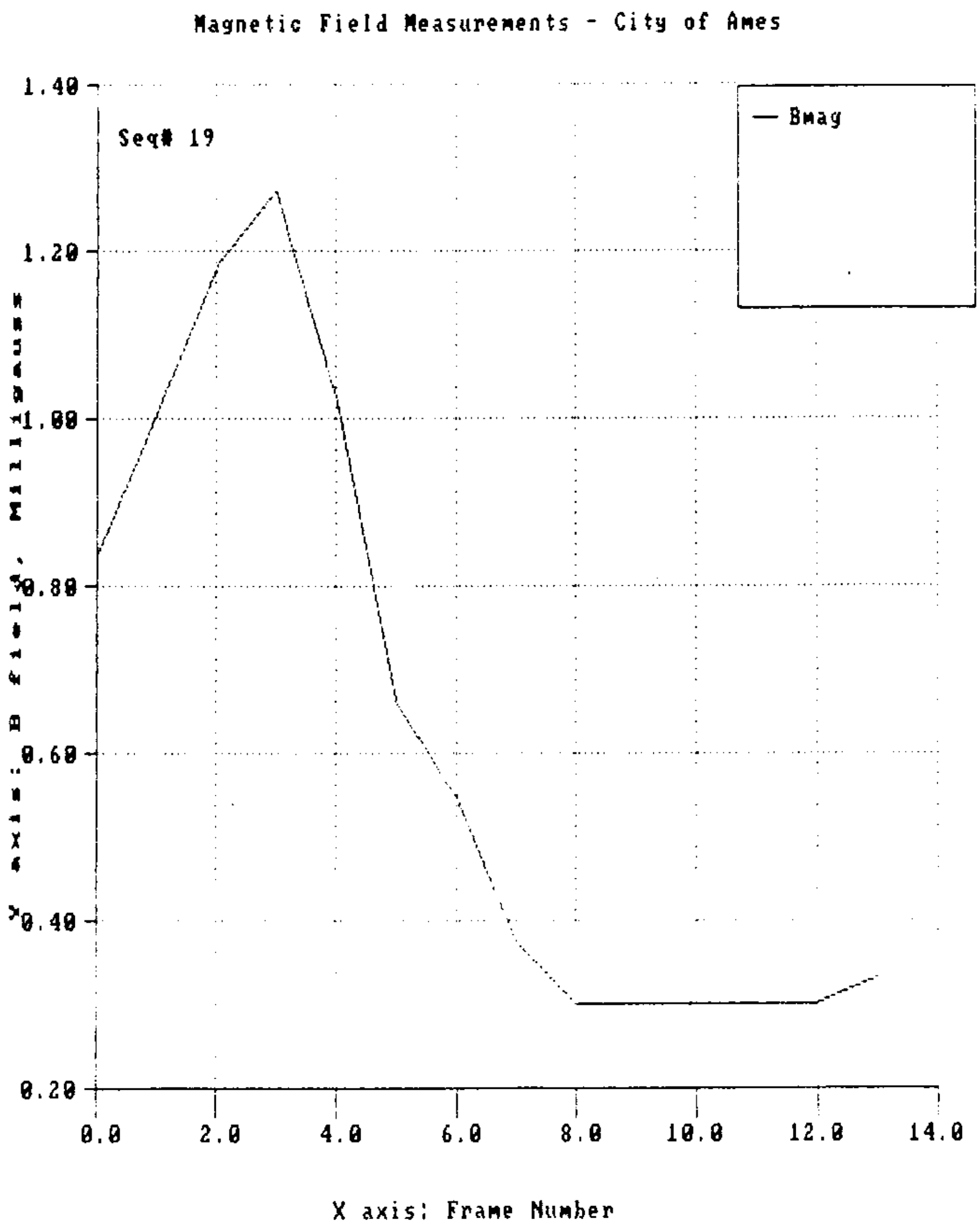


Figure 4.25. Magnetic field measurement #19

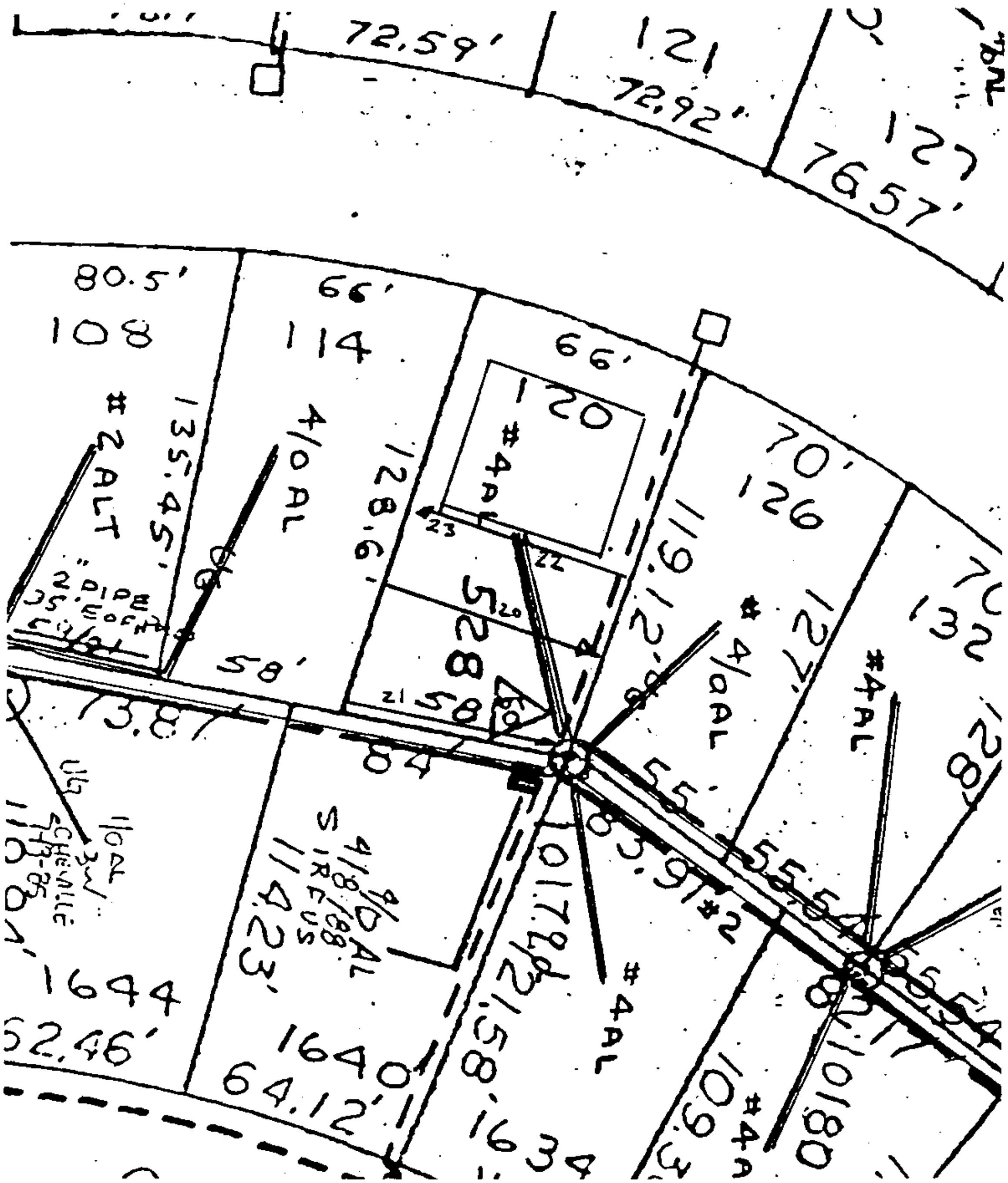


Figure 4.26. Lot at 120 O'neil

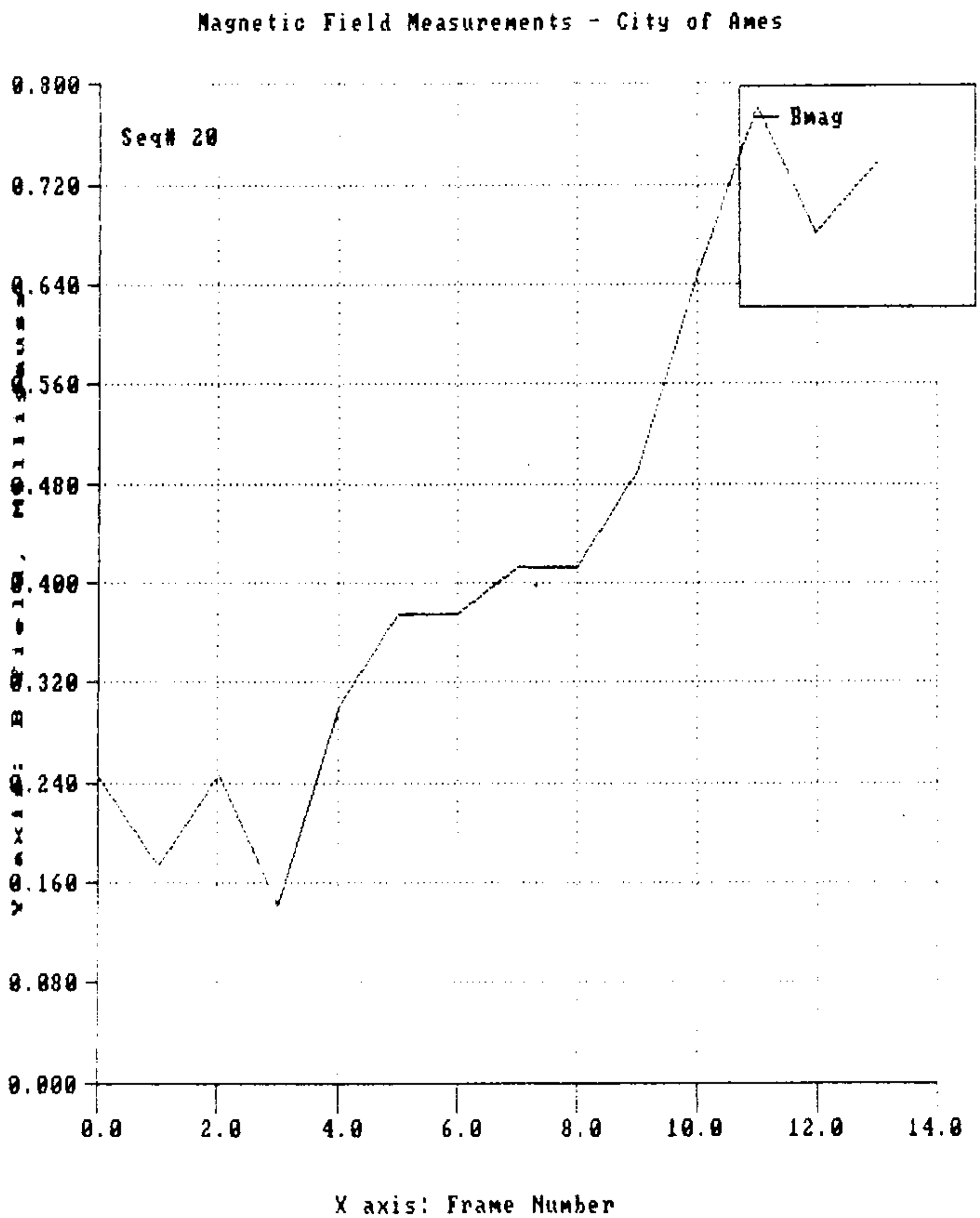


Figure 4.27. Magnetic field measurement #20

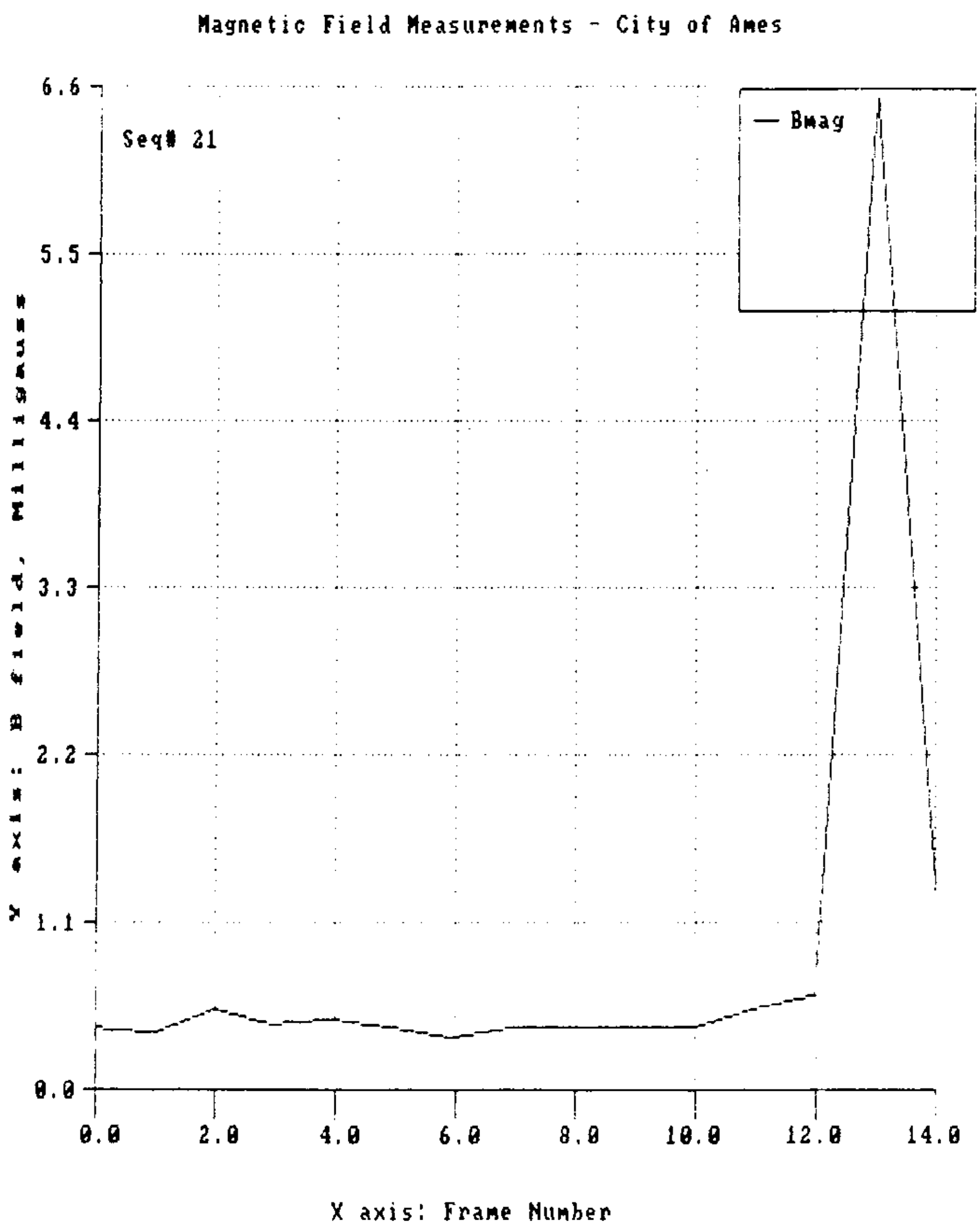


Figure 4.28. Magnetic field measurement #21

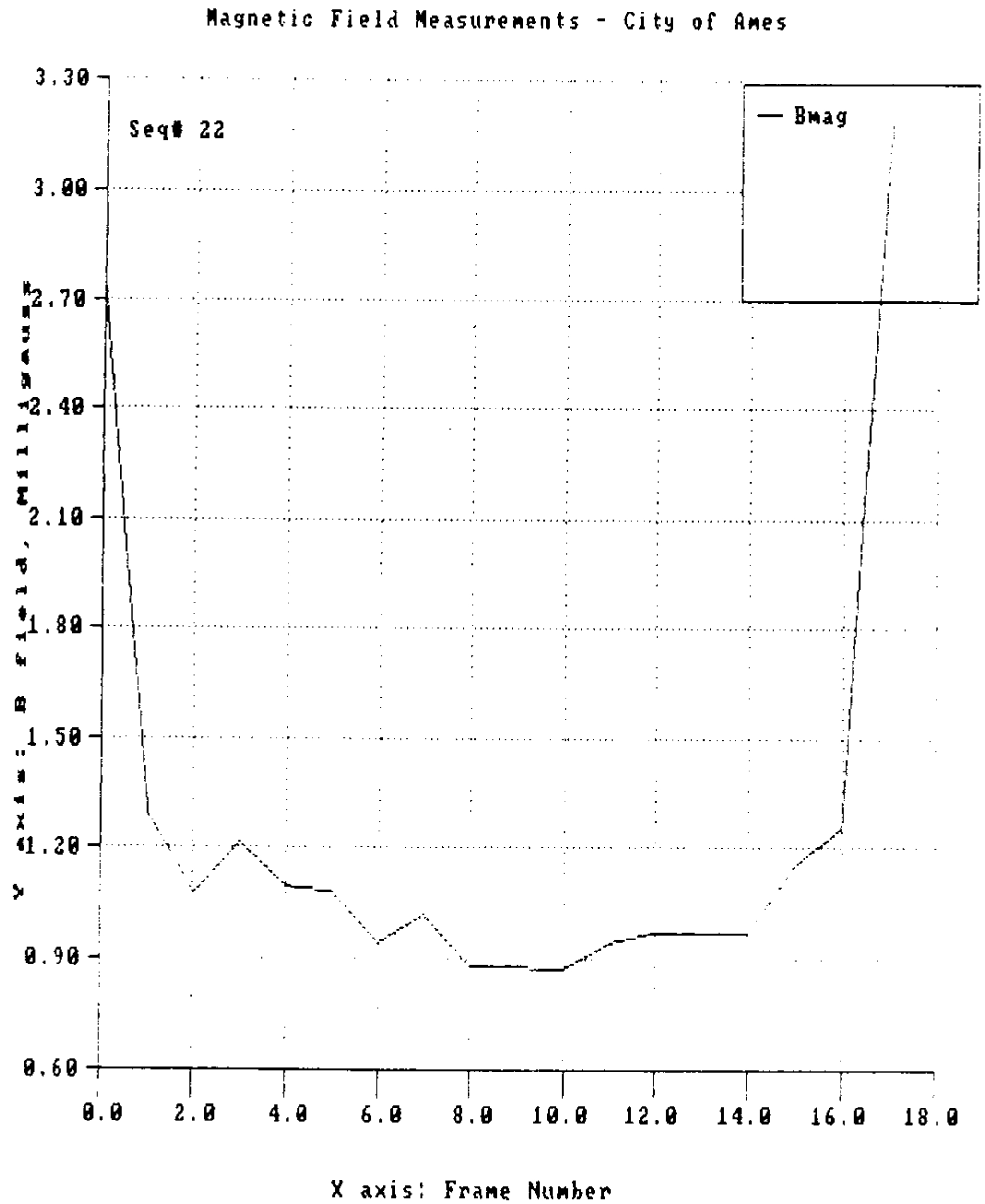


Figure 4.29. Magnetic field measurement #22

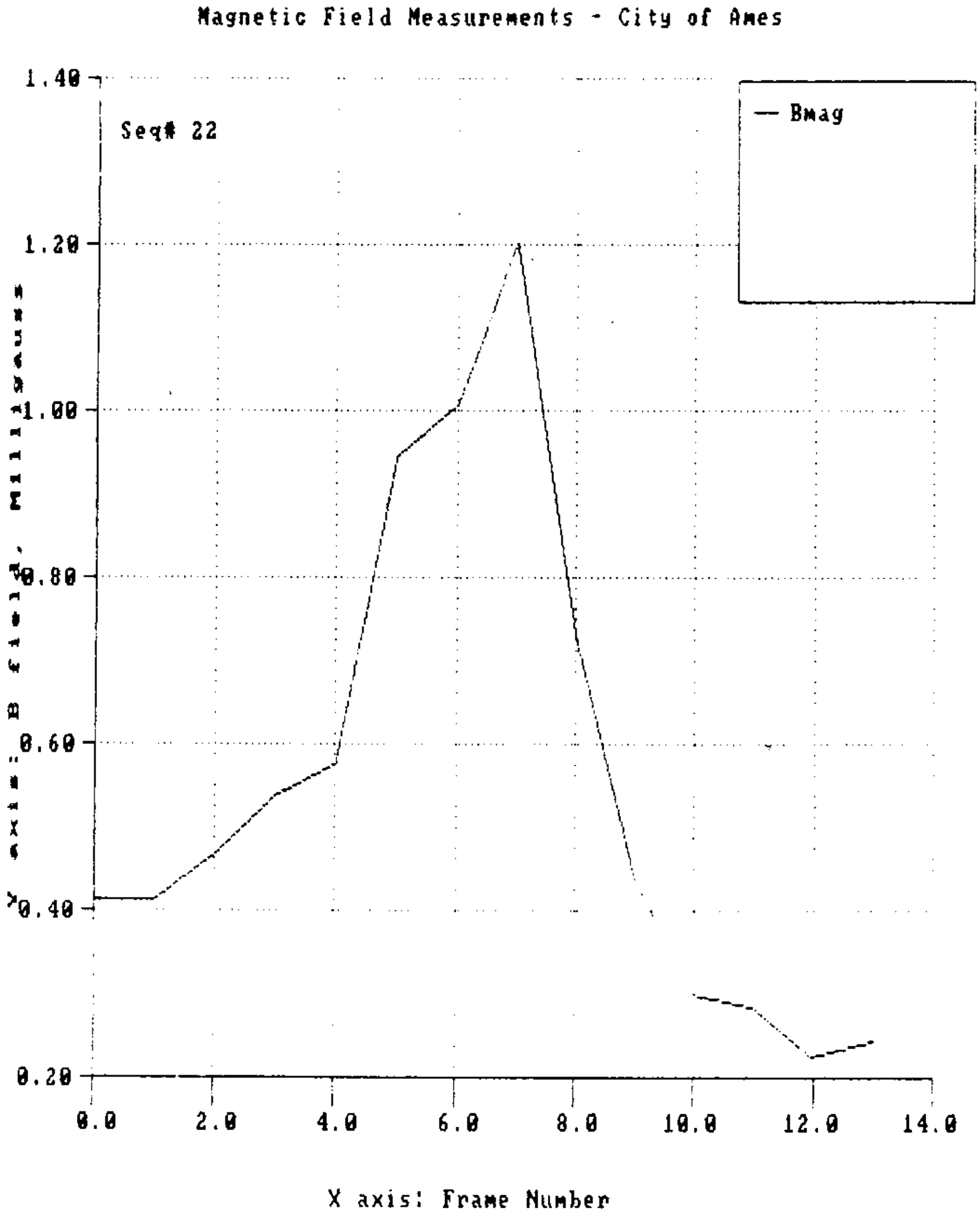


Figure 4.30. Magnetic field measurement #23

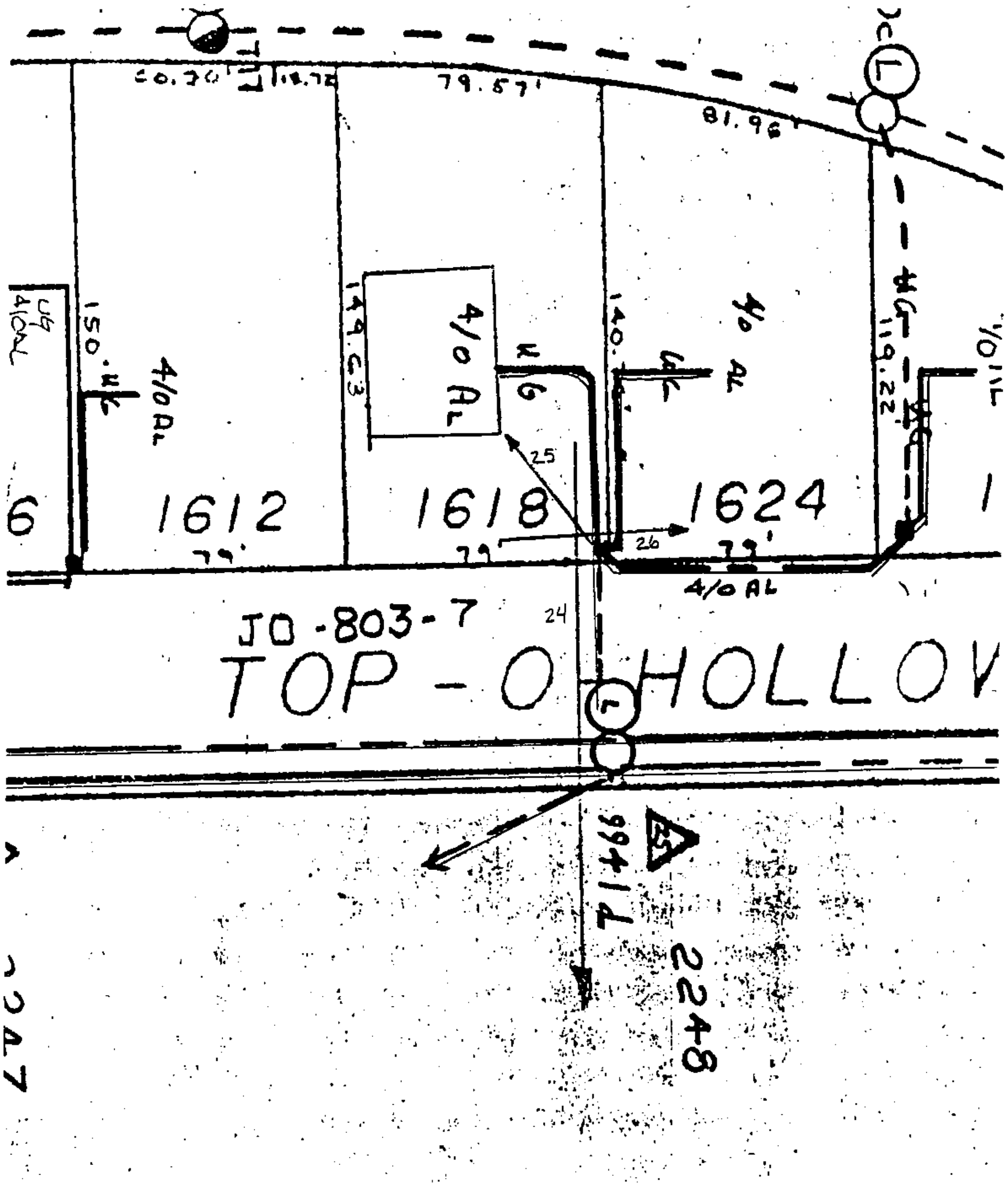


Figure 4.31. Lot at 1618 Top–O–Hollow

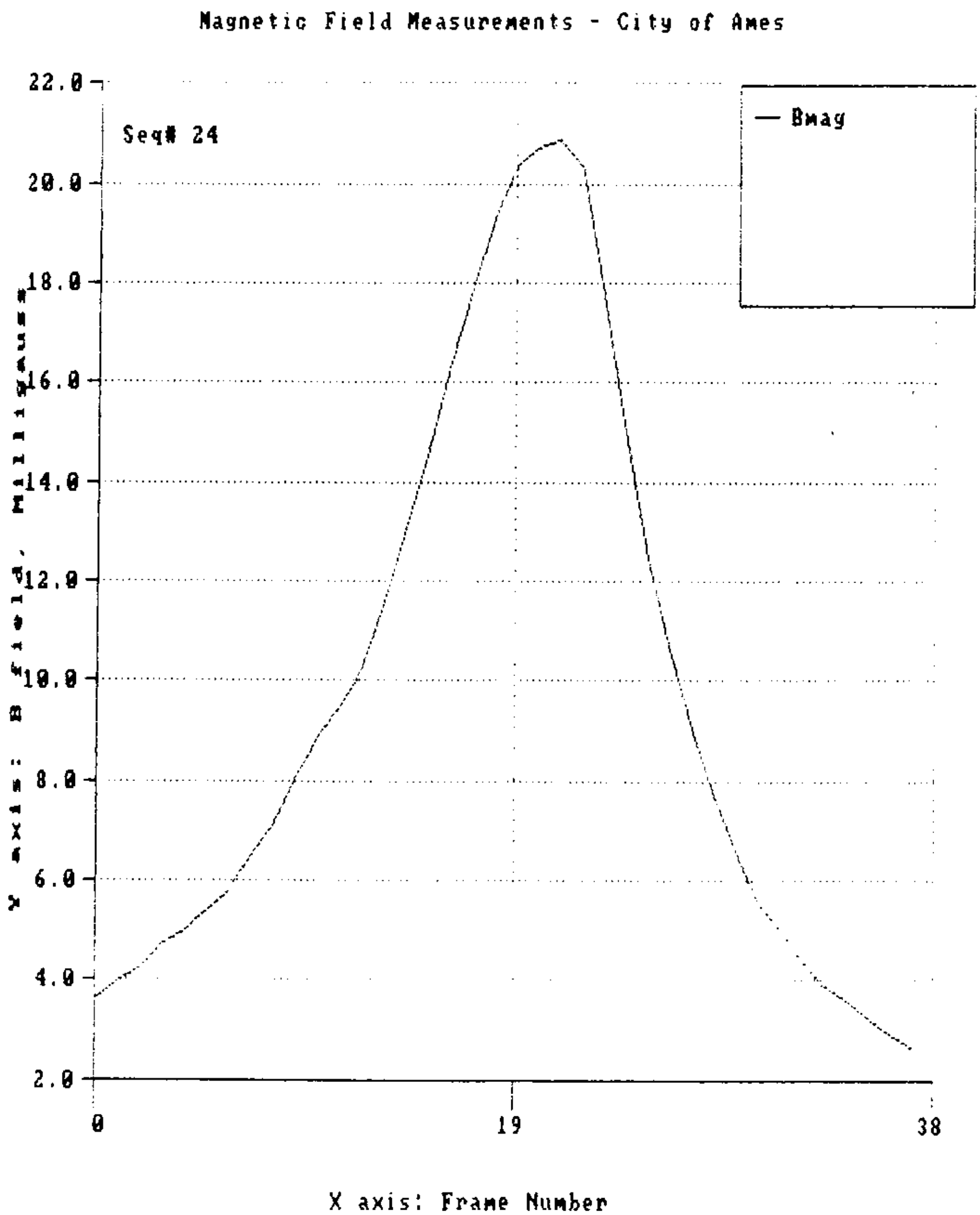


Figure 4.32. Magnetic field measurement #24

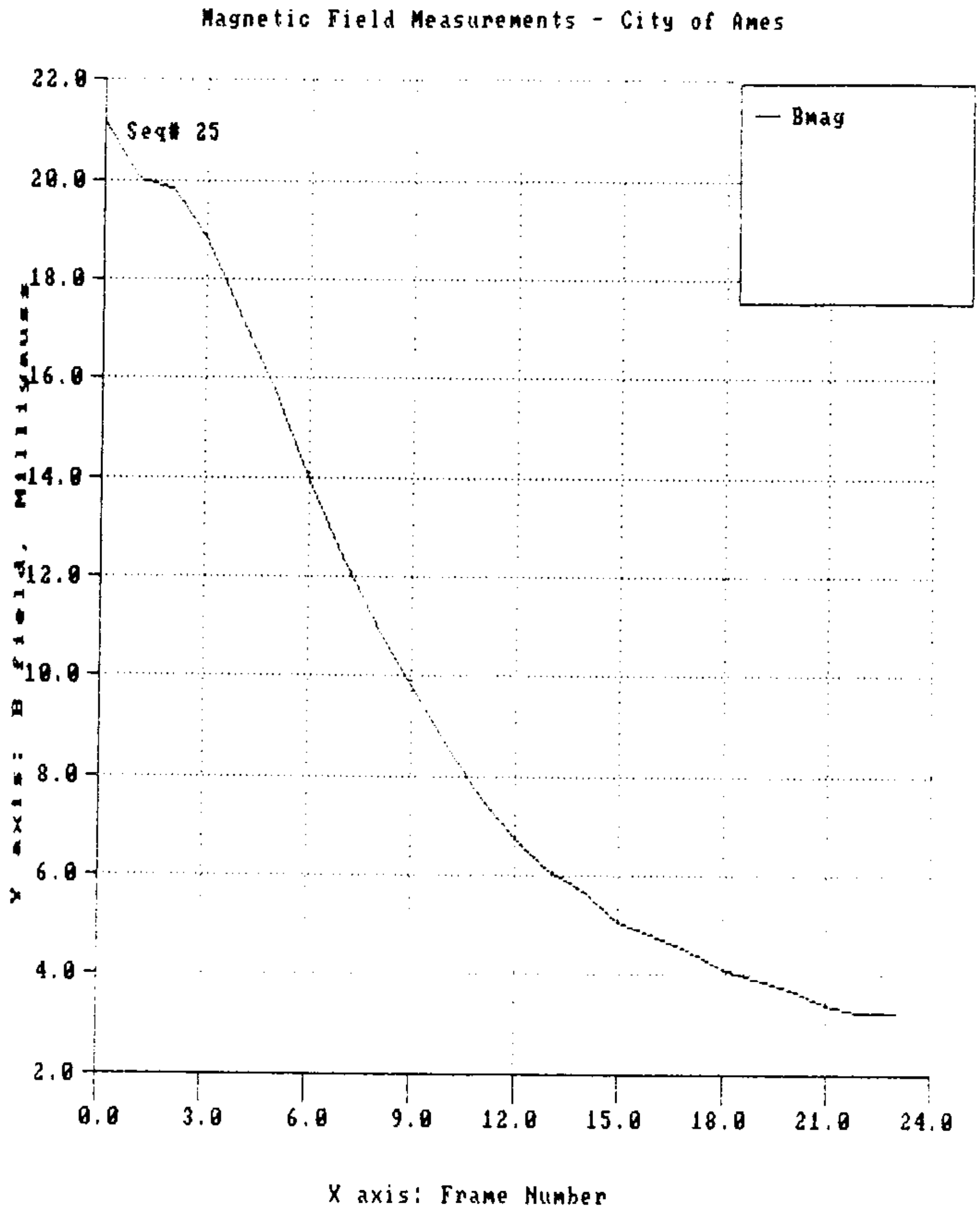


Figure 4.33. Magnetic field measurement #25

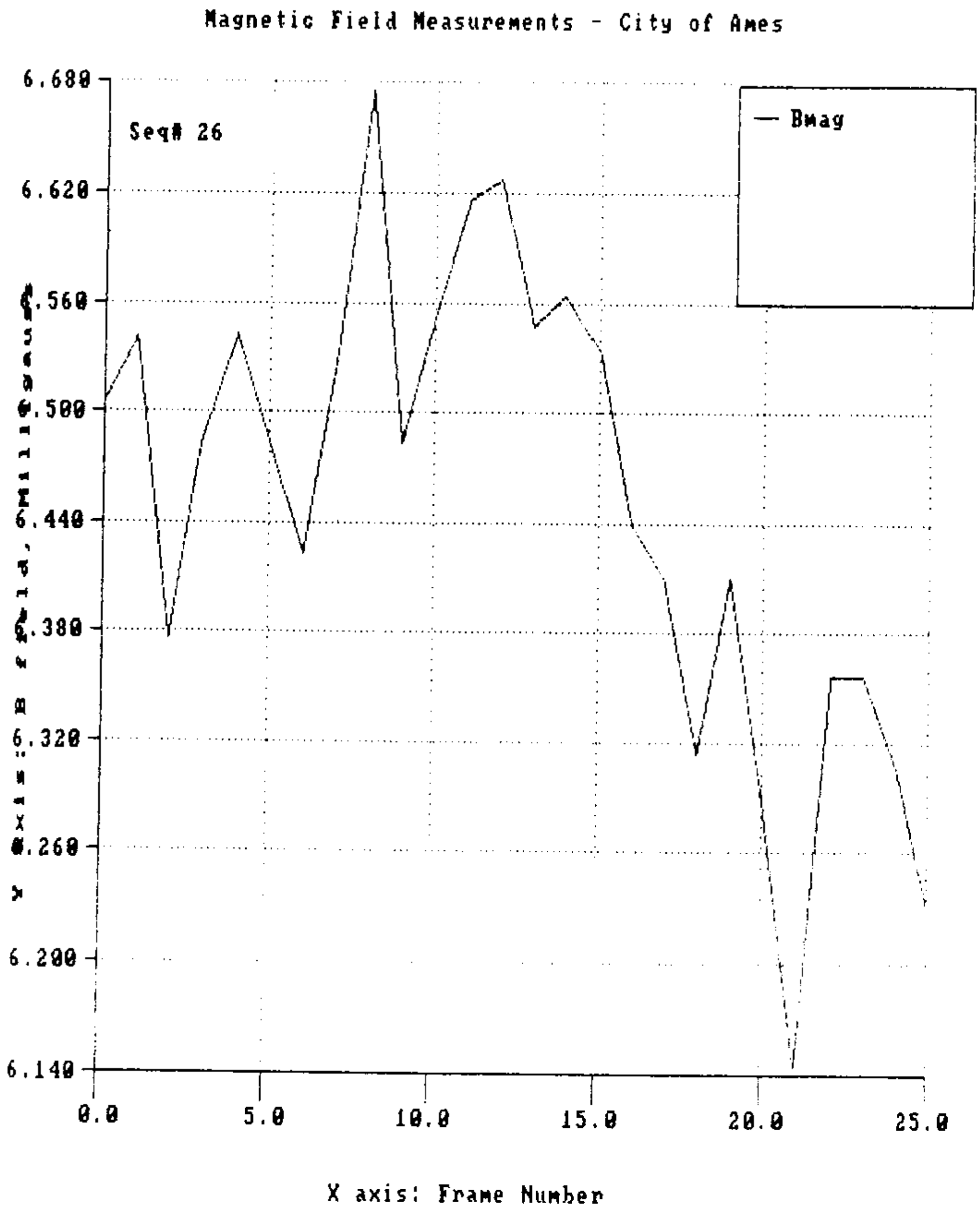


Figure 4.34. Magnetic field measurement #26

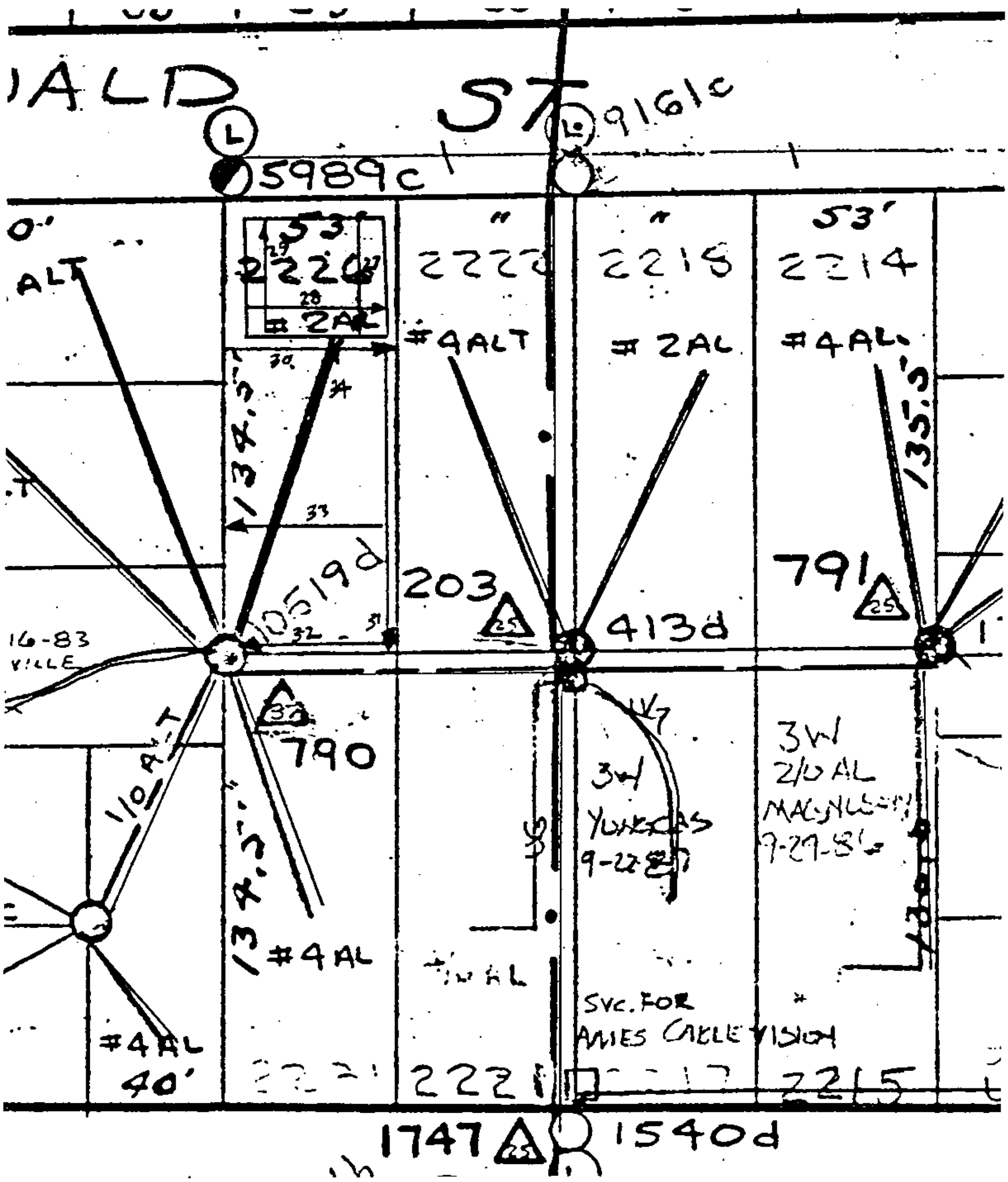


Figure 4.35. Lot at 2226 Donald Street

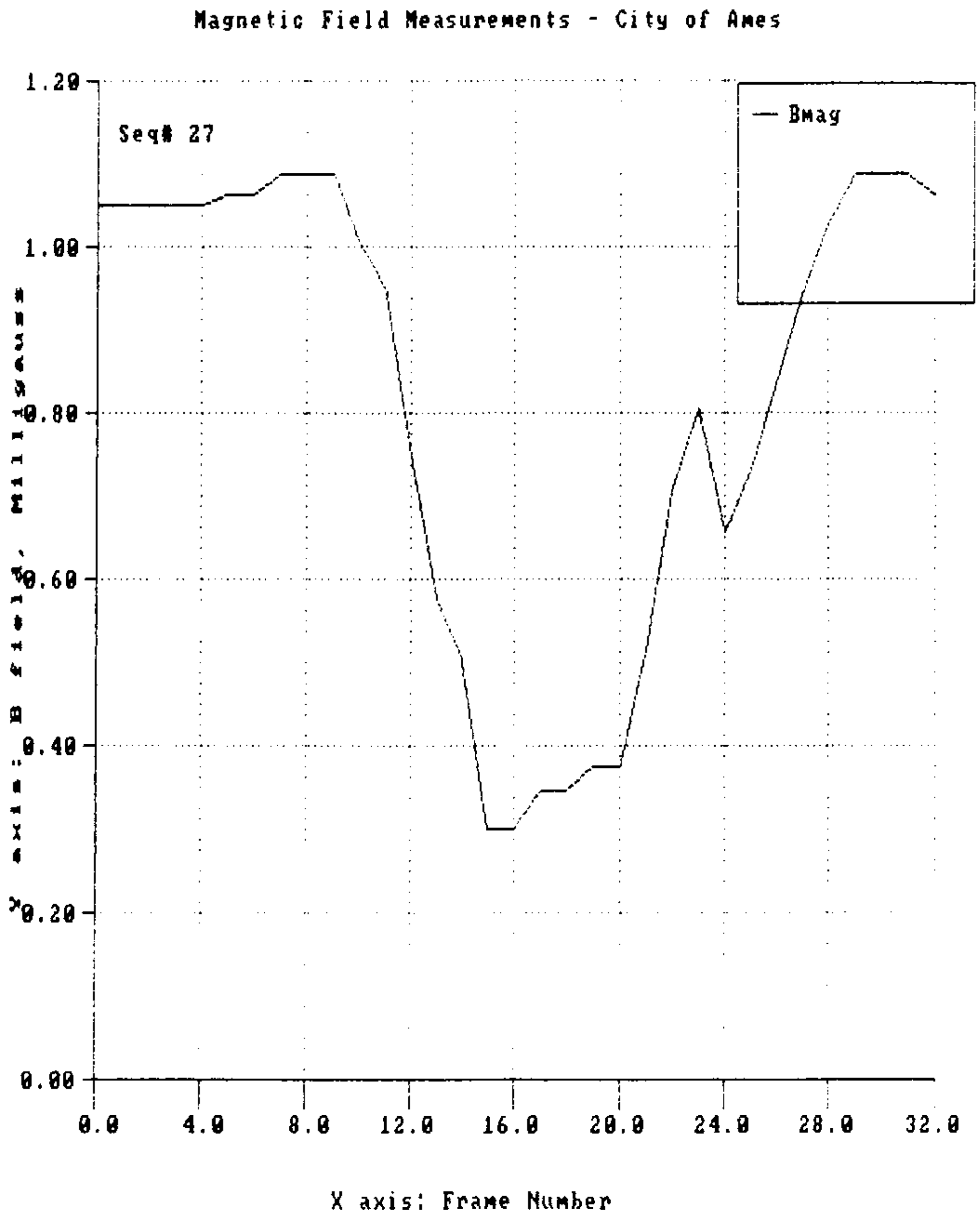


Figure 4.36. Magnetic field measurement #27

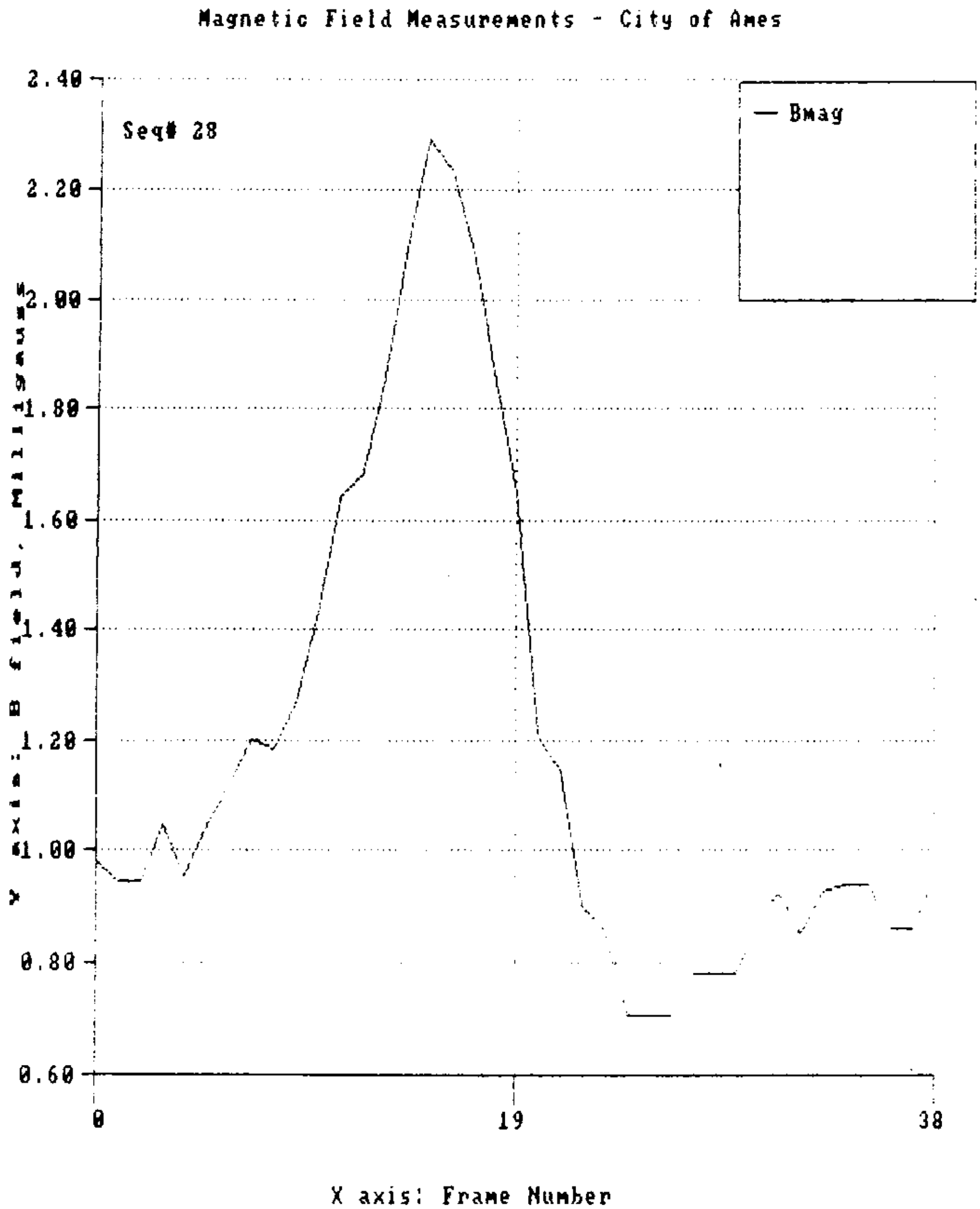


Figure 4.37. Magnetic field measurement #28

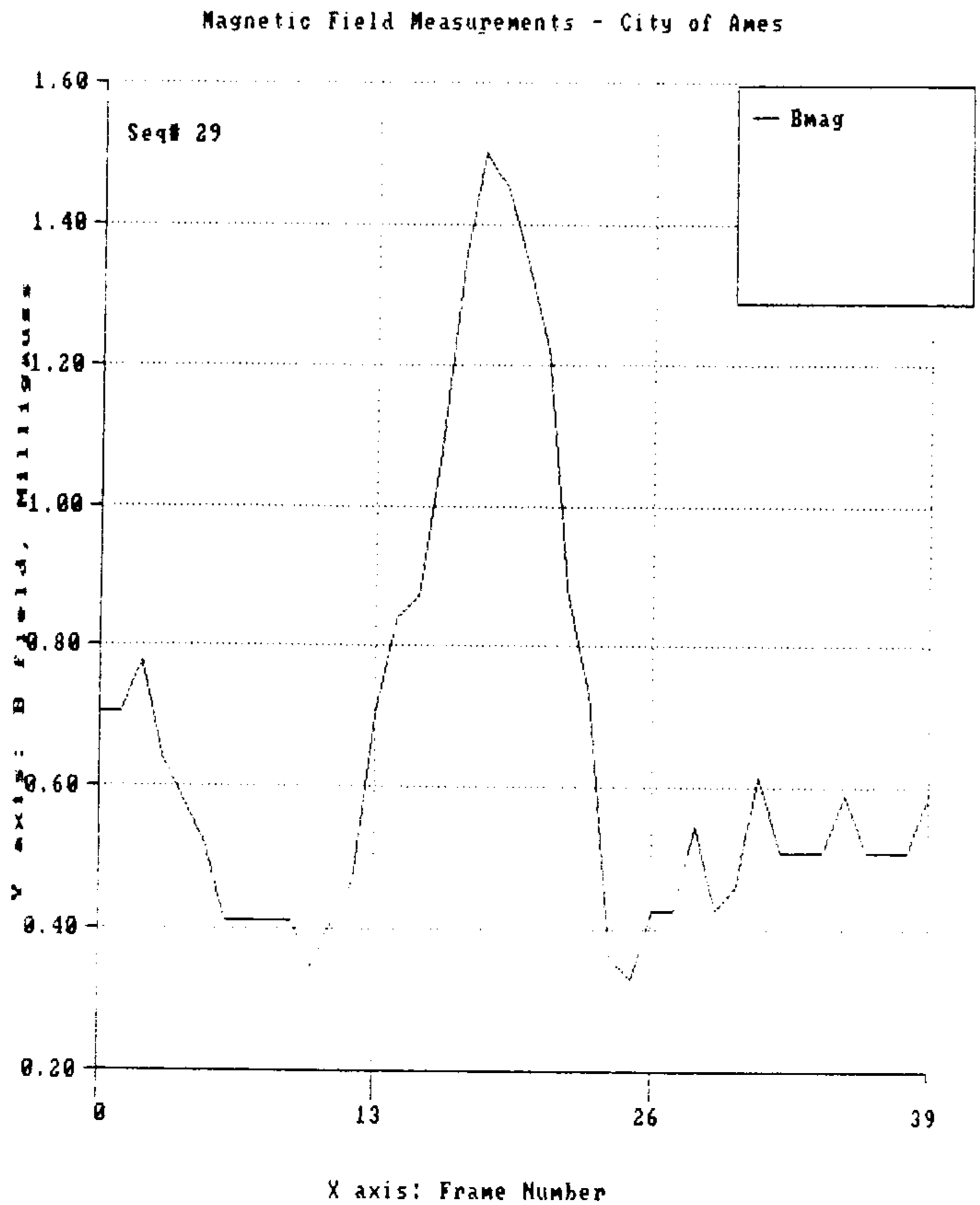


Figure 4.38. Magnetic field measurement #29

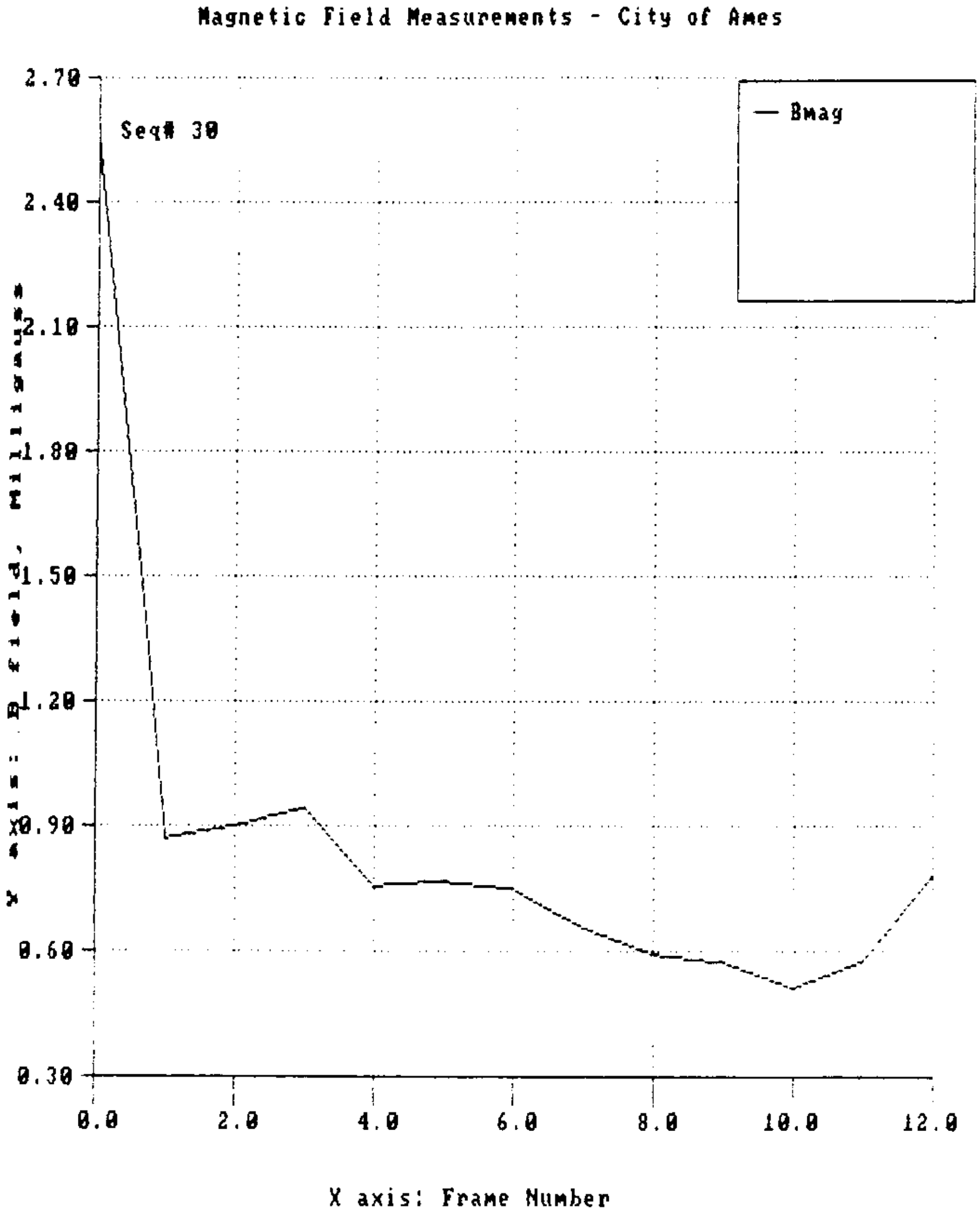


Figure 4.39. Magnetic field measurement #30

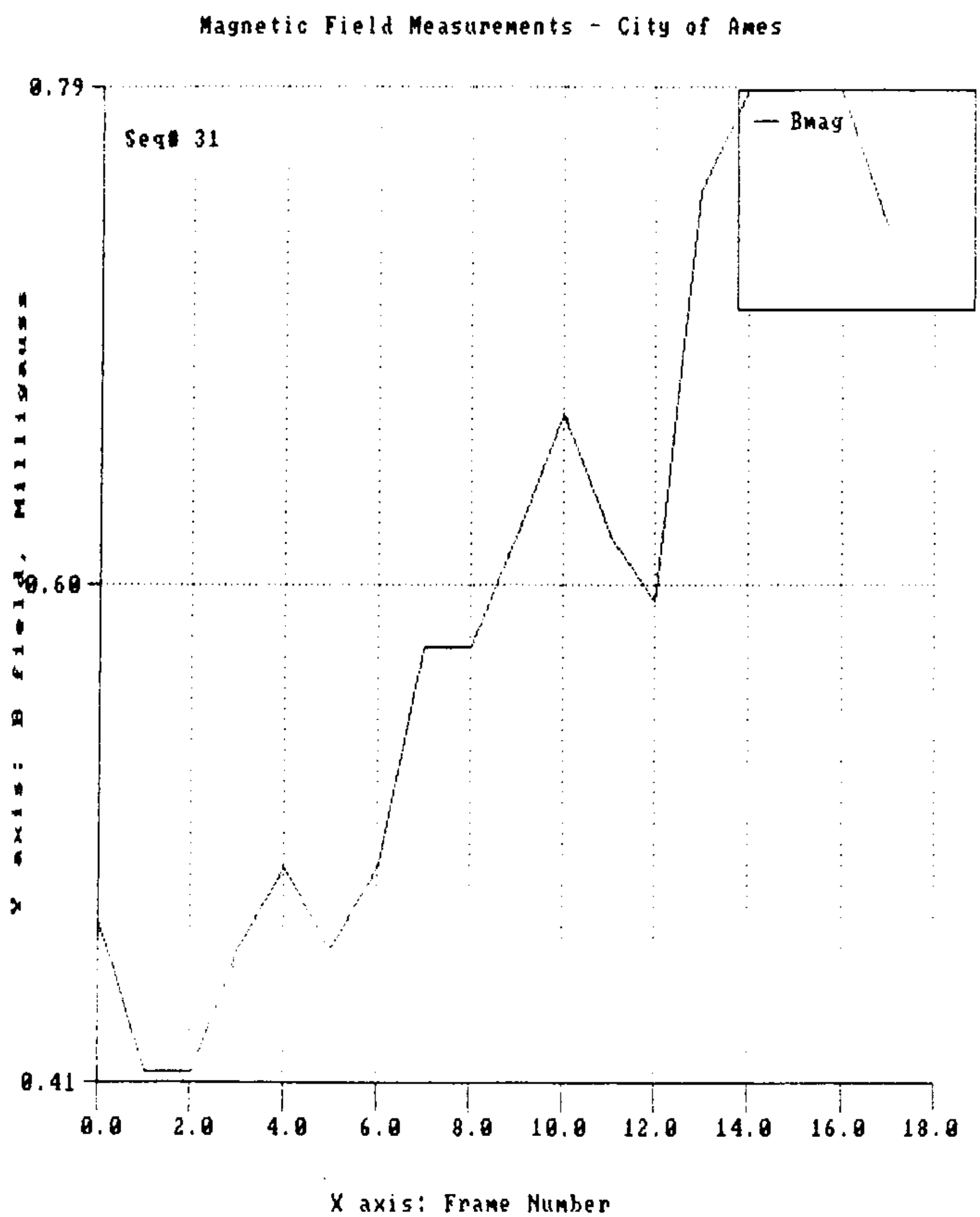


Figure 4.40. Magnetic field measurement #31

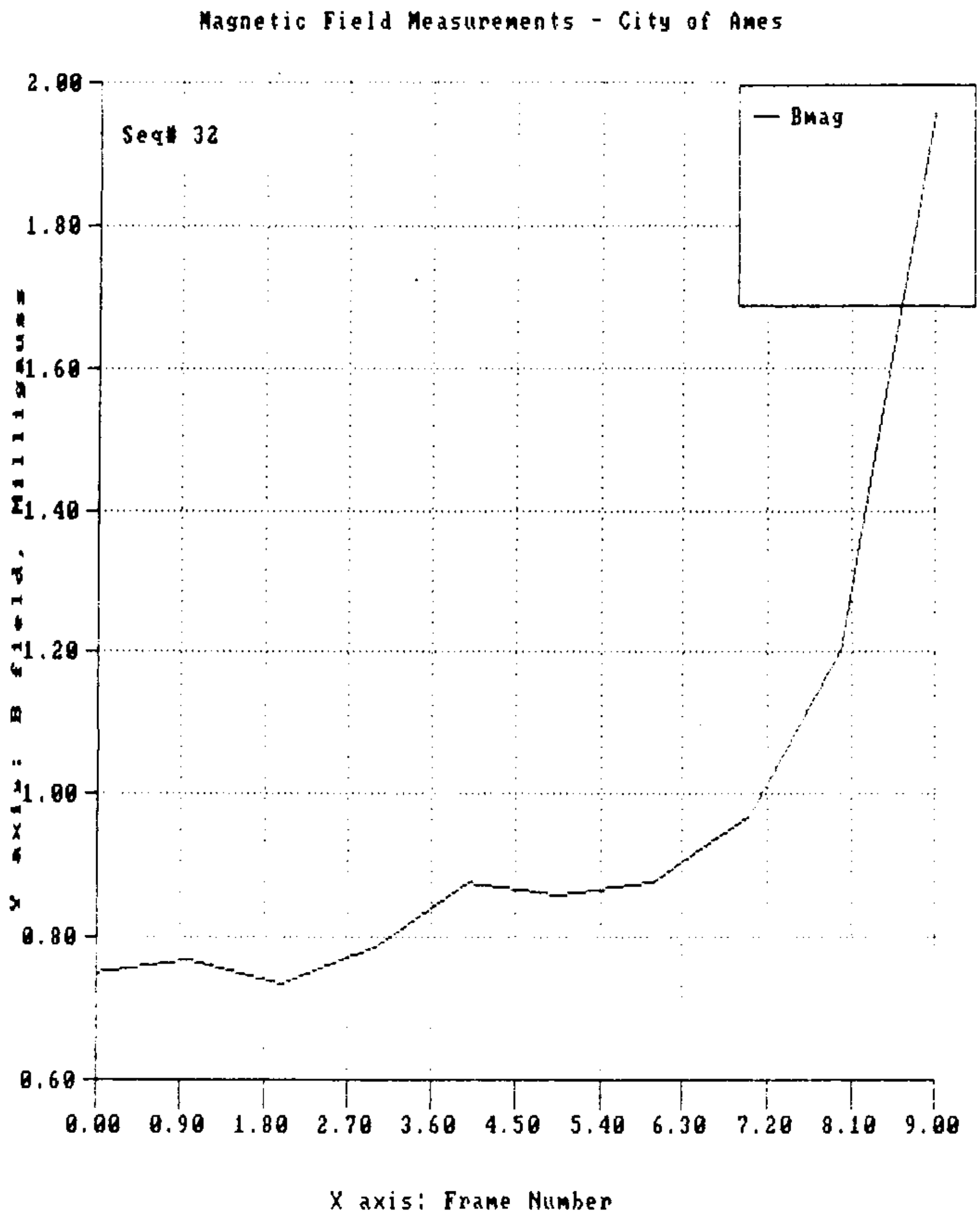


Figure 4.41. Magnetic field measurement #32

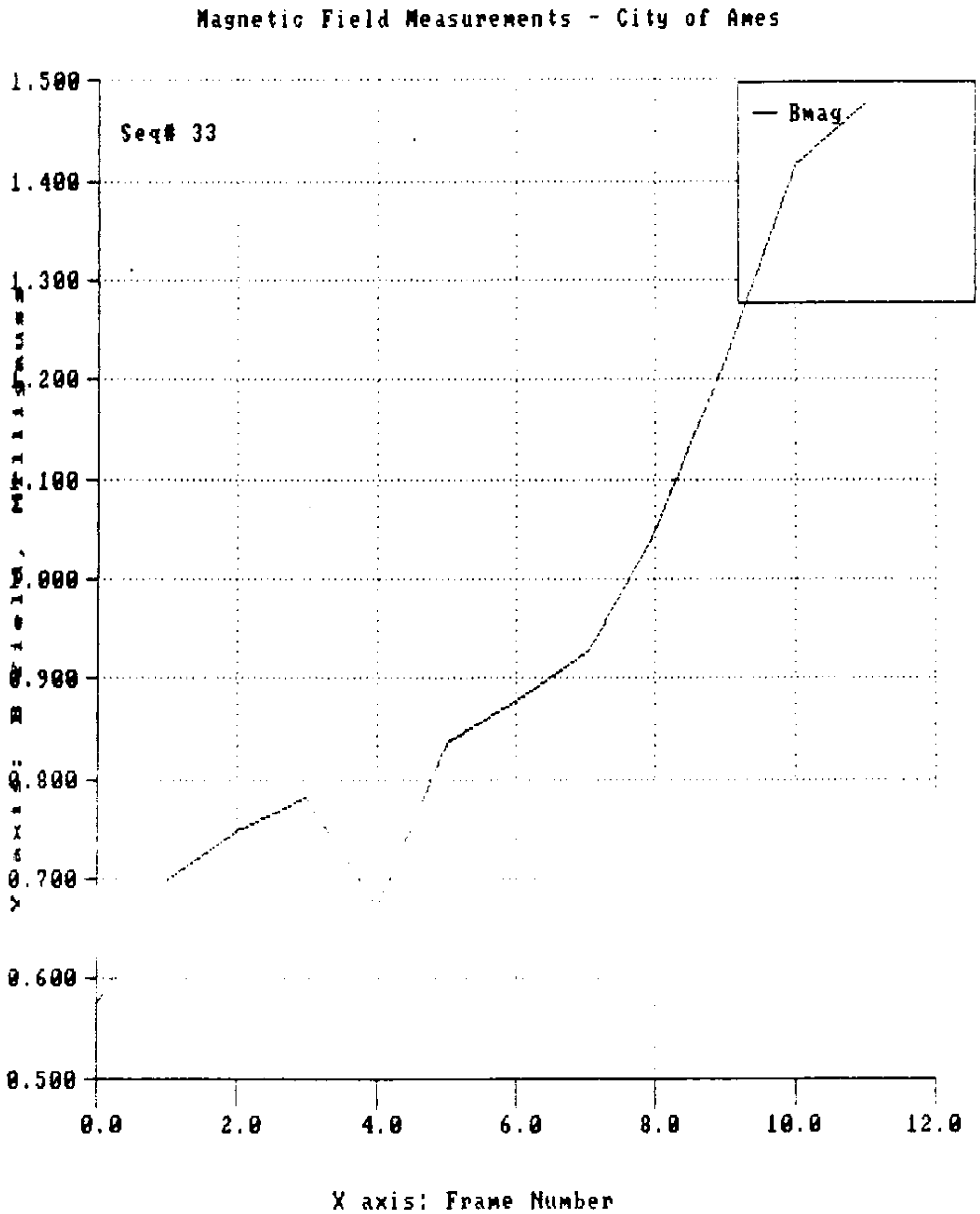


Figure 4.42. Magnetic field measurement #33

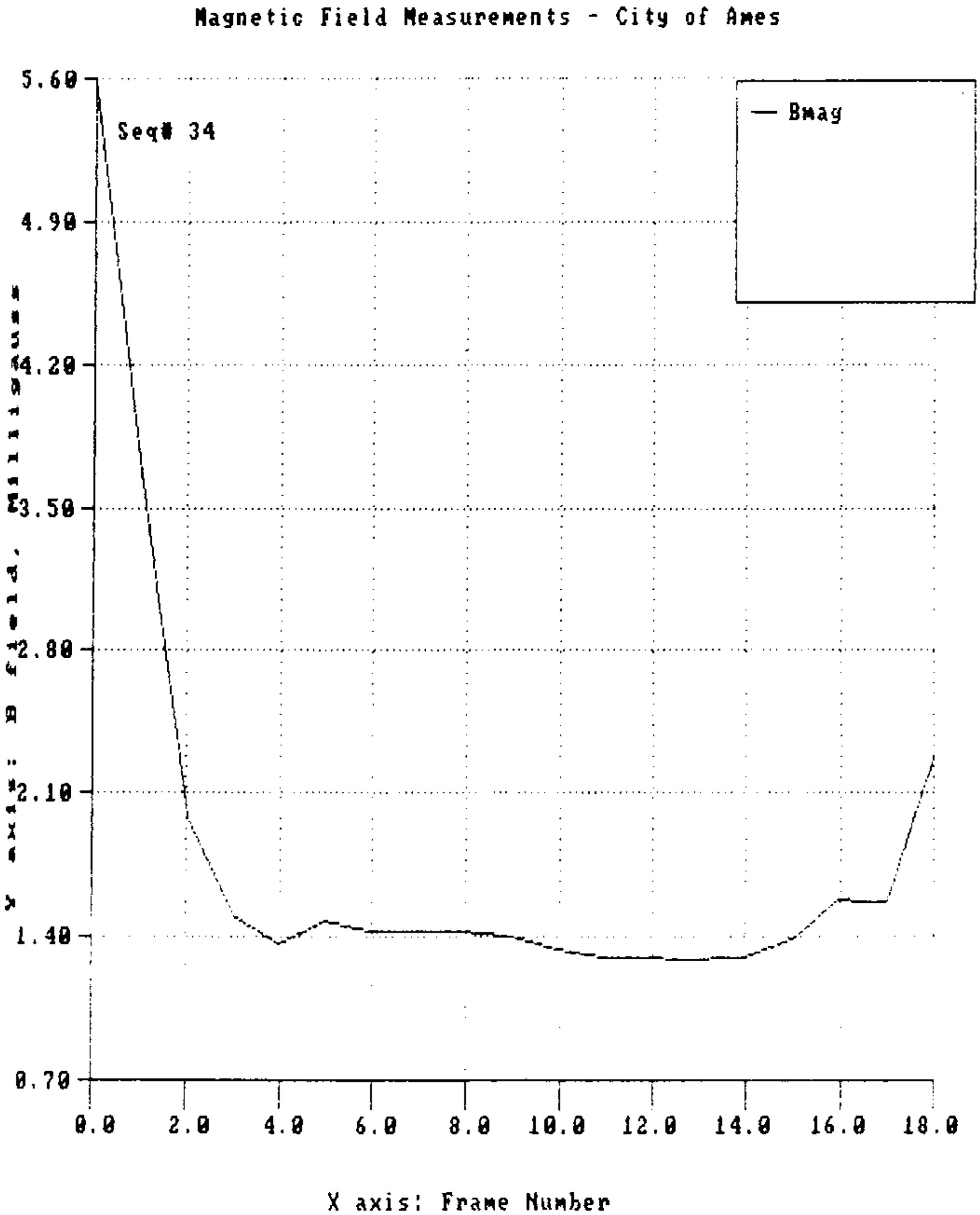


Figure 4.43. Magnetic field measurement #34

The procedure used in taking measurements was to lay out a four foot grid over the entire back yard and take measurements with an EMDEXC at each grid crossing. This was made possible with the measuring wheel described in the previous chapter. This method would describe the strengths of the fields throughout the yard. After completing the data collection, the data were downloaded, results were obtained, and are displayed in Figures 4.44 and 4.45.

The values obtained in the back yard ranged from 0.82 milligauss to 8.97 milligauss as shown on the following pages. Magnetic field sources identified in the rear of the yard were the transformer, a 240/120 volt underground secondary running along the rear lot line, and a two–phase 13–kV underground feeder that feeds the transformer. The highest readings were found near the transformer, but diminished rapidly with distance. A consistent range of values from 5 to 7 milligauss was found along the south side of the yard above where the two–phase underground feeder ran that fed the pad–mounted transformer.

The results of this study indicate that distribution transformers do have magnetic fields that are inherit with them, but when placed sufficiently far from the home, have little effect on the background fields found in the home. What does seem to contribute to the background field in the home are the underground lines that supply electricity to the pad–mount transformer. It is assumed that the underground service drop is located in the same trench with the underground feeder, thus contributing to the higher values found in this area of the yard.

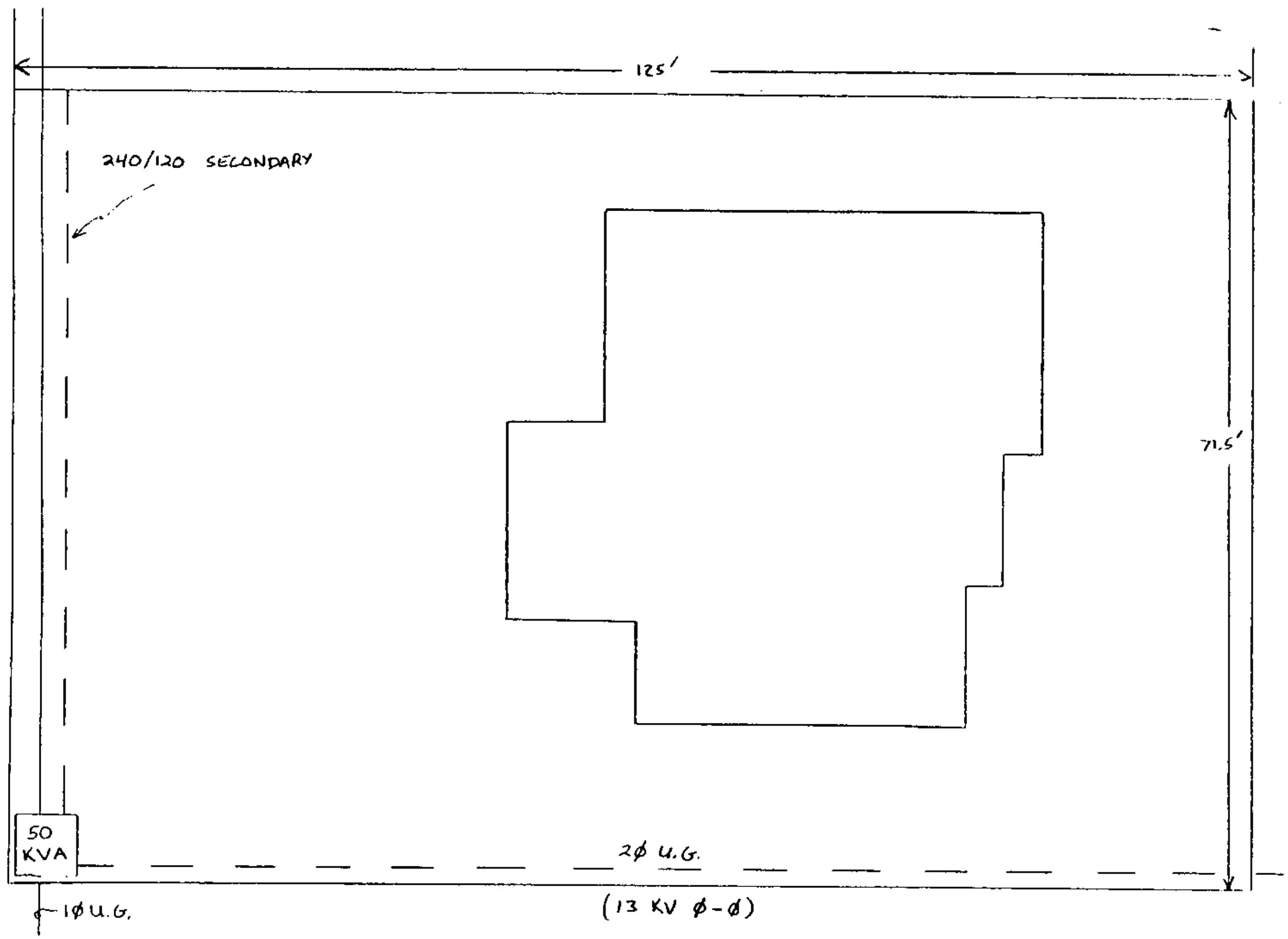
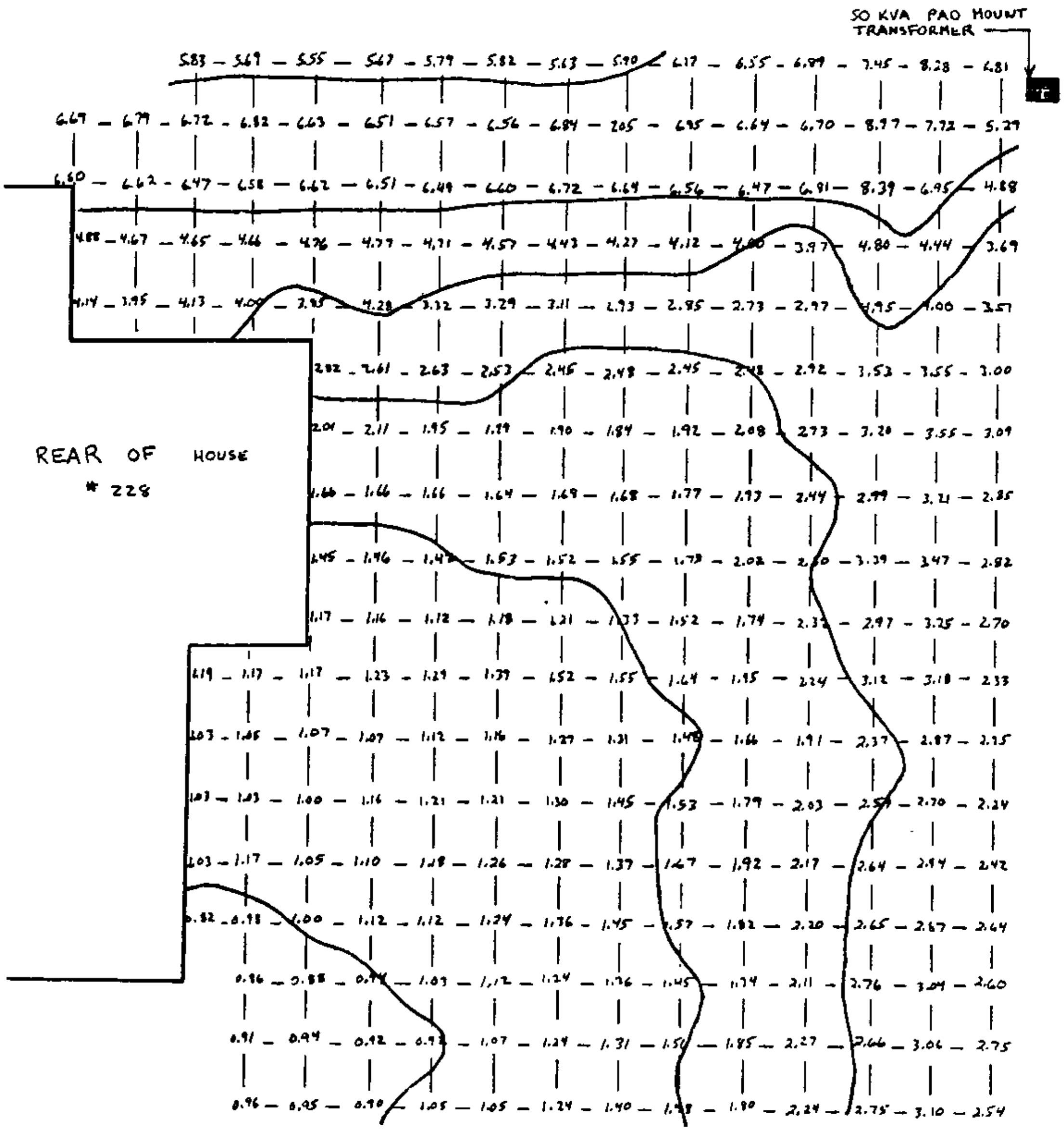


Figure 4.44. Location of pad–mount transformer study



NOTE: THE ABOVE GRID IS LAYED OUT IN 4' x 4' SECTIONS.

Figure 4.45. Data gathered for pad–mount transformer

4.4 Plaza Condominiums

The Plaza Condominium study was a study of magnetic fields that existed in several offices. The offices are located in the Plaza Condominiums, a downtown Des Moines office and condominium tower. Iowa Power and Light Company had received a call from a law firm who had just moved into an office space on the second floor (Figure 4.46). After the law firm had installed their computer equipment, they noticed that the text that appeared on their computer monitor screens was unstable. They moved the computers to another area in the office, and the phenomena ceased. They contacted the people who leased them their computer equipment, and with their help decided to call Iowa Power and Light Company. After finding that the rooms directly under the office contained the transformers that transform the voltage to the level that is distributed throughout the building, David R. Ahlberg, Senior Customer Representative at Iowa Power and Light Company, contacted Iowa State University to take measurements to see if the problem was one of magnetic fields.

After learning the specifics about the problem, Iowa State University representatives went to Des Moines to measure the magnetic fields that existed in the office complex and to determine if magnetic fields were indeed the problem. A two–foot grid was laid throughout the part of the office where the problem seemed to exist. At every intersection of the grid, a measurement was taken with an EMDEXC. Originally, the measuring wheel was going to be used with triggering every two feet, but because of the size of the rooms and the furniture in them, it was decided that this would not be very practical, so the grid was laid out. The same type of grid

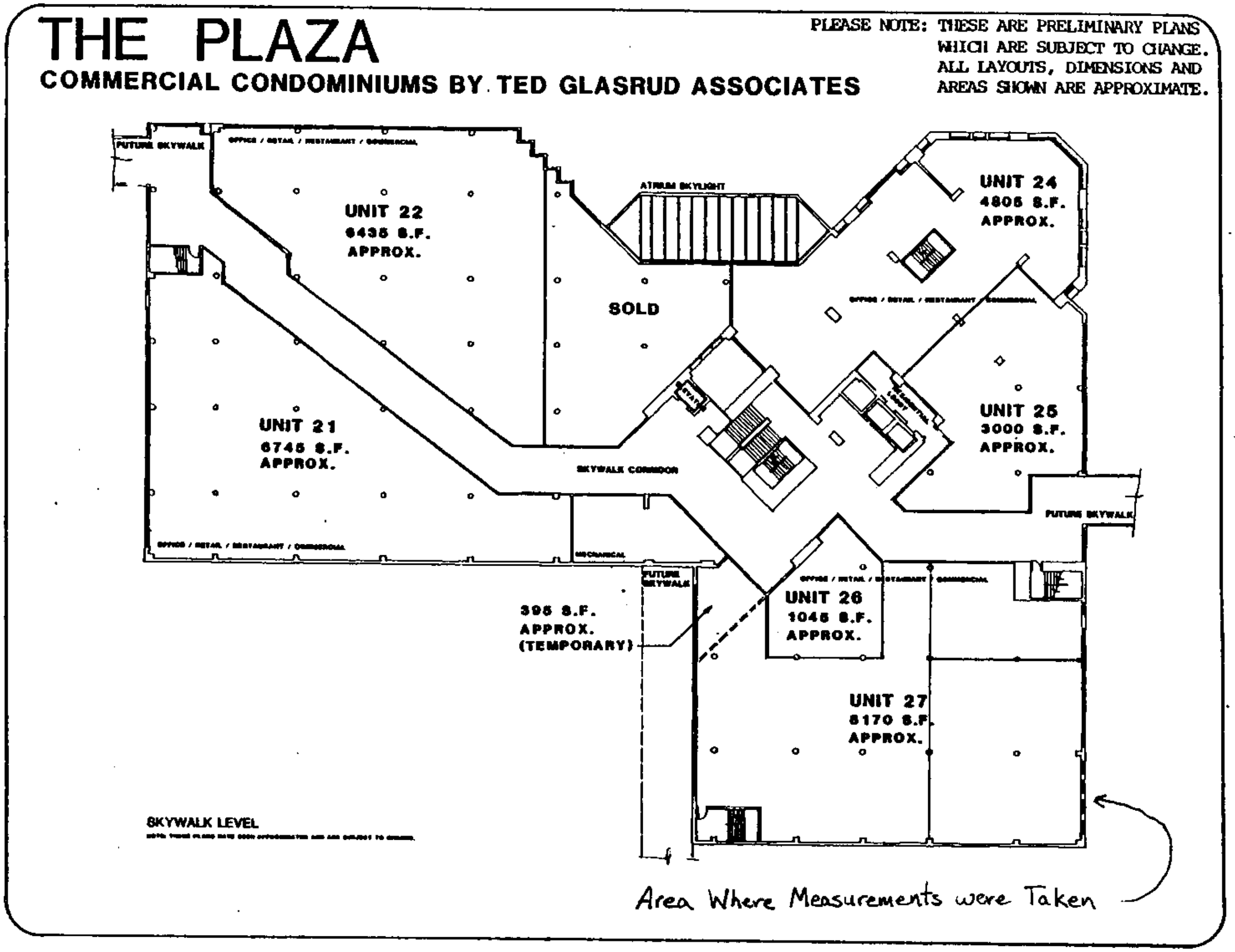


Figure 4.46. Plaza condominium office space

was used in taking measurements in the transformer vault, the suspected source of the magnetic fields. The data from this room were also collected and stored on the EMDEXC unit. Both sets of data were then downloaded and analyzed.

After downloading the data, a scale diagram of the transformer vault (Figure 4.47) and the office space (Figure 4.48) were drawn with the two–foot grid pattern laid out. At each grid crossing, the measurement recorded at that spot was written on the diagram. After all the values had been placed on the grid, a contour map was drawn with the aid of another computer program. Values of the magnetic fields within the office space varied from 1.42 milligauss to 146 milligauss. There were two areas within the office space that registered consistently above 100 milligauss. After overlaying the transformer vault drawing on the office space drawing, it was evident that the areas of highest readings were where the three phase currents from the transformer bus work passed through the wall at the ceiling of the vault and continued to the office building switch gear. Values of magnetic fields that were collected in the transformer vault ranged from 8 milligauss to 314 milligauss.

The conclusions of the study seem to point to magnetic fields as being the cause of the computer problems. Until the concern about high magnetic fields is resolved, the computers have been moved to other parts of the office. Various methods and techniques are being investigated to determine how to reduce these field levels. Extremely helpful is a paper entitled "Shielding Against Extra-Low-Frequency (ELF) Magnetic Fields" [47] presented by L. A. Cresswell and C. K. Gowers at the Electric Energy Conference in Sydney, 1989. Also helpful is a set of handbooks entitled "A Handbook Series on Electromagnetic Interference and Compatibility". Particularly useful is Volume 1, "Fundamentals of Electromagnetic

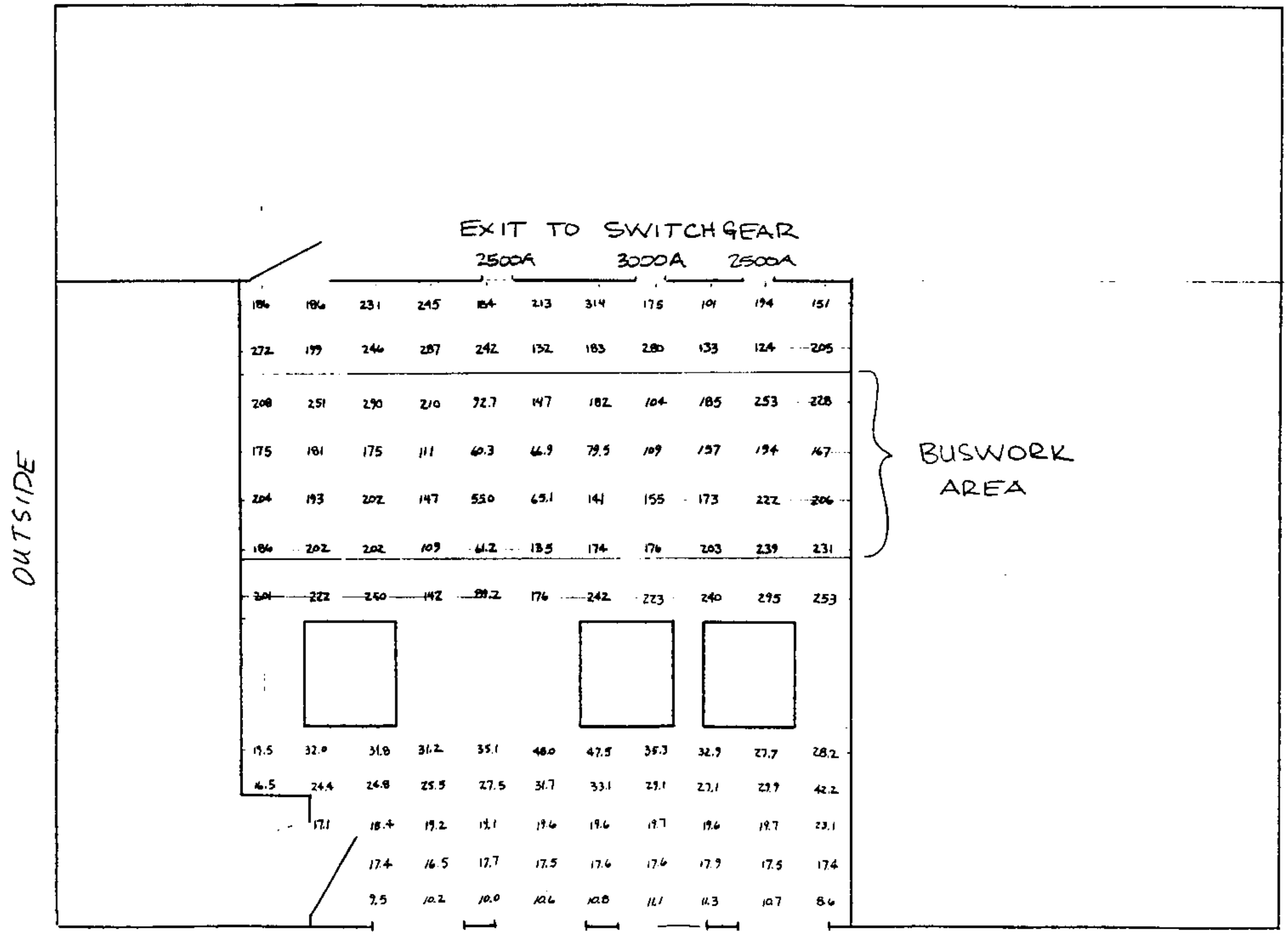


Figure 4.47. Scale drawing of transformer vault

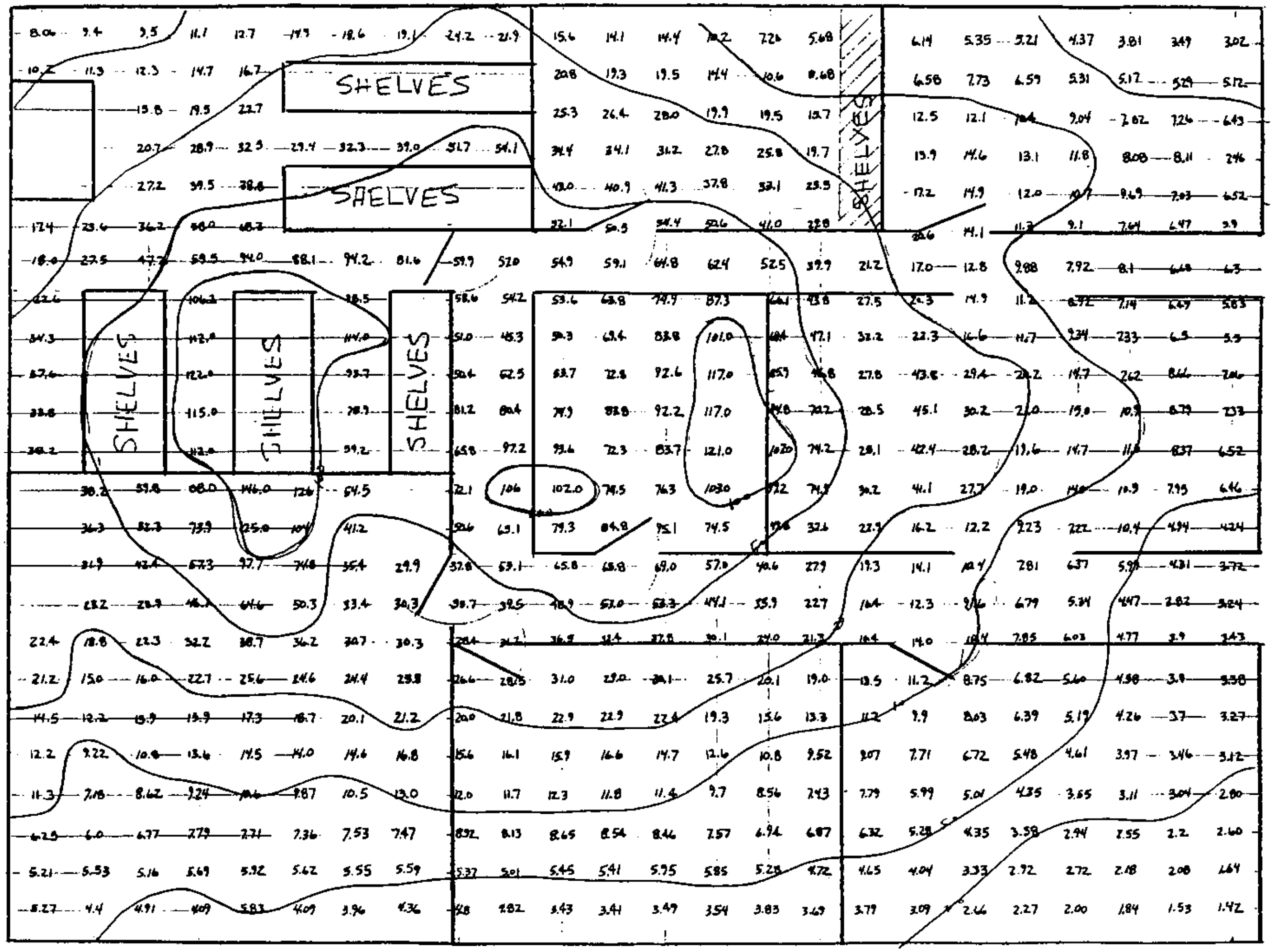


Figure 4.48. Scale drawing of office space

Capabilities" [46], and Volume 3, "Electromagnetic Shielding" [45] which describes in more depth the procedures used in reducing magnetic fields. Other ideas have been to relocate the bus work from the ceiling of the transformer vault, which is also the floor of the office, thus creating a greater distance between the source and the computers. Another possibility is moving the bus work closer together, allowing for greater cancellation of the fields.

4.5 College of Veterinary Medicine

Collecting data for the College of Veterinary Medicine at Iowa State University is an on–going joint project with the Department of Electrical Engineering. The College of Veterinary Medicine has the capability of removing a freshly fertilized egg from a mother species of about a dozen animals, and sustaining the life of the egg for about seventy–two hours in an incubator, before having to replace it in the mother, another female of the same species, or a female of another species. They have actually had a rat give birth to rabbits. The Department of Electrical Engineering originally built an exposure chamber for Veterinary Medicine, more specifically Dr. Michael Dooley, DVM, so he could expose freshly fertilized eggs to a known and controlled magnetic field. The logic behind this was that rapid cell growth takes place at this stage of development, and many of the off-springs' traits are established during this period. It is felt that if any cell damage is done by magnetic field exposure, this damage will manifest itself in the offspring. If any unusual conditions are found in the later developing animal, it is felt that they will be due to the effects of the magnetic fields exposure of the fertilized egg. Of course, control groups that are not exposed to magnetic fields will also be studied.

A problem arose when background magnetic fields were being measured in the lab incubator used for this research. Surprisingly, the magnetic fields found in the incubator ranged from about 800 milligauss on the top shelf, to about 60 milligauss on the bottom shelf. A desirable magnetic field level would be a maximum ambient background field of approximately 5 milligauss. It was determined that the source of the fields was a fan in the incubator. It was determined that it was impossible to find a control group where no magnetic field exposure would exist!

Various alternatives are being studied in trying to reduce the magnetic fields in the incubator. The first alternative was to try to shield the magnetic fields being generated by the fan. Various materials such as Mumetal and CO–NETIC, which are both materials that are capable of shielding magnetic fields, have been tried with very limited success. Some reduction of the magnetic fields did occur, but not to the magnitude that is desired. Another approach was to attempt to find an incubator that did not use a fan. Measurements were taken in a variety of incubators, but high magnetic fields caused by a variety of sources, such as heaters, or other electrical controls always seemed to be a problem. Manufacturers were contacted to see if an incubator with low magnetic fields was available. Most manufacturers gave the impression that this is the first time they have been approached with this type of concern.

The current status of the project is that the College of Veterinary Medicine is still attempting to correct the magnetic fields in the incubator. Probably more promising in the immediate future is a technique developed where the eggs can be maintained outside an incubator, although for a much shorter period of time. This will allow some studies to begin on the effects from magnetic fields, while the incubator problem is being corrected.

4.6 Background Magnetic Field Measurements

The objective of taking home measurements was to determine a typical value for the level of background magnetic fields. Although our effort did not consist of a large number of homes, it is believed that a fairly representative sample was obtained. The measurements that we found were similar to those that were found by Dr. David Savitz. His measurements of background magnetic fields in residences were found to be around 2.0 milligauss.

Measurements were taken in three homes on January 19, 1989, at various locations throughout the house. Most measurements were taken for approximately one hour and are displayed in Figures 4.49 through 4.58. The first set of measurements were in Alan J. Mitchell's home at 115B University Village (#7, Figure 4.7). His home is a two story condominium–type apartment where he has neighbors on both sides. All electrical services that are in the area are underground. Readings were taken in the kitchen with the unit on the kitchen table where measurements ranged from 0.3 milligauss to 1.5 milligauss. The next measurements were taken in the living room with the unit on the couch. Measurements here ranged from 0.2 milligauss to 0.4 milligauss. Finally measurements were taken in the master bedroom with the unit placed on the bed. Measurements here ranged from 0.2 milligauss to 0.4 milligauss.

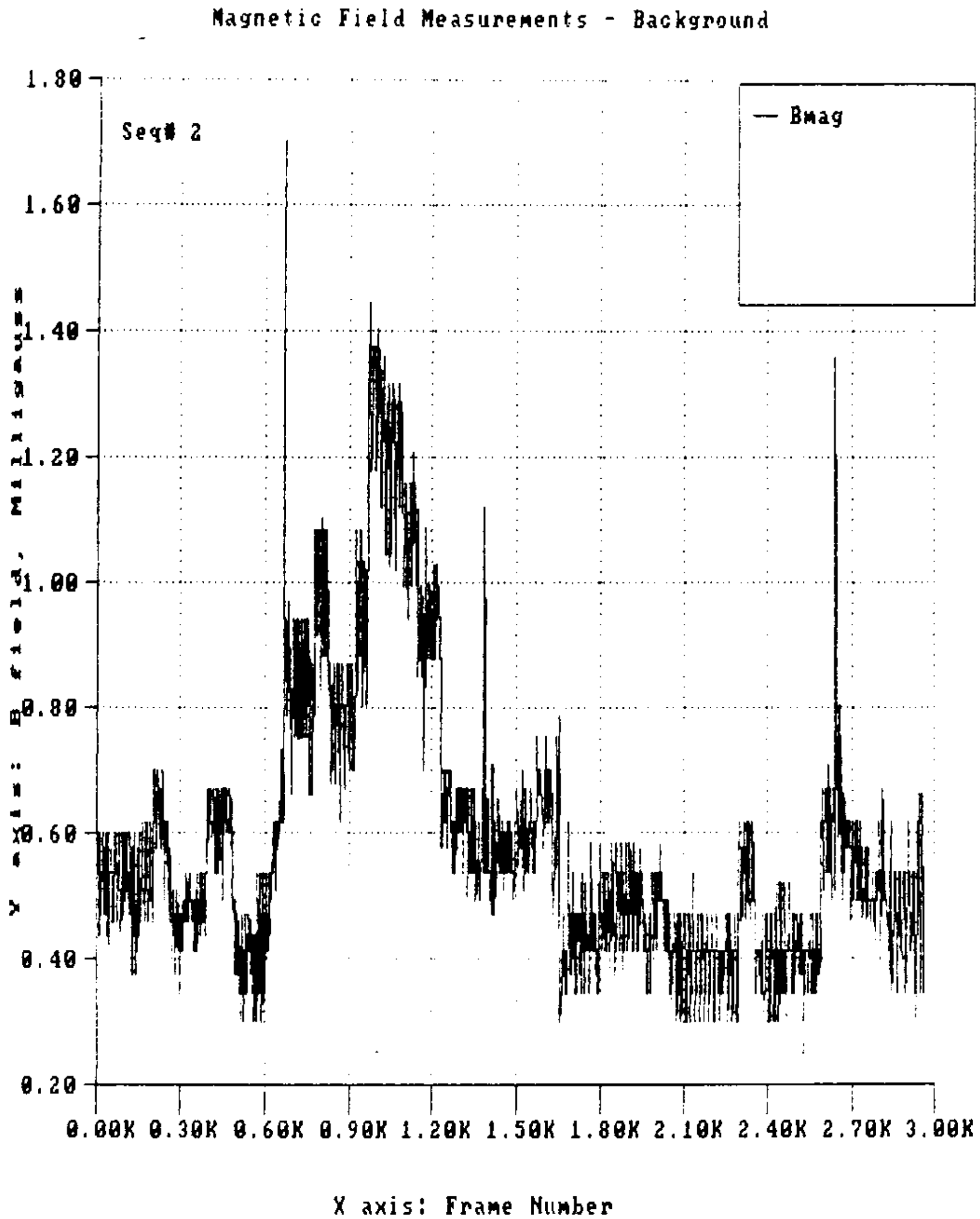


Figure 4.49. Background magnetic fields in Alan Mitchell's kitchen

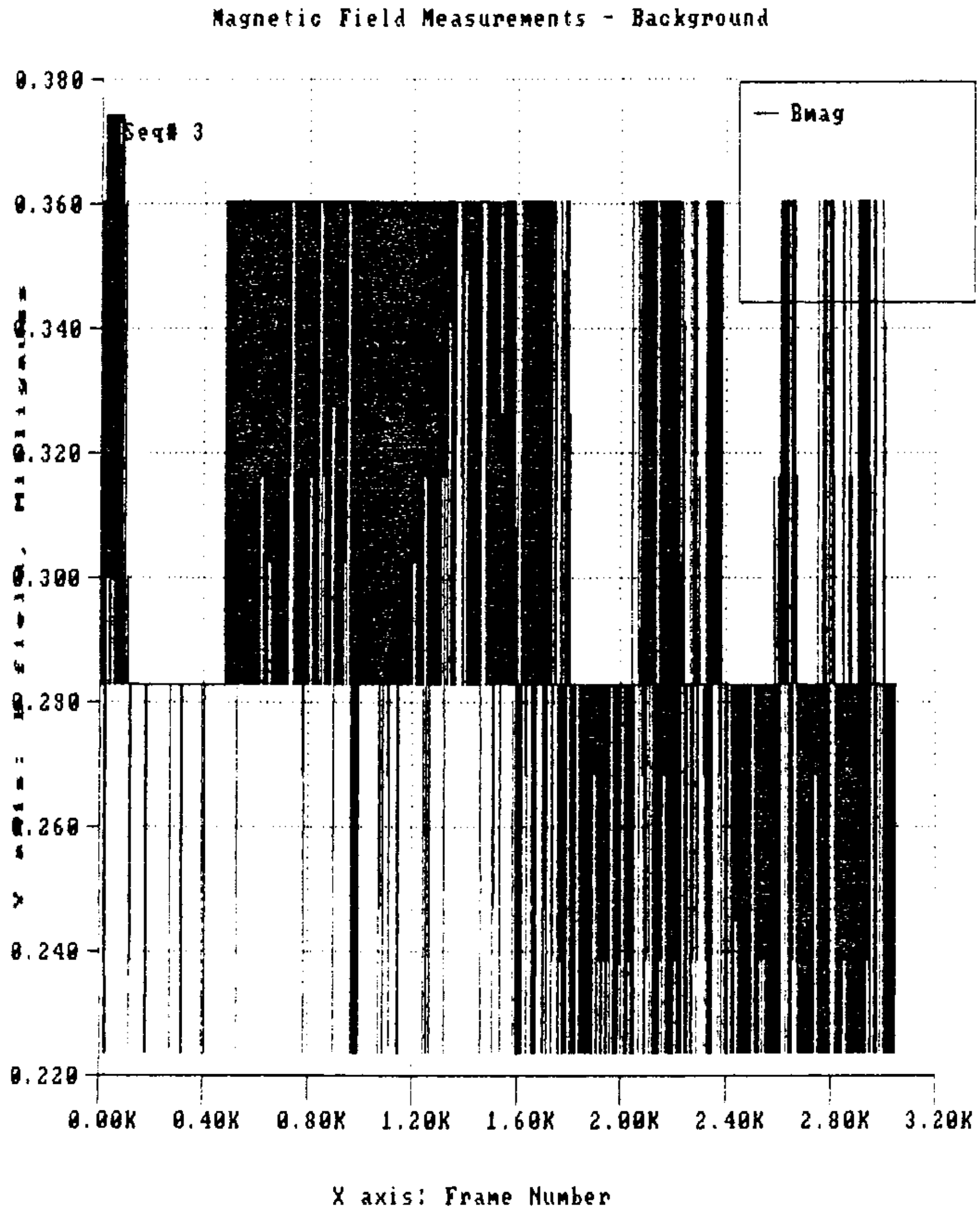


Figure 4.50. Background magnetic fields in Alan Mitchell's livingroom

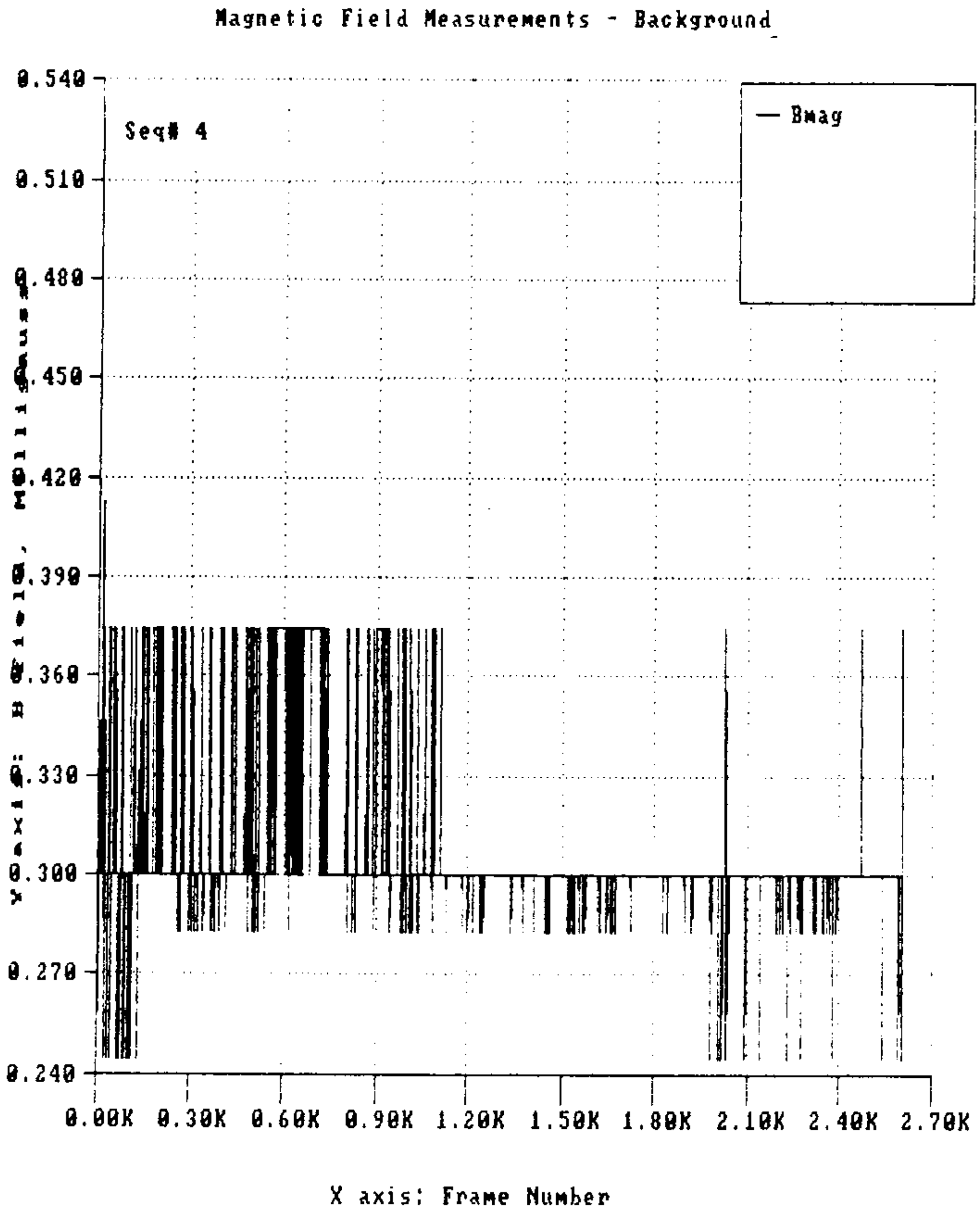


Figure 4.51. Background magnetic fields in Alan Mitchell's bedroom

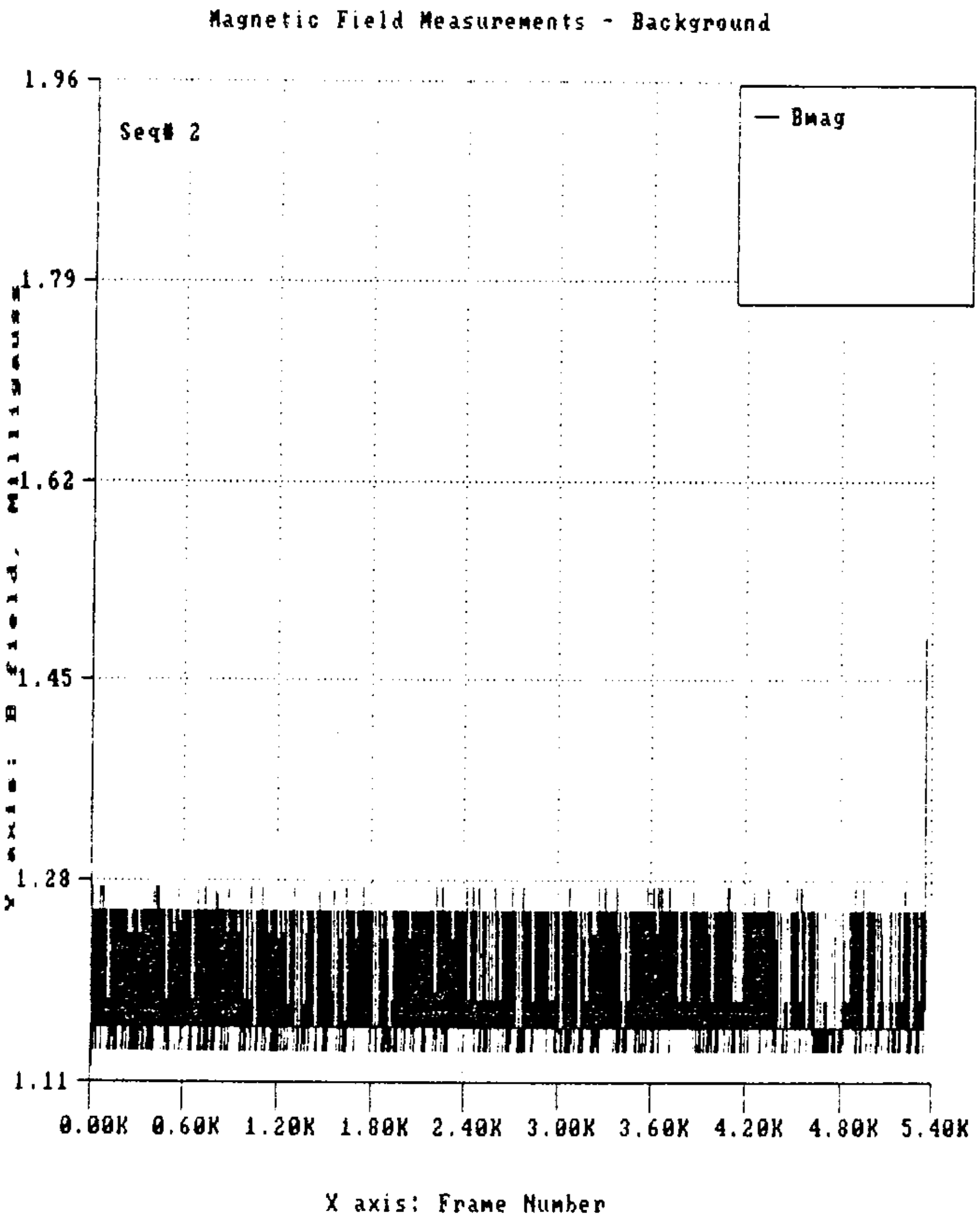


Figure 4.52. Background magnetic fields in Glenn Hillesland's great room

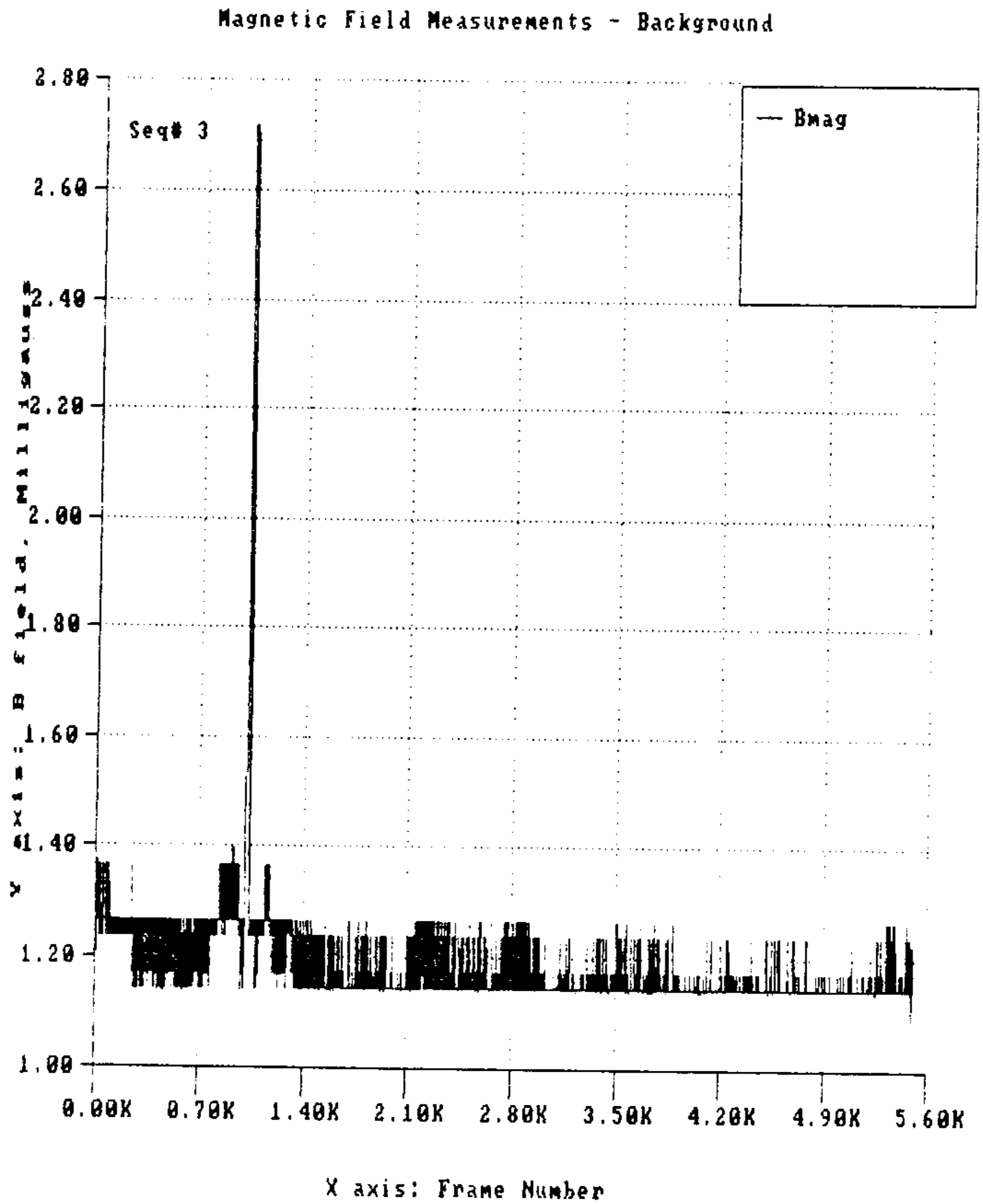


Figure 4.53. Background magnetic fields in Glenn Hillesland's livingroom

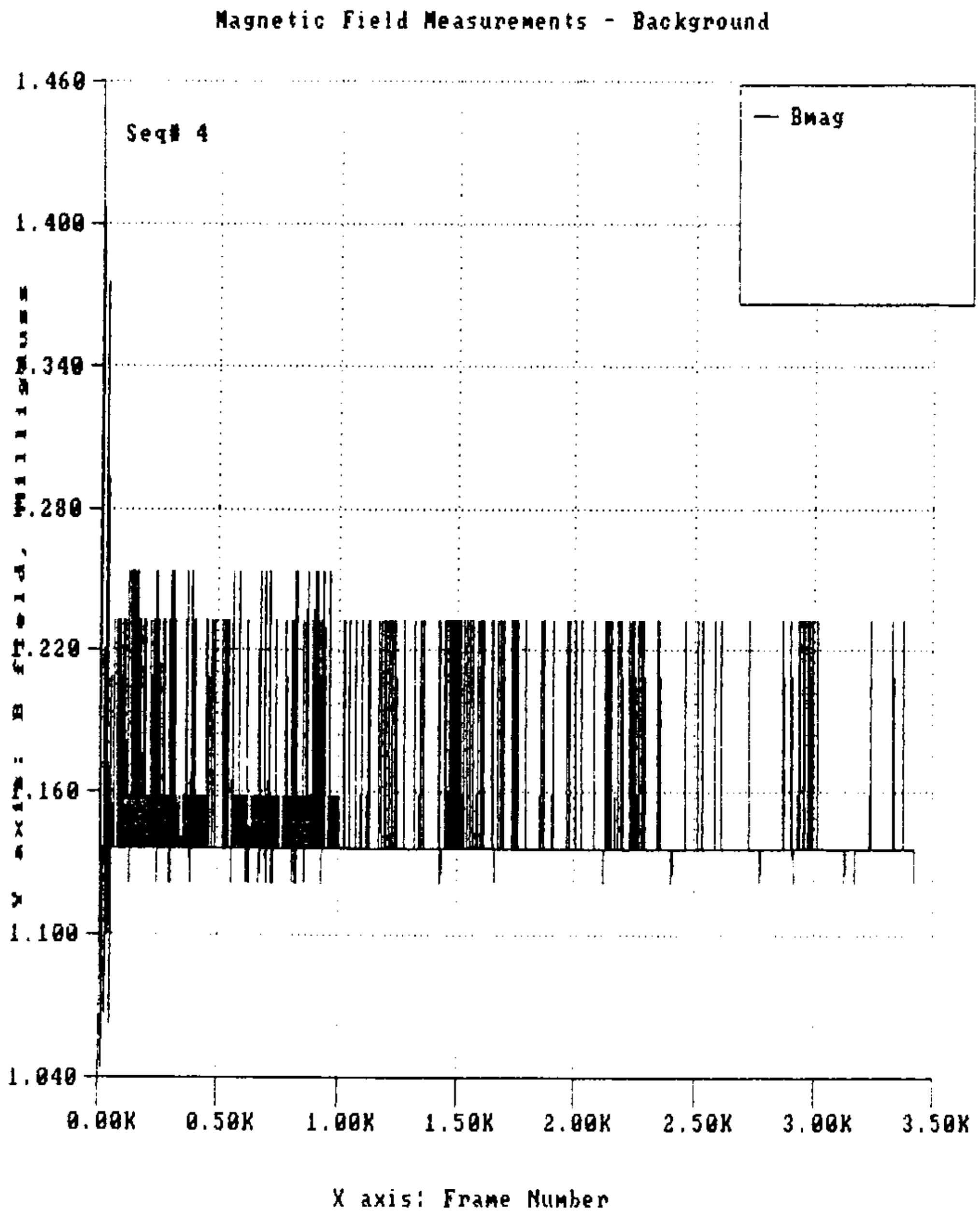


Figure 4.54. Background magnetic fields in Glenn Hillesland's bedroom

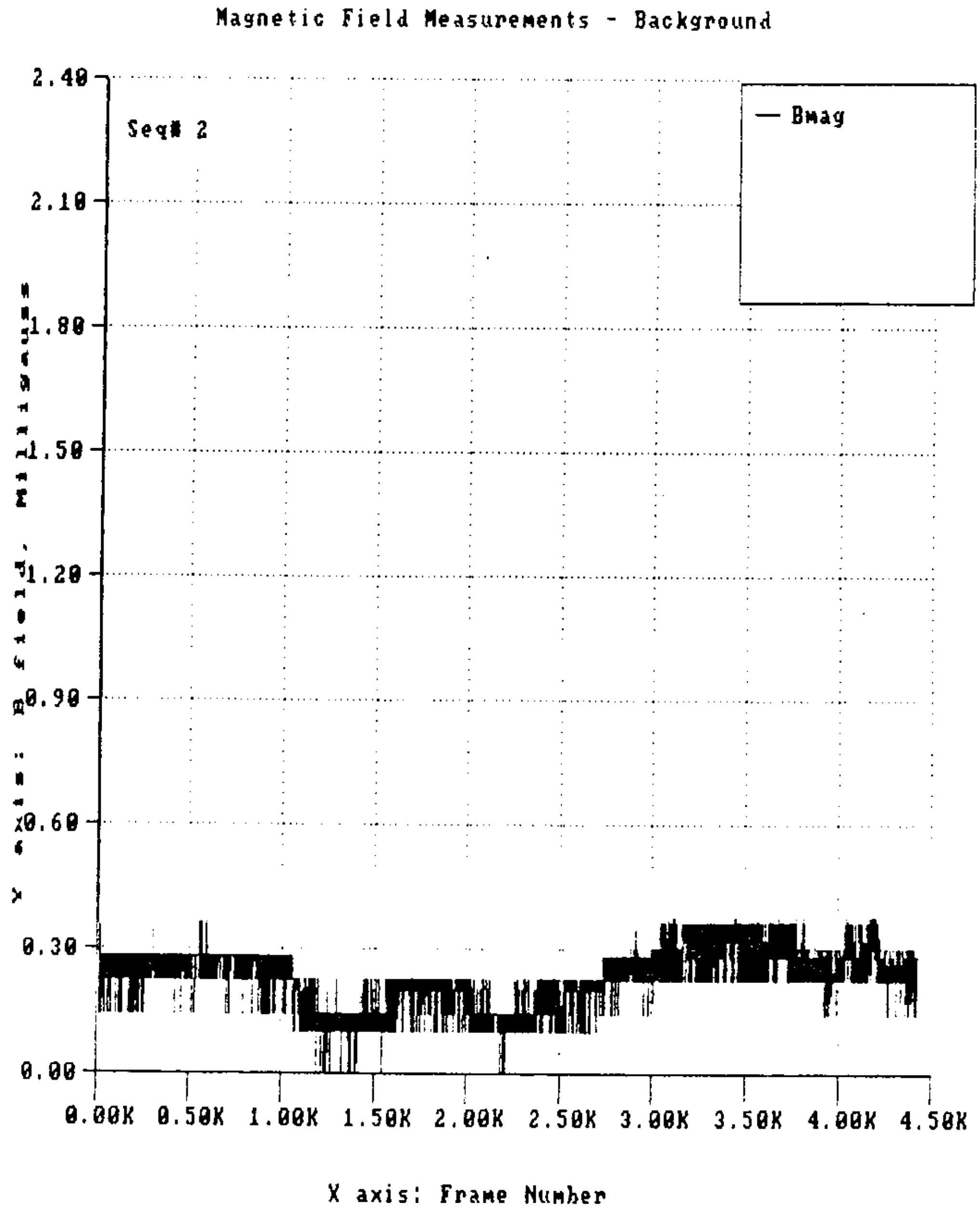


Figure 4.55. Background magnetic fields in John Lamont's dining room

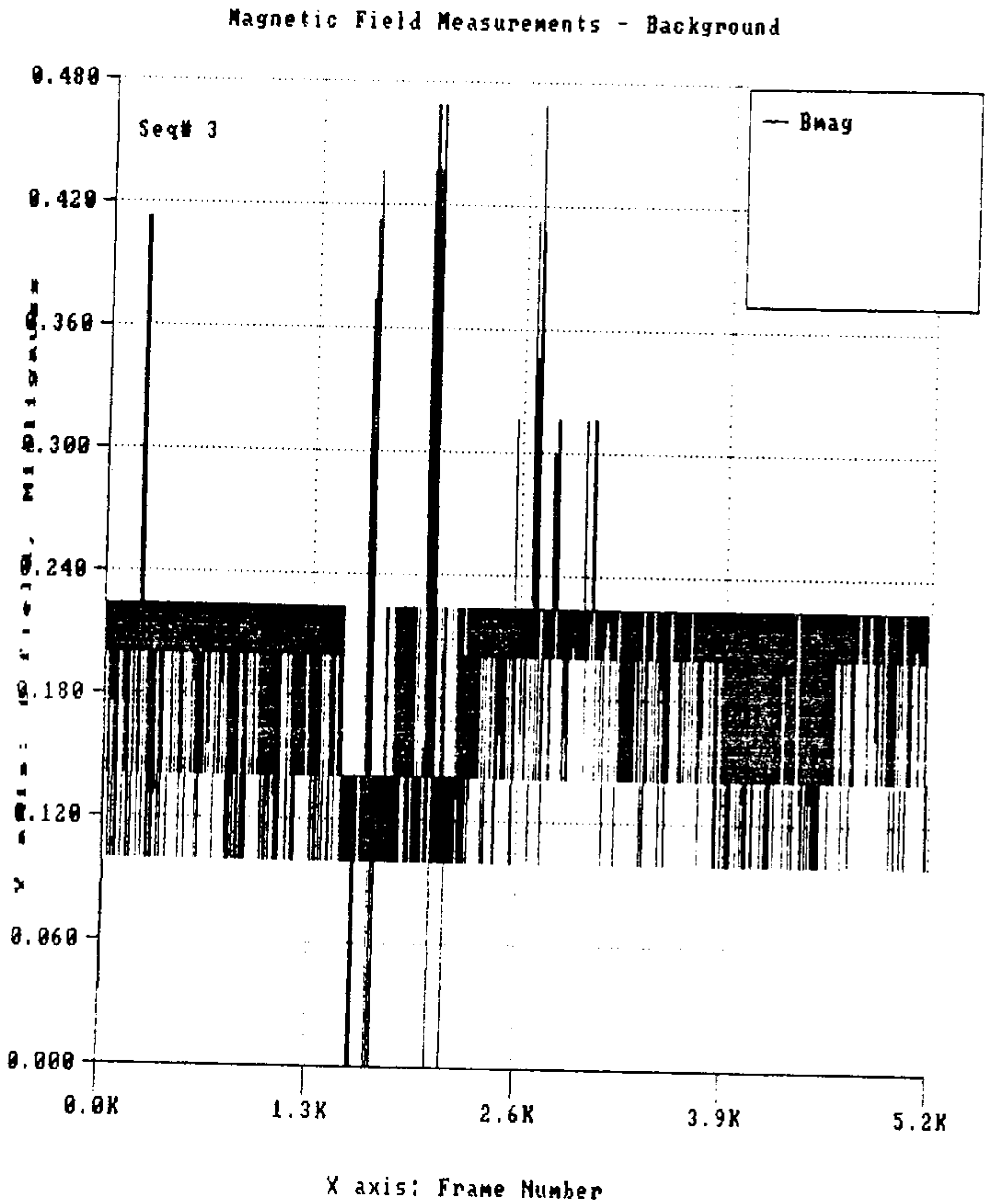


Figure 4.56. Background magnetic fields in John Lamont's study

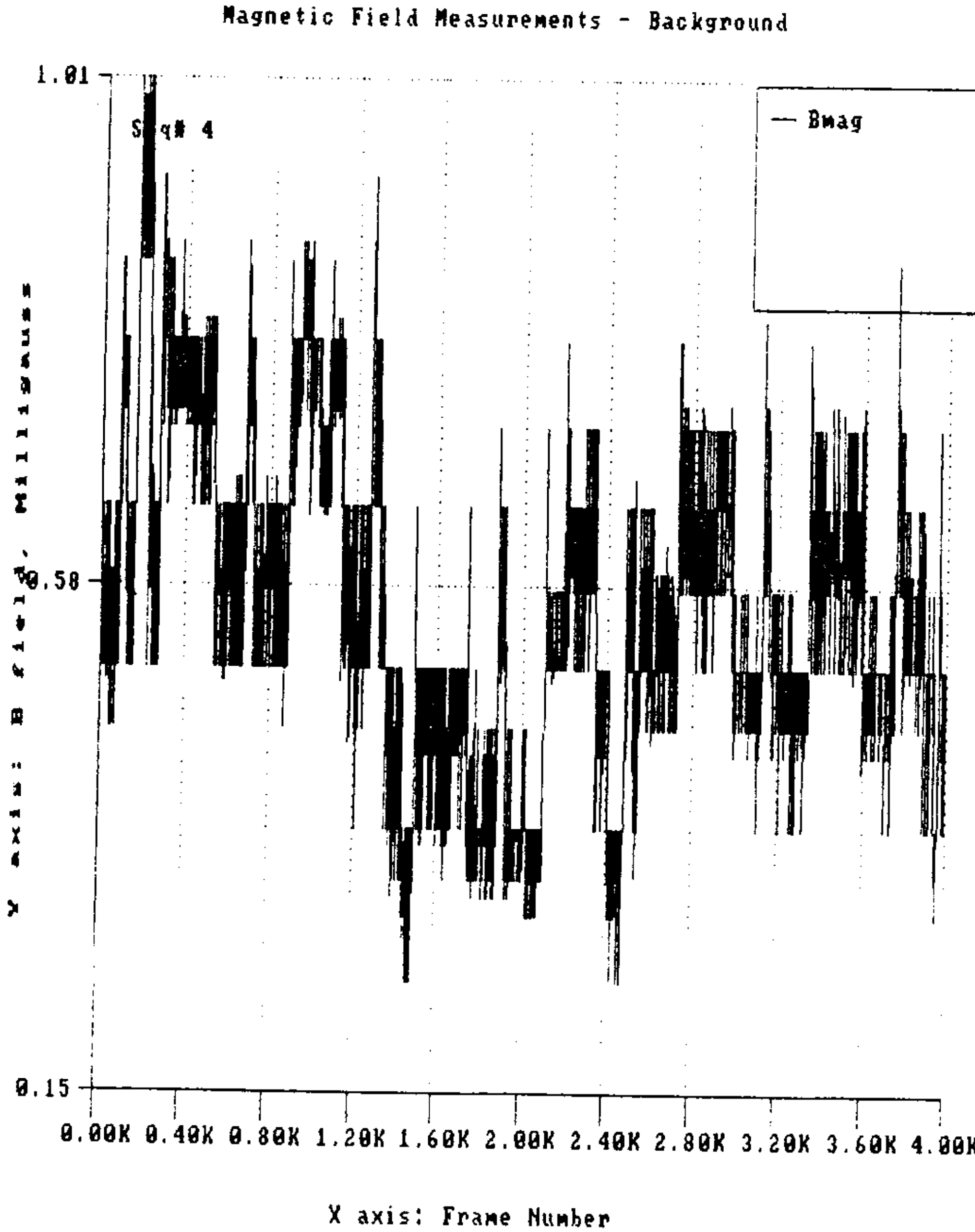


Figure 4.57. Background magnetic fields in John Lamont's family room

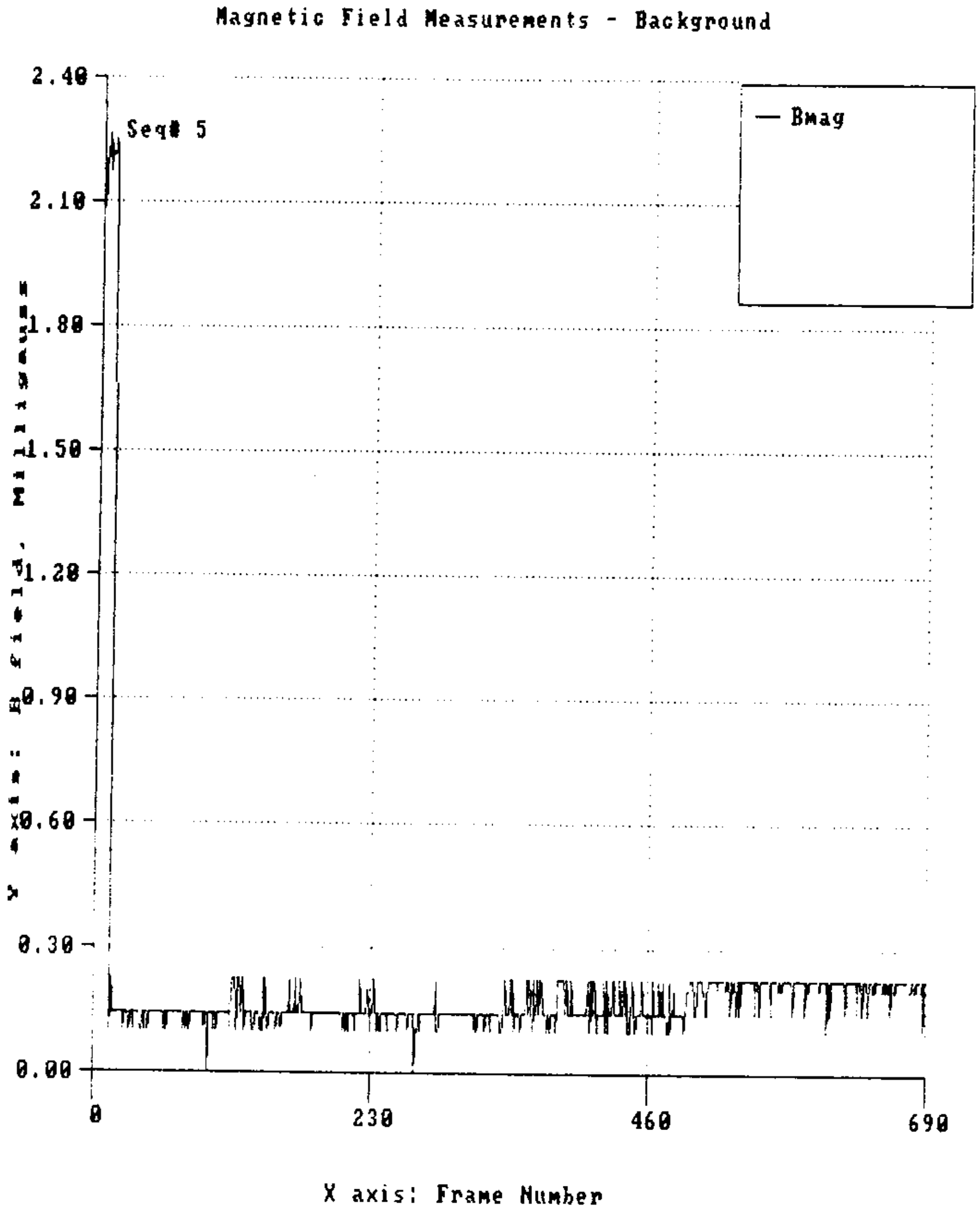


Figure 4.58. Background magnetic fields in John Lamont's bedroom

The next home where background magnetic field information was collected belongs to Glenn G. Hillesland at 2315 Buchanan Drive (#8, Figure 4.7). His home is a two story house with an underground service drop, an underground secondary and primary located in front of the house, and an overhead primary and transmission line located one hundred fifty feet to the side of his house. Measurements were taken first in the great room where measurements ranged from 1.1 milligauss to 1.3 milligauss. The next measurements were taken in the living room where measurements range from 1.2 milligauss to 1.4 milligauss with a short period of time around 2.7 milligauss. Lastly measurements were taken in the master bedroom where readings ranged from 1.1 milligauss to 1.3 milligauss.

The last of the three homes where background magnetic field data were collected belongs to John Wm. Lamont at 1005 Idaho Avenue (#9, Figure 4.7). His home is two stories with an underground one phase primary running along the back, and an underground secondary and service drop. Measurements taken in the dining room ranged from 0.0 milligauss to 0.4 milligauss. In the family room, measurements showed readings varying from 0.2 milligauss to 1.0 milligauss. Measurements taken in the master bedroom had fields that varied between 0.1 milligauss to 0.2 milligauss. Data were also gathered in a study. In this room, measurements were taken for two hours rather than one hour. Here measurements ranged from 0.0 milligauss to 0.5 milligauss.

4.7 Measurements Around Electrical Appliances

Once data had been gathered concerning the general background magnetic fields that exist in the home environment, it was desirable to find out what our magnetic field exposure was from electrical appliances in the home.

Before taking measurements around electrical appliances, a methodology was prepared dictating how measurements were to be taken. The following procedure was used in our study in measuring the magnetic fields around appliances:

1. Initialize an EMDEXC to gather and store data vs. time at a sample rate of one measurement per second.
2. Select an electrical device, and set it away from any known magnetic field. This can be found by using the EMDEXC to locate an area of low magnetic fields.
3. Record specific information about the electrical device, including information such as name brand, model number, and electrical rating.
4. Place the EMDEXC directly next to the electrical device. Take measurements for ten seconds with the device turned off, then turn the device on and continue to take measurements for another ten seconds.
5. Repeat Step 3 again at distances of one foot away from the device, and also at three feet away from the device.
6. Define a typical exposure distance. This is the distance that the person is from the source of the magnetic field when normally operating it. For example, the typical exposure distance for an electric knife or electric hand drill is zero feet, because the user is in contact with the device when using it. On the other hand, the typical exposure distance for a television may be ten feet. The magnetic field measurement taken at this typical exposure distance is called the typical exposure value.
7. If the typical exposure distance is something other than zero, one, or three feet, collect data as in Step 3 at this typical exposure distance.
8. Download the EMDEXC to analyze the data.

This procedure was used in measuring approximately 300 electrical devices in 10 different homes. Each device was put into different groups based on the type of activity associated with the device. Within each group, the minimum, maximum, and average value for each device at the typical exposure distance was reported and is listed in Table 4.1. Also shown for each electrical device is the number of devices which were measured and the typical exposure distance. The last three columns in this table give the minimum, maximum, and average value of the mG/Watt rating. This value was found by taking either the name plate rating of the appliance or the actual measurement of the power that was consumed by that device, and dividing this value by the typical exposure value found at the typical exposure distance. This value can be used in making rough approximations for calculating the magnitude of magnetic fields that could be found around electrical devices of that type with only knowing the name plate rating.

Table 4.1. Magnetic field data for home electrical devices

ITEM	NO OF ITEMS	TYP EXP DIST FEET	MIN PWR RATE WATT	AVE PWR RATE WATT	MAX PWR RATE WATT	MIN TYP EXP VALUE mG	AVE TYP EXP VALUE mG	MAX TYP EXP VALUE mG	MIN EXP PER WATT mG/W	AVE EXP PER WATT mG/W	MAX EXP PER WATT mG/W
NOTES:		1	2	2	2	3	3	3	4	4	4
PERSONAL CARE-RELATED											
ALARM CLOCK	7	3	3	5	8		0.3	1.1		0.052	0.367
BATHTUB SPA	1	1				45.0	45.0	45.0			
CURLERS, HAIR	1	3	720	720	720						
CURLING IRON, HAIR	5	0	16	32	40	0.3	1.2	3.0	0.045	0.060	0.075
DRYER, GUN-TYPE HAIR	7	0	600	1129	1500	23.0	129.7	280.0	0.031	0.107	0.204
DRYER,HOOD TYPE HAIR	1	0	750	750	750	3700.0	3700.0	3700.0	4.933	4.933	4.933
FAN, BATHROOM EXHAUST	6	3				1.0	2.2	4.0			
HEATING PAD, ELECTRIC	3	0	40	50	55	8.5	33.2	77.0	0.154	0.635	1.400
SHAVER, ELECTRIC	4	0				5.8	371.2	820.0			
VAPORIZER	2	3	44	44	44	0.9	2.1	1.2	0.021	0.021	0.021
CLOTHING-RELATED											
DRYER, ELEC CLOTHES	3	3					4.0	8.0			
DRYER, GAS CLOTHES	1	3									
IRON, PORT CLOTHES	4	0	1100	1125	1200	41.0	68.8	100.0	0.037	0.061	0.091
SEWING MACHINE	4	1				5.7	6.8	8.5			
WASHING MACHINE	2	3					0.2	0.4			
ENTERTAINMENT-RELATED											
BOOM BOX STEREO	1	3									
CLOCK RADIO	7	3	4	8	14	0.3	0.5	0.6	0.025	0.025	0.025
COMPUTER PRINTER	1	3									
COMPUTER	5	1				0.9	2.8	3.6			
FIREPLACE, ELECTRIC	1	3				1.3	1.3	1.3			
NINTENDO	1	0									
ORGAN, ELECTRONIC	1	0	200	200	200	1.6	1.6	1.6	0.008	0.008	0.008
READING LAMP	1	3									
SLIDE PROJECTOR	1	3				6.2	6.2	6.2			
STEREO	3	3				0.8	0.8	0.9			
TELEVISION, B&W	1	10									
TELEVISION, COLOR	11	10									
TRAIN TRANSFORMER	1	3				1.2	1.2	1.2			
VCR	2	10	19	19	19						
WALKMAN, TAPE PLAYING	1	1				0.3	0.3	0.3			
TOOLS - OTHER											
ADDING MACHINE	1	0				17.0	17.0	17.0			
AIRLESS PAINTER	1	0	100	100	100	5100.0	5100.0	5100.0	51.000	51.000	51.000
BAND SAW	3	1	200	225	250	2.5	12.5	29.0	0.024	0.085	0.145
CORDLESS DRILL	1	0				6.0	6.0	6.0			
CORDLESS SCREWDRIVER	2	0				0.6	1.6	2.7			
DRILL BIT SHARPNER	1	0				4800.0	4800.0	4800.0			
DRILL PRESS, TABLETOP	1	1				29.0	29.0	29.0			
DRILL, PORTABLE	6	0	207	266	327	300.0	2250.0	4200.0	0.917	8.280	16.739
ENGRAVER, ELECTRIC	1	0	15	15	15	740.0	740.0	740.0	49.333	49.333	49.333
GLUE GUN, ELECTRIC	2	0				0.9	1.3	1.6	0.046	0.046	0.046
GRINDER, BENCH	1	1	373	373	373	21.0	21.0	21.0	0.056	0.056	0.056
ROUTER, HAND	2	0	327	518	709	600.0	1800.0	3000.0	1.833	3.032	4.231
SANDER, PORT BELT	3	0	355	442	538	120.0	1273.3	2000.0	0.338	2.666	3.947
SANDER, PORT PAD	3	0	164	225	240	580.0	2393.3	4700.0	3.544	10.031	19.583
SAW, CIRCULAR	4	0	1023	1136	1250	275.0	1543.7	2800.0	0.220	1.382	2.464
SAW, PORTABLE JIG	5	0	243	289	347	375.0	1165.0	2000.0	1.296	4.073	7.814
SAW, RADIAL ARM, 10"	1	0				2.4	2.4	2.4			
SAW, RECIPROCATING	2	0	100	108	117	33.0	341.5	650.0	0.330	2.951	5.572
SOLDERING GUN	3	0	140	180	250	13000.0	19166.7	22500.0	86.667	111.270	157.143
SOLDERING IRON	3	0	25	86	132	0.6	2207.5	6600.0	0.001	16.962	50.000
TYPEWRITER, ELECTRIC	3	0				3.7	116.1	335.0			
VACUUM, SHOP	5	3	605	878	1678	1.7	3.9	7.0	0.002	0.005	0.009

NOTE 1: A PLUS SYMBOL (+) MEANS THAT THE TYPICAL EXPOSURE DISTANCE IS THE HANDLE OF THE DEVICE.
NOTE 2: BLANK SPACES INDICATE WATT METER READINGS WERE NOT TAKEN.
NOTE 3: BLANK SPACES INDICATE VALUES WHICH COULD NOT BE DISTINGUISHED FROM BACKGROUND READINGS.
NOTE 4: BLANK SPACES INDICATE VALUES WHICH WERE EITHER ZERO OR NOT AVAILABLE BASED ON NOTES 2 OR 3.

Table 4.1. (Continued)

ITEM	NO OF ITEMS	TYP EXP DIST FEET	MIN PWR RATE WATT	AVE PWR RATE WATT	MAX PWR RATE WATT	MIN TYP EXP VALUE mG	AVE TYP EXP VALUE mG	MAX TYP EXP VALUE mG	MIN EXP PER WATT mG/W	AVE EXP PER WATT mG/W	MAX EXP PER WATT mG/W
NOTES:		1	2	2	2	3	3	3	4	4	4
MEAL-RELATED											
BLENDER	4	0	375	421	520	220.0	581.2	1000.0	0.423	1.472	2.667
CAN OPENER	2	0				5600.0	5800.0	6000.0			
COFFEE GRINDER	2	0	130	130	130	350.0	420.0	490.0	2.692	3.231	3.769
COFFEE MAKER, DRIP	3	3	610	787	1000		0.3	0.8			0.001
COFFEE MAKER, PERC	2	3	1090	1145	1200		1.0	2.0		0.001	0.002
CROCK POT	3	3	150	150	150	0.4	0.5	1.2		0.001	0.005
DISHWASHER	2	3					0.4	8.0			
ESPRESSO MAKER	1	1	800	800	800	1.5	1.5	1.5	0.002	0.002	0.002
FAN, STOVE EXHAUST	6	3				1.1	1.8	2.7			
FOOD PROCESSOR	6	0	60	331	500	102.0	365.0	900.0	0.314	1.246	1.829
FREEZER, UPRIGHT	6	3					1.2	2.4			
FRY PAN,ELEC BRL LID	1	1	1250	1250	1250	18.5	18.5	18.5	0.015	0.015	0.015
FRYING PAN, ELECTRIC	3	1	1200	1233	1250	1.6	11.0	7.5	0.001	0.003	0.007
GARBAGE DISPOSAL	4	3				0.3	0.5	1.0			
ICE CREAM MAKER	2	3	114	126	137	3.1	3.9	4.7	0.023	0.032	0.042
KNIFE SHARPNER	1	1				53.0	53.0	53.0			
KNIFE, ELECTRIC	3	0	100	100	100	104.0	2434.7	3600.0	1.040	18.520	36.000
MEAT SLICER	1	1	125	125	125	5.0	5.0	5.0	0.040	0.040	0.040
MICRO\OVEN (MICRO)	1	3				3.0	3.0	3.0			
MIXER, ELECTRIC HAND	4	0	90	102	120	120.0	1205.0	2700.0	1.333	11.667	27.000
MIXMASTER, COUNTERTOP	5	1	120	199	250	2.5	3.9	5.9	0.010	0.023	0.049
OVEN (BAKE)	5	3				0.5	1.1	1.4			
OVEN (BROILER)	2	3				1.1	2.5	3.9			
OVEN, MICROWAVE	6	3				2.7	4.9	7.6			
POPCORN POPPER, AIR	2	3	1250	1250	1250	0.5	6.7	13.0		0.005	0.010
RANGE, ELECTRIC	7	1				4.9	42.0	110.0			
REFRIGERATOR	6	3					1.2	2.4			
TOASTER	3	1	800	898	996	1.5	2.1	2.3	0.002	0.002	0.003
TOASTER OVEN	4	1	1400	1467	1500	1.7	3.6	5.4	0.001	0.003	0.004
WAFFLE IRON	3	1	500	683	900	1.9	2.1	2.2	0.002	0.003	0.004
WARMER, FOOD	3	3	75	148	250						
WOK, ELECTRIC	1	1	1500	1500	1500	1.6	1.6	1.6	0.001	0.001	0.001
HOUSE/YARD-RELATED											
AIR CLEANER/DEODOR	1	3				3.0	3.0	3.0			
AIR CONDITIONER, CEN	1	3				0.5	0.5	0.5			
AIR COND, CEN (STRT)	1	10									
AIR COND, WINDOW	3	3									
BLOWER, ELECTRIC YARD	1	*				1500.0	1500.0	1500.0			
CLIPPERS, ELECT HEDGE	2	0				380.0	1190.0	2000.0			
DEHUMIDIFIER	5	3	280	520	636		2.0	7.0		0.004	0.011
FAN, CEILING	5	3					0.2	1.0			
FAN, FURNACE	2	10	186	186	186						
FAN, NON-OSCILLATING	7	3	25	81	155		2.7	10.5		0.057	0.186
FAN, OSCILLATING	8	3	27	40	76		2.6	9.0		0.056	0.181
GARAGE DOOR OPENER	3	3				0.4	3.9	9.0			
MOWER, ELECTRIC LAWN	1	*	2237	2237	2237	15.0	15.0	15.0	0.007	0.007	0.007
VACUUM CLEANER, TANK	4	3				1.0	3.4	7.6			
VACUUM CLEANER, UPRT	3	*					5.7	14.0			
VACUUM PWR NOZ, TANK	3	*					4.9	14.0			
VACUUM, CEN CANISTER	1	10									
VACUUM, CORDLESS	4	0				1.9	2.8	3.6			
VACUUM, ELEC BROOM	3	*				1.9	2.1	2.3			
VAC, CEN POWER NOZZLE	1	*				22.0	22.0	22.0			
WATER BED HEATER	1	0				8.8	8.8	8.8			
WEED-EATER, ELEC LAWN	3	*	213	246	280	3.0	3.5	4.0	0.011	0.014	0.017

5. COMPUTER PROGRAMS

5.1 Introduction

Chapter 5 describes a set of computer programs that Iowa State University is using to analyze magnetic and electric fields created by utility power lines and equipment in Iowa. The first program is an EPRI package called the TLWorkstation (Transmission Line Workstation) [53] which performs a variety of calculations for power lines. EXPOCALC [54], a second EPRI program, performs contour mapping of fields around power lines. A third program, which was originally developed by Commonwealth Edison and rewritten by Iowa State University, performs magnetic and electric field profiles around utility power lines from a user friendly menu. The last program determines the proper phasing to minimize magnetic fields for a given structure.

5.2 EPRI TLWorkstation

The EPRI TLWorkstation consists of programs that perform foundation design, tower structure design, and environmental impact of transmission lines. TLWorkstation is a PC–based design tool used by over one hundred utilities and consultants in the design of all aspects of transmission lines. Two programs, ENVIRO and DYNAMP, were developed primarily for electric and magnetic field calculations.

ENVIRO mathematically models overhead transmission lines and theoretically calculates the resultant magnetic fields, electric fields, and audible noise profiles. It is capable of handling parallel transmission lines, a variety of conductor bundles and configurations, up to twelve phases per circuit, and incorporates data for most conductor and shield wire types. This program is used mainly to experiment with how making various changes to structures affect the resultant magnetic fields. Because of its acceptance, it is useful as a check for other programs that are being developed to model electric and magnetic fields from transmission lines. Tables 5.1–5.3 lists sample inputs and outputs of magnetic and electric field profiles from ENVIRO for a 100% thermally loaded 345 kV line (Figure 5.1).

The ENVIRO program does not provide any graphical printout capabilities. A program named TLRead (Appendix B) was developed to read an output file from the TLWorkstation and produces an output file that can be easily imported into LOTUS–123, where profile plots of report quality can be obtained. Figure 5.2 shows an example of the type of graphs produced. Although the program created was specific for magnetic fields, it could easily be altered to produce output for electric fields or audible noise graphs.

The second EPRI program used in the study of magnetic and electric fields is the DYNAMP program. DYNAMP calculates the temperature of a conductor as a function of weather conditions and loading on a particular conductor. These data can be used in a sag–tension program to calculate the theoretical height of a conductor under which measurements are taken. Because of the better estimate of the actual conductor heights, theoretical values compare much closer to measured values. Figure 5.3 shows a sample comparing a theoretical versus a measured magnetic field for a three phase flat 345 kV line belonging to Iowa Power and Light Company. In general, the theoretical magnetic field profiles compare well with measured profiles of transmission lines because the transmission phases are operated

Table 5.1. TLWorkstation input data for flat 345 kV structure

BUNDLE INFORMATION

BNDL #	CIRC #	VOLTAGE (kV)	VOLTAGE ANGLE (DEG)	LOAD (AMPS)	CURRENT ANGLE (DEG)	# OF COND	COORDINATES X (FT)	COORDINATES Y (FT)	PHASE
1	1	345.0	.0	1780.0	.0	2	-31.0	92.7	A
2	1	345.0	240.0	1780.0	240.0	2	.0	91.7	B
3	1	345.0	120.0	1780.0	120.0	2	31.0	92.7	C
4	2	.0	.0	.0	.0	1	-20.3	119.5	GND
5	3	.0	.0	.0	.0	1	20.3	119.5	GND

MINIMUM GROUND CLEARANCE = 91.700 FT.

SUBCONDUCTOR INFORMATION - REGULAR BUNDLES

BNDL #	DIAMETER (IN)	SPACING (IN)	DC RESIST. (OHMS/MI)	AC RESIST. (OHMS/MI)	AC REACT. (OHMS/MI)
1	1.110	18.000	.11520	.11700	.399000
2	1.110	18.000	.11520	.11700	.399000
3	1.110	18.000	.11520	.11700	.399000
4	.360	.000	6.51000	6.75000	1.500000
5	.360	.000	6.51000	6.75000	1.500000

Table 5.2. Electric field output for 345 kV flat structure

```
**************************************
*                                    *
*    AC  ELECTRIC FIELD PROFILE      *
*   at   3.28 feet above ground      *
*                                    *
**************************************
```

LATERAL DISTANCE (feet)	(meters)	MAXIMUM FIELD (kV/m)	MINOR/MAJOR ELLIPSE AXES (ratio)	VERTICAL (kV/m)	HORIZONTAL (kV/m)	SPACE POTENTIAL (kV)
-150.0	-45.72	.387	.002	.386	.016	.386
-140.0	-42.67	.438	.002	.438	.018	.438
-130.0	-39.62	.496	.002	.496	.020	.496
-120.0	-36.58	.561	.003	.561	.022	.561
-110.0	-33.53	.631	.003	.630	.024	.630
-100.0	-30.48	.703	.004	.703	.024	.703
-90.0	-27.43	.775	.005	.775	.023	.774
-80.0	-24.38	.838	.007	.838	.019	.837
-70.0	-21.34	.884	.009	.884	.014	.883
-60.0	-18.29	.901	.013	.901	.012	.899
-50.0	-15.24	.877	.017	.876	.022	.874
-40.0	-12.19	.802	.024	.801	.039	.799
-30.0	-9.14	.673	.036	.671	.057	.669
-20.0	-6.10	.497	.062	.493	.072	.491
-10.0	-3.05	.295	.156	.288	.081	.286
.0	.00	.150	.564	.150	.085	.149
10.0	3.05	.295	.156	.288	.081	.286
20.0	6.10	.497	.062	.493	.072	.491
30.0	9.14	.673	.036	.671	.057	.669
40.0	12.19	.802	.024	.801	.039	.799
50.0	15.24	.877	.017	.876	.022	.874
60.0	18.29	.901	.013	.901	.012	.899
70.0	21.34	.884	.009	.884	.014	.883
80.0	24.38	.838	.007	.838	.019	.837
90.0	27.43	.775	.005	.775	.023	.774
100.0	30.48	.703	.004	.703	.024	.703
110.0	33.53	.631	.003	.630	.024	.630
120.0	36.58	.561	.003	.561	.022	.561
130.0	39.62	.496	.002	.496	.020	.496
140.0	42.67	.438	.002	.438	.018	.438
150.0	45.72	.387	.002	.386	.016	.386

Table 5.3. Magnetic field output for 345 kV flat structure

```
***************************************
*                                     *
*       MAGNETIC FIELD PROFILE        *
*     at    3.28 feet   above ground  *
*                                     *
***************************************
```

LATERAL DISTANCE (feet)	(meters)	AC MAGNETIC FIELD MAJOR AXIS (mG)	MINOR/ MAJOR (RATIO)	VERTICAL COMP (mG)	HORIZONTAL COMP (mG)	RMS RESULTANT (mG)
-150.0	-45.72	20.59	.063	9.13	18.50	20.63
-140.0	-42.67	22.78	.069	8.76	21.08	22.83
-130.0	-39.62	25.25	.075	8.05	24.01	25.33
-120.0	-36.58	28.06	.083	6.88	27.30	28.16
-110.0	-33.53	31.23	.091	5.26	30.91	31.35
-100.0	-30.48	34.77	.101	3.79	34.74	34.94
-90.0	-27.43	38.69	.112	5.12	38.59	38.93
-80.0	-24.38	42.95	.124	9.87	42.13	43.27
-70.0	-21.34	47.47	.137	16.74	44.90	47.92
-60.0	-18.29	52.12	.152	25.27	46.27	52.72
-50.0	-15.24	56.70	.167	35.01	45.59	57.48
-40.0	-12.19	60.95	.182	45.23	42.34	61.95
-30.0	-9.14	64.61	.196	54.89	36.36	65.85
-20.0	-6.10	67.44	.208	62.86	28.18	68.89
-10.0	-3.05	69.24	.216	68.09	19.55	70.84
.0	.00	69.91	.219	69.91	15.33	71.57
10.0	3.05	69.39	.217	68.06	20.23	71.00
20.0	6.10	67.73	.210	62.79	29.07	69.20
30.0	9.14	65.02	.198	54.79	37.31	66.29
40.0	12.19	61.46	.185	45.09	43.29	62.51
50.0	15.24	57.30	.170	34.83	46.53	58.12
60.0	18.29	52.78	.156	25.06	47.18	53.42
70.0	21.34	48.17	.142	16.52	45.76	48.66
80.0	24.38	43.67	.129	9.71	42.95	44.04
90.0	27.43	39.42	.117	5.17	39.36	39.69
100.0	30.48	35.51	.107	4.25	35.45	35.71
110.0	33.53	31.96	.098	5.82	31.58	32.11
120.0	36.58	28.78	.090	7.44	27.92	28.89
130.0	39.62	25.95	.083	8.59	24.59	26.04
140.0	42.67	23.46	.077	9.30	21.61	23.53
150.0	45.72	21.25	.072	9.66	18.99	21.31

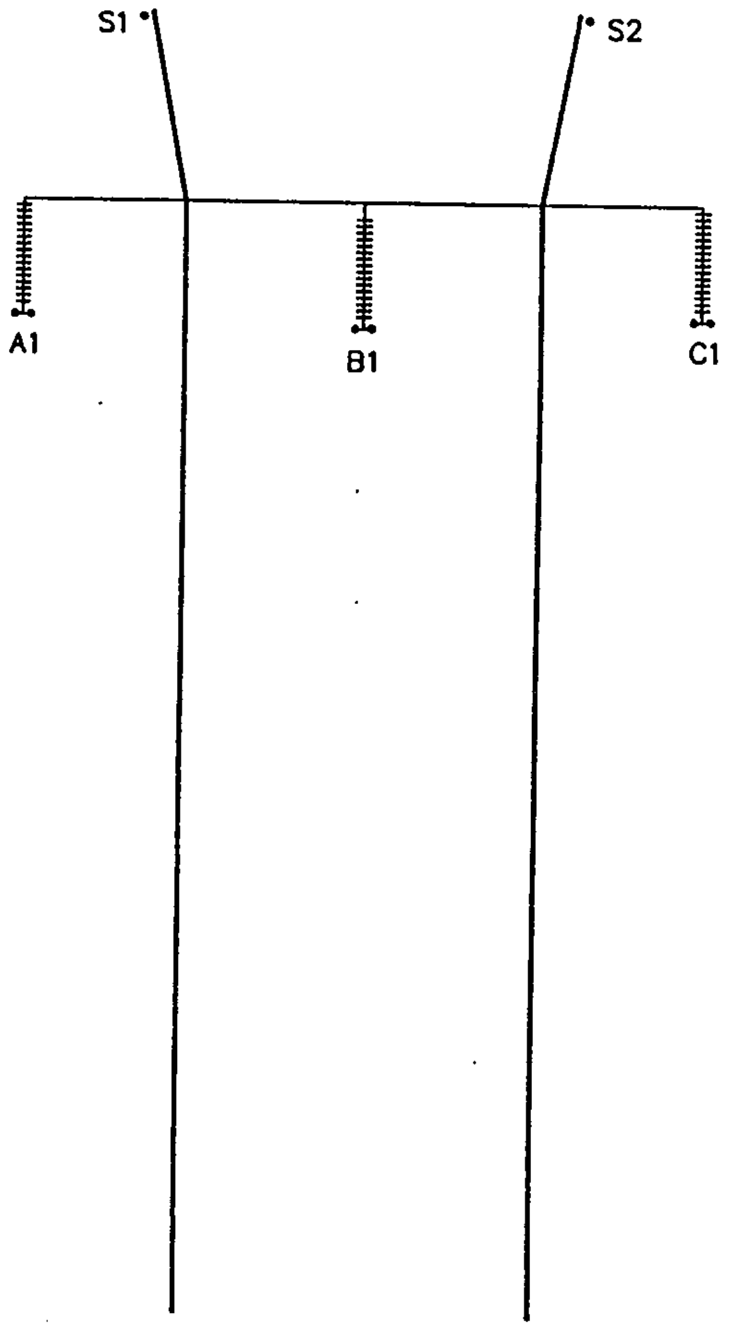


Figure 5.1. Flat 345 kV structure

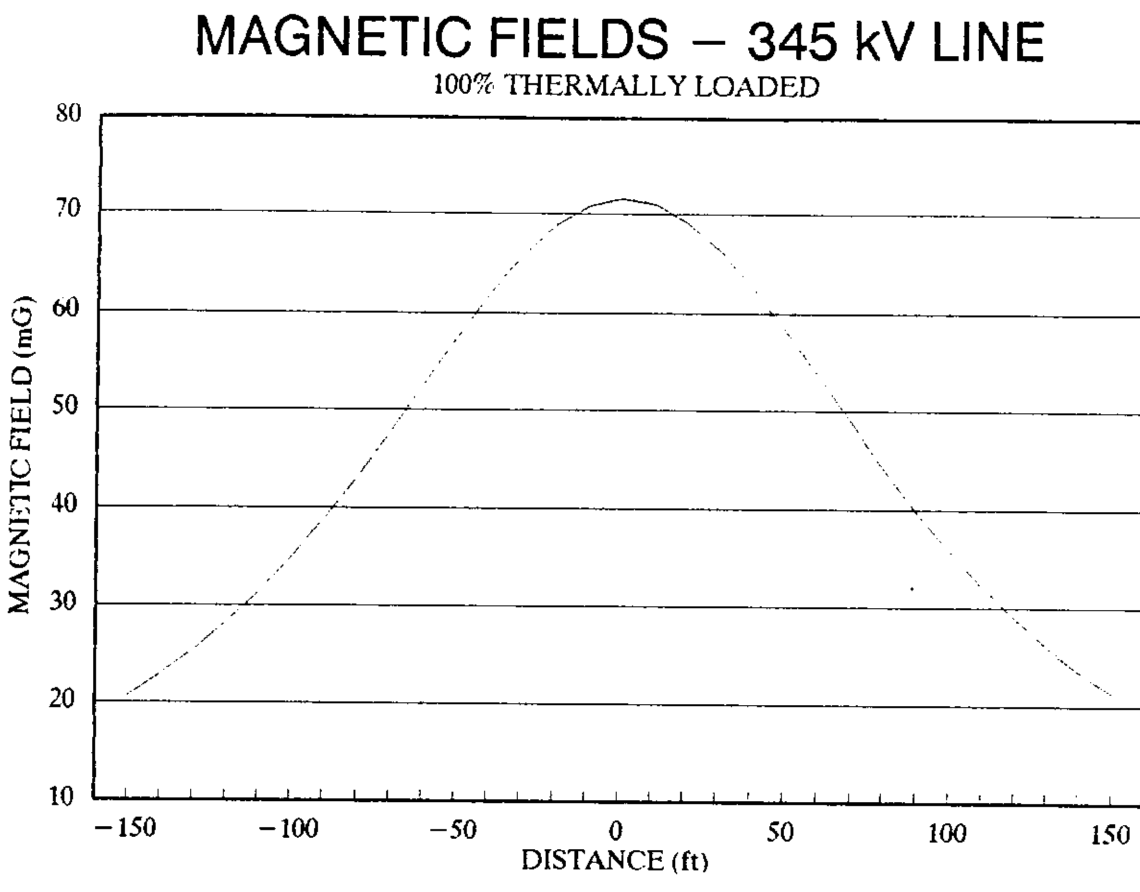


Figure 5.2. LOTUS–123 plot made with aid of TLRead

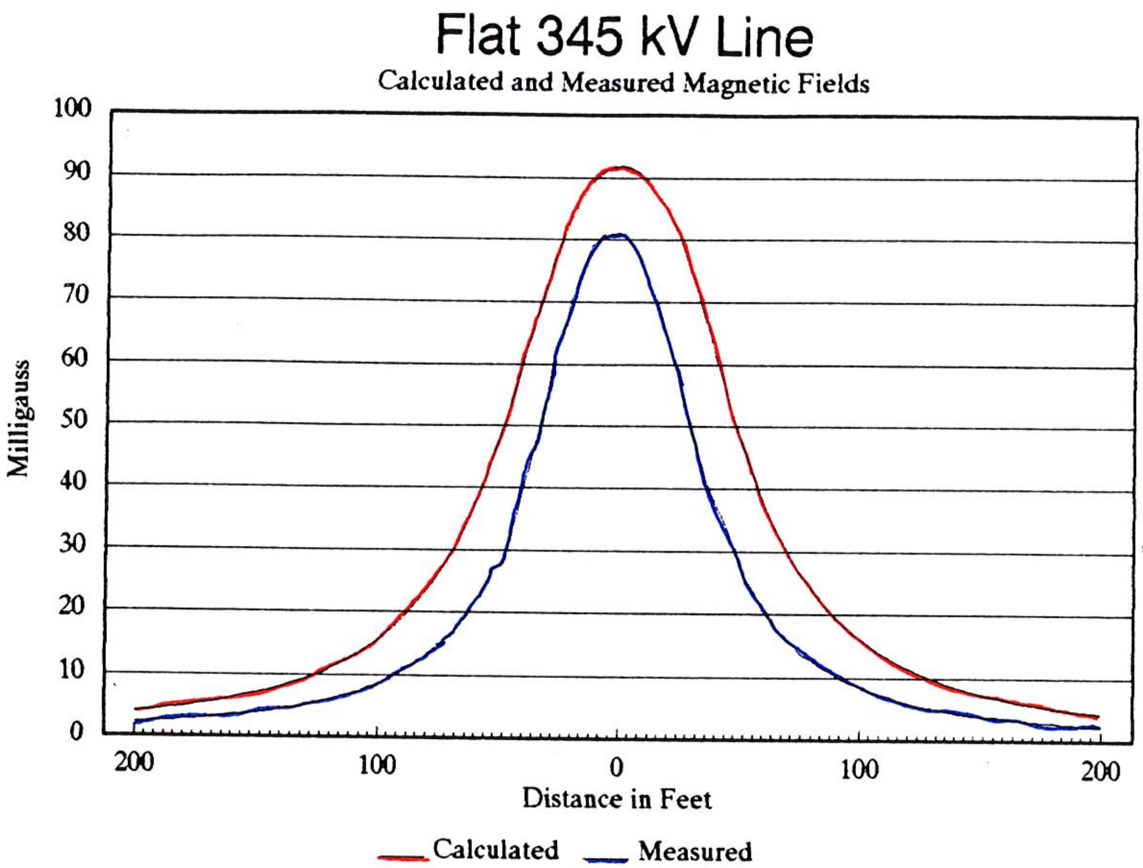


Figure 5.3. Comparison of theoretical versus measured magnetic fields

nearly balanced. As the phases become unbalanced or the number of lines increases, the theoretical values tend to not correlate as well with measured values for a variety of reasons. Examples include: proper determination of the phasing of multiple lines, estimation of the unbalances involved, and knowledge of where return currents flow.

5.3 EPRI EXPOCALC

EXPOCALC was the first readily available micro–computer program to calculate theoretical human exposure to electric and magnetic fields from transmission lines. First released by EPRI, in 1986, it has been used by more than one hundred utilities.

Input into the program includes the line conductor spacing and design parameters, line voltage, current, and objects in the vicinity that may shield the electric fields. Additional input is an activity systems model that simulates the type of human activity under the transmission line that is to be modeled. The output of the program consists of both magnetic and electric field contour plots, as well as time histograms of human exposure levels. These data can be used to estimate, or quantify, human exposure. The main use of this program is to evaluate abatement or reduction strategies in dealing with magnetic and electric field exposure. It is also used to analyze the electric field shielding effects of objects.

The following is an example illustrating the types of calculations that EXPOCALC performs. The example model includes an area (Figure 5.4) with a flat construction 345 kV line running across it. There are three transmission towers: one on the left side, one in the center, and the third on the right side of the area.

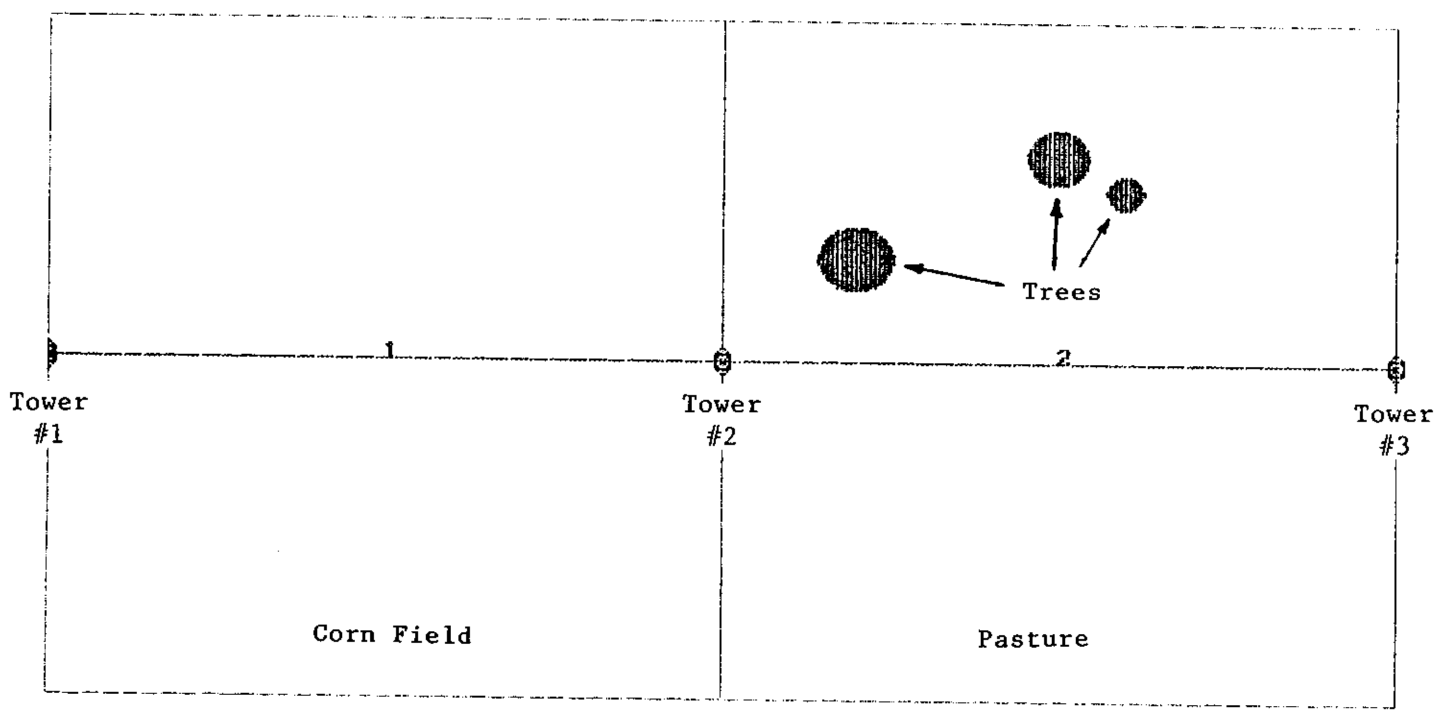


Figure 5.4. EXPOCALC example area

The area is sub–divided into two areas: a corn field on the left, and a pasture with trees on the right. Input data, similar to that specified for the TLWorkstation, are used to model the transmission line. Additional input includes any objects such as trees or buildings that are to be modeled. Also defined is a human activity model used in calculating the exposure to magnetic and electric fields. An internal database within the program contains all types of activities and associated times for each type of activity. In this example, the activities chosen were all those associated with the annual production of corn (i.e., planting, harvesting, etc.). Using the user's input data and the program's internal database, magnetic and electric field profiles and contour results are produced. Outputs include tables and contour maps (Tables 5.4–5.7, Figures 5.4–5.6).

5.4 Commonwealth Edison Program

This set of programs was originally written by Ken Steele, of Commonwealth Edison. In its original version, different programs determined magnetic and electric field profiles resulting from overhead and underground electric lines. One program computed induced voltages from utility lines on items that may be found underneath them such as vehicles or buildings. The Iowa State University package is a single menu–driven program that retains all the original capabilities. One enhancement is the ability to vary one or all of a group of parameters to determine the effect of varying that parameter.

One of the major changes made within the program was the implementation of a menu system to control the program. The main menu (Figure 5.7) consists of the following six parts:

Table 5.4. EXPOCALC example electric field output

Electric Field Profiles - kV/m
Sensor Height - 3.28 ft.

Distance from CL (ft)	Ground Clearance(s)--to Center of Bundle or Conductor (ft)											
	35.0	40.0	45.0	50.0	55.0	60.0	65.0	70.0	75.0	80.0	85.0	90.0
0	3.347	2.420	1.782	1.331	1.006	0.768	0.591	0.457	0.355	0.276	0.214	0.165
10	3.170	2.449	1.913	1.511	1.205	0.970	0.788	0.645	0.532	0.442	0.370	0.312
20	3.631	2.945	2.405	1.978	1.637	1.364	1.144	0.966	0.821	0.701	0.603	0.521
30	4.546	3.637	2.963	2.446	2.042	1.719	1.459	1.246	1.071	0.926	0.805	0.703
40	4.644	3.803	3.155	2.647	2.241	1.913	1.644	1.421	1.235	1.079	0.948	0.835
50	3.931	3.389	2.924	2.531	2.198	1.917	1.678	1.474	1.300	1.151	1.022	0.910
60	2.999	2.732	2.467	2.216	1.985	1.777	1.590	1.425	1.278	1.148	1.034	0.932
70	2.199	2.101	1.976	1.839	1.699	1.562	1.431	1.309	1.196	1.092	0.997	0.911
80	1.607	1.591	1.548	1.485	1.410	1.329	1.245	1.161	1.080	1.002	0.929	0.860
90	1.187	1.208	1.206	1.186	1.153	1.110	1.061	1.008	0.953	0.898	0.844	0.792
100	0.893	0.927	0.945	0.948	0.938	0.920	0.894	0.863	0.829	0.792	0.754	0.716
110	0.685	0.722	0.747	0.761	0.765	0.761	0.751	0.735	0.715	0.692	0.666	0.640
120	0.535	0.570	0.597	0.616	0.627	0.631	0.630	0.624	0.614	0.601	0.585	0.567
130	0.424	0.457	0.483	0.503	0.517	0.526	0.530	0.531	0.527	0.520	0.511	0.500
140	0.342	0.371	0.395	0.415	0.430	0.441	0.448	0.452	0.453	0.451	0.447	0.441
150	0.280	0.305	0.327	0.345	0.360	0.372	0.381	0.387	0.390	0.392	0.391	0.388
160	0.232	0.254	0.273	0.290	0.304	0.316	0.326	0.333	0.338	0.341	0.342	0.342
170	0.194	0.213	0.230	0.246	0.259	0.270	0.280	0.287	0.293	0.297	0.300	0.301
180	0.164	0.181	0.196	0.210	0.222	0.233	0.242	0.250	0.256	0.261	0.264	0.266
190	0.140	0.154	0.168	0.180	0.192	0.202	0.210	0.218	0.224	0.229	0.233	0.236
200	0.120	0.133	0.145	0.156	0.166	0.176	0.184	0.191	0.197	0.202	0.207	0.210
210	0.104	0.116	0.126	0.136	0.145	0.154	0.161	0.168	0.174	0.179	0.184	0.187
220	0.091	0.101	0.111	0.120	0.128	0.135	0.142	0.149	0.154	0.159	0.164	0.168
230	0.080	0.089	0.097	0.105	0.113	0.120	0.126	0.132	0.138	0.142	0.147	0.150
240	0.070	0.079	0.086	0.093	0.100	0.107	0.113	0.118	0.123	0.128	0.132	0.135
250	0.063	0.070	0.077	0.083	0.089	0.095	0.101	0.106	0.110	0.115	0.119	0.122
260	0.056	0.062	0.068	0.074	0.080	0.085	0.090	0.095	0.099	0.103	0.107	0.111

Table 5.5. EXPOCALC example electric field exposure summary

Exposure Index Tabulation: farming

Exposure Bin (kV/m)	Time (h)	Time Weighted Avg Eeq	Exposure Index (kV/m)h	Exp (%)	Cum Exp (%)	Area (acres)	Area Weighted Avg E
0.000 < 0.050:	3.96	0.035	0.137	2.8	2.8	0.00	0.035
0.050 < 0.100:	3.24	0.072	0.232	4.7	7.5	0.44	0.084
0.100 < 0.250:	3.94	0.167	0.657	13.3	20.9	1.50	0.163
0.250 < 0.500:	2.95	0.350	1.033	21.0	41.8	0.99	0.364
0.500 < 1.000:	2.55	0.725	1.849	37.6	79.4	0.98	0.731
1.000 < 2.000:	0.87	1.167	1.013	20.6	100.0	0.96	1.415
2.000 < 6.000:	0.00	0.000	0.000	0.0	100.0	0.87	3.073
6.000 <10.000:	0.00	0.000	0.000	0.0	100.0	0.00	0.000
	17.50	0.281	4.921			5.74	0.937

The max electric field is 4.729 kV/m at 36 ft from C/L at min ht.
The min electric field is 0.067 kV/m at (255, 5).
The max exposure index point is 0.010 (kV/m)h at (255, 215).

Note: Time weighted avg Eeq includes effect of activity factor, whereas the area weighted avg E does not.

Table 5.6. EXPOCALC example magnetic field output

Magnetic Flux Density Profiles - mG
Sensor Height - 3.28 ft.

Distance from CL (ft)	Ground Clearance(s)--to Center of Bundle or Conductor (ft) 35.0	40.0	45.0	50.0	55.0	60.0	65.0	70.0	75.0	80.0	85.0	90.0
0	308.61	263.01	225.04	193.62	167.62	146.06	128.09	113.03	100.33	89.55	80.34	72.43
10	312.92	263.22	223.72	191.83	165.82	144.41	126.65	111.80	99.28	88.67	79.60	71.81
20	311.19	257.69	217.05	185.29	159.91	139.28	122.28	108.11	96.19	86.07	77.42	69.97
30	288.55	238.85	201.44	172.39	149.27	130.50	115.03	102.11	91.20	81.91	73.93	67.03
40	245.57	207.29	177.49	153.76	134.52	118.65	105.41	94.22	84.68	76.49	69.39	63.20
50	195.97	170.73	149.79	132.29	117.55	105.05	94.36	85.15	77.17	70.22	64.12	58.75
60	152.35	136.96	123.27	111.19	100.56	91.21	82.98	75.71	69.28	63.57	58.49	53.95
70	118.62	109.35	100.61	92.51	85.08	78.31	72.15	66.58	61.53	56.97	52.83	49.07
80	93.67	87.97	82.35	76.93	71.78	66.93	62.40	58.19	54.30	50.71	47.39	44.34
90	75.30	71.67	67.98	64.31	60.71	57.24	53.92	50.76	47.78	44.98	42.35	39.90
100	61.61	59.21	56.72	54.18	51.64	49.14	46.69	44.32	42.04	39.86	37.79	35.82
110	51.23	49.59	47.86	46.07	44.24	42.41	40.59	38.80	37.05	35.35	33.72	32.15
120	43.21	42.06	40.83	39.53	38.20	36.83	35.46	34.10	32.75	31.42	30.13	28.87
130	36.91	36.08	35.18	34.23	33.23	32.20	31.16	30.11	29.05	28.01	26.98	25.97
140	31.88	31.26	30.59	29.88	29.12	28.34	27.53	26.71	25.88	25.05	24.23	23.42
150	27.80	27.34	26.83	26.28	25.70	25.09	24.46	23.81	23.16	22.49	21.83	21.17
160	24.45	24.10	23.70	23.28	22.82	22.34	21.85	21.33	20.81	20.27	19.73	19.19
170	21.67	21.39	21.09	20.75	20.39	20.01	19.61	19.20	18.77	18.34	17.90	17.45
180	19.34	19.12	18.87	18.60	18.32	18.01	17.69	17.35	17.01	16.65	16.29	15.92
190	17.36	17.18	16.99	16.77	16.54	16.29	16.03	15.75	15.47	15.17	14.87	14.56
200	15.67	15.53	15.37	15.19	15.00	14.80	14.58	14.35	14.12	13.87	13.62	13.36
210	14.22	14.10	13.97	13.82	13.66	13.49	13.31	13.13	12.93	12.72	12.51	12.30
220	12.95	12.86	12.75	12.63	12.50	12.35	12.20	12.05	11.88	11.71	11.53	11.34
230	11.85	11.77	11.68	11.58	11.47	11.35	11.22	11.09	10.95	10.80	10.65	10.49
240	10.89	10.82	10.74	10.66	10.56	10.46	10.35	10.24	10.12	10.00	9.87	9.73
250	10.03	9.98	9.91	9.84	9.76	9.67	9.58	9.48	9.38	9.27	9.16	9.05
260	9.28	9.23	9.17	9.11	9.04	8.97	8.89	8.81	8.72	8.62	8.53	8.43

Table 5.7. EXPOCALC example magnetic field exposure summary

Exposure Index Tabulation: farming

Exposure Bin (mG)	Time (h)	Time Weighted Avg B	Exposure Index (mG)h	Exp (%)	Cum Exp (%)	Area (acres)	Area Weighted Avg B
5.00 < 20.00:	5.43	13.95	75.80	6.8	6.8	1.78	13.95
20.00 < 50.00:	4.94	31.75	156.93	14.0	20.8	1.62	31.75
50.00 <100.00:	3.18	72.08	229.15	20.5	41.3	1.04	72.08
100.00 <150.00:	1.67	121.39	202.30	18.1	59.3	0.55	121.39
150.00 <200.00:	0.85	173.07	147.84	13.2	72.6	0.28	173.07
200.00 <250.00:	0.62	222.67	137.20	12.3	84.8	0.20	222.67
250.00 <300.00:	0.62	275.79	169.93	15.2	100.0	0.20	275.79
	17.31	64.66	1119.14			5.67	64.66

The max magnetic flux density is 314.12 mG at 14 ft from C/L at min ht.
The min magnetic flux density is 9.54 mG at (5, 5).
The max exposure index point is 2.183 (mG)h at (255, 235).

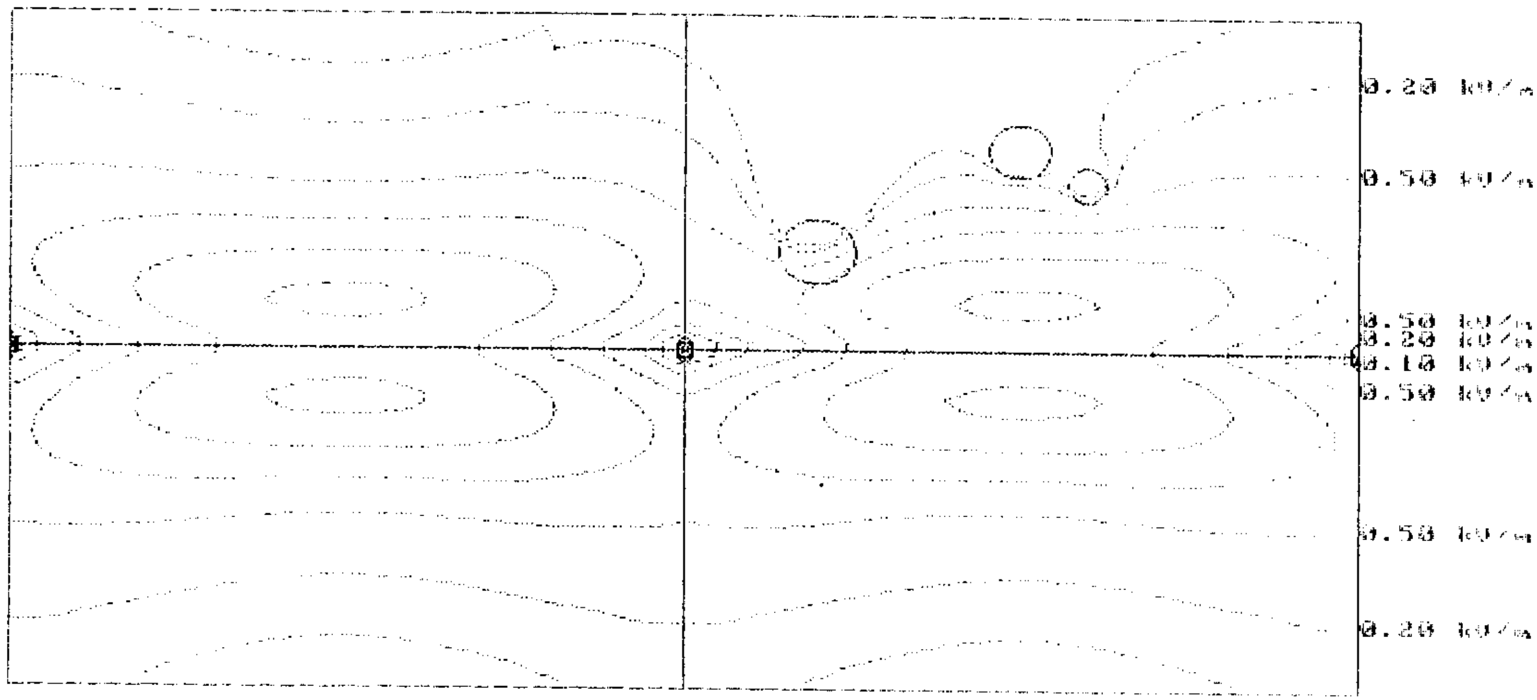


Figure 5.5. EXPOCALC example electric field contour plot

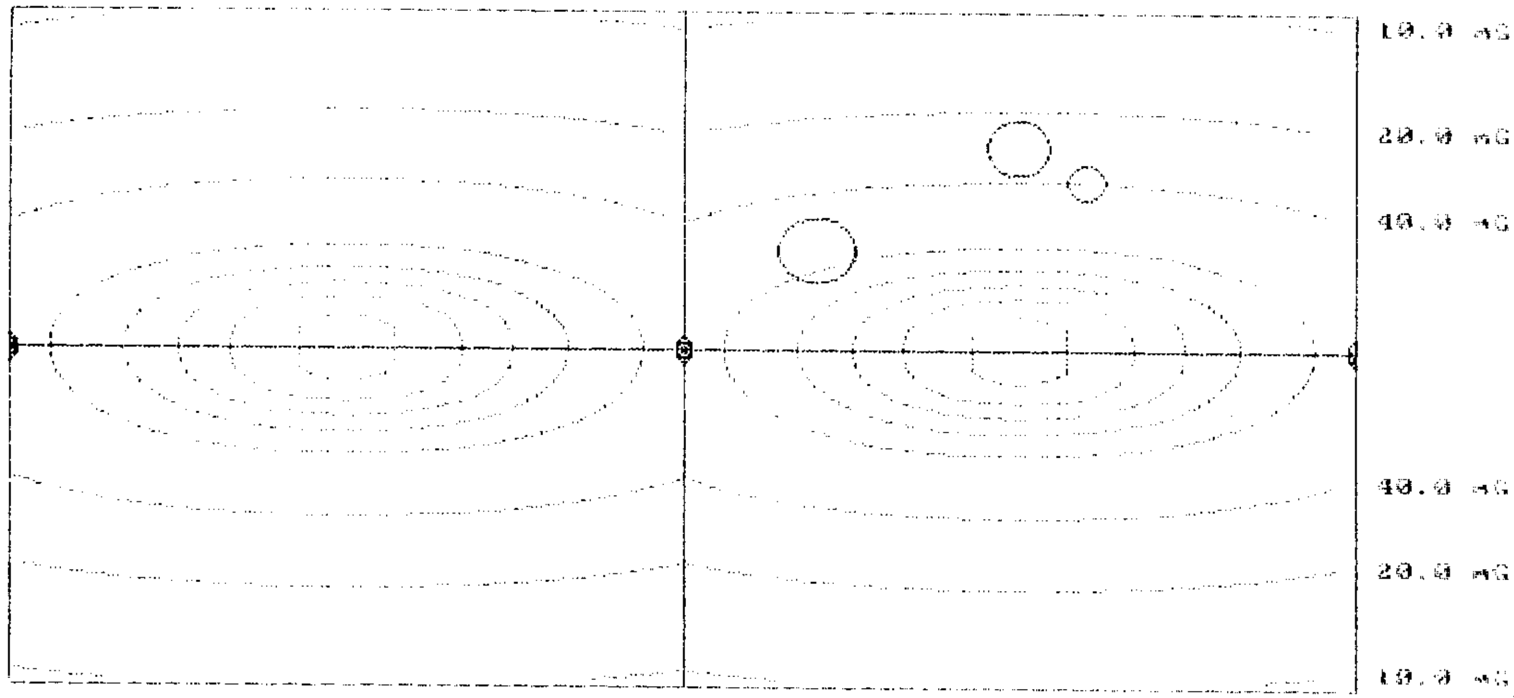


Figure 5.6. EXPOCALC example magnetic field contour plot

MAIN MENU

Choose one of the following options:

SETUP
1) Reinitialize Program
INPUT
2) Enter New Data Set
3) Recall Existing Data set
CHANGE DATA
4) Change One or More Existing Parameters
5) Vary a Single Parameter Over a Range
EXECUTE
6) Compute Electric Field Quantities
7) Computer Magnetic Field Quantities
8) Compute Both Electric and Magnetic Field Quantities
OUTPUT
9) Display Results
10) Print Results
11) Save Results to a File
12) Save Existing Data Set
TERMINATE
13) Quit
==>?

Figure 5.7. Revised Commonwealth Edison main menu

SETUP – This is where the program variables are initialized. This is to enable the running of a completely different case without restarting the program.

INPUT – The user has the option of inputting a new data set or recalling a previous data set to be used for calculations. An added feature is that an input file may be edited in the case of a mistake without retyping all the input data.

CHANGE DATA – This option allows the user to change a parameter or vary a parameter over a given range. An example of this would be the case of a user wanting to determine the magnetic field profiles for a given structure with its original conductor heights, varied in one foot increments to a height of ten feet higher than the original. This option can be used in the case of magnetic field abatement investigations.

EXECUTE – Execute allows the user to run either the magnetic field calculations, electric field calculations, induced voltage calculations, or all of these calculations in a single run.

OUTPUT – Output from the program can be viewed on the screen, sent to the printer, or sent to an output file. Existing data sets can also be saved from here. Graphical output is contingent on the arrival of a package of graphic routines at the time of this document.

TERMINATE – Used to leave the program.

This program duplicates many of the same types of calculations done by the TLWorkstation program ENVIRO. The main advantage of this program over the TLWorkstation program is the ease and speed of varying a single parameter. This allows for faster, easier, and more in–depth studies of a modified structure and associated magnetic fields. Tables 5.8–5.13 show a magnetic field study where a given 69 kV structure (Figure 5.8) is raised by two foot increments over a ten foot range. In Figure 5.9 is a LOTUS–123 plot of the six cases.

5.5 Minimization Program

The minimization program determines the proper phasing to minimize the magnetic fields for a given single three phase circuit or a double three phase circuit line. For a double three phase circuit line, the voltages of the line may be the same voltage, or they may be different. The program's calculations are based on the original Commonwealth Edison program magnetic field calculations written by Ken Steele discussed previously. The minimization program was written in FORTRAN so it could easily be used with other subroutines that were required for its implementation. Another reason for the conversion to FORTRAN was that the program could then be run on the Sun Workstation where the program would run much quicker, because it was found to be a computationally extensive program.

Table 5.8. 69 kV line with 32 feet to bottom conductor

PHASE CONDUCTOR SUMMARY

PHASE CONDUCTOR no.	X COORD feet	Y COORD feet	CURRENT amps	PHASE ANGLE degrees
1	0.50	32.00	775	0
2	-0.50	36.00	775	240
3	0.50	40.00	775	120

STATIC WIRE SUMMARY

X COORD feet	Y COORD feet	SPAN feet	GMR feet	COND RESIST Ohms/Mile	CURRENT amps	PHASE ANGLE degrees	INDUCED VOLTAGE PHASE TO PHASE volts	degrees
0.00	46.80	200	0.015600	6.750	2.80	50.3	4.180	234.0

MAGNETIC FIELD FLUX DENSITIES

HORIZONTAL PROFILE AT 3.28 feet

X COORD feet	MAXIMUM/MINIMUM FLUX DENSITIES OF ELLIPSE milligauss		HORIZONTAL COMPONENT milligauss	VERTICAL COMPONENT milligauss
-150.00	1.486	0.121	1.345	0.643
-140.00	1.694	0.149	1.513	0.777
-130.00	1.948	0.183	1.710	0.950
-120.00	2.262	0.227	1.944	1.178
-110.00	2.655	0.284	2.221	1.482
-100.00	3.156	0.360	2.548	1.897
-90.00	3.807	0.461	2.930	2.474
-80.00	4.668	0.600	3.361	3.295
-70.00	5.835	0.796	3.811	4.490
-60.00	7.451	1.075	4.186	6.257
-50.00	9.737	1.484	4.242	8.889
-40.00	13.018	2.081	3.499	12.711
-30.00	17.680	2.922	3.081	17.653
-20.00	23.848	3.954	10.612	21.720
-10.00	30.335	4.783	24.477	18.547
0.00	33.603	4.751	33.572	4.967
10.00	30.875	3.888	26.216	16.766
20.00	24.517	2.926	11.945	21.610
30.00	18.231	2.206	2.900	18.134
40.00	13.416	1.705	2.976	13.192
50.00	10.015	1.350	4.074	9.248
60.00	7.645	1.093	4.157	6.508
70.00	5.974	0.902	3.834	4.669
80.00	4.770	0.758	3.400	3.430
90.00	3.882	0.646	2.971	2.581
100.00	3.214	0.558	2.587	1.987
110.00	2.700	0.487	2.255	1.562
120.00	2.297	0.430	1.974	1.251
130.00	1.977	0.383	1.736	1.020
140.00	1.718	0.344	1.535	0.844
150.00	1.506	0.311	1.364	0.709

FLUX DENSITY PEAK: X-COORD	MAXIMUM/MINIMUM		HORIZONTAL	VERTICAL
0.00	33.603	4.751	33.572	4.967

Table 5.9. 69 kV line with 34 feet to bottom conductor

PHASE CONDUCTOR SUMMARY

PHASE CONDUCTOR no.	X COORD feet	Y COORD feet	CURRENT amps	PHASE ANGLE degrees
1	0.50	34.00	775	0
2	-0.50	38.00	775	240
3	0.50	42.00	775	120

STATIC WIRE SUMMARY

X COORD feet	Y COORD feet	SPAN feet	GMR feet	COND RESIST Ohms/Mile	CURRENT amps	PHASE ANGLE degrees	INDUCED VOLTAGE PHASE TO PHASE volts	degrees
0.00	48.80	200	0.015600	6.750	2.80	50.2	4.180	234.0

MAGNETIC FIELD FLUX DENSITIES

HORIZONTAL PROFILE AT 3.28 feet

X COORD feet	MAXIMUM/MINIMUM FLUX DENSITIES OF ELLIPSE milligauss		HORIZONTAL COMPONENT milligauss	VERTICAL COMPONENT milligauss
-150.00	1.478	0.120	1.322	0.673
-140.00	1.684	0.147	1.483	0.811
-130.00	1.934	0.181	1.671	0.990
-120.00	2.243	0.225	1.892	1.225
-110.00	2.629	0.281	2.151	1.537
-100.00	3.119	0.355	2.452	1.960
-90.00	3.753	0.453	2.795	2.545
-80.00	4.588	0.588	3.168	3.370
-70.00	5.709	0.774	3.531	4.553
-60.00	7.247	1.039	3.775	6.273
-50.00	9.393	1.418	3.653	8.768
-40.00	12.409	1.960	2.786	12.250
-30.00	16.574	2.698	3.291	16.466
-20.00	21.874	3.565	10.694	19.412
-10.00	27.200	4.232	22.489	15.875
0.00	29.790	4.217	29.765	4.389
10.00	27.632	3.543	23.915	14.289
20.00	22.436	2.741	11.930	19.198
30.00	17.057	2.104	3.471	16.832
40.00	12.770	1.645	2.282	12.671
50.00	9.650	1.313	3.467	9.101
60.00	7.431	1.069	3.731	6.515
70.00	5.842	0.886	3.543	4.729
80.00	4.686	0.746	3.200	3.503
90.00	3.827	0.638	2.832	2.652
100.00	3.176	0.552	2.488	2.050
110.00	2.673	0.483	2.183	1.616
120.00	2.278	0.427	1.921	1.297
130.00	1.962	0.381	1.696	1.058
140.00	1.707	0.342	1.504	0.876
150.00	1.497	0.309	1.341	0.735

FLUX DENSITY PEAK: X-COORD	MAXIMUM/MINIMUM		HORIZONTAL	VERTICAL
0.00	29.790	4.217	29.765	4.389

Table 5.10. 69 kV line with 36 feet to bottom conductor

PHASE CONDUCTOR SUMMARY

PHASE CONDUCTOR no.	X COORD feet	Y COORD feet	CURRENT amps	PHASE ANGLE degrees
1	0.50	36.00	775	0
2	-0.50	40.00	775	240
3	0.50	44.00	775	120

STATIC WIRE SUMMARY

X COORD feet	Y COORD feet	SPAN feet	GMR feet	COND RESIST Ohms/Mile	CURRENT amps	PHASE ANGLE degrees	INDUCED VOLTAGE PHASE TO PHASE volts	degrees
0.00	50.80	200	0.015600	6.750	2.80	50.2	4.180	234.0

MAGNETIC FIELD FLUX DENSITIES

HORIZONTAL PROFILE AT 3.28 feet

X COORD feet	MAXIMUM/MINIMUM FLUX DENSITIES OF ELLIPSE milligauss		HORIZONTAL COMPONENT milligauss	VERTICAL COMPONENT milligauss
-150.00	1.470	0.119	1.297	0.701
-140.00	1.673	0.146	1.451	0.844
-130.00	1.919	0.180	1.630	1.029
-120.00	2.223	0.222	1.839	1.269
-110.00	2.602	0.277	2.079	1.588
-100.00	3.081	0.349	2.354	2.018
-90.00	3.698	0.445	2.659	2.608
-80.00	4.506	0.574	2.976	3.431
-70.00	5.582	0.753	3.256	4.596
-60.00	7.043	1.003	3.382	6.259
-50.00	9.053	1.355	3.112	8.608
-40.00	11.822	1.846	2.225	11.757
-30.00	15.543	2.494	3.615	15.321
-20.00	20.110	3.226	10.632	17.371
-10.00	24.516	3.771	20.688	13.685
0.00	26.594	3.768	26.574	3.907
10.00	24.866	3.236	21.867	12.273
20.00	20.583	2.566	11.759	17.087
30.00	15.967	2.005	3.991	15.590
40.00	12.149	1.585	1.790	12.121
50.00	9.292	1.275	2.915	8.915
60.00	7.217	1.044	3.325	6.490
70.00	5.709	0.870	3.259	4.768
80.00	4.600	0.735	3.002	3.562
90.00	3.769	0.630	2.692	2.713
100.00	3.136	0.546	2.387	2.106
110.00	2.645	0.479	2.110	1.665
120.00	2.257	0.424	1.866	1.339
130.00	1.947	0.378	1.655	1.094
140.00	1.695	0.340	1.472	0.906
150.00	1.489	0.308	1.316	0.761

FLUX DENSITY PEAK: X-COORD	MAXIMUM/MINIMUM		HORIZONTAL	VERTICAL
0.00	26.594	3.768	26.574	3.907

Table 5.11. 69 kV line with 38 feet to bottom conductor

PHASE CONDUCTOR SUMMARY

PHASE CONDUCTOR no.	X COORD feet	Y COORD feet	CURRENT amps	PHASE ANGLE degrees
1	0.50	38.00	775	0
2	-0.50	42.00	775	240
3	0.50	46.00	775	120

STATIC WIRE SUMMARY

X COORD feet	Y COORD feet	SPAN feet	GMR feet	COND RESIST Ohms/Mile	CURRENT amps	PHASE ANGLE degrees	INDUCED VOLTAGE PHASE TO PHASE volts	degrees
0.00	52.80	200	0.015600	6.750	2.80	50.2	4.180	234.0

MAGNETIC FIELD FLUX DENSITIES

HORIZONTAL PROFILE AT 3.28 feet

X COORD feet	MAXIMUM/MINIMUM FLUX DENSITIES OF ELLIPSE milligauss		HORIZONTAL COMPONENT milligauss	VERTICAL COMPONENT milligauss
-150.00	1.461	0.118	1.272	0.728
-140.00	1.661	0.145	1.419	0.875
-130.00	1.904	0.178	1.589	1.065
-120.00	2.203	0.220	1.784	1.310
-110.00	2.574	0.273	2.006	1.635
-100.00	3.042	0.344	2.255	2.070
-90.00	3.641	0.436	2.523	2.661
-80.00	4.422	0.561	2.786	3.479
-70.00	5.454	0.732	2.989	4.621
-60.00	6.840	0.967	3.008	6.219
-50.00	8.720	1.293	2.621	8.416
-40.00	11.260	1.738	1.838	11.244
-30.00	14.584	2.309	3.943	14.230
-20.00	18.530	2.931	10.465	15.571
-10.00	22.202	3.381	19.062	11.875
0.00	23.889	3.388	23.872	3.501
10.00	22.488	2.964	20.044	10.619
20.00	18.931	2.402	11.482	15.242
30.00	14.957	1.909	4.416	14.417
40.00	11.556	1.526	1.537	11.555
50.00	8.941	1.238	2.422	8.696
60.00	7.004	1.020	2.942	6.437
70.00	5.575	0.853	2.983	4.786
80.00	4.512	0.723	2.806	3.607
90.00	3.711	0.621	2.552	2.764
100.00	3.095	0.540	2.286	2.156
110.00	2.616	0.474	2.035	1.710
120.00	2.236	0.420	1.810	1.379
130.00	1.931	0.375	1.612	1.128
140.00	1.684	0.338	1.440	0.936
150.00	1.479	0.306	1.290	0.786

FLUX DENSITY PEAK: X-COORD	MAXIMUM/MINIMUM		HORIZONTAL	VERTICAL
0.00	23.889	3.388	23.872	3.501

Table 5.12. 69 kV line with 40 feet to bottom conductor

PHASE CONDUCTOR SUMMARY

PHASE CONDUCTOR no.	X COORD feet	Y COORD feet	CURRENT amps	PHASE ANGLE degrees
1	0.50	40.00	775	0
2	-0.50	44.00	775	240
3	0.50	48.00	775	120

STATIC WIRE SUMMARY

X COORD feet	Y COORD feet	SPAN feet	GMR feet	COND RESIST Ohms/Mile	CURRENT amps	PHASE ANGLE degrees	INDUCED VOLTAGE PHASE TO PHASE volts	INDUCED VOLTAGE PHASE TO PHASE degrees
0.00	54.80	200	0.015600	6.750	2.80	50.2	4.180	234.0

MAGNETIC FIELD FLUX DENSITIES

HORIZONTAL PROFILE AT 3.28 feet

X COORD feet	MAXIMUM/MINIMUM FLUX DENSITIES OF ELLIPSE milligauss (maximum)	(minimum)	HORIZONTAL COMPONENT milligauss	VERTICAL COMPONENT milligauss
-150.00	1.452	0.117	1.246	0.754
-140.00	1.649	0.143	1.386	0.905
-130.00	1.888	0.176	1.546	1.098
-120.00	2.181	0.217	1.728	1.349
-110.00	2.545	0.269	1.933	1.677
-100.00	3.001	0.338	2.156	2.115
-90.00	3.584	0.428	2.388	2.706
-80.00	4.337	0.548	2.599	3.514
-70.00	5.325	0.710	2.730	4.627
-60.00	6.639	0.932	2.656	6.155
-50.00	8.394	1.234	2.184	8.199
-40.00	10.723	1.638	1.638	10.723
-30.00	13.694	2.141	4.229	13.200
-20.00	17.115	2.672	10.222	13.984
-10.00	20.195	3.048	17.596	10.369
0.00	21.578	3.062	21.564	3.156
10.00	20.431	2.723	18.420	9.250
20.00	17.456	2.250	11.136	13.630
30.00	14.023	1.816	4.744	13.320
40.00	10.991	1.468	1.518	10.985
50.00	8.600	1.201	1.992	8.451
60.00	6.792	0.995	2.584	6.360
70.00	5.440	0.836	2.718	4.786
80.00	4.424	0.711	2.614	3.639
90.00	3.651	0.613	2.413	2.807
100.00	3.054	0.534	2.184	2.200
110.00	2.586	0.469	1.960	1.751
120.00	2.214	0.416	1.753	1.415
130.00	1.915	0.373	1.569	1.160
140.00	1.671	0.336	1.406	0.963
150.00	1.470	0.304	1.264	0.810

FLUX DENSITY PEAK: X-COORD	MAXIMUM/MINIMUM		HORIZONTAL	VERTICAL
0.00	21.578	3.062	21.564	3.156

Table 5.13. 69 kV line with 42 feet to bottom conductor

PHASE CONDUCTOR SUMMARY

PHASE CONDUCTOR no.	X COORD feet	Y COORD feet	CURRENT amps	PHASE ANGLE degrees
1	0.50	42.00	775	0
2	-0.50	46.00	775	240
3	0.50	50.00	775	120

STATIC WIRE SUMMARY

X COORD feet	Y COORD feet	SPAN feet	GMR feet	COND RESIST Ohms/Mile	CURRENT amps	PHASE ANGLE degrees	INDUCED VOLTAGE PHASE TO PHASE volts	degrees
0.00	56.80	200	0.015600	6.750	2.80	50.2	4.180	234.0

MAGNETIC FIELD FLUX DENSITIES

HORIZONTAL PROFILE AT 3.28 feet

X COORD feet	MAXIMUM/MINIMUM FLUX DENSITIES OF ELLIPSE milligauss		HORIZONTAL COMPONENT milligauss	VERTICAL COMPONENT milligauss
-150.00	1.442	0.116	1.219	0.779
-140.00	1.637	0.142	1.352	0.933
-130.00	1.872	0.174	1.503	1.130
-120.00	2.160	0.214	1.672	1.384
-110.00	2.515	0.265	1.858	1.716
-100.00	2.960	0.332	2.056	2.155
-90.00	3.525	0.419	2.253	2.743
-80.00	4.251	0.534	2.416	3.538
-70.00	5.196	0.689	2.481	4.617
-60.00	6.439	0.898	2.327	6.071
-50.00	8.078	1.178	1.803	7.962
-40.00	10.211	1.544	1.609	10.201
-30.00	12.870	1.988	4.458	12.235
-20.00	15.843	2.444	9.928	12.586
-10.00	18.444	2.762	16.275	9.107
0.00	19.588	2.781	19.577	2.860
10.00	18.641	2.508	16.972	8.107
20.00	16.135	2.109	10.746	12.219
30.00	13.159	1.727	4.984	12.301
40.00	10.454	1.412	1.656	10.418
50.00	8.268	1.163	1.631	8.188
60.00	6.584	0.970	2.252	6.262
70.00	5.306	0.818	2.464	4.770
80.00	4.335	0.699	2.427	3.659
90.00	3.590	0.604	2.275	2.841
100.00	3.011	0.527	2.082	2.238
110.00	2.555	0.464	1.884	1.788
120.00	2.192	0.413	1.696	1.449
130.00	1.898	0.370	1.525	1.190
140.00	1.659	0.333	1.372	0.990
150.00	1.460	0.303	1.237	0.833

FLUX DENSITY PEAK: X-COORD	MAXIMUM/MINIMUM		HORIZONTAL	VERTICAL
0.00	19.588	2.781	19.577	2.860

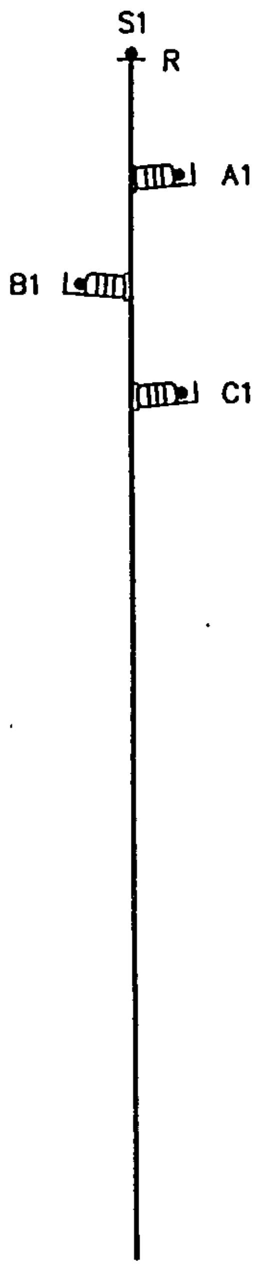


Figure 5.8. Vertical 69 kV structure

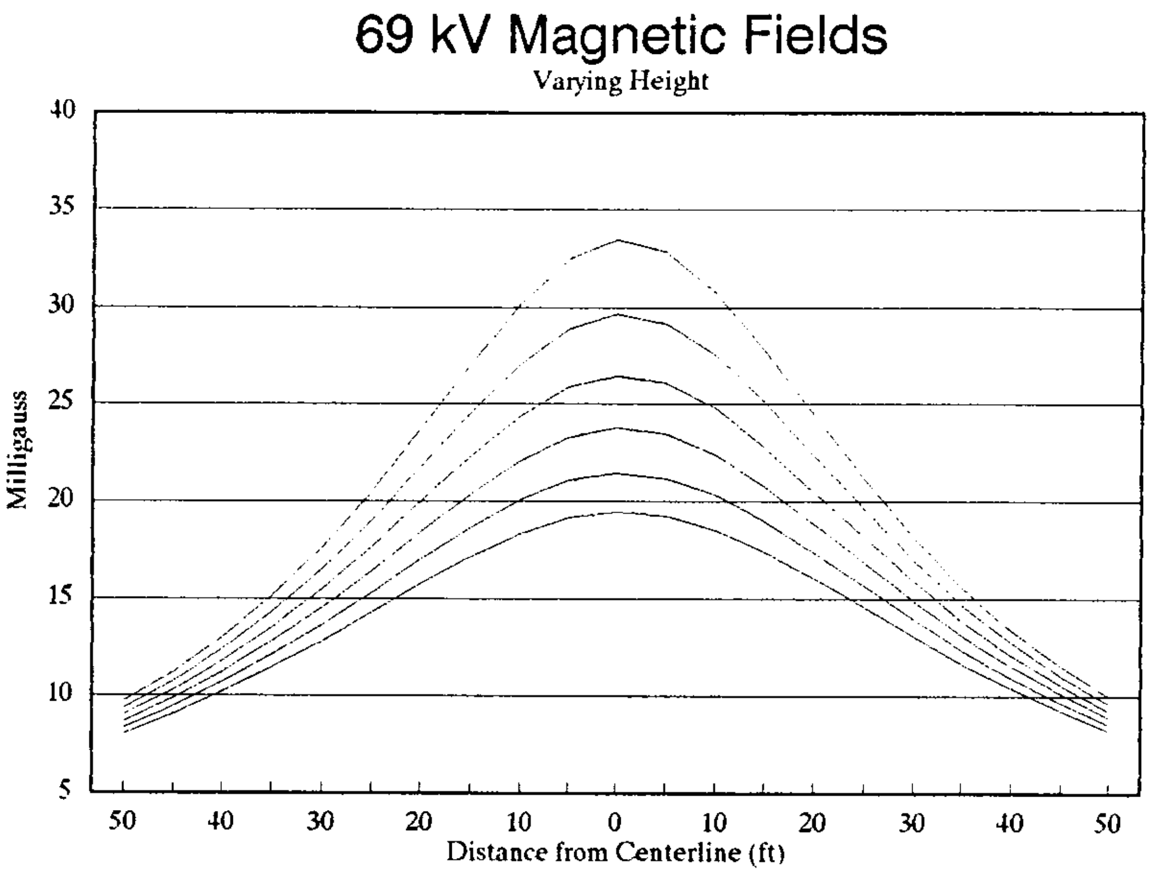


Figure 5.9. Summary graph of six case run by modified Commonwealth Edison program

The program was designed to minimize the magnetic fields associated with power lines by proper conductor positioning in the construction of new lines, or by retro–fitting existing lines. Input into the program consists of the same information required by the Commonwealth Edison program, along with a few other inputs. One of the additional inputs into the program is dependent on the number of phase conductors (three or six). If a six conductor case is to be run, it must be input whether or not the conductors can be swapped from three phase circuit to three phase circuit, or if they must remain in their respective three phase circuit. Conductor positions are input in order, with the first three positions corresponding to the first three phase circuit, and if a second three phase circuit is studied, with the next three positions corresponding to it. Conductors for the first three phase circuit are labeled as a1, b1, c1, and if a second three phase circuit exists, its conductors are labeled as a2, b2, c2. Once all the data have been input, the program can be run and output can be obtained. Output for the program is a file that contains the summary of all the cases run, with the magnetic fields calculated at 150 feet away from the conductor, and the maximum magnetic field. Also computed is a file for each combination of conductor positioning containing magnetic field magnitudes at every five feet for the line being studied from 150 on one side of the line to 150 feet on the other side (–150 to 150). Listed below are three examples of the use of the program.

The first example is a single 34.5 kV three phase line shown in Figure 5.10. This case will consist of six possible combinations of phase conductor positioning. They are a1b1c1, a1c1b1, b1a1c1, b1c1a1, c1a1b1, and c1b1a1, where the first conductor listed is always in the phase conductor position input first, etc. When

PHASE CONDUCTOR SUMMARY

PHASE CONDUCTOR no.	X COORD feet	Y COORD feet	CURRENT amps	PHASE ANGLE degrees
1	1.5	43.7	375	0.0
2	-1.5	40.7	375	240.0
3	1.6	37.7	375	120.0

STATIC WIRE SUMMARY

X COORD feet	Y COORD feet	SPAN feet	GMR feet	COND RESIST Ohms/Mile
0.00	46.0	150	0.03750	0.117

Figure 5.10. Single 34.5 kV three phase line

running the program, all six possible combinations are calculated and compared to find the case of minimum magnetic fields. As the results show in Table 5.14, this is not an interesting case. In the case of three conductors, the phasing of the line does not matter, and all cases result in the same magnetic field profile.

The second and more interesting example is a double three-phase circuit line, with one circuit operated at 161 kV, and the second circuit operated at 69 kV (Figure 5.11). Here, it can be seen that the three 69 kV phases must be kept at the bottom of the structure, and the 161 kV phases must be kept at the top of the structure, or spacing violations will occur. In this case, thirty–six possible phase conductor positionings exist. The 161 kV circuit conductor positions were input first (a1, b1, c1) with the 69 kV circuit positions input second (a2, b2, c2), so the 161 kV phases are listed first (the top of the circuit), with the 69 kV phases listed second (the bottom of the circuit). Example of possible circuit labels are a1b1c1a2b2c2 and c1b1a1b2a2c2. This case gives a little more interesting results, with the output for the thirty–six different cases shown in Table 5.15.

The third example is a double three-phase circuit line (Figure 5.12), with both circuits being operated at 161 kV. Again, one 161 kV line is designated as being circuit one (a1, b1, c1), and the second circuit as being circuit two (a2, b2, c2). The difference between this case and the previous case is that these 161 kV lines can be swapped from one circuit to the other, since the spacing is the same for both circuits, which allows for seven hundred twenty different combinations. This case allows for much more diverse output which is summarized in Table 5.16.

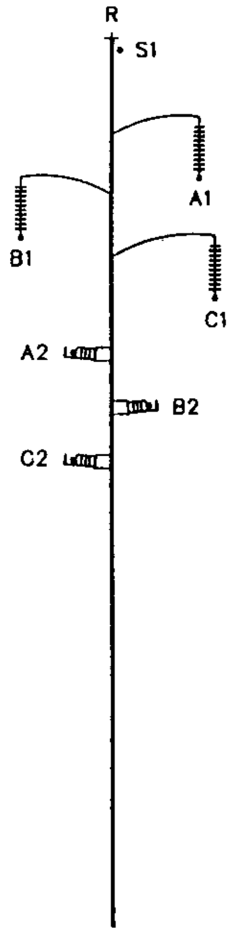
This program shows the magnetic field strengths found near a multi–circuit line are functions of both line currents (magnitude and angle) and phase arrangement. The result of the program is the phase arrangement that would produce the minimum magnetic fields directly under the line for a given set of currents.

Table 5.14. Minimization output for 34.5 kV three phase line

RANK	CASE #	PHASE ARRANGEMENT	MAGNETIC FIELD -150	MAX	150
1	1	a1b1c1	0.61	10.66	0.63
2	2	a1c1b1	0.61	10.66	0.63
3	3	b1a1c1	0.61	10.66	0.63
4	4	b1c1a1	0.61	10.66	0.63
5	5	c1a1b1	0.61	10.66	0.63
6	6	c1b1a1	0.61	10.66	0.63

Table 5.15. Minimization output for double three phase line, 161 kV and 69 kV

RANK	CASE #	PHASE ARRANGEMENT	MAGNETIC FIELD -150	MAX	150
1	6	a1b1c1c2b2a2	1.88	7.92	1.79
2	20	b1c1a1a2c2b2	1.88	7.92	1.79
3	27	c1a1b1b2a2c2	1.88	7.92	1.79
4	10	a1c1b1b2c2a2	1.77	9.62	2.01
5	17	b1a1c1c2a2b2	1.77	9.62	2.01
6	31	c1b1a1a2b2c2	1.77	9.62	2.01
7	1	a1b1c1a2b2c2	3.06	18.10	3.18
8	22	b1c1a1b2c2a2	3.06	18.10	3.18
9	29	c1a1b1c2a2b2	3.06	18.10	3.18
10	8	a1c1b1a2c2b2	3.13	18.19	3.18
11	15	b1a1c1b2a2c2	3.13	18.19	3.18
12	36	c1b1a1c2b2a2	3.13	18.19	3.18
13	9	a1c1b1b2a2c2	3.25	20.83	3.47
14	18	b1a1c1c2b2a2	3.25	20.83	3.47
15	32	c1b1a1a2c2b2	3.25	20.83	3.47
16	4	a1b1c1b2c2a2	3.52	21.16	3.48
17	23	b1c1a1c2a2b2	3.52	21.16	3.48
18	25	c1a1b1a2b2c2	3.52	21.16	3.48
19	5	a1b1c1c2a2b2	3.36	21.57	3.55
20	19	b1c1a1a2b2c2	3.36	21.57	3.55
21	28	c1a1b1b2c2a2	3.36	21.57	3.55
22	11	a1c1b1c2a2b2	3.80	21.60	3.49
23	13	b1a1c1a2b2c2	3.80	21.60	3.49
24	34	c1b1a1b2c2a2	3.80	21.60	3.49
25	12	a1c1b1c2b2a2	3.57	21.82	3.55
26	14	b1a1c1a2c2b2	3.57	21.82	3.55
27	33	c1b1a1b2a2c2	3.57	21.82	3.55
28	3	a1b1c1b2a2c2	4.12	24.41	3.93
29	24	b1c1a1c2b2a2	4.12	24.41	3.93
30	26	c1a1b1a2c2b2	4.12	24.41	3.93
31	2	a1b1c1a2c2b2	3.55	24.45	4.02
32	21	b1c1a1b2a2c2	3.55	24.45	4.02
33	30	c1a1b1c2b2a2	3.55	24.45	4.02
34	7	a1c1b1a2b2c2	3.93	26.44	4.31
35	16	b1a1c1b2c2a2	3.93	26.44	4.31
36	35	c1b1a1c2a2b2	3.93	26.44	4.31



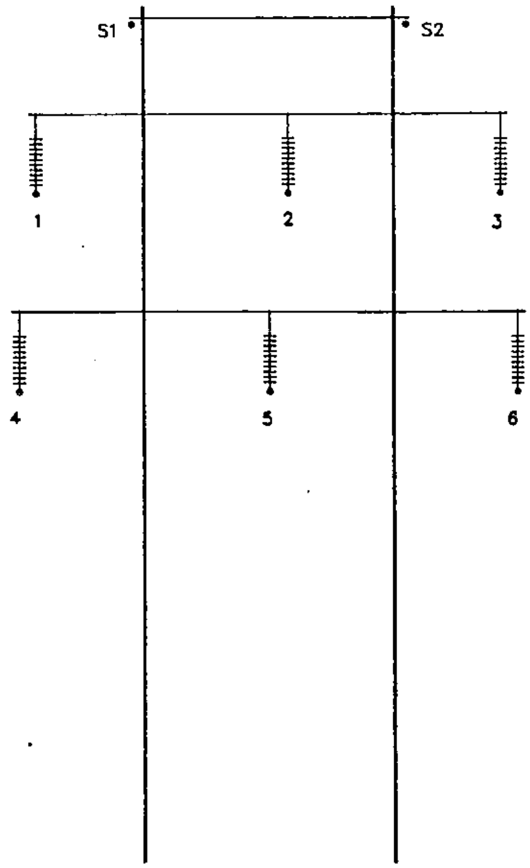
PHASE CONDUCTOR SUMMARY

PHASE CONDUCTOR no.	X COORD feet	Y COORD feet	CURRENT amps	PHASE ANGLE degrees
1	8.1	80.0	650	-11.5
2	-8.1	74.5	650	228.5
3	9.6	69.0	650	108.5
4	-3.5	64.0	510	0.0
5	3.5	59.0	510	240.0
6	-3.5	54.0	510	120.0

STATIC WIRE SUMMARY

X COORD feet	Y COORD feet	SPAN feet	GMR feet	COND RESIST Ohms/Mile
0.50	92.0	300	0.03750	0.117

Figure 5.11. Double three phase line, 161 kV and 69 kV



PHASE CONDUCTOR SUMMARY

PHASE CONDUCTOR no.	X COORD feet	Y COORD feet	CURRENT amps	PHASE ANGLE degrees
1	-19.0	80.0	650	-11.5
2	-34.0	55.0	650	228.5
3	-19.0	30.0	650	108.5
4	19.0	30.0	600	-16.3
5	34.0	55.0	600	223.7
6	19.0	80.0	600	103.7

STATIC WIRE SUMMARY

X COORD feet	Y COORD feet	SPAN feet	GMR feet	COND RESIST Ohms/Mile
-10.0	105.7	300	0.03750	0.117
10.0	105.7	300	0.03750	0.117

Figure 5.12. Double 161 kV three phase line

Table 5.16. Minimization output for double 161 kV three phase line

RANK	CASE #	PHASE ARRANGEMENT	MAGENTIC FIELD -150	MAX	150	RANK	CASE #	PHASE ARRANGEMENT	MAGNETIC FIELD -150	MAX	150
1	408	a2b1c2b2c1a1	12.90	83.11	13.12	66	329	c1b2a2c2a1b1	9.80	99.90	9.48
2	545	b2c1a2c2a1b1	12.90	83.11	13.12	67	403	a2b1c2a1c1b2	9.92	101.23	9.68
3	623	c2a1b2a2b1c1	12.90	83.11	13.12	68	543	b2c1a2b1a1c2	9.92	101.23	9.68
4	23	a1b1c2b2c1a2	12.78	83.75	12.90	69	621	c2a1b2c1b1a2	9.92	101.23	9.68
5	155	b1c1a2c2a1b2	12.78	83.75	12.90	70	393	a2b1c1b2a1c2	9.68	102.47	9.92
6	255	c1a1b2a2b1c2	12.78	83.75	12.90	71	533	b2c1a1c2b1a2	9.68	102.47	9.92
7	41	a1c1b2c2b1a2	13.12	85.03	12.90	72	603	c2a1b1a2c1b2	9.68	102.47	9.92
8	141	b1a1c2a2c1b2	13.12	85.03	12.90	73	22	a1b1c2a2b2c1	4.11	102.88	4.55
9	273	c1b1a2b2a1c2	13.12	85.03	12.90	74	120	a1c2b2a2c1b1	4.55	102.88	4.11
10	454	a2b2c2b1c1a1	12.33	85.71	12.72	75	154	b1c1a2b2c2a1	4.11	102.88	4.55
11	599	b2c2a2c1a1b1	12.33	85.71	12.72	76	191	b1a2c2b2a1c1	4.55	102.88	4.11
12	691	c2a2b2a1b1c1	12.33	85.71	12.72	77	258	c1a1b2c2a2b1	4.11	102.88	4.55
13	426	a2c1b2c2b1a1	12.90	85.90	12.78	78	330	c1b2a2c2b1a1	4.55	102.88	4.11
14	504	b2a1c2a2c1b1	12.90	85.90	12.78	79	452	a2b2c2a1c1b1	9.66	103.18	9.54
15	641	c2b1a2b2a1c1	12.90	85.90	12.78	80	597	b2c2a2b1a1c1	9.66	103.18	9.54
16	117	a1c2b2c1b1a2	13.26	86.66	13.50	81	696	c2a2b2c1b1a1	9.66	103.18	9.54
17	187	b1a2c2a1c1b2	13.26	86.66	13.50	82	3	a1b1c1b2a2c2	9.54	103.65	9.66
18	327	c1b2a2b1a1c2	13.26	86.66	13.50	83	150	b1c1a1c2b2a2	9.54	103.65	9.66
19	91	a1b2c2b1c1a2	12.24	86.79	12.50	84	242	c1a1b1a2c2b2	9.54	103.65	9.66
20	231	b1c2a2c1a1b2	12.24	86.79	12.50	85	100	a1c2b1a2b2c1	9.80	103.78	9.25
21	301	c1a2b2a1b1c2	12.24	86.79	12.50	86	118	a1c2b2c1a2b1	9.25	103.78	9.80
22	480	a2c2b2c1b1a1	13.01	87.35	13.38	87	178	b1a2c1b2c2a1	9.80	103.78	9.25
23	572	b2a2c2a1c1b1	13.01	87.35	13.38	88	188	b1a2c2a1b2c1	9.25	103.78	9.80
24	717	c2b2a2b1a1c1	13.01	87.35	13.38	89	318	c1b2a1c2a2b1	9.80	103.78	9.25
25	30	a1c1b1c2b2a2	12.72	91.29	12.33	90	328	c1b2a2b1c2a1	9.25	103.78	9.80
26	122	b1a1c1a2c2b2	12.72	91.29	12.33	91	29	a1c1b1c2a2b2	8.90	103.81	8.96
27	267	c1b1a1b2a2c2	12.72	91.29	12.33	92	121	b1a1c1a2b2c2	8.90	103.81	8.96
28	420	a2c1b1c2b2a1	12.50	92.42	12.24	93	268	c1b1a1b2c2a2	8.90	103.81	8.96
29	490	b2a1c1a2c2b1	12.50	92.42	12.24	94	475	a2c2b2a1b1c1	8.96	103.81	8.90
30	630	c2b1a1b2a2c1	12.50	92.42	12.24	95	574	b2a2c2b1c1a1	8.96	103.81	8.90
31	394	a2b1c1b2c2a1	13.50	93.01	13.26	96	719	c2b2a2c1a1b1	8.96	103.81	8.90
32	534	b2c1a1c2a2b1	13.50	93.01	13.26	97	33	a1c1b2a2b1c2	10.22	104.21	9.30
33	604	c2a1b1a2b2c1	13.50	93.01	13.26	98	143	b1a1c2b2c1a2	10.22	104.21	9.30
34	4	a1b1c1b2c2a2	13.38	93.44	13.01	99	275	c1b1a2c2a1b2	10.22	104.21	9.30
35	149	b1c1a1c2a2b2	13.38	93.44	13.01	100	425	a2c1b2c2a1b1	9.30	104.21	10.22
36	241	c1a1b1a2b2c2	13.38	93.44	13.01	101	503	b2a1c2a2b1c1	9.30	104.21	10.22
37	98	a1c2b1c1b2a2	12.89	93.56	12.99	102	642	c2b1a2b2c1a1	9.30	104.21	10.22
38	176	b1a2c1a1c2b2	12.89	93.56	12.99	103	97	a1c2b1c1a2b2	8.68	106.04	8.96
39	313	c1b2a1b1a2c2	12.89	93.56	12.99	104	175	b1a2c1a1b2c2	8.68	106.04	8.96
40	466	a2c2b1c1b2a1	12.65	94.68	12.89	105	314	c1b2a1b1c2a2	8.68	106.04	8.96
41	566	b2a2c1a1c2b1	12.65	94.68	12.89	106	464	a2c2b1a1b2c1	8.96	106.04	8.68
42	698	c2b2a1b1a2c1	12.65	94.68	12.89	107	568	b2a2c1b1c2a1	8.96	106.04	8.68
43	448	a2b2c1b1c2a1	12.99	95.52	12.89	108	700	c2b2a1c1a2b1	8.96	106.04	8.68
44	580	b2c2a1c1a2b1	12.99	95.52	12.89	109	2	a1b1c1a2c2b2	9.50	106.53	8.32
45	680	c2a2b1a1b2c1	12.99	95.52	12.89	110	147	b1c1a1b2a2c2	9.50	106.53	8.32
46	21	a1b1c2a2c1b2	9.15	95.68	8.69	111	246	c1a1b1c2b2a2	9.50	106.53	8.32
47	153	b1c1a2b2a1c2	9.15	95.68	8.69	112	453	a2b2c2b1a1c1	8.32	106.53	9.50
48	257	c1a1b2c2b1a2	9.15	95.68	8.69	113	600	b2c2a2c1b1a1	8.32	106.53	9.50
49	407	a2b1c2b2a1c1	8.69	95.68	9.15	114	692	c2a2b2a1c1b1	8.32	106.53	9.50
50	546	b2c1a2c2b1a1	8.69	95.68	9.15	115	25	a1c1b1a2b2c2	10.16	107.60	9.00
51	624	c2a1b2a2c1b1	8.69	95.68	9.15	116	124	b1a1c1b2c2a2	10.16	107.60	9.00
52	80	a1b2c1b1c2a2	12.89	96.33	12.65	117	269	c1b1a1c2a2b2	10.16	107.60	9.00
53	217	b1c2a1c1a2b2	12.89	96.33	12.65	118	479	a2c2b2c1a1b1	9.00	107.60	10.16
54	295	c1a2b1a1b2c2	12.89	96.33	12.65	119	571	b2a2c2a1b1c1	9.00	107.60	10.16
55	24	a1b1c2b2a2c1	8.54	97.86	8.90	120	718	c2b2a2b1c1a1	9.00	107.60	10.16
56	96	a1b2c2a2c1b1	8.90	97.86	8.54	121	99	a1c2b1a2c1b2	4.64	108.19	4.71
57	156	b1c1a2c2b2a1	8.54	97.86	8.90	122	177	b1a2c1b2a1c2	4.64	108.19	4.71
58	233	b1c2a2b2a1c1	8.90	97.86	8.54	123	317	c1b2a1c2b1a2	4.64	108.19	4.71
59	256	c1a1b2a2c2b1	8.54	97.86	8.90	124	404	a2b1c2a1b2c1	4.71	108.19	4.64
60	308	c1a2b2c2b1a1	8.90	97.86	8.54	125	544	b2c1a2b1c2a1	4.71	108.19	4.64
61	42	a1c1b2c2a2b1	9.48	99.90	9.80	126	622	c2a1b2c1a2b1	4.71	108.19	4.64
62	119	a1c2b2a2b1c1	9.80	99.90	9.48	127	419	a2c1b1c2a1b2	8.71	108.22	9.44
63	142	b1a1c2a2b2c1	9.48	99.90	9.80	128	421	a2c1b2a1b1c2	9.44	108.22	8.71
64	192	b1a2c2b2c1a1	9.80	99.90	9.48	129	489	b2a1c1a2b1c2	8.71	108.22	9.44
65	274	c1b1a2b2c2a1	9.48	99.90	9.80	130	499	b2a1c2b1c1a2	9.44	108.22	8.71

Table 5.16. (Continued)

RANK	CASE #	PHASE ARRANGEMENT	MAGNETIC FIELD -150	MAX	150
131	629	c2b1a1b2c1a2	8.71	108.22	9.44
132	639	c2b1a2c1a1b2	9.44	108.22	8.71
133	82	a1b2c1a2c2b1	9.32	108.83	8.23
134	92	a1b2c2b1a2c1	8.23	108.83	9.32
135	222	b1c2a1b2a2c1	9.32	108.83	8.23
136	232	b1c2a2c1b2a1	8.23	108.83	9.32
137	300	c1a2b1c2b2a1	9.32	108.83	8.23
138	302	c1a2b2a1c2b1	8.23	108.83	9.32
139	40	a1c1b2a2c2b1	5.28	108.84	3.66
140	95	a1b2c2a2b1c1	3.66	108.84	5.28
141	144	b1a1c2b2a2c1	5.28	108.84	3.66
142	234	b1c2a2b2c1a1	3.66	108.84	5.28
143	276	c1b1a2c2b2a1	5.28	108.84	3.66
144	305	c1a2b2c2a1b1	3.66	108.84	5.28
145	415	a2c1b1a1b2c2	9.38	110.20	8.42
146	465	a2c2b1c1a1b2	8.42	110.20	9.38
147	488	b2a1c1b1c2a2	9.38	110.20	8.42
148	565	b2a2c1a1b1c2	8.42	110.20	9.38
149	625	c2b1a1c1a2b2	9.38	110.20	8.42
150	697	c2b2a1b1c1a2	8.42	110.20	9.38
151	93	a1b2c2c1b1a2	14.36	111.41	14.91
152	229	b1c2a2a1c1b2	14.36	111.41	14.91
153	303	c1a2b2b1a1c2	14.36	111.41	14.91
154	1	a1b1c1a2b2c2	4.95	111.47	3.82
155	148	b1c1a1b2c2a2	4.95	111.47	3.82
156	245	c1a1b1c2a2b2	4.95	111.47	3.82
157	476	a2c2b2a1c1b1	3.82	111.47	4.95
158	573	b2a2c2b1a1c1	3.82	111.47	4.95
159	720	c2b2a2c1b1a1	3.82	111.47	4.95
160	456	a2b2c2c1b1a1	14.43	111.52	14.81
161	596	b2c2a2a1c1b1	14.43	111.52	14.81
162	693	c2a2b2b1a1c1	14.43	111.52	14.81
163	20	a1b1c2c1b2a2	14.57	111.57	14.72
164	152	b1c1a2a1c2b2	14.57	111.57	14.72
165	253	c1a1b2b1a2c2	14.57	111.57	14.72
166	406	a2b1c2c1b2a1	14.66	111.85	14.64
167	542	b2c1a2a1c2b1	14.66	111.85	14.64
168	620	c2a1b2b1a2c1	14.66	111.85	14.64
169	392	a2b1c1a1c2b2	10.23	112.11	9.37
170	447	a2b2c1b1a1c2	9.37	112.11	10.23
171	529	b2c1a1b1a2c2	10.23	112.11	9.37
172	579	b2c2a1c1b1a2	9.37	112.11	10.23
173	602	c2a1b1c1b2a2	10.23	112.11	9.37
174	679	c2a2b1a1c1b2	9.37	112.11	10.23
175	478	a2c2b2b1c1a1	14.47	112.21	14.77
176	575	b2a2c2c1a1b1	14.47	112.21	14.77
177	715	c2b2a2a1b1c1	14.47	112.21	14.77
178	115	a1c2b2b1c1a2	14.69	112.39	14.59
179	189	b1a2c2c1a1b2	14.69	112.39	14.59
180	325	c1b2a2a1b1c2	14.69	112.39	14.59
181	424	a2c1b2b1c2a1	14.66	113.16	14.64
182	502	b2a1c2c1a2b1	14.66	113.16	14.64
183	638	c2b1a2a1b2c1	14.66	113.16	14.64
184	38	a1c1b2b1c2a2	14.86	113.24	14.42
185	139	b1a1c2c1a2b2	14.86	113.24	14.42
186	271	c1b1a2a1b2c2	14.86	113.24	14.42
187	26	a1c1b1a2c2b2	5.26	113.39	4.22
188	123	b1a1c1b2a2c2	5.26	113.39	4.22
189	270	c1b1a1c2b2a2	5.26	113.39	4.22
190	451	a2b2c2a1b1c1	4.22	113.39	5.26
191	598	b2c2a2b1c1a1	4.22	113.39	5.26
192	695	c2a2b2c1a1b1	4.22	113.39	5.26
193	79	a1b2c1b1a2c2	9.29	114.31	10.05
194	218	b1c2a1c1b2a2	9.29	114.31	10.05
195	296	c1a2b1a1c2b2	9.29	114.31	10.05
196	446	a2b2c1a1c2b1	10.05	114.31	9.29
197	578	b2c2a1b1a2c1	10.05	114.31	9.29
198	622	c2a2b1c1b2a1	10.05	114.31	9.29
199	391	a2b1c1a1b2c2	5.42	115.64	3.86
200	463	a2c2b1a1c1b2	3.86	115.64	5.42
201	530	b2c1a1b1c2a2	5.42	115.64	3.86
202	567	b2a2c1b1a1c2	3.86	115.64	5.42
203	601	c2a1b1c1a2b2	5.42	115.64	3.86
204	699	c2b2a1c1b1a2	3.86	115.64	5.42
205	19	a1b1c2c1a2b2	13.73	115.73	13.53
206	151	b1c1a2a1b2c2	13.73	115.73	13.53
207	254	c1a1b2b1c2a2	13.73	115.73	13.53
208	94	a1b2c2c1a2b1	13.79	115.86	14.07
209	230	b1c2a2a1b2c1	13.79	115.86	14.07
210	304	c1a2b2b1c2a1	13.79	115.86	14.07
211	468	a2c2b1b2c1a1	14.42	115.94	14.86
212	569	b2a2c1c2a1b1	14.42	115.94	14.86
213	701	c2b2a1a2b1c1	14.42	115.94	14.86
214	101	a1c2b1b2c1a2	14.64	115.96	14.66
215	179	b1a2c1c2a1b2	14.64	115.96	14.66
216	315	c1b2a1a2b1c2	14.64	115.96	14.66
217	28	a1c1b1b2c2a2	14.77	116.35	14.47
218	125	b1a1c1c2a2b2	14.77	116.35	14.47
219	265	c1b1a1a2b2c2	14.77	116.35	14.47
220	418	a2c1b1b2c2a1	14.59	116.42	14.69
221	492	b2a1c1c2a2b1	14.59	116.42	14.69
222	628	c2b1a1a2b2c1	14.59	116.42	14.69
223	6	a1b1c1c2b2a2	14.81	117.02	14.43
224	146	b1c1a1a2c2b2	14.81	117.02	14.43
225	243	c1a1b1b2a2c2	14.81	117.02	14.43
226	81	a1b2c1a2b1c2	4.68	117.27	4.76
227	221	b1c2a1b2c1a2	4.68	117.27	4.76
228	299	c1a2b1c2a1b2	4.68	117.27	4.76
229	422	a2c1b2a1c2b1	4.76	117.27	4.68
230	500	b2a1c2b1a2c1	4.76	117.27	4.68
231	640	c2b1a2c1b2a1	4.76	117.27	4.68
232	83	a1b2c1c2b1a2	14.64	117.31	14.66
233	219	b1c2a1a2c1b2	14.64	117.31	14.66
234	297	c1a2b1b2a1c2	14.64	117.31	14.66
235	396	a2b1c1c2b2a1	14.91	117.35	14.36
236	532	b2c1a1a2c2b1	14.91	117.35	14.36
237	606	c2a1b1b2a2c1	14.91	117.35	14.36
238	405	a2b1c2c1a1b2	14.15	117.42	14.07
239	455	a2b2c2c1a1b1	14.18	117.42	14.52
240	541	b2c1a2a1b1c2	14.15	117.42	14.07
241	595	b2c2a2a1b1c1	14.18	117.42	14.52
242	619	c2a1b2b1c1a2	14.15	117.42	14.07
243	694	c2a2b2b1c1a1	14.18	117.42	14.52
244	450	a2b2c1c2b1a1	14.72	117.55	14.57
245	582	b2c2a1a2c1b1	14.72	117.55	14.57
246	683	c2a2b1b2a1c1	14.72	117.55	14.57
247	477	a2c2b2b1a1c1	13.68	118.40	14.03
248	576	b2a2c2c1b1a1	13.68	118.40	14.03
249	716	c2b2a2a1c1b1	13.68	118.40	14.03
250	116	a1c2b2b1a2c1	14.18	118.82	14.12
251	190	b1a2c2c1b2a1	14.18	118.82	14.12
252	326	c1b2a2a1c2b1	14.18	118.82	14.12
253	467	a2c2b1b2a1c1	13.58	119.96	13.73
254	570	b2a2c1c2b1a1	13.58	119.96	13.73
255	702	c2b2a1a2c1b1	13.58	119.96	13.73
256	102	a1c2b1b2a2c1	14.07	120.14	13.79
257	180	b1a2c1c2b2a1	14.07	120.14	13.79
258	316	c1b2a1a2c2b1	14.07	120.14	13.79
259	423	a2c1b2b1a1c2	14.20	120.75	14.46
260	501	b2a1c2c1b1a2	14.20	120.75	14.46

Table 5.16. (Continued)

RANK	CASE #	PHASE ARRANGEMENT	MAGNETIC FIELD -150	MAX	150
261	637	c2b1a2a1c1b2	14.20	120.75	14.46
262	416	a2c1b1a1c2b2	4.69	120.98	5.09
263	445	a2b2c1a1b1c2	5.09	120.98	4.69
264	487	b2a1c1b1a2c2	4.69	120.98	5.09
265	577	b2c2a1b1c1a2	5.09	120.98	4.69
266	526	c2b1a1c1b2a2	4.69	120.98	5.09
267	681	c2a2b1c1a1b2	5.09	120.98	4.69
268	37	a1c1b2b1a2c2	14.66	121.05	14.52
269	140	b1a1c2c1b2a2	14.66	121.05	14.52
270	272	c1b1a2a1c2b2	14.66	121.05	14.52
271	417	a2c1b1b2a1c2	14.07	121.35	14.15
272	491	b2a1c1c2b1a2	14.07	121.35	14.15
273	527	c2b1a1a2c1b2	14.07	121.35	14.15
274	27	a1c1b1b2a2c2	14.52	122.02	14.18
275	126	b1a1c1c2b2a2	14.52	122.02	14.18
276	266	c1b1a1a2c2b2	14.52	122.02	14.18
277	5	a1b1c1c2a2b2	14.03	122.96	13.68
278	145	b1c1a1a2b2c2	14.03	122.96	13.68
279	244	c1a1b1b2c2a2	14.03	122.96	13.68
280	84	a1b2c1c2a2b1	14.12	123.40	14.18
281	220	b1c2a1a2b2c1	14.12	123.40	14.18
282	298	c1a2b1b2c2a1	14.12	123.40	14.18
283	395	a2b1c1c2a1b2	14.46	124.77	14.20
284	531	b2c1a1a2b1c2	14.46	124.77	14.20
285	605	c2a1b1b2c1a2	14.46	124.77	14.20
286	449	a2b2c1c2a1b1	14.52	125.10	14.66
287	581	b2c2a1a2b1c1	14.52	125.10	14.66
288	684	c2a2b1b2c1a1	14.52	125.10	14.66
289	35	a1c1a2c2b1b2	12.76	127.79	16.14
290	135	b1a1b2a2c1c2	12.76	127.79	16.14
291	287	c1b1c2b2a1a2	12.76	127.79	16.14
292	377	a2a1b2c2b1c1	16.14	127.79	12.76
293	528	b2b1c2a2c1a1	16.14	127.79	12.76
294	665	c2c1a2b2a1b1	16.14	127.79	12.76
295	36	a1c1a2c2b2b1	12.77	128.45	16.18
296	65	a1a2b2c2b1c1	16.18	128.45	12.77
297	136	b1a1b2a2c2c1	12.77	128.45	16.18
298	216	b1b2c2a2c1a1	16.18	128.45	12.77
299	288	c1b1c2b2a2a1	12.77	128.45	16.18
300	353	c1c2a2b2a1b1	16.18	128.45	12.77
301	58	a1a2c1b2c2b1	16.43	133.58	12.93
302	86	a1b2a2b1c2c1	12.93	133.58	16.43
303	198	b1b2a1c2a2c1	16.43	133.58	12.93
304	238	b1c2b2c1a2a1	12.93	133.58	16.43
305	308	c1a2c2a1b2b1	12.93	133.58	16.43
306	346	c1c2b1a2b2a1	16.43	133.58	12.93
307	374	a2a1b2b1c2c1	19.14	133.91	19.13
308	526	b2b1c2c1a2a1	19.14	133.91	19.13
309	662	c2c1a2a1b2b1	19.14	133.91	19.13
310	62	a1a2b2b1c2c1	19.34	134.08	19.32
311	214	b1b2c2c1a2a1	19.34	134.08	19.32
312	350	c1c2a2a1b2b1	19.34	134.08	19.32
313	373	a2a1b2b1c1c2	19.38	135.21	19.54
314	525	b2b1c2c1a1a2	19.38	135.21	19.54
315	661	c2c1a2a1b1b2	19.38	135.21	19.54
316	61	a1a2b2b1c1c2	19.57	135.35	19.73
317	213	b1b2c2c1a1a2	19.57	135.35	19.73
318	349	c1c2a2a1b1b2	19.57	135.35	19.73
319	375	a2a1b2c1b1c2	16.50	135.44	13.23
320	413	a2c1a1c2b1b2	13.23	135.44	16.50
321	483	b2a1b1a2c1c2	13.23	135.44	16.50
322	523	b2b1c2a1c1a2	16.50	135.44	13.23
323	635	c2b1c1b2a1a2	13.23	135.44	16.50
324	663	c2c1a2b1a1b2	16.50	135.44	13.23
325	10	a1b1a2b2c2c1	13.75	135.52	16.71
326	72	a1a2c2b2c1b1	16.71	135.52	13.75
327	162	b1c1b2c2a2a1	13.75	135.52	16.71
328	209	b1b2a2c2a1c1	16.71	135.52	13.75
329	262	c1a1c2a2b2b1	13.75	135.52	16.71
330	360	c1c2b2a2b1a1	16.71	135.52	13.75
331	63	a1a2b2c1b1c2	16.55	135.87	13.26
332	211	b1b2c2a1c1a2	16.55	135.87	13.26
333	351	c1c2a2b1a1b2	16.55	135.87	13.26
334	414	a2c1a1c2b2b1	13.26	135.87	16.55
335	484	b2a1b1a2c2c1	13.26	135.87	16.55
336	636	c2b1c1b2a2a1	13.26	135.87	16.55
337	85	a1b2a2b1c1c2	13.01	136.13	16.75
338	237	b1c2b2c1a1a2	13.01	136.13	16.75
339	307	c1a2c2a1b1b2	13.01	136.13	16.75
340	370	a2a1c1b2c2b1	16.75	136.13	13.01
341	510	b2b1a1c2a2c1	16.75	136.13	13.01
342	658	c2c1b1a2b2a1	16.75	136.13	13.01
343	56	a1a2c1b1c2b2	16.14	136.52	12.62
344	193	b1b2a1c1a2c2	16.14	136.52	12.62
345	344	c1c2b1a1b2a2	16.14	136.52	12.62
346	434	a2b2a1b1c2c1	12.62	136.52	16.14
347	586	b2c2b1c1a2a1	12.62	136.52	16.14
348	686	c2a2c1a1b2b1	12.62	136.52	16.14
349	59	a1a2c1c2b1b2	19.13	137.43	19.14
350	195	b1b2a1a2c1c2	19.13	137.43	19.14
351	347	c1c2b1b2a1a2	19.13	137.43	19.14
352	60	a1a2c1c2b2b1	19.32	137.58	19.34
353	196	b1b2a1a2c2c1	19.32	137.58	19.34
354	348	c1c2b1b2a2a1	19.32	137.58	19.34
355	9	a1b1a2b2c1c2	13.84	137.99	17.04
356	161	b1c1b2c2a1a2	13.84	137.99	17.04
357	261	c1a1c2a2b1b2	13.84	137.99	17.04
358	384	a2a1c2b2c1b1	17.04	137.99	13.84
359	521	b2b1a2c2a1c1	17.04	137.99	13.84
360	672	c2c1b2a2b1a1	17.04	137.99	13.84
361	69	a1a2c2c1b1b2	19.44	138.85	19.61
362	205	b1b2a2a1c1c2	19.44	138.85	19.61
363	357	c1c2b2b1a1a2	19.44	138.85	19.61
364	67	a1a2c2b1c1b2	16.43	138.89	13.48
365	207	b1b2a2c1a1c2	16.43	138.89	13.48
366	355	c1c2b2a1b1a2	16.43	138.89	13.48
367	368	a2a1c1b1c2b2	16.45	138.89	12.69
368	388	a2b1a1b2c2c1	13.48	138.89	16.43
369	433	a2b2a1b1c1c2	12.69	138.89	16.45
370	505	b2b1a1c1a2c2	16.45	138.89	12.69
371	540	b2c1b1c2a2a1	13.48	138.89	16.43
372	585	b2c2b1c1a1a2	12.69	138.89	16.45
373	610	c2a1c1a2b2b1	13.48	138.89	16.43
374	656	c2c1b1a1b2a2	16.45	138.89	12.69
375	685	c2a2c1a1b1b2	12.69	138.89	16.45
376	111	a1c2a2c1b1b2	13.23	138.99	16.63
377	181	b1a2b2a1c1c2	13.23	138.99	16.63
378	333	c1b2c2b1a1a2	13.23	138.99	16.63
379	366	a2a1b1c2b2c1	16.63	138.99	13.23
380	514	b2b1c1a2c2a1	16.63	138.99	13.23
381	654	c2c1a1b2a2b1	16.63	138.99	13.23
382	70	a1a2c2c1b2b1	19.63	139.07	19.81
383	206	b1b2a2a1c2c1	19.63	139.07	19.81
384	358	c1c2b2b1a2a1	19.63	139.07	19.81
385	371	a2a1c1c2b1b2	19.54	139.38	19.38
386	507	b2b1a1a2c1c2	19.54	139.38	19.38
387	659	c2c1b1b2a1a2	19.54	139.38	19.38
388	372	a2a1c1c2b2b1	19.73	139.50	19.57
389	508	b2b1a1a2c2c1	19.73	139.50	19.57
390	660	c2c1b1b2a2a1	19.73	139.50	19.57

Table 5.16. (Continued)

RANK	CASE #	PHASE ARRANGEMENT	MAGNETIC FIELD -150	MAX	150
391	54	ala2blc2b2cl	16.70	139.86	13.26
392	112	alc2a2clb2bl	13.26	139.86	16.70
393	182	bla2b2alc2cl	13.26	139.86	16.70
394	202	blb2cla2c2al	16.70	139.86	13.26
395	334	clb2c2bla2al	13.26	139.86	16.70
396	342	clc2alb2a2bl	16.70	139.86	13.26
397	381	a2alc2clblb2	19.86	140.94	19.83
398	517	b2bla2alclc2	19.86	140.94	19.83
399	669	c2clb2blala2	19.86	140.94	19.83
400	392	a2alc2clb2bl	20.05	141.14	20.03
401	518	b2bla2alc2cl	20.05	141.14	20.03
402	670	c2clb2bla2al	20.05	141.14	20.03
403	379	a2alc2blclb2	16.76	141.15	13.56
404	387	a2blalb2clc2	13.56	141.15	16.76
405	513	b2bla2clalc2	16.76	141.15	13.56
406	539	b2clblc2ala2	13.56	141.15	16.76
407	609	c2alcla2blb2	13.56	141.15	16.76
408	667	c2clb2albla2	16.76	141.15	13.56
409	364	a2alblb2c2cl	19.61	142.90	19.44
410	516	b2blclc2a2al	19.61	142.90	19.44
411	652	c2clala2b2bl	19.61	142.90	19.44
412	52	ala2blb2c2cl	19.81	143.22	19.63
413	204	blb2clc2a2al	19.81	143.22	19.63
414	340	clc2ala2b2bl	19.81	143.22	19.63
415	363	a2alblb2clc2	19.83	144.19	19.86
416	515	b2blclc2ala2	19.83	144.19	19.86
417	651	c2clala2blb2	19.83	144.19	19.86
418	51	ala2blb2clc2	20.03	144.49	20.05
419	203	blb2clc2ala2	20.03	144.49	20.05
420	339	clc2ala2blb2	20.03	144.49	20.05
421	34	alcla2b2c2bl	10.28	145.28	10.05
422	89	alb2a2c2blcl	10.05	145.28	10.28
423	138	blalb2c2a2cl	10.28	145.28	10.05
424	240	blc2b2a2clal	10.05	145.28	10.28
425	296	clblc2a2b2al	10.28	145.28	10.05
426	311	cla2c2b2albl	10.05	145.28	10.28
427	361	a2alblclb2c2	16.97	145.45	13.67
428	459	a2c2alclblb2	13.67	145.45	16.97
429	512	b2blclalc2a2	16.97	145.45	13.67
430	559	b2a2blalclc2	13.67	145.45	16.97
431	649	c2clalbla2b2	16.97	145.45	13.67
432	711	c2b2clblala2	13.67	145.45	16.97
433	49	ala2blclb2c2	17.04	146.11	13.71
434	200	blb2clalc2a2	17.04	146.11	13.71
435	337	clc2albla2b2	17.04	146.11	13.71
436	460	a2c2alclb2bl	13.71	146.11	17.04
437	560	b2a2blalc2cl	13.71	146.11	17.04
438	712	c2b2clbla2al	13.71	146.11	17.04
439	32	alcla2blc2b2	10.41	148.65	10.21
440	133	blalb2cla2c2	10.41	148.65	10.21
441	284	clblc2alb2a2	10.41	148.65	10.21
442	437	a2b2alc2blcl	10.21	148.65	10.41
443	588	b2c2bla2clal	10.21	148.65	10.41
444	689	c2a2clb2albl	10.21	148.65	10.41
445	87	alb2a2clblc2	10.07	151.30	10.39
446	235	blc2b2alcla2	10.07	151.30	10.39
447	309	cla2c2blalb2	10.07	151.30	10.39
448	412	a2clalb2c2bl	10.39	151.30	10.07
449	486	b2alblc2a2cl	10.39	151.30	10.07
450	634	c2blcla2b2al	10.39	151.30	10.07
451	12	albla2c2b2cl	11.23	151.31	10.96
452	114	alc2a2b2clbl	10.96	151.31	11.23
453	160	blclb2a2c2al	11.23	151.31	10.96
454	185	bla2b2c2alcl	10.96	151.31	11.23
455	264	clalc2b2a2bl	11.23	151.31	10.96
456	336	clb2c2a2blal	10.96	151.31	11.23
457	109	alc2a2blclb2	11.07	154.36	11.36
458	183	bla2b2clalc2	11.07	154.36	11.36
459	331	clb2c2albla2	11.07	154.36	11.36
460	390	a2blalc2b2cl	11.36	154.36	11.07
461	538	b2clbla2c2al	11.36	154.36	11.07
462	612	c2alclb2a2bl	11.36	154.36	11.07
463	410	a2clalblc2b2	10.47	154.58	10.19
464	435	a2b2alclblc2	10.19	154.58	10.47
465	481	b2alblcla2c2	10.47	154.58	10.19
466	583	b2c2blalcla2	10.19	154.58	10.47
467	632	c2blclalb2a2	10.47	154.58	10.19
468	687	c2a2clblalb2	10.19	154.58	10.47
469	7	albla2clb2c2	11.25	157.29	11.07
470	158	blclb2alc2a2	11.25	157.29	11.07
471	259	clalc2bla2b2	11.25	157.29	11.07
472	462	a2c2alb2clbl	11.07	157.29	11.25
473	563	b2a2blc2alcl	11.07	157.29	11.25
474	714	c2b2cla2blal	11.07	157.29	11.25
475	385	a2blalclb2c2	11.35	160.26	11.14
476	457	a2c2alblclb2	11.14	160.26	11.35
477	536	b2clblalc2a2	11.35	160.26	11.14
478	561	b2a2blclalc2	11.14	160.26	11.35
479	607	c2alclbla2b2	11.35	160.26	11.14
480	709	c2b2clalbla2	11.14	160.26	11.35
481	15	alblb2a2clc2	17.03	165.80	16.83
482	167	blclc2b2ala2	17.03	165.80	16.83
483	251	clala2c2blb2	17.03	165.80	16.83
484	378	a2alb2c2clbl	16.83	165.80	17.03
485	527	b2blc2a2alcl	16.83	165.80	17.03
486	666	c2cla2b2blal	16.83	165.80	17.03
487	16	alblb2a2c2cl	17.00	166.66	16.83
488	66	ala2b2c2clbl	16.83	166.66	17.00
489	168	blclc2b2a2al	17.00	166.66	16.83
490	215	blb2c2a2alcl	16.83	166.66	17.00
491	252	clala2c2b2bl	17.00	166.66	16.83
492	354	clc2a2b2blal	16.83	166.66	17.00
493	57	ala2clb2blc2	16.89	169.48	16.94
494	197	blb2alc2cla2	16.89	169.48	16.94
495	345	clc2bla2alb2	16.89	169.48	16.94
496	428	a2clc2alb2bl	16.94	169.48	16.89
497	494	b2ala2blc2cl	16.94	169.48	16.89
498	646	c2blb2cla2al	16.94	169.48	16.89
499	46	alclc2a2b2bl	17.10	170.25	16.89
500	71	ala2c2b2blcl	16.89	170.25	17.10
501	130	blala2b2c2cl	17.10	170.25	16.89
502	210	blb2a2c2clal	16.89	170.25	17.10
503	282	clblb2c2a2al	17.10	170.25	16.89
504	359	clc2b2a2albl	16.89	170.25	17.10
505	75	alb2bla2clc2	16.92	170.70	16.91
506	227	blc2clb2ala2	16.92	170.70	16.91
507	293	cla2alc2blb2	16.92	170.70	16.91
508	376	a2alb2clc2bl	16.91	170.70	16.92
509	524	b2blc2ala2cl	16.91	170.70	16.92
510	664	c2cla2blb2al	16.91	170.70	16.92
511	64	ala2b2clc2bl	16.91	171.40	16.90
512	76	alb2bla2c2cl	16.90	171.40	16.91
513	212	blb2c2ala2cl	16.91	171.40	16.90
514	228	blc2clb2a2al	16.90	171.40	16.91
515	294	cla2alc2b2bl	16.90	171.40	16.91
516	352	clc2a2blb2al	16.91	171.40	16.90
517	369	a2alclb2blc2	17.15	171.66	16.96
518	427	a2clc2alblb2	16.96	171.66	17.15
519	493	b2ala2blclc2	16.96	171.66	17.15
520	509	b2blalc2cla2	17.15	171.66	16.96

Table 5.16. (Continued)

RANK	CASE #	PHASE ARRANGEMENT	MAGNETIC FIELD -150	MAX	150
521	645	c2b1b2c1a1a2	16.96	171.66	17.15
522	657	c2c1b1a2a1b2	17.15	171.66	16.96
523	45	a1c1c2a2b1b2	17.13	172.51	17.18
524	129	b1a1a2b2c1c2	17.13	172.51	17.18
525	281	c1b1b2c2a1a2	17.13	172.51	17.18
526	383	a2a1c2b2b1c1	17.18	172.51	17.13
527	522	b2b1a2c2c1a1	17.18	172.51	17.13
528	671	c2c1b2a2a1b1	17.18	172.51	17.13
529	55	a1a2c1b1b2c2	16.82	172.61	16.93
530	194	b1b2a1c1c2a2	16.82	172.61	16.93
531	343	c1c2b1a1a2b2	16.82	172.61	16.93
532	470	a2c2c1a1b2b1	16.93	172.61	16.82
533	554	b2a2a1b1c2c1	16.93	172.61	16.82
534	706	c2b2b1c1a2a1	16.93	172.61	16.82
535	68	a1a2c2b1b2c1	16.84	173.35	17.11
536	106	a1c2c1a2b2b1	17.11	173.35	16.84
537	172	b1a2a1b2c2c1	17.11	173.35	16.84
538	208	b1b2a2c1c2a1	16.84	173.35	17.11
539	324	c1b2b1c2a2a1	17.11	173.35	16.84
540	356	c1c2b2a1a2b1	16.84	173.35	17.11
541	33	a1c1a2b2b1c2	13.97	173.59	16.83
542	137	b1a1b2c2c1a2	13.97	173.59	16.83
543	285	c1b1c2a2a1b2	13.97	173.59	16.83
544	431	a2c1c2b2a1b1	16.83	173.59	13.97
545	497	b2a1a2c2b1c1	16.83	173.59	13.97
546	648	c2b1b2a2c1a1	16.83	173.59	13.97
547	365	a2a1b1c2c1b2	17.08	173.61	17.18
548	397	a2b1b2a1c1c2	17.18	173.61	17.08
549	513	b2b1c1a2a1c2	17.08	173.61	17.18
550	543	b2c1c2b1a1a2	17.18	173.61	17.08
551	615	c2a1a2c1b1b2	17.18	173.61	17.08
552	653	c2c1a1b2b1a2	17.08	173.61	17.18
553	53	a1a2b1c2c1b2	17.10	174.52	17.15
554	201	b1b2c1a2a1c2	17.10	174.52	17.15
555	341	c1c2a1b2b1a2	17.10	174.52	17.15
556	398	a2b1b2a1c2c1	17.15	174.52	17.10
557	550	b2c1c2b1a2a1	17.15	174.52	17.10
558	616	c2a1a2c1b2b1	17.15	174.52	17.10
559	367	a2a1c1b1b2c2	17.08	174.78	16.94
560	469	a2c2c1a1b1b2	16.94	174.78	17.08
561	506	b2b1a1c1c2a2	17.08	174.78	16.94
562	553	b2a2a1b1c1c2	16.94	174.78	17.08
563	655	c2c1b1a1a2b2	17.08	174.78	16.94
564	705	c2b2b1c1a1a2	16.94	174.78	17.08
565	18	a1b1b2c2a2c1	16.79	174.87	13.51
566	90	a1b2a2c2c1b1	13.51	174.87	16.79
567	166	b1c1c2a2b2a1	16.79	174.87	13.51
568	239	b1c2b2a2a1c1	13.51	174.87	16.79
569	250	c1a1a2b2c2b1	16.79	174.87	13.51
570	312	c1a2c2b2b1a1	13.51	174.87	16.79
571	105	a1c2c1a2b1b2	17.13	175.58	17.12
572	171	b1a2a1b2c1c2	17.13	175.58	17.12
573	323	c1b2b1c2a1a2	17.13	175.58	17.12
574	380	a2a1c2b1b2c1	17.12	175.58	17.13
575	520	b2b1a2c1c2a1	17.12	175.58	17.13
576	668	c2c1b2a1a2b1	17.12	175.58	17.13
577	13	a1b1b2c1a2c2	17.08	176.31	13.93
578	164	b1c1c2a1b2a2	17.08	176.31	13.93
579	248	c1a1a2b1c2b2	17.08	176.31	13.93
580	438	a2b2a1c2c1b1	13.93	176.31	17.08
581	587	b2c2b1a2a1c1	13.93	176.31	17.08
582	690	c2a2c1b2b1a1	13.93	176.31	17.08
583	48	a1c1c2b2a2b1	17.23	176.58	14.39
584	113	a1c2a2b2b1c1	14.39	176.58	17.23
585	132	b1a1a2c2b2c1	17.23	176.58	14.39
586	186	b1a2b2c2c1a1	14.39	176.58	17.23
587	280	c1b1b2a2c2a1	17.23	176.58	14.39
588	335	c1b2c2a2a1b1	14.39	176.58	17.23
589	31	a1c1a2b1b2c2	14.07	177.46	16.96
590	134	b1a1b2c1c2a2	14.07	177.46	16.96
591	282	c1b1c2a1a2b2	14.07	177.46	16.96
592	473	a2c2c1b2a1b1	16.96	177.46	14.07
593	557	b2a2a1c2b1c1	16.96	177.46	14.07
594	708	c2b2b1a2c1a1	16.96	177.46	14.07
595	362	a2a1b1c1c2b2	17.14	178.20	17.04
596	439	a2b2b1a1c1c2	17.04	178.20	17.14
597	511	b2b1c1a1a2c2	17.14	178.20	17.04
598	591	b2c2c1b1a1a2	17.04	178.20	17.14
599	650	c2c1a1b1b2a2	17.14	178.20	17.04
600	675	c2a2a1c1b1b2	17.04	178.20	17.14
601	78	a1b2b1c2a2c1	16.55	178.62	13.45
602	88	a1b2a2c1c2b1	13.45	178.62	16.55
603	226	b1c2c1a2b2a1	16.55	178.62	13.45
604	236	b1c2b2a1a2c1	13.45	178.62	16.55
605	292	c1a2a1b2c2b1	16.55	178.62	13.45
606	310	c1a2c2b1b2a1	13.45	178.62	16.55
607	411	a2c1a1b2b1c2	13.74	178.88	16.62
608	429	a2c1c2b1a1b2	16.62	178.88	13.74
609	485	b2a1b1c2c1a2	13.74	178.88	16.62
610	495	b2a1a2c1b1c2	16.62	178.88	13.74
611	633	c2b1c1a2a1b2	13.74	178.88	16.62
612	643	c2b1b2a1c1a2	16.62	178.88	13.74
613	50	a1a2b1c1c2b2	17.17	179.06	17.03
614	199	b1b2c1a1a2c2	17.17	179.06	17.03
615	338	c1c2a1b1b2a2	17.17	179.06	17.03
616	440	a2b2b1a1c2c1	17.03	179.06	17.17
617	592	b2c2c1b1a2a1	17.03	179.06	17.17
618	676	c2a2a1c1b2b1	17.03	179.06	17.17
619	11	a1b1a2c2c1b2	14.40	179.28	17.18
620	159	b1c1b2a2a1c2	14.40	179.28	17.18
621	263	c1a1c2b2b1a2	14.40	179.28	17.18
622	401	a2b1b2c2a1c1	17.18	179.28	14.40
623	552	b2c1c2a2b1a1	17.18	179.28	14.40
624	618	c2a1a2b2c1b1	17.18	179.28	14.40
625	73	a1b2b1c1a2c2	16.82	180.01	13.85
626	224	b1c2c1a1b2a2	16.82	180.01	13.85
627	290	c1a2a1b1c2b2	16.82	180.01	13.85
628	436	a2b2a1c1c2b1	13.85	180.01	16.82
629	584	b2c2b1a1a2c1	13.85	180.01	16.82
630	688	c2a2c1b1b2a1	13.85	180.01	16.82
631	108	a1c2c1b2a2b1	17.38	180.33	14.50
632	110	a1c2a2b1b2c1	14.50	180.33	17.38
633	174	b1a2a1c2b2c1	17.38	180.33	14.50
634	184	b1a2b2c1c2a1	14.50	180.33	17.38
635	322	c1b2b1a2c2a1	17.38	180.33	14.50
636	332	c1b2c2a1a2b1	14.50	180.33	17.38
637	389	a2b1a1c2c1b2	14.77	180.58	17.44
638	399	a2b1b2c1a1c2	17.44	180.58	14.77
639	537	b2c1b1a2a1c2	14.77	180.58	17.44
640	547	b2c1c2a1b1a2	17.44	180.58	14.77
641	611	c2a1c1b2b1a2	14.77	180.58	17.44
642	613	c2a1a2b1c1b2	17.44	180.58	14.77
643	43	a1c1c2b1a2b2	17.04	181.88	14.18
644	127	b1a1a2c1b2c2	17.04	181.88	14.18
645	278	c1b1b2a1c2a2	17.04	181.88	14.18
646	461	a2c2a1b2b1c1	14.18	181.88	17.04
647	564	b2a2b1c2c1a1	14.18	181.88	17.04
648	713	c2b2c1a2a1b1	14.18	181.88	17.04
649	409	a2c1a1b1b2c2	13.83	182.62	16.73
650	471	a2c2c1b1a1b2	16.73	182.62	13.83

Table 5.16. (Continued)

RANK	CASE #	PHASE ARRANGEMENT	MAGNETIC FIELD -150	MAGNETIC FIELD MAX	MAGNETIC FIELD 150
651	482	b2a1b1c1c2a2	13.83	182.62	16.73
652	555	b2a2a1c1b1c2	16.73	182.62	13.83
653	631	c2b1c1a1a2b2	13.83	182.62	16.73
654	703	c2b2b1a1c1a2	16.73	182.62	13.83
655	8	a1b1a2c1c2b2	14.33	182.99	16.92
656	157	b1c1b2a1a2c2	14.33	182.99	16.92
657	260	c1a1c2b1b2a2	14.33	182.99	16.92
658	443	a2b2b1c2a1c1	16.92	182.99	14.33
659	594	b2c2c1a2b1a1	16.92	182.99	14.33
660	678	c2a2a1b2c1b1	16.92	182.99	14.33
661	386	a2b1a1c1c2b2	14.69	184.25	17.17
662	441	a2b2b1c1a1c2	17.17	184.25	14.69
663	535	b2c1b1a1a2c2	14.69	184.25	17.17
664	589	b2c2c1a1b1a2	17.17	184.25	14.69
665	608	c2a1c1b1b2a2	14.69	184.25	17.17
666	673	c2a2a1b1c1b2	17.17	184.25	14.69
667	103	a1c2c1b1a2b2	17.17	185.51	14.28
668	169	b1a2a1c1b2c2	17.17	185.51	14.28
669	320	c1b2b1a1c2a2	17.17	185.51	14.28
670	458	a2c2a1b1b2c1	14.28	185.51	17.17
671	562	b2a2b1c1c2a1	14.28	185.51	17.17
672	710	c2b2c1a1a2b1	14.28	185.51	17.17
673	17	a1b1b2c2c1a2	19.64	192.77	19.46
674	165	b1c1c2a2a1b2	19.64	192.77	19.46
675	249	c1a1a2b2b1c2	19.64	192.77	19.46
676	432	a2c1c2b2b1a1	19.46	192.77	19.64
677	498	b2a1a2c2c1b1	19.46	192.77	19.64
678	647	c2b1b2a2a1c1	19.46	192.77	19.64
679	47	a1c1c2b2b1a2	19.84	194.79	19.94
680	131	b1a1a2c2c1b2	19.84	194.79	19.94
681	279	c1b1b2a2a1c2	19.84	194.79	19.94
682	402	a2b1b2c2c1a1	19.94	194.79	19.84
683	551	b2c1c2a2a1b1	19.94	194.79	19.84
684	617	c2a1a2b2b1c1	19.94	194.79	19.84
685	14	a1b1b2c1c2a2	19.85	195.29	19.75
686	163	b1c1c2a1a2b2	19.85	195.29	19.75
687	247	c1a1a2b1b2c2	19.85	195.29	19.75
688	474	a2c2c1b2b1a1	19.75	195.29	19.85
689	558	b2a2a1c2c1b1	19.75	195.29	19.85
690	707	c2b2b1a2a1c1	19.75	195.29	19.85
691	77	a1b2b1c2c1a2	19.24	196.21	19.26
692	225	b1c2c1a2a1b2	19.24	196.21	19.26
693	291	c1a2a1b2b1c2	19.24	196.21	19.26
694	430	a2c1c2b1b2a1	19.26	196.21	19.24
695	496	b2a1a2c1c2b1	19.26	196.21	19.24
696	644	c2b1b2a1a2c1	19.26	196.21	19.24
697	107	a1c2c1b2b1a2	20.13	197.26	20.15
698	173	b1a2a1c2c1b2	20.13	197.26	20.15
699	321	c1b2b1a2a1c2	20.13	197.26	20.15
700	400	a2b1b2c1c2a1	20.15	197.26	20.13
701	548	b2c1c2a1a2b1	20.15	197.26	20.13
702	614	c2a1a2b1b2c1	20.15	197.26	20.13
703	44	a1c1c2b1b2a2	19.64	198.23	19.54
704	128	b1a1a2c1c2b2	19.64	198.23	19.54
705	277	c1b1b2a1a2c2	19.64	198.23	19.54
706	444	a2b2b1c2c1a1	19.54	198.23	19.64
707	592	b2c2c1a2a1b1	19.54	198.23	19.64
708	677	c2a2a1b2b1c1	19.54	198.23	19.64
709	74	a1b2b1c1c2a2	19.46	198.66	19.55
710	223	b1c2c1a1a2b2	19.46	198.66	19.55
711	289	c1a2a1b1b2c2	19.46	198.66	19.55
712	472	a2c2c1b1b2a1	19.55	198.66	19.46
713	556	b2a2a1c1c2b1	19.55	198.66	19.46
714	704	c2b2b1a1a2c1	19.55	198.66	19.46
715	104	a1c2c1b1b2a2	19.94	200.63	19.75
716	170	b1a2a1c1c2b2	19.94	200.63	19.75
717	319	c1b2b1a1a2c2	19.94	200.63	19.75
718	442	a2b2b1c1c2a1	19.75	200.63	19.94
719	590	b2c2c1a1a2b1	19.75	200.63	19.94
720	674	c2a2a1b1b2c1	19.75	200.63	19.94

6. CONCLUSIONS

6.1 Introduction

Exposure to magnetic fields is a topic of great importance right now. Currently, medical experts have not found out how or if magnetic fields interact with biological systems. It is believed that different magnitudes of magnetic fields may be harmful, while other magnitudes may not be. Researchers also suspect different frequencies may be harmful, while other frequencies may not be. In a typical dose–response relationship, if a little is bad, then more should be worse. Examples of this are ionizing radiation and harmful chemicals. Magnetic fields do not seem to behave in this typical dose–response relationship. This is probably where most of the research in the area of magnetic fields is needed. Both the scientific community and the medical community must cooperate in resolving this issue. The scientific community must find out the levels of fields that exist in our environment, while the medical community must find out if magnetic fields interact with biological systems, and if they do, at what levels and frequencies.

6.2 Summary of Work Completed

Work that has been completed at Iowa State University falls into the area of measuring and attempting to characterize magnetic fields that exist in our environment. This attempt began with obtaining a device to measure magnetic fields.

The original EPRI EMDEX unit was the first of its kind. It was a portable device that not only measured magnetic and electric field data at periodic intervals, it also stored this data in an on–board microprocessor. This data could later be off–loaded and analyzed. This device was used in the original EPRI EMDEX project which gathered magnetic and electric field data to which utility employees were exposed. The EMDEXC is the second generation of the EMDEX that has been released commercially. The EMDEXC has improvements over the original EMDEX in both the hardware and the software. This unit is currently being used in the follow–up EPRI EMDEX project where background magnetic field data is being gathered in homes all across the United States. Developed at Iowa State University for use with the EMDEXC is a measuring wheel that can be used to trigger the EMDEXC to collect data versus distance. This makes it possible to more accurately obtain field profiles around utility lines and to conduct field mapping studies.

Once the EMDEX and EMDEXC devices were obtained, it was possible to gather data when requested. Measurement activities involved going to a variety of sites, making measurements, off–loading the data, and analyzing it. After the analysis, a report was written and returned to the concerned party. This type of activity served two purposes. First, it informed the concerned party of the type of exposure to which they were being exposed. Second, it helped to educate Iowa State University of the levels that exist in particular environments.

Computer programs also play an important role in the understanding of magnetic and electric field behavior. Several programs are used in calculating the theoretical fields that exist because of the presence of electrical lines. Exposure assessment calculations are performed by one software package. A program was developed that varies a parameter over a given range, to determine the affects on fields produced. Another program developed calculates how to properly arrange the phase conductors to minimize the fields from a double three phase line.

6.3 Suggestion for Future Work

As suggested earlier, the scientific community needs to continue to develop tools to measure or predict the magnetic and electric fields that exist in our environment. Only then can meaningful magnetic and electric field limits be set if required in the future. This can be done through a variety of activities.

Whenever the opportunity exists, field data should be collected. These data can be used in building a database of fields that exist in our environment. Programs and techniques should continue to be developed to model field exposure. Only through the knowledge of current exposure levels, can future exposure levels be lowered if required.

The scientific community should continue to keep up to date on what the medical community is finding on the health effects issue. The scientific community can then keep its research working in the same direction as the medical community.

7. APPENDIX A

DNA – Deoxyribonucleic acid

DVM – Doctor of Veterinary Medicine

ELF – Extremely low frequency

EMDEX – Electric and magnetic field digital exposure

EMDEXC – Commercial version of EMDEX

EMF – Electric and magnetic fields

EPA – Environmental Protection Agency

EPRI – Electric Power Research Institute

ITEF – Iowa Test and Evaluation Facility

PC – Personal computer

TLWorkstation – Transmission Line Workstation

8. APPENDIX B

```
      Program TLRead

c*************************************************************************
c** Program TLRead      **************************************************
c** by Alan J. Mitchell **************************************************
c** February 3, 1990    **************************************************
c*                                                                       *
c* This program is designed to reformat the EN*.005 file output from     *
c* the TLWorkstation.  It puts the output file in the form of            *
c*                                                                       *
c*                      x f(x)                                           *
c*                                                                       *
c* where x is a distance and f(x) is the magnitude of the resultant      *
c* magnetic field at that distance.  This output file can be imported    *
c* into LOTUS123 and graphed.                                            *
c*                                                                       *
c** VARIABLES           **************************************************
c*                                                                       *
c* InName is the name of the EN*.005 file output from the TLWorkstation *
c* OutName is the name of the output file from TLRead                    *
c* X is the distance                                                     *
c* Mag is the magnetic field at that particular distance                 *
c*************************************************************************

      Character InName*12, OutName*12, X*12, Mag*12

c** Input and Output filenames are declared ****************************

      Write(*,*)'What is the input file name?'
      Read(*,9)InName
    9 Format(a12)
      Write(*,*)'What is the output file name?'
      Read(*,9)OutName

      Open(unit=8, File = InName, status = 'old')
      Open(unit=7, File = OutName, status = 'new')

c** Data is read in from InName, and written back out to OutName ********

      Read(8,6)
    6 Format(1x)
    7 Read(unit=8,fmt=9,end=200) X
      Read(8,9) Mag
      Write(7,10) X, Mag
   10 Format(1x, a12, 4x, a12)
      Goto 7

  200 End
```

9. APPENDIX C

```
      PROGRAM MAGFIELD

      INTEGER P,nc,done,pc
      CHARACTER*30 D2
      CHARACTER*1 swap
      CHARACTER*80 F2,P2
      CHARACTER*6 FILE2,FILE1
      DOUBLE PRECISION PII

      INCLUDE "shvar"

   23 write(*,*)'How many 3 phase ciruits will you have (1 or 2)?'
      read(*,*)nc
      if ((nc.ne.1).and.(nc.ne.2)) then
         goto 23
      end if
      pc=nc*3
      if (pc.eq.6) then
         write(*,*)'Can these lines be swapped from circuit to circuit
     & (y or n)?'

         read(*,24)swap
   24    format(a1)
      endif

      done = 6
      if (pc.eq.6) then
         if (swap.eq.'y') then
            done = 720
         else
            done = 36
         endif
      endif

      CALL LINE(done,nc,pc)
C     ****************************************************************
C        subroutine for inputing general data
C        input general data

      INDX = 0
      OPEN (UNIT=99,FILE='ed.dat',STATUS='OLD')
C     Enter Name
   10 INDX=INDX+1
      READ(99,6,err=103) F2
    6 FORMAT(A80)
C     Enter Today's Date
      READ(99,7) D2
    7 FORMAT(A30)
C     Enter a Description of the Problem
      READ(99,6) P2
      CALL XYDATA

      READ(99,8) FILE1
      READ(99,8) FILE2
    8 FORMAT(A6)


C     FCT = factor, K = constant, TOG = toggle, DELT = difference
      RHO = 0.d0
      GRT = 0.d0
      gw = 0
      DSTRT = 0.d0
      DSTOP = 0.d0
      STP = 0.d0
      PLINE = 0.d0
C     ****************************************************************
C     subroutine for inputing phase conductor data
```

```
      CALL PHDATA
C     ***********************************************************************
C     subroutine for inputing static wire data
      CALL STWRDATA

      CALL HPDATA

C     ***********************************************************************
C     convert phase currents to rectangular form
      PII = 4.d0*DATAN(1.d0)
      DO 100 P = 1,PC
         IPR(P) = CUR(P) * DCOS(ANG(P) * PII / 180.D0)
         IPM(P) = CUR(P) * DSIN(ANG(P) * PII / 180.D0)
  100 CONTINUE
C     ***********************************************************************
C     subroutine for calculating static wire currents
      CALL STCURR
C     ***********************************************************************

      CALL HPROFILE(P2,FILE2)
      GOTO 10
  103 CALL SORT(done)
      END


      SUBROUTINE BFIELD(J)

      INTEGER G
      DOUBLE PRECISION K1,DELTX,DELTY,DELIM,HVEC,VVEC,S1,S2,BXSQR,
     &   THETA,ATOP,ABOT,OMEG1,OMEG2,TCOS1,TCOS2,PCOS1,PCOS2,B2SQR,
     &   B1SQR,PHI,PII
      INCLUDE "shvar"

C     this K1 is for dimensions in feet and output in milligauss
      K1 = 6.5616798d0
      PII = 4.d0*DATAN(1.d0)
      BXR(J) = 0.D0
      BXM(J) = 0.D0
      BYR(J) = 0.D0
      BYM(J) = 0.D0
C     ***********************************************************************
C     calculate B-field from phase conductors
      DO 200 I = 1,PC
C        clause to prevent division by zero
         IF ((XT(J) .EQ. PX(I)) .AND. (YT(J) .EQ. PY(I))) THEN
            XT(J) = XT(J) + .1d0
         ENDIF
C        calculate unit vectors
         DELTX = PX(I) - XT(J)
         DELTY = PY(I) - YT(J)
         DELIM = YT(J) + 2887.d0
C        s1 is square of distance from phase to test point
         S1 = DELTX**2 + DELTY**2
C        s2 is square of distance from image of phase to test point
         S2 = DELTX**2 + DELIM**2
         HVEC = DELTY / S1 + DELIM / S2
         VVEC = DELTX / S1 - DELTX / S2
C        calculate horizontal flux density component
         BXR(J) = BXR(J) +  K1 * IPR(I) * HVEC
         BXM(J) = BXM(J) +  K1 * IPM(I) * HVEC
C        calculate vertical flux density component
         BYR(J) = BYR(J) +  K1 * IPR(I) * VVEC
         BYM(J) = BYM(J) + K1 * IPM(I) * VVEC
  200 CONTINUE
      IF (GW .NE. 0) THEN
C        ***********************************************************************
C        calculate B-field from static wires
         DO 300 G = 1 ,gw
C           clause to prevent division by zero
```

```
            IF ((XT(J) .EQ. gx(G)) .AND. (YT(J) .EQ. GY(G))) THEN
               XT(J) = XT(J) + .1d0
            ENDIF
C           calculate unit vectors
            DELTX = gx(G) - XT(J)
            DELTY = GY(G) - YT(J)
C           depth of earth return current is 880 meters or 2887 feet
            DELIM = YT(J) + 2887.D0
C           s1 is square of distance from static wire to test point
            S1 = DELTX**2 + DELTY**2
C           s2 is square of distance from image of static wire to test point
            S2 = DELTX**2 + DELIM**2
            HVEC = DELTY / S1 + DELIM / S2
            VVEC = DELTX / S1 - DELTX / S2
C           calculate horizontal flux density component
            BXR(J) = BXR(J) + K1 * IGR(G) * HVEC
            BXM(J) = BXM(J) + K1 * IGM(G) * HVEC
C           calculate vertical flux density component
            BYR(J) = BYR(J) + K1 * IGR(G) * VVEC
            BYM(J) = BYM(J) + K1 * IGM(G) * VVEC
 300     CONTINUE
      ENDIF
C     ******************************************************************
C     convert horizontal flux density to polar form
      BXSQR = BXR(J)**2 + BXM(J)**2
C     check for division by zero
      IF (DABS(BXR(J)) .lt. .00001d0) THEN
         THETA = PII / 2.D0
      ELSE
         THETA = DATAN(BXM(J) / BXR(J))
      ENDIF
C     convert vertical flux density to polar form
      BYSQR = BYR(J)**2 + BYM(J)**2
C     check for division by zero
      IF (DABS(BYR(J)) .lt. .00001d0) THEN
         PHI = PII / 2.D0
      ELSE
         PHI = DATAN(BYM(J) / BYR(J))
      ENDIF
C     ******************************************************************
C     calculate major / minor axis angles of the ellipse
      ATOP = BXSQR * DSIN(2.D0 * THETA) + BYSQR * DSIN(2.D0 * PHI)
      ABOT = BXSQR * DCOS(2.D0 * THETA) + BYSQR * DCOS(2.D0 * PHI)
      OMEG1 = .5D0 * DATAN(-ATOP / ABOT)
      OMEG2 = OMEG1 + 1.5707963D0
C     ******************************************************************
C     calculate the maximum/minimum flux densities
      TCOS1 = (DCOS(OMEG1 + THETA))**2
      PCOS1 = (DCOS(OMEG1 + PHI))**2
      B1SQR = BXSQR * TCOS1 + BYSQR * PCOS1
      B1 = (B1SQR)**.5d0
C     cannot predict if B1 or B2 will be the maximum --test it
      TCOS2 = (DCOS(OMEG2 + THETA))**2
      PCOS2 = (DCOS(OMEG2 + PHI))**2
      B2SQR = BXSQR * TCOS2 + BYSQR * PCOS2
      B2 = (B2SQR)**.5d0
      IF (B1 .lt. B2) THEN
         MX(J) = B1
         MN(J) = B2
      ELSE
         MX(J) = B2
         MN(J) = B1
      ENDIF
      BX(J) = (BXSQR)**.5d0
      BY(J) = (BYSQR)**.5d0
      END

      SUBROUTINE BFMUTZ(I,P)
```

```
      INTEGER P,I
      DOUBLE PRECISION DELTX,DELTY,S1,S2,KEP,KSP,THETA

C     calculate mutual impedance between wires
C     reference EPRI red book - section 3.4

      double precision kep,ksp

      INCLUDE "shvar"

      DELTX = gx(I) - PX(P)
      DELTY = GY(I) - PY(P)
      DELIM = GY(I) + PY(P)
C     s1 is distance (feet) between phase & static
      S1 = (DELTX**2 + DELTY**2)**.5d0
C     s2 is distance (feet) from phase image & static
      S2 = (DELTX**2 + DELIM**2)**.5d0
      KEP = S2 / (RHO)**.5d0
      KSP = S2 / S1
      THETA = DATAN(DABS(DELTX / DELIM))
C     mutual impedance by Carson's earth return equations
      RPG=9.530153199999999D-02 - .00037948027D0 * KEP * DCOS(THETA)
      RPG=RPG+.000004260004D0 * KEP**2 * DCOS(2.D0*THETA)
      RPG=RPG-.00000066756096D0 * KEP**2 * DCOS(2.D0*THETA) * DLOG(KEP)
      RPG=RPG+.00000066756096D0 * THETA * KEP**2 * DSIN(2.D0*THETA)
      RPG=RPG+.0000000011134452D0 * DCOS(3.D0*THETA) * KEP**3
      RPG=RPG-9.6148048D-13 * DCOS(4.D0 * THETA) * KEP**4
C     reactance formula includes Xd(ij)
      XPG=.68332844D0 + .12134168D0 * DLOG(KSP) - .12134168D0*DLOG(KEP)
      XPG=XPG + .00037948027D0 * KEP * DCOS(THETA)
      XPG=XPG - .000000052430115D0 * KEP**2 * DCOS(2.D0*THETA)
      XPG=XPG + .0000000011134452D0 * DCOS(3.D0*THETA) * KEP**3
      XPG=XPG - 8.3222085D-12 * DCOS(4.D0*THETA) * KEP**4
      XPG=XPG + 1.224195D-12 * DCOS(4.D0*THETA) * KEP**4 * DLOG(KEP)
      XPG=XPG - 1.224195D-12 * THETA * DSIN(4.D0*THETA) * KEP**4
      END


      SUBROUTINE HPDATA

      INCLUDE "shvar"

C     subroutine for inputing horizontal profile data
C     Enter the  'X' COORDINATE of the START of the Profile
      READ(99,400) DSTRT
C     Enter the  'X' COORDINATE of the FINISH of the Profile
      READ(99,400) DSTOP
  400 FORMAT(d8.2)
C     Enter the STEP or INCREMENT SIZE in feet
      READ(99,410) STP
  410 FORMAT(d5.2)
      PLINE = 3.28D0
      END


      SUBROUTINE HPROFILE(P2,FILE2)

      INTEGER M,J
      CHARACTER*6 FILE2
      CHARACTER*80 P2
      DOUBLE PRECISION X(100)

      INCLUDE "shvar"

C     subroutine for horizontal profile
C     flux density format
      M = INT(DABS((DSTOP - DSTRT) / STP)) + 1.D0
      OPEN(unit=101,file=file2)
```

```
      If(INDX.eq.1) then
         write(*,*)'COMPUTING B-FIELDS CASES'
      endif
      WRITE(101,*) INDX
      WRITE(101,500) P2
 500  FORMAT(A80)
      DO 510 J = 1,M
         YT(J) = PLINE
         XT(J) = DSTRT + (J - 1) * STP
         X(J) = XT(J)
         CALL BFIELD(J)
         WRITE(101,505)XT(J),(BX(J)**2 + BY(J)**2)**.5d0
 505     FORMAT(f8.2,f7.2)
 510  CONTINUE
      CLOSE(101)
      END


      SUBROUTINE LINE (done,nc,pc)
      integer i,gw,done,nc,pc
      character*8 outfile
      character*1 ans
      Double Precision af(2),pii,pf(2),span(2),gmr(2),pgmr(2),
     &presist(2)

      INCLUDE "shvar1"

      ****************************************************************
      open(unit=9,file='infile',status='old')
      pii = 4.0*atan(1.0)
 201  write(*,*)'What is the output file name? '
      read(9,5)outfile
    5 format(a8)
      open(unit=8,file=outfile,status='unknown')
      write(*,*)'What is your name or initials? '
      read(9,5) name
      write(*,*)'What is the date? '
      read(9,5) date
      do 240 i = 1,nc
         write(*,*)'What is the magnitude of the current in circuit #',i
     &,'?'
         read(9,*)mag(i**2)
         mag(i**2+1)=mag(i**2)
         mag(i**2+2)=mag(i**2)
         write(*,*)'What is the power factor in circuit #',i,'? (- indic
     &ates lag) '
         read(9,*)pf(i)
         if (pf(i).lt.0.0) then
            af(i)=acos(pf(i))*180.0/pii-180.0
         else
            af(i)=acos(pf(i))*180.0/pii
         endif
 240  continue
      ang(1)=0.0+af(1)
      ang(2)=240.0+af(1)
      ang(3)=120.0+af(1)
      ang(4)=0.0+af(2)
      ang(5)=240.0+af(2)
      ang(6)=120.0+af(2)
      write(*,*)'Output filename is ',outfile
      write(*,*)'Your name or initials are    ',name
      write(*,*)'The date is                   ',date
      do 241 i = 1, nc
         write(*,*)'Current in circuit #',i,' is    ',mag(i**2),'   /_',a
     &f(i)
 241  continue
      write(*,*)'Are these O.K.?'
      read(*,501)ans
      if (ans .eq. 'n') then
```

```
        goto 201
      endif
 601  do 3 i = 1,pc
         write(*,1)i
  1      format('What is X',i1,'? ')
         read(9,*)px(i)
         write(*,2)i
  2      format('What is Y',i1,'? ')
         read(9,*)py(i)
  3   continue
      write(*,*)'How many shield wires will you have?'
      read(*,32)gw
 32   format(i1)
      do 4 i = 1,gw
         write(*,1)i
         read(9,*)sx(i)
         write(*,2)i
         read(9,*)sy(i)
  4   continue
      write(*,*)'                     x(i)        y(i)'
      do 506 i = 1,pc
         write(*,507)i,px(i),py(i)
 506  continue
 507  format('Phase #',i1,6x,f7.2,2x,f7.2)
      do 606 i = 1,gw
         write(*,607)i,sx(i),sy(i)
 606  continue
 607  format('Shield #',i1,5x,f7.2,2x,f7.2)
      write(*,*)'Are these O.K.?'
      read(*,501)ans
 501  format(a1)
      if (ans .eq. 'n') then
         goto 601
      endif
 701  do 702 i = 1,gw
       write(*,*)'For circuit with static wire #',i,':'
       write(*,*)'What is the average span of towers? '
       read(9,*)span(i)
       write(*,*)'What is the geometric mean radius of the phase wire? '
       read(9,*)pgmr(i)
      write(*,*)'What is the geometric mean radius of the shield wire? '
       read(9,*)gmr(i)
       write(*,*)'What is the resistance of the phase wire (ohms/mile)?'
       read(9,*)presist(i)
      write(*,*)'What is the resistance of the shield wire (ohms/mile)?'
       read(9,*)resist(i)
 702  continue
      do 703 i = 1,gw
         write(*,*)'For circuit with static wire #',i,':'
         write(*,*)'The average span is                      ',span(i)
         write(*,*)'The GMR of the phase wire is            ',pgmr(i)
         write(*,*)'The GMR of the shield wire is            ',gmr(i)
         write(*,*)'The resistance of the phase wire is   ',presist(i)
         write(*,*)'The resistance of the shield wire is   ',resist(i)
 703  continue
      write(*,*)'Are these O.K.?'
      read(*,501)ans
      if (ans .eq. 'n') then
         goto 701
      endif
      if (done.eq.720) then
         CALL CASE720
      endif
      if (done.eq.36) then
         CALL CASE36
      endif
      if (done.eq.6) then
         CALL CASE6
      endif
```

```
      end

      SUBROUTINE CASE6

      integer i,count,a1,b1,c1
      character*2 ph(3)

      INCLUDE "shvar1"

      count=0
      ph(1)='a1'
      ph(2)='b1'
      ph(3)='c1'

      write(*,*)'GENERATING THE 6 INPUT CASES'
    5 format(a8)
      do 100 a1 = 1,3
         do 200 b1 = 1,3
            if (b1.eq.a1) then
               goto 200
            endif
            do 300 c1 = 1,3
               if ((c1.eq.a1).or.(c1.eq.b1)) then
                  goto 300
               endif
               count = count + 1
               write(8,6)name
               write(8,6)date
    6          format(a8)
               write(8,7)ph(a1),ph(b1),ph(c1)
    7          format(a2,a2,a2)
               write(8,*)'3'
               write(8,31)px(1)
               write(8,31)py(1)
               write(8,31)px(2)
               write(8,31)py(2)
               write(8,31)px(3)
               write(8,31)py(3)
               write(8,8)count
    8          format('tot00',i1)
               write(8,11)count
   11          format('lot00',i1)
   30          write(8,*)'100'
               write(8,*)'.5'

               write(8,31)mag(a1)
               write(8,31)ang(a1)
               write(8,31)mag(b1)
               write(8,31)ang(b1)
               write(8,31)mag(c1)
               write(8,31)ang(c1)
   31          format(f5.1)

               write(8,32)gw
   32          format(i1)
               do 35 i = 1,gw
                  write(8,31)sx(i)
                  write(8,31)sy(i)
                  write(8,37)span(i)
   37             format(i4)
                  write(8,38)gmr(i)
   38             format(f5.4)
                  write(8,39)resist(i)
   39             format(f6.4)
   35          continue
               write(8,*)'-150.0'
               write(8,*)'150.0'
               write(8,*)'5.0'
```

```
300         continue
200      continue
100  continue
     close(31)
     end

     SUBROUTINE CASE36

     integer i,count,a1,b1,c1,a2,b2,c2
     character*2 ph(6)

     INCLUDE "shvar1"

     count=0
     ph(1)='a1'
     ph(2)='b1'
     ph(3)='c1'
     ph(4)='a2'
     ph(5)='b2'
     ph(6)='c2'

     write(*,*)'GENERATING THE 36 INPUT CASES'
  5  format(a8)
     do 100 a1 = 1,3
        do 200 b1 = 1,3
           if (b1.eq.a1) then
              goto 200
           endif
           do 300 c1 = 1,3
              if ((c1.eq.a1).or.(c1.eq.b1)) then
                 goto 300
              endif
              do 400 a2 = 4,6
                 do 500 b2 = 4,6
                    if (b2.eq.a2) then
                       goto 500
                    endif
                    do 600 c2 = 4,6
                       if ((c2.eq.a2).or.(c2.eq.b2)) then
                          goto 600
                       endif
                       count = count + 1
                       write(8,6)name
                       write(8,6)date
 6                     format(a8)
                       write(8,7)ph(a1),ph(b1),ph(c1),ph(a2),ph(b2),
    &ph(c2)
 7                     format(a2,a2,a2,a2,a2,a2)

                       write(8,*)'6'
                       write(8,31)px(1)
                       write(8,31)py(1)
                       write(8,31)px(2)
                       write(8,31)py(2)
                       write(8,31)px(3)
                       write(8,31)py(3)
                       write(8,31)px(4)
                       write(8,31)py(4)
                       write(8,31)px(5)
                       write(8,31)py(5)
                       write(8,31)px(6)
                       write(8,31)py(6)

                       if (count.le.9) then
                          write(8,8)count
 8                        format('tot00',i1)
                          goto 20
                       endif
```

```
                       write(8,9)count
 9                     format('tot0',i2)
20                     if (count.le.9) then
                          write(8,11)count
11                        format('lot00',i1)
                          goto 30
                       endif
                       write(8,12)count
12                     format('lot0',i2)
30                     write(8,*)'100'
                       write(8,*)'.5'

                       write(8,31)mag(a1)
                       write(8,31)ang(a1)
                       write(8,31)mag(b1)
                       write(8,31)ang(b1)
                       write(8,31)mag(c1)
                       write(8,31)ang(c1)
                       write(8,31)mag(a2)
                       write(8,31)ang(a2)
                       write(8,31)mag(b2)
                       write(8,31)ang(b2)
                       write(8,31)mag(c2)
                       write(8,31)ang(c2)
31                     format(f5.1)

                       write(8,32)gw
32                     format(i1)
                       do 35 i = 1,gw
                          write(8,31)sx(i)
                          write(8,31)sy(i)
                          write(8,37)span(i)
37                        format(i4)
                          write(8,38)gmr(i)
38                        format(f5.4)
                          write(8,39)resist(i)
39                        format(f6.4)
35                     continue
                       write(8,*)'-150.0'
                       write(8,*)'150.0'
                       write(8,*)'5.0'
600                 continue
500               continue
400            continue
300          continue
200        continue
100     continue
        close(31)
        end

        SUBROUTINE CASE720

        integer i,count,a1,b1,c1,a2,b2,c2
        character*2 ph(6)

        INCLUDE "shvar1"

        count=0
        ph(1)='a1'
        ph(2)='b1'
        ph(3)='c1'
        ph(4)='a2'
        ph(5)='b2'
        ph(6)='c2'

        write(*,*)'GENERATING THE 720 INPUT CASES'
 5      format(a8)
        do 100 a1 = 1,6
```

```
      do 200 b1 = 1,6
         if (b1.eq.a1) then
            goto 200
         endif
         do 300 c1 = 1,6
            if ((c1.eq.a1).or.(c1.eq.b1)) then
               goto 300
            endif
            do 400 a2 = 1,6
               if ((a2.eq.a1).or.(a2.eq.b1).or.(a2.eq.c1)) then
                  goto 400
               endif
               do 500 b2 = 1,6
                  if ((b2.eq.a1).or.(b2.eq.b1).or.(b2.eq.c1).or.
     &(b2.eq.a2)) then
                     goto 500
                  endif
                  do 600 c2 = 1,6
                     if ((c2.eq.a1).or.(c2.eq.b1).or.(c2.eq.c1).or.
     &(c2.eq.a2).or.(c2.eq.b2)) then
                        goto 600
                     endif
                     count = count + 1
                     write(8,6)name
                     write(8,6)date
 6                   format(a8)
                     write(8,7)ph(a1),ph(b1),ph(c1),ph(a2),ph(b2),
     &ph(c2)
 7                   format(a2,a2,a2,a2,a2,a2)

                     write(8,*)'6'
                     write(8,31)px(1)
                     write(8,31)py(1)
                     write(8,31)px(2)
                     write(8,31)py(2)
                     write(8,31)px(3)
                     write(8,31)py(3)
                     write(8,31)px(4)
                     write(8,31)py(4)
                     write(8,31)px(5)
                     write(8,31)py(5)
                     write(8,31)px(6)
                     write(8,31)py(6)

                     if (count.le.9) then
                        write(8,8)count
 8                      format('tot00',i1)
                        goto 20
                     endif
                     if (count.le.99) then
                        write(8,9)count
 9                      format('tot0',i2)
                        goto 20
                     endif
                     write(8,10)count
 10                  format('tot',i3)
 20                  if (count.le.9) then
                        write(8,11)count
 11                     format('lot00',i1)
                        goto 30
                     endif
                     if (count.le.99) then
                        write(8,12)count
 12                     format('lot0',i2)
                        goto 30
                     endif
                     write(8,13)count
 13                  format('lot',i3)
 30                  write(8,*)'100'
```

```
                              write(8,*)'.5'

                              write(8,31)mag(a1)
                              write(8,31)ang(a1)
                              write(8,31)mag(b1)
                              write(8,31)ang(b1)
                              write(8,31)mag(c1)
                              write(8,31)ang(c1)
                              write(8,31)mag(a2)
                              write(8,31)ang(a2)
                              write(8,31)mag(b2)
                              write(8,31)ang(b2)
                              write(8,31)mag(c2)
                              write(8,31)ang(c2)
   31                         format(f5.1)

                              write(8,32)gw
   32                         format(i1)
                              do 35 i = 1,gw
                                 write(8,31)sx(i)
                                 write(8,31)sy(i)
                                 write(8,37)span(i)
   37                            format(i4)
                                 write(8,38)gmr(i)
   38                            format(f5.4)
                                 write(8,39)resist(i)
   39                            format(f6.4)
   35                         continue
                              write(8,*)'-150.0'
                              write(8,*)'150.0'
                              write(8,*)'5.0'
  600                      continue
  500                   continue
  400                continue
  300             continue
  200        continue
  100 continue
      close(31)
      end

      SUBROUTINE PHDATA

      INTEGER I
      INCLUDE "shvar"

C     subroutine for inputing phase conductor data
C     Enter the EARTH RESISTIVITY ( RHO ) in Ohm-Meters

      READ(99,600) RHO
  600 FORMAT(d5.0)
C     Enter the Average 'Apparent' RESISTANCE of the TOWER Ground in Ohms
      READ(99,610) GRT
  610 FORMAT(d7.3)
C     *********************************************************************

      DO 620 I = 1,PC
         IC = I + 7
         IF (I .GT. 15) THEN
            IC = I - 8
         ENDIF
C        Enter the CURRENT in amps
         READ(99,615) CUR(I)
  615    FORMAT(d7.2)
C        Enter the PHASE ANGLE in degrees
         READ(99,618) ANG(I)
  618    FORMAT(d8.2)
  620 CONTINUE
      END
```

```
      SUBROUTINE SORT(done)

      integer i,index(720),switch,itemp,done
      Double Precision min(720),max(720),temp,chk,num(720),x
      character*12 title(720),atemp
      character*10 infile
      character*3 char3
      character*2 char2
      character*1 char1

      open(unit=8,file='sum.dat',status='unknown')
      write(*,*)'REVIEWING'
      do 100 i = 1,done
         if (i.le.9) then
            write(char1,'(i1)')i
            infile = 'lot00'//char1
            open(unit=7,file=infile,status='old')
            goto 110
         endif
         if (i.le.99) then
            write(char2,'(i2)')i
            infile = 'lot0'//char2
            open(unit=7,file=infile,status='old')
            goto 110
         endif
         write(char3,'(i3)')i
         infile = 'lot'//char3
         open(unit=7,file=infile,status='old')
110      read(7,*)index(i)
         read(7,*)title(i)
         chk=0.0
         read(7,115)x,min(i)
 70      read(7,115,err=100)x,chk
115      format(f8.2,f7.2)
         if (chk.gt.max(i)) then
            max(i)=chk
            goto 70
         endif
116      read(7,115)x,num(i)
         if (x.lt.150.0)then
            goto 116
         endif
100   continue
      switch=1
      write(*,*)'SORTING'
120   if (switch.eq.1) then
         switch=0
         do 130 j = 2,done
            if (max(j).lt.max(j-1)) then
               temp=max(j)
               max(j)=max(j-1)
               max(j-1)=temp
               temp=min(j)
               min(j)=min(j-1)
               min(j-1)=temp
               atemp = title(j)
               title(j)=title(j-1)
               title(j-1)=atemp
               itemp=index(j)
               index(j)=index(j-1)
               index(j-1)=itemp
               temp=num(j)
               num(j)=num(j-1)
               num(j-1)=temp
               switch=1
            endif
130      continue
```

```
            goto 120
        endif
        do 150 i = 1,done
           write(8,131)i,index(i),title(i),min(i),max(i),num(i)
  131      format(i3,1x,i3,1x,a12,1x,f6.2,1x,f6.2,1x,f6.2)
  150   continue
        end

        SUBROUTINE STCURR

        INTEGER P
        double precision kes,kss,rgg,xgg,rgs,xgs,rg,xg,fct1,fct2
        double precision fct3,fct4,PII
        INCLUDE "shvar"

C       subroutine for calculating static wire currents
C       routine for developing the 'A' impedance matrix
C       calculate mutual impedance between phase and static wires
C       reference EPRI red book - section 3.4

        PII = 4.d0*DATAN(1.d0)
        DO 700 I = 1,gw
           VGR(I) = 0.D0
           VGM(I) = 0.D0
           DO 710 P = 1,PC
              RPG = 0.D0
              XPG = 0.D0
              CALL BFMUTZ(I, P)
C             build static wire voltage matrix 'C'
C             summation of voltages from all phases (volts per mile)
              VGR(I) = VGR(I) + IPR(P) * RPG - IPM(P) * XPG
              VGM(I) = VGM(I) + IPR(P) * XPG + IPM(P) * RPG
  710      CONTINUE
C           real & imaginary are kept separate in 'C' matrix
            J = (2 * I) - 1
            K = 2 * I
            CM(J) = VGR(I) * SPAN(I) / 5280.D0
            CM(K) = VGM(I) * SPAN(I) / 5280.D0
            VG(I) = 1.7320508D0 * (CM(J)**2 + CM(K)**2)**.5d0
            VGANG(I) = DATAN(CM(K) / CM(J)) * 180.D0 / PII
            IF (CM(J) .LT. 0.d0) THEN
               VGANG(I) = VGANG(I) + 180.D0
            ENDIF
  700   CONTINUE
C       ***********************************************************
C       compute mutual impedance between static wires
        IF (GW .NE. 1) THEN
           DO 730 I = 1,gw
              DO 740 G = (I + 1),gw
                 RGG = 0.D0
                 XGG = 0.D0
                 CALL BFMUTZ(I, G)
C                build static wire impedance  matrix 'A'
                 Q = 2 * I
                 R = (2 * I) - 1
                 J = (2 * G) - 1
                 K = 2 * G
C                mutual R + jX are the off-diagonal elements of matrix
                 A(J,R) = -RGG * SPAN(I) / 5280.D0
                 A(J,Q) = XGG * SPAN(I) / 5280.D0
                 A(K,R) = -XGG * SPAN(I) / 5280.D0
                 A(K,Q) = -RGG * SPAN(I) / 5280.D0
                 A(R,J) = -RGG * SPAN(I) / 5280.D0
                 A(Q,J) = -XGG * SPAN(I) / 5280.D0
                 A(R,K) = XGG * SPAN(I) / 5280.D0
                 A(Q,K) = -RGG * SPAN(I) / 5280.D0
  740         CONTINUE
  730      CONTINUE
```

```
      ENDIF
C     ******************************************************************
C     calculate the self impedance of static wires
      DO 750 I = 1,gw
         RGS = 0.D0
         XGS = 0.D0
         KES = GY(I) / (RHO)**.5d0
         KSS = GY(I) / GMR(I)
C        Carson's earth equations for self impedance (combined)
         RGS = 9.530153299999999D-02 - .00075896054D0 * KES
         RGS= RGS + .00001518913D0 * KES**2
         RGS=RGS - .000002670243SD0 * KES**2 * DLOG(KES)
         RGS=RGS+.0000000089075616D0*KES**3 - 1.5383687D-11*KES**4
C        reactance formula includes Xa
         XGS=.68332844D0 + .12134168D0 * DLOG(KSS)
         XGS=XGS - .12134168D0 * DLOG(KES)
         XGS=XGS + .00075896053D0 * KES
         XGS=XGS - .0000020972045D0 * KES**2
         XGS=XGS + .0000000089075616D0 * KES**3
         XGS=XGS - 1.1957858D-10 * KES**4
         XGS=XGS + 1.9587119D-11 * DLOG(KES) * KES**4
c         write(*,*)'RGS    XGS',rgs,xgs
C        add conductor resistance and resistance of two towers
         RG = (SPAN(I) / 5280.D0) * (GRI(I) + RGS) + (2.D0 * GRT)
         XG = (SPAN(I) / 5280.D0) * XGS
C        add to static wire impedance matrix 'A'
         J = (2 * I) - 1
         K = 2 * I
C        self R + jX are the on-diagonal elements of matrix
         A(J,J) = -RG
         A(K,K) = -RG
         A(K,J) = -XG
         A(J,K) = XG
  750 CONTINUE
C     ******************************************************************
C              'A' MATRIX (3 STATIC WIRES)                        'C' MAT
C     ***********************************************************
C     * -RG1-G1   +XG1-G1 * -RG1-G2   +XG1-G2 * -RG1-G3   +XG1-G3 *  VGR1
C     * -XG1-G1   -RG1-G1 * -XG1-G2   -RG1-G2 * -XG1-G3   -RG1-G3 *  VGM1
C     *    *    *    *    *    *    *    *    *    *    *    *    *
C     * -RG2-G1   +XG2-G1 * -RG2-G2   +XG2-G2 * -RG2-G3   +XG2-G3 *  VGR2
C     * -XG2-G1   -RG2-G1 * -XG2-G2   -RG2-G2 * -XG2-G3   -RG2-G3 *  VGM2
C     *    *    *    *    *    *    *    *    *    *    *    *    *
C     * -RG3-G1   +XG3-G1 * -RG3-G2   +XG3-G2 * -RG3-G3   +XG3-G3 *  VGR3
C     * -XG3-G1   -RG3-G1 * -XG3-G2   -RG3-G2 * -XG3-G3   -RG3-G3 *  VGM3
C     ******************************************************************
C     subroutine for inverting the impedance matrix 'A'
C     ******************************************************************
C     create identity matrix 'B'
      N = 2 * gw
      DO 760 I = 1,N
         DO 770 M = 1,N
            B(M,I) = 0.D0
  770    CONTINUE
  760 CONTINUE
C     diagonal elements = 1, off-diagonal elements = 0
      DO 780 I = 1,N
         B(I,I) = 1.d0
  780 CONTINUE
C     ******************************************************************
C     invert matrix 'A'
C     work lower left half of matrix , top to bottom
C     start by dividing row 1 by (1,1)
C     A# and B# receive identical operations
C     multiply row 1 by (2,1) and subtract from row 2
C     multiply row 1 by (3,1) and subtract from row 3, etc...
C     C will move sequence to 2nd column starting with (2,2)
      DO 790 C = 1,(N - 1)
```

```
         FCT1 = A(C,C)
         DO 795 I = 1,N
            A(C,I) = A(C,I) / FCT1
            B(C,I) = B(C,I) / FCT1
 795     CONTINUE
         DO 800 R = (C + 1),N
            FCT2 = A(R,C)
            DO 810 I = 1,N
               A(R,I) = A(R,I) - A(C,I) * FCT2
               B(R,I) = B(R,I) - B(C,I) * FCT2
 810        CONTINUE
 800     CONTINUE
 790  CONTINUE
C     work upper right half of matrix. start in bottom right corner
      C = N
      FCT3 = A(C,C)
      DO 820 I = N,1,-1
         A(C,I) = A(C,I) / FCT3
         B(C,I) = B(C,I) / FCT3
 820  CONTINUE
      DO 830 C = N,2, -1
         DO 840 R = (C - 1),1,-1
            FCT4 = A(R,C)
            DO 850 I = N,1,-1
               A(R,I) = A(R,I) - A(C,I) * FCT4
               B(R,I) = B(R,I) - B(C,I) * FCT4
 850        CONTINUE
 840     CONTINUE
 830  CONTINUE
C     'B' array is now the inverse of the 'A' array
C     *****************************************************************
C     compute the static wire currents
C     MULTIPLY THE 'C' MATRIX BY THE 'B' MATRIX
      N = 2 * gw
      DO 860 I = 1,gw
         IGR(I) = 0.D0
         IGM(I) = 0.D0
         DO 870 J = 1, N
            K = (2 * I) - 1
            IGR(I) = IGR(I) + CM(J) * B(K, J)
            K = 2 * I
            IGM(I) = IGM(I) + CM(J) * B(K, J)
 870     CONTINUE
         GCUR(I) = (IGR(I)**2 + IGM(I)**2)**.5d0
         GANG(I) = (DATAN(IGM(I) / IGR(I))) * 180.D0 / PII
         IF (0 .GT. IGR(I)) THEN
            GANG(I) = GANG(I) + 180.D0
         ENDIF
 860  CONTINUE
      END


      SUBROUTINE STWRDATA

      INTEGER I
      INCLUDE "shvar"

C     subroutine for inputing static wire data

C     How many STATIC WIRES will you have
      READ(99,900) gw
 900  FORMAT(I1)
       IF (GW .NE. 0 ) THEN
          DO 910 I = 1,gw
             IC = I + 7
C            Enter the  'X' COORDINATE in feet
             READ(99,905) gx(I)
 905         FORMAT(d7.2)
C            Enter the  'Y' COORDINATE in feet
```

```
              READ(99,905) GY(I)
C             Enter the SPAN Between Grounded Towers in feet
              READ(99,906) SPAN(I)
  906         FORMAT(d6.0)
C             Enter the GEOMETRIC MEAN RADIUS (GMR) in feet
              READ(99,907) GMR(I)
  907         FORMAT(d7.5)
C             Enter the WIRE RESISTANCE at 75 ^F in Ohms per mile
              READ(99,907) GRI(I)
  910       CONTINUE
         ENDIF
      END

      SUBROUTINE XYDATA

      INTEGER I
      INCLUDE "shvar"

C     "How many PHASE CONDUCTORS will you have ?";
      READ (99,1000) PC
 1000 FORMAT(I2)
      DO 1010 I = 1,PC
          IC = I + 7
          IF (I .GT. 15) THEN
             IC = I - 8
          ENDIF
          READ(99,1005) PX(I)
          READ(99,1005) PY(I)
 1005     FORMAT(d7.2)
 1010 CONTINUE
      END
```

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10. ACKNOWLEDGMENTS

The author would like to thank Dr. John Wm. Lamont and Glenn Hillesland for their advice and leadership throughout his research activities. The contributions of Dr. Robert J. Weber and Dr. Terry J. Wipf, additional members of his graduate committee, are also appreciated.

The author would also like to thank the rest of the Iowa State University power area faculty and staff for its contributions in his education and research efforts. The Iowa Test and Evaluation Facility (ITEF) must also be thanked for their financial support of the many research activities and the author's education. Without the funding, this work would not have been possible.

Finally, the author would like to thank his family, friends, and especially his wife, Joann, for their patience and support throughout his master's work.