INTERN EXPERIENCE AT

THE GENERAL ELECTRIC COMPANY

An Internship Report

by

Bruce Michael Aucoin

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ABSTRACT

Intern Experience at the General Electric Company (December 1982)

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This report examines my internship with the General Electric Company. During the internship, I primarily worked on the Arcing Fault Detector, a device which Texas A&M University had developed. The Arcing Fault Detector improves the detection of fallen conductor faults on electric power distribution systems. This report describes my technical and business-related activities during the internship. The report also discusses the progress we made on the Arcing Fault Detector project.

General Electric intended that I design a commercial model of the detector. I did not accomplish this objective because substantial design and marketing efforts were needed for General Electric to develop a successful fault detector. Also, General Electric could not assign additional personnel to this project. We experienced goal-setting problems during the internship because the project status was misunderstood and because there was excessive enthusiasm for the project.

The accomplishments of the internship advanced the Arcing Fault Detector toward commercialization. I transferred the results of the Texas A&M research to General Electric. We improved the fault detection concept. I converted the Texas A&M research design of the detector into a design compatible with General Electric practices. I also helped General Electric to evaluate the obstacles to commercializing this product. These accomplishments enable General Electric to develop the Arcing Fault Detector into a marketable product.

ACKNOWLEDGEMENTS

I am grateful for the help and support of my family, friends and associates during the internship. I particularly want to thank the General Electric Company Advanced Systems Operation for hosting my internship.

I deeply appreciate the sacrifice and encouragement of my parents, Mr. and Mrs. Elwood Aucoin, and my grandparents, Mr. and Mrs. Sidney Aucoin, for making my education possible.

My thanks goes to Dr. B.D. Russell for his guidance and for providing me the opportunity to work on the Arcing Fault Detector Project.

I am grateful for my association with the present and former members of the Power Systems Automation Laboratory at Texas A&M. In particular, Mr. John Zeigler provided me invaluable assistance during the internship.

I sincerely appreciate the efforts of Ms. Lynne Divis for reviewing this manuscript and for providing moral support.

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EXECUTIVE SUMMARY

I completed the internship requirements for the Doctor of Engineering degree with the General Electric Company. My primary responsibility during the internship was to develop the Arcing Fault Detector, a device which I had helped research at Texas A&M.

The Arcing Fault Detector improves the detection of fallen electric distribution wires. Distribution circuits commonly employ overcurrent protective devices which interrupt power when the current in the circuit exceeds a safe level. Often, overcurrent protective devices cannot identify fallen power lines because these lines do not draw enough current. Fallen conductors which remain energized are hazardous. Utility companies desire to improve the detection of fallen conductors to improve safety.

Texas A&M University researched the detection concept for the Arcing Fault Detector and demonstrated a prototype of the device. The prototype identified several fallen conductor occurrences which overcurrent protective devices did not recognize. The Texas A&M research also identified the limitations of the detection concept.

General Electric purchased a patent license for the Arcing Fault Detector from Texas A&M and embarked on a program to market the device. The purpose of my internship was to transfer the results of the Texas A&M research to General Electric.

General Electric assigned me to their Digital Systems Operation office. The objectives they set for my internship were to construct prototype fault detectors and to develop a production plan for the device.

I did not accomplish the objectives of General Electric because the product was not ready to be commercialized. Much more work was required to develop the Texas A&M detector into a marketable product. The detection concept exhibited two characteristics which limited its usefulness as a product. Capacitor banks attenuate the signal which the detector monitors. Tuning devices placed on capacitor banks permit the signal to propagate, but these devices are expensive. Additionally, a detector on one circuit may identify a fallen conductor on another circuit. To be useful, the Arcing Fault Detector must detect only those faults on the circuits which it monitors.

There are several other problems associated with bringing the Arcing Fault Detector to the market. Manufacturers and utilities face sensitive and contradictory liability problems with the product. It is difficult to justify economically why we should improve the detection of fallen conductor faults. The Arcing Fault Detector could interrupt customer service more often and for longer periods of time than would existing overcurrent devices, possibly reducing safety. It is difficult to market a product which many utilities would feel forced to use to avoid liability. These business-related problems complicate any attempt to predict the potential success of the detector.

The GE management team and I had difficulty agreeing on the goals for my internship and for the Arcing Fault Detector project. The management team misunderstood the status and the scope of the project. They believed that we could easily convert the Texas A&M prototype into a successful product. The misunderstanding apparently began with a breakdown in the communication of the project status from Texas A&M to General Electric. Excessive enthusiasm and expectations for the product caused the goal-setting problems we experienced. I contributed to the goal-setting problems by not asserting, from the start, that I disagreed with the internship objectives. We did not agree on the direction of the project until well into the second half of the internship.

My assignments during the first half of the internship were directed toward constructing prototype detectors. I developed a product plan for the detector and scheduled activities to meet the goal of prototype delivery. I developed an architecture for the detector which incorporated major improvements in the detection concept. I also designed the hardware for the prototypes and wrote the algorithm for fault detection in a design language.

Approximately halfway through the internship, the organizational structure was changed. At about the same time, the management team recognized that we would not meet the goal of quick commercialization. Accordingly, my assignments during the second half of the internship were directed toward investigating the problems with marketing the Arcing Fault Detector. We gauged the demand for the product by attempting to sell prototype detectors. We also surveyed how utility companies reacted to the Arcing Fault Detector. Negative reactions from several utilities caused us to investigate ways to improve the product. We discussed the product liability issues with a company lawyer. I helped to identify and to evaluate options for the future of the program. Before concluding the internship, I submitted to General Electric a final report of my activities during the internship and a summary of the business and technical status of the project.

During the internship I helped to develop the Arcing Fault Detector and helped investigate the problems with commercializing it. I did not meet the objective of quick commercialization because we needed more technical development, marketing analysis, and personnel to develop the detector into a marketable product. My contributions to General Electric were the following:

1. I transmitted the Texas A&M research results to General Electric.
2. I further developed the fault detection concept.
3. I produced a design of the detector which conforms to General Electric standards and practices.
4. I helped General Electric identify and evaluate the obstacles to commercializing the Arcing Fault Detector.

My internship experience was rewarding and helped me to mature as an engineer and as a person. I have learned that it is important to foster good communication. I enjoyed the opportunity to apply my problem-solving skills in industry.

CHAPTER I

INTRODUCTION

Overview of Internship

This report describes my internship with the General Electric Company (GE) in King of Prussia, Pennsylvania. The internship was completed as one of the requirements for the Doctor of Engineering degree at Texas A&M University (TAMU). The Doctor of Engineering program is geared to educate students in technical management. The internship enables the student to apply his knowledge in an industrial environment and to experience the organizational approach to solving problems.

During the nine month internship, I was responsible for commercially developing the Arcing Fault Detector (AFD). Dr. B.D. Russell of TAMU invented this device. I participated in research on the AFD while I pursued graduate studies at TAMU during the period 1977-1981. Intending to market the AFD, General Electric purchased a patent license for the product from Texas A&M. I was employed by GE to transfer my knowledge of the fault detector to their company.

The IEEE Transactions on Power Apparatus and Systems was used as a model for style and format for this report.

Product Purpose

The purpose of the Arcing Fault Detector is to improve the detection of fallen electric distribution conductors. Occasionally, electric utility distribution wires break and fall to the ground. Falling tree limbs or accumulated ice may cause wires to break. The wires may also fall when an automobile strikes a utility pole. Usually, existing protective devices detect these fallen conductors and then interrupt power to the affected circuit. However, some fallen conductors are not detected and remain energized for a long time. This situation is hazardous. Arcing often occurs when a high voltage conductor contacts the ground; the Arcing Fault Detector provides more sensitive detection of this arcing than do existing protective devices.

TAMU Research

The intent of the research at Texas A&M was to determine if the AFD could detect fallen conductors. A prototype detector was first tested with data recordings from many fallen conductor incidents and was then tested under actual fault conditions. The AFD successfully identified many fallen conductor occurrences which existing protective devices did not recognize. While it was shown that the detection concept was feasible, several limitations of the detection device were also noted during the research.

Goal Conflict During Internship

General Electric developed interest in the TAMU research and executed a license agreement with the University for the AFD. General Electric then initiated a program to commercialize the detector. The intent of my internship was to transfer the results of the TAMU research to GE.

Soon after the internship began, problems developed. These problems involved setting objectives for my internship and for the AFD project.

The goal of GE for my internship was to develop prototypes and a commercial production plan for the AFD. We did not achieve this goal because the GE management team misunderstood the project status. They apparently believed that the AFD was well developed and could be quickly marketed, when substantial effort remained to develop the AFD into a marketable product. It was not until well into the second half of the internship, after a reorganization of the management team, that we reached substantial agreement on the status and the direction of the program.

The internship took place in this environment of goal conflict. The goal-setting problems were the most important part of the internship experience. Accordingly, I have devoted a reasonable portion of this report to their discussion. Despite the goal-setting problems, the accomplishments of the internship have brought the AFD much closer to being a marketable product.

Report Outline

This report serves both as a discussion of my activities during the internship and as a case study of the Arcing Fault Detector project. Chapter II presents background material on the AFD project to acquaint the reader with the project status at the start of the internship. Chapter III identifies and describes the internship position. These two chapters set the foundation for the discussion of the internship itself.

Chapter IV describes the problems which must be solved to develop a successful detector. The development of this Project Scope was one of the most important achievements of the internship. Discussion of the scope identifies many of the issues I addressed during the internship and provides the reasons why I disagreed with quick commercialization. Chapter V discusses goal conflicts.

Chapters VI and VII describe my assignments during the internship. Chapter VI covers my assignments prior to the office reorganization, and Chapter VII covers the assignments thereafter. I chose this approach because the tasks I performed during each of these two segments depended on the goals of the corresponding supervisors. Finally, Chapter VIII lists the results of the internship.

Fulfillment of Requirements

I intend to demonstrate in this report that I functioned professionally in an industrial engineering organization. In so doing, I fulfilled the requirements for and the intent of the internship. I believe that my activities and decisions were ones that can be reasonably expected of a Doctor of Engineering candidate.

CHAPTER II

PROJECT BACKGROUND

Overview

This chapter provides background on the Arcing Fault Detector project prior to the internship. I begin with a discussion of feeder protection practices. This discussion identifies the need for the AFD. I also present the results of the Texas A&M research to establish the project status at the beginning of the internship.

Distribution Feeder Protection

Distribution feeders supply electric power to the majority of homes and small businesses in the United States. Feeders "distribute" power to particular neighborhoods. A feeder originates at a distribution substation where it receives power from a utility's transmission network. Figure 1 shows an electrical diagram of a substation which supplies several distribution feeders. Most feeder circuits are constructed overhead on poles, and they generally carry conductors (primary conductors) which are energized to a line-to-ground potential of 7,200 volts. This voltage is transformed to 120 and 240 volts near the point of service for use by the consumer.

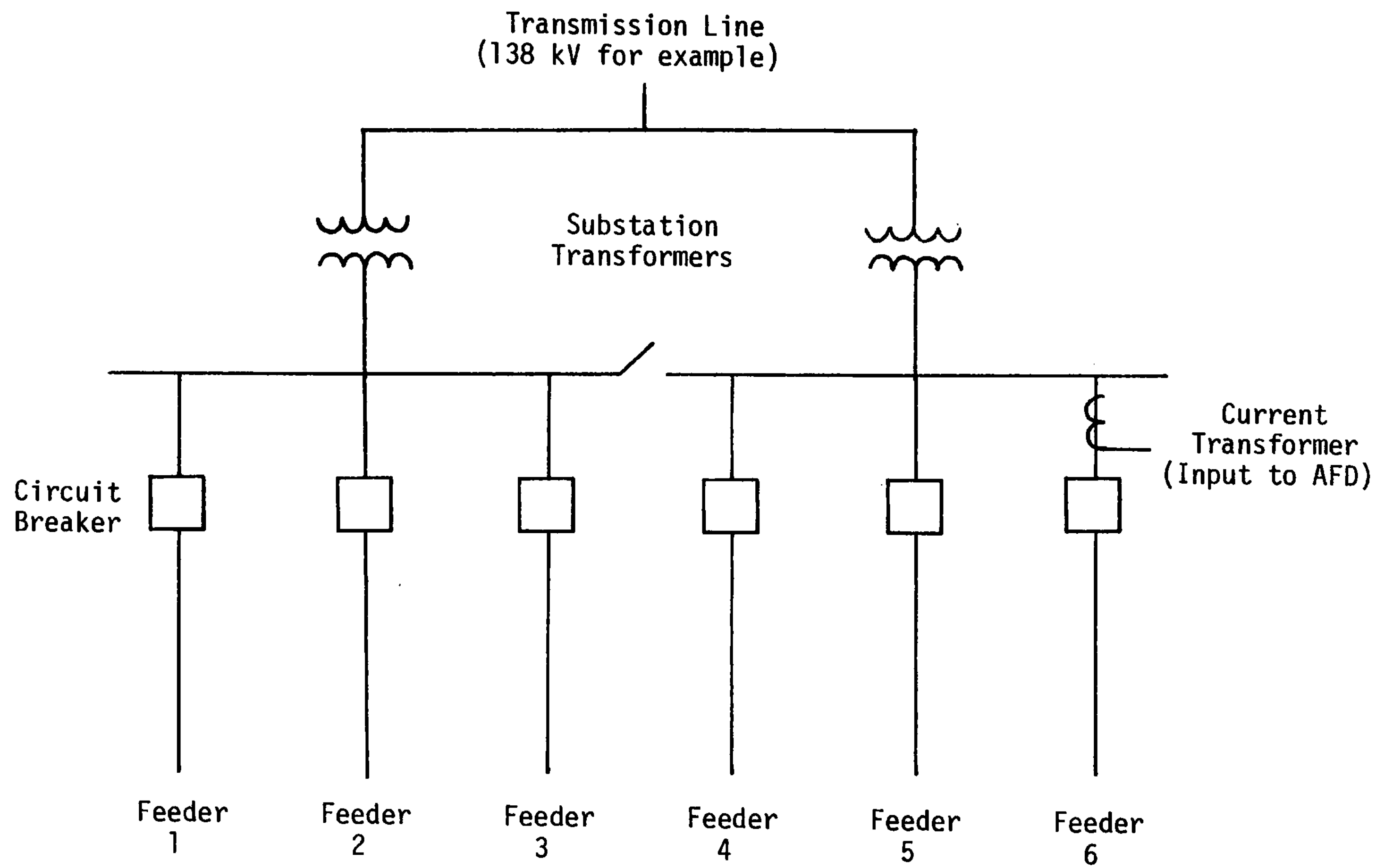

Figure 1. One Line Diagram of Distribution Substation

Occasionally, abnormal conditions occur on feeder circuits. One type of abnormal condition is commonly called a fault or short circuit. A fault is an unintentional connection between one conductor and another or between a conductor and ground. A fault occurs when wires become entangled or when a wire falls to the ground. Figure 2 gives a sketch of a fallen primary conductor. A conductor which breaks but does not contact any other object is called an open conductor.

If the connection between a fallen conductor and ground has a low electrical impedance or resistance, very high current flows in the circuit. High current heats the conductor and would cause melting if the current was not interrupted. For this reason, a utility installs protective devices which de-energize the affected circuit if the current rises above a certain level. These devices are fuses and overcurrent relays, and they are installed on all distribution feeders.

In many cases, the impedance of a connection between a fallen conductor and ground is high. The current remains low in such a high impedance fault. The current may be no higher than the level of current in a circuit serving several homes. The above-mentioned overcurrent devices sometimes cannot distinguish a high impedance fault from customer load.

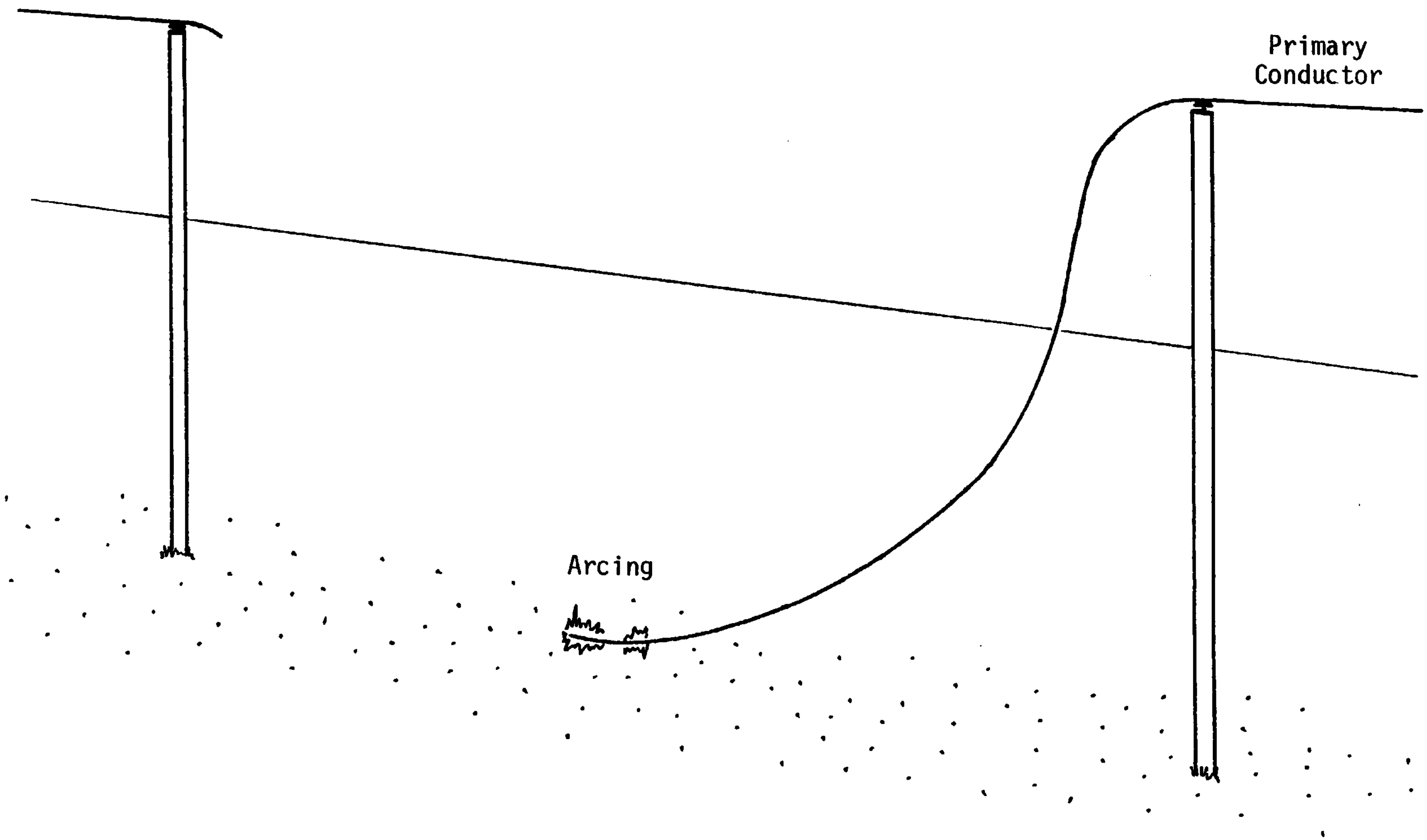

Figure 2. Sketch of Downed Conductor Fault

If the current during a fallen conductor fault remains low, the conductor may remain energized for an indefinite period of time. High impedance faults are hazardous because energized high voltage conductors may fall within easy reach of the public. Therefore, the desire to improve safety motivates the detection of high impedance faults.

Utility Interest

Utilities wish to improve the detection of high impedance faults to reduce the chance of electrocution accidents. Many researchers throughout the history of the electric utility industry have sought to improve high impedance fault detection, but none of them have identified a satisfactory method to improve detection. A suitable fault detector would probably be a successful product.

Arcing Fault Detector

The Arcing Fault Detector improves the detection of high impedance faults on distribution feeders. Dr. B.D. Russell of Texas A&M University invented the AFD. The University filed a patent application for this device in September 1981.

The overcurrent protective devices described above monitor 60 Hz current. Only slight changes occur in this electrical parameter during a high impedance fault. Therefore, one may enhance fault detection by monitoring other circuit parameters.

Arcing commonly occurs when a high voltage conductor contacts ground, as Figure 2 shows (p. 9). Arcing increases the high frequency components of current. The AFD uses a microcomputer to identify an increase in the 2-10 kHz components of current as an arcing fault.

Three utility companies staged over 100 high impedance faults for the Texas A&M research project. Analysis of the data from these tests indicated that many of the faults which were not identified by existing overcurrent protection devices could be detected by a device which monitors high frequency current. Texas A&M researchers tested a prototype fault detector which applies the high frequency principle of detection. The prototype was installed on a distribution feeder. The detector successfully identified several staged faults which were not interrupted by the overcurrent protective devices. During three months of monitoring, the detector did not falsely indicate the presence of a fault.

The Texas A&M research indicated that the AFD could improve the detection of high impedance faults. However, the detector had two technical limitations which would make general application more difficult. Chapter IV identifies these limitations.

License Agreement

General Electric recognized that the market desires a high impedance fault detector and that the AFD could potentially fill that need. General Electric and TAMU negotiated a license agreement which was executed in February 1982.

Project Status at Start of Internship

Texas A&M used the prototype detector to demonstrate that the AFD could improve the detection of high impedance faults. The prototype design was very basic. It did not include all the techniques for fault detection which were known at the time. Texas A&M did not attempt to make a commercial design of the AFD. Many design enhancements were needed before the detector could be sold.

Although we learned much during the TAMU research about the effectiveness of the AFD, much remained unknown. For example, the AFD may identify certain customer loads as downed conductors. We need substantial experience with the detector in service before we can determine its ultimate effectiveness.

Texas A&M had made little effort to evaluate the marketing problems with the AFD. These problems were addressed during the internship.

The Texas A&M research had demonstrated only a concept. No one had yet determined whether the detector could become a successful product. Even if market research predicted success for the AFD, much work was needed to develop the TAMU design into a marketable product.

In summarizing the results of the Texas A&M research and the results of two other research projects on high impedance faults, one source stated "...although some progress has been made toward understanding the nature and causes of high-impedance faults, the work still has not yielded an effective, economic detection device."[1]

Closure

The Arcing Fault Detector addresses a need in the utility industry for more sensitive detection of high impedance faults. The Texas A&M research prior to the internship demonstrated the AFD detection technique and indicated its limitations. Much more technical and marketing work was needed to successfully commercialize the device.

CHAPTER III

INTERNSHIP POSITION

Overview

This chapter provides the following information on the internship position: the internship requirements, the purpose of my internship, information about the internship company, the internship goal, and a summary of my responsibilities.

Internship Requirements

The Doctor of Engineering internship provides an opportunity for the student to function professionally in an industrial, engineering environment. In particular, the College of Engineering has identified the following reasons for the internship:

> "(a) to enable the student to apply his knowledge and training to the solution of a specific practical and relevant problem...
> (b) to enable the student to function in a non-academic environment in a position where he will become aware of the organizational approach to problems in addition to those of traditional engineering design or analysis."[2]

The focus of my internship was to develop the Arcing Fault Detector commercially. General Electric identified a potential market for this product and decided to manufacture it. Therefore, GE assigned me a task which they deemed relevant.

My position at GE required me to pursue a wide range of technical and non-technical problems associated with the Arcing Fault Detector project. These activities followed the intention of the Doctor of Engineering program.

The internship began on July 10, 1981 and ended on April 15, 1982. Therefore, I fulfilled the nine month duration requirement for the internship.

Internship Company

The General Electric Company is a large, multi-national corporation. It produces a variety of consumer, industrial and military products, the majority of which are electrical goods.

The company is divided into several product divisions. The department for which I worked is part of the Power Delivery Division. This group supplies electrical products to electric utilities and industrial plants. I was assigned to the Digital Systems Operation (DSO) of the Power Systems Management Business Department (PSMBD). This department manufactures protective devices such as overcurrent relays. The Digital Systems Operation is a venture group within the department. Figure 3 gives a sketch of the organizational structure of PSMBD. The DSO office is located in King of Prussia, Pennsylvania, which is a suburb of Philadelphia.

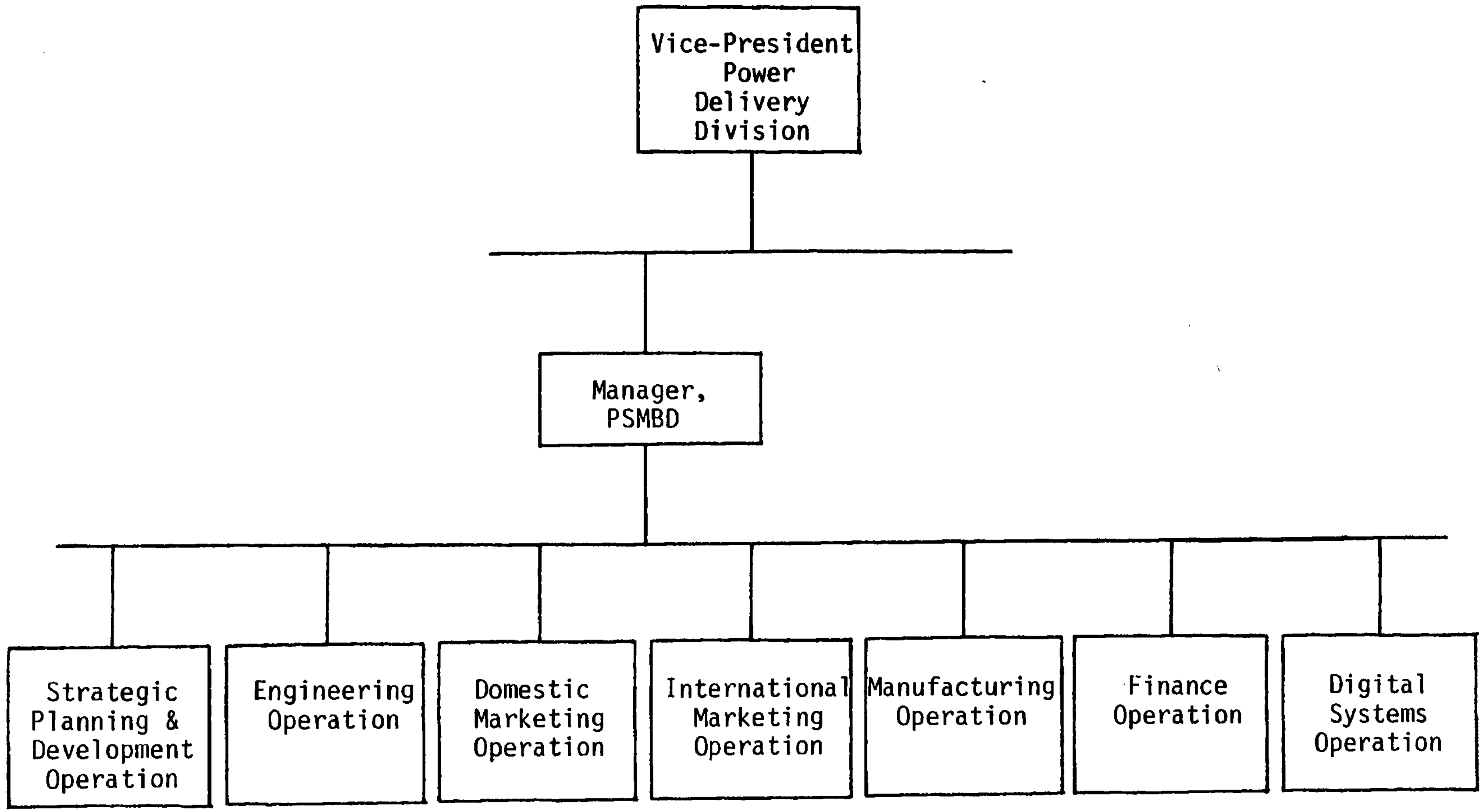

Figure 3. PSMBD Organizational Structure

The Digital Systems venture was formed to develop new products which apply microcomputers to protect and to control power systems. Most devices which presently protect power systems are electromechanical. The flexibility and computational power of microcomputers allow them to perform more functions than electromechanical devices do. In the past 10-15 years, many researchers have developed computer hardware and software which perform protective functions. Utility companies have expressed an interest in this research. Recognizing this potential market, GE formed the Digital Systems venture to develop prototypes of commercial protective products. Power systems products which incorporate microcomputers are commonly known as automation products.

Organizational Structure

Figure 4 shows a diagram of the DSO organizational structure during the first half of my internship. The manager of the operation, Mr. Jack Fink, was named my internship supervisor. I was assigned to the Design Engineering subsection. My title was Digital Electronics Engineer, and I reported to Mr. Jack Ridgeway, the manager of Design Engineering.

In early December, approximately halfway through the internship, Mr. Fink was transferred to another GE office and was replaced by Mr. Larry Mankoff. Soon thereafter, Mr. Mankoff changed the structure of the organization. I was transferred to the Distribution Automation Products subsection, and my title was changed to Systems Engineer. I

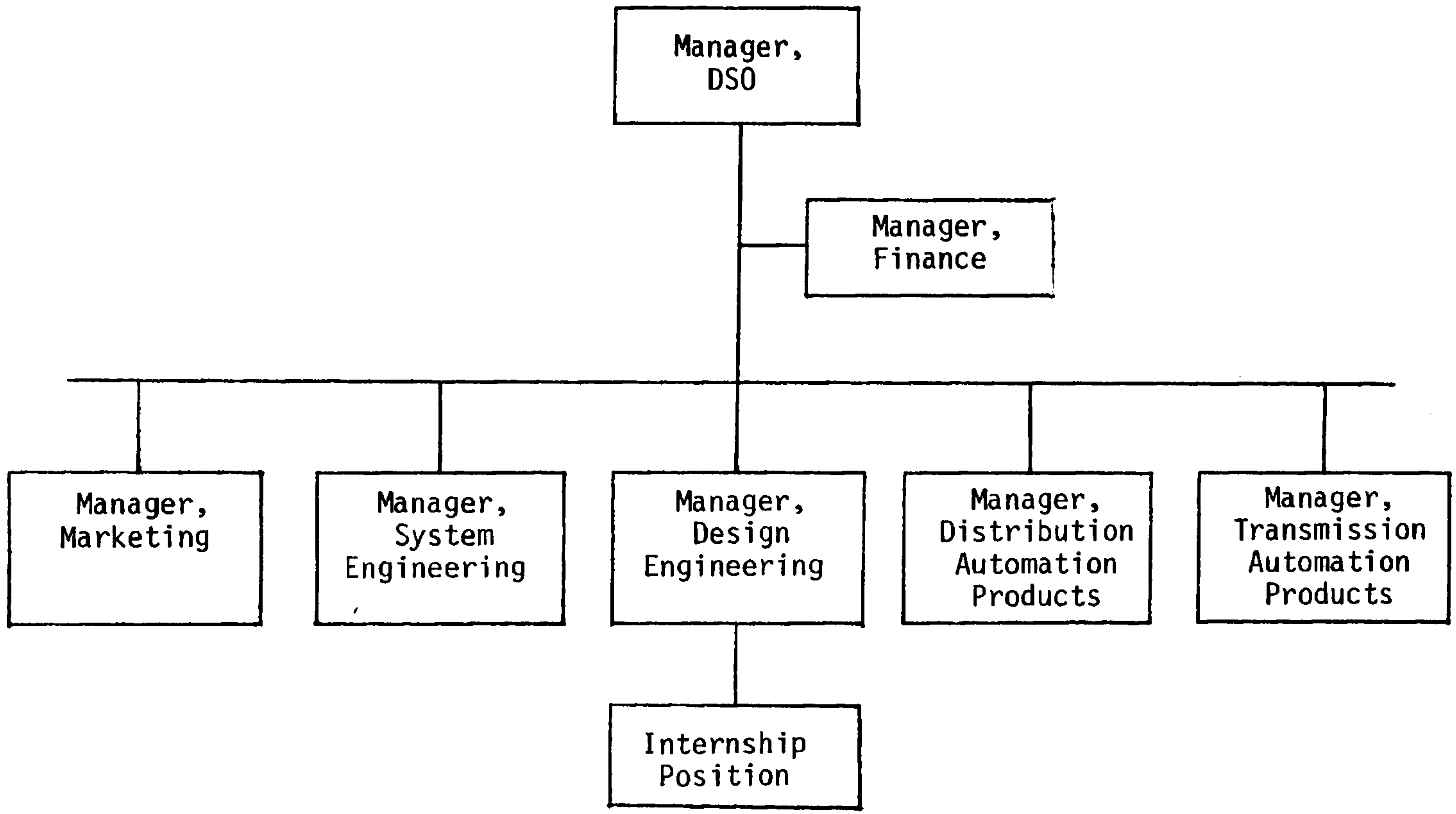

Figure 4. DSO Organizational Structure

subsequently reported to Mr. Peter Schnieper, the manager of that subsection. Figure 5 presents this revised organizational structure. After Mr. Fink was transferred, Mr. Schnieper was named my internship supervisor.

Internship Goal and Responsibilities

When I arrived at GE, Mr. Fink identified the goals for my internship. I was to construct prototype fault detectors by late 1981 and to develop a production plan by the end of the internship. My primary responsibility was engineering. I was responsible for the hardware design and software programming of the prototype detectors. Additionally, I was responsible for several non-technical activities including developing a product plan and interacting with the Marketing subsection.

Throughout the internship, I was the only full time employee assigned to the AFD project. Mr. Robert Manley worked part time on the project. He was a member of the Marketing subsection during the first half of the internship. After the office reorganization, Mr. Manley entered the Distribution Automation Products subsection. He was then assigned to lead the Arcing Fault Detector project.

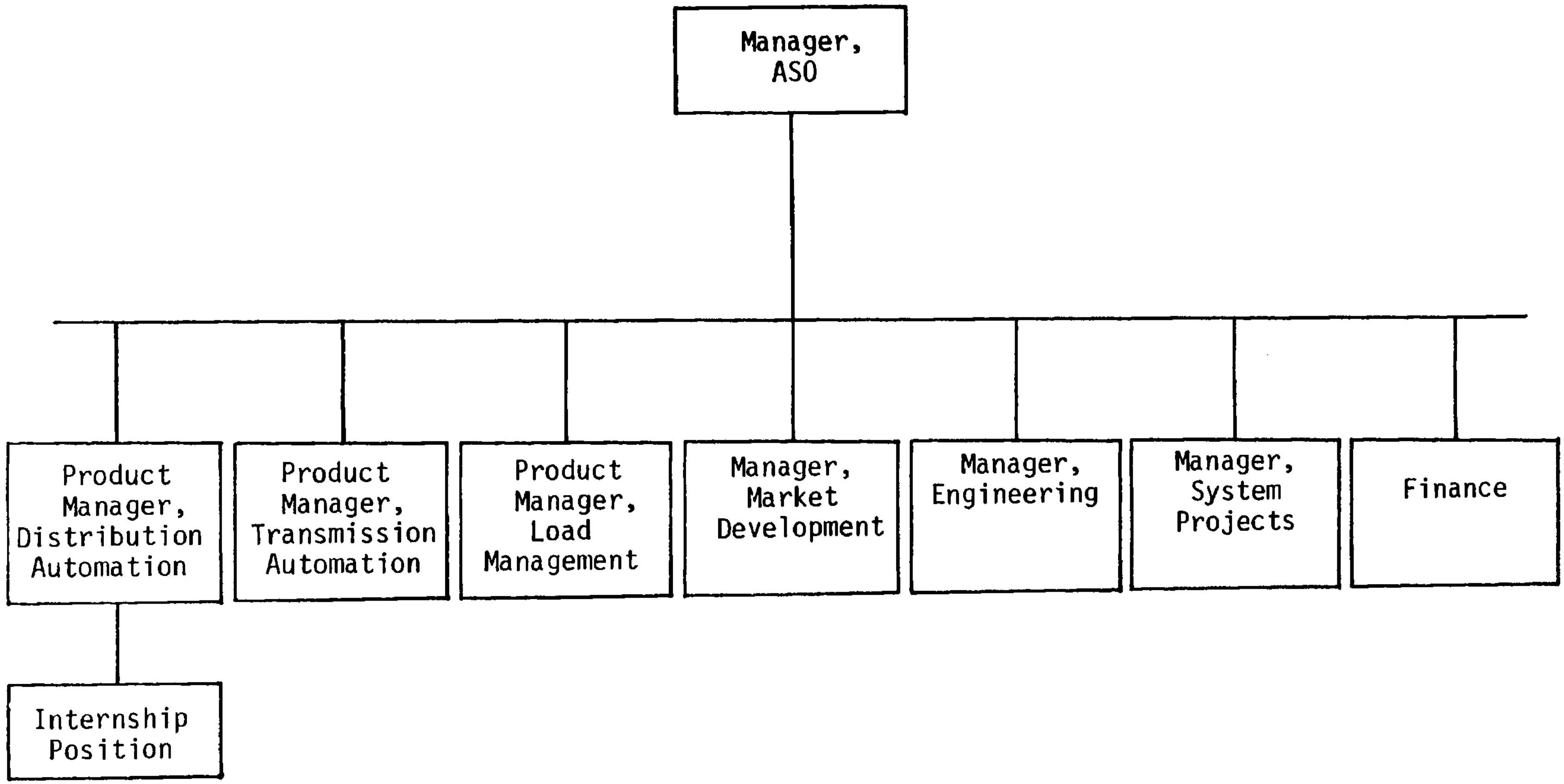

Figure 5. ASO Organizational Structure

CHAPTER IV

PROJECT SCOPE

Overview

This chapter identifies many of the problems associated with commercializing the Arcing Fault Detector. To develop a successful fault detector, we must overcome significant technical, legal, and marketing problems.

Introduction

The discussion of the AFD project scope describes portions of two stages in the evolution of a new product: business analysis and product development.[3] The business analysis is an estimation of the profit which the new product would generate. Product development is the process of converting research results into a marketable product. The project scope identifies many of the business-related and product-related characteristics of the AFD which hinder commercial success. In this discussion, I do not intend to convey that the commercial prospects for the AFD are poor. Instead, I am merely identifying issues which, if overcome, would increase its chances for success. I therefore intend the scope to be a part of a commercialization plan.

Compiling the project scope was one of my assignments during the internship. Discussions with other GE engineers provided some of the information in this chapter. The project scope is one of the most important accomplishments of the internship because it helps provide direction toward commercialization.

The discussion of the project scope serves three purposes. First, the discussion demonstrates that the issues covered during the internship involved a spectrum of technical and non-technical issues, therefore fulfilling the intent of the Doctor of Engineering program. During the internship, I addressed all the issues listed here. Second, identifying commercialization problems will help the reader understand the goal-setting and communications problems during the internship. Third, the information presented here serves as a background for the discussion of project assignments in Chapters VI and VII.

Growth of the Product

Many of the problems with commercializing the AFD involve its growth from a detector to a relay. A detector signals an abnormal situation, whereas a relay detects an abnormal situation and then interrupts power on the affected circuit to eliminate a potential hazard. Although the name "Detector" has been assigned to the product, it could be used as a detector or as a relay.

A utility which installs the AFD may, through perception or fact, be obligated to operate it as a relay. The purpose of the AFD is to identify a potentially hazardous condition. Knowing that a potentially hazardous condition exists implies a responsibility to remove the hazard quickly. The easiest way to fulfill this obligation is to interrupt the power by operating the AFD as a relay.

Interrupting power eliminates some electrocution hazards but creates other hazards. As an example, someone may fall down a dark stairwell during a power outage.

The growth of the AFD from a detector to a relay is a significant product development. The implications of this product development will be discussed at several places in this chapter.

Limitations of Detection Concept

While the AFD improves the detection of many high impedance faults, the detection concept has two major limitations which make general application difficult and costly.

Most utilities install capacitor banks at several locations on each feeder. Capacitor banks help the utility to deliver power more efficiently to the customer, but they attenuate the 2-10 kHz signal which the AFD uses. During several of the staged tests, faults were conducted with capacitor banks both in and out of service. In general, the AFD could detect faults when the capacitors were switched out, but it could not detect faults when the banks were switched in.

The installation of tuning devices, called traps, on all capacitor banks could overcome the problem but would be very costly.

This limitation is a formidable obstacle. The Arcing Fault Detector "...would be almost useless for companies that use grounded-wye capacitor banks. With capacitor traps, the detector would probably be very useful but the cost of trap installation would probably make widespread use of the detector economically unattractive."[4]

A second limitation of the detection concept is its susceptibility to sympathetic tripping. A detector on one circuit could sense a fault on another circuit. In this way, a detector could interrupt power on a "healthy" circuit when it should have allowed the circuit to remain in service. Neither the utilities nor their customers would accept the effects of excessive sympathetic tripping.

I performed tasks during the internship which attempted to solve both the capacitor bank and the sympathetic tripping problems. These two problems require significant product development to achieve a marketable detector.

Legal Environment

The motivation to improve the detection of high impedance faults is to reduce liability. However, additional legal problems arise when a manufacturer introduces such a fault detector.

When someone sues a utility, as the result of an electrocution accident, the utility usually attempts to settle the case out of court. If such a case reaches court, the utility often uses the defense of "best available technology." Under this principle, the utility asserts that no product was available which could have prevented the accident, thus hopefully limiting the utility's liability. If a new product is introduced which provides more sensitive fault detection, a utility is practically obligated to install it. In fact, many utilities feel that they must install the new product on all feeders to avoid any indication of negligence. Even if a utility does not subscribe to this viewpoint, court cases or public utility commission rulings could literally force a utility to install a product. The AFD should not be placed in this legal environment until the capabilities and limitations of the detector are better known.

The use of a high impedance fault detector could reduce the number of electrocution accidents. However, it is quite likely that the detector would interrupt service more often than present protection devices do. Injuries and deaths occur during power outages. Conceivably, someone who was injured during an outage could sue a utility. These legal issues place a utility company in a very difficult position.

The legal problems for the manufacturer of a fault detector are also difficult. In recent years, the theory of strict liability has evolved in product liability lawsuits. Under this theory, someone who received an injury by using a product need not prove that the manufacturer was negligent in the design of the product. The injured party need only prove that his injuries resulted from a defect in the product.

Product liability law has serious consequences for a manufacturer. With the litigious atmosphere in the United States today, a manufacturer must expect lawsuits involving its products, especially products which relate to public safety. A fault detector must provide large profits to offset the damages from these lawsuits.

A recent lawsuit provides evidence of the confusing issues of product liability law. One of GE's competitors recently introduced a product which improves the detection of open conductors. Someone suffered an injury by contacting a downed conductor. The injured party sued both the utility and this manufacturer because the utility had not installed the new device on that feeder.

The legal issues described here are sensitive and sometimes contradictory. The implications of introducing a high impedance fault detector must be examined carefully.

Lack of Economic Incentive

Utilities find difficulty in economically justifying why they should improve the detection of high impedance faults. Such a fault usually causes little damage to utility equipment. The utility incurs only the cost to repair the damaged line. If injury or property damage occurs, the utility may be required to pay damages. The issue a utility addresses in a cost-benefit analysis is the cost of installing and maintaining a fault detector weighed against the benefit of reduced liability. We must remember that a utility may expose itself to additional liability from more frequent power outages.

The costs associated with a fault detector are capital investment, installation costs, maintenance costs, the expense of locating faults, and lost revenues during power outages. These expenditures are difficult to estimate because they depend on the selling price of a detector and on how frequently the detector interrupts power. These costs may be significant.

Utilities also find difficulty in estimating the benefit of reduced liability because most cases are settled out of court. One survey [5] indicated that only half the utilities carried liability insurance for electrocutions. This fact indicates that the utilities do not consider electrocution accident claims economically important. The "...cost of improved protection is highly unlikely to be justified by a conventional cost/benefit analysis."[6]

Importance of Solution

Despite the lack of economic incentive, utilities strongly desire to improve high impedance fault detection.

> "It appears that an accident resulting from a fallen conductor receives an inordinant [sic] amount of attention ... compared to other electrical accidents, such as electrocution around the house, which are far more frequent. The analogy would seem to be similar to aircraft accidents as compared with automobile accidents. The number of deaths due to air crashes is dwarfed by the number due to automobile accidents, yet a single air crash receives more attention than several thousand automobile accidents."[7]

It is this emphasis which we bestow upon fallen conductor faults which strongly motivates utilities to detect them. The desire to avoid liability further induces a utility to detect these faults.

Operational Problems

No one in the utility industry has sufficiently addressed how a high impedance fault detector would affect the operation of a distribution circuit. When a detector identifies a fault, a utility would most likely interrupt power to the affected circuit to reduce the chance of electrocution. Then the task of locating the fault begins, a process which may take several hours. In the meantime, perhaps several thousand customers are without electricity.

The utility desires to detect as many potentially hazardous conditions as possible. However, if a detector is very sensitive, electricity may be interrupted quite often. Sometimes a relay interrupts service to remove a condition which is not hazardous. For example, the AFD may detect arcing from a tree limb touching a conductor, a situation which would probably cause little trouble. Utilities and their customers find unnecessary and frequent service outages unacceptable.

Marketing Problems

It is difficult to forecast sales for the AFD because there is little economic incentive to purchase the product and because liability issues dominate the market. Some utilities may resent their perceived or real obligation to buy a high impedance fault detector. This resentment could adversely affect other business transactions between the manufacturer and these utilities.

Another marketing problem arises from the implementation of the AFD. The AFD uses microcomputer technology which has not been sufficiently developed for widespread use on utility systems. Utilities are accustomed to electromechanical products which last for 40 years or more. The infancy of the fault detection concept and of microcomputer technology may make a present-day fault detector obsolete within a few years. It would be difficult to encourage a utility to purchase a product with such a short life.

Trade-off

In general, the problems with improved fault detection can be related to a statistical test of a null hypothesis and to the implications of the test results. A fault detector examines a set of data and decides whether or not a fault exists. Assume that the null hypothesis is that a fault does exist. Two types of error could be made when testing this hypothesis. A Type I error is made when a correct null hypothesis is rejected. A Type II error is made when an incorrect null hypothesis is accepted. The fault detector makes a Type I error when it does not detect a fallen conductor. Presently, utilities experience Type I error. The fault detector makes a Type II error when it incorrectly signals the presence of a fault.

It is difficult to make the trade-off between these two types of errors. We wish to reduce Type I errors and thereby reduce the number of fallen conductor accidents. But a reduction in the probability of Type I error increases the chance of Type II error. Correspondingly, customer aggravation increases. The probability of injuries occurring due to a power outage also increases. The experts disagree on whether a fault detector design should be biased in favor of Type I or Type II errors.

Closure

The major obstacles to commercializing the Arcing Fault Detector have been presented. Identification of the project scope provides a better understanding of the project status during the internship and describes what is required to develop the fault detector into a marketable product.

CHAPTER V

GOAL CONFLICT

Overview

This chapter presents a discussion of the problems we faced at General Electric with setting the goals for the internship and for the Arcing Fault Detector project. Overenthusiasm caused these problems. It caused a misunderstanding of the project status and a disagreement on the seriousness of the obstacles in the path of commercialization.

Introduction

General Electric planned the following goals for my internship. I was to build prototype detectors by late 1981 and to develop a production plan for the AFD by the end of the internship. Initially, I attempted to meet these goals. As the internship progressed, I realized more clearly that I could not meet their goals unless GE assigned several more people to the project. However, manpower was not the most critical issue. I believed that we needed to develop the product much further and to evaluate the market more carefully before making a commitment to production. I derived this position from an evaluation of the project status and the project scope, which I discussed in previous chapters.

My goals were to continue to develop the product and to evaluate barriers to market entry. Our goals conflicted. Although I attempted to communicate my position to my supervisors, I met with only modest success during the first half of the internship. We could not resolve this conflict until later in the internship.

Communication Breakdown

The goal conflict apparently originated with a breakdown in communication before the internship began. Texas A&M and General Electric personnel discussed the AFD project on several occasions prior to the internship. The quick commercialization goal of the GE management team indicated that they believed the Texas A&M research design could be easily converted to a commercial product. I feel that this belief was based upon an incorrect understanding of the project status. I conclude that a breakdown occurred in communicating the project status from Texas A&M to General Electric and that this breakdown led to a misinterpretation of the status.

Disagreement on Project Scope

The major obstacles to commercializing the AFD were presented in Chapter IV. Many in the utility industry believe that several of these obstacles are sufficiently serious to render the fault detector useless. The GE management team did not fully recognize the seriousness of these impediments or perhaps felt that the benefits of the product surpassed its flaws. I believed that the product could fail if we did not overcome its problems.

I also felt that we could not expect to eliminate the shortcomings of the detector after market entry. The sensitivity of product liability law would not permit us to sell a research prototype. "...[A] manufacturer, by marketing and advertising his product, impliedly represents that it is safe for its intended use."[8] We had not developed the product sufficiently to understand fully its capabilities and limitations.

Furthermore, by entering the market with a product at the research stage, we risked alienating the utilities. Utility personnel may feel obligated to purchase a fault detector to avoid appearing negligent. They may especially resent the obligation to buy an immature product.

Cause of Goal Conflict

I believe that excessive enthusiasm for the AFD project caused the goal conflict we experienced. Utilities view the detection of high impedance faults as an important goal. General Electric perhaps became anxious to meet this market need. A competitor began marketing an open conductor relay in 1981. This competition possibly encouraged GE to accelerate marketing the AFD.

The enthusiasm and expectations for this product did not match the status of the project. Rosenberg [9] states that overenthusiasm causes product failure more often than does any other factor. Persons closely associated with a product often become too subjective when evaluating the product. Potential customers are often less excited about a product than is the manufacturer. It is important for one to remain objective in product decisions.

Loyalty Dilemma

Initially, I was excessively enthusiastic about the prospects for the AFD. I attempted to meet the goal of quick commercialization which my supervisors outlined. At the same time, I attempted to tell them we could not achieve their goal. I did not wish to confront them with the issue; I dealt with the conflict by smoothing [10]. Smoothing reduces conflict by denying it or avoiding it.

By avoiding conflict, I created a dilemma. I continued working toward quick commercialization although I believed this to be an unwise goal. Webber [11] describes this situation as a common problem which young managers experience. Some supervisors equate loyalty to the company with obedience; an obedient employee follows the instructions of his supervisor. Other supervisors view loyalty as honesty; an honest employee warns a superior of a potential problem before it occurs.

Assignment of AFD to Product Development Office

The assignment of the Arcing Fault Detector to the Digital Systems Operation also caused a portion of the goal-setting problems. DSO is a product development office. This office develops prototypes of commercial products. There are pressures at a development office to complete and to market a product quickly to generate profit. The AFD was in its infancy and could not supply income. It may have been better to assign the AFD project to a research and development office, where it could have been evaluated more thoroughly. Assigning the project to DSO may also be the result of misunderstanding the status of the project.

Closure

Excessive enthusiasm for the Arcing Fault Detector led to goal-setting problems during the internship. These problems were characterized by a misunderstanding of the project status and discord on the scope of the project.

CHAPTER VI

ASSIGNMENTS DURING FIRST HALF OF INTERNSHIP

Introduction

This chapter describes many of the assignments I carried out during the first half of the internship. During this time, GE intended to develop the AFD into a commercial product quickly. We planned to construct prototypes in early 1982 and geared assignments toward meeting this goal. As time progressed, goal conflict became more obvious, and this conflict affected the outcome of the various assignments. I performed many of the following tasks hastily or incompletely. I had to progress rapidly to meet the prototype installation date.

My approach to the program of constructing prototypes was as follows. I began by outlining the product plan. The product plan provided an overall description of the detector for the next several years. I then scheduled the activities which were needed to meet the date for delivering prototypes. As part of this activity, I estimated the manpower needed to meet the prototype delivery schedule.

By analyzing data from staged fault tests, I devised a solution to the sympathetic tripping problem. I incorporated this solution into a new architecture for the detector. After identifying the new architecture, I designed the hardware for the detector. I also wrote the detection algorithm in GE Program Design Language.

These were my major activities during the first half of the internship. I will now discuss these and other related activities in detail.

Product Plan

The objective of the product plan was to develop a framework or outline of what the AFD would be. The plan included a brief statement of the tangible and perceived characteristics of the product. From these characteristics, I developed a scenario which described the product over the next several years. One could then use the product plan to determine how to assign resources and how to develop a marketing strategy for the product.

I approached the product plan by evaluating the technical and business status of the project. I realized that the product was still very much in a research stage. At the time, I also accepted that GE intended to market the AFD as soon as possible. I conjectured that the product would undergo several major changes in its first few years of production. There were three reasons for this conclusion.

First, the detection concept was still in its infancy. While Texas A&M had made substantial progress toward the detection of arcing faults, much research was still needed. Further research could identify means to detect faults more accurately. Other investigations could signify ways to overcome the TAMU design limitations.

Second, the AFD uses a microcomputer system in its design. Microcomputer devices have had relatively little application in power system substations to date. The substation provides a harsh environment for these devices. Techniques are still being developed for making designs which can survive this environment and for making these designs cost-effective. Furthermore, digital technology progresses rapidly, making some products obsolete within a few years.

Third, detection of high impedance faults is a new concept in power system protection. Operating personnel would need time to gain experience with and to optimize the use of this new capability. The experiences during this learning period may suggest further changes in the AFD.

Based upon these three descriptions of the product status, one should expect the AFD to be a dynamic product during its first few years of production. I recommended that GE plan for the initial model of the detector to have a product life-cycle (PLC) of less than three years. The implications of such a short PLC are significant. Utility personnel may resist purchasing a product which would be obsolete in a short time. I encouraged GE to evaluate ways to make product obsolescence easier to handle. I suggested they consider leasing early models of the AFD or establishing agreements whereby customers who purchased early models of the AFD would receive a price reduction on subsequent models. Additionally, I noted that the project would require GE to perform research and development on the AFD for several years.

Project Planning and Scheduling

In September 1981, Mr. Ridgeway directed me to compose a schedule of activities for the AFD project to meet the goal of delivering prototypes in the spring of 1982. Scheduling the project required that I organize the project tasks and estimate the time needed to complete each task.

Conflicting project goals caused problems with scheduling. To meet the prototype delivery date, I assumed that we would use a design similar to that developed at TAMU. I made this assumption to save time, but I felt that we would learn little by taking this short cut. I also assumed that some of the subsystems which DSO had developed could be used in the AFD.

I then identified the tasks needed to complete construction of the prototypes. These tasks included a definition of the device requirements, design, programming, construction, and testing. I assumed that the delivery date was fixed. I worked backwards from that date to determine the necessary completion date for each task.

I sketched a Program Evaluation Review Technique (PERT) diagram of the project tasks. Figure 6 presents this PERT diagram which illustrates the schedule. Several of the tasks required additional personnel to meet the project milestones. I superimposed the manpower estimates on the PERT diagram of Figure 6. Mr. Fink was unable to add personnel to the project.

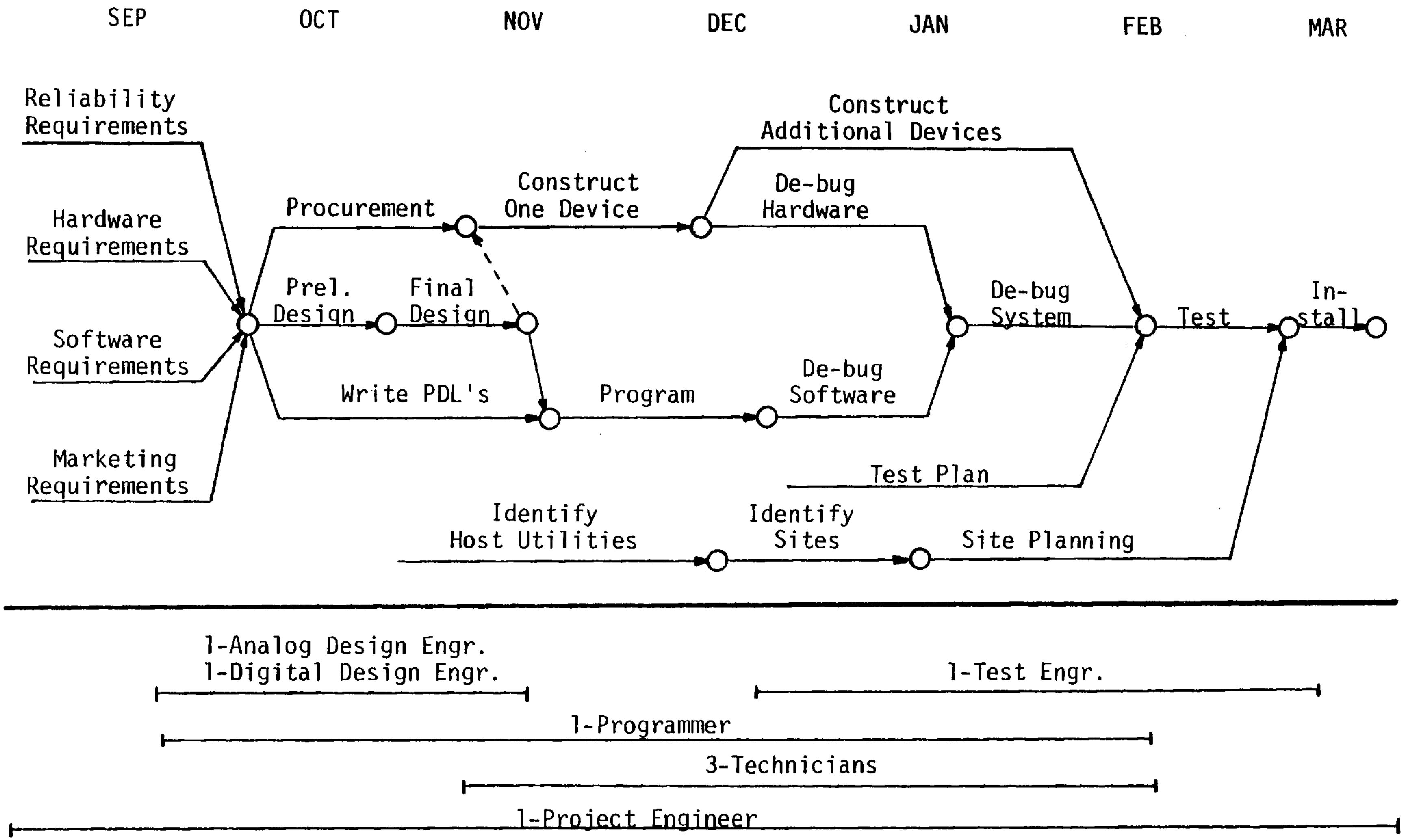

Figure 6. Project Schedule and Manpower Requirements Estimate

Subsequently, I provided a revised schedule to my supervisors. The original assumption of using several existing DSO subsystems had been proven false. Only one DSO subsystem could be used in the AFD. Other subsystems required a new design. I assumed that no engineering support would be available. I also assumed that we would market the AFD in two phases. The first phase was prototype testing. The second phase involved redesigning the product before entering the market. The new schedule I proposed provided for prototype delivery in August 1982.

Sympathetic Tripping Problem

One of the most serious limitations of the fault detector was its susceptibility to sympathetic tripping. This problem was significant enough to cause a product failure. Texas A&M had collected little data on the sympathetic tripping problem, so we needed to learn more about it.

I scheduled staged fault tests with Texas Electric Service Company (TESCo) in Fort Worth. During these tests, the utility lowers a 7,200 volt conductor to the ground to simulate a fallen conductor fault. At the same time, we record signals at the substation. The objective of these particular tests was to record data from several feeders during an arcing fault. We would use the data to determine if the faulted feeder could be positively identified.

I alone was responsible for arranging the tests, recording the signals, and analyzing the data. Much planning was needed to complete this research successfully. I scheduled the tests with TESCo personnel and submitted a plan to them. I also secured the necessary signal recording and analysis equipment. I rented an instrumentation tape recorder and signal conditioning equipment from Texas A&M. I rented an oscilloscope and spectrum analyzer from a rental agency.

I developed a test procedure and an instrumentation procedure. The test procedure described the number of faults to be performed at each of two locations. It also described the switching operations needed to arrange the feeder circuits properly. The instrumentation procedure helped me to coordinate the location of monitoring devices at specific times.

After I completed the testing, I spent two days analyzing the recorded data. The data indicated that a feeder with a fault always had a higher magnitude signal than that of the unfaulted feeders. One could compare the magnitudes of the signals on each circuit in a substation to identify properly the faulted circuit. We originally planned to have an independent fault detector on each feeder. It now appeared that we needed a system approach whereby the unit monitors all the feeders in a substation and determines which one is faulted. This approach was incorporated in the prototype architecture.

The system approach provided the necessary "quick fix" to the sympathetic tripping problem. However, the fact that we were dealing with a basic problem such as this reinforced the research nature of the project. We should not have made such a major product decision based upon observed data at one location. I had made no attempt to determine if the magnitude comparison approach provided optimum results. My approach was unscientific but necessary to meet the prototype delivery plans.

I analyzed the data again at a later date to determine the phase relationship of the feeder signals.

Utility personnel disliked the system approach because it required long cable runs on circuits which must be kept short. I recommended later in the internship that GE once again address the sympathetic tripping problem. I suggested that GE investigate using a magnitude-dependent timeout characteristic for the AFD. This characteristic would allow independent units to be installed at each feeder.

Architecture

The original AFD concept used an independent detector on each feeder. The system approach required that I develop a new architecture.

The first step in developing a satisfactory architecture was to identify the requirements for the device. Proper function required the AFD to monitor the signal from each feeder in a substation and to compare the magnitudes of these signals. A distribution substation may have from two to twenty-five feeders. Easy marketing of the device required that the architecture be flexible enough to handle any number of inputs within this range. A further requirement was that the design be compatible with existing DSO products, which used Intel components. The Texas A&M design had incorporated Motorola components.

The next step in developing the architecture was to determine how to implement the detection function. I calculated the amount of processor execution time needed to analyze each signal and the amount of time needed to compare signal magnitudes. These benchmarks were calculated for several processors. These calculations provided an estimate of how much processing power we needed. I developed several architectures which met the performance criteria. I then considered the additional factors of flexibility, cost, and complexity for each architecture. I ranked architecture characteristics by their importance. Figure 7 shows the architecture I selected.

This architecture assigns one Intel 8085 processor and analog-to-digital converter per feeder. Each of these feeder processors performs fault detection and transmits data to an Intel 8086 substation processor which identifies the faulted feeder. I chose this architecture for the following reasons.

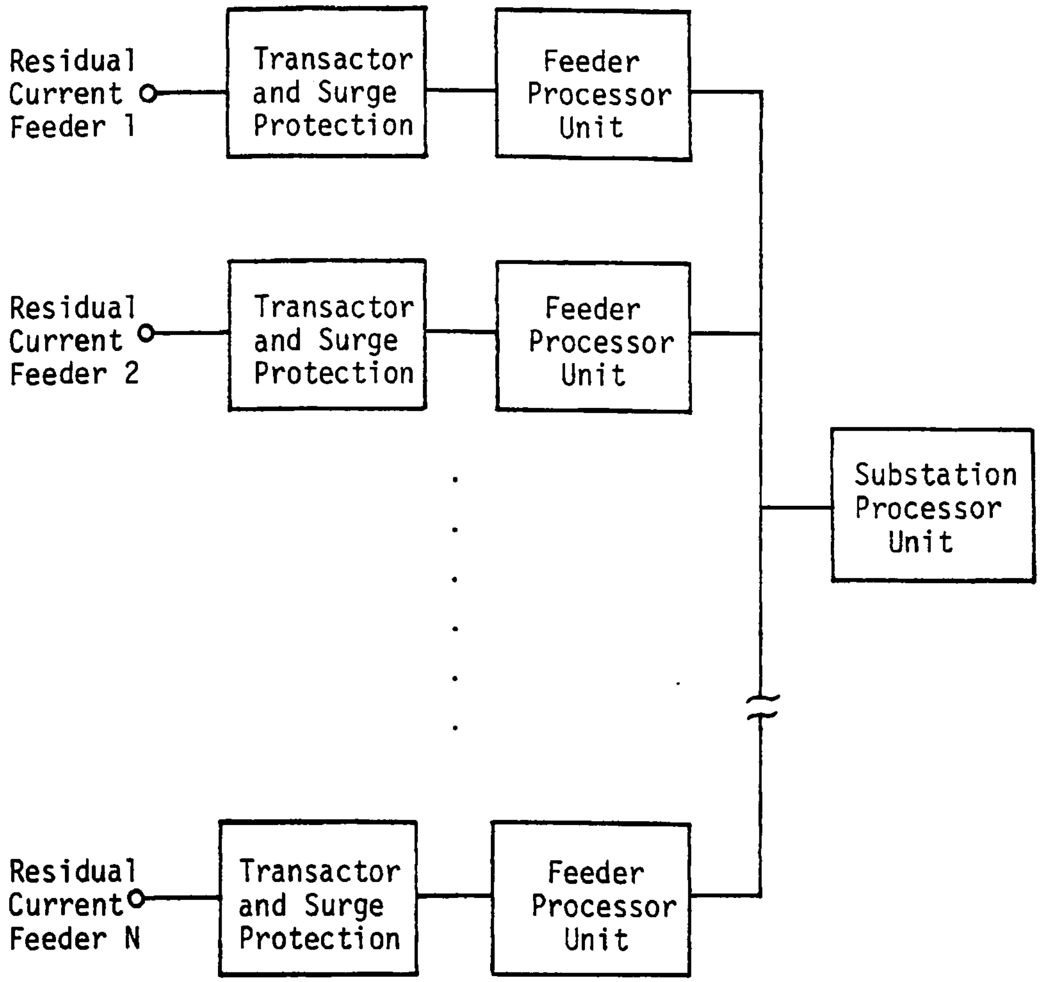

Figure 7. Arcing Fault Detector Architecture
Applying System Approach

1. It provided the most logical allocation of processor power for the functional requirements.
2. It provided the most flexible implementation.
3. Although it was the most costly architecture, it was the simplest. I considered this factor important because GE could not provide additional personnel for the project.
4. I could use an existing DSO design for the 8086 substation processor.
5. Each processor had approximately a 50% duty cycle, allowing the addition of more functions if needed.
6. The AFD could easily be combined with other DSO products.

Hardware Design

After I identified the architecture, I designed the AFD hardware. First, I designed the feeder processor unit. The data acquisition portion of this unit included a 2-10 kHz bandpass filter, a sample hold, and an analog-to-digital converter. An 8085 microprocessor and associated memory components composed the data processing portion of the board. A bi-directional interface permitted communication between the substation processor and the feeder processor. Figure 8 gives a block diagram of the feeder unit. The Appendix provides the schematic diagram of the feeder unit. The filter was the only portion of the unit which was constructed.

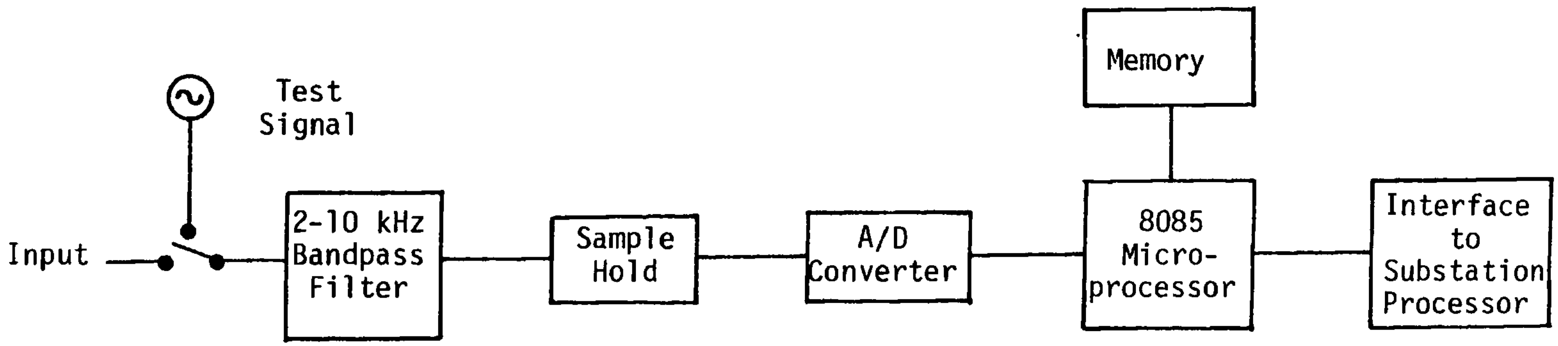

Figure 8. Feeder Processing Unit Conceptual Design

The substation processor unit incorporated an existing DSO design based on an 8086 microprocessor. The unit was responsible for identifying a faulted feeder, communicating with other devices, and recording data. Figure 9 shows the conceptual design of the substation processor unit and its associated peripheral devices. I worked no further on the design of the substation unit.

Software Design

I was responsible for the software design of the fault detector. General Electric required a top-down approach to software design. They used GE Program Design Language (PDL), instead of flowcharts, to describe algorithms. My first step of the software design was to learn PDL.

I subsequently converted the flowcharts of the TAMU software with enhancements into PDL. Once I accomplished this, GE required me to submit my software to a walkthrough. A walkthrough is a peer review of software involving three or more other engineers and is performed to eliminate mistakes in an algorithm. The walkthrough uncovered several basic problems with the program structure. I changed the program structure and revised the PDL programs. The software design was left at that stage.

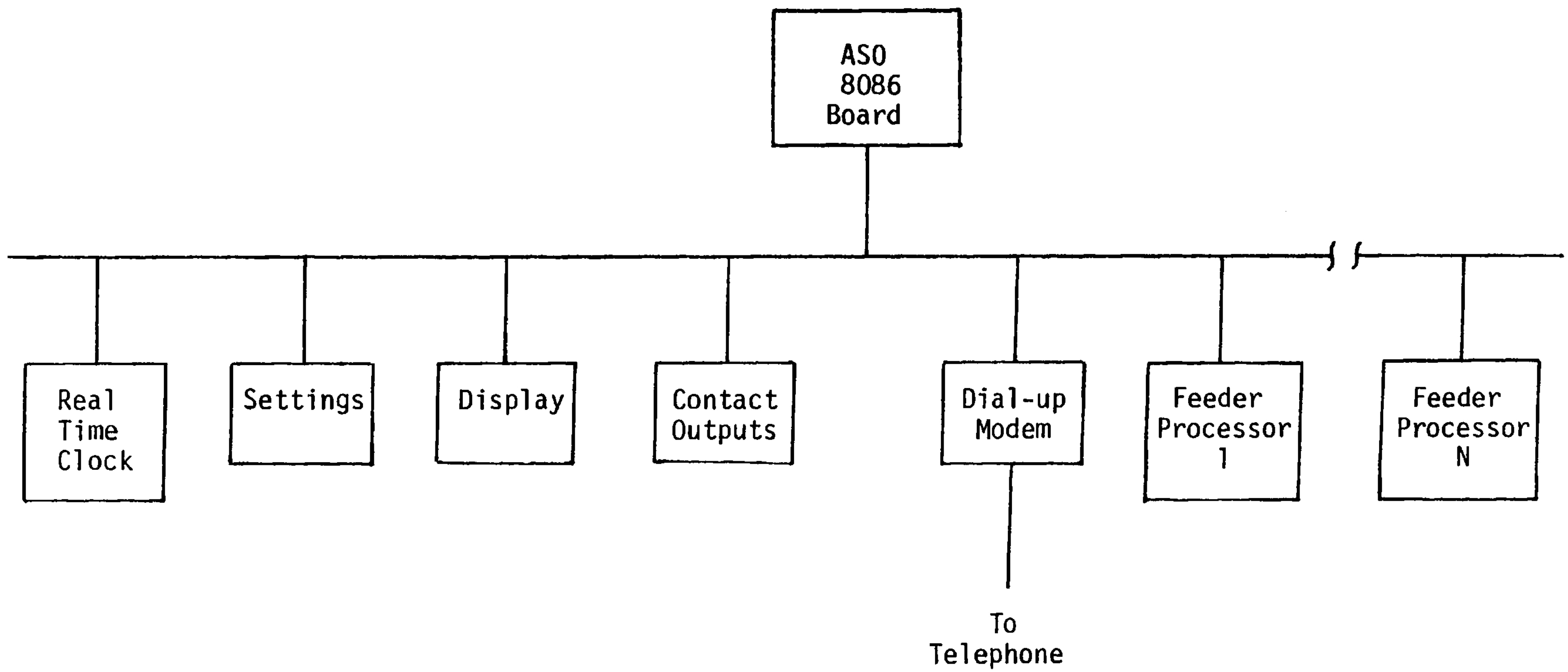

Figure 9. Substation Processing Unit Conceptual Design

Software Subcontract

We hired a consulting firm to convert my PDL programs into microprocessor assembly language code. We agreed that they would perform two phases of work. The first phase was to write a statement of work. The second phase was to convert the programs. I was the GE liaison with the contractor.

We encountered many problems with executing this contract. We were not ready to identify the work to be done. GE cancelled the contract during the Statement of Work phase.

Product Specifications

Before I arrived, Mr. Manley had begun writing product specifications for the AFD. I became briefly involved in this task after I began the internship. The objective was to compose a document which provided a functional and physical description of the AFD and which provided performance and testing specifications for the device to meet.

While we took some steps toward defining specifications, we left several important areas undone. We could not define several characteristics or requirements of the device either because they were not known or because they were changing.

Evaluation of Competition

One of GE's competitors had marketed an open conductor relay. Several other organizations were pursuing methods to improve high impedance fault detection. General Electric requested me to evaluate these competitive techniques.

I gathered all the information I could on these other methods. I then analyzed the strengths and the weaknesses of each method especially as compared to those of the AFD. I evaluated each product by its probable performance, cost, and implementation and by what problems the product introduced. For most of the competitive techniques, my analysis was brief. However, I evaluated the open conductor relay in detail because it was already being sold. I also participated in writing a discussion of a technical paper describing the open conductor relay.

Open Conductor Detection Enhancement

After their competitor had introduced the open conductor relay, GE asked me if the AFD could be made to detect open conductors in addition to arcing faults.

To answer this question, I first identified how the competitor detected open conductors. I defined the implementation necessary for the AFD to perform this function. I sketched a functional diagram of a suitable implementation. The architecture of the open conductor relay matched another DSO product more closely than it matched the

AFD. I recommended that the open conductor detector be included in this other device and not in the AFD.

Signal Level Considerations

The Arcing Fault Detector monitors a signal which is small in magnitude compared to the magnitude of 60 Hz current. It is difficult to filter and to amplify this signal without also amplifying electrical noise. The microcomputer hardware used in the AFD compounds this problem because the hardware generates electrical noise. I was especially concerned about placing several microcomputers near the sensitive signal conditioning system. I needed a signal transducer which provided sufficient gain in the 2-10 kHz passband while rejecting 60 Hz and its harmonics.

Initially, I hoped to use an auxiliary current transformer which DSO had designed. After evaluating this current transformer, I concluded that it would not be adequate. I then gave my specifications to a magnetics engineer at the PSMBD office. He designed and constructed a suitable transactor which overcame many of the signal level problems. I tested the transactor and graphed its transfer function.

Reliability Study

Digital Systems Operation standards required that all products meet a 10 year mean-time-between-failure (MTBF) specification. This standard is high for digital equipment, but DSO requires this standard because utilities expect new protective devices to be as reliable as the devices they replace.

Statistical methods are used to predict the failure rate of each transistor in a device at a given maximum temperature. One can then compute the failure rate of the entire system based upon the total number of transistors in the device.

I calculated a preliminary failure rate for the AFD. The calculated MTBF value was much lower than the required 10 year MTBF specification. I worked no further to improve the reliability of the AFD.

Visit to R & D Facility

General Electric Research and Development in Schenectady, New York analyzed signal propagation on distribution feeders. Their research intended to characterize communication signal propagation from devices located at residences to a device at a substation. The signal propagation problems they encountered were similar to propagation problems we experienced with the AFD. I visited this facility to learn more about their work.

Bandwidth of Current Transformer

The AFD derives its input from the secondary of an existing current transformer installed on a distribution feeder. Little research had been done on the fidelity of these devices at several kilohertz. We were interested in the fidelity of the devices because we had decided to compare the magnitudes of signals from several feeders. If the current transformers did not accurately reproduce the signals from the feeders, the magnitude comparison could provide incorrect results.

I contacted several magnetics engineers both in GE and in other companies. They indicated that current transformers provide suitable accuracy at frequencies up to 20 kHz. We would have no problem with the current transformers.

Presentation to the Staff

On several occasions, my supervisors requested that I present the project status to the staff. In general, I would prepare a presentation and would review the topics of discussion with Mr. Ridgeway prior to a meeting.

The following were my major presentations to the staff.

1. July 27, 1981. I reviewed the project status and the results of the TAMU research. I discussed the technical and business problems with the AFD and

summarized the plan for delivering a product to the market.

2. September 11, 1981. I presented the results of the staged fault tests and identified the system approach. I presented the initial project schedule and personnel requirements.

3. November 11, 1981. I reviewed the architecture for the AFD.

Closure

I have presented the major assignments I carried out during the first half of the internship. The objective of these assignments was to deliver prototype fault detectors in early 1982.

CHAPTER VII

ASSIGNMENTS DURING SECOND HALF OF INTERNSHIP

Introduction

On December 8, 1981, Dr. Russell met with the DSO staff to discuss the status of the Arcing Fault Detector project. At this meeting, many of the problems with the project were discussed. Just prior to this meeting, Mr. Mankoff had become the manager of the office. He soon rearranged the organizational structure of the operation.

This chapter presents the assignments I carried out during the second half of the internship. During December 1981, the emphasis for the AFD project shifted from commercializing quickly to investigating the problems of the project and evaluating their implications. With this shift in emphasis, my assignments were directed toward determining if it was feasible to commercialize the product.

Our approach to investigating the market for the detector was as follows. We delivered presentations to several utility companies. We sought to have these utilities purchase prototype detectors. During these presentations, we also surveyed the reactions of the utilities to the Arcing Fault Detector. Many of the utilities gave negative opinions of some of the characteristics of the detector. Their views caused us to investigate ways to improve the detector. I evaluated a method of performing fault detection with a low frequency signal. This method could drastically reduce the cost of the detector.

In a meeting with the staff, the company lawyer described to us the implications of product liability law. I provided GE with a list of options to follow and recommended a particular course of action for the future of the program. Before I left GE, I wrote final reports which summarized the technical and business status of the project.

These were the major activities of the second half of the internship. I will now present these and other related activities in detail.

Market Research

The management team wanted to investigate the market need for the Arcing Fault Detector. They determined that we could accomplish this by making presentations to several utility companies. The main objective of the presentations was to encourage the utilities to purchase prototype fault detectors. The second objective of the presentations was to determine whether the utilities would accept the characteristics of the AFD.

We delivered the presentations to ten utilities. I participated in three of these meetings and was primarily responsible for describing the function of the device. Later, I further surveyed four of these utilities by telephone.

In general, while these utilities eagerly discussed the AFD, they resisted purchasing a prototype detector. Many utility personnel disliked the problems with the detector. They recognized the legal factors which could affect application of the product. One utility felt obligated to purchase a prototype once they learned of the program. Another utility wanted to buy a detector just to prove it would not work. A third utility would not buy an AFD unless they were forced to buy one. This same company indicated it was not willing to fund GE product development.

These opinions from the ultimate users of the AFD emphasized the need to evaluate carefully the project before we proceeded further.

Cost Estimating

Two of the items we presented to the utilities during our presentations were an estimate of the selling price of a prototype detector and an estimate of the selling price of a production model detector. I estimated the selling price of the prototypes based upon the material cost of the components in my design.

To estimate a price for the production model, Mr. Manley and I visited the PSMBD production facility. Engineers at this plant described the materials they would use in a commercial product and estimated the amount of labor needed to assemble a unit. Using the material and labor costs, we calculated the variable and fixed costs for a single detector. By combining these costs with a standard contribution margin, we determined a selling price.

Low Frequency Fault Detection

Several utilities disapproved of the capacitor bank attenuation problems with the Arcing Fault Detector. They indicated it would be too costly to install the capacitor bank tuning devices which permit the arcing signal to propagate to the substation.

Mr. Schnieper suggested that we design the AFD to monitor frequencies below 1 kHz. Capacitor banks do not attenuate low frequency signals. Unfortunately, at low frequencies the harmonics of 60 Hz current are large compared to the arcing fault signal. The Texas A&M concept was to monitor frequencies above 2 kHz to avoid these large 60 Hz harmonics. Mr. Schnieper and I conjectured that we might avoid both the harmonics problem and the capacitor bank attenuation problem by designing the AFD to monitor signals between harmonics below 1 kHz.

To provide more insight on this potential improvement, I performed additional analysis of recorded fault data. I rented a spectrum analyzer and arranged to play the tape recordings at Texas A&M.

I observed the behavior of the signal at several specific frequencies on harmonics of 60 Hz and between harmonics. I also observed wideband signals in several frequency ranges. I examined tests with the capacitor banks both in service and not in service. I compared my observations with the behavior of the signal above 2 kHz. With capacitor banks in service, one could detect the presence of a fault by observing frequencies between harmonics below 750 Hz. Under the same conditions one could not identify faults when monitoring the 2-10 kHz signal which the Texas A&M design used. These results suggested that we could significantly reduce the installed cost of the AFD by designing it to monitor current between 60 Hz harmonics below 1 kHz.

These results were preliminary. I had only begun the needed analysis. We would have to perform more rigorous signal processing work to characterize the signal behavior adequately. Additionally, the rejection of 60 Hz harmonics could prove difficult or costly. Nevertheless, the fault detection method using low frequency signals shows promise.

Additional Work on Sympathetic Tripping Problem

During my analysis of the recorded data, I also sought a solution to the sympathetic tripping problem. The utility companies we contacted in our market research disliked the system approach as a means to avoid sympathetic tripping. They desired independent detectors on each feeder. My objective in the analysis of the recorded data was to identify any method which would permit a detector to ignore a fault on another feeder. I had no particular technique in mind but hoped that some method would become apparent during data analysis. I examined voltage waveforms on the substation bus and current waveforms on faulted and unfaulted feeders. I could not identify any unique characteristics in the signals on the faulted feeder. My examination was cursory. Detailed analysis might suggest a solution.

I later developed the concept of using a magnitude dependent time characteristic for the AFD. This technique is similar to that used in overcurrent relays. The length of time before the detector senses a fault depends on the magnitude of the signal. The unit with the highest magnitude signal, presumably on the faulted feeder, is the first to detect the fault. Assuming that the AFD on each feeder in a substation is operated as a relay, the faulted feeder is the only one de-energized during a fault. Independent detectors on each feeder can implement this technique.

Manufacturer Liability

The management team expressed concern about the potential for product liability lawsuits with the Arcing Fault Detector. We arranged to discuss the issue with the company lawyer.

The lawyer provided the comments on manufacturer product liability which were mentioned in the "Legal Environment" section of Chapter IV. He summarized that the AFD would have to be very profitable to offset the payment of damages from lawsuits.

I asked the lawyer if GE could be found negligent for not marketing the AFD. He answered that GE would not be negligent.

International Marketing

The manager of International Marketing for PSMBD asked if the AFD could be used on foreign power systems. He asked this question because foreign power system construction differs substantially from that used in the United States. Foreign countries commonly use two feeder construction practices. I identified the characteristics of each of these types of feeders. I also determined how foreign utilities implemented their protective relaying. Based upon my investigations, I determined that the AFD could provide little or no improvement over existing protective relaying on foreign systems.

Distribution Line Carrier

Several manufacturers market systems which can communicate information on a distribution feeder. These distribution line carrier (DLC) systems allow two-way communication between a central computer and devices located at residences. Some of these communications systems inject a signal on the distribution feeder at a frequency of several kilohertz. The presence of the signal poses a problem for fault detection because the AFD monitors these frequencies. The detector could mistakenly identify a communications operation as a fault. Unfortunately, the communications systems use several different frequencies and modulation techniques.

My approach to this problem was first to identify and to characterize as many communications systems as possible. I was hindered because some of the necessary information was unavailable and because some companies have not selected a particular communications frequency. The information I gathered indicated that there was little in common among the various systems, thus making a general solution difficult.

I noted three potential solutions.

1. We could design filters to reject specific communication signals. This approach would be costly because it would require tailoring each detector to ignore a specific signal.
2. An integrate-and-dump circuit could remove a carrier.
3. We could also devise an algorithm to distinguish intermittent arcing signals from the steady DLC signals.

We worked no further on this problem.

Harmonic Avoidance

Harmonics of 60 Hz are present on a distribution feeder at frequencies of several kilohertz. They are of the same order of magnitude as the signal used for arcing fault detection. Some DLC systems reject these harmonics and transmit the carrier at a frequency between the harmonics. This harmonic avoidance allows approximately a

30 dB improvement in signal-to-noise ratio. I investigated whether the principle of harmonic avoidance could be applied to arcing fault detection. Arcing generates a wideband signal which could be detected between harmonics. Rejection of harmonics could improve the sensitivity of the AFD.

I had recorded spectral traces in the substation at TESCo following the series of staged fault tests. These traces included spectra from one phase of the bus voltage and from the residual current on one feeder. The AFD monitors residual current. I monitored narrow frequency ranges near 5 kHz.

I noted that the harmonics were smaller in magnitude in the residual current than they were on the phase voltage. I conjectured that the residual harmonics were small because the residual is formed by the vector addition of three signals which are nearly equal in magnitude and 120 degrees apart from each other. In the residual current, harmonic peaks were only about 10 dB above the system noise level. It appeared that harmonic avoidance would not significantly improve the sensitivity of the fault detector. However, I recommended that we research the matter further.

Program Options

As the internship neared its end, Mr. Schnieper asked me to list the available options for proceeding with the AFD program. I addressed this assignment by first identifying the various approaches which GE could take. Two approaches stood out, namely, the original concept of monitoring signals above 2 kHz, and the potential improvement of monitoring signals below 1 kHz. I then identified the advantages and disadvantages of each approach, emphasizing the potential for success of the low frequency design. Finally, I estimated the resources needed to complete each option.

Recommendations

After outlining the future options for the AFD program, I detailed the program which I believed was necessary to lead to market entry. The following summary describes my recommendation. I divided the project into a Business Program and a Technical Program which are to be pursued simultaneously. I also identified several points at which GE could decide to proceed with or to stop activity. The goal of this effort was to develop a feeder-independent detector which did not require capacitor bank conditioning and which had a selling price of one thousand dollars.

Business Program

1. Develop a plan to reduce product liability.
2. Develop sales forecasts based on several scenarios.
3. Identify customer and market characteristics, especially problems with liability.
4. Evaluate the implications of this product for GE.
5. Solidify the product offering. Try to avoid the emphasis on safety.
6. Identify reasonable approaches to operational problems.

7. Develop a systematic method to incorporate solutions to these marketing problems into the product.

Technical Program

1. Stage additional fault tests to record low frequency data.
2. Perform computer analysis to characterize the signal.
3. Perform additional computer analysis to solve the sympathetic tripping problem.
4. Simulate fault detection algorithms and model filtering techniques on a computer.
5. Write the product specifications.
6. Design the fault detector. Consider an analog implementation for the detector.
7. Demonstrate a prototype fault detector.

Thermal Loading

All digital devices have temperature ratings. When the temperature of a digital device exceeds its rating the device may malfunction. The AFD was to be installed in outdoor metal cabinets which occasionally reach an internal temperature of 175 degrees F. Digital devices also generate heat, complicating the problem. I calculated the heat dissipation of the unit and discussed the results with another GE engineer. We determined that industrial grade components could tolerate the above conditions if a fan provided cooling. We also developed a preliminary physical layout for the unit.

IEEE Presentation

At the request of GE, I delivered a presentation on the Arcing Fault Detector Project to the Philadelphia chapter of the Institute of Electrical and Electronics Engineers Power Engineering Society.

Presentation to Staff

During the second half of the internship, I delivered one presentation to the staff regarding the AFD project. Soon after the office reorganization, I presented the project status to several members of the management team.

Final Reports

Before concluding the internship, I wrote two reports which described my activities during the internship and which summarized all that we had learned in the AFD project. My objective was to transfer in writing to GE all that I knew about the detector.

The first report dealt with technical matters. It summarized the results of the TAMU research, described the major technical assignments of the internship, and described the problems which we addressed.

The second report discussed the business and marketing aspects of the project. This report described the project scope, which I presented in Chapter IV. I described how we had addressed the marketing problems. I also summarized the results of our market research and of the meeting with the lawyer. The report covered the misunderstandings which had occurred previously in the program. Finally, I described the future program which appeared to have the best chance for success.

Time Overcurrent Algorithm Evaluation

This assignment did not relate to the AFD but related to another ASO product which performs overcurrent relaying. This device uses an algorithm which simulates the time overcurrent curves of a standard electromechanical relay which it replaces. I was instructed to determine the amount of error in the approximation used by this algorithm when compared with the characteristic values of the electromechanical relay. If the error was large, I was to identify any potential method of reducing the error.

I began by overlaying the time overcurrent curves from the digital relay on the curves from the electromechanical relay. I computed the error at several different time-dial settings. I also observed that the digital relay provided total coverage of the electromechanical curves. I then noted that analog overcurrent relay curves do not match the corresponding electromechanical relay curves. Because the difference between the analog and electromechanical relay curves is acceptable, I concluded that the difference between the digital and electromechanical relay curves would also be acceptable. I reported my findings to another ASO engineer who decided to accept the digital overcurrent relay algorithm.

Event Recorder Preliminary Product Description

This assignment was also not related to the AFD project. I was instructed to develop a preliminary product description for a digital device which was to perform slow oscillography and sequence-of-events recordings. The device would store data automatically on cassette tape. The objectives of my assignment were to describe the functions of the device, to suggest specifications, and to provide a conceptual design or architecture for the unit. The product description was to be a foundation from which to pursue further work.

I began the task by identifying all the types of signals which would be recorded. I then calculated the amount of data which had to be handled during the longest recording. Two methods would allow the transfer of data to cassette tape. The first method would be to record monitored signals on tape in real time. The second method would be first to store the data in random access memory and then to transfer it to tape at a slow rate. I outlined the trade-offs for evaluating which method to choose and reviewed some of the basic design considerations. I also provided an architecture which allowed additional capabilities such as time-tagging and communication with other devices.

Closure

I have discussed my assignments during the second half of the internship. Most of these assignments were directed toward investigating the status of the project and the market and determining the future options for the program.

CHAPTER VIII

RESULTS OF INTERNSHIP

Overview

This chapter summarizes the results of the internship experience. First, I evaluate the internship goals. Then, I review what I contributed to General Electric during the internship. Finally, I summarize what I learned during the internship.

Outcome of Internship Goals

During the internship I continued to develop the Arcing Fault Detector. I also helped GE gather marketing information they needed to judge the potential success of this product. What I accomplished during the internship was not what GE sought at the start of the internship. Their goals were to deliver prototypes and to develop a production plan during my stay. Their objectives were not met for the following reasons.

First, much more work was needed to determine if the product could be successful. General Electric had recognized that the market wanted a high impedance fault detector. However, GE perhaps did not realize that it would be difficult to satisfy the market need. Furthermore, manufacturer and utility liability for this product pose serious obstacles to the commercialization of the AFD. The marketing problems for the AFD are not impossible to overcome, but they require close examination.

Second, General Electric misunderstood the technical status of the project. They apparently believed that we could easily convert the TAMU prototype into a commercial product. Substantial work was needed just to convert the TAMU design into a commercial design. Moreover, market research indicated that further technical development was needed to produce a salable detector. The AFD project was in a research stage, not in a development stage.

Third, inadequate resources were assigned to the project. Even if the market was clearly defined and if the fault detection technology was mature, it is unlikely that any one person could have finished a commercial design of the product in nine months.

Contribution to GE

The development and investigative work I did benefitted the project. I made four major contributions to General Electric.

First, I transmitted my knowledge of the Texas A&M project results to GE. This knowledge will permit GE to build the AFD if they so decide.

Second, I substantially developed the Texas A&M fault detection concept during my employment at GE. I improved the concept by developing the system approach to handle sympathetic tripping. The system approach may not be a desirable solution, but it may turn out to be the only solution to sympathetic tripping. I also improved the concept by enhancing the fault detection algorithm to provide more sensitive and reliable detection of faults. Additionally, we advanced the detection concept by investigating fault detection at low frequencies.

Third, I converted the enhanced Texas A&M design into a design which is compatible with ASO standards. I designed the detector hardware with procedures and components which ASO used. I wrote the fault detection algorithm in General Electric Program Design Language.

Fourth, I helped GE to evaluate the Arcing Fault Detector as a product. My major contribution in this area was identifying the obstacles to commercializing the detector. This contribution was the most important one of the internship. Identifying the project scope provides GE with more information with which they can decide whether to market the AFD.

In summary, the internship advanced the product development and business analysis phases of commercializing the Arcing Fault Detector.

My Experience

The internship provided me with invaluable experience in an industrial organization. The experience benefitted my growth as an engineer and as a person.

Most importantly, I learned the necessity for open and honest communication. Poor communication caused many of the problems we encountered at GE. I contributed to the misunderstandings by not being assertive in my communications with other GE personnel. My attempts to meet the goal of quick commercialization exacerbated these problems.

Closely allied with the need for good communication is the need to accept conflict. In any organization, conflict is inevitable and necessary. Conflict is beneficial when it is promoted properly because it leads to the search for better solutions to problems.[12] Conflict is destructive when it is repressed too often. Good communication leads to better acceptance of conflict and vice versa. The combination of good communication and acceptance of conflict leads to the solution of problems.

At GE, I applied much that I learned at Texas A&M. The most significant aspect of my education that I used was a systematic approach to problem-solving. This approach applies to any type of problem: technical, business, or organizational.

As a major component of systematic problem-solving, one must view the entirety of a project while working on any particular area of the project. For example, it was helpful to observe how the marketing and engineering functions of the AFD project interacted. When the utilities rejected the high frequency detection concept as too expensive, it became an engineering problem to determine the feasibility of low frequency fault detection. Likewise, one must consider the long-term effects of a decision.

Closure

The internship goal of commercializing the fault detector was not met. Instead, I further developed the detector and investigated the problems with commercialization. I also transmitted the results of the TAMU project to GE and developed a GE-compatible design of the TAMU detector with enhancements.

CHAPTER IX

CONCLUSIONS

I completed the internship requirement for the Doctor of Engineering degree with the General Electric Company. The purpose of my internship was to transfer to GE the results of research at Texas A&M on the Arcing Fault Detector. The objective of General Electric for my internship was to develop a commercial model of the AFD. I did not meet their objective for the following reasons:

1. Substantially more engineering effort was needed to produce a high-quality commercial design.
2. Much more market research and product development were required to provide a marketable device.
3. General Electric was unable to assign additional personnel to the project.

These reasons for failing to meet the project objective are indicative of the goal-setting problems we experienced during the internship. Excessive enthusiasm for the project led to a misunderstanding of the project status and a disagreement on the extent of work required to reach market entry.

The internship accomplished the following:

1. I transmitted the results of the Texas A&M research to General Electric.

2. We advanced the fault detection concept.

3. I converted an enhanced version of the Texas A&M detector into a GE-compatible design.

4. I investigated the roadblocks to commercializing the AFD.

These accomplishments of the internship enable General Electric to continue the business analysis of and the product development for the Arcing Fault Detector.

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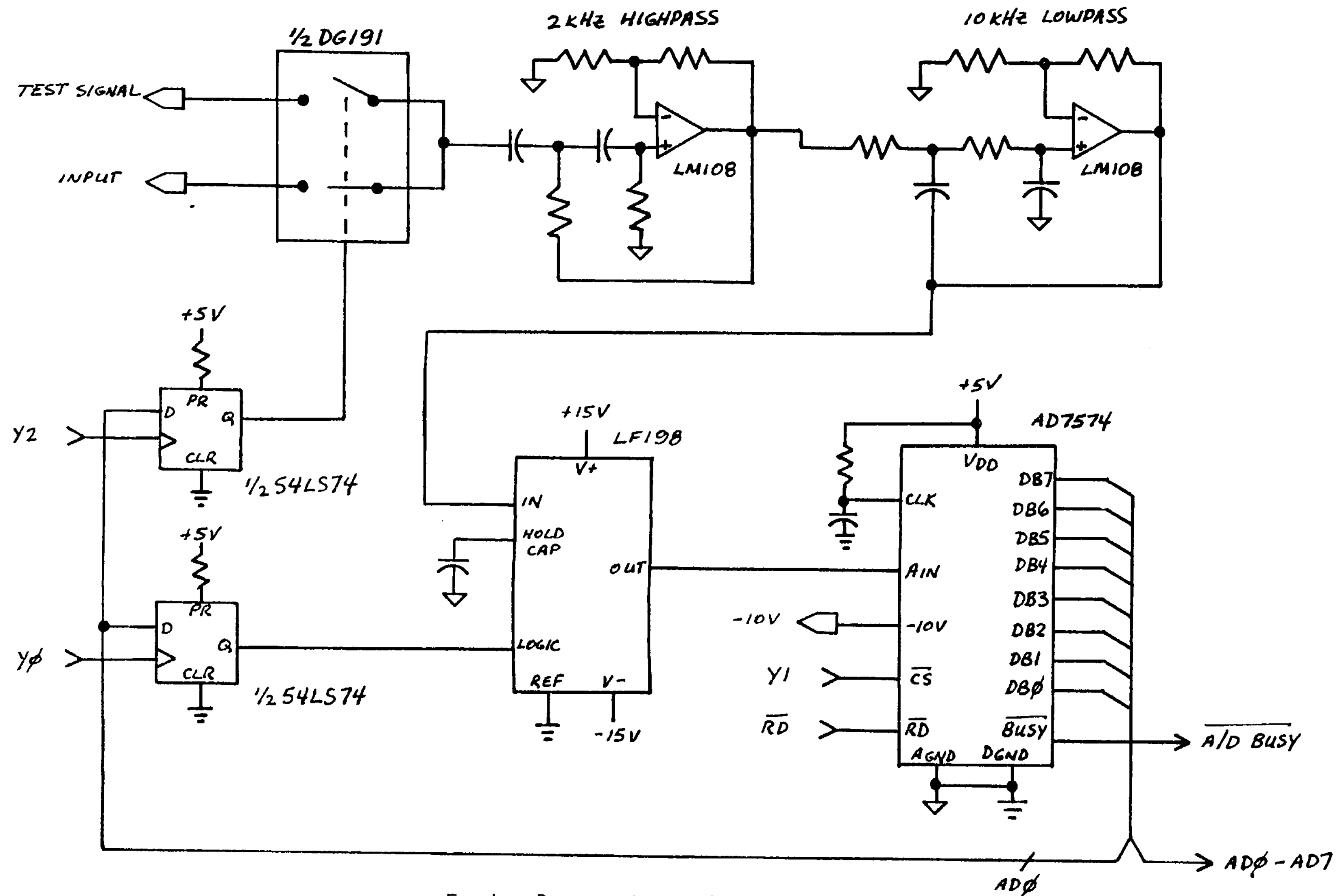
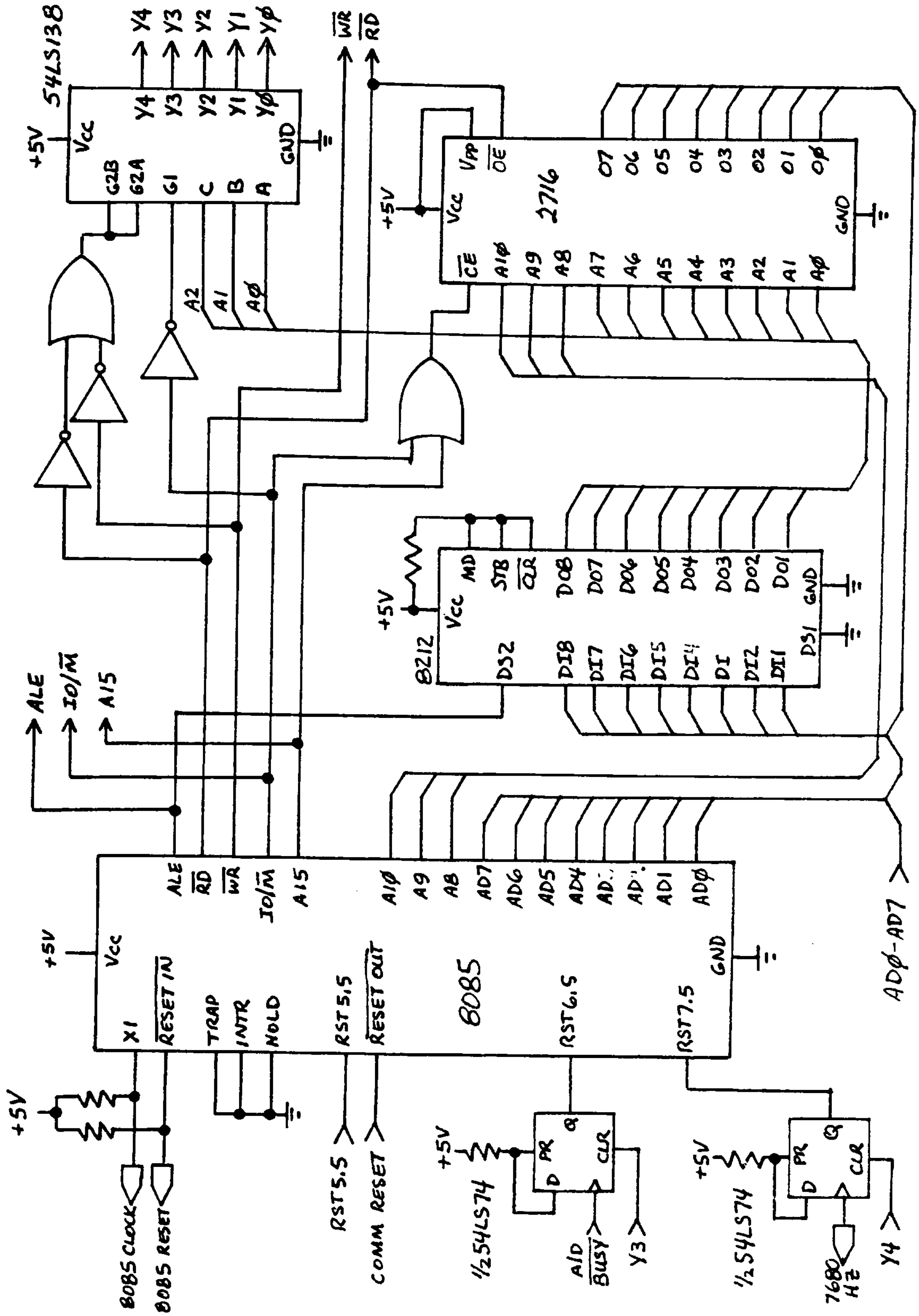
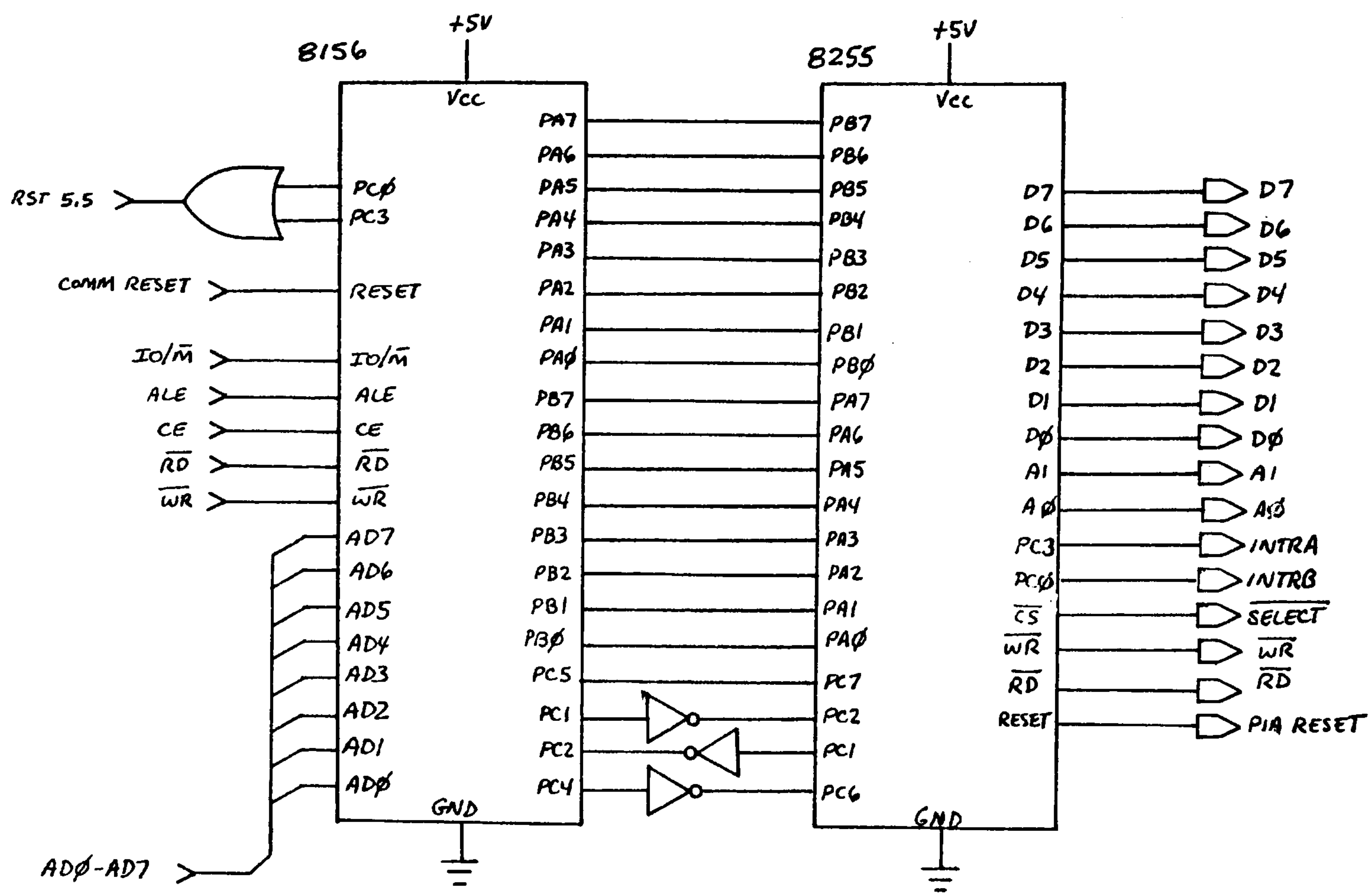
APPENDIX



Feeder Processing Unit Sheet 1 of 3



Feeder Processing Unit Sheet 2 of 3



Feeder Processing Unit Sheet 3 of 3

VITA

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Mr. Aucoin received a Bachelor of Science degree with a major in Engineering Sciences from the University of New Orleans in 1976. He received a Master of Engineering degree with a major in Electrical Engineering from Texas A&M University in 1978.

Mr. Aucoin worked as a Graduate Research Assistant for Texas A&M University on their Arcing Fault Detector project. The National Society of Professional Engineers named the Arcing Fault Detector as one of the Ten Outstanding Engineering Achievements of 1981. Mr. Aucoin continued this work on the Arcing Fault Detector in his Doctor of Engineering internship with the General Electric Company.

The author's field of expertise is the application of microcomputer systems to electric power system control and protection.

The typist for this report was Mrs. Debbie Hemphill.