COMPU-GUARD

FEASIBILITY DEMONSTRATION

OF THE

CITIZENS ALARM SYSTEM

VOLUME I: FINAL REPORT

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ABSTRACT

The Citizens Alarm System (CAS) is a personal emergency communication system which enables quicker response and assistance to victims of crime. The system was developed for users within a building, and its feasibility was demonstrated in this three-phase program.

CAS is basically a hardware information link between victim and response agent. The system facilitates response by identifying the victim and the location of the crime. Based on a consideration of human, environmental, technical, and cost factors, a system is comprised of four types of components: actuators, internal and external receiver-relays, and a central station. The actuator is a personal watch-styled unit that can be triggered to transmit an encoded UHF radio signal. Internal receiver-relays (IRR) are strategically located in the protected building and communicate with the central station either directly, using carrier communication on the 110 V AC power line, or indirectly, via power line and dedicated voice-grade phone line, with an external receiver-relay (ERR) between the two types of line. The IRR receives the actuator code and adds a location code prior to signal transmission.

System tests, conducted in the laboratory and in two real-world scenarios, demonstrate a high degree of operational reliability and a response time better than 10 seconds. The system is also protected against message interference due to multiple simultaneous triggerings, and minimizes false alarms due to user negligence or error.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

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SUMMARY

CHAPTER I. INTRODUCTION

The Citizen's Alarm System (CAS), an advanced personal security system, was designed to assist the victim of crime by enabling quick and automatic notification of law enforcement response agents.

The CAS, developed under this contract with The Aerospace Corporation meets the operational requirements for use in buildings by all types of people in differing living conditions.

The system was developed and tested in a three-phase program, and this report explains the analyses, design, development, and feasibility demonstration of the system.

A. Scope of Citizen's Alarm System and Its Coverage

Many people have been affected by the rapid increase in personal crime and consequent high level of fear. The four major personal crimes -- murder, rape, assault, and robbery -- reflect the growing level of violence in this society. Two kinds of answers have been proposed in response: long term and immediate. The sociological solution, the long-range answer, provides neither short-term relief nor any comfort to a victim of crime. Even for the long-term, there is no infallible sociological approach. The second answer, a hardware solution, benefits the immediate health and safety of the victim which the long-range consequences or the cause-effect relationships that led to the occurrence of the crime do not.

The hardware allows the user to call for help in an emergency: silently, covertly, quickly and reliably. The hardware improves the process of notification and response and allows a timely and effective response by law enforcement officials. At least conceptually, such a system can save lives, minimize injury to a victim, increase the apprehension rate of criminals, and serve as a deterrent to crime.

The Citizen's Alarm System is this hardware solution. Because the system interfaces with the user at one end and the response agent (e.g. police) at the other, careful consideration of human factors is therefore an important requirement.

Other system requirements deal with configuration, versatility of application, reliability, hardware response time, and the minimization of false alarms. To be effective, the system must indicate the location of the emergency (to direct the response agent), and identify the victim (to prevent the misuse of the system, either carelessly or maliciously). Finally, the system must be inexpensive to the user and the owner/operator. The general system configuration is shown in Figure I-1.

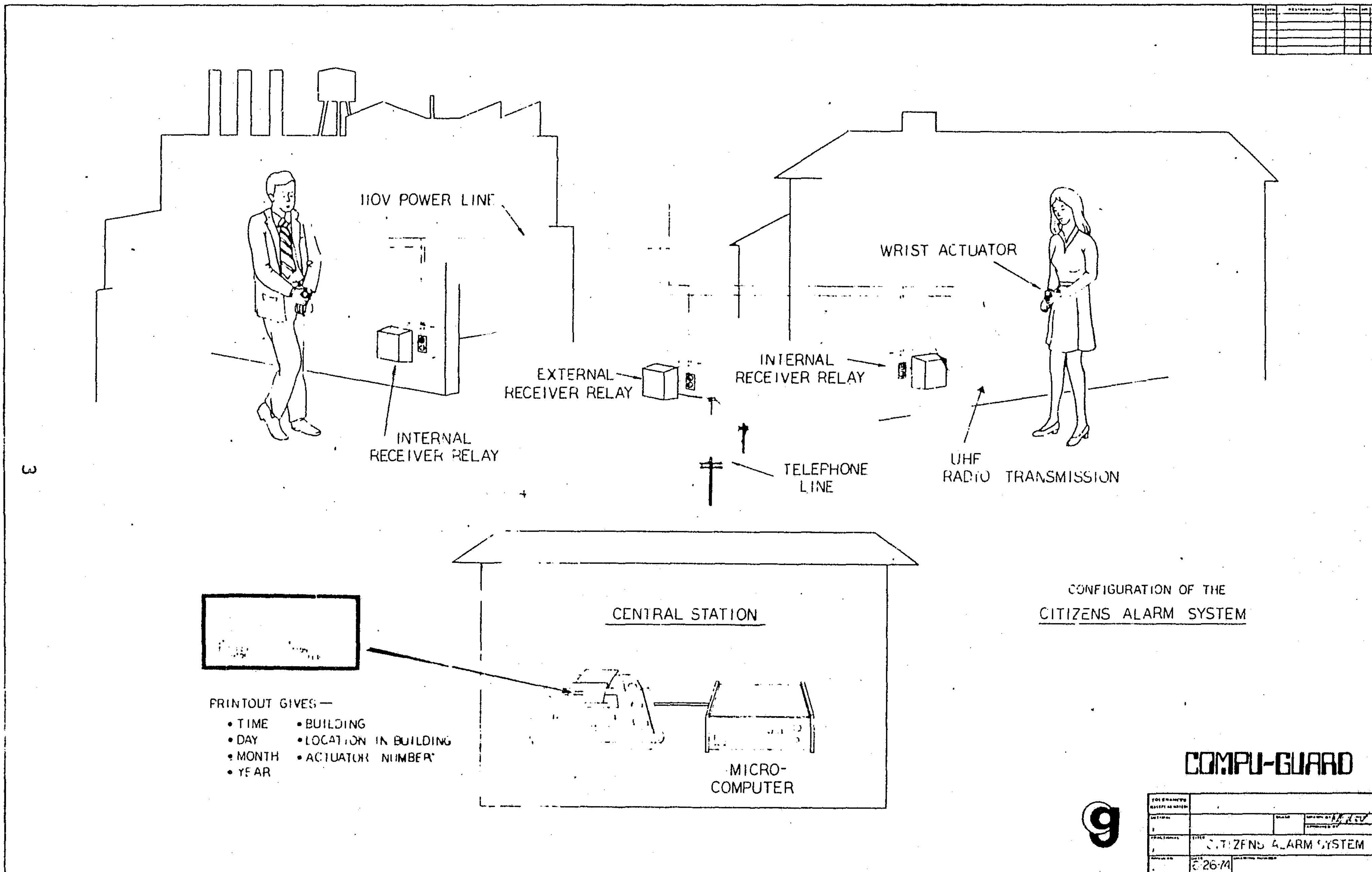

110V POWER LINE
WRIST ACTUATOR
EXTERNAL RECEIVER RELAY
INTERNAL RECEIVER RELAY
INTERNAL RECEIVER RELAY
TELEPHONE LINE
UHF RADIO TRANSMISSION
CENTRAL STATION
CONFIGURATION OF THE
CITIZENS ALARM SYSTEM
PRINTOUT GIVES —
• TIME
• DAY
• MONTH
• YEAR
• BUILDING
• LOCATION IN BUILDING
• ACTUATOR NUMBER
MICRO-COMPUTER
COMPU-GUARD
CITIZENS ALARM SYSTEM

FIGURE I-1

There is a wide diversity of potential users, environments, and scenarios in which CAS may be used. Under this contract, the system was defined for use within a building and the range of in-building scenarios for CAS is shown in Table I-1 . The system therefore, must be versatile enough to be applicable in convenience stores, institutions, and residential areas.

The system was developed in three phases. Phase I was the analysis and assessment of user needs and attitudes, as the basis for human factors considerations in the system, and resulted in detailed description of system requirements. Phase II, the analysis and design of the system , resulted in the fabrication of several prototype units. The hardware was then extensively tested and its performance and capabilities demonstrated in Phase III.

B. Background

The development of the Citizen's Alarm System has been influenced by two major factors: the needs and attitudes of the user and the availability of relevant cost-effective technology. The need of the user, the potential victim, have never been greater. The benefits of such a system are many, and have been summarized in Table I-2. However, given the need for a system, successful hardware implementation depends on the application of technology. Two

TABLE I-1: REPRESENTATIVE LIST OF CAS APPLICATIONS

INSTITUTIONAL	RESIDENTIAL	COMMERCIAL
. SCHOOLS	. PUBLIC HOUSING	. CONVENIENCE STORES
. PRISONS	. APARTMENTS	. BANKS
. SENIOR CITIZENS HOME	. HOUSES	. WAREHOUSES

TABLE I-2: POTENTIAL BENEFITS OF THE CITIZENS ALARM SYSTEM

* Increased crime reporting
* Signalling for help possible before or during the perpetration of the crime, rather than after
* Quicker response time
* Increased probability of timely medical and other assistance
* Improved quality of response, specific location of crime
* Increased criminal apprehension rate
* Reduced rate of personal crime
* Reduced fear of victimization
* Increased user confidence in the criminal justice system

years prior to the award of this development contract, Compu-Guard had begun its own R & D activity to develop a personal, digital emergency communication system. This system included personal, encoded UHF radio-frequency transmitters, used power lines (110V AC) within a building as one of the communication links in the system, and had a low-cost, micro-computer system for the central station. Independently, the Aerospace Corporation had sub-contracted Sylvania to study and characterize power lines as a viable communication link. Sylvania's results in this effort matched those of Compu-Guard. Prior to contract award, The Aerospace Corporation had also built breadboard prototypes to explore system feasibility.

The development of the Citizen's Alarm System was, therefore, focussed at the understanding of user needs and the design of a human-engineered system, based on an upgrading and adaptation of this available technology.

C. <u>Organization of Final Report</u>

The format of the final report follows the three phases in the development of the system.

Chapter II offers the system overview and the detailed objectives and methodology behind system design. This includes a background study of the basic hardware and its interaction with the user and the response agent.

Chapter III develops the overall requirements of the system as they relate to system configuration and other parameters such as response time, reliability, false alarms, packaging, environmental restraints, and cost. The rationale for these requirements is examined in detail, based on a consideration of human, environmental, technical, and cost factors. This chapter also covers much of the work done in Phase I, and some of the early work in Phase II.

Chapter IV describes the design of each of the major components and transmission links, and their relationship to the design of the overall CAS information system. All this work was done in Phase II of the project.

Chapter V covers the plan to determine the performance of the components, the transmission links, and the system as a whole -- both in the laboratory and in the two test scenarios in the field. The results of the lab and scenario tests are presented, together with an evaluation of data and analyses of system performance and some conclusions. This testing phase corresponds to Phase III of the project.

Finally, Chapter VI summarizes the final conclusions and recommendations with some guidelines for future development and action.

CHAPTER II. SYSTEM OVERVIEW, DETAILED OBJECTIVES AND APPROACH

The primary purpose of CAS is to assist a victim of crime by serving as the emergency communication link to the response agent. The implementation of this requires the formulation of program objectives and a design methodology that recognizes the human and hardware elements, and the environmental restraints within which the system must operate.

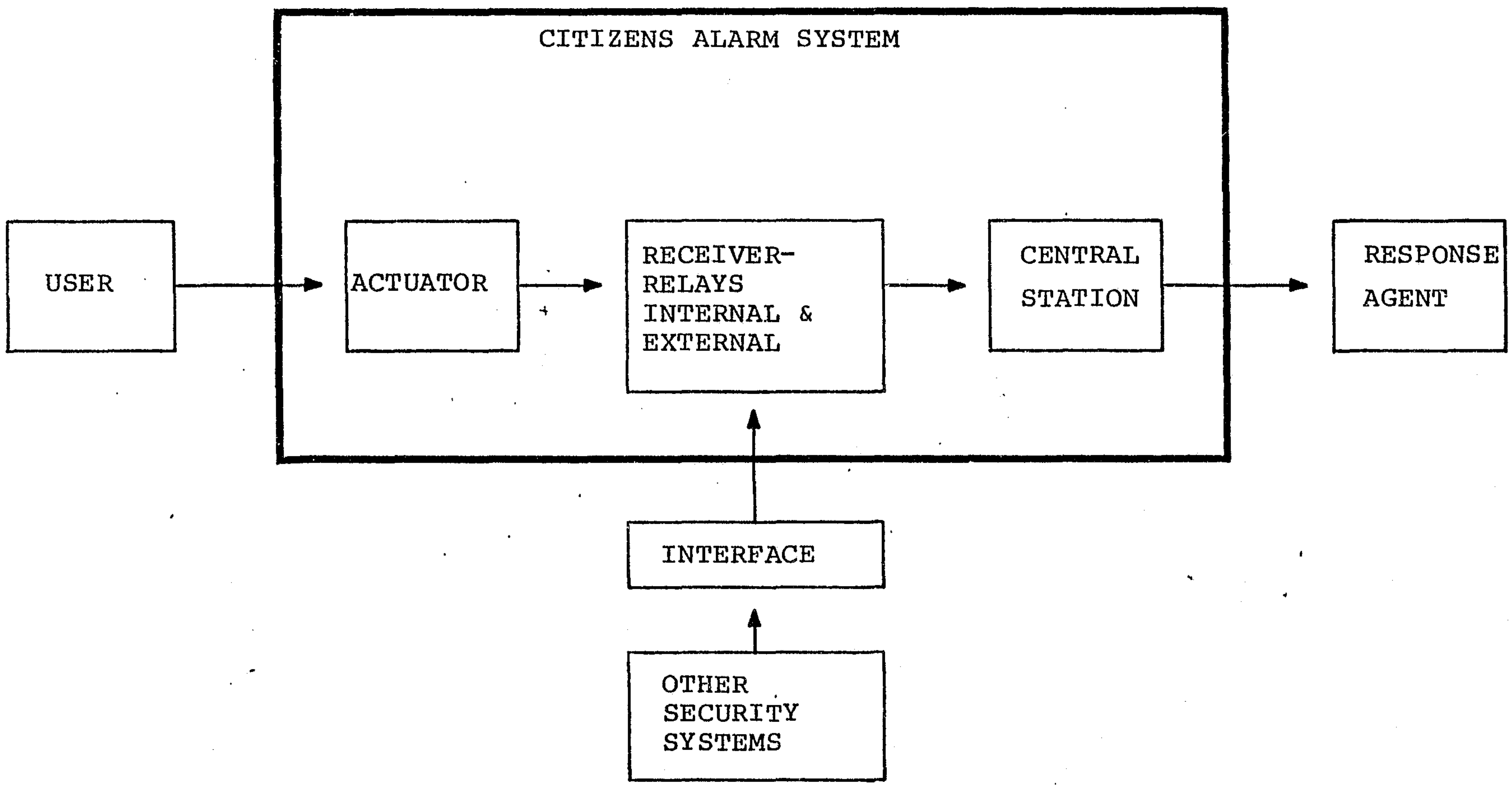
A. System Overview

CAS is a hardware system that operates in a larger security environment including users, response agents, and other security systems (hardware or software). The central role of CAS in this environment is shown in Figure II-1. Good system design, then, calls for a careful consideration of the interface between CAS and its operating environment.

1. System Configuration

CAS will serve a large variety of users and response agents within a large range of locations and operating conditions (human and environmental). This wide range of applications for CAS leads to a system objective: that it be a versatile system with functional components as its "building blocks".

FIGURE II-1: THE ROLE OF CAS IN THE OVERALL SECURITY ENVIRONMENT



The cost-effective transfer of information from the user to the response agent via CAS requires the use of several information transmission links in series.. Human and physical environmental considerations determine the choice of these links. The minimum hardware configuration, therefore, requires that each functional component provide an information transfer from one link to another. The configuration of the system and the transmission links used have been shown in Figure I-1. The entire system has four different kinds of components; as shown in the photographs (Figure II-2.)

Actuator

Internal Receiver-Relay (IRR)

External Receiver-Relay (ERR)

Central Station (CS)

The actuator is the personal device worn or carried by the user. The central station is the central receiving point where all information is received, processed, and displayed for action by a response agent. The receiver-relays are the intermediate data transfer points between the actuator and central station.

The actuator transmits a unique identification code which assigns the responsibility for the call to a specific user. The internal receiver-relay which receives

FIGURE II-2a: ACTUATOR

FIGURE II-2b: INTERNAL RECEIVER-RELAY

FIGURE II-2c: CENTRAL STATION MICRO-COMPUTER this signal adds-on a location code, pinpointing the location of the emergency, and relays the messages down to the central station -- using an external receiver-relay, if necessary. The nature of the specific transmission links and information flow is given in Table II-1.

2. The User

The range of CAS applications is also indicative of the wide range of potential users. Users will differ in sex, age, physical and mental ability, income, type of household, social and cultural background, etc., as well as different types of emergency need. Each of these parameters relates to the human factors involved in the design of the interface of system and user. For example, the actuator must be designed to be operable by most people, and have almost universal aesthetic appeal. Also, the user must feel confident about the operational reliability and effectiveness of the system. Conversely, the system hardware should minimize the problem of false alarms.

3. The Response Agent

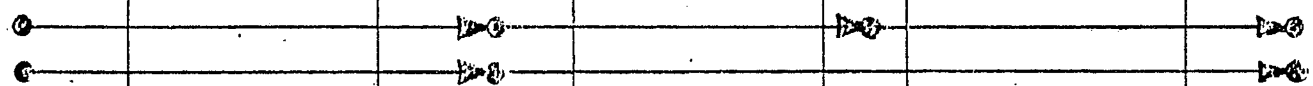
The nature of the response agent depends on the location of the central station. If this is located on the protected premises, the agent may be a local private guard or security person. For a remotely located central station (e.g. Police

Headquarters or at a central alarm company), the response agent may be a police officer or a guard or both.

The central station should be flexible enough to meet the needs of the response agent, specially in terms of ease of operation and maintenance, and the clarity of display/print-out. It should also minimize record-keeping and clerical tasks.

The hardware development is felt to be essentially independent of response agent policy or economic considerations. The hardware system developed here can be implemented under a broad range of user-response needs, policies, and economic conditions.

TABLE II-1: DETAILS ON SYSTEM TRANSMISSION LINKS

ITEM	ACTUATOR	TRANSMISSION LINK TO IRR	INTERNAL RECEIVER-RELAY (IRR)	TRANSMISSION LINK TO ERR OR CENTRAL STATION (ON PREMISES)	ERR	TRANSMISSION LINK TO CENTRAL STA. (OFF PREMISES)	CENTRAL STATION
INFORMATION FLOW (alternatives)							
INTRINSIC INFORMATION GENERATED	ID Code (32 bits)		Location Code (7 bits)		--		--
TRIGGERED BY	User		Actuator		IRR		IRR or ERR
TRANSMISSION CHANNEL		UHF radio (460 MHz)		Power line (250 to 350 kHz)		Telephone Line (400-1200 Hz)	
DATA TRANSMISSION SPEED		500 baud		60 baud		60 baud	
ONE-WAY v/s TWO-WAY COMMUNICATION		One-way		Two-way		Two-way	
REAL TIME v/s DELAYED COMMUNICATION		Real Time & delayed		Delayed		Real Time	
TYPICAL INFORMATION TRANSMISSION TIME		1 Second		4 secs (min) 5 secs (typ)		0.2 secs	

B. Detailed Objectives and Approach

The development effort has been conducted in three phases, following an analysis of detailed program objectives. The methodology used is illustrated in Figure II-3.

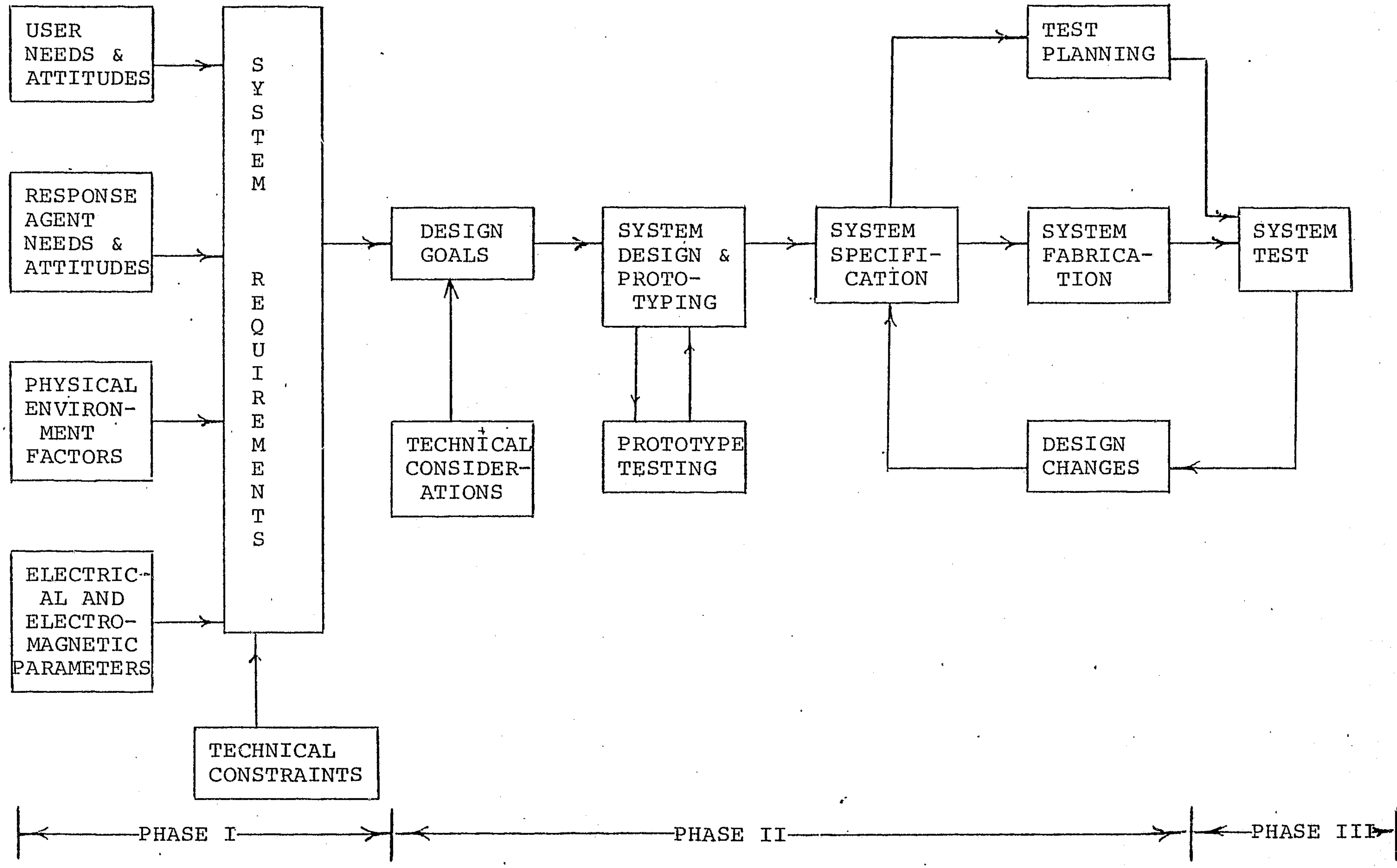
1. Program Objectives

The basic objective of the program has been to develop, demonstrate, and evaluate a personal alarm system for in-building use by citizens in various high stress situations, e.g. violent crime. The system identifies the victim (to minimize false alarms) and his/her location (to facilitate response). The development includes the consideration of human, environmental, and cost factors. Basic hardware feasibility had been demonstrated prior to the start of this program, and one of the program objectives has been to apply state-of-the-art technology in the development of an effective, inexpensive system with appeal to both user and response agent.

2. Phase I: Investigation of System Requirements

This phase included an assessment of user needs and requirements, as the basis for determining system specifications and hardware requirements. The user's attitudes and behavior in high stress situations were

FIGURE II-3: CAS DEVELOPMENT METHODOLOGY



explored, particularly in terms of perception of crime and potential behavior given the availability of CAS. Human and environmental factors and restraints governing the use of the system were defined. Emergency response services, such as those provided by police and guards, were analyzed in terms of supply and demand relationships. This helps to determine the range of response times likely for different scenarios in which CAS may be used. Regulations and policies impacting on system development (e.g. FCC regulations) were studied. Quantitative models for system reliability and effectiveness were used to evaluate tradeoffs. Alternative procedures to minimize the occurrence and effects of false alarms were then analyzed. This resulted in the development of general system requirements to best serve the users. Finally, Phase I included the analysis of alternative scenarios for system testing and demonstration. The scenarios were considered in terms of the architectural layout, type of construction, age of the physical plant and facilities, the demographics of the residents, and the prevalence of crime. Two test sites -- Arlington Heights and Amberson Gardens -- were selected for this purpose. The former is a public housing project of the City of Pittsburgh, and the latter a private high-rise apartment complex. These two scenarios embrace a wide range of user and environmental differences, allowing a realistic basis for testing the System.

3. Phase II: Component Design and Development

The requirements of Phase I were first translated into component requirements. The choice of the most appropriate technology for each component (actuator, internal receiver-relay, external receiver-relay, central station) was made on a consideration of performance, reliability, human factors, cost, and the program time schedule. In particular, a hybrid micro-circuit was developed for the digital section of the actuator for its miniaturization. A micro-computer system was developed for the central station, for maximum reliability and cost-effectiveness. Major areas of attention included the radio frequency (UHF) link from the actuator, and the power link (e.g. 110V AC) link from the internal receiver-relay.

Phase II also included the planning of laboratory and field tests to measure the performance of the system and its components. These tests included the measurement of parameters related to transmission reliability, component reliability, hardware response time, and message interference.

4. Phase III: Testing and Evaluation

Five different types of test were planned and conducted:

Component hardware tests in the laboratory.

Transmission link tests in the laboratory.

Sub-system tests in the laboratory.

Sub-system tests in the field.

Feasibility demonstration in the field.

The data from these tests was analyzed and evaluated to determine the reliability of the components and the system as well as overall system effectiveness. The feasibility demonstration in the two scenarios established the operability of the system in addition to its reliability.

CHAPTER III. SYSTEM REQUIREMENTS

The Statement of Work, for this project, included a preliminary definition of system requirements as a basis for design and development. In the initial phase of project implementation these requirements were analyzed in detail. A background study was conducted in several areas impacting on the definition of system requirements: user needs and perception of crime, human and environmental factors, and technical trade-offs and feasibility analyses. Some of these relationships are indicated in Table III-1. The basic system requirements were then defined in terms of hardware parameters, as exemplified in Table III-2, and finalized after analysis. Some of these final requirements differ from the preliminary ones in the SOW.

The final system requirements are presented first in this chapter. The underlying rationale and justification is given next.

A. Statement of System Requirements

The entire set of system requirements cover a range of parameters relating to system function, architecture, performance and cost. A detailed statement of requirements in each category is presented below.

TABLE III-1: GENERAL SYSTEM REQUIREMENTS AS RELATED TO USER, RESPONSE AGENT, AND ENVIRONMENTAL FACTORS

FACTORS \ SYSTEM REQUIREMENTS	MODULARITY	VERSATILITY OF USAGE	RESPONSE TIME	TRANSMISSION RELIABILITY	COMPONENT RELIABILITY	RANGE	SUSCEPTIBILITY TO FALSE ALARMS	LOCATION CODE	USER CODE	EASE OF USE	RUGGEDNESS	RESISTANCE TO TAMPERING	SUSCEPTIBILITY TO MESSAGE INTERFERENCE	COST
System Architecture	x	x	x	x	x	x	x	x	x				x	
User Factors			x	x	x	x				x	x			x
Response Agent Factors			x	x	x		x	x	x			x	x	
Environmental Factors				x	x						x	x	x	

TABLE III-2: RELATIONSHIP BETWEEN TYPICAL SYSTEM REQUIREMENTS AND HARDWARE PARAMETERS

SYSTEM REQUIREMENTS \ HARDWARE PARAMETERS	OPERATING FREQUENCY	ACTUATOR ERR	IRR RECEIVER SENSITIVITY	ACTUATOR BATTERY	DATA TRANS-MISSION RATE	MEMORY TYPE/SIZE	REPEATED MESSAGE TRANSMISSION	ERROR CORRECTION	CHOICE OF COMPONENTS	MINIATURIZATION OF COMPONENTS	PACKAGING, COMP. LAYOUT & FABRICATION	PACKAGING, EXTERIOR	HARD-COPY PRINTOUT
MODULARITY	x					x			x				
RESPONSE TIME	x				x		x	x	x				
TRANSMISSION RELIABILITY	x	x	x	x	x	x	x	x					
RANGE	x	x	x	x									
SUSCEPTIBILITY TO FALSE ALARMS	x		x		x			x	x		x	x	
LOCATION CODE						x	x						
USER CODE					x	x	x						
EASE OF USE (USER)										x	x	x	x
EASE OF USE (RESPONSE AGENT)										x	x	x	x
RUGGEDNESS										x	x	x	
SUSCEPTIBILITY TO MESSAGE INTERFERENCE	x						x	x					
COST	x	x	x	x	x	x	x	x	x	x	x	x	x
HARDWARE RELIABILITY				x		x			x	x	x	x	

1. System Configuration

a) For modularity, the system consists of components.

b) Each component represents a change in the mode of transmission of information from one transmission link to another.

c) The system consists of actuators, internal receiver-relays, external receiver-relays, and a central station.

d) Actuators convert manually-entered information (e.g. the triggering of an actuation mechanism) into a digitally coded UHF radio signal.

e) Internal receiver-relays receive signals transmitted by an actuator and relay them, along an in-building power line, to an external receiver-relay.

f) The external receiver-relay receives signals from internal receiver-relays and relays them, along a dedicated voice-grade telephone line to a central station.

g) The central station receives signals from internal or external receiver-relays, and displays or annunciates alarm messages, as necessary.

h) The CAS network may encompass a region of any size, but any system within the network shall be contained within a closed physical environment, e.g. an in-building scenario. Each system consists of one or more internal receiver-relays tied either into an external receiver-relay (if central station is remotely located) or to a central station on the premises.

2. Information Transmission

a) The transmission link from actuator to internal receiver-relay shall be by UHF radio, at frequencies between 450 MHz and 500 MHz.

b) The transmission link from internal receiver-relay to external receiver-relay shall be the internal power lines (e.g. 110V AC) at carrier frequencies between 200 kHz and 400 kHz.

c) The transmission link from the external receiver-relay to a remote central station shall be a dedicated, voice-grade telephone line.

d) The actuator shall transmit identification code of 32 bits total size, with at least 16 bits, BCD coded, or 4 BCD characters, of user-identification information. This will allow at least 10,000 different combinations.

e) The actuator code will be transmitted repeatedly for one second or less.

f) To comply with FCC regulations, each active period of one second for an actuator shall be followed by a latency period of 30 seconds or more in which no transmission is possible.

g) The internal receiver-relay receives and stores the message from the actuator, and adds on a location code with a length of at least 7 bits. This allows up to 128 internal receiver-relays per external receiver-relay.

h) The external receiver-relay receives repeated messages from the internal receiver-relays: with 8 repeats of the location code and the stored actuator message (8 repeats of the actuator code).

i) Under normal conditions, the actuator shall have a range of about 50 feet from the internal receiver-relay.

j) Simultaneous transmissions by two or more internal receiver-relays shall not be possible, to avoid message interference.

k) Simultaneous transmissions by two or more actuators within the range of 50-100feet may cause interference. In case of interference, however, a receiver-relay shall still be activated and though the user-identification code may be lost, the location code shall be transmitted.

3. <u>Hardware Response Time</u>

a) Hardware response time, exclusive of delays due to queuing, shall be as follows:

* Actuator to Internal Receiver-Relay: 1 second (1st message)
35 seconds (2nd message)

* Internal Receiver-Relay to External Receiver-Relay: 6 to 8 seconds

* External Receiver-Relay to Central Station: 0.2 seconds

b) Hardware response time, in case of queuing: the number of internal receiver-relays in the queue shall determine the response time of the hardware.

4. Reliability

a) Hardware reliability, for each CAS component, shall be better than the failure-rates shown below in Table III-3 :

Component	Failure Rate (Failures in 10^6 Hours)
Actuator	40
Internal Receiver-Relay[+]	100
External Receiver-Relay	300
Central Station	300

Table III-3 : CAS Component Reliability Requirements

b) The number of components at each hierarchical level and the nature of the information tree, shall determine overall system or network reliability.

c) Reliability of transmission along an in-building power line shall exceed 99.9% (.i.e., an error rate of 0.001).

d) Reliability of transmission along a voice-grade, leased telephone line shall exceed 99.9% (i.e., an error rate of 0.001).

e) Using hardware/software techniques with a micro-computer system, error-correction procedures to improve system reliability shall be implemented in the central station.

f) The actuator mechanical package shall resist accidental triggering, tampering, and the normal range of environmental conditions.

g) The mechanical packages for the internal and external receiver-relays shall resist tampering and withstand the normal range of environmental conditions.

h) Self-test capability shall be provided in the form of user procedures, rather than with special hardware.

i) The system shall resist all but sophisticated attempts at jamming and malicious interference.

5. <u>False Alarms</u>

a) False-alarms due to hardware malfunction, transmission failure, or susceptibility to noise transients and jamming, will be minimized as indicated in the requirements of 4. above.

b) The mechanical design of the actuator, as indicated in 4. above, shall minimize false alarms from inadvertent triggering.

6. Packaging

a) The actuator shall be small, about the size of a man's wrist-watch, and packaged in an appealing way.

b) The internal receiver-relay shall be installed and mounted outside a wall power receptacle, or elsewhere, rather than inside.

c) All CAS components resist tampering.

d) Batteries shall be easily replaced in the actuator package.

e) Actuator battery shall exceed six months, under normal use.

7. Environment

a) The actuator shall operate reliably in the following range of environmental conditions:

Temperature	50^0F to 122^0F
Humidity	25% to 95%
Shock	3 feet drop to a carpeted floor
Vibration	Normal

b) The receiver relays (internal and external) and central station operate reliably in the following range of environmental conditions.

Temperature	50^{0}F to 122^{0}F
Humidity	25% to 95%
Shock/vibration	Normal building vibration

c) All components resist tampering and abuse.

8. Cost

The per-unit manufacturing cost of CAS components shall be within the limits set below, assuming average direct labor and direct overhead rates as shown in Table III-4.

B. Human and Environmental Factors in Requirements

Several different human and environmental factors were analyzed and evaluated in the development of system requirements. These background studies are presented in this section.

1. Users Perception of Crime

Recent victimization studies show that the actual rate of crime occurrence (as measured by surveys) is much greater than the reported rate of crime (as measured by the FBI). Moreover, the fear of victimization far exceeds the statistical risk, for any given crime. This fear runs highest for the four personal crimes -- attempted

TABLE III-4 : Cost Requirements For CAS Components

CAS COMPONENT	PRODUCTION QUANTITY		
	Low (<1,000)	Medium (1,000-10,000)	High (>10,000)
Actuator	$60	$30	$20
Internal Receiver Relay	$80	$50	$30
External Receiver Relay	$350	$250	$200
	(10)	(10-100)	(100)
Central Station	$3,000	$2,000	$1,500

homicide, rape, assault, and robbery -- in which CAS is potentially most useful. CAS may, therefore, be helpful both in a crime situation, and in alleviating the fear of victimization. Recently, some victimization data on personal crime has become available, for eight major metropolitan areas from the LEAA High Impact Anti-Crime Program. These are based on surveys conducted in 1971-72. Table III - 5 shows that the estimated victimization levels are at least twice that indicated by police reports filed with the FBI. This suggests a high degree of non-reporting of crime, as shown in Table III - 6.

Many of the personal assaults on victims required hospital treatment, as indicated in Table III - 7. Perhaps this fear of injury is one of the primary reasons for the high level of fear perceived by the citizen. The injury may or may not be physical, but it usually traumatic. Some of the fear also results from the frustrating inability to do anything meaningful once a crime has been initiated. Cas serves two different functions from the standpoint of the user. The availability of a means of self-help, reduces the user's fear of victimization. Secondly, in an emergency, the victim can be assisted by response agents soon after the initiation of the criminal attack. System requirements, therefore, address the issues of hardware

TABLE III-5: APPROXIMATE COMPARISONS OF UCR REPORTS AND CRIME PANEL ESTIMATES, IMPACT CITIES, FOR PERSONAL CRIMES

Offense	Reported incidents UCR	Estimated incidents Crime Panel	Ratio Crime Panel/ UCR
Total, all offenses	409,208	913,800	2.2:1
Rape	3,090	6,600	2.1:1
Aggrevated assault .	24,095	37,600	1.6:1
Robbery	34,274	78,100	2.3:1

APPROXIMATE COMPARISONS OF UCR REPORTS AND CRIME PANEL ESTIMATES

Impact Cities - By City

Seven "Part I" Offenses* Total

City	Reported incidents UCR	Estimated incidents Crime Panel	Ratio Crime Panel/ UCR
Total, all cities	409,208	913,800	2.2:1
Atlanta	42,104	98,700	2.3:1
Baltimore	69,554	151,100	2.2:1
Cleveland	48,921	118,900	2.4:1
Dallas	64,876	166,500	2.6:1
Denver	47,704	139,800	2.9:1
Newark	35,423	49,300	1.4:1
Portland	35,736	93,700	2.6:1
St. Louis	64,890	95,800	1.5:1

* Rape, aggravated assault, robbery, burglary, larceny $50 and over, larceny less than $50, auto theft.

NOTE: These tables are for illustrative purposes only! UCR and Crime Panel city measures are not directly cooperable. UCR reports all crimes which occur in a city. The Crime Panel measures victimization of residents of the city regardless of where the crime occurs. Crimes against residents which occur outside the city are included, crimes against non-residents are not included in the Crime Panel. In addition, definitional differences make direct comparisons impossible.

TABLE III-6: Estimated Rates of Non-Reporting for Personal Victimizations, 1971-1972[a]

	Atlanta	Baltimore	Cleveland	Dallas	Denver	Newark	Portland	St.Louis
Assaultive Violence With Theft	40% (1,500)	35% (5,700)	34% (3,100)	27% (1,800)	37% (2,000)	38% (2,100)	39% (1,000)	39% (2,300)
Assaultive Violence Without Theft	58% (10,800)	53% (18,900)	59% (15,100)	60% (20,000)	60% (19,800)	50% (3,100)	61% (12,400)	52% (11,000)
Personal Theft Without Assault	57% (7,700)	48% (20,500)	53% (13,600)	59% (6,800)	60% (7,100)	58% (8,300)	60% (4,900)	46% (8,100)
Total Personal Victimizations	56% (20,000)	49% (45,100)	54% (31,800)	58% (28,600)	60% (7,100)	53% (13,500)	59% (18,900)	48% (21,400)

[a]Numbers in parenthesis are the bases on which the percentages have been calculated.

TABLE III-7: PERCENTAGE OF ASSAULTIVE VIOLENCE VICTIMIZATION REQUIRING HOSPITAL TREATMENT, 1971-72[a]

HOSPITAL TREATMENT	ATLANTA	BALTIMORE	CLEVELAND	DALLAS	DENVER	NEWARK	PORTLAND	ST. LOUIS
OVERNIGHT OR LONGER	15%	16%	14%	24%	16%	16%	14%	21%
EMERGENCY ROOM ONLY	64%	70%	71%	45%	56%	66%	58%	62%
NONE	19%	14%	14%	28%	28%	15%	33%	14%
NON ASCER-TAINABLE	2%	1%	0%	2%	0%	3%	0%	4%
TOTAL	100% (1,770)	101% (5,220)	99% (3,050)	99% (2,880)	100% (2,770)	100% (1,400)	100% (1,330)	101% (2,190)

[a]Numbers in parenthesis are the bases on which the percentages have been calculated; percentages may not sum to 100% due to rounding.

response time and transmission reliability to best serve the user at acceptable cost.

The rate of occurrence of personal crime is a function of many demographic and regional factors. There are significant differences in the patterns of crime in different cities as indicated in Tables III - 5, III - 6, and III - 7. These relate to population, population density, ethnic mix, income, age, sex, etc. The LEAA study shows that the victimization levels are generally high for all citizens, but the most likely victim of crime is a poor, young, male. The rates of victimization for whites and non-whites show differences with one or the other being greater depending on the city. It is reasonable to expect that a citizen's perception of crime is likely to be a function of the experience of victimization within his or her community, family, or circle of friends. Thus, the statistical measures of victimization may also be good indicators of the community's perceived need for and acceptance of a CAS-type system.

Many of the results of this 1971-72 study correspond, in principle, to those obtained in a survey by the National Opinion Research Center in 1965-66. The NORC survey showed under-reporting of personal crimes by a factor of about two. Although the patterns of crime have changed in these six years, the citizens' faith in the "system" apparently has not.

2. User Attitudes

The acceptability of CAS to the user, and hence the effectiveness of the system, will be largely determined by user attitudes.

In an attempt to explore these attitudes toward CAS, a small survey (about 100 people) was conducted in Pittsburgh. The sample was not selected on any scientific basis, but was considered to represent potential users and potential scenarios for the use of CAS. The questionnaire and the responses are presented as Appendix I. About 60% of the respondents were male, 40% female. Of all respondents, 75% were white and 15% were black. Their ages varied widely (16 to over 50), and a wide spread of income level was also noted (below $2,000/year to over $25,000/year).

One important parameter determining user attitudes toward CAS in the perceived threat of crime. The results from the questionnaire, in this area, are shown in Table III - 8. Over 35% of all respondents perceived a medium-to-high level of crime in the neighborhood. This rose to nearly 45% for the place of work. This tends to suggest a high degree of perceived need for additional security. In response to a different question, over 40%

TABLE III-8: PERCEIVED THREAT OF CRIME

LEVEL OF PERCEIVED CRIME	AT HOME	AT WORK
High	9.8	12.9
Medium	26.1	31.8
Low	38.3	28,9
Negligible	23.7	15.1

worried about emergency situations in which they would be unable to summon assistance by phone -- a significantly high number.

The respondents were asked to rank the priority of different types of emergency situations for which they considered CAS useful. The results are shown in Table III - 9. Assaults and medical emergencies ranked high, while fires and burglaries ranked much lower. Hold-ups also ranked low, possibly because many respondents did not work in businesses susceptible to or subjected to hold-ups. These results can be compared with the response to another series of questions in which four scenarios were presented, and respondents were asked to identify when they would use CAS. Sixty-nine percent would use it if they heard an intruder in the home, 73% in a severe medical emergency. Only 44% thought they would use it in a fire. However, 30% would use it if they heard unidentifiable noises. This indicates that 30% of the respondents would start off with a low threshold, for triggering CAS. This suggests careful consideration of means to educate the potential CAS user, and other procedures to "raise" this "threshold of triggering".

In terms of hardware, 35% preferred a watch-type actuator -- the most popular package design. Some 60%

TABLE III-9:

PRIORITY RANKING OF EMERGENCY SITUATIONS

EMERGENCY SITUATION		PRIORITY							
		1	2	3	4	5	6	7	8
Noise	25.6	3.6	1	.7	1.9	5	11.7	45.4	5
Hold-up	19.8	10.5	9.8	10.8	9.6	17.5	18.1	3.3	.5
Falls/Accidents	21.8	11.7	7.4	12.9	13.4	12.4	16.5	3.3	.5
Burglary	21.2	11.7	18.1	16.7	14.1	10.7	6.0	1	.2
Fire	20.3	15.5	18.7	16.0	14.1	8.6	4.3	1.9	.5
Medical	19.8	27.0	13.1	8.1	12.6	8.8	7.6	1.9	.7
Assault	19.4	25.6	7.6	8.6	7.6	10.0	8.8	10.7	1.4
Other	32.5	.2	.9	.7	1.0	.5	.5	5.5	58.1

↑ NO RESPONSE

of the respondents were prepared to pay up to $25 as the initial cost and up to $2 per month for the system. Nearly 10% were prepared to go up to $30 initial cost and up to $6 per month. This suggests the need to minimize the cost of components, installation, and service. Component cost can be minimized by good electronic design. Installation cost is minimized by using an existing two-wire link, the power-line, as a primary communication link. Further reduction in installation cost is enabled by careful design of the IRR package, so as to allow it to be easily connected to (or disconnected from) a power line, e.g. via a 110V wall-receptacle. Finally, on-going service costs are minimized with reliable hardware, actuator batteries that have a long shelf life and are easy to replace, IRR's that are easy to connect and disconnect, etc. As a means to minimize false alarms, a majority felt that all alarm calls should be treated equally and billed for. This suggests that a charge should be levied for all calls -- true or false. This could tend to raise the threshold at which users trigger alarms, thereby reducing false alarms.

The response to this questionnaire, though a small sample, was valuable in identifying user attitudes relating to hardware design (e.g. actuator package design), response procedures, usage profiles, and potential problem areas.

3. The False Alarm Problem

One of the system parameters of major interest to the response agent is the measure of false alarms generated via the system. Traditionally, the false alarm ratio (ratio of false alarms to all alarms) and the false alarm rate have been used by the police and others, to judge the false alarm performance of a system. It is intuitively obvious that if the false alarms received by the response agent (e.g. the police) were to increase indiscriminately, this would cause an increased, and perhaps intolerable drain on the available response resources. Thus, the design of CAS seeks to minimize the potential false alarm problem.

A quantitative estimate of this expected problem is difficult without any large scale field experience. The closest analogy to the problem are the burglary and hold-up alarms encountered by the central station alarm companies. In an effort to analyze the nature of the problem, data from a typical central station alarm company was tabulated over a six-month period of operation (January to June, 1973). Data on real alarms, false alarms, repair calls, guard response time, and police response time, was taken directly from central station logs, runner dispatch cards, and service call sheets. The data was then coded, key-punched, and analyzed on the Carnegie-Mellon IBM 360/67 computer system.

Real alarms, classified into nine different types of emergencies and false alarms, have been tabulated in Table III - 10. This shows that over 80% of all hold-up alarms and over 98% of all burglary alarms were false. Table III - 11A shows the distribution of false alarms, by cause, at the one central station analyzed. Table III - 11B shows a similar distribution on an industry wide basis, as obtained from statistics developed by the Alarm Industry Committee for Combatting Crime (AICCC). Both of these show that user error and negligence is responsible for 30 to 40% of the false alarms. This number is, of course, high because of the opening and closing procedures involved. However, it does suggest that user negligence runs at a fairly high level, even in a situation as important as security. CAS design should, therefore, seek to minimize user participation other than the simple act of triggering. Even this should be arranged such as to minimize the possibility of accidental triggering.

The statistics of Table III - 11 also indicate that the CAS hardware should withstand tampering and changes in the physical environment (e.g. weather), to minimize false alarms.

The analysis of central station data also showed marked variations in false alarms and real alarms with time -

TABLE III-10

A. TRUE ALARMS BY TYPE

Types of Crimes	Number of Crimes	Percentage of Total
Burglary	15	16.7
Hold-up	5	5.5
Parking Lot Violations	12	13.4
Fire	6	6.7
Vandalism	24	26.7
Attempted Burglary	15	16.7
Arson	3	3.3
Medica/Accident	2	2.2
Other	8	8.9
	90	100.0

B. FALSE ALARM BY TYPE

Type	Number of False Alarms A*	Number of False Alarms B*	% of Total
Burglary	921	1064	97.5
Hold-up	24	27	2.5
TOTAL	945	1091	100.0

*A -- excludes situations in which response agents were recalled
*B -- all situations

TABLE III-11A
CLASSIFICATION OF FALSE ALARMS BY CAUSE IN ONE CENTRAL STATION (6 months)
(A: 1091 False Alarms, all situations)

1.	Unknown	58.4%
2.	User Error	33.5
3.	Weather/Environment Susceptibility	3.1
4.	Equipment Malfunction	1.6
5.	Installation	0.1
6.	Transmission Line (external)	0.2
7.	Other	3.0
	TOTAL	100.0%

TABLE III-11B
DISTRIBUTION OF ALARMS BY CAUSE, INDUSTRY-WIDE (2 weeks)
(AICCC Study)

	Cause	Percent
1.	Internal Any alarm initiated at the protected premises caused by other than intruders, property damage, or equipment malfunction. This category includes user error at the protected premises	41.0
2.	Alarm Installation Equipment Malfunction Any alarm initiated by malfunction of the alarm equipment installed on the premises	23.0
3.	Unknown	19.0
4.	External Any alarm initiated in a place other than the protected premises	9.0
5.	Intruder or Property Damage Alarms caused by actual or attempted entry by an intruder or by damage to property detected by the alarm installation	8.0

by day of week and by month of year. Representative results are shown in Figure III - 1. Similarly, temporal variations in false alarm activity due to CAS can be expected - such variations being due to different patterns of user and criminal activity with time. The understanding of these patterns can help to minimize the impact of false alarms by allowing response agents to plan their resources.

The CAS actuator is voluntarily triggered by a user who perceives an emergency to exist. For any given situation, the threshold of perception of an emergency is a function of the users attitudes, fears, and experience. The triggering of an actuator at too low a threshold could become a major cause of "false" alarms, given the uncontrolled, widespread use of the system. This suggests the implementation of user procedures to keep the threshold at a reasonable level.

Given well-designed hardware, the further reduction of false alarms can only result from the improved training of users and some sort of penalty or deterrent for arbitrary or capricious triggering. The response to the questionnaire of Appendix I suggests that users prefer that a standard charge be levied for all responses -- real or false. This will reduce bickering between user and response agent and would keep the user conscious of the cost of a false alarm. This cost would raise the threshold at which an emergency condition is perceived to exist.

4. <u>The Physical Environment</u>

In the normal course of a day, the average urban resident spends between 50% and 70% of the time within a physical structure: house, office, factory, or institution. Depending on the location and type of this physical structure, this resident is exposed to the risk of personal crime. Table III - 12 shows the distribution of personal crimes by place of occurrence for Chicago in 1965-66. This shows that about 50% of all personal crimes against men occur within a physical structure, nearly 70% for women. This tabulation also shows the wide range of physical scenarios in which CAS may be used: residences, schools, businesses, taverns, etc.

The occurrence of crime within a physical structure varies in location depending on the characteristics of the building. A comparative study, for public housing in New York City, is shown in Figure III - 2. This suggests that CAS components are needed not just within apartments, but also in the elevators, lobbies, hallways, stairwells, etc. From a design standpoint, this suggests a maximum range between actuator and IRR that can meet the need in large apartments as well as in the hallways and lobbies. A range of 50 feet is probably a good compromise between the need for coverage at minimum cost, and the need for

Table III-12

CRIMES AGAINST PERSONS (EXCEPT HOMICIDE)

(In Percent)

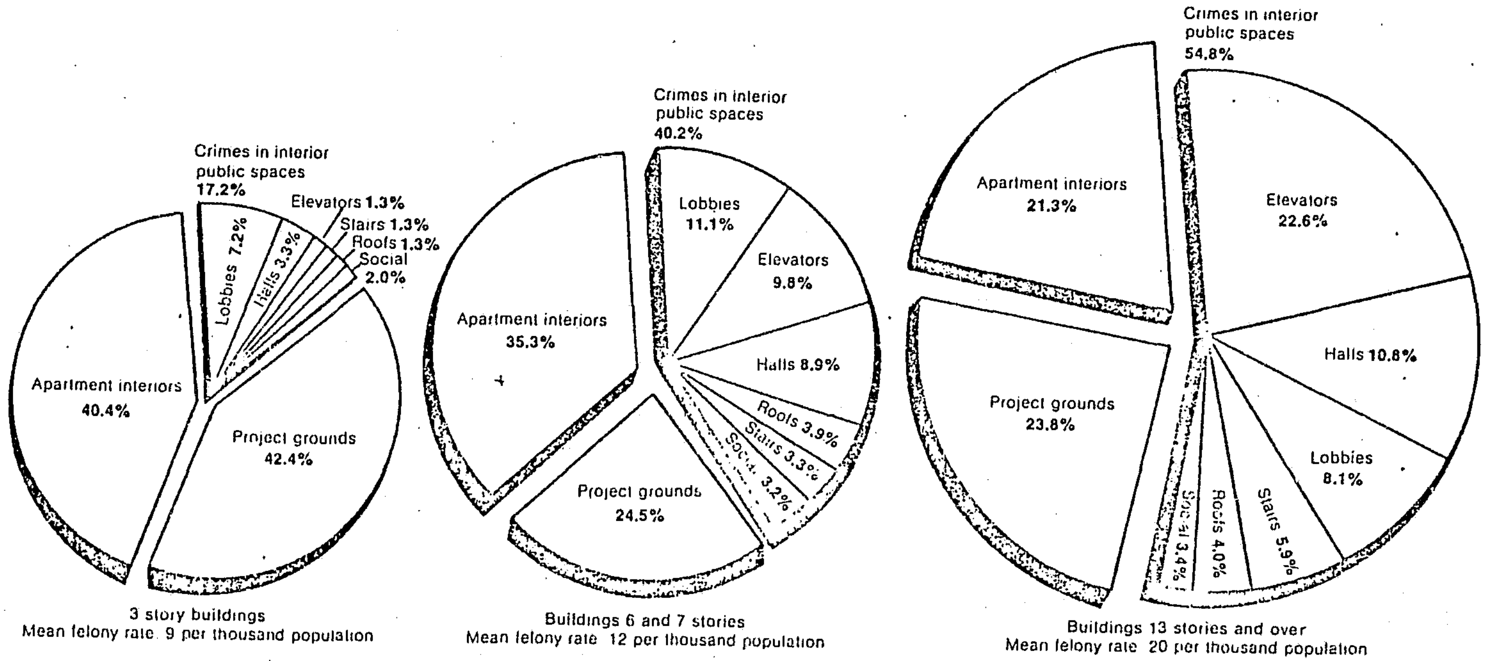
Place of occurrence	Victims of major crimes against person: Male	Female
School property	3.2	2.4
Residence	20.5	46.1
Transport property	1.4	.4
Taxis and delivery trucks	2.6	-
Businesses	3.2	1.1
Taverns and liquor stores	5.7	2.8
Street	46.8	30.7
Parks	.8	.5
All other premises	16.0	16.0
Total percent	100.0	100.0
Total number	(8,047)	(5,666)

SOURCE: Special tabulation from Chicago Police Department Data Systems Division for period September 1965 to March 1966, adapted from Reiss studies.

Figure III- 2:

PLACE OF OCCURRENCE OF CRIMES IN BUILDINGS OF DIFFERENT HEIGHTS

(Source: New York City Housing Authority Police-1969 data)



Place of occurrence of crimes in buildings of different heights
Source. New York City Housing Authority Police–1969 data

accurate location information. The potential need for IRR's in the elevators of high-rise apartments and public buildings is another factor in favor of the power-line transmission link between IRR and central station. Finally, the IRR's and central station must be designed to withstand the range of environmental conditions likely to be encountered in terms of temperature, humidity, building vibration, shock, etc.

5. <u>Electro-Magnetic and Electronic Interference</u>

The system uses radio-frequency transmission along two of its information links. UHF radio is used between actuator and internal receiver relay, and an RF carrier (200 to 500 KHz range) is superimposed on the power-line between the internal and external receiver relays. Both these links are susceptible to electro-magnetic and electronic interference: random and burst noise.

a) UHF Transmission Link (Acutator → IRR)

This link is implemented in CAS in the UHF spectrum, for reasons of actuator size, antenna efficiency, and signal propagation. However, as seen in Figure III - 3., this spectrum is heavily utilized by the public safety services and by TV channels (Channels 14 upwards). Assuming the CAS actuator to be a low-cost device, with no crystal-control of carrier frequency, the transmitted carrier center frequency is likely to vary over a band of several

FIGURE III-3:FREQUENCY ASSIGNEMNTS FOR

PUBLIC SAFETY RADIO SERVICE.

SOURCE: FCC DOCKET NO. 18261

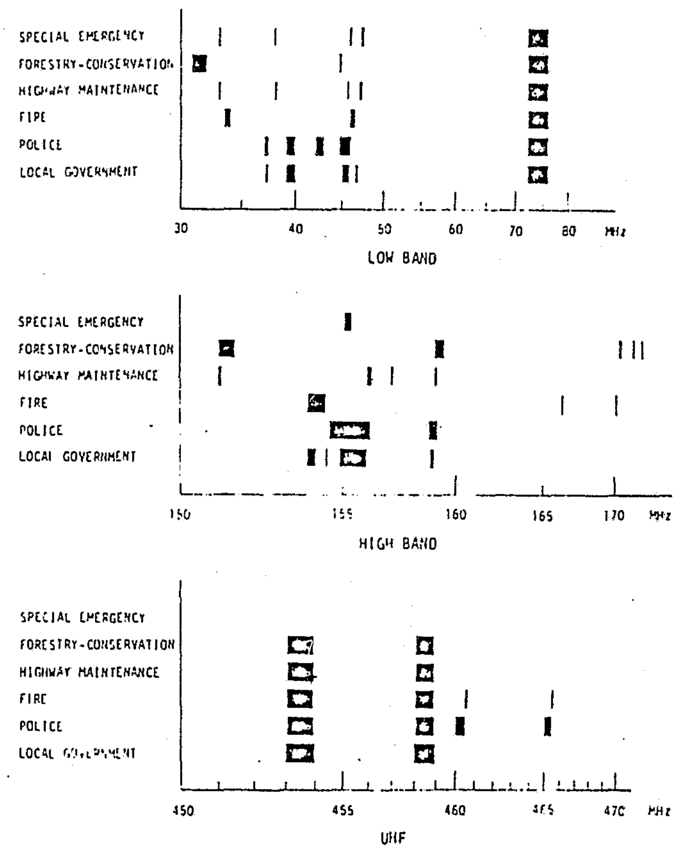
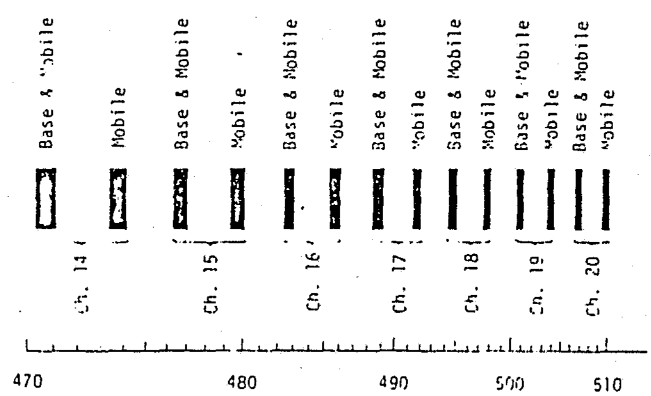


Figure 4. Frequency allocations.



MHz -- due to temperature and environmental effects, body detuning, etc. This would make the internal receiver relay susceptible to triggering by UHF signals generated by TV stations or land-mobile stations in the same range of frequencies.

Another major consideration is the effect of man-made RF noise. The two major sources of background UHF noise, especially in urban areas, are automotive ignition noise and external power line transmission noise.

1) Automotive Traffic Ignition Noise - This is a major source of RF (UHF) noise near the highway (e.g. in cities like Los Angeles). Ignition interference from a single vehicle manifests a predominantly periodic waveform with irregular pulse amplitudes. The effects of many vehicles produces signal trains that are random both in period and amplitude. Automotive interference, the most predominant source of noise up to 180 feet from a typical highway, has a measurable correlation with population density, and may display 16-dB daily variations between periods of maximum and minimum traffic density.

2) Power Transmission Line Noise - Power transmission lines and their components that have deteriorated or have been damaged, show a significant increase in impulsive noise emissions at frequencies about 50MHz. Bursts

of interference, lasting several milliseconds, are common.

Finally, there is the noise due to household appliances and devices such as TV sets, vaccuum cleaners, dish-washers, etc. The UHF components of this kind of noise are localized in the vicinity of the device, but can be of large amplitude.

Spurious triggering due to these kind of noises can be largely eliminated by the use of an encoded sub-carrier. However, under certain circumstances, this noise may be strong enough to affect the quality of data transmission on the UHF link. This effect can be minimized by the choice of an appropriate carrier frequency (e.g. the 460-470 MHz range).

b) Power Line (in building) Transmission Link. Substantial work has been done by Compu-guard and others in investigating the original propagation and noise characteristics of in-building power lines. Noise on the power lines is of the random and burst kinds.

Random noise is due to a variety of factors: thermal, environmental RF pick-up, line loading, etc. The noise is almost uniformally distributed over the entire spectrum from 100 kHz to 500 kHz. The level of this background is low, of the order of lmV or less, and does not seem to change much from one scenario to another. Typical noise data are shown in Figures III - 4 through III - 6.

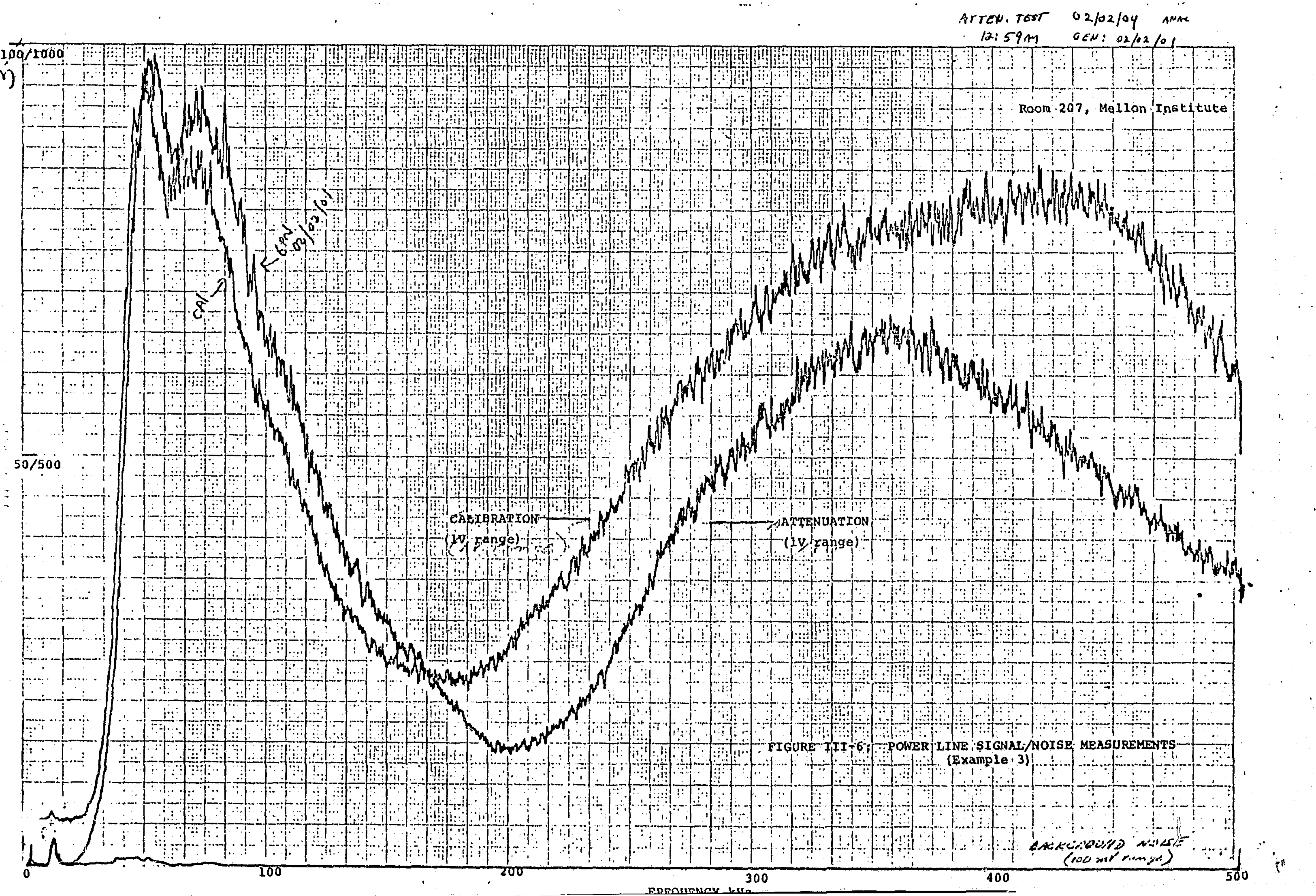


FIGURE III-6; POWER LINE SIGNAL/NOISE MEASUREMENTS
(Example 3)

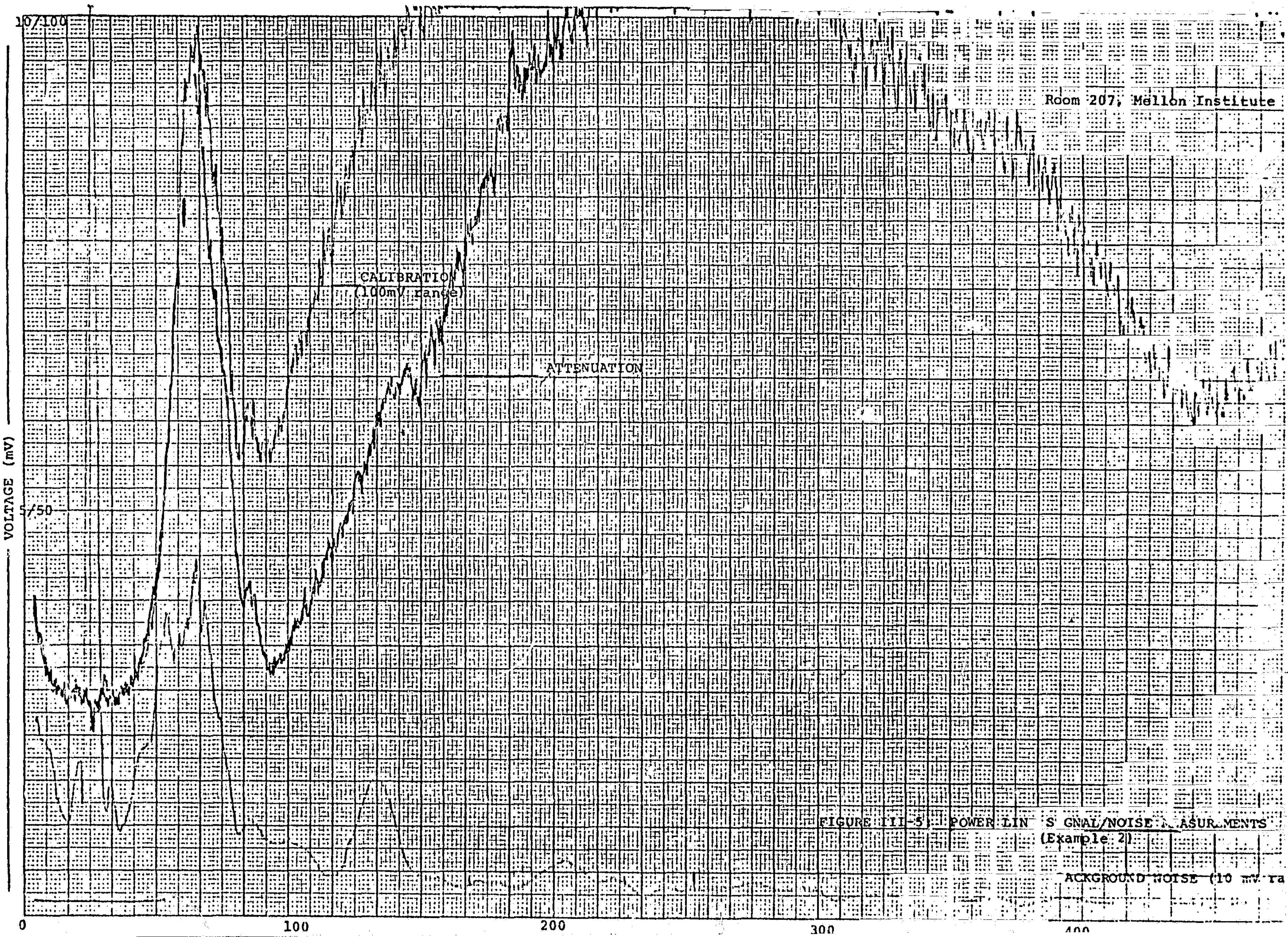


FIGURE III-5: POWER LIN S GNAL/NOISE ASUR MENTS
(Example 2)

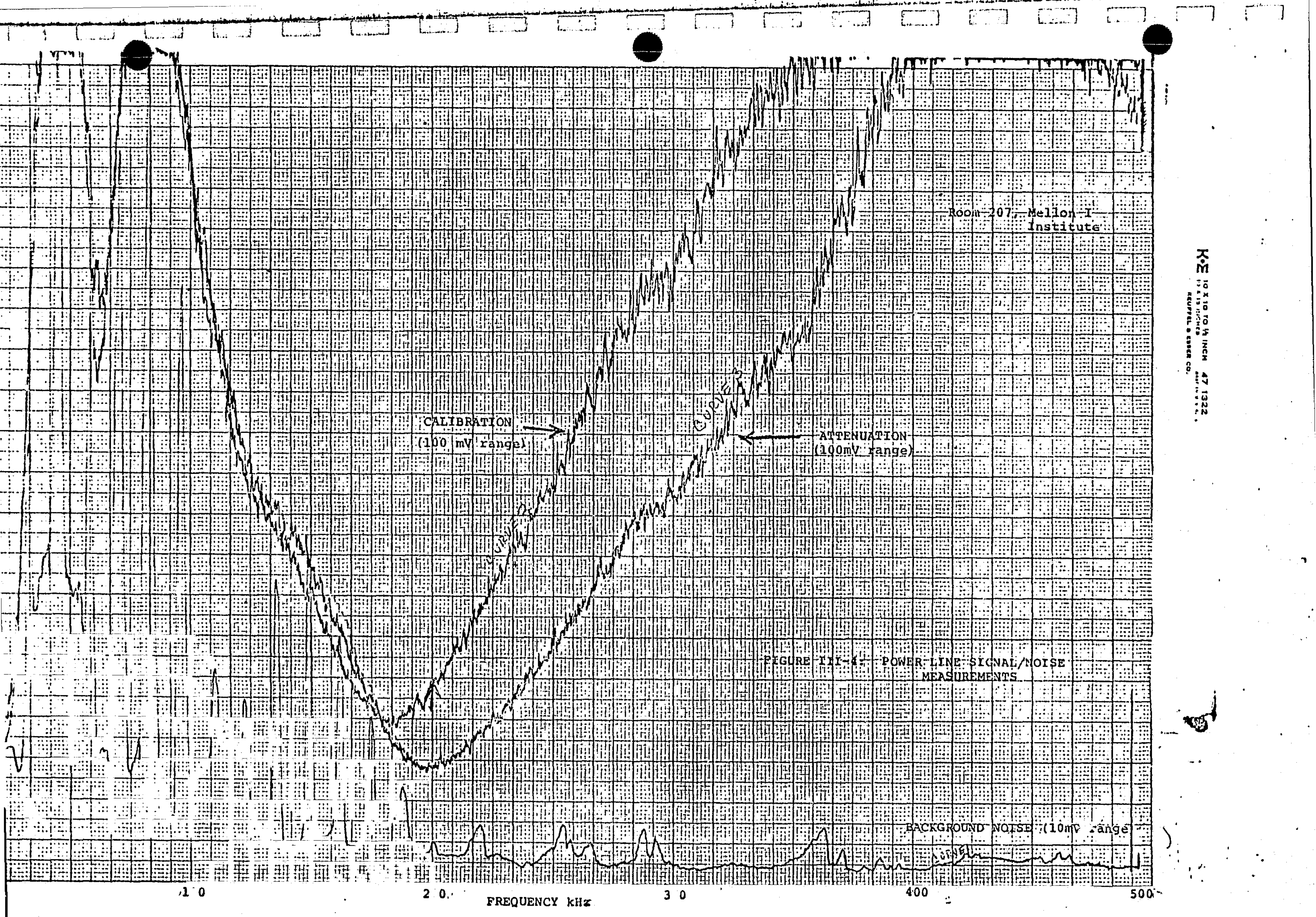


FIGURE III-4. POWER LINE SIGNAL/NOISE MEASUREMENTS

However, burst noise can occur with large voltage amplitudes and can represent a source of interference.

The existence of a variety of noise sources and the possibility of interference indicate that the system design should protect against this. Actuator transmission reliability can be improved by transmitting two sets of messages spaced about 30 seconds apart (FCC regulations) rather than just one with each set consisting of the actuator id code repeated several times. Similarly, messages from the IRR to the central station can be repeated. Finally, error-detection and error-correction algorithms can be applied at the central station, to correct the affects of noise on transmitted data.

6. The Size Problem: Packaging

The actuator, a personal device that will be worn by each user, represents the most severe packaging requirements. The packaging of the actuator must answer several needs:

Aesthetic appeal

Unobtrusive appearance similar to that of generally used articles of jewelry (e.g. watch, pendant)

Ease of use

Covert actuation

Resistance to tampering and abuse

Resistance to accidental triggering

Operability in the entire range of environmental conditions anticipated.

Table III - 13 presents the trade-offs in actuator packaging and the rationale in the final determination of the packaging requirements. The packaging problems of the receiver relays are less severe, and relate primarily to aesthetic appeal and resistance to tampering and abuse. The self-contained antenna for the RF receiver necessitates a plastic (Kydex) front cover. Also, the package design must allow ease in connecting the IRR to a power line, (e.g. a plug-in type of enclosure).

C. Technical Considerations and Tradeoffs

1. Transmission Link Alternatives.

There are three transmission links in CAS: actuator to IRR, IRR to ERR, and ERR to central station. Different candidates for each link were evaluated prior to the final definition of system requirements. Table III - 14 summarizes the advantages and disadvantages of each alternative. Following this comparison, the radio-frequency link (actuator to IRR), the power-line RF carrier link (IRR to ERR), and the dedicated telephone line link (ERR to central station) were selected.

2. Hardware Design Tradeoffs

a) Type of Logic

A number of different logic alternatives are

TABLE III-13: ANALYSIS OF ACTUATOR PACKAGING REQUIREMENTS

PARAMETER	ALTERNATIVES	CHOICE/RATIONALE
Appearance	Watch/Pendant/Ring	Watch: demonstrates technical feasibility, aesthetic appeal, ease of use, less susceptible to accidental triggering
Size	Oversized watch, very large ring	Oversized watch: less obtrusive, less interference with movement of hands/arms
Actuation	One button, two button	Two button:* less susceptible to accidental triggering
Case	Plastic, metal	Plastic (epoxy): minimum interference with RF signal, easy to fabricate
Batteries	Various types	Long shelf life, ease of replacement

* The choice of "pincer" type of two-button triggering mechanism was found to be easiest to use and most reliable, based on a study of user physiognomy and mechanical skills.

TABLE III-14: COMPARISON OF TRANSMISSION LINK ALTERNATIVES

	ALTERNATIVES	ADVANTAGES	DISADVANTAGES
ACTUATOR TO INTERNAL RECEIVER RELAY	1. Radio Frequency*	Range, coverage, reliability, size of actuator, encoding feasibility, cost	Poor control over signal propagation, frequency detuning due to body
	2. Ultrasonic	Signal contained within physical boundaries	Susceptible to false triggering by ambient noise, directional, poor range and coverage, larger actuator size
	3. Optical	Signal contained within physical boundaries	Highly directional, poor coverage
INTERNAL RECEIVER RELAY TO EXTERNAL RECEIVER RELAY	1. Radio Frequency* (Power Line)	Low cost (uses existing power lines)	Needs protection against EMI and electrical line noise, load changes on power line
	2. Radio Frequency (Wireless)	-	Susceptible to EMI noise and interference, high hardware cost, FCC licensing may be necessary
	3. Hard Wire	Secure, relatively noise-free	High installation and maintenance cost
EXTERNAL RECEIVER RELAY TO CENTRAL STATION	1. Telephone line* (Dedicated)	Secure, reliable, quick response time	High cost *if* used in a very small system configuration
	2. Telephone line (Switched network)	Low cost	Poor reliability and response time
	3. Radio Frequency	Quick response time	High cost, FCC licensing necessary susceptible to EMI noise and interference

* Transmission links used in CAS

available in the hardware implementation of the components of the system. Complimentary metal-oxide semiconductor (CMOS) logic has been used exclusively, in the actuator, for its low-power dissipation, high noise immunity, and non-critical voltage requirements. The internal and external receiver relays use CMOS extensively, with the use of transistor-transistor logic (TTL) only in devices such as the 512 - bit shift register. Most of the devices used in the micro-computer system are TTL, for the higher operating speeds made possible.

b) Miniaturization of Actuator (Digital Section)

The miniaturization of the digital section of the actuator requires the hardware implementation of one of two alternatives: a hybrid micro-circuit, or a custom monolithic integrated circuit. The former approach was chosen, because of the shorter development time and the lower development cost involved.

c) Miniaturization of Actuator (RF Section)

This can be accomplished primarily with a reduction in the size of the transmitter antenna. The design of an antenna with acceptable efficiency was one of the major factors in favor of actuator RF transmission in the ultra-high frequency spectrum.

d) Central Station Design

The central station has to handle a large number of information processing functions.

System monitoring

Data input control and interfacing

Data output control and interfacing

Time and data clock

Service interrupt handling

Data storage (memory)

Arithmetic processing

Command, control, timing

These functions can be implemented in one of two ways: total hardware or a combination hardware/software approach. The latter was selected as being the more cost-effective and flexible solution to the problem. The use of software to implement some of the functions reduces complexity of system hardware, and is expected to increase the reliability of the central station.

A micro-computer system was developed to provide all the hardware and software capabilities required. To minimize the development problems, a standard off-the-shelf micro-computer was used and augmented to meet the functional needs of the central station.

3. Software Considerations

The decision to use a combined hardware/software approach to implementation of the central station requires a serious consideration of all the software development

CONTINUED

1 OF 4

activity necessary. For ease of programming, it was decided to write most of the software in a high-level language.

To simplify debugging of the system, a number of diagnostic routines were also developed. A consideration of system modularity led to the development of a modular software package with an operating system, a main program, and a number of sub-programs to perform specific functions (e.g. error detection, error correction).

Finally, a software simulator was developed to facilitate software design. This decision was based on a consideration of the difficulty in developing hardware and software simultaneously.

4. Regulatory Guidelines

The Citizen's Alarm System uses transmission links that are regulated by the Federal Communications Commission (FCC). The RF link between actuator and IRR can require licensing depending on the type and power of transmission. Such licensing is considered to pose many problems. The need for a wide band (e.g. about 10 MHz, since the transmitter is not crystal controlled) is in conflict with the FCC's policy of narrow-band frequency allocations. Licensed operation would require each user or the system operator to hold a license for each actuator, and would necessitate regular frequency calibration --

increasing the cost of service and maintenance. Finally, the licensing procedure is long and complex and increases the start-up and operating costs of the system. Based on these considerations, it was decided to develop an unlicensed low-power transmitter, operable under Part 15, Subpart E, of the FCC regulations.

CAS actuator transmission is specifically covered under Part 15.211 (FCC regulations) for low-power communication devices. This allows operation at any frequency above 70 MHz, so long as each transmission period of one second is followed by RF silence for at least 30 seconds (i.e. a duty cycle of 1 in 30). Thus, if two sets of messages are transmitted for increased reliability of operation, these must be separated by at least 30 seconds. Additionally, the field strength at 100 feet, is limited to a specific value. This limits the effective radiated power (ERP) that may be transmitted.

Since RF carrier is used on the power-line, this link also falls within FCC regulations. A set of field-strength requirements applies to such communications, but the operating requirements are well below the prescribed FCC limits.

5. Hardware Response Time

The delay in information transmission that constitutes the hardware response is the sum of:

Information processing time in each component

Information transmission time in each transmission link

The preliminary choice of 10 seconds as the hardware response time requirement was more or less arbitrary, and represented a small percentage (perhaps 5% or less) of the overall response time yet one that seemed to be technically feasible at reasonable cost. However, prior to finalizing this as a system requirement, an analysis was conducted to determine the significant components of hardware response time, and the consequent design trade-offs.

It was found that the actuator and the UHF radio link to the internal receiver relay represents a delay of only one second, or 10% of the hardware response time. This left the emphasis on the other components and transmission links.

The speed of data transmission is a major consideration in the design of the power line and telephone line data links. The tradeoffs here include the bandwidth available, the signal/noise characteristics desired, and the cost and reliability of the modem used at each end. A 60 baud data transmission rate was found to be cost-effective, with the added advantage that it could be synched (if necessary) to the frequency of the power line. This speed was found to be adequate for transmission. Estimates were made of the amount of data to be transmitted, and of the processing delays expected within the IRR and ERR. Based on this, the hardware response time requirement of 10 seconds was judged feasible and finalized.

6. Actuator Power Supply Requirements

The power supply for the actuator presents a special problem. The batteries used must provide adequate power to drive RF transmitter and must have a voltage greater than 3V, to operate the integrated circuits in the digital section, assuming the use of CMOS devices. For ease of use and system reliability, the batteries should have long shelf life and be able to sustain many triggerings. Yet, the batteries must be small, leak-proof, and operable under the anticipated range of environmental conditions.

An analysis of several alternative commercial types of cells was performed. It was found that silver-oxide cells would meet the general requirements of size, environmental stability, and cost. The use of several 1.5V cells would provide the necessary voltage, and the choice of cell would determine the maximum power available and the operating life (measured in mA-hours).

D. Response Considerations

The effective implementation of CAS requires its acceptance by response agents such as the police, security guards, etc. This necessitates a consideration of the system's impact on the response agent, and its ability to improve the agent's performance.

1. Increase in Notification of Crimes

The availability of CAS is likely to increase the notification of personal crimes. It was shown in a previous section that only about 50% of all serious crimes are reported to the police. The notification rate for crimes such as rape is even lower. This low rate seems to indicate a low degree of confidence in the available systems for reporting crime and in the ability of the criminal justice system to respond. However, the ease of notification possible with CAS is likely to encourage greater notification, for two reasons: because it is a simple process to initiate, and because this notification is possible as the crime is just beginning and assistance is extremely desirable.

This increase in notification is not expected to have a significant impact on the overall workload of the response agent. For example, the workload distribution for the Pittsburgh Police (January-March, 1973) is shown in Table III - 15. This shows that only 0.5% of all

TABLE III-15: PITTSBURGH POLICE WORKLOAD STATISTICS (Jan-March 1973)

1.	TOTAL NUMBER OF POLICE PATROL HOURS AVAILABLE	=	118,738
2.	TOTAL NUMBER OF POLICE PATROL HOURS SPENT ON SERVICING CALLS FOR ASSISTANCE	=	24,188
3.	TOTAL NUMBER OF POLICE PATROL HOURS LOST DUE TO VEHICLES BEING DOWN	=	19,998
4.	TOTAL NUMBER OF SERVICE CALLS ANSWERED	=	48,690
5.	TOTAL NUMBER OF PART I CRIME RELATED SERVICE CALLS ANSWERED	=	5,095
6.	PERCENT OF ALL PART I SERVICE CALLS THAT RELATE TO PERSONAL CRIMES: MURDER, ROBBERY, RAPE, AND ASSAULT (1972 Statistics)	=	23.8%
7.	PERCENT OF ALL SERVICE CALLS THAT ARE PART I CALLS	=	10.5%
8.	PERCENT OF ALL SERVICE CALLS THAT RELATE TO PERSONAL CRIMES: MURDER, ROBBERY, RAPE, AND ASSAULT	=	2.5%
9.	PERCENT OF POLICE PATROL CAR HOURS SPENT ON <u>ALL</u> SERVICE CALLS	=	20.4%
10.	PERCENT OF POLICE PATROL CAR HOURS SPENT ON SERVICE CALLS RELATED TO PERSONAL CRIMES: MURDER, RAPE, ROBBERY, AND ASSAULT.	=	0.5%

available police patrol-car hours are spent in assisting victims of the four personal crimes. Thus, even a 100% increase in notification has a negligible impact on the overall workload, especially when it is recognized that over 15% of all patrol-car hours are lost due to vehicle down-time and that only 20% of all hours are utilized for service calls.

2. False Alarms

The high rate of false alarms in burglary and hold-up alarm systems has made law enforcement officials wary of new security systems. Their acceptance of CAS will depend on their faith in the usefulness of the system and in the level of false alarms expected. This is the justification for providing a system requirement on false alarms, even though the rate cannot be controlled strictly by hardware design. False alarm control requires efforts in several directions:

- Adequate hardware design, to minimize hardware-induced false alarms.
- Human factors design to minimize accidental triggering, e.g. the use of a two-button trigger for the actuator.
- User training to minimize arbitrary or capricious triggering.

- Penalties to deter false triggering
- Planned user-activated system tests, to deter uncontrolled "testing" by the user

The actual false alarm rate is determined by the false alarm characteristics of the system and the actual coverage (% of total population protected) provided. For example, assuming conditions of 25% coverage for the city of Pittsburgh, and a system false alarm ratio of 90%,assuming a doubled notification rate, the calls due to CAS will represent only 2.5% of all patrol-car hours. This is still a very small percentage of the hours available, even though 25% represents a significantly high coverage. It is, therefore, seen that the police workload is not a very sensitive function of coverage or the false alarm ratio, so long as the latter is at or below the 90% level. This number, 90%, is not a system requirement but merely an indicator as to the relationships involved. CAS design is based on a requirement to minimize false alarms, without assigning a specific value to the false alarm ratio ,since this cannot be controlled by hardware design alone.

3. Improvement in Response Time

The primary objective of CAS is to provide speedier assistance to the victims of crime. The hardware response requirement of 10 seconds and the pre-emptive signalling capability of the system can reduce the overall response time (communication time plus field response time) by several minutes. However, the field response time remains outside the control of CAS hardware. Improvements are possible with a more efficient utilization of response resources, but this requires an extensive study of local socio-economic and other factors, parameters such as population density, income levels, physical environment, etc. Analysis of these relationships was explored in Phase I of this project, and it was determined that some improvement was possible with a more scientific approach to resource allocation. However, this improvement can only be suggested, not directly implemented, by the use of CAS.

E. Deviations from the Statement of Work

In finalizing the system requirements it was found that some of the preliminary requirements given in the Statement of Work were not attainable or desirable. These are discussed below, in brief.

A false alarm ratio of less than 75% was called for in the SOW. It was felt that this ratio could not be determined by the system hardware alo ne, in fact that it was far more related to usage practice. No specific quantitative requirement was therefore developed.

The low-cost production goal of $25 was considered to be low, for the first design of the system. Cost requirements were developed for each component, as a function of production quantity.

In terms of packaging, the design of an actuator in the form of a ring was infeasible. The user questionnaire also indicated a dislike for the ring. The packaging of the IRR within a power receptacle was found to be undesirable from the standpoint of the component miniaturization necessary, the use of an inefficient antenna, and the high cost of installation (a licensed electrician, power turned off during installation, etc.), and the high degree of variability in the size of the cavity behind the receptacle from one home to another.

Finally, it was decided that the self-test capability could be effectively implemented only in the form of a user test procedure rather than an intrinsic hardware check. This allows the testing of the actuator and the UHF link between actuator and IRR, in addition to all other system components.

CHAPTER IV. HARDWARE AND SOFTWARE DESIGN PROCEDURES

The system requirements defined earlier on the basis for establishing design goals and procedures. The design and engineering of the information system and each of the components is discussed here.

A. Actuator Design Procedures

The development of the actuator required innovation in both electronic and packaging design. It involves the development of a custom thick film hybrid micro-circuit, the design of an effective, small RF transmitter, and the overall packaging for minimum electrical interference, low cost, ease of use, and minimum accidental triggerings.

1. Description of Operation.

The operation of the actuator can be segmented into four basic functions: the

- sensing and storage of an alarm condition (i.e. upon triggering of the actuator), the
- generation of a coded message which identifies the user, timing and regulation of message transmission, and
- generation and transmission of an encoded UHF carrier signal which carries the message.

The first three of these are digital functions, and were implemented on a single custom hybrid micro-circuit. The UHF radio transmitter (the fourth function) was implemented on a printed circuit board module, using a small number of discrete components.

The sequence of operations of the actuator can be summarized as follows:

a - Upon closure of the actuator triggering switch contacts, the timing sequence is initiated.

b - 500Hz clock pulses are generated along with the actuator ID code data bits.

c - A 20kHz and subcarrier signal, phase-modulated by the clock and data bits is generated and used to frequency modulate the UHF carrier of about 462MHz.

d - The UHF-FM carrier is generated and transmitted for a period of 1 second. This allows the repeated transmission of the ID code.

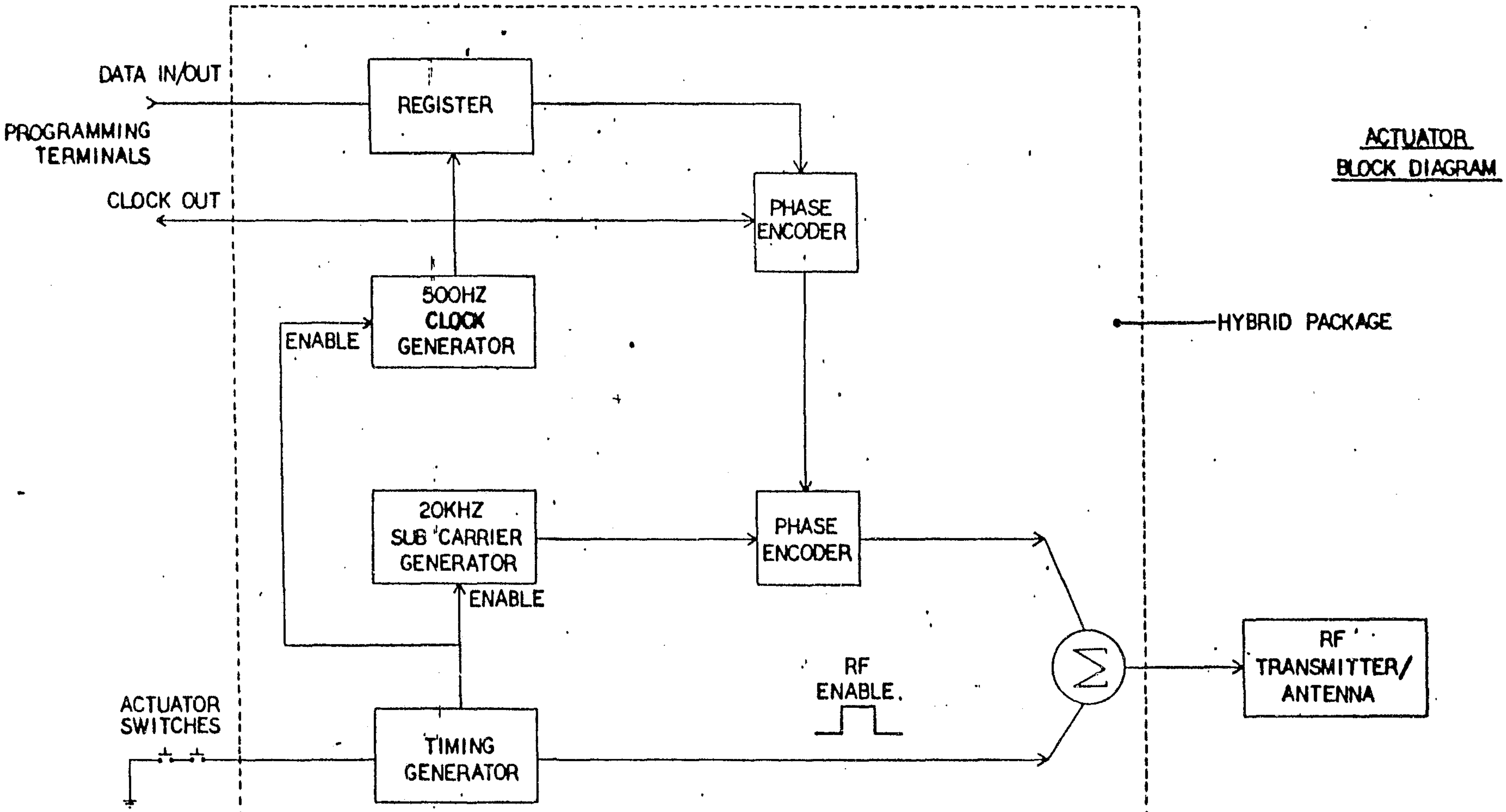
e - At the end of 1 second transmission, a 30 second period of silence follows.

f - Processes b through d are repeated once more at the end of which the actuator resets itself.

The block diagram of the actuator is shown in Figure IV-1.

2. Digital Section Design.

A number of design trade-offs were investigated in the design of the digital section of the actuator (implemented as a hybrid micro-circuit). These are summarized in Table



COMPU-GUARD

CAS ACTUATOR BLOCK

409M 08010-01-0103

FIGURE IV-1: ACTUATOR BLOCK DIAGRAM

TABLE IV-1: ACTUATOR DIGITAL DESIGN TRADE-OFFS

FUNCTION	ALTERNATIVES	DESIGN CHOICE
Type of semi-conductor technology	PMOS, NMOS, CMOS, TTL	CMOS (low power)
Type of memory for ID code storage	Diode matrix, RAM, Static shift register	Static shift register (circuit simplicity)
Data transmission rate	100 baud - 1000 baud	500 baud (acceptable signal/noise, ~16 repeated ID code messages in one second)
Sub-carrier frequency	1 kHz - 100 kHz	20 kHz (optimum tradeoff between RF bandwidth and IRR lock time)

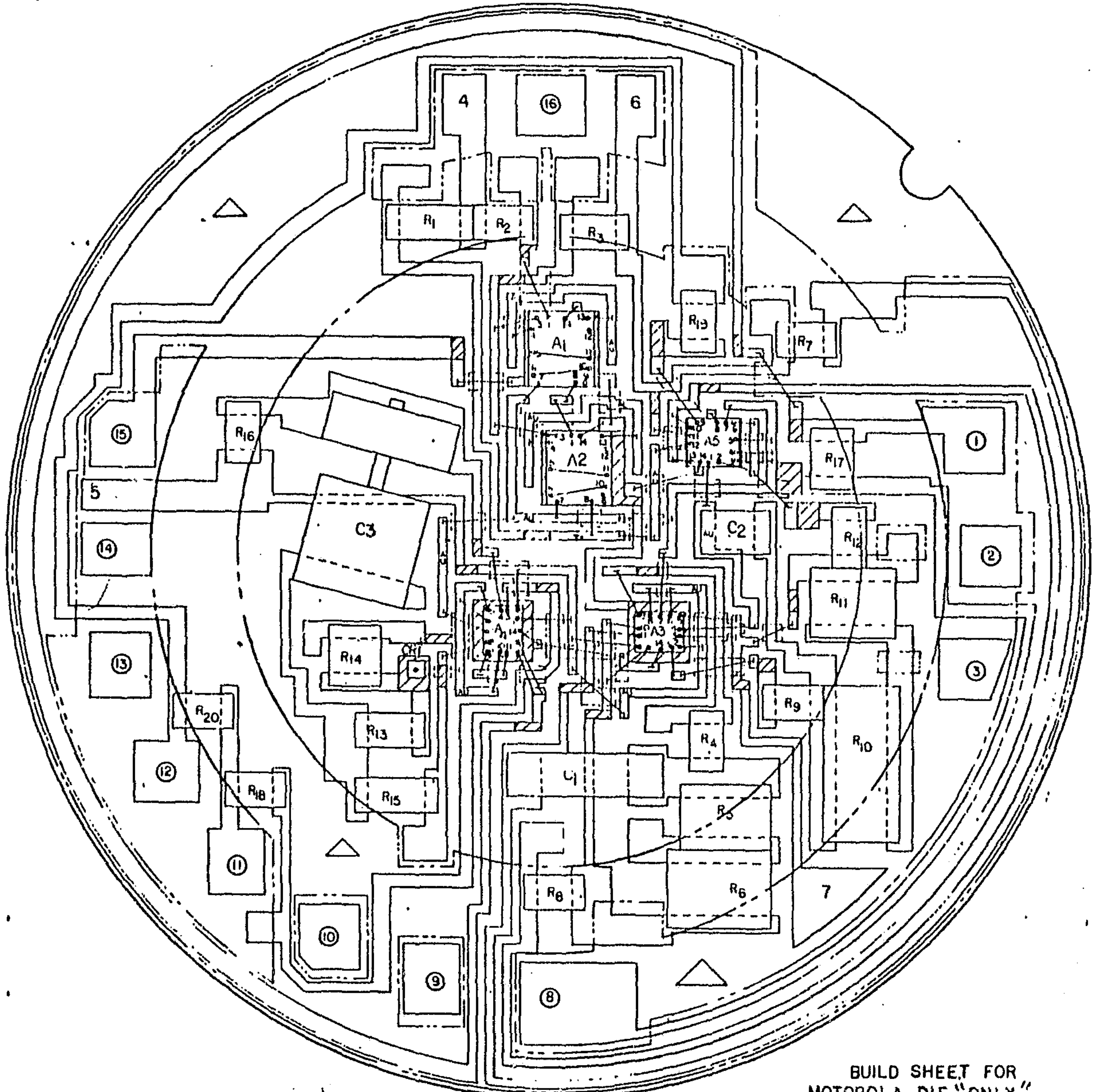
IV-1.

3. Hybrid Micro-circuit Development.

The translation from discrete packaged integrated circuits and standard resistors and capacitors on a breadboard into a hybrid circuit was done using standard industrial practices. A disc shaped alumina substrate was used. For the basic interconnections, patterns were screened using thick film silver palladium metalization. Connections to components off the hybrid substrates were, however, provided via pads in which gold-palladium film was used. The IC dice were bonded to the substrate by means of gold-eutectic bonding, and gold wires were thermally bonded to the interconnect pads. The thick film resistors were sand and laser-trimmed to the required tolerances. Capacitor chips and contact pins were bonded by means of epoxy-silver adhesive. The side which contained the active circuit elements was encapsulated under a Kovar cover, and epoxy sealed for environmental protection. The layout of the hybrid micro-circuit is shown in Figure IV-2. The hybrid were fabricated by Integrated Micro-Systems, Inc.

4. RF Antenna Design.

The design of the UHF link to meet requirements involved the development of a special RF antenna for the actuator. An extensive effort was first undertaken to



R#	L	W	L/W	R	DES	ACT	TOL
1	[illegible]	.40	[illegible]	[illegible]K	[illegible]K	[illegible]K	
2	.10	.10	1	100K	[illegible]	[illegible]	
3	.10	.10	1	100K	100K	[illegible]	
4	.10	.10	1	[illegible]	[illegible]	[illegible]	
5	.35	.10	[illegible]	[illegible]	[illegible]	[illegible]K	
6	.60	[illegible]	[illegible]	[illegible]K	50K	50K	
7	.40	.40	1	[illegible]K	[illegible]K	1K	
8	.40	.40	1	[illegible]	[illegible]	120K	
9	.40	.40	1	[illegible]	[illegible]	[illegible]K	
10	[illegible]	.150	[illegible]	[illegible]	[illegible]	12K	
11	[illegible]	.100	[illegible]	[illegible]K	[illegible]K	5K	
12	[illegible]	.40	1	[illegible]	100K	[illegible]	
13	[illegible]	.10	[illegible]	[illegible]K	[illegible]	[illegible]K	
14	.40	.60	[illegible]	[illegible]	[illegible]	[illegible]	
15	.65	.40	1.6	[illegible]	[illegible]	[illegible]	
16	.40	.40	1	[illegible]K	3K	[illegible]	
17	.40	.50	.80	[illegible]	[illegible]	[illegible]	
18	.40	.40	1	[illegible]	[illegible]	4K	
19	[illegible]	.40	1	[illegible]	5K	4K	
20	[illegible]	.40	1	100K	100K	[illegible]	

DIE #	DESC
A1-2	MCC 14006
A3-4	MCC 14001
A5	MCC 14016
C1	.001 FF NPO
C2	330 PF NPO
C3	[illegible] uF
CR1	IN4148

BUILD SHEET FOR
MOTOROLA DIE "ONLY"

GLAZE ---- —

FIGURE IV-2:

HYBRID THICK-FILM MICRO-CIRCUIT MECHANICAL LAYOUT

CAS DRAWING NO. 08010-03-0901

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CIC 0076

study the theoretical aspects of small antennas. Table IV-2 shows the relevant relationships and trade-offs. It is apparent that the design of a small efficient antenna is an extremely difficult and complex problem. Antenna efficiencies of a few percent are the best that can be expected.

Based on the analytic studies of these trade-offs, it was decided to operate the highest frequency possible from a practical and economical standpoint. From the point of view of circuit complexity and the cost of both actuators and IRR's, 500MHz seems to be the upper limit. The antenna was then designed with the following features:

- Antenna type: loaded loop, etched on printed circuit board with 1.1 inch outer diameter.
- Operating frequency: any frequency between 450 and 500MHz
- Tank circuit: the loop antenna was made part of the tank circuit of the transmitter/RF oscillator, to minimize circuit complexity, eliminate matching problems, and minimize problems due to signal drift.

The present antenna design has an efficiency of slightly better than 1 percent.

5. <u>RF Transmitter Design</u>.

TABLE IV - 2: DESIGN TRADE-OFFS FOR A SMALL RF ANTENNA

Parameter	Limiting Factors, Problems
Antenna Size	Radiation resistance decreases as size decreases Efficiency approximately $\propto (\frac{\ell}{\lambda})^3$ Q of antenna increases with decrease in size
Operating Frequency	Increase in frequency results in higher efficiency and higher radiation resistance, but propagation losses increase as well as receiver-circuit complexity and cost
Body Effect on Antenna Detuning	The proximity of the body affects efficiency and center frequency (detuning). This effect gets larger as the Q of the antenna increases.
Type of Antenna	A magnetic dipole (loop) is less sensitive to dielectric perturbation (e.g. body) than an electric dipole antenna
Losses	Copper loss in the antenna (stein effect) Inductive losses due to secondary current generated in circuits adjacent to the antenna (e.g. batteries, etc.) Losses due to body absorption. Propagation losses.

The RF transmitter design cannot be completely separated from the antenna design since it includes the a antenna as part of the tank circuit of the oscillator.

The design features for the RF transmitter include the following:

- Simple circuitry, incorporating the antenna into the tank circuit.
- Tunable between 450 and 500MHz, center operating frequency.
- Input power between 15 to 20mW, operated at 4.5V (3 x 1.5V batteries)
- Frequency modulated by a 20kHz subcarrier.
- Minimum detuning due to body proximity.

A modified Colpitts RF oscillator circuit was used, for simplicity and stablity. The final design of the transmitter and antenna involved considerable experimentation, since the close proximity of actuator components, including the batteries and the hybrid module, to the RF transmitter causes interaction such as detuning, signal attenuation.

6. Power Source.

The selection of a power source was critical since it had to meet several requirements:

- Long shelf life (minimum 1 year).

- Ability to provide a stable voltage of 4 V or better, for the operation of the digital and RF sections.
- Low impedance characteristic.
- High current under pulsed condition, without degrading the batteries' life time or performance.
- Small size.
- Operability over an acceptable temperature range.
- Low cost.

Many alternatives were explored, including silver-oxide cells, mercury cells and lithium cells. The final choice was a silver-oxide cell made by Ray-O-Vac, type RW-22, which met and exceeded the necessary size and electrical requirements. Three of the cells were used in the actuator to provide a 4.5V (nominal) power source.

7. <u>Packaging</u>.

There were three major factors which determined the packaging design:

- <u>Human:</u> user acceptability, wearability, ease of use, resistance to accidental triggering.
- <u>Environmental factors</u>: Resistance to normal wear and tear and some abuse (normal shocks, etc.), resistance to temperature and humidity within the range of user environments.
- <u>Other factors</u>: ease of fabrication, ease of assembly,

ease of servicing (e.g. tuning, code programming, battery replacement, etc.)

The basic package consists of a clear, cast, monolithic epoxy case sealed with two standard watch crystals serving as bottom and top cover seals, as shown in Figure IV-3. Replacement of the battery or tuning of RF components is allowed by access from above, after removal of the upper crystal as shown in Figure IV-3. Code programming requires the removal of the lower crystal, thereby exposing the connection pads to the digital section of the actuator circuitry.

The actuator is triggered by simultaneously depressing a pair of switches mounted on the two sides of the case. Because it is not possible to trigger it by pressing one switch, accidental triggering is greatly reduced.

8. <u>Alignment and Programming</u>.

Frequency selection is the only alignment operation required in the actuator. To do this, a trimmer capacitor accessible below the upper crystal of the actuator, is adjusted. The frequency is measured by a frequency counter or a calibrated spectrum analyzer.

Code programming and digital testing is accomplished with a testing/programming jig specially designed for this purpose. The testing and programming inputs can be accessed by removing the lower crystal cover.

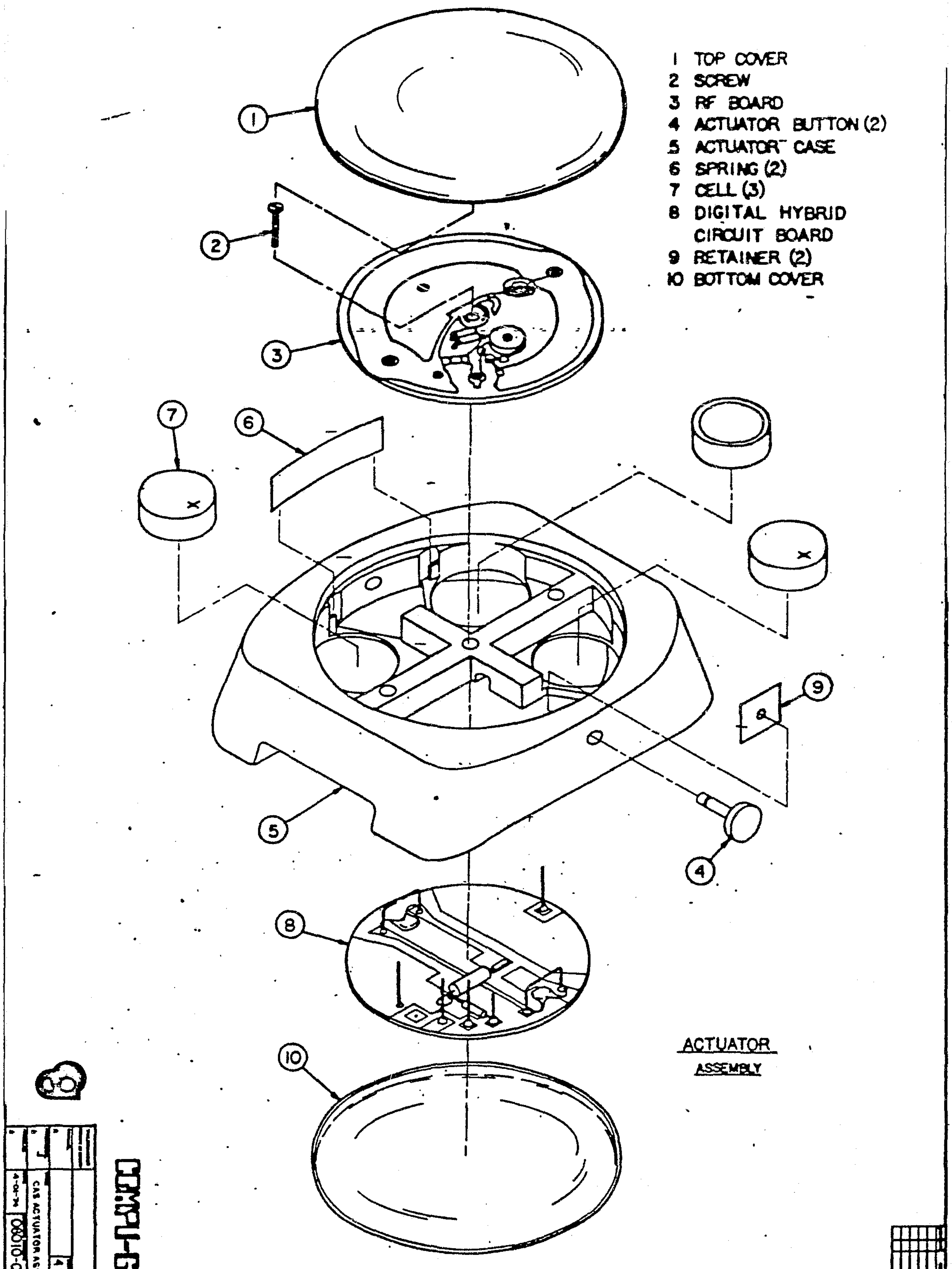


FIGURE IV-3: ACTUATOR ASSEMBLY

The testing jig can be used for the following:

- Programming the actuator code
- Testing the frequency of the subcarrier and data transmission rate
- Testing the operation of the actuator
- Testing the correctness of the actuator code.

Final actuator testing is performed to check the following parameters:

- ERP, measured by a calibrated antenna and a spectrum analyzer located at a reference distance from the actuator.
- Modulation characteristics, measured by a calibrated IRR RF receiver.

9. Actuator Programmer.

The actuator is a coded device with a reprogrammable memory. This is a major advantage in the field, since it allows the repeated use of the same actuator by different people, e.g. residents in a public housing complex (with a generally high turnover).

The programming of each actuator ID code is accomplished with an actuator programmer. This programmer has been constructed with the following controls:

- BCD thumbwheel switches (6 digits) to set the actuator ID code

- ON/OFF switch
- PROGRAM/CHECK switch
- LED check light
- DATA, CLOCK terminals

The programmer enters the code into the actuator and checks the code stored within an actuator. The programmer is then connected to the test pads on the hybrid micro-circuit of the actuator, using a test fixture. The only two connections required are the CLOCK and DATA lines. The CLOCK is the internal clock generated within the digital section of the actuator. The DATA line is used either to enter data into the actuator ("Program" mode) or to read data stored in the actuator ("Check" mode).

To program the actuator, the following procedure is used.

- Set the ID code on the Thumbwheel Switches of the programmer, e.g. 839417.
- Connect the CLOCK and DATA lines between actuator and programmer via the test fixture.
- Set PROGRAM/CHECK switch to program mode.
- Push data button.

The actuator is now programmed with ID code, e.g. 839417. To check the presence of this data in the actuator:

- Set PROGRAM/CHECK switch to check mode.

- Push data button.

If the stored ID code in the actuator is wrong, the LED will light up.

B. Internal Receiver Relay Design Procedures

The IRR is the junction between the UHF and the power line links. The development of this component included the design of a UHF antenna and receiver, a power line transmitter and receiver, and all the related digital circuits for data storage and handling.

1. Description of Operation.

A typical installation of the Citizen's Alarm System will consist of one or more IRR's strategically located in the premises to be protected. When an actuator is triggered within range, the nearest IRR receives the transmitted UHF encoded radio signal. It then processes it, adds a location code, and relays it to the central station, either directly or via the external receiver-relay (ERR).

The functional block diagram of the IRR is shown in Figure IV-4. The unit consists of an UHF antenna and two functional modules: the RF section and the digital section.

2. RF Antenna Design.

The design of the RF antenna for the IRR followed a procedure similar to that for the actuator antenna, except

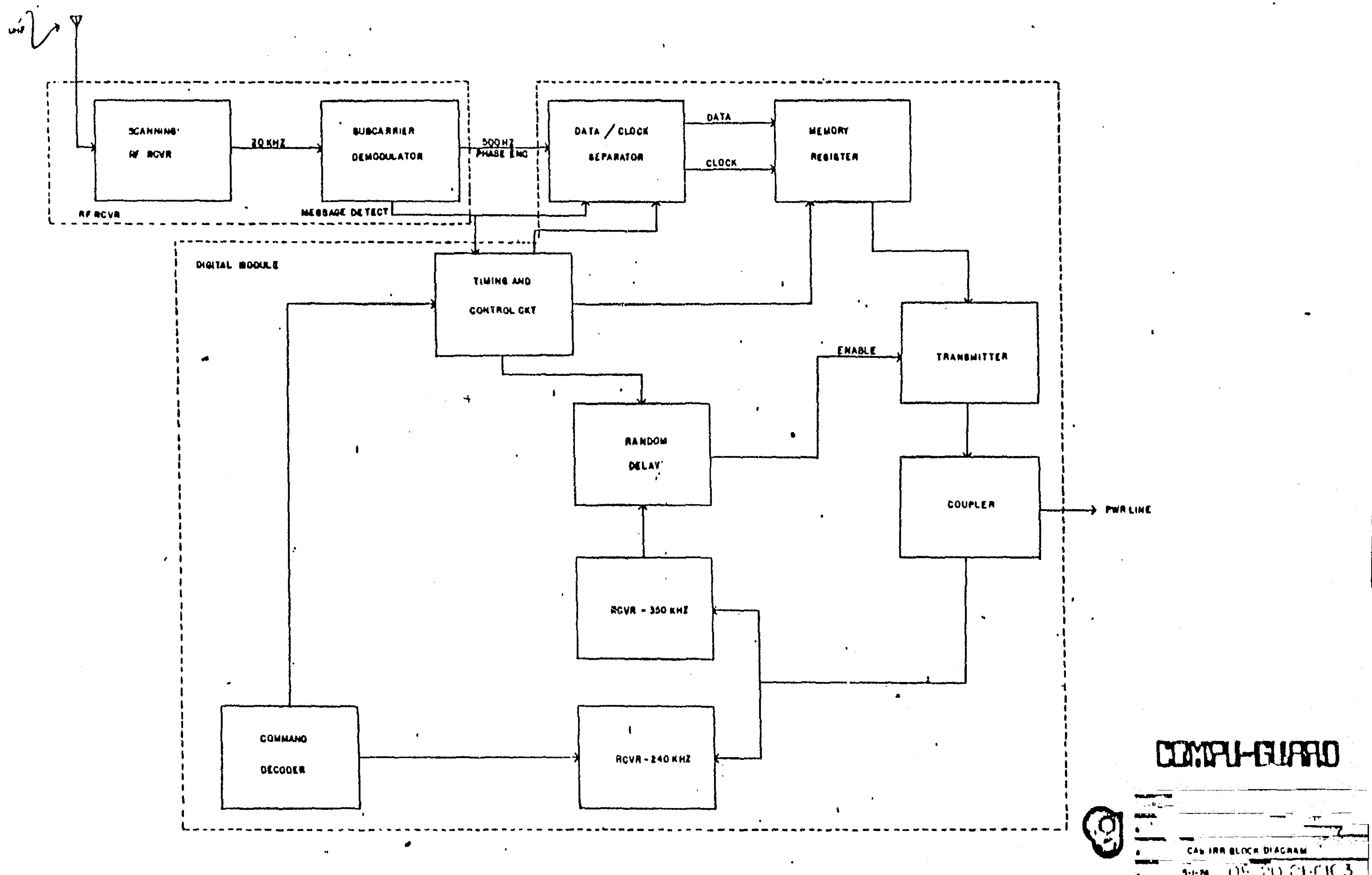


FIGURE IV-4: INTERNAL RECEIVER RELAY BLOCK DIAGRAM for a less stringent requirement in size and a tighter requirement in efficiency. A loaded loop dipole was chosen to ease impedance matching requirement to the RF receiver input. The load inductancies were adjusted to give impedance matching to 50 ohms input impedance at 460MHz with a bandwidth of approximately 50MHz.

3. RF Receiver Design.

The design of the RF receiver was tailored to the performance of the actuator. Since body detuning can shift the actuator frequency by 2MHz and long term drift of the frequency can be several MHz, it was decided that the RF receiver should automatically scan within a 10 to 12 MHz bandwidth and lock onto the actuator signal after it was found on a sweep (o.1 second sweeptime). The following design was incorporated into the RF receiver.

- Center frequency tunable between 450 and 500MHz.
- Automatic scanning with a 10MHz bandwidth in 100msecs.
- Circuit to lock onto the actuator signal, characterized by the 20kHz subcarrier.
- Receiver sensitivity of 2 μV at 50 Ω input impedance
- Circuit to demodulate the 20kHz phase encoded subcarrier and extract the data signal.

- Rejection of other (spurious) signals
- Simple adjustment and alignment procedures
- Low cost.

The above design requirement resulted in the design of an RF receiver with the following circuit features:

- A 2 FET preamplifier with a 10MHz bandwidth
- A hot-carrier diode mixer
- A one-transistor voltage controlled oscillator with almost linear voltage-frequency characteristics
- IF amplifier - FM demodulator built around a sensitive IC chip (RCA CA3089E).
- A phase-locked loop circuit for detecting and demodulating the subcarrier signal.
- A simple frequency locking circuit.

The entire RF receiver and subcarrier demodulator was built on a 5 3/4" x 5 3/4" PC Motherboard with 1" x 3" x 3/4" plug-in RF and IF modules.

4. <u>Digital Section Design and Circuit Description</u>.

The functions of the IRR digital section include the storage of actuator code and location code, central station command receiving and decoding, queuing, and the conversion of data for power line transmission. An information flow diagram is shown in Figure IV-5. The signalling frequencies

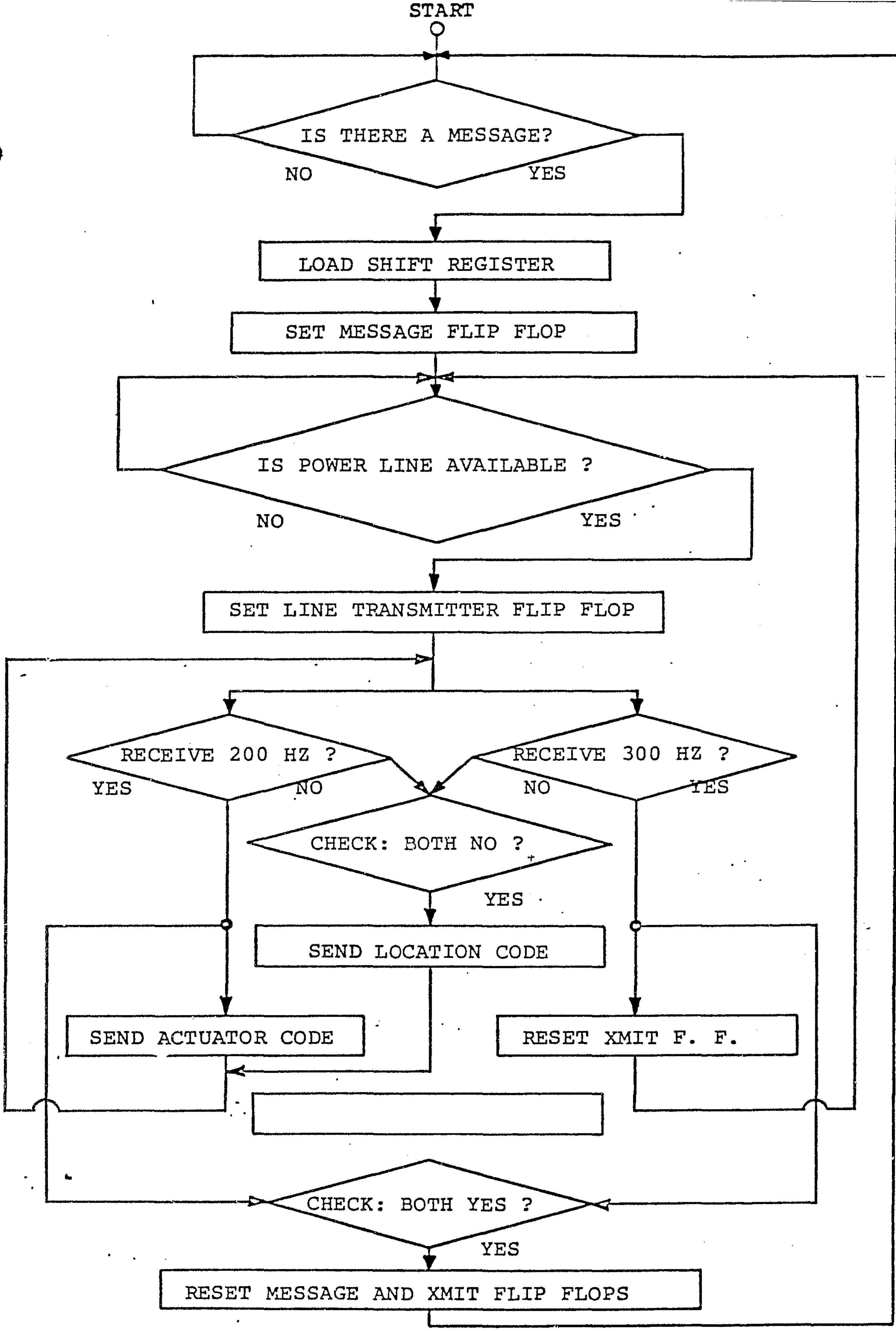


FIGURE IV-5:INTERNAL RECEIVER-RELAY, INFORMATION FLOW DIAGRAM used between the IRR and central station ~~as~~ are summarized in Table IV-3. This table also shows the effects of signalling via an external receiver-relay, rather than directly on the power line.

The actuator code is stored in a 512 bit dynamic shift register, with a read clock of 1kHz, synchronized to the incoming data which is at a frequency of 500 hz. Once a message is detected, the shift register begins writing and continues for a period of 600 ms $\pm$ 25 ms. The 512 bit shift register therefore, overfills, rewriting the first 100 ms or so of the message. The overfill guarantees that the shift register does fill completely.

Location code is stored in the form of diodes hardwired to the outputs of a 1 of 8 decoder. The location code format is as follows: 8 bits of zero as a "front porch", a start bit and 7 data bits, with the LSB first. The particular format simplifies encoding hardware and decoding software and permits easy expansion.

The IRR's are tied to the central station by a two-way communication power line link, data from the IRR to the central station in one direction, and commands from the central station to the IRR in the other. Commands are transmitted FSK at a 240 kHz carrier frequency, using 200 Hz

TABLE IV-3: SIGNALLING BETWEEN IRR AND CENTRAL STATION

	FUNCTION	SIGNAL TRANSMISSION CARRIER	SUB-CARRIER	CENTRAL STATION	EXTERNAL RECEIVER RELAY	INTERNAL RECEIVER RELAY
COMMANDS	"Send actuator code"	240 kHz	200 Hz	•———	————	——→
		240 kHz	200 Hz		•———	——→
		400 Hz	---	•———	——→	
	"Send location code"	240 kHz	300 Hz	•———	————	——→
		240 kHz	300 Hz		•———	——→
		600 Hz	---	•———	——→	
	"Reset IRR"	240 kHz	200/300 Hz	•———	————	——→
		240 kHz	200/300 Hz		•———	——→
		400/600 H	---	•———	——→	
	ERR supervision	2700 Hz	---	•———	——→	
	ERR response	900 Hz	---	←———	————	
DATA	IRR actuator and location code	347.5 kHz	60 Hz	←———	————	——•
		347.5 kHz	60 Hz		←———	——•
		900 Hz	60 Hz	←———	——•	

and 300 Hz tones. The tone decoder interprets three commands:

- 200 Hz, send actuator code
- 300 Hz, garbled message - send location code again
- 200 Hz and 300 Hz alternating at 10Hz, reset command.

The IRR's are queued to protect the system from message interference due to simultaneous multiple IRR transmissions. The queuing is accomplished with a random delay and line monitor system. After an IRR is triggered, it waits for a random length of time, 1-3 seconds, before transmitting along the power line link. During this delay time, the IRR monitors the power line. If the power line link is already in use, the IRR waits until no other IRR is transmitting before beginning to transmit its message.

Data is transmitted along the power line FSK at a carrier frequency of 347.5 kHz, at a data rate of 60 baud. Either location code or actuator code is selected upon command. The power line module puts 3 to 5 volts pk-pk on the line, and is designed for a worst-case line impedance of 5 ohms. The trade-offs involved in the design of the digital section of the IRR are summarized in Table IV-4.

5. Power Supply.

The unit has a regulated 9V power supply (regulation: 1%, full load) that is used to provide the following voltages:

TABLE IV-4 TRR DIGITAL SECTION
SOME DESIGN TRADEOFFS

FUNCTION	ALTERNATIVES	ADVANTAGES	DISADVANTAGES	WHICH USED
ACTUATOR CODE STORAGE	ACTUATOR CODE STORAGE			
	Intel 1405A Dynamic Shift Register	Availability, low cost, low current drain	Needs many extra components, needs constant recirculation, needs two power supplies	*****
	Static Shift Register	Circuit simplicity	Higher cost, not easily available, high current drain	
LOCATION CODE STORAGE	LOCATION CODE STORAGE			
	Hardwired Diodes	Availability	Circuit complexity	*****
	Multiplexer	Circuit simplicity	Not easily available	
COMMAND TONE DETECTORS	COMMAND TONE DETECTORS			
	567 Type PLL's	Simple circuit	High cost, not readily available, lower noise immunity	
	Locked Oscillator PLL	Low cost, easily available, wide-band-noise immune	Circuit complexity	*****
LINE MONITOR RECEIVER	LINE MONITOR RECEIVER			
	Detection From Data Rate	Lower cost, slightly better theoretical immunity to jamming	Complex circuit, difficult to align & keep in alignment, lower actual reliability	
	Detection of Carrier	Simple circuit, better availability	Higher cost	*****
OUTPUT COUPLING STAGE	OUTPUT COUPLING STAGE			
	Emiter Follower	Simple circuit, low cost, good impedence match	High power drain, poor isolation from line	
	Torroid Transformer	Good isolation, good match	Very expensive	
	455KC IF Transformer	Low cost, good isolation	Poor impedence match	*****

+9V @ 70mA

+5V @ 40mA

-8.vV @ 1mA

The unit has provision for standby operation, standard 9V radio cells. A simple radio cell (rated at 1 amp hour) has a standby life of 10 hours.

6. Packaging.

The three printed circuit boards (antenna, RF mother board, digital section board) are all vertically mounted within a Kydex high-impact cover, as shown in Figure IV-6. The cover is about 6" x 6" x 3 1/2" and has aesthetic appeal (consistent with its size!). The unit can be directly plugged into a twin 110V wall receptacle, and resists impact, shock and normal abuse. The vertical mounting of the PC boards within the housing allows cooling of the devices on the boards by free-air convection.

7. Testing and Alignment.

The RF and digital sections of the IRR are tested and aligned separately, prior to the final assembly of the unit. Detailed, step-by-step, instructions on the procedures involved are available in the Data Package, Appendix I.

C. External Receiver - Relay (ERR) Design Procedures

The ERR enables the transmission of emergency messages

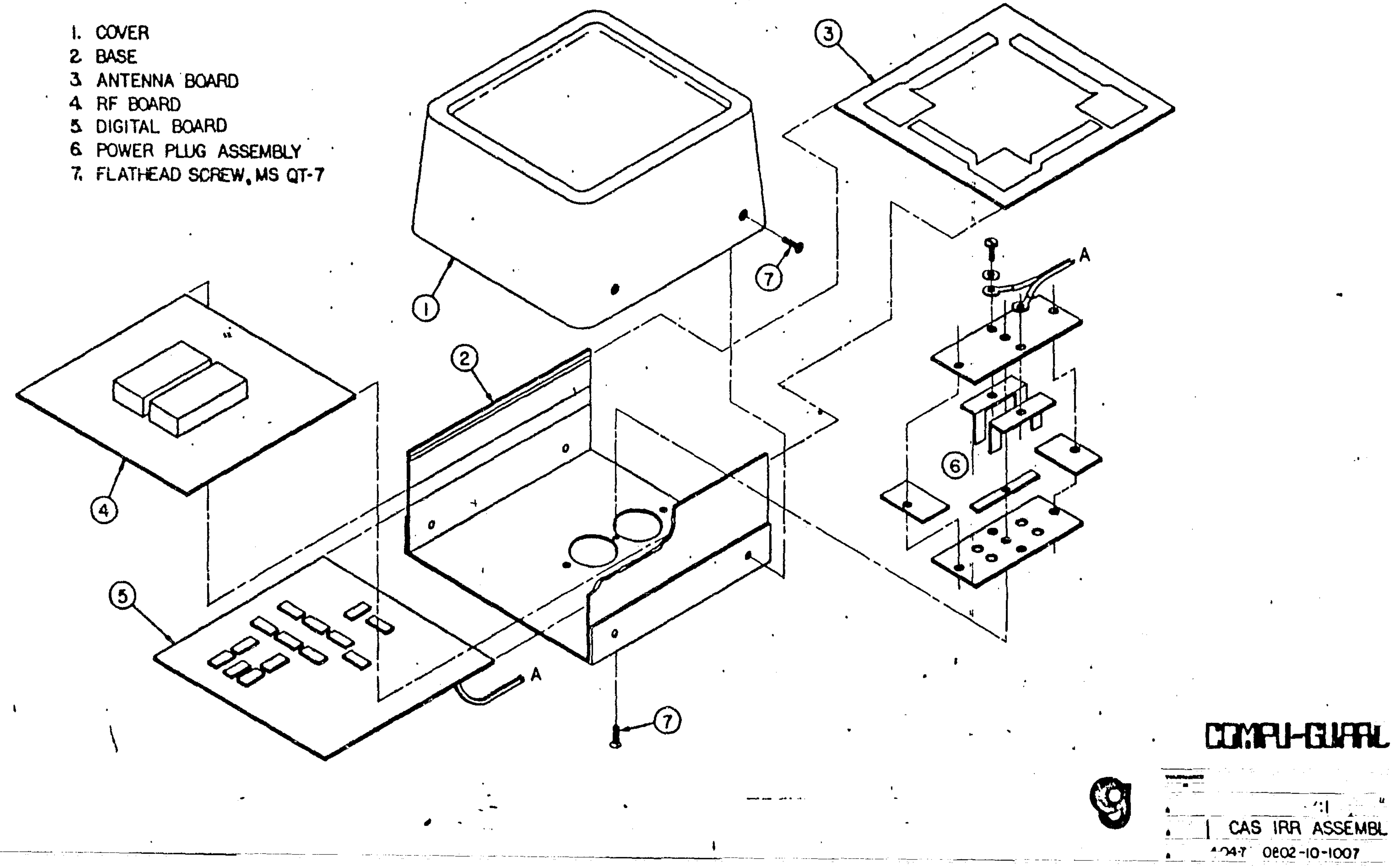


FIGURE IV-6: <u>INTERNAL RECEIVER RELAY ASSEMBLY CAS</u>

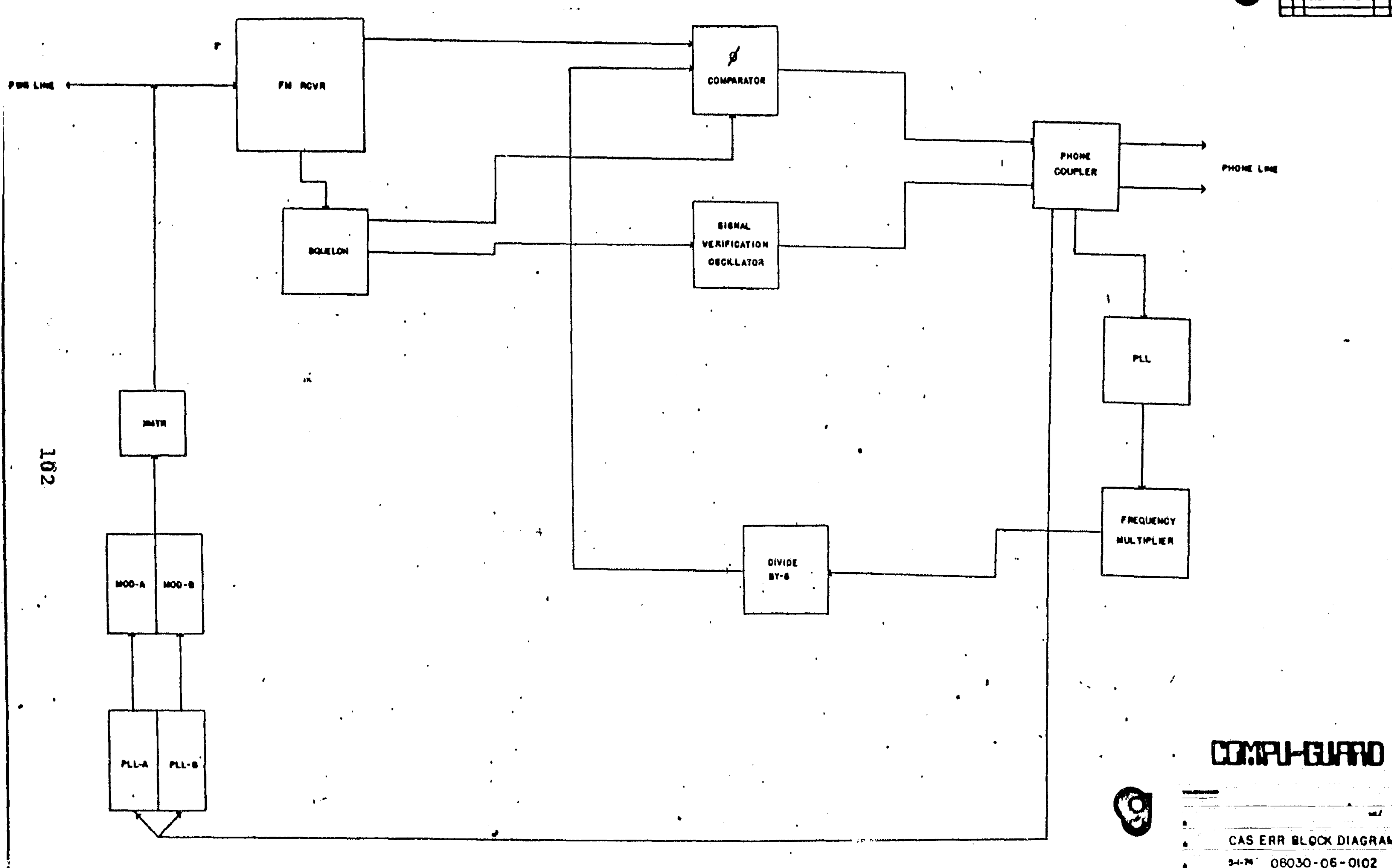
from a protected building to a remote central station. This allows the same central station to serve a number of different buildings. The ERR is designed to couple to a power line on one side and to a dedicated voice grade phone line on the other.

1. Description of Operation.

The ERR is a two-way link between the two transmission channel (power line, phone line), is fully supervised by the central station, and operates in real time. Though it does not have any digital identification code of its own, each ERR is uniquely identified by the central station by the phone line to which it is connected. The ERR has three modules: power line module, signal processor module, and phone line module. The signal processor communicates with the IRR's at carrier frequencies of 240 and 347.5kHz on the power line, and with the central station at carrier frequencies of 900Hz, 1500Hz, and 2700Hz on the phone line. The ERR relays both commands and data, in both directions, between the two transmission channels. The block diagram of the entire unit is shown in Figure IV-7, and the functional logic diagram in Figure IV-8.

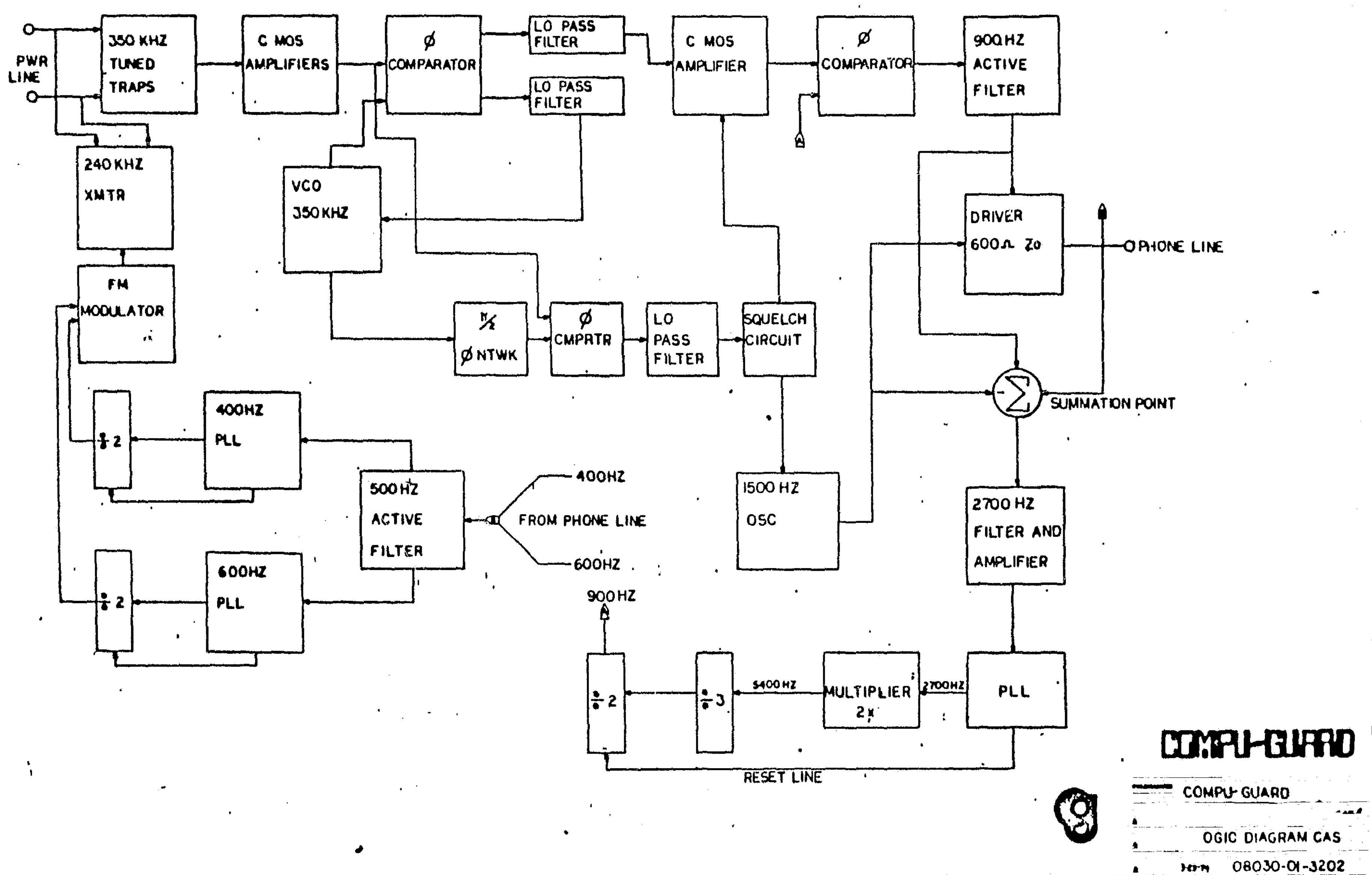
2. Power Line Coupler Module.

The power line coupler module sends and receives digital messages, via RF carrier, on the 60Hz AC power line and rejects the 60Hz AC. As a result, design of the



FM RCVR
COMPARATOR
SIGNAL
VERIFICATION
OSCILLATOR
PHONE
COUPLER
PHONE LINE
PLL
FREQUENCY
MULTIPLIER
DIVIDE
MOD-A
MOD-B
PLL-A
PLL-B
COMPU-GUARD
CAS ERR BLOCK DIAGRAM
08030-06-0102

FIGURE IV-7



103

FIGURE IV-8 ; EXTERNAL RECEIVER RELAY FUNCTIONAL LOGIC DIAGRAM power line coupler module requires proper line and noise rejection and the prevention of unwanted spurious oscillations at low cost. The incoming signal develops across a tuned, tank circuit which is a hi-Q circuit capacitor-tuned at 347.5 ± 3kHz. Voltage spike protection is provided by limiting diodes that provide a maximum signal amplitude of 600mV to the input of the RF (FM) receiver section.

3. Signal Processor.

The signal processor amplifies and detects the incoming data from the IRR on the 347.5kHz carrier, and converts this for re-transmission on the phone line. The incoming carrier which is at 347.5kHz ± 3kHz is frequency modulated at 60Hz is just amplified 40dB, then demodulated, and the data further amplified 40dB.

The central station sends three types of signals via the phone line:

- 2700Hz telephone supervision signal
- 400Hz command signal (request actuator code)
- 600Hz command signal (request location code)

The external receiver-relay receives and filters the 2700Hz signal and returns a 900Hz response signal to the central station, verifying the integrity of the phone line.

The 400Hz and 600Hz signals are separately received from the central station, divided by 2, and relayed to the

IRR by frequency modulating a 240kHz carrier. In the internal receiver-relay, the reception of 200Hz is an indication to send data. The 300 Hz is an indication that a garbled message is being sent, and the reception of both 200Hz and 300Hz indicates a reset condition.

4. Telephone Line (Voice Grade) Coupler Module.

This module sends data to the central station and receives data from the central station and relays this to the IRR's via the power line. A 2700Hz signal, used for line supervision, is also received. This module includes a command detector, a message detector, and the phone line interface.

5. Power Supply.

A simple power supply is used with the unit, to provide 12V AC @ 125 mA secondary. The 3-terminal 7805 regulator is capable of handling loads up to 1.5 amps; the system itself only draws 67.0 mA (tested). The power supply provides +5V DC regulated and +12V unregulated.

6. Packaging.

The unit is mounted inside the same kydex cover and in the same basic housing as the IRR.

D. Central Station Design Procedures

1. Background

The CAS central station is the final hardware component in the link between the CAS user and the response agent. It is the one central point at which information is received, processed, and displayed for the benefit of the response agent. The functions that must be performed by the central station, to meet requirements, include:

- Interfacing to the input transmission links (power line/dedicated voice grade phone line).
- Control over communications with the field network of receiver-relays.
- Supervision of the communication link with the external receiver-relays.
- Data input control and handling.
- Data processing (arithmetic processing, conditional analysis, etc.).
- Memory, for storage of intermediate results.
- Time and date clock.
- Error detection and correction.
- Data formatting.
- Data output control.
- Interfacing to display/print-out output devices.

The implementation of all these functions can be done in one of two ways: entirely by hardware or by a combination of hardware and software. The latter approach was chosen as being more versatile, flexible, and cost-effective in the long run. Again, this approach can be implemented with a mini-computer or with one of the emerging breed of micro-computers. The micro-processor alternative was selected on the basis of its significantly lower cost, smaller size and other advantages, as shown in Table IV - 5.

2. Description of operation

A micro-computer system was developed around commercially available, micro-processor components: central processing LSI chips, programmable read-only memories, random access memories, etc. The architecture of the system is illustrated in the block diagram shown as Figure IV - 9. The hardware and software are both modular, for easy development of the system and its later expansion or upgrading. A description of the hardware modules and their basic functions is given below.

a. Micro-Computer SIM8-01: The block diagram of the micro-processor is shown in Figure IV - 10. This unit is a byte-oriented (8 bits per byte) computing system including a processor (Intel 8008), 1k bytes of random access memory, six input/output ports, and a two-phase clock

TABLE IV-5: CENTRAL STATION DESIGN ALTERNATIVES

DESIGN PARAMETER	MICRO-COMPUTER SYSTEM (HARDWARE - SOFTWARE)	MINI-COMPUTER SYSTEM (HARDWARE-SOFTWARE)	ALL HARDWARE APPROACH
Total number of hardware modules (PC boards)	5	6 - 8	8 - 10
Modules available off-the-shelf	All but 2	All but 1	None
Hardware design necessary	Some	Some	Great deal
Software design necessary	Some	Some	None
Software complexity	Medium	Low	-
Size	About 19" x 12" x 8"	About 19" x 18" x 20"	About 19" x 18" 24
Estimated cost	$1,500	$ 8,000	$ 3,000

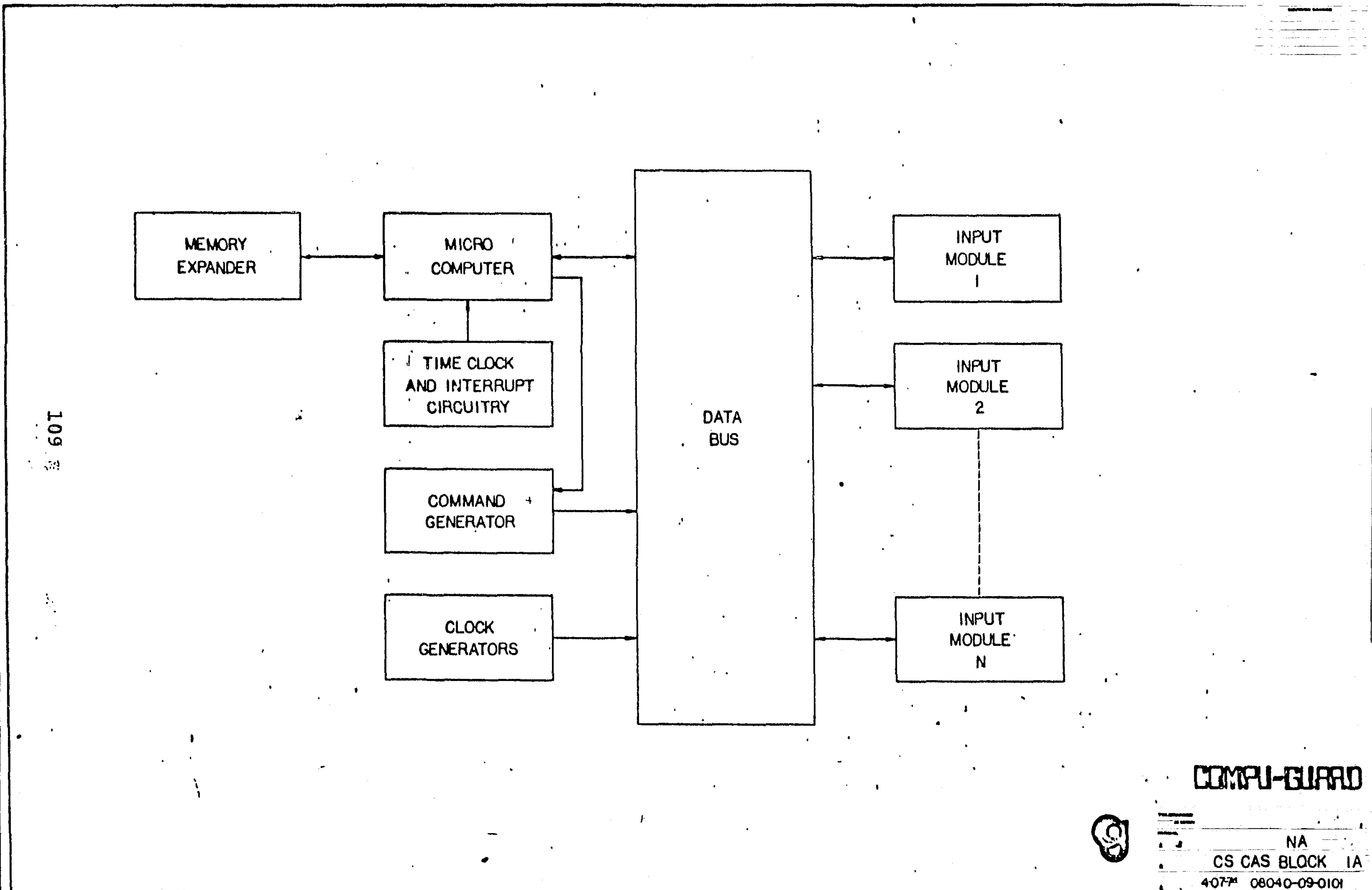


FIGURE IV-9: CENTRAL STATION-CAS BLOCK DIAGRAM

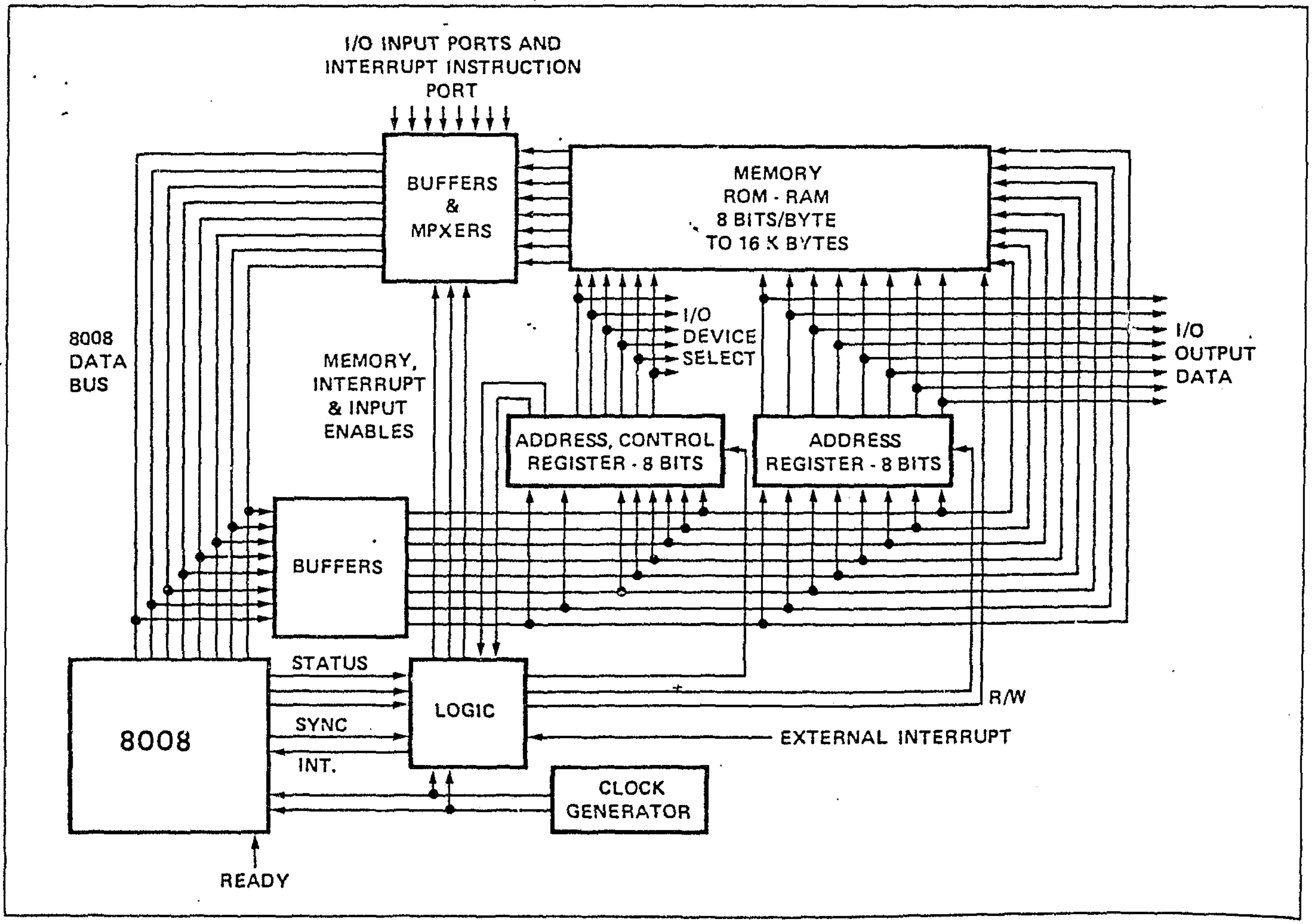


FIGURE IV-10: BLOCK DIAGRAM OF MICRO-COMPUTER generator. The unit has plug-in capability for 2k bytes of programmable read-only memory for system micro-programming. The unit operates with a 500kHz clock, a 2μsec clock period, and a typical instruction cycle of 20μsecs. The basic memory system for the SIM8-01 micro-computer is shown in Figure IV - 11, and the complete system schematic in Figure IV - 12. Further details are available in the Data Package, Appendix II.

(1) System input/output. The SIM8-01 communicates with other systems or peripherals through two input ports and four output ports. The control and I/O selection decoding lines available can be used for expansion to the full complement of eight input ports and twenty-four output ports.

(2) Teletype interface. The 8008 can be operated with different types of terminal devices. The output device chosen for CAS is the teletype (ASR-33). The SIM8-01 contains the three simple transistor TTY interface circuits necessary: one for receiving serial data from the teletype, one for transmitting data back to the teletype, and the third for tape reader control. The teletype is operated in the full duplex mode.

(3) Two phase clock generator. The basic system timing for the SIM8-01 is provided by two non-

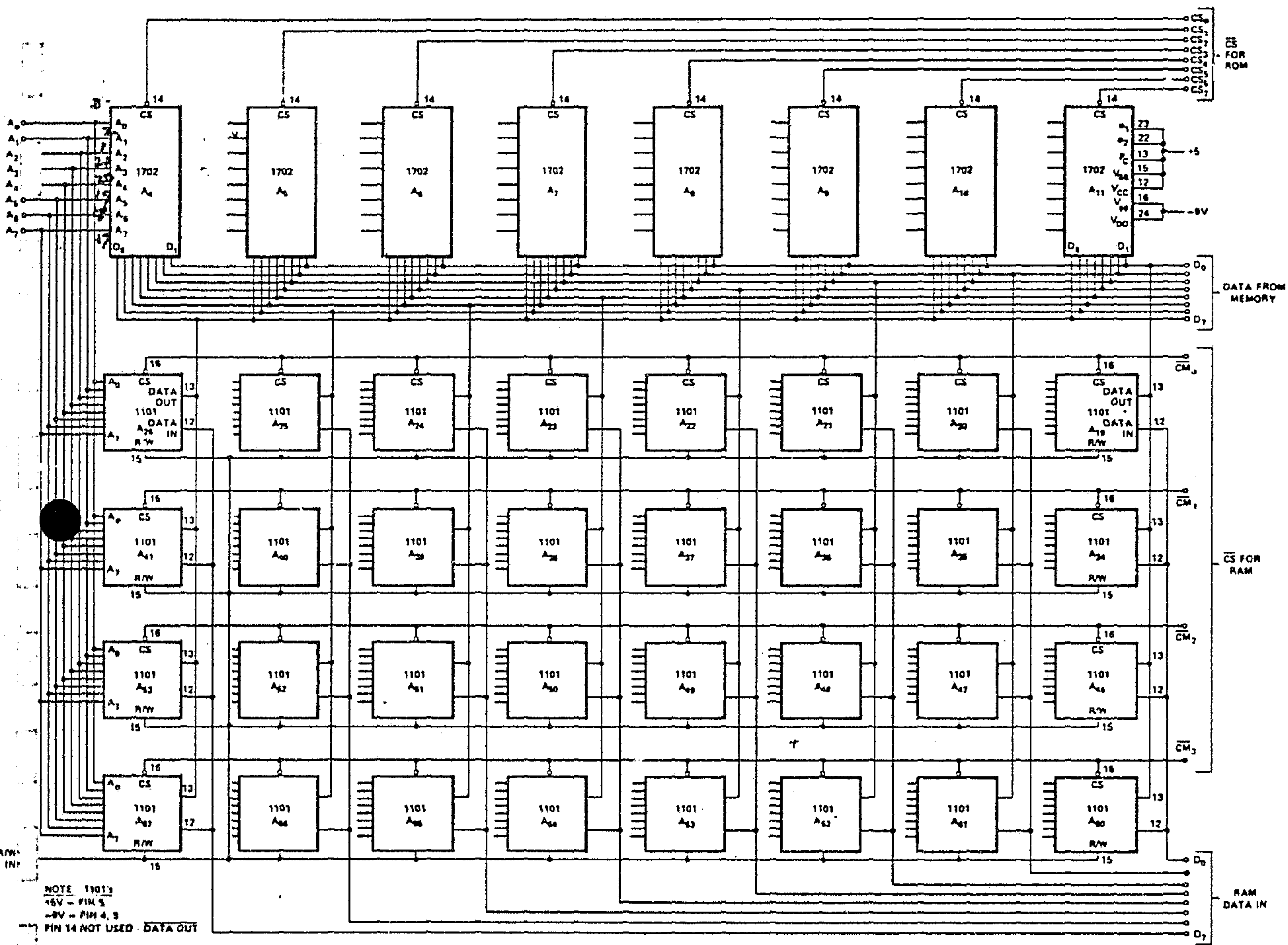
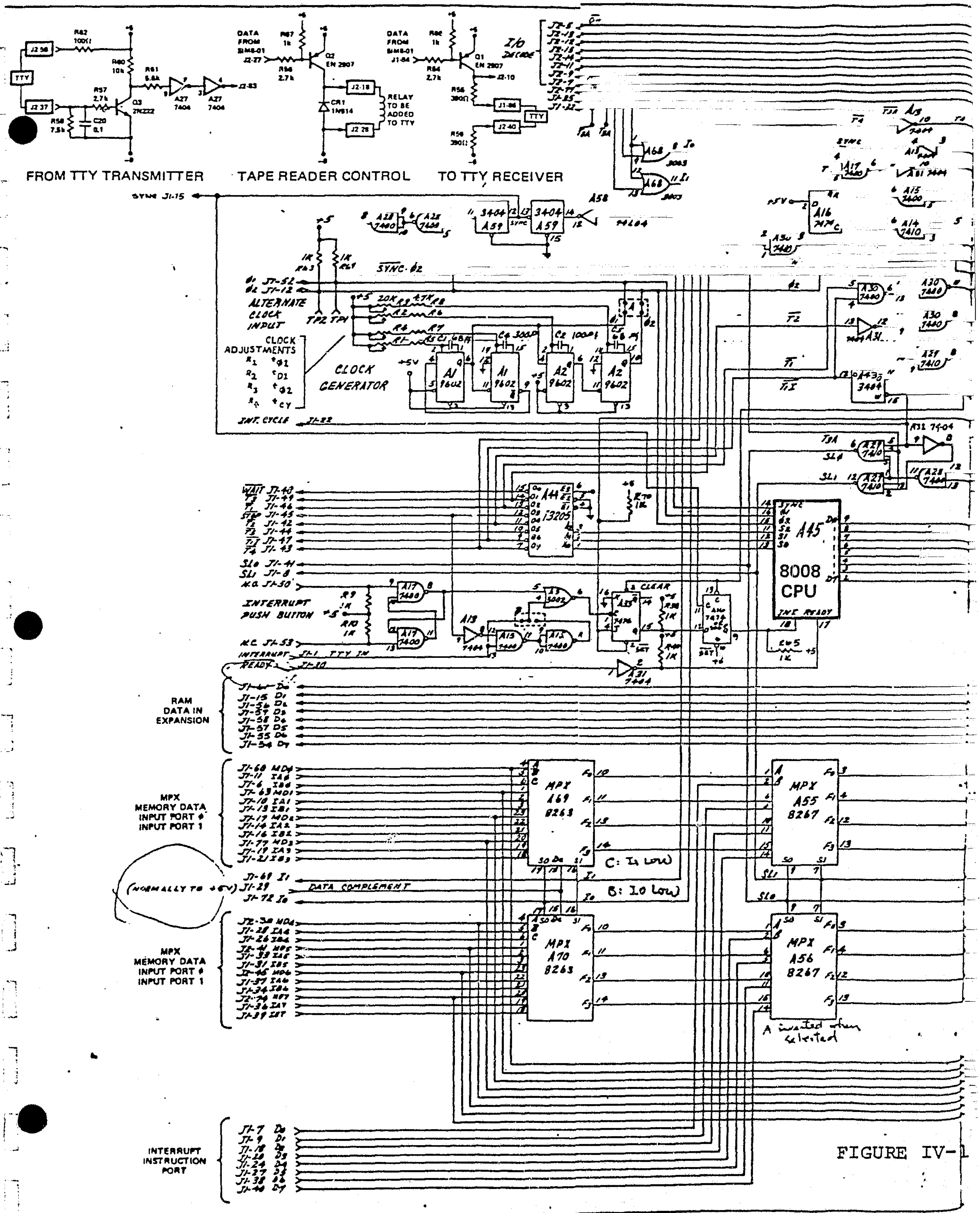
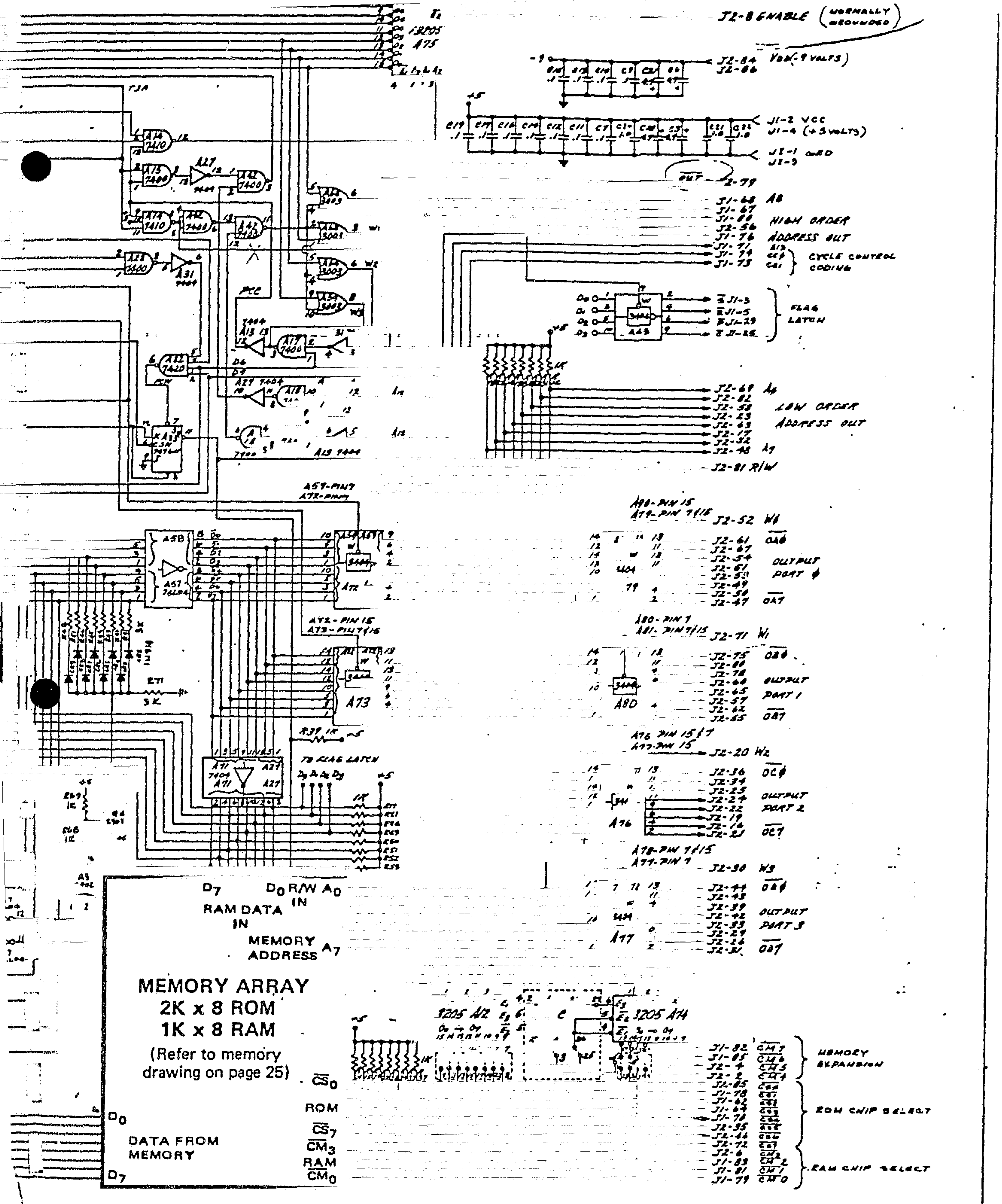


FIGURE IV-11: MICROCOMPUTER



FROM TTY TRANSMITTER
TAPE READER CONTROL
TO TTY RECEIVER
CLOCK ADJUSTMENTS
CLOCK GENERATOR
ALTERNATE CLOCK INPUT
INTERRUPT PUSH BUTTON
8008 CPU
RAM DATA IN EXPANSION
MPX MEMORY DATA INPUT PORT 0 INPUT PORT 1
MPX MEMORY DATA INPUT PORT 0 INPUT PORT 1
INTERRUPT INSTRUCTION PORT
DATA COMPLEMENT

FIGURE IV-1



WING NO. 08040-01-0301:
SCHEMATIC OF MICRO-COMPUTER SIM8-018

(No. 00014)

overlapping clock phases. The clocks are adjusted as shown in the timing diagram, Figure IV - 13, below, at the maximum specified operating frequency of the 8008.

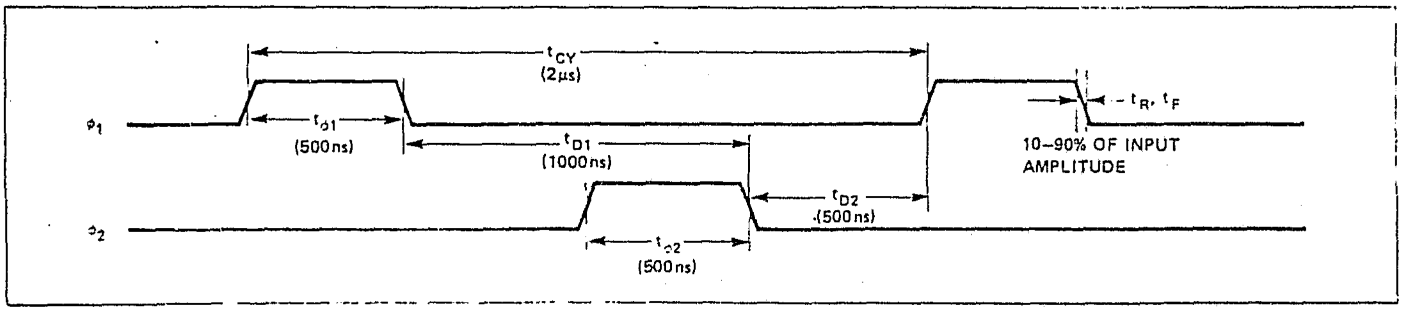


FIGURE IV-13

(4) Memory organization. The SIM8-01 used in the central station includes 2K x 8 of PROM and 1K x 8 of RAM. The memory is further expanded on the memory expander module, using the address and chip select control lines available. The SIM8-01 is organized with the PROM memory designated from address 0 - 2047, RAM memory from 2048 -- 3071, and memory expansion for all addresses 3072 and above. The system uses a one-of-eight decoder, as shown in the truth table below, Table IV - 6.

(5) Control lines. The control circuits on the interrupt handling module activate the interrupt control line. The interrupt is reset after the CPU recognizes

ADDRESS			ENABLE			OUTPUTS							
A_0	A_1	A_2	E_1	E_2	E_3	0	1	2	3	4	5	6	7
L	L	L	L	L	H	L	H	H	H	H	H	H	H
H	L	L	L	L	H	H	L	H	H	H	H	H	H
L	H	L	L	L	H	H	H	L	H	H	H	H	H
H	H	L	L	L	H	H	H	H	L	H	H	H	H
L	L	H	L	L	H	H	H	H	H	L	H	H	H
H	L	H	L	L	H	H	H	H	H	H	L	H	H
L	H	H	L	L	H	H	H	H	H	H	H	L	H
H	H	H	L	L	H	H	H	H	H	H	H	H	L
X	X	X	L	L	L	H	H	H	H	H	H	H	H
X	X	X	H	L	L	H	H	H	H	H	H	H	H
X	X	X	L	H	L	H	H	H	H	H	H	H	H
X	X	X	H	H	L	H	H	H	H	H	H	H	H
X	X	X	H	L	H	H	H	H	H	H	H	H	H
X	X	X	L	H	H	H	H	H	H	H	H	H	H
X	X	X	H	H	H	H	H	H	H	H	H	H	H

TABLE IV-6: SIM *-01 CONTROL LOGIC TRUTH TABLE the interrupt. Systems instructions are inserted automatically under interrupt control.

3. Control signalling.

The central station uses five different frequencies in controlling and monitoring the operation of the entire connected network of receiver-relays. These frequencies were chosen to allow direct transmission on a voice-grade telephone line (bandwidth 300-3000Hz), the link with the external receiver-relay. If the central station is connected to the power line, directly in communication with a set of internal receiver-relays, these frequencies are modulated onto a carrier (as explained in Section IV - E) for power-line communication.

a. ERR supervision. The central station puts out a continuous reference signal at 2700Hz. The ERR receives this and responds with 900Hz. The presence of the 900Hz "response" on each voice-grade telephone line indicates the integrity of the ERR and the transmission link.

b. ERR data flag. When the ERR recognizes incoming data from an IRR, it sends a 1500Hz signal flagging the central station to get ready to receive and process incoming data.

c. ERR data transmission. All data (actuator ID code, location code) is transmitted from the ERR to the central station on a 900Hz carrier, using phase-shift keying.

(d) IRR control. Two frequencies, 400Hz and 600Hz, control the operation of the IRR. The 600Hz signal starts the random time-delay cycle on the IRR, and requests transmission of the IRR location code. The 400Hz signal requests the IRR for transmission of the actuator code. An alternating 400Hz and 600Hz signal, at a rate of 10Hz, resets the signal.

4. Input interface modules.

The input modules to the central station are controlled by the micro-computer, SIM8-01. Each module includes a channel decoder, and has a unique channel number sequentially assigned to it. The current hardware configuration can accommodate a maximum of 98 channels (input modules).

The micro-computer sequentially interrogates each channel in less than 500 μsecs by putting forth (on a common bus) one specific channel number at a time. The channel decoders within the input modules decode the channel number, and only the specific channel (for which a match occurs) is enabled for communication with the micro-computer.

The driving circuit which couples the interface to the phone line has an impedance of 600 ohms (to match it to the line), and a maximum signal level of 0 dBm. Attenuation in the line can be expected to lie in the range of 10-20dB, and the interface is designed to handle incoming signals which are 20dB below the level of the outgoing signals. The receiving circuitry in the interface therefore includes a rejection circuit, to prevent "leakage" of outgoing signals into the receiver.

All the control frequencies identified in 2. above are generated in the interrupt module of the central station, and are available to all input modules via the connector which couples the interface module to the system data bus. The 2700Hz and the 400/600Hz command frequencies are fed into a summing amplifier, and then into the driver for transmission via the phone line.

5. Memory expander module.

This module contains the circuitry necessary to expand the memory on the SIM8-01 by 6K bytes of PROM and 3K bytes of RAM. The decoder output can allow up to 64K bytes of total memory. The memory is blocked off into pages with 256 bytes to a page.

6. Interrupt handler module. This module provides the system with a real-time clock. When the micro-computer is interrupted by this clock, control passes to an interrupt state consisting of eight interrupt cycles. A relevant instruction is sent to an output port where it also causes

an interrupt. The CPU acknowledges this interrupt and enters the interrupt cycle during which it fetches the instruction from this output port.

The CPU decodes and recognizes the instruction is a two-byte instruction, and then automatically enters the second interrupt cycle. During the second cycle the appropriate data is fetched from stack memory and placed at the interrupt instruction port. Upon completion of the two-byte instructions, the data is loaded back into register. The CPU then goes back to its normal cycle and starts execution of the next instruction. Once the interrupt has been serviced, control returns to the interrupted program via a set of instructions which restore the saved data to the internal registers.

7. Printer (hard-copy) interface unit.

A standard KSR-33 teletype based with the central station as the hard-copy printer.* The unit, a standard workhorse in the computer industry, provides alphanumeric printout.

The teletype interface is a circuit which converts the parallel 8-bit data words, sent by the micro-computer, to serial data. The serial data includes one start bit (space) followed by 8 bits of data and at least 2 stop bits (mark). The data rate is 110 baud, i.e. the bit width is 9.09 msecs.

8. System software.

The use of the Intel micro-processor MCS-8 and the SIM8-01 system requires the use of Intel software.

The Intel software system consists of four major systems:

- PL/M-1 (compiler pass 1)
- PL/M-2 (compiler pass 2)
- INTERP 8 (8008 simulator)
- ASSEM 8 (8008 assembler).

All are ANSI standard FORTRAN based and compatible with most FORTRAN compilers.

The PL/M pass - one compiler processes the input program as a stream of data, and can accept data from TTY and/or file.

I/O structure for PL/M and INTERP are basically the same. The control switches can be input from teletype or included in the source file. This structure is very flexible although there are some shortcomings in its implementation, notably that error messages are not printed at the terminal when the listing is sent elsewhere (i.e. a remote printer).

The programs are entered from file rather than interactively, since there are no built-in editing capacities in the compiler. Once a line is entered, it cannot be changed and the compiler cannot back-up.

a. System programming: high-level language (PL/M). The availability of a high level language (PL/M) for the Intel SIM8-01 micro-computer makes the system programming easier. High level programming languages, if properly designed, greatly increase the program understandability, and thus decrease development time. PL/M is a block structured language with a syntax related to IBM's PL/1.

b. System programs; flow diagrams. The main program and all procedures used in the CAS central station were developed with individual descriptions and flow charts.

The format of each is as follows:

- The name of the routine. If BYTE is included in the name, the routine is a function that returns a value.
- The explanation of what the routine does and the algolrithms it uses.
- The variables used in the routine. Unless followed by (local) they are assumed to be globally declared.

- The routines that call it, i.e. where is it ised?
- The routines it calls, i.e. what does it use?
- The flow chart.

An example of the description and the flow charts, for the main program, is shown in Table IV - 7 and Figure IV-14. Similar data is available on each of the programs in the Data Package. Table IV - 8 summarizes the different software functions and modular program routines, and lists the key software elements (program routines and subroutines).

9. Packaging.

The entire central station is housed in a single table-top unit, as shown in Figure IV - 15. The different printed circuit modules and power supplies are all contained within the same unit, which has only two controls: one to set-up the system, and the other to reset the audible alarm. All other system inputs are provided via the teletype.

TABLE IV - 7: DESCRIPTION OF MAIN PROGRAM

EXPLANATION: Prints heading, initializes system; status, days/month, time, date, day, no. of channels, turns interrupt on. It then begins to loop forever or until unplugged. It poll's each line, and checks for a change in status. If so it is recorded and a message printed with a time signature. If an alarm is being sent, two attempts are made to read the location code. If the location code is found, the actuator code is requested. In any case, a reset command is sent, the available data is printed in a message, with a time signature, and the system continues polling lines.

VARIABLES: CONTROL, I, COND, TTDAY, .MSG9, CHAN, CHANNEL, KBRD, REPEAT, RED,

CALLED ROUTINES: PRNAPH, RCMAN, RDTE, RDAY, RTME, QCRLF, PRNTME, PRNDTE, PRNMSG, RDLOC, RDACT.

FLOWCHARTS: See next page.

TABLE IV-8: CENTRAL STATION SOFTWARE: LISTING OF PROGRAM ROUTINES AND SUB-ROUTINES

ROUTINE NAME	FUNCTIONAL DESCRIPTION
MAIN	Initialization and line monitoring
RDLOC	Reads, checks, decodes location code
RDACT	Reads, checks, decodes actuator code
HANDLE	Searches for a start bit pattern
BINARY	Maps an array of ones & Zeroes into a bit vector
PRNDTE	Prints day & date information, increments date when necessary
READ	Input's one bit of data
LDBUFF	Input's 5 words of Data (either Loc. or Act)
DECO	Calculates powers of two
STATUS	Updates line status information
MVTME	Translates a two digit number to ASCII
QCRLF	Prints carriage return and line feed
PRNMSG	Prints message with all available information on alarm or status change
RCHAN	Reads a number from TTY for number of channels
PRNTI	Print a character
PRNLC	Print location code
PRNAC	Print actuator code
PRNAPH	Print string of characters
PRNTME	Print the time

ROUTINE NAME	FUNCTIONAL DESCRIPTION
TTYIN	Input character
RNUMR	Translate 2 ASCII characters to a number
RTME	Initialize time
RDAY	Initialize day
RDTE	Initialize Date
CLOCK	Increment time, day
INTERRUPT	Saves registers, calls clock routine once per second

CENTRAL STATION SOFTWARE: CONTROL PROGRAM

FLOWCHART: MAIN PROGRAM

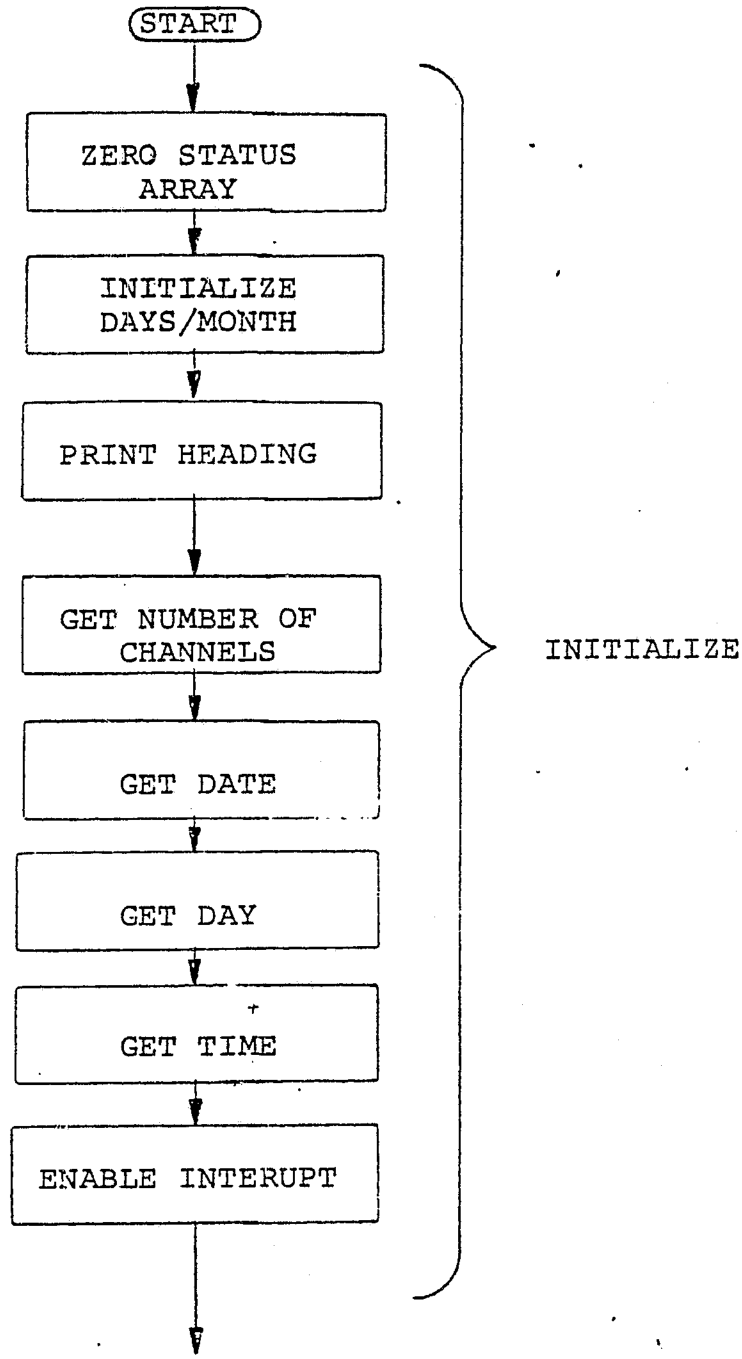


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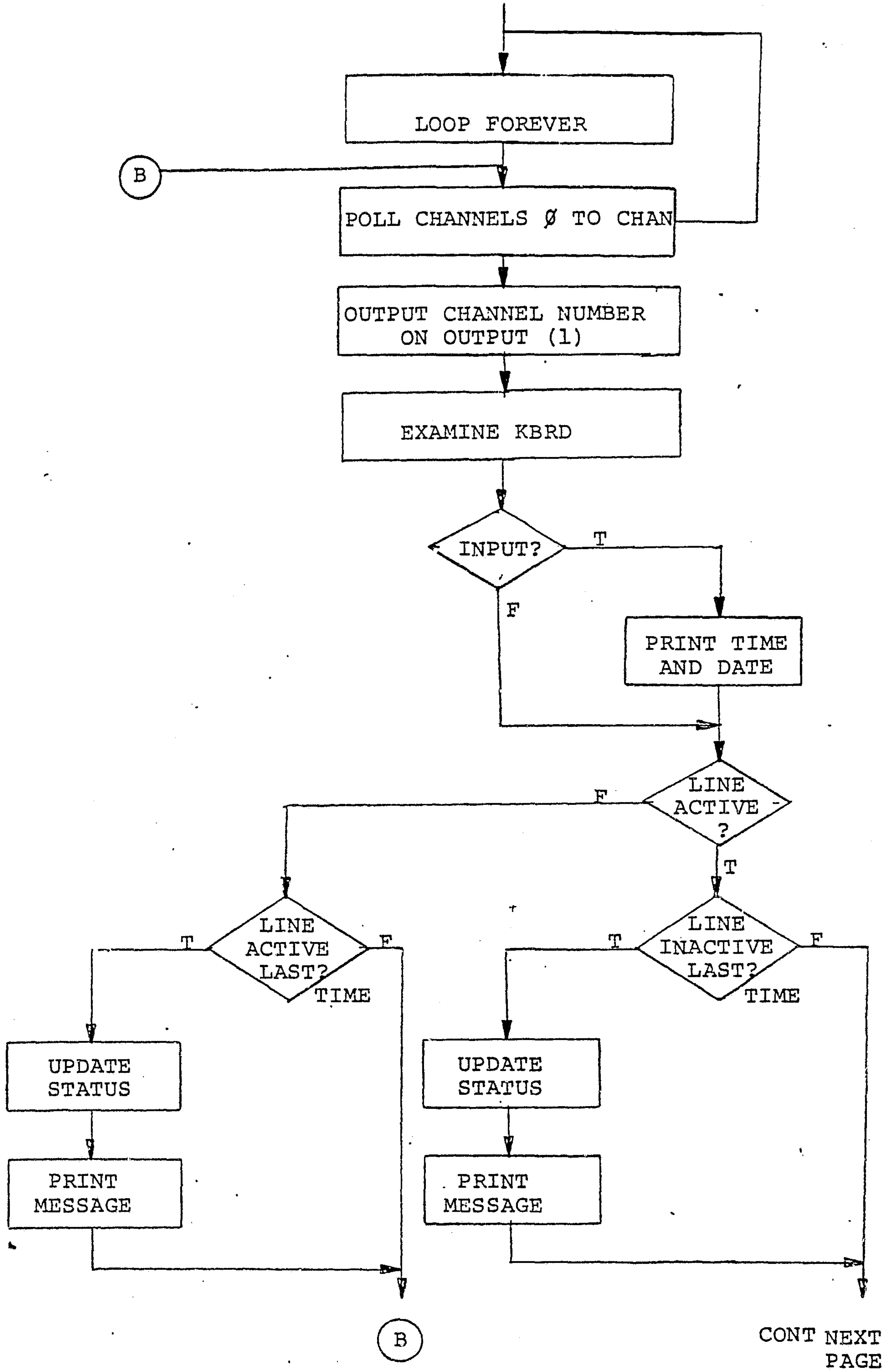
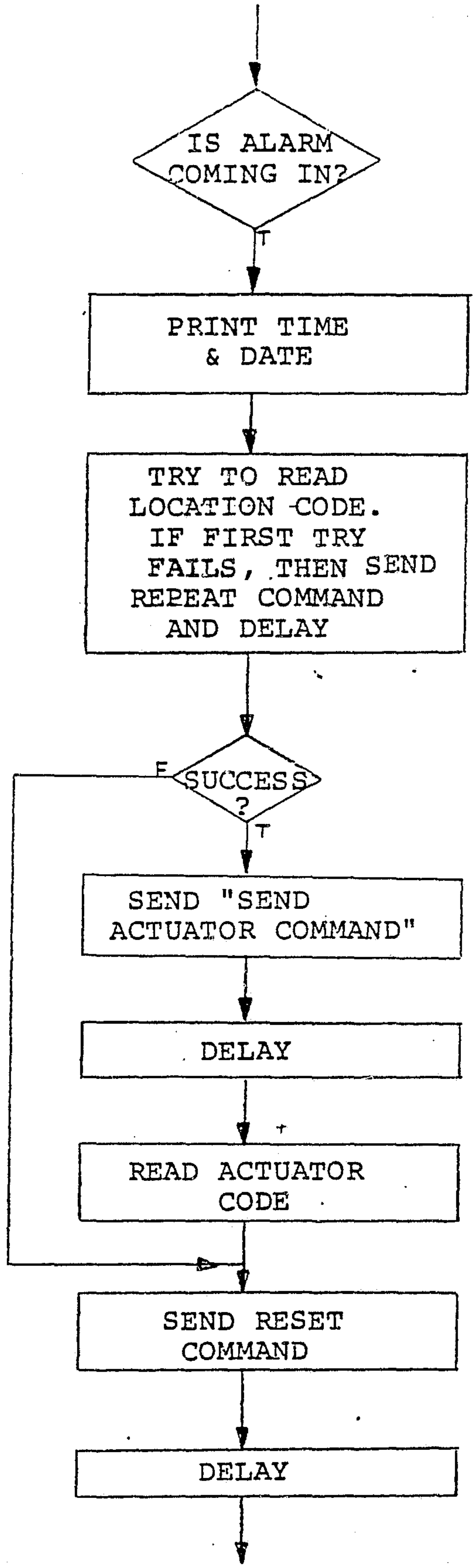
FIGURE IV-14


LOOP FOREVER
B
POLL CHANNELS Ø TO CHAN
OUTPUT CHANNEL NUMBER ON OUTPUT (1)
EXAMINE KBRD
INPUT?
T
F
PRINT TIME AND DATE
LINE ACTIVE ?
F
T
LINE ACTIVE LAST? TIME
T
F
LINE INACTIVE LAST? TIME
T
F
UPDATE STATUS
PRINT MESSAGE
UPDATE STATUS
PRINT MESSAGE
B
CONT NEXT PAGE



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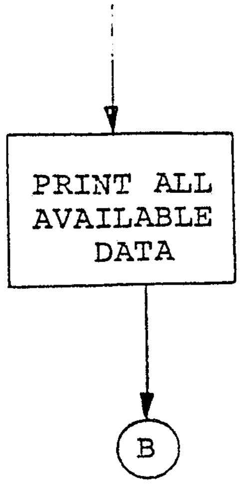

PRINT ALL AVAILABLE DATA
B

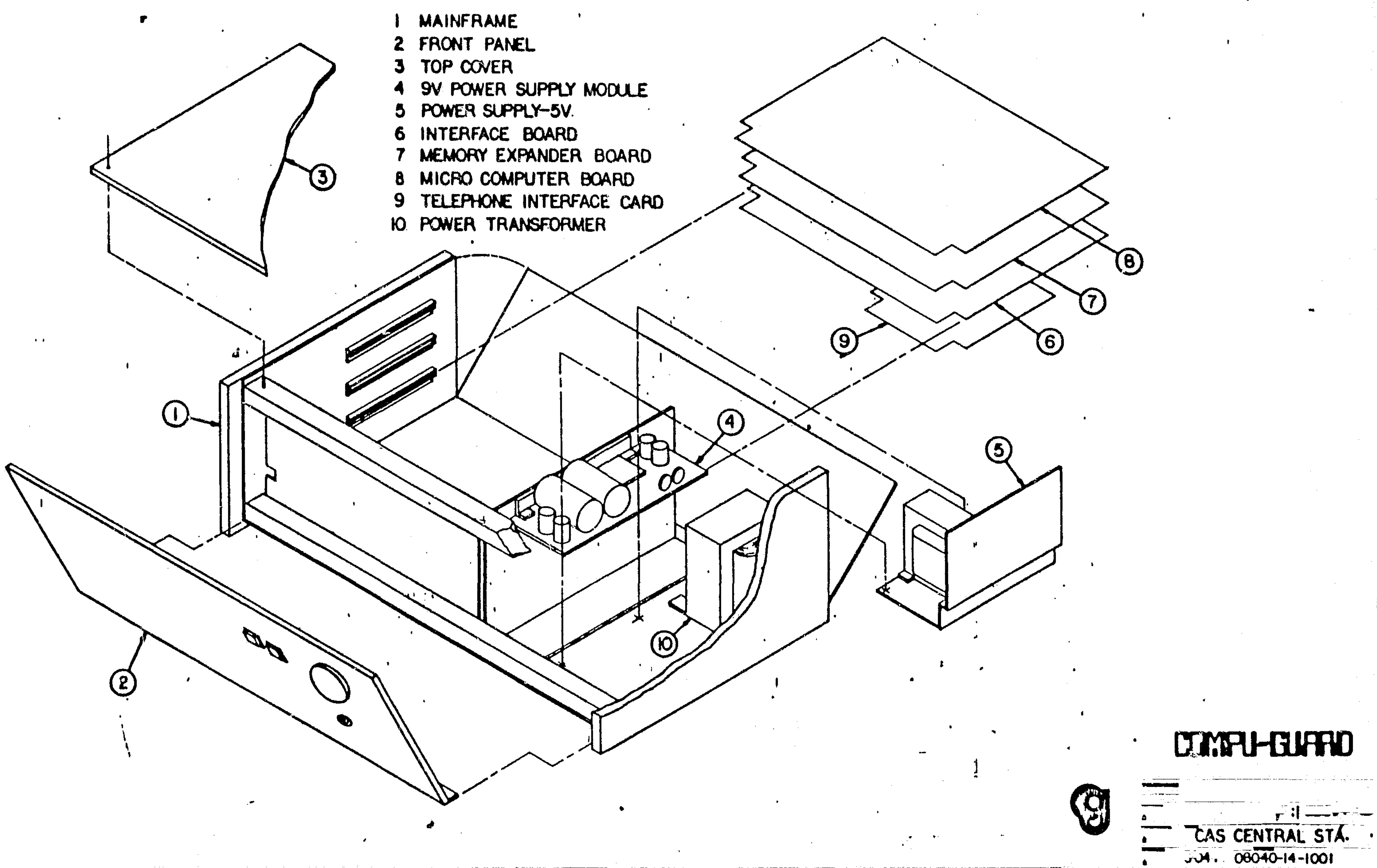


FIGURE IV-15: CENTRAL STATION-CAS

E. Information System Design Procedures

1. System architecture.

Much of the system architecture has been discussed in prior sections of this report. However, the system design embodies several basic architectural concepts.

a. Modularity: The use of component "building blocks" allows the tailoring of systems to best meet the needs of each specific scenario in which the use of CAS is contemplated. The four system components (Actuator, IRR, ERR, Central Station) provide the flexibility required to make the system applicable in a very large range of environmental conditions.

b. Digital communication: The use of digital codes for actuator and location identification enables shorter hardware response time, reduced false alarm rates, and increased transmission reliability.

c. Transmission link economy: The system is designed to make the most cost-effective usage of the necessary transmission links. In particular, the use of power lines between IRR and central station is intended to minimize the cost of system installation, maintenance, and service.

d. Transmission reliability: The use of repeated message transmission, optimized coding and modulation techniques, and sophisticated error detection and correction techniques, is intended to provide a very high degree of transmission reliability. This element of overall system reliability is expected to be far more significant than the hardware reliability (measured in terms of MTBF).

e. Human and environmental factors: The design has been greatly influenced by these factors. For example, the need for an inexpensive, small actuator has been one of the forcing requirements in design -- resulting in an actuator with a wide RF bandwidth and a matching self-scanning RF receiver (in the IRR).

2. Information channel design.

a. The communication link between each pair of components has its own unique problems, and extensive analysis and study had to be conducted prior to selection and design.

The link between the actuator and IRR must be wireless, with a range of 50 ft. and adequate coverage. It was decided to make an RF link that operates in the UHF range between 450MHz and 500 MHz. It was further decided that the RF link should be specified within the limits of Part 15, Sub-part E, of the FCC regulations regarding low power RF communication devices.

The power line link between the IRR and ERR has minimal cost of installation. A separate and extensive study was undertaken to characterize the power line for data transmission. Test results are summarized in Chapter V. This study included the study of the impedance of power lines, power level and signal attentuation, types of noise sources and transmission bit-error rates, signal coupling, signal bridging between different phases of multi-phase power lines, etc.

A dedicated voice-grade telephone line links the ERR to the Central Station. Data transmission using these lines is well characterized and, therefore, no additional study was performed on them.

b. General design considerations. Design philosophy centered around the optimization of reliability and cost and trade-offs were carefully made to attain some major goals, as follows:

- Minimize hardware complexity and components to increase hardware reliability and minimize potential trouble spots.
- Remove complex signal processing as much as possible from Actuators, Internal Receiver-Relays and External Receiver-Relays to minimize complexity and cost.

- Concentrate complex signal processing at the Central Station to fully utilize its capability.
- Minimize losses and errors in information transfer.

c. <u>RF link: Actuator to Internal Receiver-Relay</u>.

(1) <u>Propagation characteristics</u>. The RF link is UHF transmission in the 450 - 500MHz region. Propagation is primarily by line of sight transmission, though there is significant scatter by metallic objects (walls, furniture, etc.) and absorption by lossy materials (body, tress, walls, etc.).

The free space propagation loss can be calculated from equation 5.1:

$$= \left(\frac{P_r}{P_E}\right) = \left(\frac{\ }{4\ \ R}\right)^2 \qquad (5.1)$$

where:

P_r = signal power received by receiver antenna

P_E = effective radiated power from transmitter

λ = wavelength = $\frac{300}{f(MHz)}$ meters

R = distance between transmitter and receiver, meters

For a 460MHz signal at 100 feet (30.5 m) this attentuation amounts to:

$$(460MHz,\ 100\cdot) = 55.4dB \qquad (5.2)$$

In addition to this free space attentuation, other propagation losses are incurred due to body absorption, scattering effects, absorption due to building walls, furniture, etc. Measurements performed by the Aerospace Corporation indicate that additional losses of 20 to 30 dB can be expected for transmission reliability of 90% or greater.

(2) Carrier and information bandwidth. Using FM transmission, the required information bandwidth is less than 200KHz. The bandwidth, B, is given by:

$$B = 2f_m (\beta + 2) \qquad (5.3)$$

where:

f_m = modulating frequency

β = modulator index = $\frac{F}{f_m}$

F = peak frequency deviation

For:

$\beta = 2$, bandwidth = 160KHz, F = 40 KHz

$\beta = 3$, bandwidth = 200KHz, F = 60KHz

In terms of carrier bandwidth, the long term instability of the actuator is within +2 to -8MHz around the carrier center frequency, including effects of detuning due to body proximity (approximately 2MHz). It is necessary, therefore, for the UHF receiver to be able to scan over a range of 10 to 12 MHz and lock onto the actuator UHF signal.

(3) Noise sources. The most significant sources of noise in the 450 to 500 MHz range are urban or man-made, including car ignition, radio and TV receivers and other radio transmitters. The effects of noise sources detrimental to the CAS operation fall into two categories:

- The interfering noise is strong enough to prevent the actuator signal from being received.
- The noise causes false triggering of the receiver.

The nature of the noise that falls into the first category is such that it must be exactly the same frequency as the actuator signal and stronger than the latter (capture ratio effect). The diversity in frequency (i.e., the actuator center frequency can be anywhere within a 10MHz band) minimizes the possibility of such occurrence, except in the extreme case where a very strong transmitter (e.g. a nearby TV transmitter) might overload the front end of the receiver. Under such conditions, the use of trap filters and proper selection of the frequency band will remedy the situation.

The receiver was designed to look for and lock onto an actuator subcarrier of 20kHz. False triggering due to noise is highly improbable, unless the interfering signal also contains a 20 kHz subcarrier.

(4) Data Transmission: The maximum bit rate is fundamentally limited only by the frequency of the subcarrier (20kHz). However, in this case, the speed was determined primarily by the maximum number of messages/bits sent (8 to 16 messages, 32 bits each). A data transmission rate of 500 baud was selected as a compromise between the desired response time (> 8 messages in 1 second) and signal/noise considerations.

The error rate is determined by the type of modulation used (differential phase-shift keying) and carrier-to-noise ratio (C/N) of the received signal.

The error probability of DPSK is given by:

$$P_e = \frac{1}{2} \exp \left[- (C/N)\right]$$

For $P_e = 0.1$ the required (C/N) ratio is 2dB, and this can be set as the lower limit of the 20kHz subcarrier-to-noise ratio. Thus, if the error correction procedures at the central station can accept errors of 1 in 10 (easily attainable), a very poor signal/noise characteristic can be tolerated by the system.

However, if the range of detection is defined to be that range within which the FM receiver operates at or above the threshold level, the carrier/noise is always greater than 22dB (threshold C/N + Noise Improvement Figure of 20dB), giving a design data transmission error probability of better than 10-4 when the actuator is within range.

(5) Range Prediction: The range of the RF link has been defined as the maximum distance between the Actuator

and Internal Receiver-Relay to obtain a signal of sufficient strength to give better than 90% probability of the receiver operating at or above threshold level. Note, that even outside this range there is a finite probability that the receiver will still receive messages with better than 0.1 error probability.

This range is limited by the effective radiated power available from the actuator and the signal propagation environment. The worst case range can be calculated as follows:

The signal power received by the receiver antenna is given by:

$$P_r \text{ (dB)} = \text{ERP (dB)} + \alpha_o \text{(dB)} + \alpha_e + G_r$$

Where:

ERP = transmitter effective radiated power

α_o = free path losses = $\left(\frac{\lambda}{4 \quad R}\right)^2$

α_e = additional losses due to body effect + scattering $\approx$ -20dB.

G_r = Receiver antenna gain (dB)

(6) Design Implications: The above considerations help to set guidelines for the design of the Actuator, and the FM receiver section of the IRR.

Actuator Design

- Transmitter frequency modulation index desirable, β=2
- Approximate ERP required 1mW for field strength of 500μV/m at 100 ft.

FM Receiver Design

- Receiver sensitivity required, -100dBm or better

- Receiver should be able to automatically scan at least over 10MHz range.
- Receiver should lock onto actuator signal with subcarrier of 20kHz and be able to track and follow drift in the actuator center frequency.
- Receiver IF bandwidth required, 160kHz min.

d. <u>Power-Line Link: Internal Receiver-Relay to External Receiver-Relay/Central Station</u>.

(1) <u>Transmission Characteristics</u>. Studies performed on power line transmission indicate that it is possible to use the in-building powerline network as a two-way communication medium for data transmission. The powerline behaves as a poor transmission line with a characteristic impedance ranging from 10 ohms to 200 ohms, depending on type of wiring, load factors, etc. These observations also indicate that the best signal transmission characteristics are at frequencies between 150 kHz to 500 kHz, with a worst case attenuation of 30 to 40dB. The random background noise level is generally less than 1mV rms, though burst noise levels may reach peaks of 100V for very short durations (few milliseconds). Communication across two different windings of a utility transformer can be successfully accomplished at these frequencies by the insertion of suitable high-pass devices, such as capacitor coupling networks.

(2) <u>Channel Bandwidth</u>: The frequency band available for carrier transmission is effectively between 150 to

500 kHz. The information bandwidth for data transmission depends on the bit rate, but is generally less than 5 kHz for rates of better than 300 baud. This makes it possible to utilize nearly 25 channels on a given in-building power line system, assuming channel separation of approximately 10 kHz.

(3) Noise Sources. The noise present in the power line is largely generated within the utility system by various pieces of equipment (loads) connected to the line. These sources of noise include universal AC-DC brush type motors (vacuum cleaners, power drills, etc.) which tend to produce boradband burst noise signals, TV receivers which generate harmonies of the horizontal scanning frequency, SCR dimmers, etc.

(4) Data Transmission. The data transmission characterisitcs on an in-building power line network are governed by the type of modulation used, transmitted signal power, noise level (background) and burst noise sources on the line. Preliminary studies indicate that the use of frequency shift keying allows rates of up to 1200 baud at bit error rates better than 10^{-3}. Error rates above 100 baud increase due to burst type noise, although ahigher through put is obtained at these higher transmission speeds. Below 100 baud, interference from burst noise tends to be less significant than interference from random noise. Error rates of better than 10^{-6} have been achieved at 60 baud.

(5) Design Implications. Based on these considerations, some basic design guidelines were established.

(a) FSK techniques should be used for data transmission, using carrier frequencies between 15 kHz and 500 kHz.

(b) The RF line transmitter in the IRR should be capable of putting a few volts on the line, at a worst case impedence of 5 ohms.

(c) Receivers should have input sensitivities of the order of 1mV, for a signal/noise ratio of better than 20dB assuming worst case attenuation of 40dB.

(d) Data transmission should be at 60 baud synchronized to the 60Hz line frequency to minimize the effect of burst noise that often occurs at the zero corssings of the AC cycle. This choice of speed of data transmission represents a compromise between reliability and modem cost.

e. Telephone Line (Dedicated Voice-Grade Line): External Receiver-Relay to Central Station

(1) Transmission Characteristics. The transmission characteristics of the telephone link have been documented elsewhere.

(2) Bandwidth. The frequency bandwidth of transmission of voice-grade lines is generally limited to between 300 to 3000 Hz. The -10dB attenuation point generally lies around 2500 Hz.

(3) Noise Sources. Generally, noise in the telephone line arises at the telephone exchange station. The sources include: supervisory signals, line cross-talk, channel thermal noise and hum and noise pickup from power lines.

(4) Data Transmission: Industry practice is based on rates of 110 to 300 baud.

(5) Design Implications.

(a) All control and data signalling should be at frequencies between 300 and 3000 Hz.

(b) The data transmission speed of 60 baud, compatible with that of the IRR, represents an acceptable compromise between reliability (for the available bandwidth) and modem cost.

3. Information Protection.

One of the system requirements is to provide protection against message interference, jamming, etc. This is done in several ways.

a. Message Interference: Many Actuators Triggered Simultaneously. The message interference arising from several actuators being triggered simultaneously is minimized by diversity of space, frequency and time. First, the strength of s signals arriving at the IRR depends upon the location of the actuator relative to the receiver. Since the receiver only detects the strongest signal received (capture ratio effect) possible interference between several actuators transmitting at the same time is minimized.

CONTINUED

Secondly, the carrier frequency transmitted by the actuators can lie within a range of approximately 10MHz. Therefore, the probability of two actuators transmitting at exactly the same frequency simultaneously is very small. In any case, the receiver of the IRR continuously scans the spectrum over a 10MHz range, and covers the different frequencies. Since the actuators are likely to be at different frequencies, the receiver is able to examine only one actuator at a time.

Thirdly, each actuator transmits two sets of messages, the second set coming about 35 seconds ± 10% after the first. Thus, even if the first set of messages interferes, the second set is likely to come through because of the different time delay in the actuators.

b. Message Interference: Many Receiver-Relays Active. This type of message interference is minimized by providing each receiver relay with "channel-clear" monitoring circuitry. Should an IRR be transmitting on the power line, this power line channel is considered busy, and an internal inhibit circuit prevents any other IRR from sending messages until the channel is clear and ready for use. In addition, each IRR has an internal random time-delay circuit which is set when the channel is clear. Given a queue of IRR's waiting to use the channel, the one with the shortest time delay seizes the line first, and inhibits the others. This process is repeated until all IRR's have been serviced, the last one having the longest time delay.

c. Power Line Transmission: Burst Noise Protection; If the location code data transmitted on the power line by an IRR is considered garbled or undecipherable by the central station, the central station can request repeated transmission of this data as often as necessary.

d. Error Detection and Correction. The central station software includes a major section which detects errors in incoming data, and performs a bit-by-bit voting to correct this data. The algorithm used for this purpose can correct messages which have a maximum of 50% error, for any given message bit, in repeated transmissions of the message (e.g. up to 2 out of 5 incorrect for any specific message bit, in 5 repeated transmissions of the message).

4. Information Display.

The display of information at the central station should be designed to best meet the needs of the response agent.

a. Visual Display vs. Hard Copy Printout. The central station handles both temporary visual and hard copy printout of the information received at the central station. In all cases, hard copy printout with pertinent information on an alarm is desirable both for immediate response and for documentation. Furthermore, this micro-computer can handle numeric and alphanumeric information which makes the interpretation of the data relatively easy.

b. <u>Data Presentation</u>. To speed up interpretation and dispatch the response agent quickly, all information is printed in English. This includes:

- Date, time
- Location code
- Actuator code

A standard KSR-33 teletype is used for this purpose.

CHAPTER V. TESTING APPROACH AND RESULTS

A. Test Plan

The successful feasibility demonstration of CAS is based on success in testing the system and its components, both in the laboratory and in the two real world scenarios. An extensive test program was therefore anticipated and planned. The highlights of this test plan are presented in this section; details are given in Appendix III.

1. Purpose of Test Plan.

The demonstration of feasibility here is a test of hardware, as distinct from other measures of performance that are related to its impact on crime, the user, the criminal, the response agent, or the environment. This limitation is a result of the small number of components available for test. This hardware test includes two types of conditions: those in the laboratory, and those in two real-world scenarios. The scenario tests indicate the performance of hardware under realistic environmental conditions, from the standpoint of architecture, user interface, and physical and electrical interference/abuse. To this extent, the support of the residents in the scenarios is necessary. Likewise, the development of a positive relationship with the community is necessary so that an effective hardware test and demonstration can be performed. Full details on the test plan are provided in Appendix IV. : the configuration, the test equipment required, the experimental set up , the test procedure, etc.

2. Scope of Test Plan.

a. Introduction: The scope of the test plan in terms of the CAS components and system configuration under test, the parameters of interest to be measured, and the specific choice of test sites, largely follows the development of CAS hardware itself. Thus, simple operational tests of system components, e.g. CAS actuator, CAS internal receiver-relay, etc., lead to progressively more complex system tests with critical analyses of system performance factors and criteria.

The simple component tests were performed during Phase II of the CAS hardware development program, full scale sub-system, and system tests in Phase III.

b. Test Size and Environment.

(1) Laboratory Tests, Small-Scale: This includes two or three actuators, two to five internal receiver-relays, and one central station. This allows a simple demonstration of system operation. These tests include most tests of operational reliability, for each system component and each channel of transmission used.

(2) Laboratory Tests, Large-Scale: Conducted with five actuators, five internal receiver-relays, one external receiver-relay, and one central station. These tests are more extensive, and include measurements related to the message interference.

(3) Scenario Tests, Small-Scale: These were conducted with two to three actuators, two to five internal receiver-relays, and one central station. This allows a simple operational test under a realistic operating environment. These tests investigated optimum locations/installation sites for the internal receiver-relays.

(4) Scenario Tests, Large-Scale: This test with eight to twelve actuators, eight to twelve internal receiver-relays, one external receiver-relay and one central station, represents the full scale feasibility demonstration test. This was planned for Building #5 at Arlington Heights.

3. Generic Tests.

a. System Operation: These tests include: multiple triggering, many actuators; multiple triggering, many receiver-relays; effects on hardware response time (queuing, etc.) and reliability; system performance as a function of changes in the location of internal receiver-relays; system reliability as a function of physical and electrical environment - from the standpoint of MTBF and message-accuracy; human factors tests such as acceptability, ease of use, susceptibility to abuse.

b. Transmission Channel Tests; These include free space range tests; indoor range tests; inter-room UHF communication tests.

c. Noise Tests: These are intended to give information on the performance of the system under different noise environments and for different noise sources.

d. Environmental Tests: The behaviour of the components of the system under the specified range of environmental conditions is observed during these tests.

e. Component Acceptance Tests: The acceptance tests provide the benchmark against which the performance of each component is evaluated, and the compliance of each component with its specifications is determined.

4. Free Space Actuator Range Tests.

The range and coverage of the actuator are two primary parameters that affect the reliability and performance of the entire system. Two series of tests were designed to determine this under different operating conditions.

a. Radiation Pattern Measurements: These tests were planned to test and measure the pattern of radiation from the actuator under conditions approximating free space measurements.

b. Tests at 50 Feet: These were designed to provide a quantitative estimate of transmission reliability at a range of 50 feet for different irregular orientations of the user. These measurements were planned for body rotation in steps of 45° about an axis perpendicular to the ground. Both sets of tests were planned for four different positions of the actuator relative to the body.

5. Actuator Indoor Range Tests.

These were designed to measure reliability of transmission of the actuator in a room or apartment of interest. The range was 25 feet, with the following variables of interest: position of the actuator relative to body; body position relative to axis of IRR; body rotation relative to IRR.

6. <u>Actuator Inter-Room UHF Communication Tests</u>.

The primary function of this test is to determine, in a very general and very limited sense, the range of the actuator in the presence of physical boundaries such as walls, floor, ceiling, etc. This range is affected by a large number of factors related to the physical structure that can cause attenuation, multipath scattering, nulls, etc. Since most of these factors are difficult ~~or impossible~~ to quantify, the purpose of these tests is merely to get an empirical picture of the general effects of these factors on range.

These tests are conducted for the four different positions of the actuator relative to the body, in different rooms, different apartments, and different buildings in both field scenarios.

7. <u>Multiple Actuator Triggering Tests</u>.

The CAS information system has been designed to minimize the possibility of message interference due to the multiple triggering of actuators. These tests are intended to determine the effects of the simultaneous triggering by several actuators ~~with~~ of one internal receiver-relay. The tests are conducted, for only one position of the body relative to the IRR. The primary test parameter here is the relative distances of the actuators with reference to IRR.

Each actuator transmits two sets of messages, spaced about 30 seconds apart. This test is expected to give information on the reliability of message transmission for multiple, simultaneous actuation, and on the average system, response time of the hardware for the first and second sets of messages.

8. Multiple IRR Triggering Tests.

The IRR's have been designed with internal random-delay circuits to allow the queuing of messages, in case of multiple IRR triggering. These tests are intended to determine the proper operation of the queuing mechanism, and to measure average queuing delays for multiple IRR triggering. The tests are conducted with only one actuator, with two to four IRR's within range of the actuator.

9. Environmental Tests.

These are tests to determine the operational characteristics of each component of the system under various environmental conditions.

a. Actuator.

(1) Testing Parameters

Temperature: $50^{\circ}F - 122^{\circ}F$

Humidity: 20%, 50%, 90%

Shock: drop test, from 3 feet onto a hard floor

Aging: minimum 8 hr burn in at each temperature, long term drift.

(2) Measured Parameters

Frequencies: RF, 20kHz subcarrier, 500 Hz clock

Timing: "On" time, cycle time/"off" time

ERP or field strength at 10 feet

Memory retention

Expected battery life time under continuous actuation.

b. IRR

(1) Testing Parameters

Temperature: $50^{\circ}F$ - $122^{\circ}F$

Humidity: 20%, 50%, 90%

Shock: Vibration test

Aging: Burn-in for minimum of 8 hrs at each temperature, minimum 24 hrs. total time.

(2) Measured Parameters

Center frequency

Scan bandwidth

Scan time

IF bandwidth

Sensitivity

Output voltage onto power line (measured into 50 ohms)

Buffer memory functionality

Command circuits functionality

c. External Receiver-Relay

(1) Testing Parameters

Temperature: $50^{o}F$ - $122^{o}F$

Humidity: 20%, 50%, 90%

Shock: Vibration test

Aging: Burn-in for minimum of 8 hrs., at each temperature, 24 hrs. minimum total.

Power line voltage: 80v - 130v

(2) Measured Parameters

RF input sensitivity

RF input locking range

RF output frequency

RF output power/voltage level under load

Audio input sensitivity (2700Hz)

Audio output levels (900Hz, 1500Hz)

Command signal sensitivity (400Hz, 600Hz)

d. Central Station

(1) Testing Parameters

Temperature: $50^{o}F$ - $104^{o}F$

Humidity: 20%, 50%, 90%

Power line voltage: 80v - 130v

(2) Measured Parameters

Voltage levels at input interface

Memory dump listings

Control frequencies

10. Noise Tests. These test the performance of the system in the presence of noise sounds on the power-line. These sources include most types of electrical appliances and equipment.

11. Recording of Test Data. All test data is recorded in two different ways. A test log is maintained with a record of all test data. Secondly, a hardcopy printout from the central station is available for each test. This printout is retained and correlated with the test log.

In addition to the usual printout of data, time, location code, and actuator code, the central station provides a memory dump if required. This dump can be initiated at the teletype keyboard of the central station. Such a dump listing is usually generated each time the system fails to perform satisfactorily, to give an insight into the data received by the central station.

B. Laboratory Tests

These tests of the system and its components were conducted in the lab to characterize basic hardware performance and to identify any serious design weaknesses or limitations.

1. Purpose and Scope

The lab tests were conducted to determine the operating characteristics of the CAS components under controlled conditions, as summarized below.

a. Actuator and UHF Link:

- Frequency of transmitter under various conditions
- Effective radiated power
- Radiation pattern under various body positions

b. IRR:

- UHF receiver input sensitivity
- Capture range (carrier bandwidth)
- Powerline output voltage
- Power-line command receiver, sensitivity and response
- Power-line channel monitor receiver (channel busy) sensitivity

c. Power-line Link: Data transmission error rates at various baud rates and noise level.

d. ERR:

- Power-line input sensitivity

- Power-line command signal level
- Telephone line signal output level
- Telephone line command signal input sensitivity

e. Central Station:

- Telephone input sensitivity
- Telephone carrier and command output level
- Telephone line supervision

f. Systems Test:

- Free Space Range Test
- Indoor Range Test
- Multiple actuator triggering test
- Muliple IRR triggering Test
- Central Station error correction performance test

2. Implementation of Tests

The test procedures are now given in brief:

a. Actuator: Actuator carrier transmission frequency. This was determined by means of a spectrum analyzer under the following conditions:

. Worn on the left wrist, first message (during actuations, right hand removed)

. Worn on left wrist, second message (right hand removed).

. Worn on left wrist, second message with right hand over actuator without touching it.

(1) Radiation Pattern (Free space): The radiation pattern at 50 feet was determined using a field strength meter equipped with a half-wave dipole antenna. The actuator was worn on the left arm at various body positions:

Position 1 - The arm was held against the body at chest level with the actuator facing upward.

Position 2 - The arm was held against the body at chest level with the actuator facing outward from the body.

Position 3 - The arm was held away from the body at arm's length at chest height with the actuator facing upward.

Position 4 - The arm was held away from the body at arm's length at chest height with the actuator facing horizontally away from the body.

The person holding the actuator then rotated through 360^0 with respect to the antenna and measurements were taken at 30^0 intervals. Slight drifts in the actuator frequency during the measurements were compensated by retuning the field strength meter for maximum signal. The readings were taken and then the maximum signal strength at each distance was taken as the 0db point and the rest of the measurements were expressed in terms of that maximum signal strength. The db readings were then plotted on polar paper.

(2) ERP: ERP was calculated from the above measurements.

b. IRR

(1) Receiver Input Sensitivity: This was measured by feeding UHF-FM carrier modulated by a 20kHz signal (ΔF= 50kHz) from a signal generator with calibrated output. The signal level was slowly increased until a lock was obtained. The signal level at this point is taken as the input sensitivity.

(2) Capture Range: To measure the capture range, a FM signal of 20dB higher than the sensivity level was fed into the receiver input. The frequency was varied until a lock was obtained, approaching both from the lower and the upper end. These frequencies are the lower and upper limits of the capture range.

(3) Power-line Output Level: This was measured by means of a wave analyzer connected through a coupler to the power line at the IRR power plug.

(4) Power-line Command Reciever Input Sensitivity:: A 240 Khz signal modulated by command signals was fed to the power line by means of a coupler. A wave analyzer was used to monitor the power line signal level. The command signals were generated by a command control simulator which produced 200 Hz, 300 Hz, and 250 Hz FSKeyed

($\pm$ 50 Hz) at 10Hz rate. For each command, the FM signal was slowly increased until the IRR responded to the command. Proper responses were verified for each command signal.

(5) Power-line Channel Monitor Receiver Sensitivity: A 350kHz signal frequency modulated by 60Hz was fed to the powerline at the IRR power terminal. The IRR was triggered and the signal output was slowly decreased until the transmitter was activated. After resetting the IRR this signal level was increased back slowly while triggering the IRR until the transmitter was inhibited. This level, measured by a wave analyzer, was taken as the inhibit sensitivity.

c. Power-line Link Data Transmission

Data transmission measurements were conducted at the test site. Identical circuits to those used in the IRR and the ERR were used in the modem units. Pseudo random bit patterns were used in the tests with baud rates of up to 2400. The effect of wide band noise and capacitive charge/discharge transients on the power line were studied.

d. ERR

(1) Powerline Input Sensitivity: This was measured in the same way as the IRR command receiver signal sensitivity, using the message detect signal as indication of threshold point.

(2) Power-line Command Signal Level: Measured in the same manner as for the IRR power line output voltage.

(3) Telephone Line Signal Output Level: Measured using an audio frequency wave analyzer across a 600 ohm load.

(4) Telephone Line Command Signal Input Sensitivity: A 600 ohm "T" attenuator pad was connected across the ERR telephone line terminal and a telephone line command simulator was used to generate the command signals: 400 Hz, 600 Hz and 500 Hz FS Keyed ($\pm$ 100 Hz) at 10 Hz rate. The ERR power plug was connected together with an IRR to the power line. After triggering the IRR each command signal was slowly increased until a command response was indicated at the IRR. The command signal level at the telephone terminals was measured at this point with an AF wave analyzer and taken to be the command input sensitivity.

e. Central Station

(1) Telephone Input Sensitivity: This was measured in the same manner as for the ERR command sensitivity using a 2700 Hz signal and the "line active" output as threshold indication.

(2) Telephone Carrier and Command Output Levels: Measured in the same manner as for the ERR telephone signal output level.

(3) Telephone Line Supervision Test: After the Central Station was initialized the telephone line supervision test was conducted by disconnecting either the ERR or the Central Station from the telephone line. Proper operation should result in printing a message of the type "BUILDING XY NONACTIVE".

f Systems Test

(1) Free Space Range Test and Indoor Range Test: These conducted at 30, 40 and 50 feet outdoors and indoors respectively. Positions 1 and 2 were used at various body angles with 90^0 incremats.

(2) Central Station Error Correction Performance: During this test a special dump routine was incorporated in the software which enabled the memory locations containing the message bits received (5 messages total) to be printed out for analysis. Correlation between the bit patterns and code printouts was performed to measure the performance of the error correction procedure.

(3) Multiple Actuator Triggering Test: This was performed using the same procedure as indicated in the Systems Test Plan, Appendix III.

(4) Test Results: Results of the lab tests are now summarized.

(a) Actuator and UHF Link

i. Transmitter Carrier Frequency Under Various Conditions (MHz).

Actuator #	1st Message	2nd Message	2nd Message, hand on Actuator
899317	460	462	458
888888	459	461	457
152317	460	461	456
211917	461	462	456

ii. Radiation pattern and ERP measurements

Figure V-1 shows a typical ERP and radiation pattern obtained from free space measurements at 50 feet.

(b) IRR:

The following are typical of test measurements to characterize the IRR;

UHF receiver input sensitivity 85 dBm

(NOTE: The sensitivity was originally - 100 dBm but latter reduced to -85 dBm to limit range to 50 feet)

Capture Range 12 MHz

Powerline output voltage 1V RMS

Powerline command receiver sensitivity 4mV RMS

Powerline channel monitor receiver sensitivity 0.7 mV RMS

(c) Power-line Link:

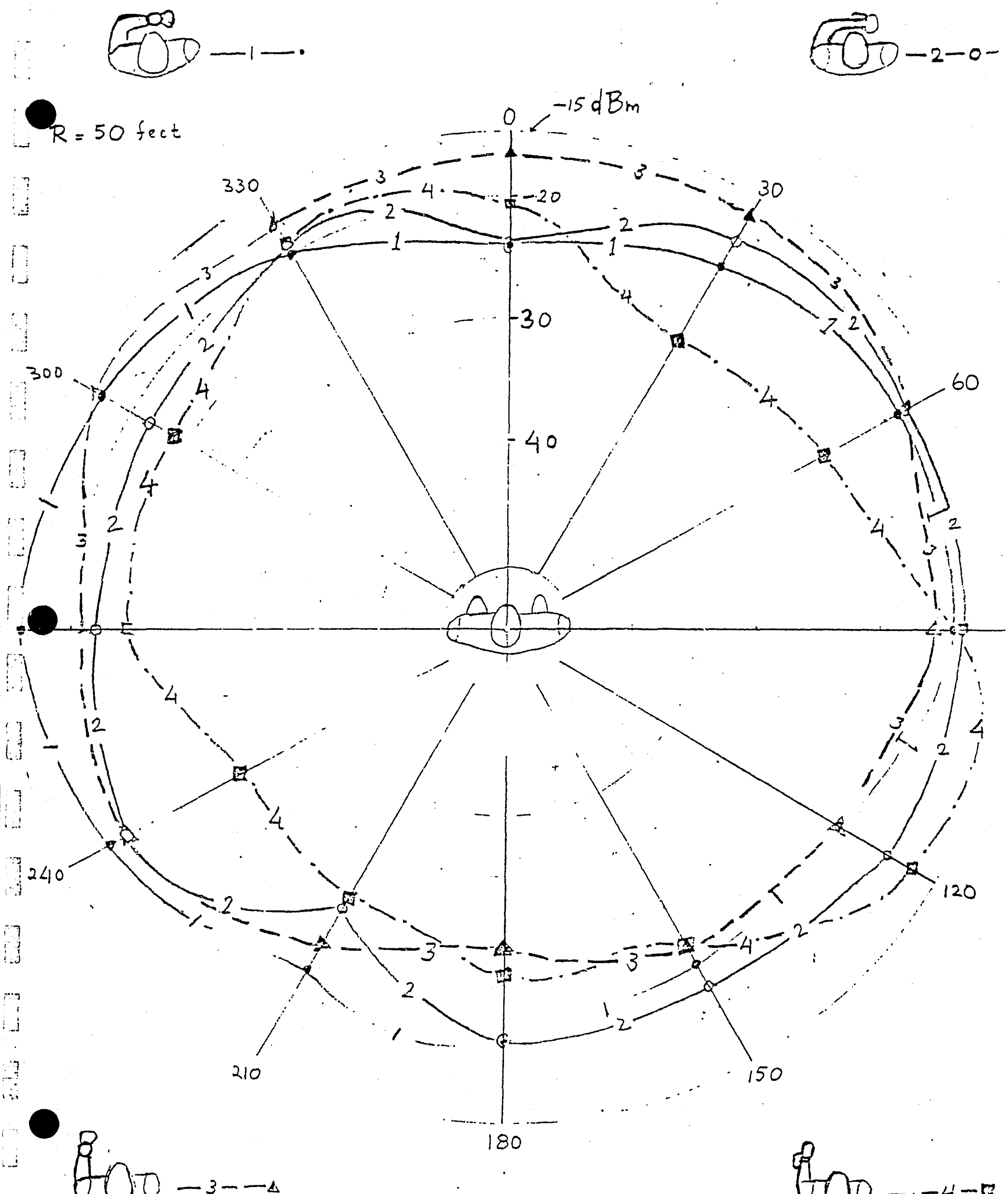
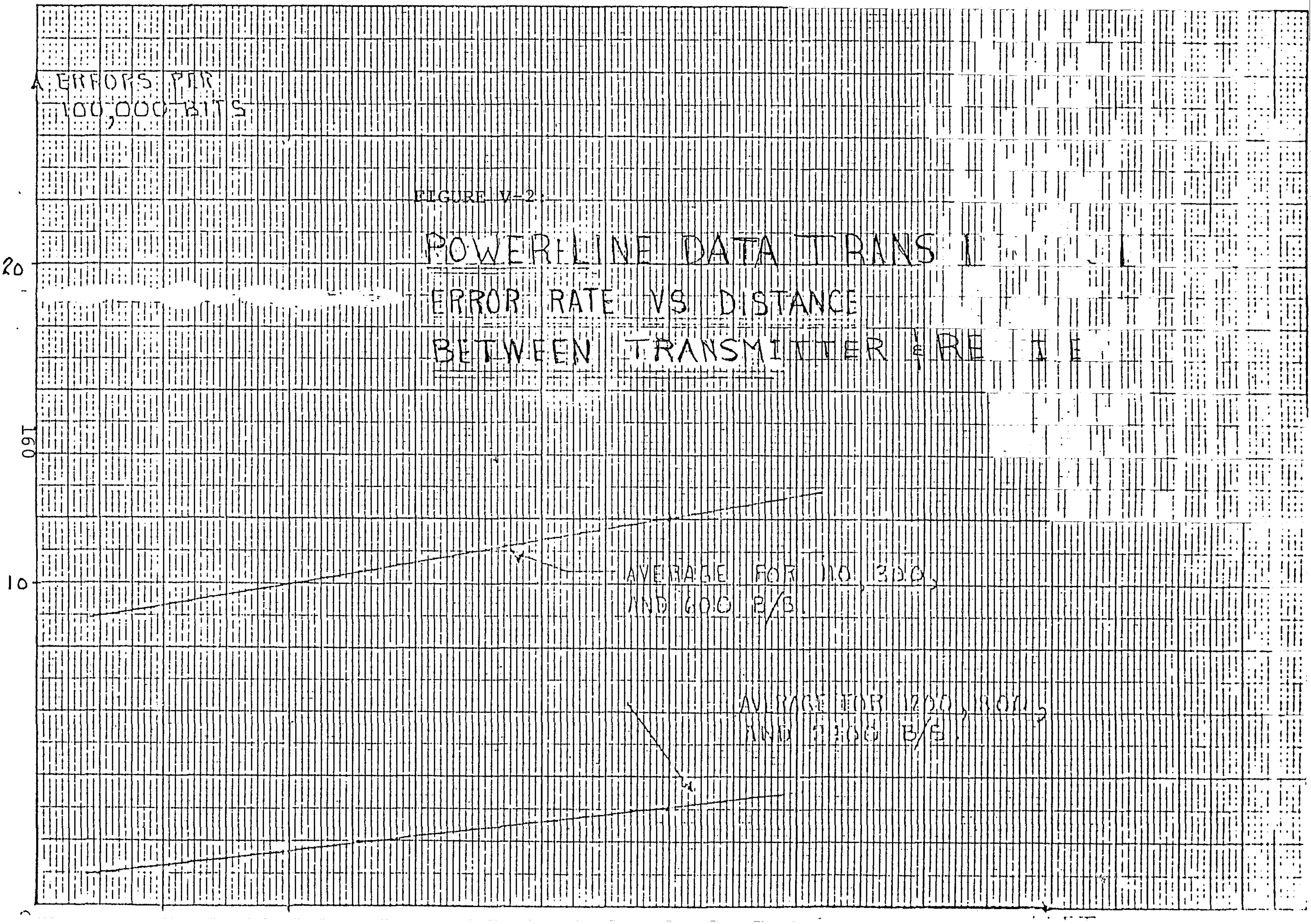


FIGURE V-1: FREE SPACE RADIATION MEASUREMENTS

Tests were performed to measure the error-rate for data transmission at different speeds. Even though these tests were conducted at Arlington Heights, this is considered to be a lab test. Typical results are shown in Figure V-2. This shows that the throughput actually improves as the speed of data transmission is increased.

(d) Other Tests:

A number of other transmission tests were performed similar to those conducted in the two real-world scenarios, as discussed in Section C. below. Since the lab tests were much more limited in scope, the results of the scenario tests are more meaningful.


ERRORS PER
100,000 BITS
FIGURE V-2:
POWER-LINE DATA TRANS
ERROR RATE VS DISTANCE
BETWEEN TRANSMITTER & RE
20
10
AVERAGE FOR 110, 300,
AND 600 B/S.
AVERAGE FOR
B/S.

C. Scenario Tests

Over a period of several weeks, extensive testing was conducted at Arlington Heights and at Amberson Gardens. Several types of tests were conducted, with variables including the following: type of room/apartment, location of IRR, body position and angle relative to actuator, multiple and simultaneous triggerings, etc. A summary of these tests is given in Table V-1.

1. <u>The Arlington Heights Public Housing Complex</u>.

Arlington Heights is a 31 building complex of public housing, covering a total area of 82.5 acres. It is accessed from Syrian Street by means of Arlington Avenue, Spring Street, and Zaruba Street, located on Pittsburgh's Southside. The Parking facilities for the buildings are situated in front of each building. The complex is serviced by one central management office adjacent to a community center. This and designated play areas provide the only recreation facilities provided by the complex. The layout of the complex is shown in Figure V-3.

The buildings are 32 years old and in very poor repair. The wiring and telephone lines are in bad condition. Each building has three floors and is serviced by either three or four entrances which allow access to six apartments a piece with two per floor. There areno elevators in any of the buildings. The apartments themselves range in size from the one bedroom type to the four bedroom types, and each has a living

TABLE V-1: SUMMARY OF SCENARIO TESTS

Scenario	Configuration	TYPE OF TEST	TEST PARAMETERS	TEST RESULT
SMALL SCALE SCENARIO	SINGLE IRR SINGLE ACTUATOR	Indoor Range	Signal Strength,	Signal Above Threshold At Any Location in an Apartment. Frequency 462,4 MHz
		Inter-Room UHF Communication	Frequency	
		Response Time	Time from Actuation to Start of Printout	5 secs. (typical) 8 secs (worst-case)
		Message Accuracy	% Messages (Actuator Code) % Messages (No Actuator Code) % No Messages	
	SINGLE ACTUATOR MULTIPLE IRR	Message Accuracy		
		Queuing	Number of Messages	Queuing worked as per specification
	MULTIPLE ACTUATOR MULTIPLE IRR	Queuing	Time of Arrival of Messages	See Response Time Histograms
		One code Both codes Neither Code	% Messages (One ID Code) % Messages (Two ID Codes) % No Messages (ID Code)	60% 35% 5%
LARGE SCALE SCENARIO		User Response	Attitude	Favorable
		Guard Response Time	Time From Reception of Alarm To Arrival	1 min
		Message Accuracy, Transmission reliability	% Messages (Actuator ID Code) % Messages (No ID Code) % No Messages	93.1% 100% 0%

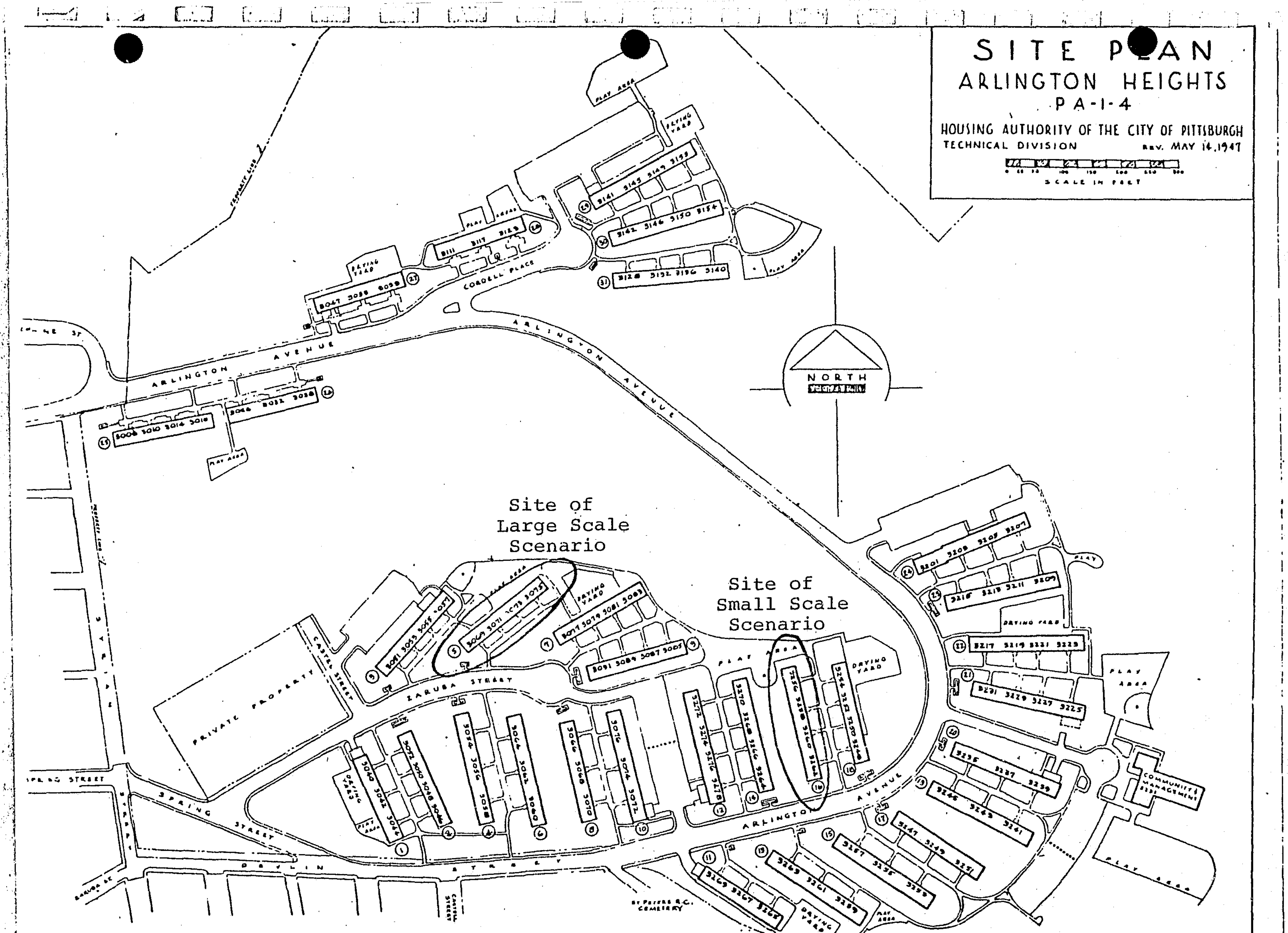


FIGURE V-3: <u>SITE PLAN OF ARLINGTON HEIGHTS</u>

area and a kitchen. The rent for families on public assistance varies from $32 to $56 per month, depending on the number of of rooms. Working families pay $90-99 per month with the number of rooms making little difference in rent.

Arlington Heights is in census tract 1604. According to the Annual Report of Major Crimes by Census Tract, in 1972, there were no murders, two rapes, fourteen robberies, sixty-one assaults, twenty-one burglaries, and twenty-five cases of larceny. These figures are derived from the reports of the Pittsburgh Police and include only clear cut cases. The actual crime rate is estimated to be very much higher. Arlington is considered to be in a high crime rate district and the population density is greater than average for the city.

Arlington Heights houses approximately 2,000 persons. About 85% of the families are on public assistance and only 15% are working. The average income is $6,000 per annum for the working families; only three families earn more than $8,000 per annum. 85% of the occupants are black. In terms of age, about 8% are elderly, and 72% are under 21. There are also many disabled and handicapped persons residing in this complex.

2. Amberson Apartments Community.

The Amberson Apartment Community is a development of six high-rise buildings consisting of Amberson Gardens (4 buildings) Amberson Towers, and Amberson Plaza, located on 8½ acres in the Shadyside section of Pittsburgh. This grouping is easily accessed by raod from Moorewood Avenue, and has a private entrance on Bayard Road. There is a centrally located management office in the Towers and a private guard station.

The Plaza has 98 one bedroom apartments, and 41 bedroom and den units. Each apartment has a kitchen and living area. Each apartment is equipped with appliances, air conditioner, carpeting, and curtains. The floor plans and general layout are shown in Figure V-4. The Gardens are about 20 years old, the Towers 5 years old, and the Plaza has just been occupied. All buildings have elevators and staisfactory physical plant facilities, telephone and power lines. For all three, parking is available in enclosed garages and a swimming club is offered for a fee to any occupant of the Community.

The Amberson Apartment Community is located in 0701 Census Tract, and according to the Annual Report of Major Crimes by Census Tract, in 1972, there were no murders, 2 rapes, 24 robberies, 4 assaults, 51 burglaries, and 58 cases of larceny. Amberson is considered to be located in a "good" area of Pittsburgh.

The occupants of this community are generally in the middle to upper income brackets, mainly white. There are a number of elderly tenants with different kinds of physical and mental disabilities.

1. Amberson Towers
2. Amberson Gardens
3. Amberson Plaza
4. Winchester Thurston School
5. Shadyside Presbyterian Church
6. Shadyside Shopping District
7. Unitarian Church
8. Rodef Shalom Temple
9. Byzantine Church
10. Carnegie-Mellon University
11. Carnegie Library & Music Hall
12. Christian Scientist Church
13. Episcopal Church of the Ascension
14. St. Paul's Cathedral
15. Webster Hall
16. Schenley Park
17. Kroger
18. Pitt Stadium
19. Mellon & Pittsburgh National Banks
20. Shopping
21. Syria Mosque
22. Cathedral of Learning
23. St. James Lutheran Church
24. Mellon Institute
25. Pittsburgh Medical Center
26. Campus—University of Pgh.
27. Shadyside Hospital

Amberson Apartment Community

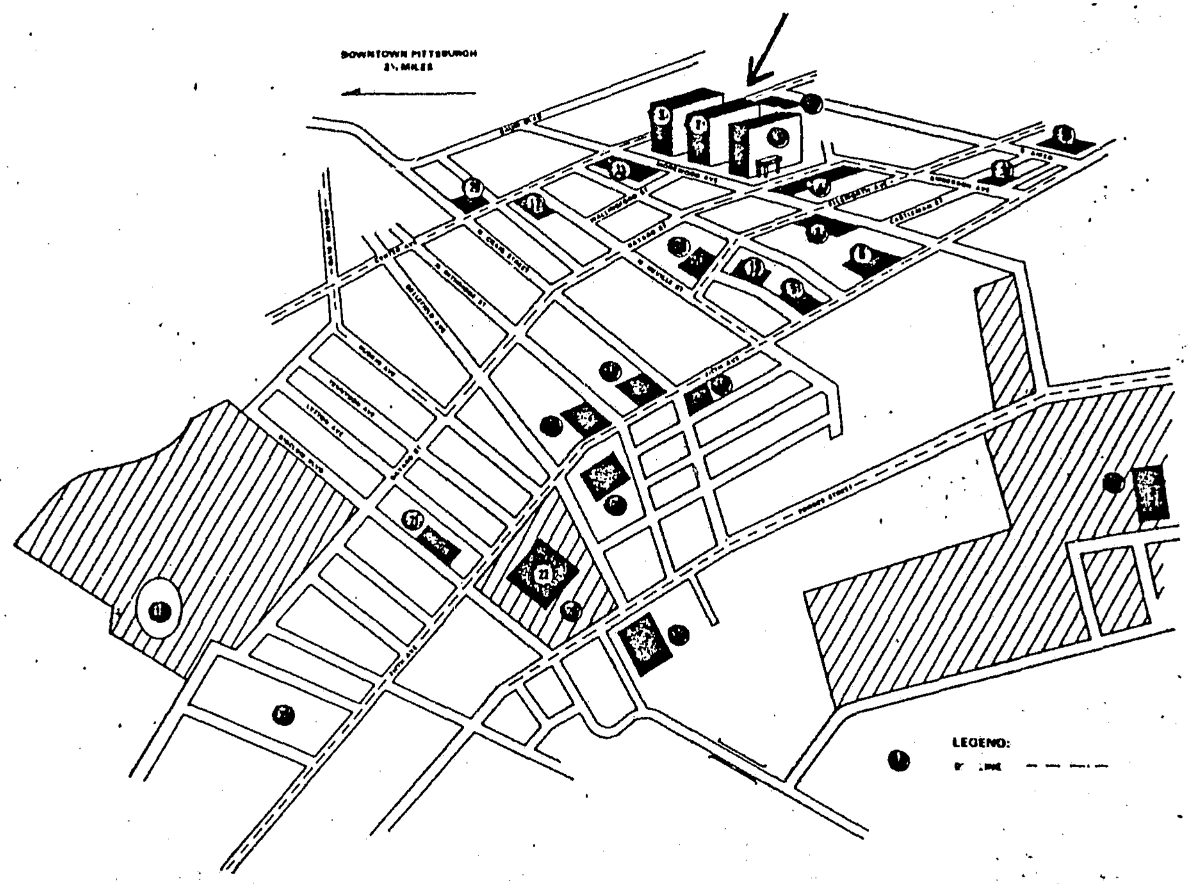


FIGURE V-4: <u>MAP OF AMBERSON APARTMENT COMPLEX & SURROUNDINGS</u>
(Arrow Indicates Test Site)

3. <u>Purpose and Scope of Tests</u>.

a. <u>Purpose of Scenario Tests</u>. The purpose of the scenario tests is to provide a test of system hardware under actual operating conditions, as well as an indication of the effectiveness of the system when used by actual users and response agents. The tests are designed to characterize actuation in terms of response time, effective range, body position and angle, and the physical environment. Also tested is the operational effectiveness of interference-prevention and queuing systems in the hardware, as well as error-correction systems in the central station software. These tests were conducted in accordance with the test plan, Appendix III.

b. <u>Scope of Scenario Tests</u>.

(1) Scenario Tests, Small Scale. These tests are conducted with two actuators, two IRR's and one central station. The tests allow an evaluation of hardware performance in a realistic operating environment. Response time, indoor range, inter-room communication, multiple actuation, and multiple IRR triggering tests provide an indication of the overall effectiveness of the hardware system.

Testing was done at two sites, 3252 Zaruba Street, in Building 18 of Arlington Heights, and the Gardens Apartments of Amberson Gardens. The Arlington test site offered six vacant apartments on three floors of a building section. The Amberson test site consisted of apartments 620 (6th floor) and

910 (9th floor). A series of actuations at Amberson was also conducted from the apartments of cooperating residents, to enable testing from locations above and below the apartment containing the IRR.

(2) Scenario Test, Large Scale. These tests were conducted with seven actuators, four IRR's, one ERR, and one Central Station. Tests were conducted in Building 5 of Arlington Heights, due to the large number of senior citizens in this building. An additional four IRR's were available for this test, but four IRR's were found to be optional for the building. Four guards were hired from Globe security to minitor the Central Station twenty-four hours a day. Three Compu-guard engineers were placed on call in the event of a hardware difficulty. Nine residents of Building 5 cooperated in this scenario test.

The Arlington test site was chosen for this scenario because the need of a system like CAS is very evident in this area. In addition to the threat of crime, elderly residents living alone are faced with the danger of a medical emergency which would prevent them from reaching a phone. Every year one or more of the residents is found dead in their apartments, many of whom could have been helped if aid was more easily available. The willingness of residents to cooperate in this scenario allows an appraisal of the human factors involved in the implementation of CAS.

4. Implementation of Tests

a. Small-Scale Scenario Tests. Experimenters selected locations within a test area from which to conduct actuations. The locations were marked on an apartment floor plan, as were the locations of the IRR's. Floor plans for the Arlington and Amberson sites are shown in Figure V-5 through V-13.

The Central Station, consisting of the micro-computer, teletype, and ERR was set up. An experimenter at the Central Station called for each test run from the expierimenter wearing the actuator, while a third experimenter recorded data in the test log. Sample data sheets are shown in Figures V-14 and V-15 The first data sheet, used for indoor range and inter-room UHF communication tests, was used for tests 001-145 at Arlington; the second data sheet was used for tests 146-1111 at Arlington and Amberson.

(1) Single Actuator, Single IRR Tests.

(a) Indoor Range Tests. The purpose of these tests was to determine the range and pattern of actuation within a room. In addition to the Central Station, IRR, and actuator, an IRR wired as a scanning analyzer connected to an oscilloscope was used to measure field strength. An IRR was mounted on the wall near the electrical outlet. The experimenter triggered an actuator from a variety of locations in the room, using various angles with respect to the IRR from each of the four positions, P1, P2, P3 and P4 (see Test Plan, Appendix III for details). Another experimenter recorded data in the test log: the signal strength, frequency, distance between actuator and IRR, position angle θ body position, and body angle $\emptyset$. The messages printed by the

359	360	365	366	371	372	377	378
357	358	363	364	369	370	375	376
355	356	361	362	367	368	373	374
3248		3250		3252		3254	

FIGURE V-5: KEY TO APARTMENT NUMBERS, ARLINGTON HEIGHTS BUILDING #18
(Front view, building has 3 floors)

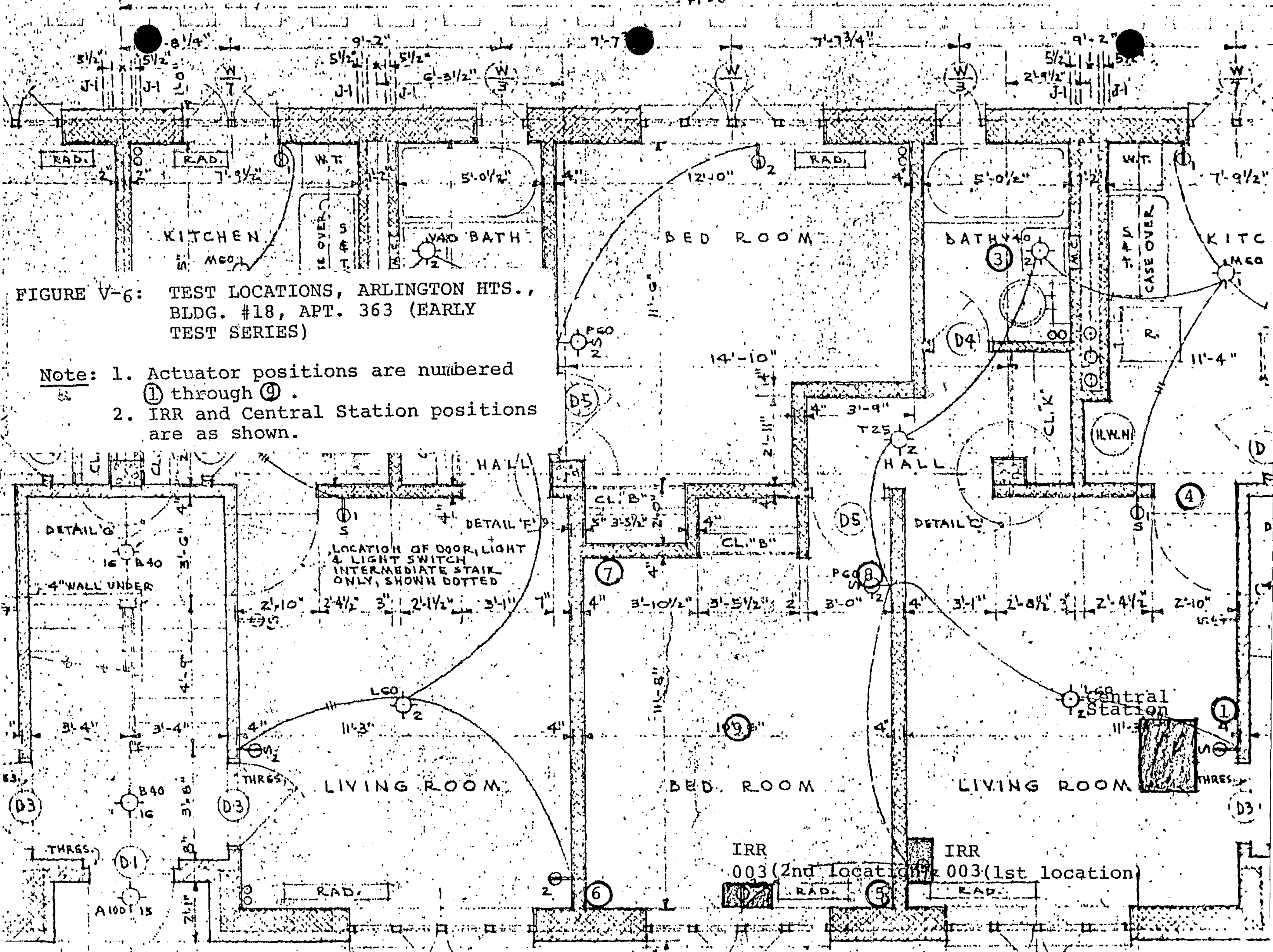


FIGURE V-6: TEST LOCATIONS, ARLINGTON HTS., BLDG. #18, APT. 363 (EARLY TEST SERIES)

Note: 1. Actuator positions are numbered ① through ⑨.
2. IRR and Central Station positions are as shown.

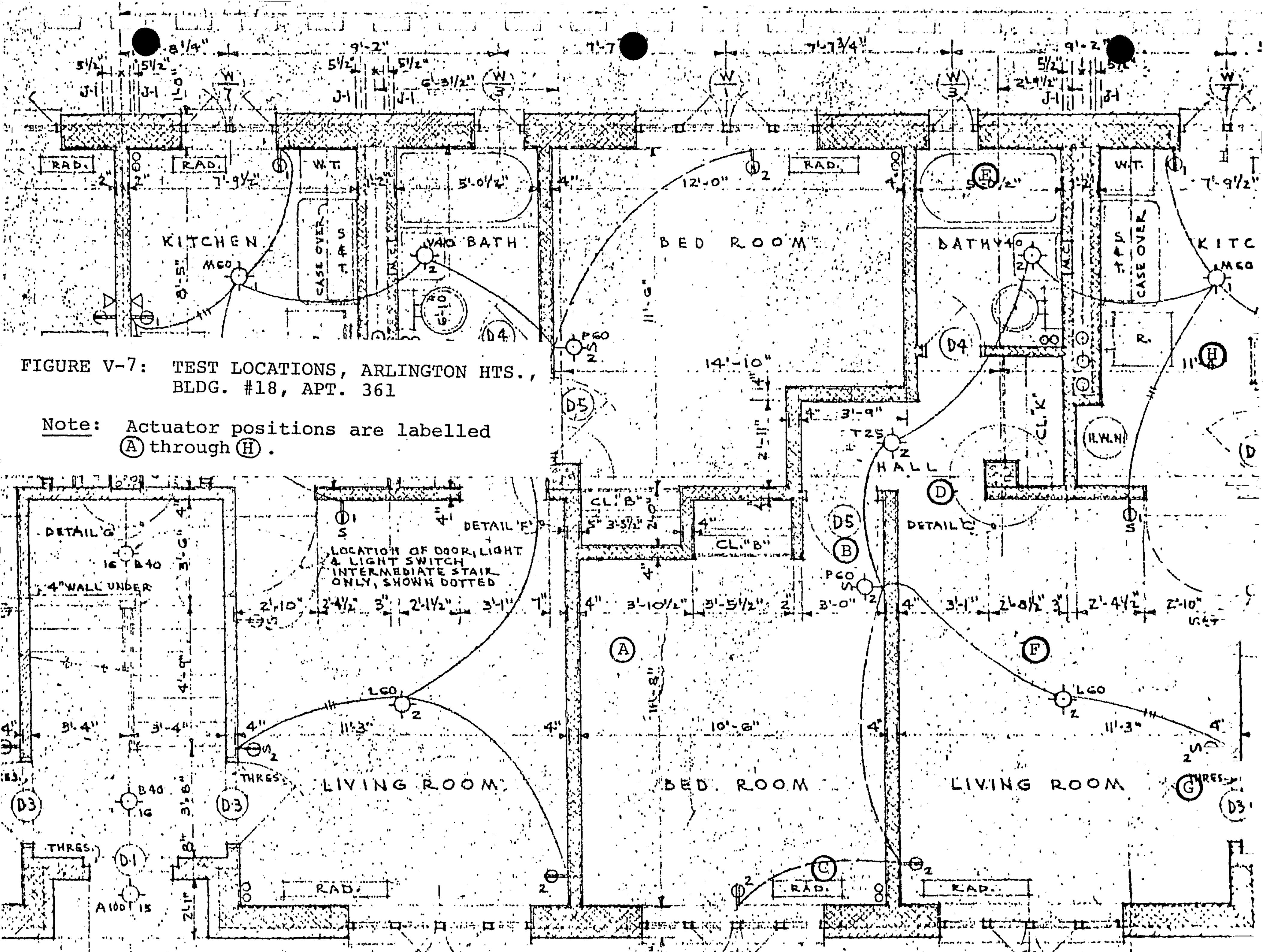


FIGURE V-7: TEST LOCATIONS, ARLINGTON HTS., BLDG. #18, APT. 361

Note: Actuator positions are labelled (A) through (H).

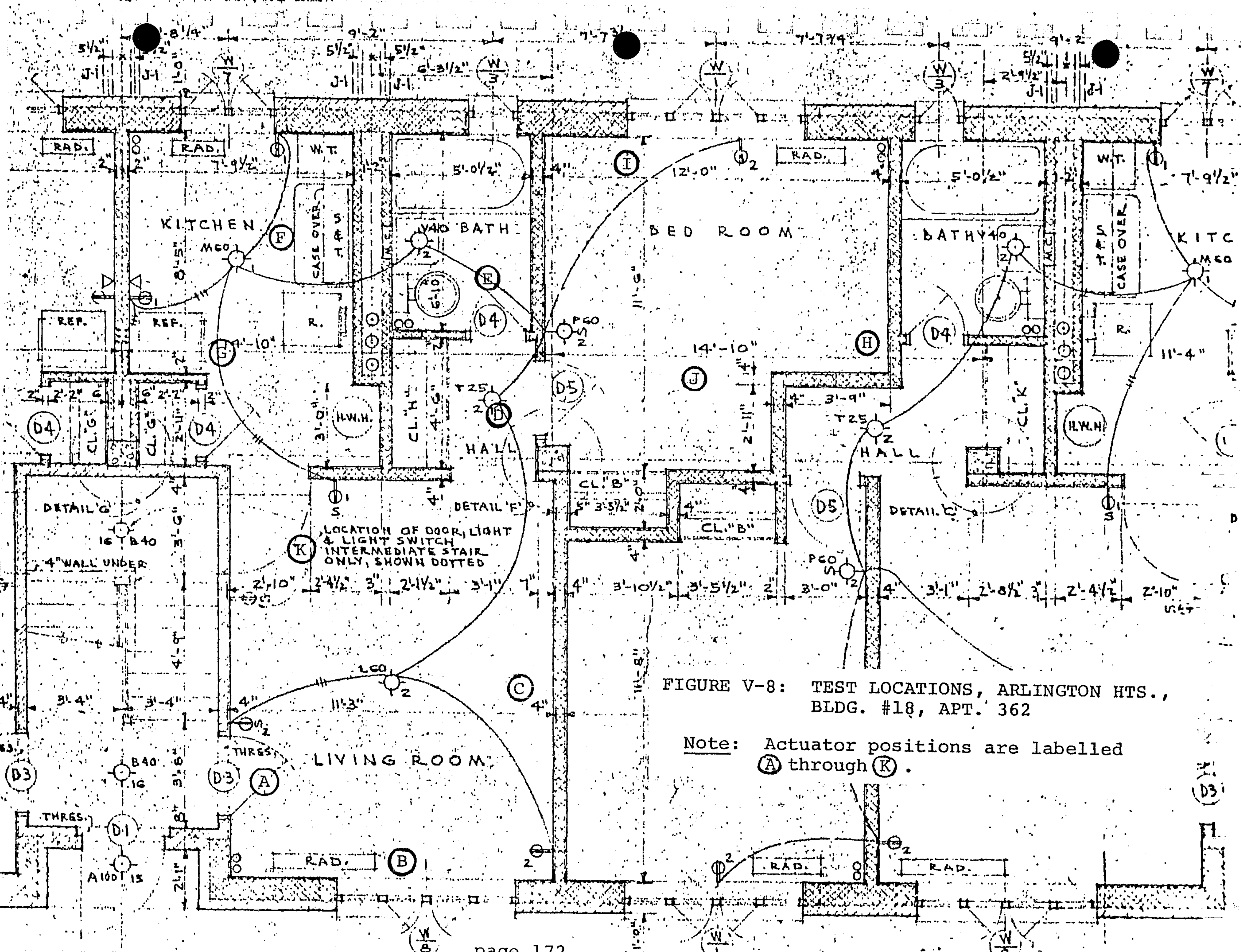


FIGURE V-8: TEST LOCATIONS, ARLINGTON HTS., BLDG. #18, APT. 362

Note: Actuator positions are labelled (A) through (K).

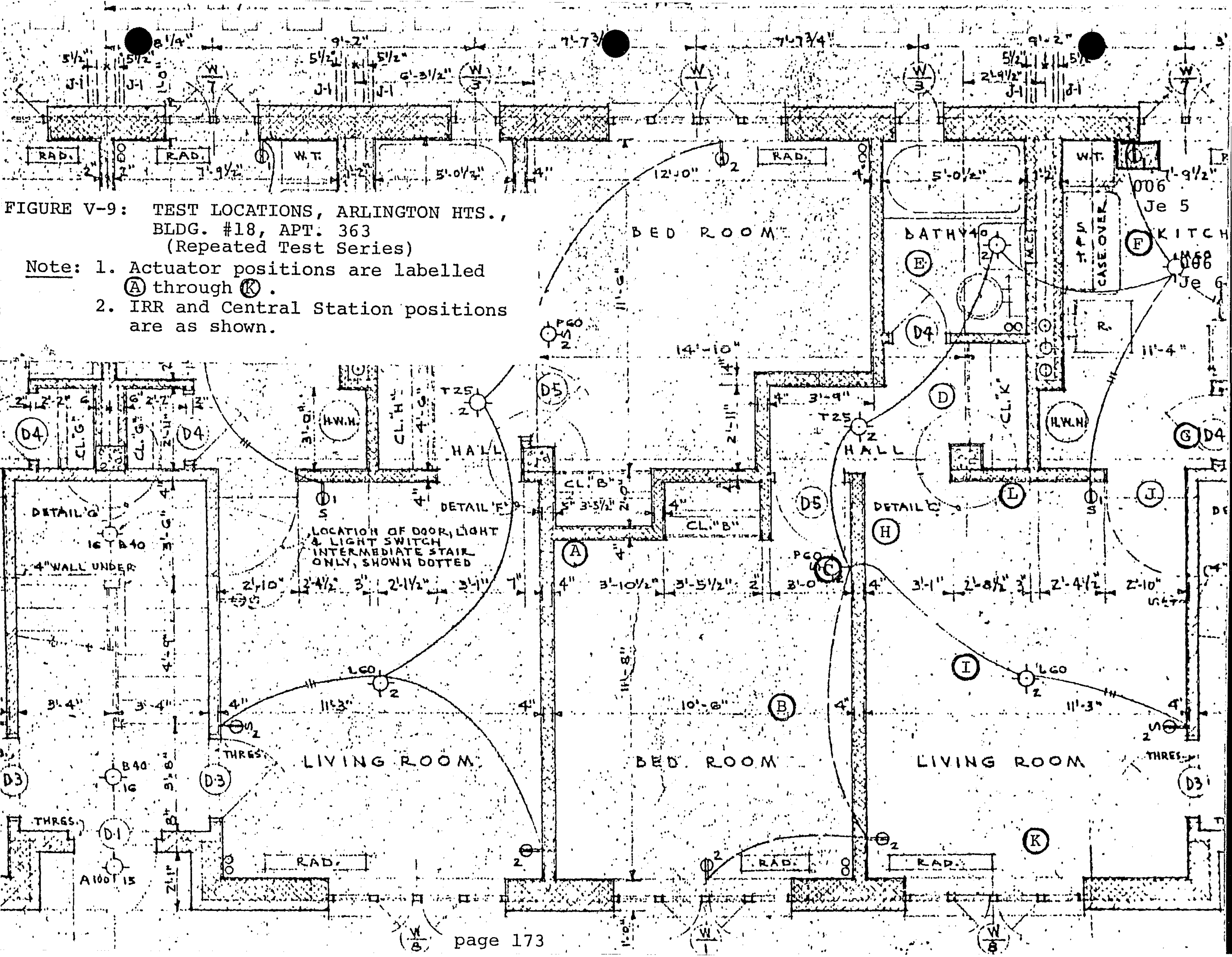
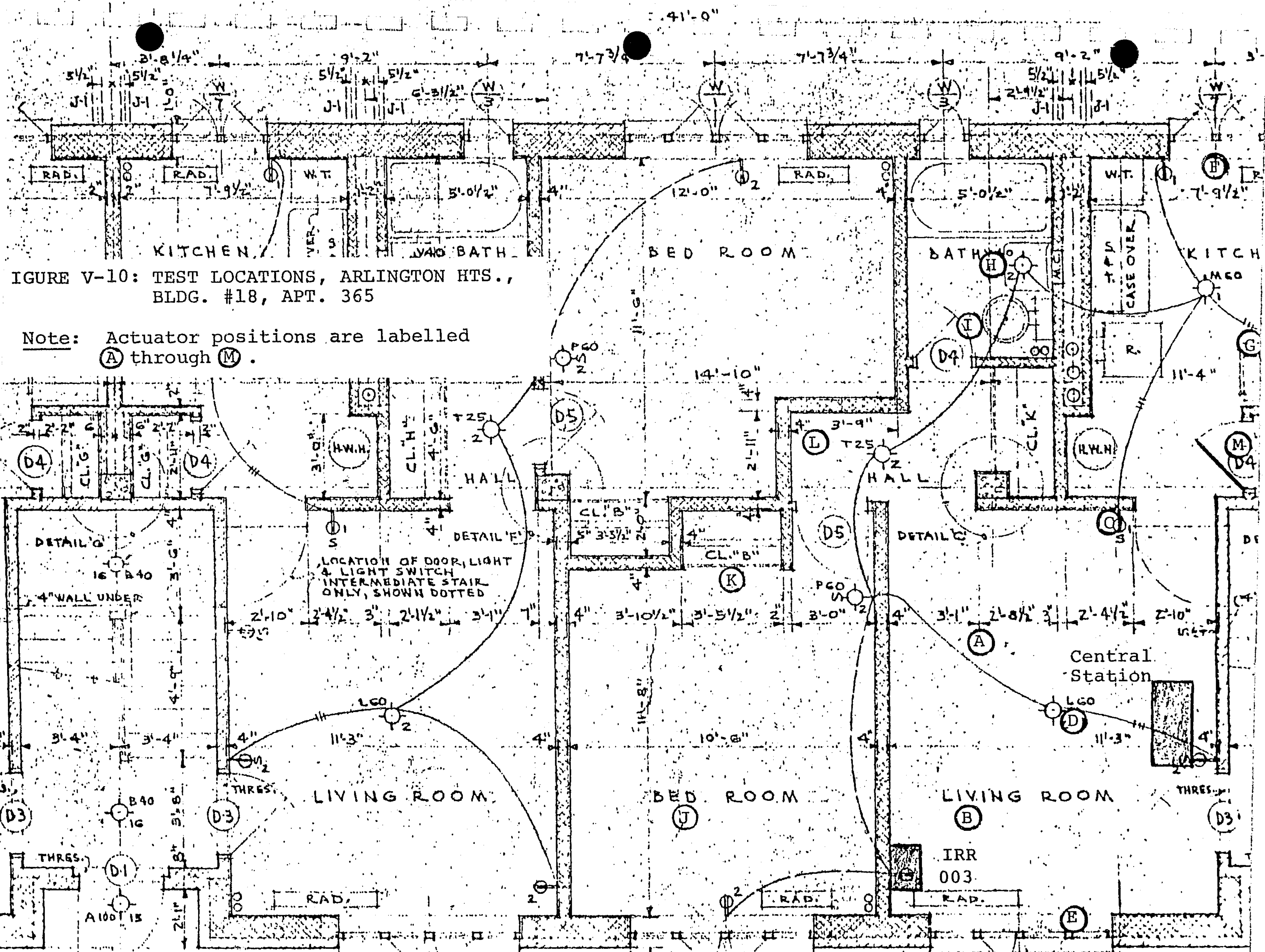


FIGURE V-9: TEST LOCATIONS, ARLINGTON HTS., BLDG. #18, APT. 363 (Repeated Test Series)

Note: 1. Actuator positions are labelled Ⓐ through Ⓚ.
2. IRR and Central Station positions are as shown.

IGURE V-10: TEST LOCATIONS, ARLINGTON HTS., BLDG. #18, APT. 365

Note: Actuator positions are labelled (A) through (M).



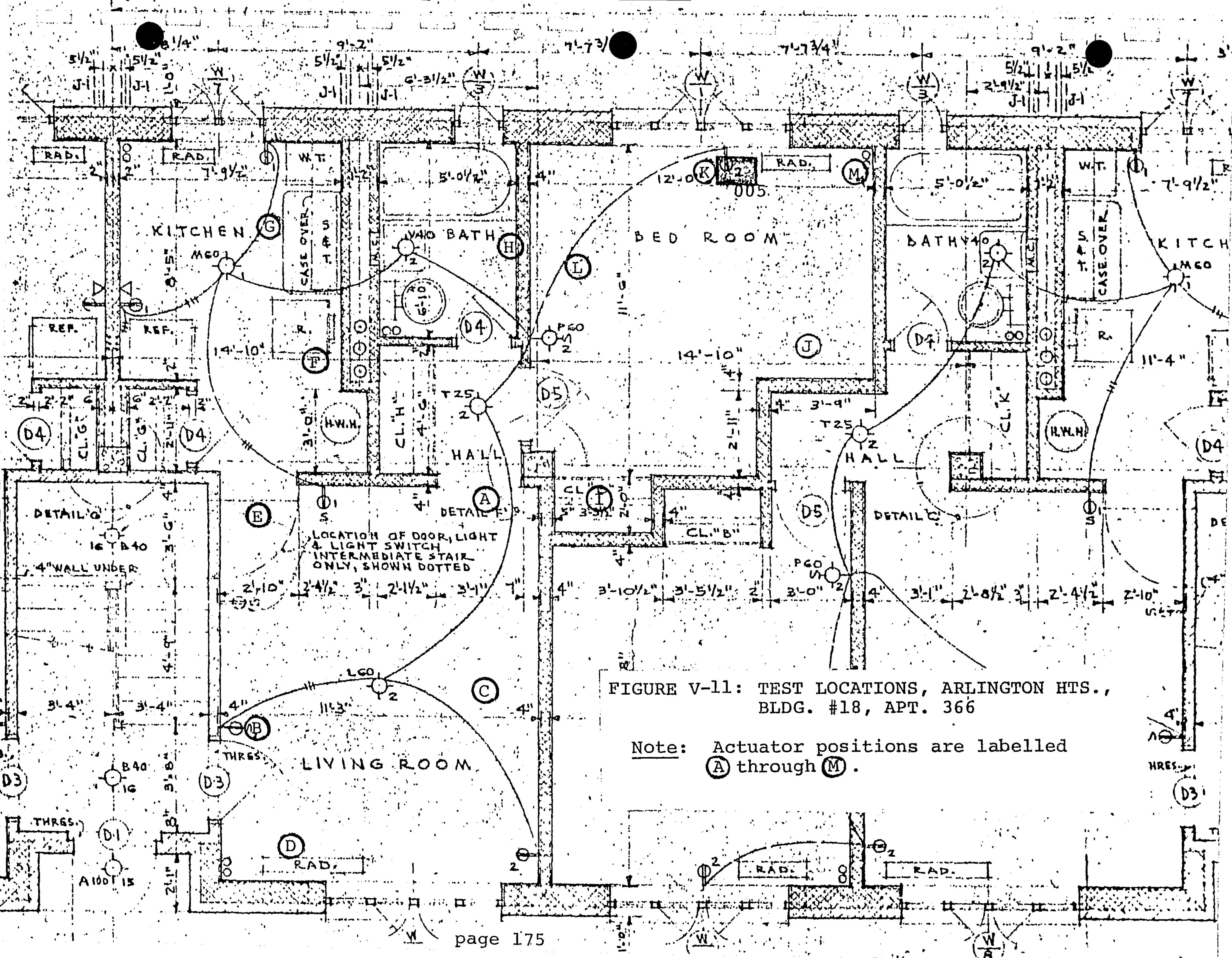


FIGURE V-11: TEST LOCATIONS, ARLINGTON HTS., BLDG. #18, APT. 366

Note: Actuator positions are labelled Ⓐ through Ⓜ.

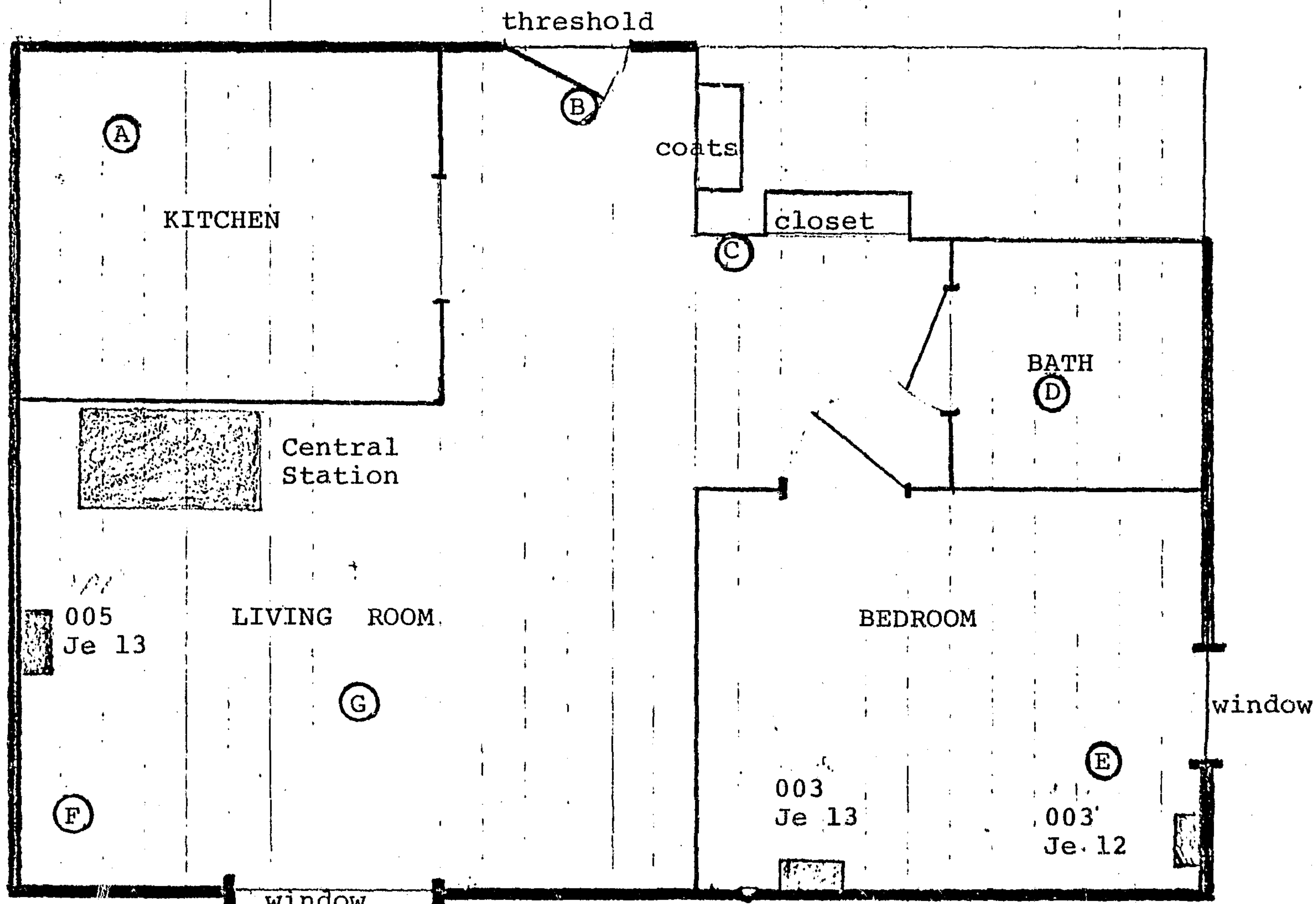


FIGURE V-12: TEST LOCATIONS, AMBERSON, APT. 620

Note: 1. Actuator positions are labelled (A) through (G).
2. IRR and Central Station positions are as shown.

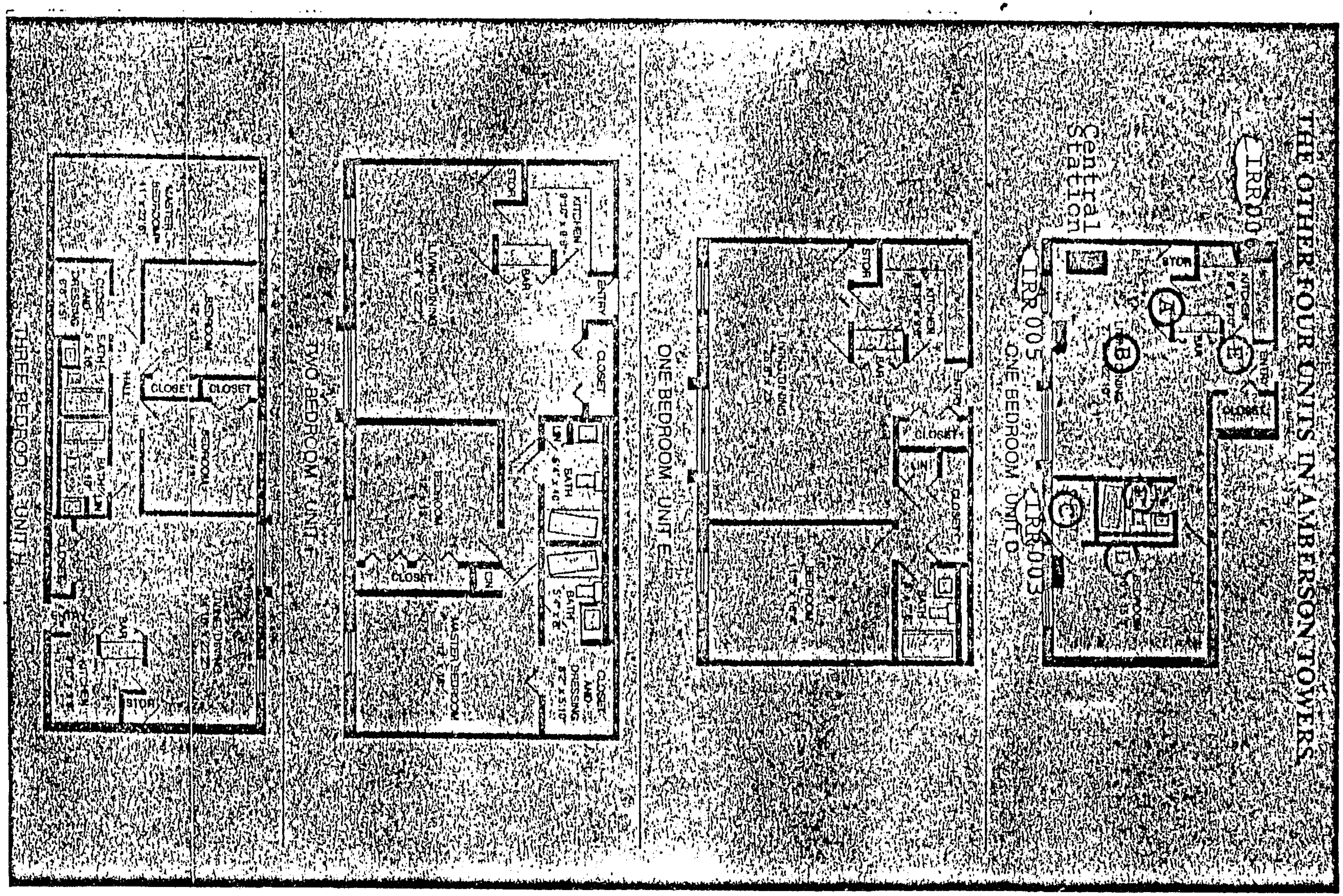


FIGURE V-13: TEST LOCATIONS, AMBERSON, APT. 910

Note: 1. Actuator positions are labelled (A) through (E).
2. IRR and Central Station positions are as shown.

SYSTEMS TEST SHEET

Building: 18

Location: 3252/363

No. 021

Date: 5/8/74

Tester: KSP [illegible]

AC NO: 899317 Code: 899317 Freq. 1 ______ MHz Freq. 2 ______ MHz

IRR NO: 3 Code: 003 Freq. Range: ______ MHz

AC SIGNALS:

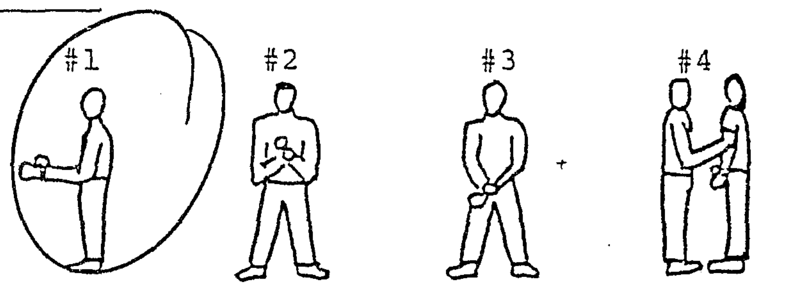
1st Msg. Freq: 462 MHz Strength 3/4

2nd Msg. Freq: 462 MHz Strength 3/4

Distance from IRR R = ______ m = ~20 ft.

Area: ______

Position:



Body Angle φ : 270 degrees Loc 2

Position Angle θ : 60 degrees

Msg. Printed: 1st: AC code: 899317 None ☐ Location: 003 None ☐

2nd: AC code: 899317 None ☐ Location: 003 None ☐

Printer Sheet No: 19

Remarks:

FIGURE V-14: SYSTEMS TEST SHEET, #I

CAS SYSTEMS TES

Building: GARDENS
Apt. : 620
Room : LIV

Sheet No: ______
Date: 0- 12, 74

IRR Code: 003 Position/Location: BED/620

Adjacent IRRs Code: 005 Room: LIV Location: 620

Actuation No.		Location	Position	Code (AC)	Printout IRR	Printout Actuator	Printout Response (sec)
990	1	LIV, C, 30, 110	P2	899317	003	X	4
"	2	"	"	"	005	X	13
"	3	"	"	"	003	899317	22
991	1	LIV, C, 60, 140	P5	888888	005	888888	2
"	2	"	"	"	003	888888	17
"	3	"	"	"	005	888888	25
992	1	LIV, C, -170, -95	P4	899317	003	899317	2
"	2	"	"	"	005	899317	12
"	3	"	"	"	003	899317	21

FIGURE V-15: SYSTEMS TEST SHEET, #II

Remarks
D.G.

teletype were copied into the test log.

(b) Inter-room UHF Communication Tests. The purpose of these tests was to determine the effect of room walls on the actuation range. The equipment was identical to that used in the Indoor Range tests. A floor plan of the rooms involved was drawn, indicating the locations of the IRR and each actuation site. The experimenter triggered the actuator from each location in adjoining rooms, taking a series of angles with respect to t the IRR in each of the four body position. Data was recorded as in the Indoor Range tests.

(c) Response Time and Message Accuracy Tests. The purpose of these tests was to evaluate the hardware response time, the accuracy of message transmission. A large number of actuations were made, using the basic system hardware (Central Station, IRR and actuator) without auxiliary test equipment. Actuations were conducted from the room containing the IRR as well as from adjoining rooms. For each actuation the location as marked on the floor plan was recorded, as well as body position and the body angle Ø. Only positions P5, P6 and P7 were used for this series of tests. These positions are documented in the Test Plan, Appendix III. The experimenter at the Central Station ran a countdown for the experimenter wearing the actuator, then measured the time at which the printout for each message began. The messages printed by the teletype were copies into the test log, to be later analyzed for the accuracy of location and actuator code information.

(2) Single Actuator, Multiple IRR Tests. The purpose of these tests was to determine the effectiveness of the queuing system within the IRR. A single actuator was used in conjunction with two or three IRR's within the actuator's range. The IRR's were placed in adjoining rooms so that data from these tests might supplement the inter-room communication test data. Location, body position, and angle with respect to the nearest IRR were re recorded; a countdown to actuation was given to facilitate the recording of response time. The messages from the teletype were then copies into the test log.

(3). Multiple Actuators, Single IRR Tests. The purpose of these tests was to determine the reliability of message interference prevention for multiple simultaneous actuation. Two actuators were used in conjunction with a single IRR; the actuators were triggered simultaneously upon a signal from the experimenter at the Central Station, who then recorded the response time for each signal. Location, position, and body angle for each actuation was recorded, as well as the data from the teletype.

(4) Multiple Actuator, Multiple IRR Tests. The purpose of these tests was to determine the response time and reliability of message transmission for multiple simultaneous actuation with two or three IRR's. The tests were conducted in the same way as the multiple actuator, single IRR tests. Although the test pl an did not specify these tests the majority of multiple

actuations were conducted in this fashion, to couple the effects of queuing and possible message interference, thereby more closely simulating the system in its operating state.

b. Large-Scale Scenario Tests. The large scale scenario tests at Arlington were begun following three weeks of small-scale scenario tests. An audible alarm at the Central Station which sounds upon actuation, disconnected for the small-scale scenario tests, was reconnected. Once the system is initialized, a key-switch is turned to activate this alarm system.

The Central Station, including the ERR, was set up in a vacant apartment (No. 97) in Building No. 5, where the test participants were housed. Participants were issued an actuator and instructed in its use by the security guards; participants were also given a four-page summary of the system and its operation. The summary is included as Appendix IV to this report. The apartments of participants were photographed to provide documentation on the layout of the apartment and the location and environment of the IRR. This procedure also provided an opportunity to talk to the participants, answering any questions they had about the test. The location of equipment is shown in Figure V-15a.

The security guards filled out a central station log upon arriving for the beginning of each twelve-hour shift. A page of the test log is shown in Figure V-16. To conduct a test, the guards telephoned a participant and told them to trigger their actuator from a specific location. The guards then

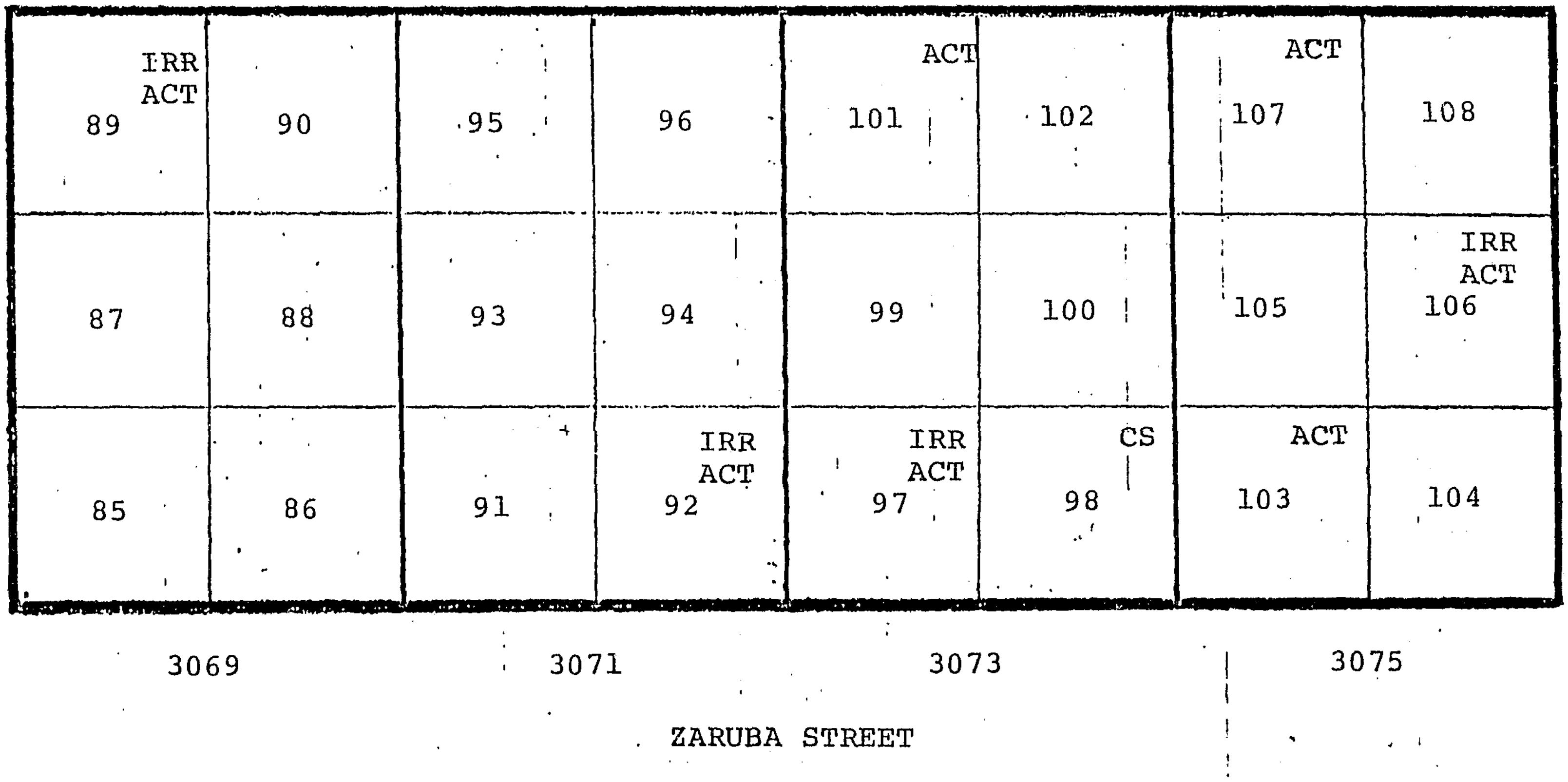


FIGURE V-15a: KEY TO APARTMENT NUMBERS AND CAS SYSTEM COMPONENTS, ARLINGTON HEIGHTS, BLDG. #5

(Front view, 3 floors)

Mr. Fred Coffee

3rd Dune

LOG FOR CAS SYSTEM TEST

Date & Time 6/20/21 7 /80

I, L. Richards, have received the Central Station in good condition as noted, by having checked the following:

GUARDSON DUTY: L. Richards, L. Miles
ALL SYSTEMS ACCOUNTED FOR: Being Serviced
CENTRAL STATION RUNNING: Yes
TELEPRINTER ON: NO
ALL WIRES AND CABLES SECURE: NO

WEATHER REPORT: TSR TIME: 11:30 (H) 80 (L) 61 WINDS: 6 MPH

ENT NO.	TIME	BLDG.	LOC.	ACT.	NAME	RUNNER DISP/ARR	POLICE DISP/ARR	SERVICE DISP/ARR	SECURED BY/TIME	TEST
	10:30	01	006	360	coffee	No /			L.R. 10:31 PM	✓
	11:30 pm	01	006	360	Coffee	No /			L.M. 11:32 PM	✓
	11:35 pm	01	006	360	Coffee	No /			L.M. 11:37 PM	✓
	1035	01	006	360	coffee	1035 1036			L.R. 1037	✓
	1035	01	006	—	coffee	1045 1047			L.R 1048	✓
	1055	01	006	—	coffee	1055 1057			L.R 1058	✓
	11:00	01	005	360	coffee	11:00 1101			L.R 1102	✓
	1201	01	006	360	coffee	1201 1202			A.P. 1203	✓
	127	01	005	350	coffee	1:28 1:2			AR 130	

FIGURE V-16: CENTRAL STATION LOG SHEET

recorded the time, name of the participant, location and data from the teletype in another test log, shown in Figure V-17. Tests were conducted about eight times a day for each participant. The participants in this test program are listed in Table V-2.

As a variation during the first two days, the residents were also instructed to trigger at their own discretion and guards were instructed to respond, as in a real emergency. For the building, the overall response time (hardware plus response agent) was less than a minute, from the time the actuator was triggered to the time that the guard located and began to assist the "victim".

In the event of a real alarm, guards were instructed to respond by proceeding to the location indicated by the location code. If several location codes were received, guards were to proceed to each location in turn. If guards found nothing at the location specified, they were instructed to check the apartment of the person with the actuator code received. If no location code was received, guards were to consider the alarm as a false triggering.

5. Test Results

a. Frequency, Field Strength, and Range. The frequency of the signals measured during indoor range and inter-room UHF communication tests shows an average value of 462.4 MHz with a minimum of 462 MHz and a maximum of 463.5 MHz. Field

CAS PROGRAMMED TESTS

8 Tests Per Person Per Day

NAME MRS. A FULLER

PHONE 481-6786

ADDRESS APT 89 3069 ZARUBA ST, 3rd FLOOR

DAY	TIME	LOCATION NO.	ACTUATOR NO.
SUN	225	004 Kitchen	889
	235	004 L. Window	889
	310	004 Bed Rm	889
	340	004 Kitchen	889
	435	004 Bath Rm	889
	5 [illegible]	004 Bed Rm 2	889
	530	[illegible] hall outside	8[illegible]

DAY	TIME	LOCATION NO.	ACTUATOR NO.
MON	6:50 pm	004 Kitchen	889
	8:20 pm	004 livingroom	889
	8:45 Pm	004 Bedroom	889
	9:35 PM.	004 Bathroom	889

FIGURE V-17: SAMPLE OF PROGRAMMED TEST BOOK

TABLE V-2: CAS SCENARIO TEST: ARLINGTON HEIGHTS LIST OF CANDIDATE PARTICIPANTS

6/20/74

NAME	ADDRESS	APARTMENT NUMBER	FLOOR	TELEPHONE NUMBER	SEX	AGE
BUILDING #5						
Mrs. Crile	3075 Zaruba St.	#103	1st	381-1163	F	
Mrs. Francis Ray	3073 Zaruba St.	#100	2nd	431-3019	F	
Mrs. A. Fuller	3069 Zaruba St.	#89	3rd	481-6336	F	
Mrs. Lee	3075 Zaruba St.	#106	3rd	431-4955	F	
Mrs. Mary Carter	3073 Zaruba St.	#101	3rd	381-9120	F	55
Mrs. Mary Ida Hairston	3073 Zaruba St.	#97	1st	481-5945	F	67
Mrs. Griffin	3069 Zaruba St.	#90	3rd	381-7925	F	
Mr. Fred Coffee	3071 Zaruba St.	#92	1st	381-5146	M	
Marian Williams	3075 Zaruba St.	#106	2nd	431-6585	F	21

Residents of Building #5, Arlington Heights, Participating in Large Sclae Scenario Tests strength was at threshold for locations within the room; the field strength was not significantly altered by moving into other rooms and closing the door.

The free-space range of an actuator is about 100 feet. The indoor range of an actuator depends on the architecture of the building as discussed in Part 5, Section E. The indoor range as determined at Arlington is about 50 feet.

b. Response Time. Response time measured in the single actuator, single IRR tests were tabulated separately for each actuator. The response time was plotted as a histogram with one-second time intervals. The total number of trials for actuator 888888, in the Arlington tests, is 66; the corresponding figure for actuator 899317 is 84. The histograms are shown in Figures V-18 and V-19.

Single actuator, multiple IRR response times were tabulated for 526 trials from the Arlington test data. The response times for these trials is plotted as a histogram in Figure V-20.

Multiple actuation, multiple IRR response times from the Arlington test data were tabulated for 72 dual actuations. In this series of tests, a hardware fault in one of the IRR's used for several tests caused the queuing system to fail to reset properly. This is the source of the signals past forty seconds. Response time for these trials is plotted as a histogram in Figure V-21. Under ordinary conditions, with a good IRR, no signals are observed past forty seconds.

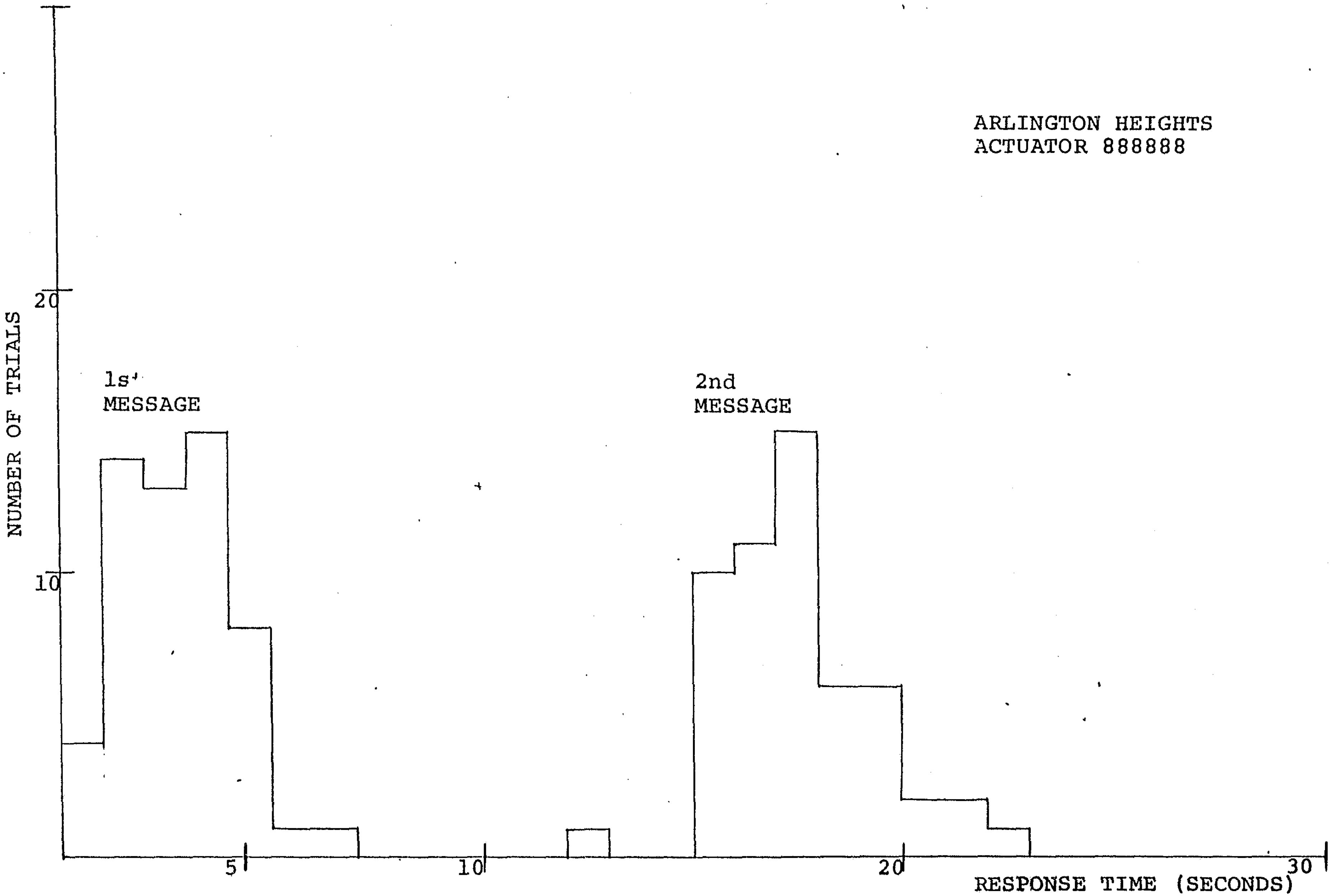


FIGURE V-18: RESPONSE TIME HISTOGRAM (Single IRR)

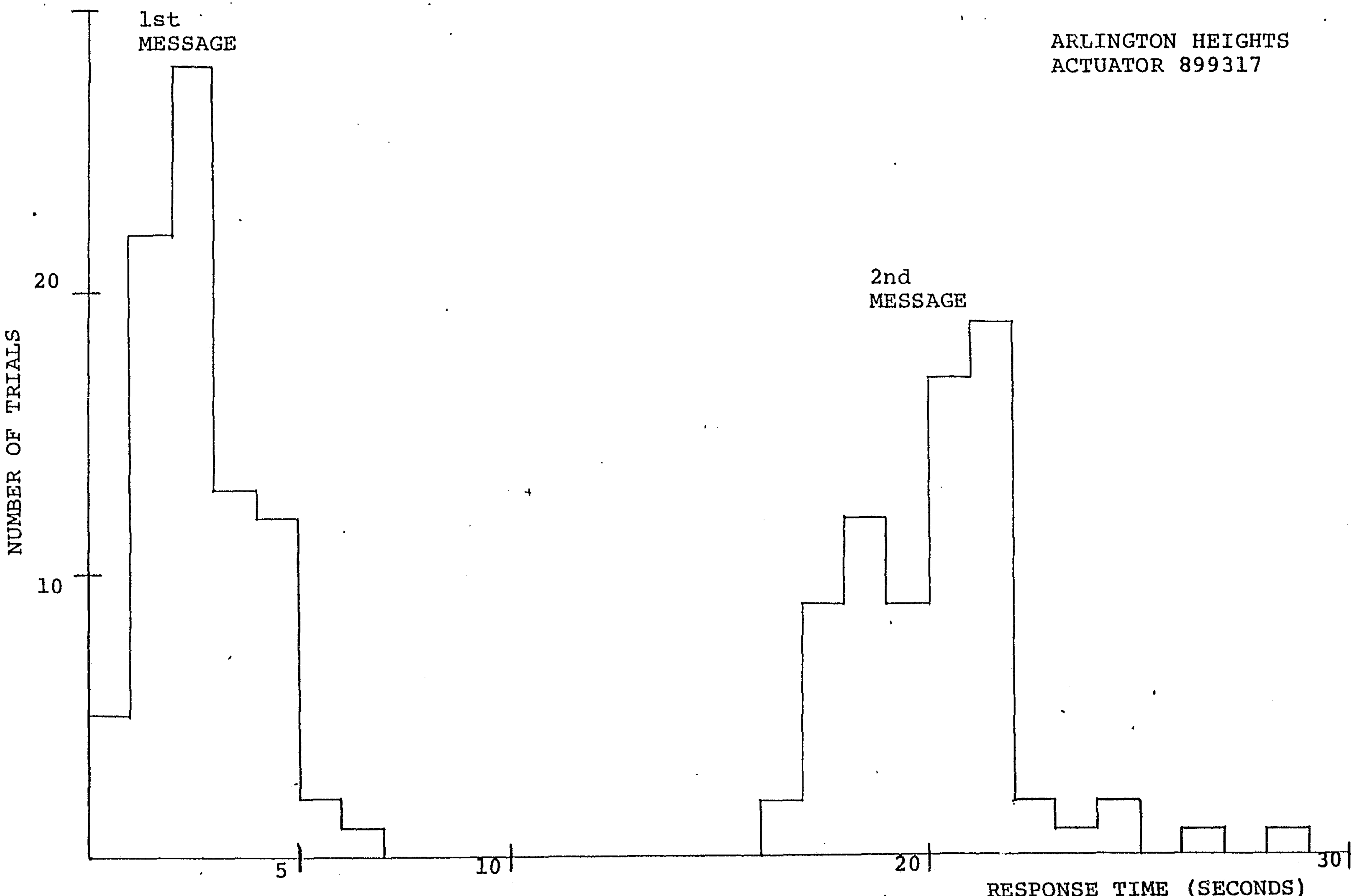


FIGURE V-19: RESPONSE TIME HISTOGRAM (Single IRR)

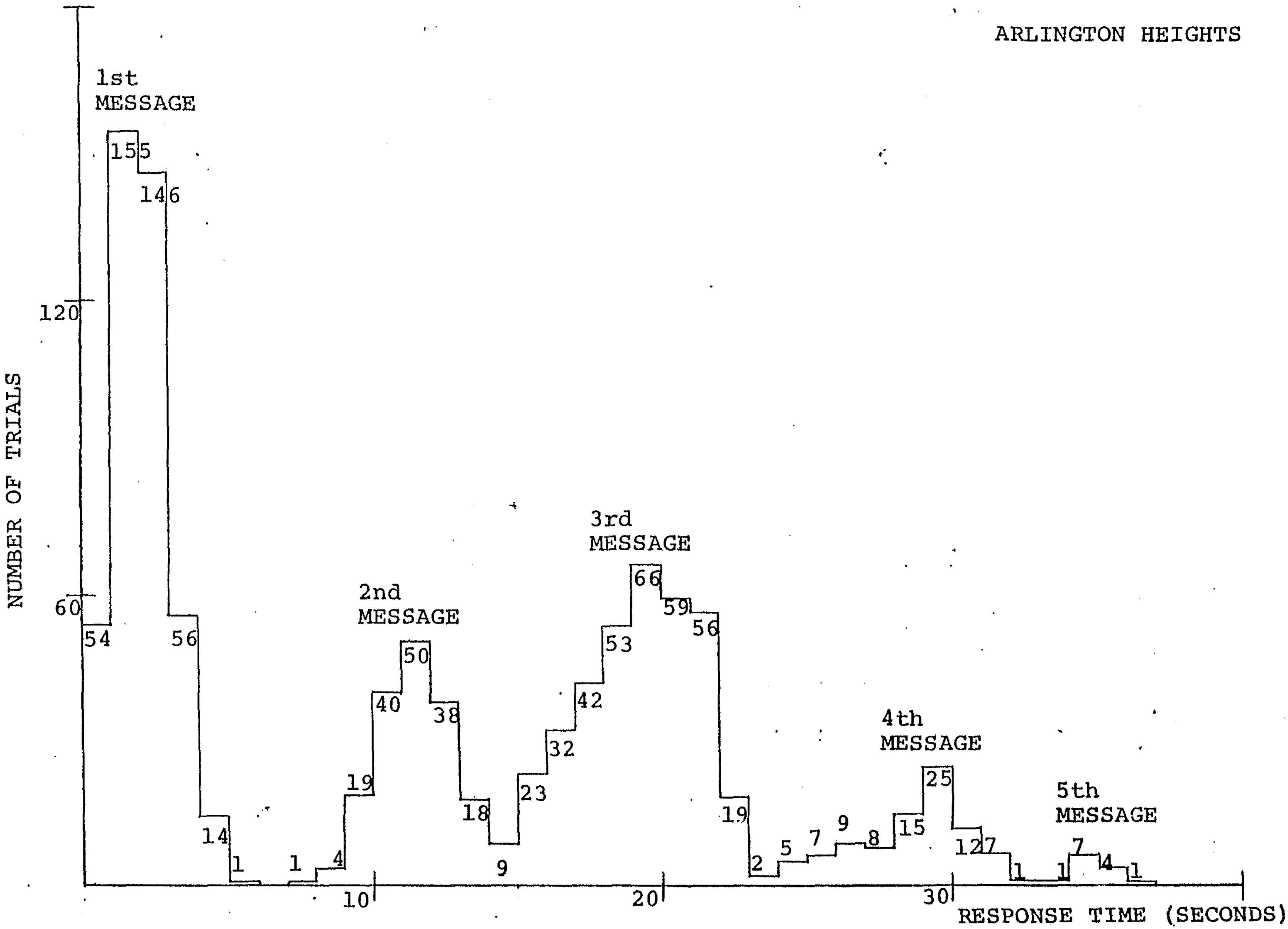


FIGURE V-20: RESPONSE TIME HISTOGRAM (Multiple IRR's, Single Actuator)
Note: Numbers on histogram represent number of trials in that time interval.

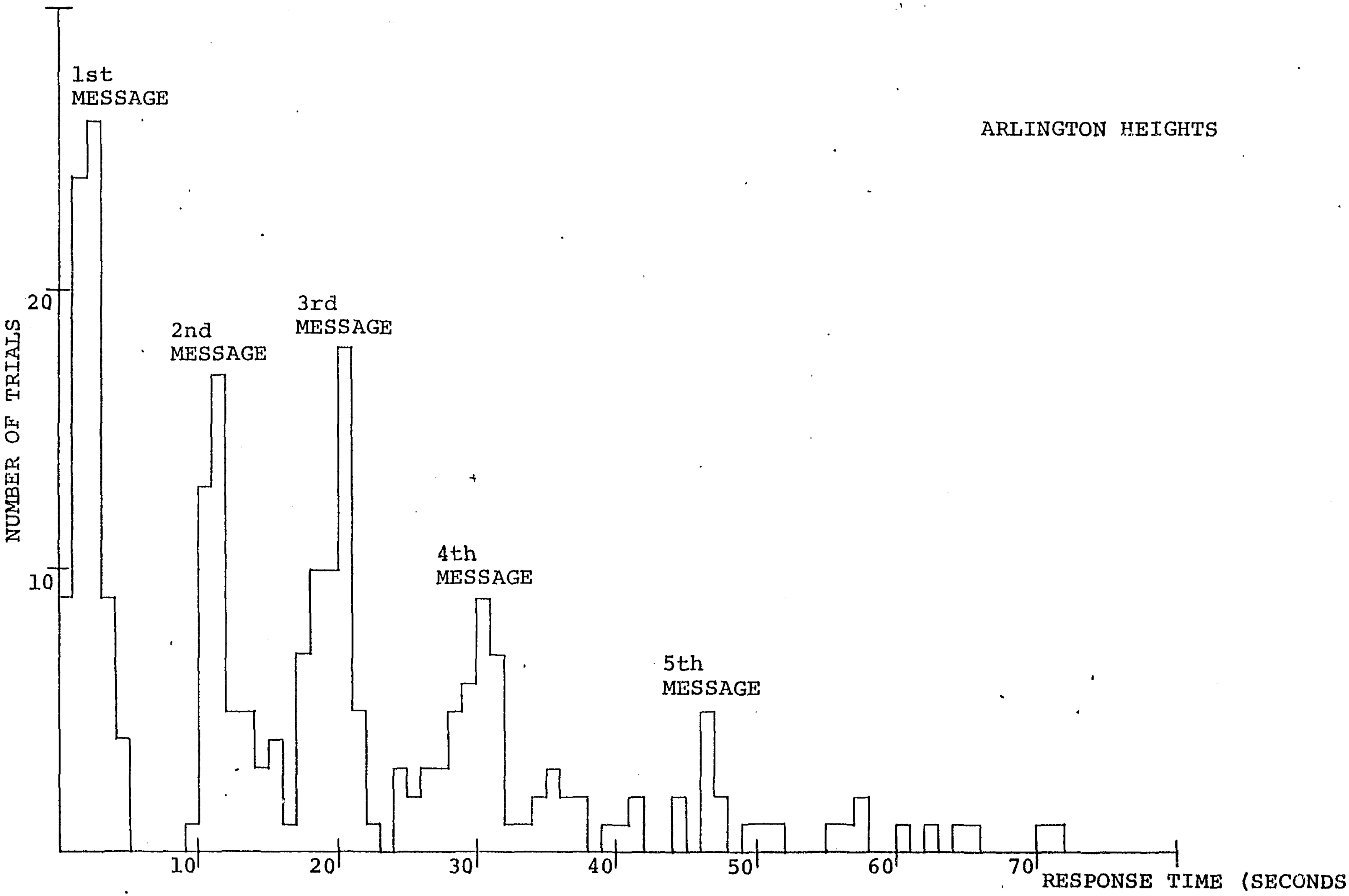


FIGURE V-21: RESPONSE TIME HISTOGRAM (MULTIPLE IRR, MULTIPLE ACTUATOR)
Note: One of the IRR's used was faulty, see text)

C. Effects of Dual Actuation. The data from the dual actuation tests with both single and multiple IRR's was analyzed for the reliability of queuing and message interference protection. For 136 dual actuations at Arlington, the tabulation is as follows:

	Number of Trials	Percent
One Actuator Code Received	82	60%
Both Actuator Codes Received	47	35%
Message Received Without Actuator Code	7	5%
No Message	0	0%
Alarm Messages Received	136	100%

d. Effects of Body Position and Angle

(1) Body Position. The effects of body position on the reliability of message transmission is evaluated by tabulating the number of signals received with an actuator code for each body position, as shown in Table V-3. The figures for the Arlington and Amberson tests are shown below, as well as a total of the two. Positions, 3, 4, and 7 were not tested at Amberson. These data are shown graphically in Figures V-22 through V-24.

(2) Body Angle. The effect of body angle with respect to the IRR is evaluated by tabulating the number of signals received with an actuator code for each body angle, as shown in Table V-4. Body angles are considered positive for a clockwise turn and negative for a counter-clockwise turn. Figures for the first signal, the second signal, and at least one signal are tabulated as they were for the position analysis.. Figures for the Arlington and Amberson tests are shown in Table V-4 with a total of the two.

TABLE V-3: TRANSMISSION RELIABILITY vs. POSITION

	1st Message w/ Actuator Code	2nd Message w/ Actuator Code	At Least 1 Message w/ Actuator Code ✓	At Least 1 Message No Actuator Code	No. of Trials
ARLINGTON					
P1	66.7	78.3	90.3	98.6	150
P2	66.4	75.2	91.2	98.5	149
P3	55.5	70.6	79.3	84.7	90
P4	62.8	75.3	89.3	97.3	78
P5	57.4	64.5	82.4	92.9	61
P6	50.0	78.3	87.3	96.4	60
P7	48.4	70.9	85.0	95.0	62
				TOTAL	650
AMBERSON					
P1	51.0	73.8	88.8	95.6	49
P2	66.7	91.9	100.0	100.00	42
P5	60.0	87.0	94.2	100.00	40
P6	55.5	92.3	97.2	97.2	45
				TOTAL	176
TOTAL					
P1	62.8	77.3	89.9	97.8	199
P2	66.5	78.6	93.3	98.9	191
P3	55.5	70.6	79.3	84.7	90
P4	62.8	75.3	89.3	97.3	78
P5	58.4	75.3	86.8	95.6	101
P5	52.4	83.8	91.2	96.7	105
P7	48.4	70.9	85.0	95.0	62
				TOTAL	826

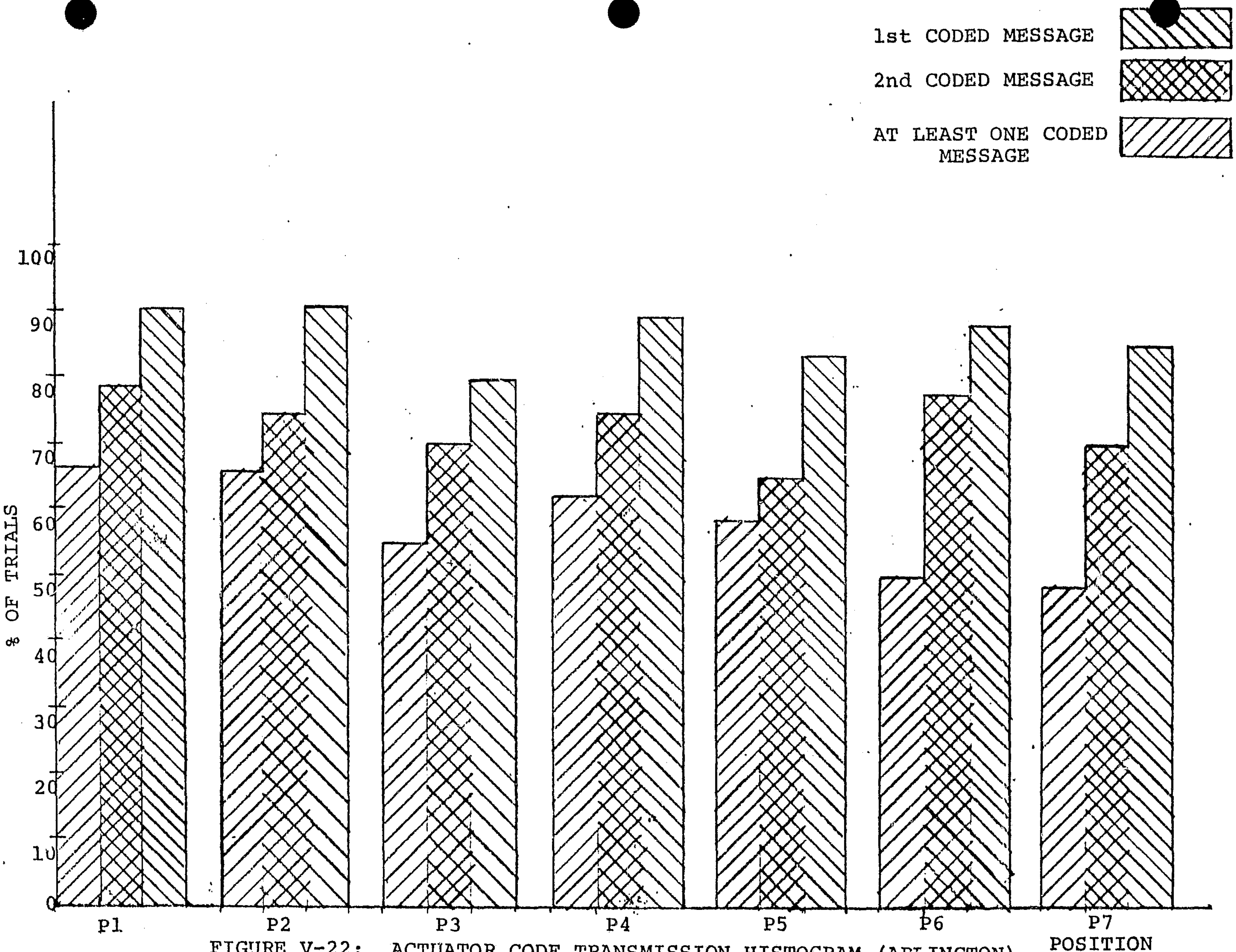


FIGURE V-22: ACTUATOR CODE TRANSMISSION HISTOGRAM (ARLINGTON)
Note: Positions are defined in the Test Plan.

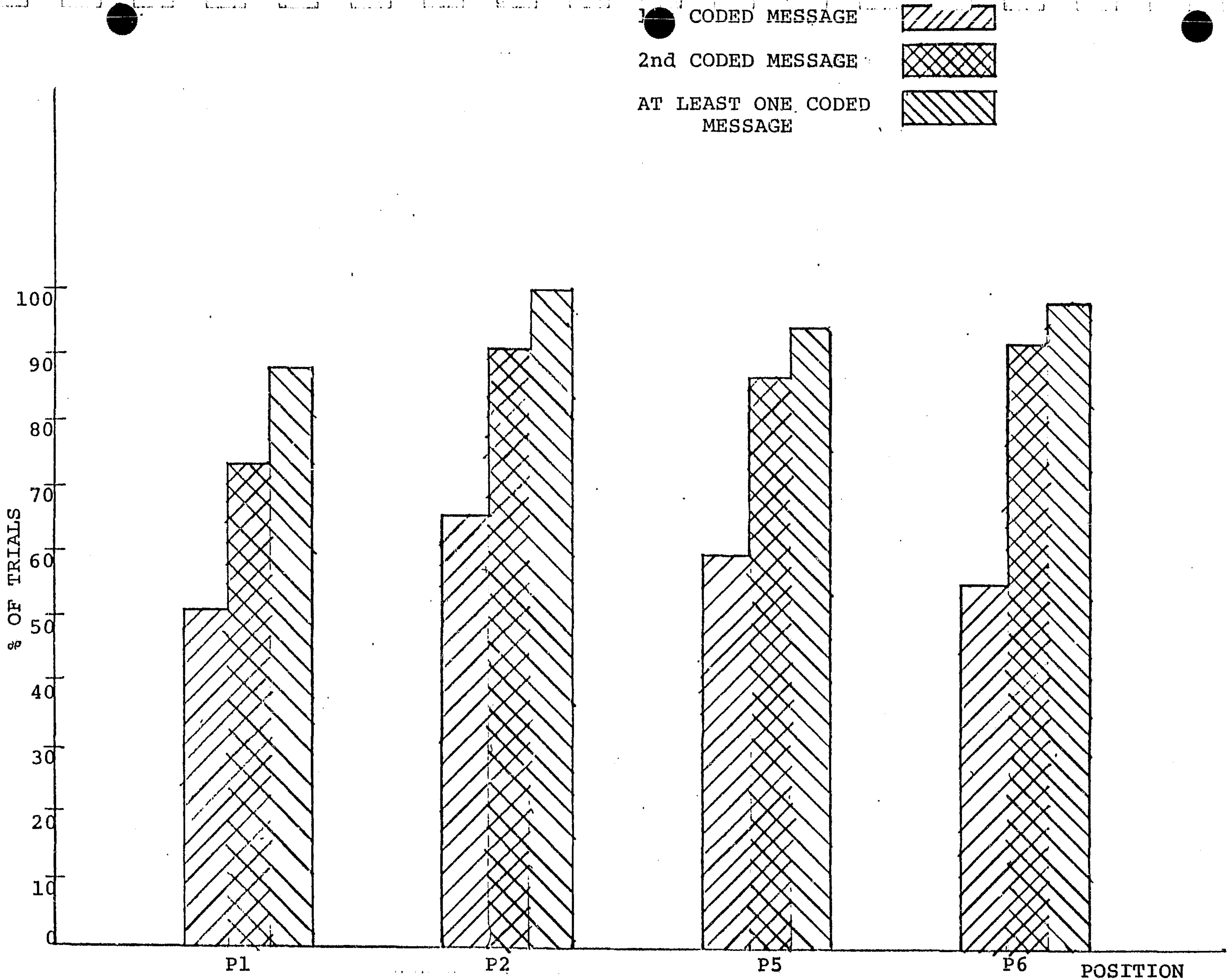


FIGURE V-23: ACTUATOR CODE TRANSMISSION HISTOGRAM (AMBERSON)

Note: Positions are defined in the Test Plan.

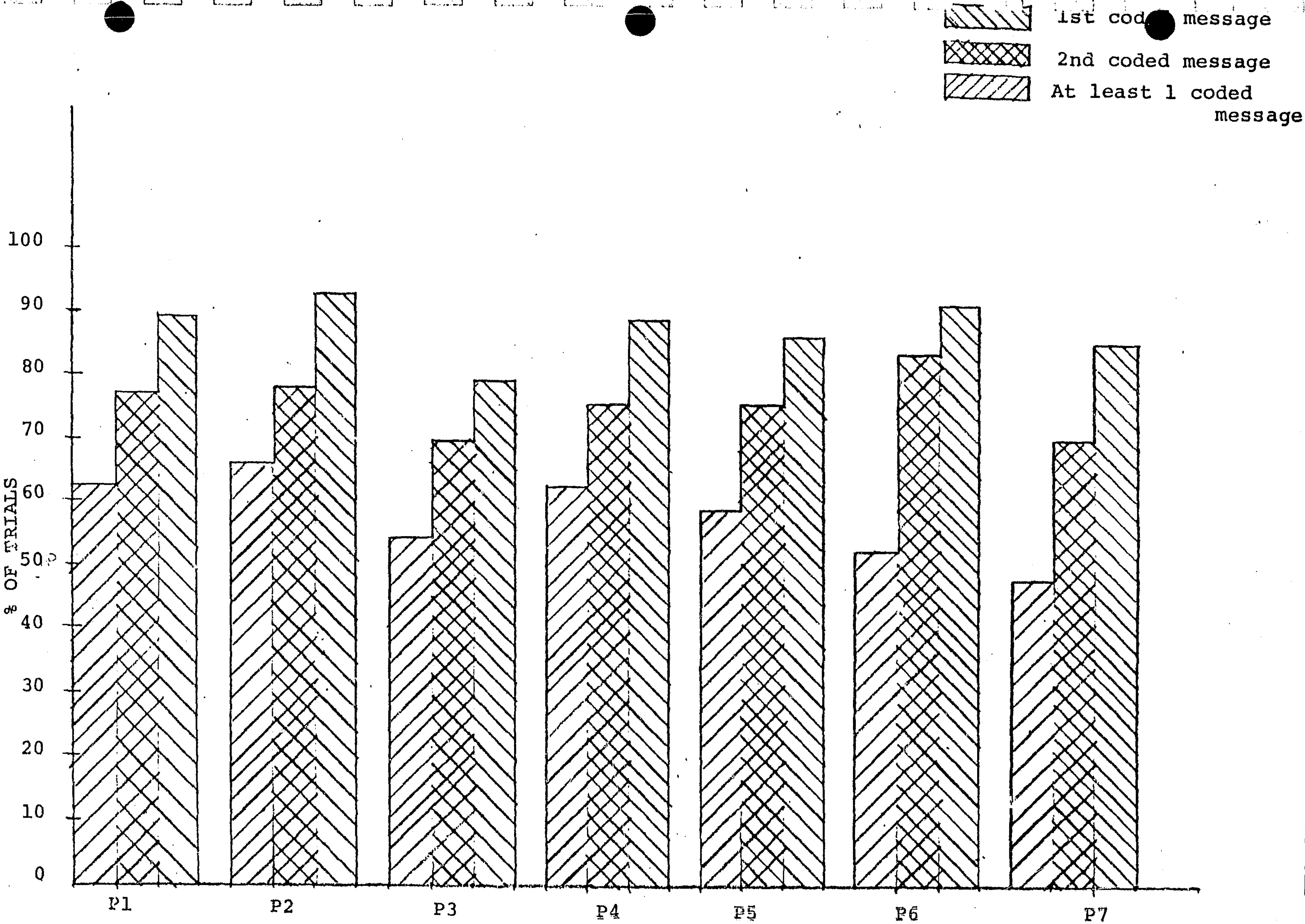


FIGURE V-24: ACTUATOR CODE TRANSMISSION HISTOGRAM (TOTAL)

TABLE V-4: TRANSMISSION RELIABILITY vs. ANGLE

	1st Message w/ Actuator Code	2nd Message w/ Actuator Code	At least 1 Message w/ Actuator Code	At least 1 Message No Actuator C Code	No. of Trials
ARLINGTON					
0	62.3	75.5	89.9	96.9	98
45	62.0	90.3	91.1	98.2	64
90	69.2	72.8	88.5	96.2	107
135	58.9	75.9	92.5	96.2	56
180	60.6	75.2	83.6	95.1	127
-135	47.0	70.6	88.6	97.7	51
- 90	60.8	65.6	78.6	90.8	97
-45	51.0	68.1	87.2	91.5	47
					657
AMBERSON					
0	47.8	82.3	95.0	100.0	23
45	57.8	93.7	94.7	100.0	19
90	38.4	82.7	92.6	96.3	26
135	68.7	75.0	93.7	93.7	16
180	46.2	83.3	91.3	95.7	26
-135	76.2	92.8	100.0	100.00	21
-90	58.3	90.0	100.0	100.00	24
-45	77.8	92.8	94.1	100.00	18
					173
TOTAL					
0	59.5	76.6	90.7	97.5	121
45	61.4	91.0	92.0	98.7	83
90	63.2	75.0	89.3	96.2	133
135	61.1	75.3	92.7	95.6	72
180	58.2	88.8	84.8	95.2	153
135	55.6	75.4	91.9	98.4	72
-90	60.3	69.9	81.9	92.3	121
-45	58.5	73.7	89.0	93.8	65
					820

These data are shown graphically in Figures V-25 through V-28. The data for position 1 and a sum of data for positions 2 and 3 was then tabulated separately in Table V-5. to check for correspondence to measurements of the field strength in free space done by The Aerospace Corporation in October 1973 and later.

These data were graphed on polar plots for comparison with measurements of the field strength for equivalent positions. The data are shown in Figures V-29 through V-31.

e. Effects of Physical Environment. Actuation within a room containing an IRR almost always results in the reception of a message. From the Amberson test data 98% of in-room actuations resulted in the reception of a location code; 94.2% of in-room actuations resulted in the reception of an actuator code. The effect of actuations outside the room containing an IRR depends on the architecture of the building. At Arlington, coded messages were received by an IRR on the third floor from actuations on the first floor. The presence of large metal objects close to the actuators was found to hinder transmission of messages; reception was impaired by a refrigerator, an oven, and a large metal sink. This effect is marked when the object is directly between the actuator and IRR but shows little effect when it is out of the way, though nearby. Another effect that hinders reception of signals is the directionality of the antenna in the IRR. If an actuation occurs within the plane of the antenna,

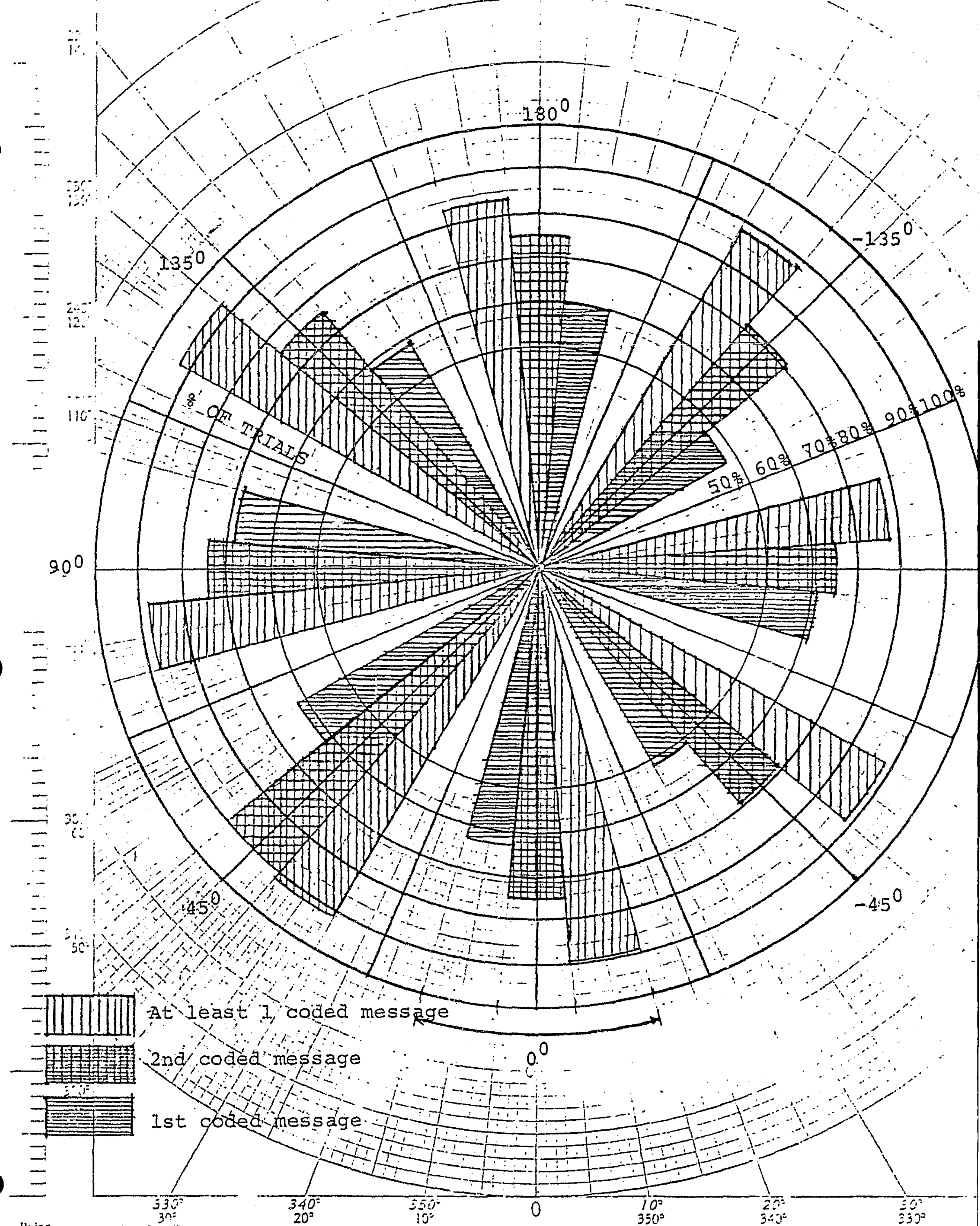


FIGURE V-25: ACTUATOR CODE TRANSMISSION, POLAR HISTOGRAM (ARLINGTON)

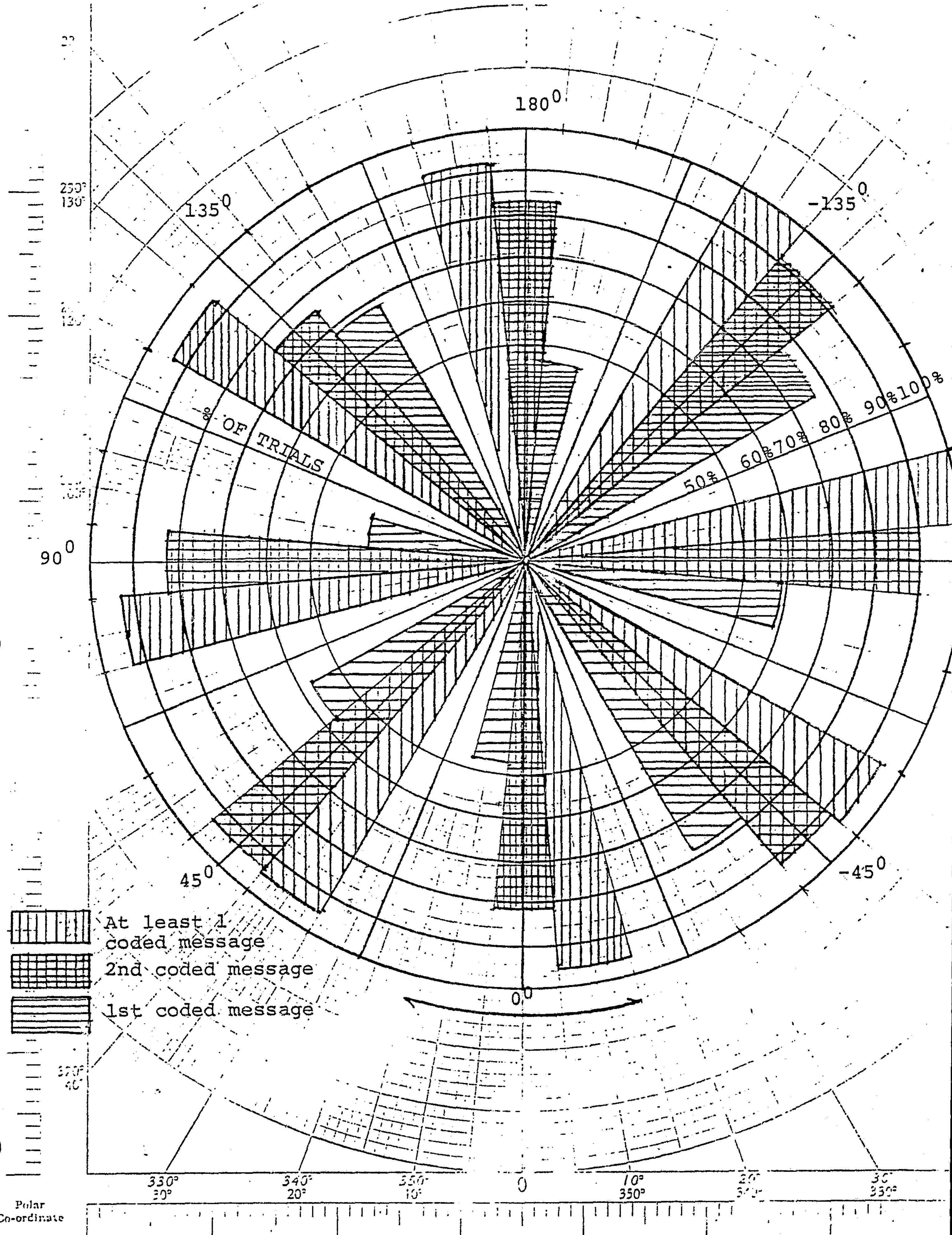
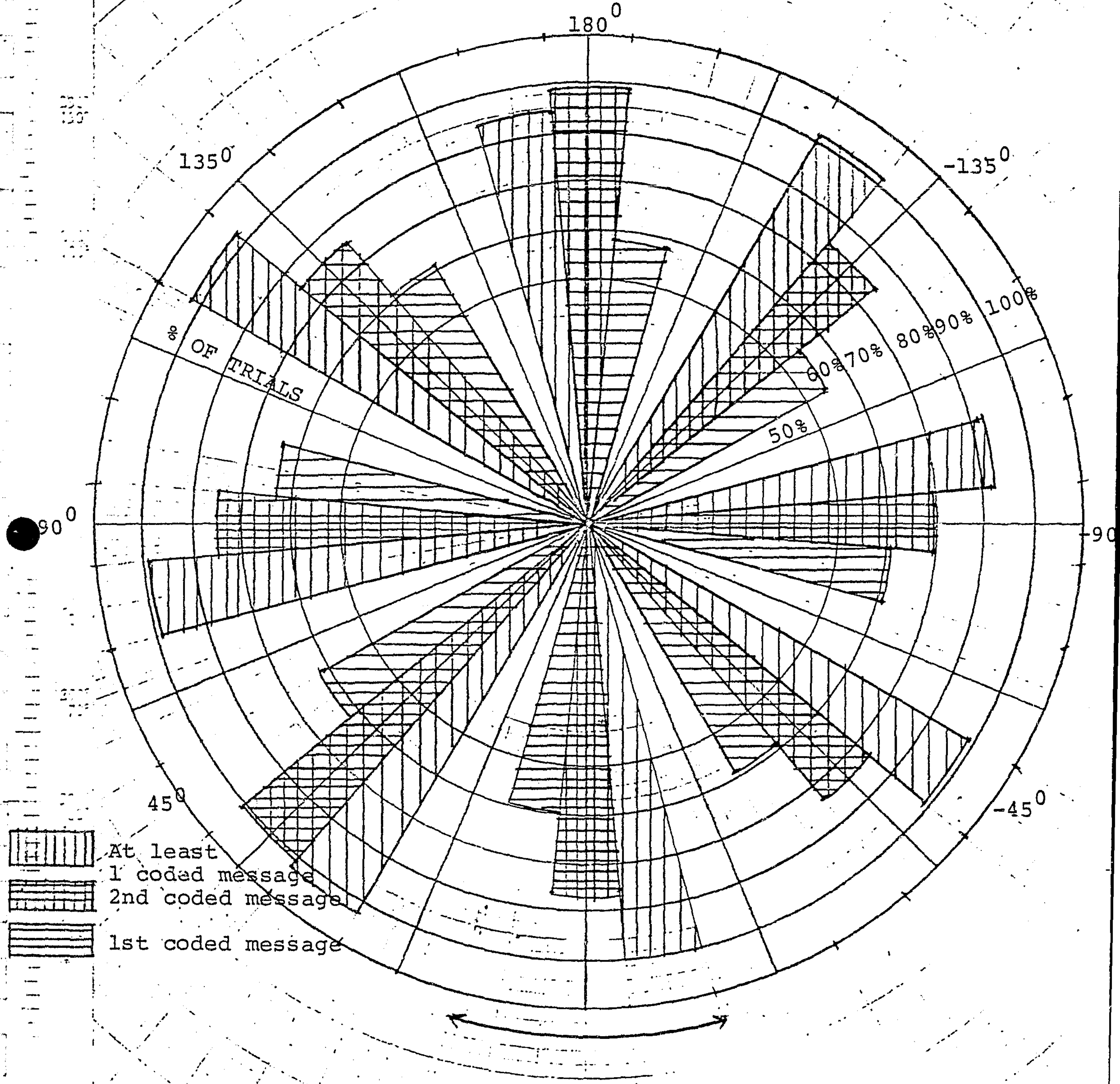


FIGURE V-26: ACTUATOR CODE TRANSMISSION, POLAR HISTORGRAM (AMBERSON)

FIGURE V-27: ACTUATOR CODE TRANSMISSION, POLAR HISTOGRAM (TOTAL)



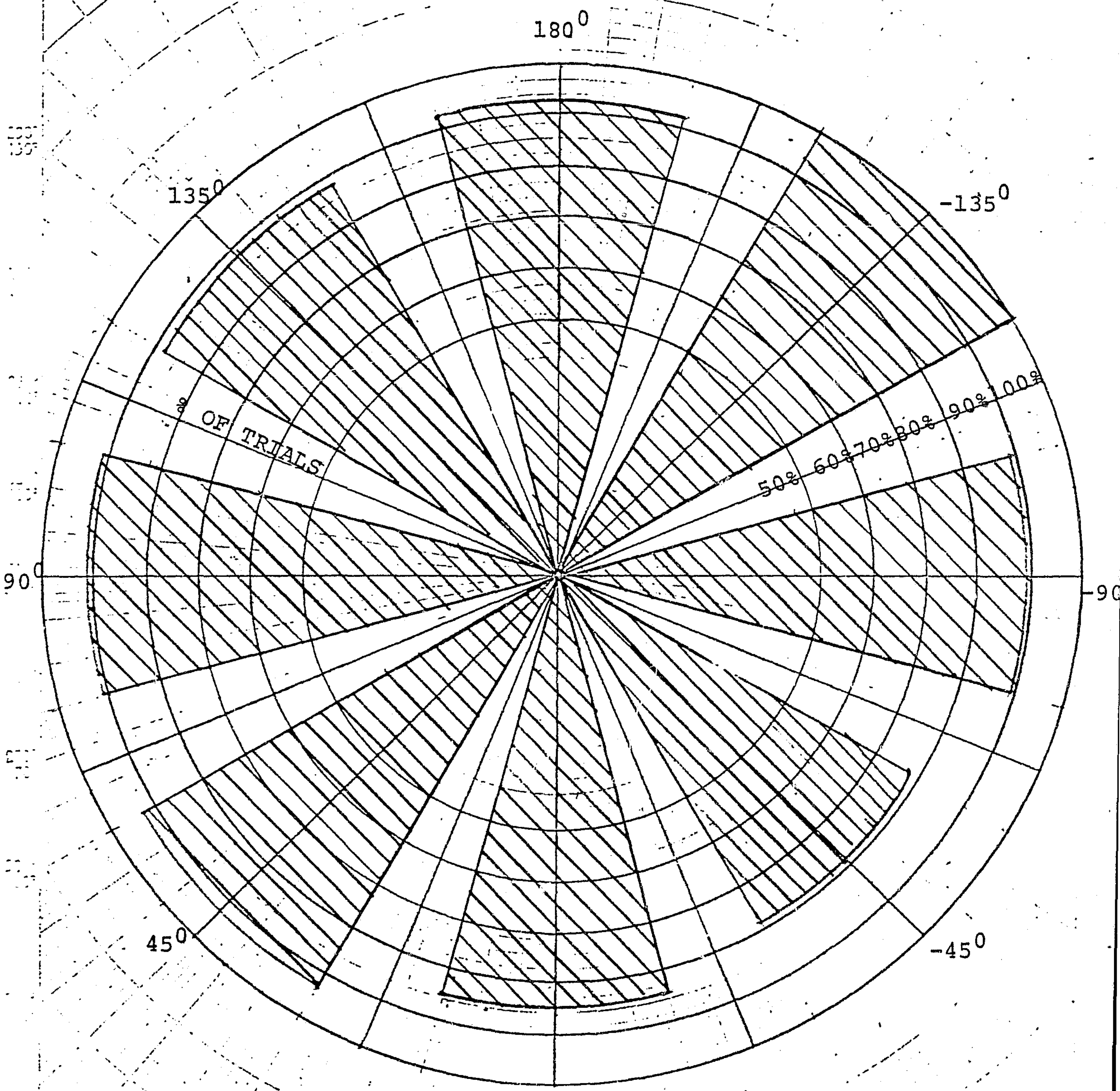


FIGURE V-28: ACTUATOR CODE TRANSMISSION, POLAR HISTOGRAM (POSITION 1, AT LEAST ONE MESSAGE RECEIVED)

3-25-74
(Re: DATA SHT. NOS. 8, 9 & 5)

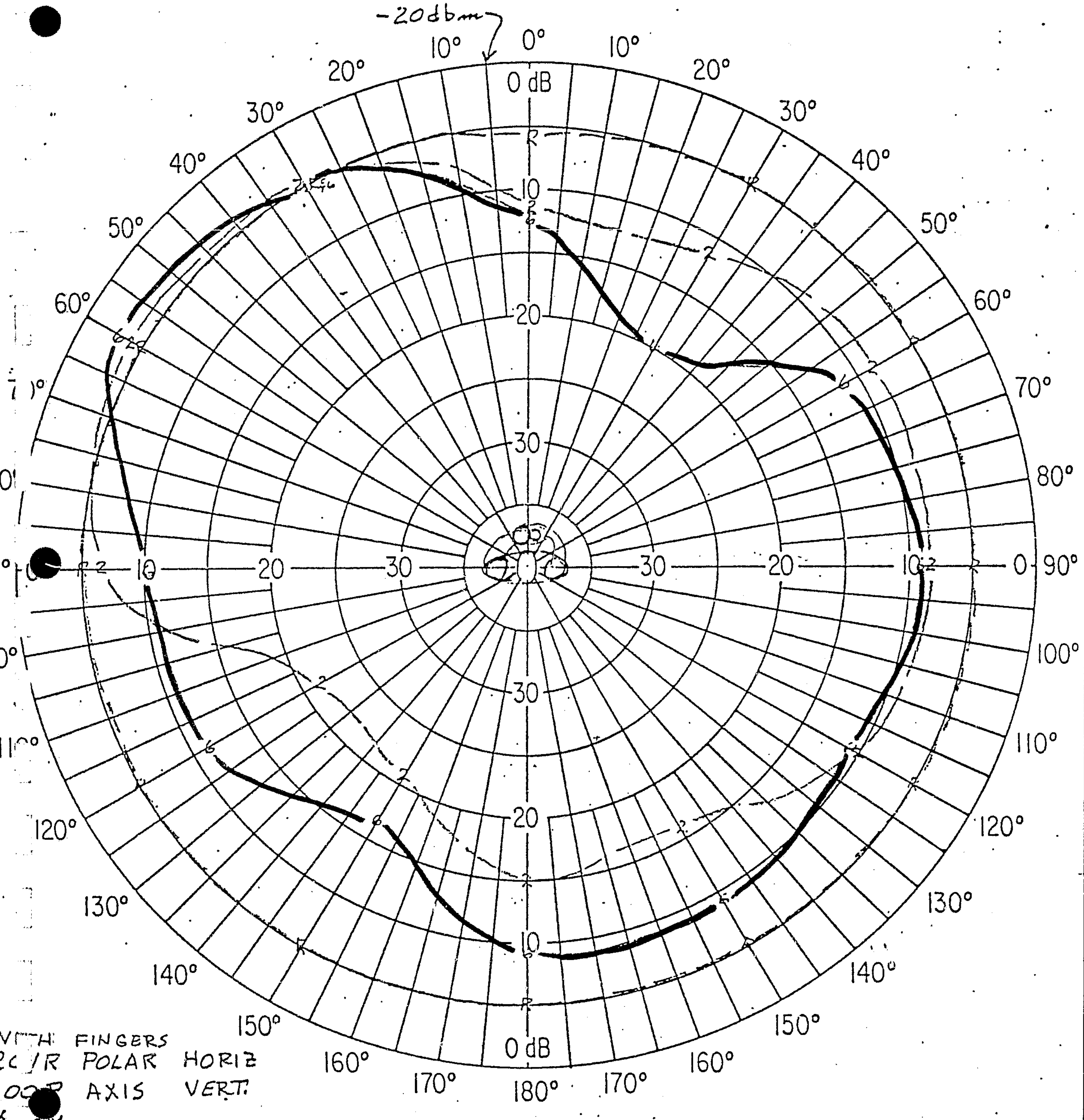


FIGURE V-29: RF RADIATION PATTERN OF ACTUATOR IN POSITION APPROXIMATING P1 AEROSPACE CORPORATION DATA (Mar.'74

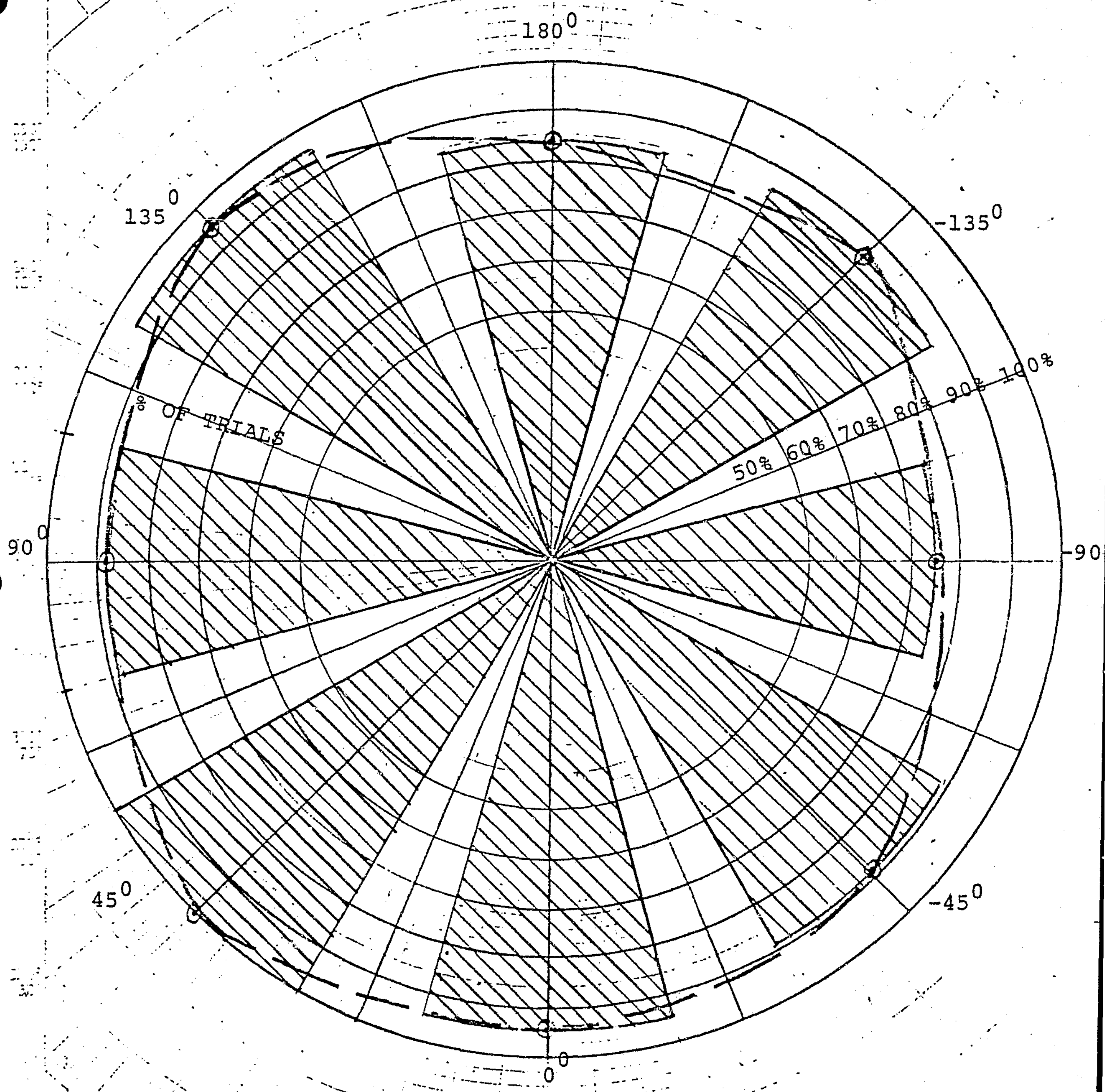


FIGURE V-30: ACTUATOR CODE TRANSMISSION, POLAR HISTOGRAM
(POSITIONS 2 & 3, AT LEAST ONE MESSAGE RECEIVED)

CONTINUED

3-25-74
(RE: DATA SHT. NOS. 6, 7 & 10.)

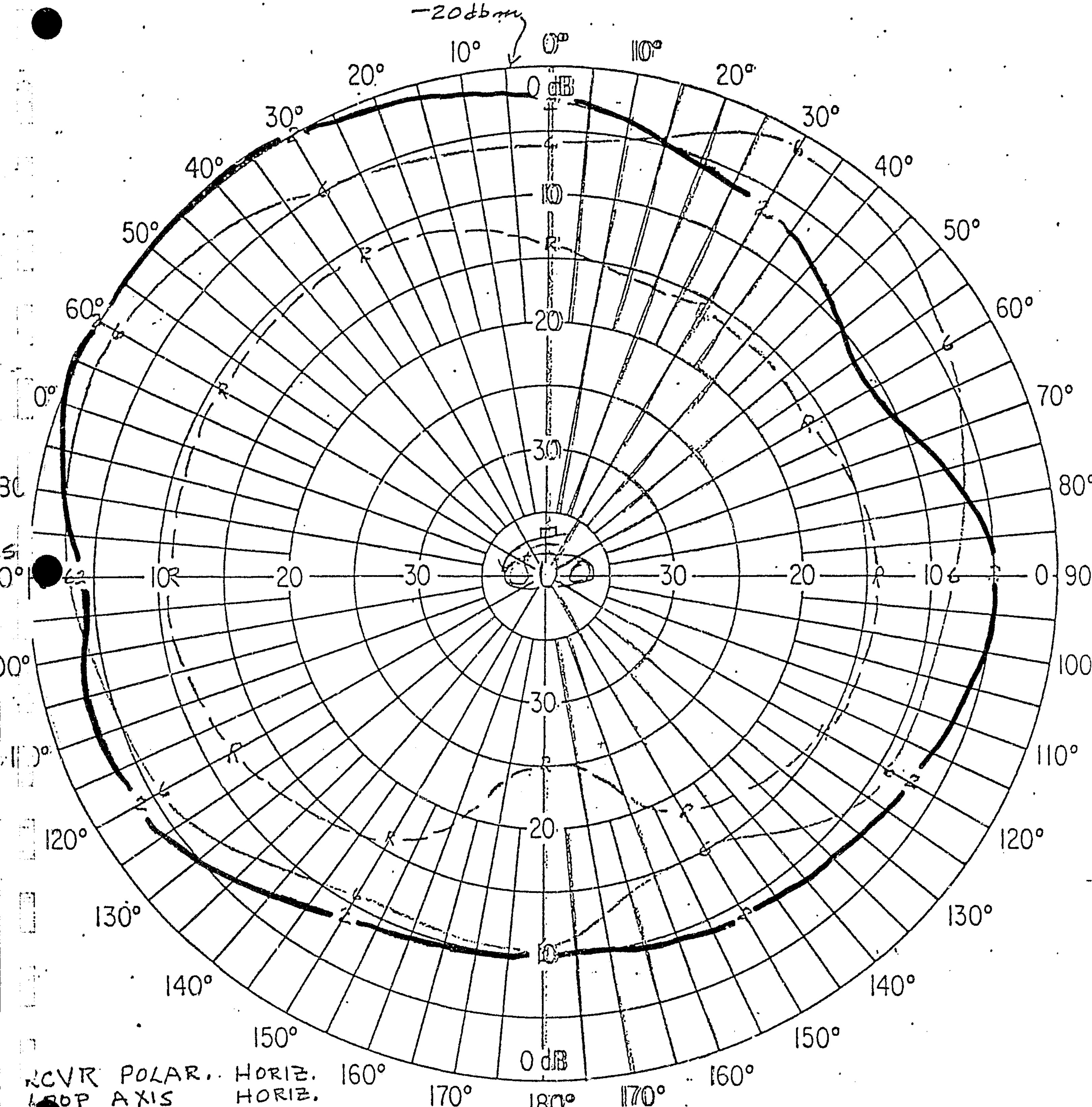


FIGURE V-31: RF RADIATION PATTERN OF ACTUATOR IN POSITION APPROXIMATING P2 and P3 (AEROSPACE CORPORATION DATA (Mar. '74) at a 90° angle to the axis of the antenna, a signal is not likely to be received. A location was discovered which had this orientation with respect to both IRR's in use; no signals were received from this location. The effects can all be avoided by proper placement of the IRR's.

The apartments at Amberson are built on a steel framework which hinders the reception of signals sent from outside the apartment containing the IRR. Signals are received readily from an actuation within any of the rooms of an apartment containing an IRR. Table V-6 shows the reliability of message reception from actuations within the apartment, the hallway outside the apartment, the apartment above the one containing the IRR, and in the vicinity of the window of the apartment above.

f. <u>Overall Reliability of CAS</u>. The overall reliability was evaluated by tabulating the results of all the scenario tests as shown in Table V-7. Messages received without actuator codes give a location code: the number of the IRR that received the signal. This would enable a response agent to answer a call even if the message was received without an actuator code. Cases where there was no response due to noise characters in the teletype were excluded from the count, as this problem has been corrected by a software modification. Data for Amberson is for actuations within the apartment containing the IRR.

TABLE V-5: TRANSMISSION RELIABILITY vs. ANGLE

BODY ANGLE	AT LEAST 1 CODED MESSAGE: BODY POSITION P1	NO. OF TRIALS	BODY POSITIONS P2 & P3	NO. OF TRIALS
0	85.3%	34	95.7%	47
45	93.7%	16	100.0%	25
90	91.2%	34	88.9%	45
135	88.9%	18	95.6%	23
180	92.8%	28	84.3%	51
-135	100.0%	18	85.7%	21
-90	89.3%	28	75.0%	40
-45	76.9%	13	89.4%	19
	Total	189 Total	Total	271 Total

TABLE V-6: TRANSMISSION RELIABILITY (AMBERSON) FOR DIFFERENT LOCATIONS

ACTUATOR POSITION	MESSAGE RECEIVED WITH ACTUATOR CODE	MESSAGE RECEIVED WITHOUT ACTUATOR CODE	NO RESPONSE	NUMBER OF CASES
Apartment Containing IRR	94%	4%	2%	156
Hallway Outside Apartment	48%	15%	38%	61
Apartment Above	0%	0%	100%	10
Apartment Above, Near Window	40%	60%	0%	10

TABLE V-7: OVERALL TRANSMISSION RELIABILITY

MESSAGE RECEIVED			MESSAGE RECEIVED WITH ACTUATOR CODE			
FIRST MESSAGE	SECOND MESSAGE	AT LEAST 1 MESSAGE	FIRST MESSAGE	SECOND MESSAGE	AT LEAST 1 MESSAGE	NUMBER OF TRIALS
ARLINGTON:						
92.3%	91.8%	94.2%	60.6%	79.5%	86.7%	843
AMBERSON:						
97.3%	96.0%	98.0%	57.6%	85.7%	94.2%	156
TOTAL:						
93.0%	92.4%	94.9%	60.2%	80.5%	87.9%	999

g. <u>Summary and Conclusions</u>. The small-scale scenario tests permit an evaluation of the effectivenss of the CAS hardware. The proposed hardware response time of ten seconds has been surpassed; the first signal is printed out at the Central Station always within eight seconds, usually in less than five seconds after actuation. Multiple actuation resulted in the reception of at least one actuator message with id code in 95% of the test cases; an actuator message (no id code) with location code, enabling a response agent to answer the call, was received in 100% of the test cases. Multiple triggering of IRR's has demonstrated the effectiveness of the queuing system; the majority of small-scale scenario tests involved multiple triggering of IRR's. The overall transmission reliability of the UHF link is 88% for the reception of at least one actuator message with id code, and 95% for the reception of at least one actuator message (no code) with location code. These figures are somewhat low due to the experimental procedure of conducting a large number of tests around "trouble spots", as well as tests to find the limits of indoor range. The reliability expected from a truly random series of actuations is higher.

Body position at the time of actuation influences the effectiveness of message transmission. Standing positions, especially P1 and P2, show a greater reliability than prone positions (P5, Pg, and P7). The presence of another body in contact with the experimenter, as in P4, does not interfere with the transmission of signals; results for this position are actually better than for an identical position without another person in contact (P3).

Body angle with respect to the IRR has little influence on the effectiveness of actuation. Field strength measurements usually show one or two weak spots in the RF field surrounding the actuator; the location of these weak spots changes greatly with the distance of the actuator from the body and the angle of the actuator's antenna with respect to the ground. Figures V-28 and V-30 show the effectiveness of message transmission for Pi, and a sum of P2 and P3. The minima in these graphs resemble the minima in field stength measurements shown in Figures V-29 and V-31.

6. <u>Results of the Large-Scale Scenario Tests</u>

The data from the test log was analyzed for the accuracy of message transmission. Out of 186 trials, actuator messages with id codes were received 93.1% of the time, actuator message (no id code) with location codes were received in 100% of the test cases. These figures are in close agreement with the results of the small-scale scenario tests indicating that the system is as reliable (or better) when used by actual users and response agents as it is when used by Compu-guard's experimenters.

The response time of the guards, from the moment an actuator is triggered until the guard arrives at the site of the actuation, was less than one minute. This means that the chance of a guard arriving at the scene of a hold-up or burglary, while the criminal is still in the immediate vicinity, is very good, assuming a guard to be located in the vicinity of the building.

In the large scale scenario tests, four IRR's were sufficient to cover the entire building (#5 Arlington Heights). The location of the IRR's is shown in Figure
With the range of the actuators set at about 50 feet, the response agent relies on the actuator code to help pinpoint the exact location of an actuation, the general location of which is given by the IRR location code. If the range of the actuators decreased, more IRR's would be needed. This would increase the usefulness and specificity of the location code in pinpointing the site of an emergency, while increasing the overall cost of the system. The actuator code in this case is still necessary in order to provide user accountability and reduce false alarms.

7. User Attitudes

It was decided that user attitudes related to the large-scale scenario tests should be surveyed by questionnaire, to provide some information on the human factors related to system design and operations.

Prior to the tests, a questionnaire (Appendix V) was circulated among the people expected to participate in the tests. The results of this questionnaire are now summarized.

The over-riding majority of potential users polled (78%) felt that too little attention has been given to the problems of personal safety for home and apartment dwellers. The citizens queried felt concerned about their ability to respond to various emergency situations. These situations include accidents, and medical emergencies, criminal incidents, fires, and various other occurences. Table V-8 summarizes the degree of concern shown by the citizens over these situations.

Eight of the nine users indicated a strong need for an emergency summoning system; no one felt that such a system was not needed at all. Given the development of an emergency response-calling system, all nine of the citizens polled would recommend its installation in their homes or apartment buildings. When questioned about its usefulness in various situations, the citizens responded that it would be most useful in assaults, intrusions, and home accidents, while it would be less applicable in fires, medical emergencies, and hold-ups outside the dwelling.

TABLE V-8: CITIZEN CONCERN ABOUT CERTAIN INCIDENTS

	Great Concern		Moderate Concern		Little Concern	
Sustaining a fall and being unable to summon help immediately	(7)	78%	(1)	11%	(1)	11%
Suffering a medical emergency and being unable to summon help immediately	(8)	89%			(1)	11%
Being surprised by an intruder in your home/ apartment	(7)	78%	(2)	22%		
Being accosted by a stranger while walking to or from your car at night	(5)	56%	(3)	33%	(1)	11%
Entering your home/ apartment in the dark	(7)	78%			(2)	22%
Leaving children at home by themselves	(5)	56%			(4)	44%
Sensing or seeing a fire start and not being able to reach a phone	(6)	67%	(1)	11%	(2)	22%
Suffering an armed or unarmed assault in the vicinity of home/apartment	(8)	89%			(1)	11%
Being forcibly disposed of personal or other property in the vicinity of home/apt.	(6)	67%	(2)	22%	(1)	11%
Being locked outside home/ apartment	(4)	44%			(5)	56%
Walking to/from neighborhood store, community center, etc.	(8)	89%	(1)	11%		

The potential users felt that the worst abuses the actuator could be subjected to were immersion in water and the shock of a fall. They felt less concerned about the accidental use of the actuator by children. The respondents felt that there were several situations in which wearing the actuator would be difficult or uncomfortable. The most frequently mentioned situations included bathing, scrubbing floors, and shopping.

When asked how to deal with false alarms, the citizens indicated that some sanctions are necessary. Four of the nine polled said only a polite warning should be issued. Five felt that the system should be taken from anyone with more than two false alarms. Three of these five felt a cash penalty should be charged for false alarms. All respondents indicated that they would take at least as good care of the actuator as they would of an expensive wrist watch.

The great concern about personal safety shown by those polled is easily understood. Of the nine citizens polled, six had been involved in an emergency situation in the last two years; three of these had been unable to summon help. Six persons had been victims of a crime involving personal injury or loss of property within the last two years.

During the large-scale scenario tests, some users tended to leave the actuator in a readily accessible place rather than wearing them. Elderly users who had difficulty in moving around quickly tended to wear the actuator at all times. The main reason given for not wearing the actuator was its bulk; a reduced size and increased attractiveness would do much to overcome this situation.

At the end of the large-scale scenario tests, most residents said they felt far more secure with the system. They also reported that in the two weeks of testing, the building and the area around it was the quietest they had seen in recent years and free of all disturbances.

8. Response Agent Attitudes

The guards from Globe Security that were hired for the large scale scenario test have worked for several years as security agents with a variety of security systems. They rated the CAS very highly and expressed enthusiasm over the system's effectiveness and ease of use. The guards were very regular in maintaining the test log and Central Station log, as well as marking the teletype output. All guards found the initializing of the system easy to perform. They gave lucid instructions to test participants concerning the use of the system.

CHAPTER VI. FINAL CONCLUSIONS AND RECOMMENDATIONS

The extensive testing of the system and its components, both in the lab and in the two real-world scenarios, have given rise to a wealth of data. This data provides valuable information on the hardware performance and transmission reliability, as well as any design or operational limitations. The analysis of this data leads to conclusions on design and performance, and recommendations for improvement.

A. Conclusions

Several different types of conclusions have been arrived at in the course of this project. These relate to the final system specifications in terms of the requirements, and the performance of the system in terms of parameters such as reliability and hardware response time. These are summarized in this section.

1. System Configuration

The system was designed exactly in accordance with requirements with the four different components: actuator, IRR, ERR, and central station. The configuration gives the desired modularity, and flexibility in installation and use.

2. Information Transmission

This deals with one of the most important parameters of system performance. For clarity, the conclusions are presented separately for each of the transmission links.

a. UHF Radio Link, Actuator to IRR

This link has been implemented at 462 MHz, a frequency found to have low noise and limited activity due to other transmitters. The large scale scenario tests indicated that 100% transmission reliability was attained for actuator messages without code, and about 94% for messages with code. Results of the small scale scenario tests show an lower reliability,about 95-98% for messages without code and 80-90% for messages with code. The lower numbers in these tests may be due to the test procedure which called for a large number of trials to be conducted under adverse conditions (i.e. conditions in which difficulty in transmission was encountered).

The tests show that the simple antenna and transmitter used in the actuator are adequate for the desired range of 50 feet. The polar pattern of RF transmission is generally ommidirectional, with one or two null areas. The transmission of two sets of messages, 30 seconds apart, is found to be a major advantage and significantly improves transmission reliability (sometimes as much as 30%). This feature helps to offset the variations due to body position and angle.

The repetition of the actuator ID code within each one second transmission is also a valuable feature. It enables error correction at the central station. The success of this approach is indicated in the negligible numbers of messages with an inaccurate actuator code.

No problems were encountered due to transmitter drift or most types of detuning. The wide bandwidth of the scanning receiver seems to be adequate to compensate for this. However, the reliability of transmission of the second message is greater than that of the first. Since the tests were conducted such that the only difference between the two is the act of triggering at the time of the first message, it is possible (though not confirmed) that the movement of the berylbium-copper switch mechanism could sometimes cause detuning transients. This can be corrected by the use of a smaller triggering mechanism with a smaller mass of RF-conductive material. The UHF link was found to resist spurious triggering. Simultaneous multiple actuations did not affect the performance of the systems and did not cause any significant loss in the data necessary for response. This indicates the proper functioning of the design elements introducted to handle message-interference problems.

b. Power-line Link, IRR to ERR

This link operates satisfactorily, for data transmission. Some of the lab tests show that a data transmission rate much higher than 60 baud is possible with no significant degradation in error-rate or transmission reliability. These higher speeds can be implemented in future generations of the system.

The IRR is insensitive to most types of random and burst noise on the power-line. In the earlier phase of testing, the IRR reset mechanism was sometimes affected by broad-band high level RF noise on the power line. This was later corrected and the problem was eliminated.

The reset mechanism, however, represents an area where design improvement is desirable. In the present system, the failure of this mechanism can cause system problems. The addition of a fail-safe mechanism (e.g. automatic reset after one minute) is expected to eliminate this as a potential source of problems.

Transmission reliability on the power-line in excess of the requirement of 99.9%. Moreoever, the signal levels used give this reliability at any location on the power-line on the secondary winding of a power transformer, even a multi-phase secondary. This eliminates the need for by-pass coupling between different power phases on the same transformer.

In terms of message interference due to the simultaneous triggering of many IRR's, the random-time delay technique used for message queuing works satisfactorily. Test results show that multiple IRR triggerings do not result in loss of data, merely an increase in the hardware response time for the IRR's at the end of the queue.

c. Telephone Line Link, ERR to Central Station

The dedicated voice-grade telephone link works satisfactorily, with a reliability in excess of the 99.9% requirement. The speed of data transmission can be increased to 300 baud or greater with no appreciable increase in error-rate, to keep up with any future increase in the data-transmission rate on power-lines.

3. Hardware Response Time

This time is largely determined by the link between IRR and ERR. In more than 80% of the trials, the hardware response time for each message is less than five seconds. The worst case hardware response time for a single message is less than eight seconds. This is significantly better than the requirement of 10 seconds. If a number of IRR's are simultaneously triggered and they form a queue, the first message has a response time of less than five seconds (typical) or less than eight seconds (worst-case). Other messages, however, come in sequence, the delay depending on the position in the queue. (See Figures V-19, V-20 for details).

This suggests that the present data transmission rate is probably adequate, for any one message. However, to reduce the queuing delay, two techniques can be considered, The data transmission rate on the power line and phone line can be increased, possibly by a factor of 5. Secondly, the random time-delay technique being used can be replaced by a fast time division multiplexing scheme in which IRR's are scanned at a uniform rate.

4. Component Design

The tests give an insight into the performance of the hardware, both from a technical and a human factors standpoint.

a. Actuator: This meets all the requirements established for its operation. It is relatively small, easy to wear and operate, and reliable. It seems to be acceptable to users, and its two-button actuation minimizes accidental triggering. However, there are several areas where improvement is possible.

It its present form it would be difficult to manufacture on a large-scale. The effective radiated power (ERP) is a very sensitive function of small changes in antenna location relative to the battery and the switch mechanism. Detuning of the carrier can occur due to the battery and the switch mechanism. Both the ERR and the detuning effects can be minimized by using smaller switches of different design, and by changing the location of the battery away from the immediate vicinity of the antenna. Also, carrier detuning due to the body can be minimized by increasing the distance between the antenna and the upper watch crystal. With these changes, transmission reliability can also be increased.

A further improvement in transmission reliability is possible with an increase in the ERR. The present ERP level is below that allowable under FCC regulations, Part 15, Sub-part E.

The RF transmitter has performed well, and the absence of a crystal-controlled oscillator does not seem to affect reliability given the wide-band scanning receiver in the IRR. The use of the antenna as part of the tank circuit seems to be a significant design feature.

The static shift-register memory used has performed flawlessly. No problems have been noted in the memory retention of the actuator ID code. Battery life is estimated to be well in excess of requirements.

The hybrid micro-circuit used is susceptible to severe shocks, such as the drop of an actuator six feet or more to a hard floor. Such shocks tend to shake loose one or more of the components on the sub-strate. This problem can be corrected by improved (and more expensive) bonding techniques, or by replacing the hybrid by a custom monolithic chip.

The present packaging is adequate and can handle all the environmental requirements defined. A reduction in size is, however, desirable from a human factors standpoint.

b. Internal Receiver Relay: The performance of the IRR can be considered in terms of the performance of its three constituent modules: the antenna, the UHF receiver, and the digital section.

The antenna has a satisfactory polar pattern and provides adequate coverage. It is well matched to the front end of the UHF receiver, and is an inexpensive printed-circuit design.

The UHF receiver has a scanning front end which sweeps over a 10MHz band, for the actuator signal. This receiver has performed well. However, the alignment and tuning procedures have turned out to be more complex than expected. Some simplification in these is desirable especially for large scale manufacture. The receiver does not respond to spurious signals or EMS noise. Its sensitivity of 2μvolts and noise figure are reasonable and adequate in terms of the desired range, reliability, and cost.

The digital section of the IRR performs adequately, but has room for significant improvement. The failure of the reset mechanism in one IRR can block transmission by other IRR's. This is a potential weakness which can be corrected either by introducing a fail-safe reset mechanism, or by using time-division multiplexing. The IRR's are not presently supervised, disconnection of an IRR from the power-line is not annunciated at the central station. The integrity of the system can be increased by adding this supervisory feature, possible with time-division multiplexing. Finally, the hardware response time for messages in a queue can be improved by increasing the data transmission rate and by providing a better means for queuing. Time-division multiplexing can be used for this purpose as well. The reason for not using this time-division multiplexed approach at the time of design was the high cost of the hardware necessary. However, with improvements in design and the availability of certain electronic components at reduced prices, this TDM approach may represent a major area of improvement in component design.

The installation of the IRR is easy and inexpensive. It can be screwed into a 2-receptacle 110V wall panel, to resist tampering. A reduction in volume is possible and desirable.

c. External Receiver Relay: The ERR was designed at a cost below that indicated in the requirements by an order of magnitude. The unit has performed satisfactorily, but can be improved in some ways. Protection against RF interference on the power line in the power line module can be improved. The phone-line coupler can be improved to handle a higher data rate.

d. Central Station: The implementation of the micr-computer approach created a number of unforeseen problems. The use of the micro-computer was intended to provide a versatile and powerful, low-cost, central station with a technology that would be cost-effective for several years to come. However, the off-the-shelf micro-computer components bought had hardware and software problems. In addition to building the central station work had to be done on reqriting basic software and developing diagnostic programs. This led to delays in the completion of the central station, but the final product has performed well. The first version of the central station was susceptible to thermal and other transients, affecting the operation of the time-and-date check. The second version has been corrected for this.

The present central station represents a state-of-the -art product which offers performance in small size at low cost. Further improvements in software can greatly increase its capability. Improvements in the fabrication of the printed circuit boards developed for the hardware can improve reliability in the field. However, the basic architecture of the central station seems to be effective and sound, and still represents the best approach to implementation.

.5. Cost

The estimated cost of manufacturing the system hardware is shown in Table VI -1. This shows that the cost of

TABLE VI-1: ESTIMATED MANUFACTURING COST OF CAS COMPONENTS

Component	Production Quantity		
	< 1000	1000-10,000	> 10,000
Actuator	$ 40	$ 30	$ 25
IRR	$120	$ 80	$ 60
ERR	$ 50	$ 35	$ 25
	< 10	(10-100)	100>
Central Station	$2800	$1800	$1300

the actuator is within requirements, the IRR is on the high side, the ERR is an order of magnitude below, and the central station is within requirements. Substantial reductions in manufacturing cost are possible with additional work in product engineering and tooling (special jigs, fixtures, etc.).

6. Technical Limitations

The system in its present design has some technical limitations in terms of use and operation, as summarized below:

- Range of 50 feet
- Unsupervised operation of IRR
- Size of actuator, IRR package
- Length of actuator id code, IRR location code
- Hardware response time for queued messages

These limitations can be changed by improvements in design, many of which have been discussed in the sections above.

7. Manufacturing Limitations

The design of the components is not presently geared to large scale manufacturing. The limitations lie in the following areas:

- Variations in the ERP (effective radiated power) of the actuator due to batteries and switches
- Slow procedure in the tuning and aligning

the UHF receiver of the IRR

- Layout of PC boards used
- Packaging

8. <u>Marketing Limitations</u>

These are related to the manufacturing limitations, in terms of cost to the user. From a standpoint of aesthetics, the size of the actuator and IRR should be reduced. Attention needs to be given to the field serviceability of the components, the ease of installation, and maintenance in different scenarios.

B. <u>Recommendations</u>

This project has resulted in two kinds of recommendations. The first kind deals with improvements within the context of the present set of requirements for CAS. The second kind deals with the upgrading of CAS to play an expanded role in the security environment.

1. <u>Improvements to Basic Citizens Alarm System</u>

The testing of the system and the experience gained in its design suggest that some improvements are possible which should be considered in future generations of such systems. These are summarized in Table VI-2.

2. <u>Expansion of CAS Capabilities</u>

The Citizens Alarm System is basically a personal digital communication system. It's scope and range of application can be greatly increased with some modifications in system design and upgrading in performance. These recommendations are summarized in Table VI-3.

3. Follow-up.

In conclusion, Compu-guard submits that the recomendations summarized in Tables VI-2 and VI-3 be evaluated and acted upon as follow-up to this program. It is also important to note that the testing conducted in this program was, at best, a very limited test of hardware performance. A true test of system performance, including the interface of CAS with users and response agents, will only be possible in a large-scale operational demonstration of the system in several real-world scenarios.

TABLE VI-2: RECOMMENDATIONS FOR IMPROVEMENT IN CAS DESIGN

COMPONENT/LINK	FUNCTIONAL AREA	SPECIFIC RECOMMENDATIONS
Actuator	Size	Reduce
	ERP	Increase up to FCC limit (Part 15, E)
	Frequency	Define bands or channels, for optimum use and signal/noise
	Antenna	Reduce the effect of nulls in radiation pattern
	Digital section	Use monolithic chip for improved reliability, cost
	Batteries	Change location, smaller size
	Switch (trigger)	Reduce in size, less copper
UHF link	Transmission reliability	Increase to 97-98%, worse-case
	Range	Adjustable from 20 feet to 100 feet
IRR	RF Sensitivity	Adjustable for adjustable range
	Frequency	Bands or channels, same as the actuator
	Alignment, Tuning	Simplify
	Supervision	Add supervisory circuit e.g. by time-division multiplexing.
	Queuing	Reduce delay
	Reset mechanism	Increase reliability
	Size	Reduce
	PC layout	Improve to allow large-scale manufacture

TABLE VI-2: (Continued)

COMPONENT/LINK	FUNCTIONAL AREA	SPECIFIC RECOMMENDATIONS
Power-line Link	Data transmission	Increase speed
Telephone Link	Data transmission	Increase speed
Central Station	Supervision	Add circuit to supervise IRR's, e.g. by time-division multiplexing
	Signal Processing	Provide ability to receive IRR data while messages are being printed for another
	Software	Improve efficiency of programming code

TABLE VI-3: RECOMMENDATIONS FOR EXPANSION OF CAS CAPABILITIES

APPLICATION	RECOMMENDATIONS
Indoor Use	Adjustable range, reduce actuator and IRR size, increase reliability, add supervision of IRR's
Outdoor Use	Increase range (300-500 feet), increase environmental requirements
Simplified Use (e.g. in convenience stores)	Interface IRR to a phone-dialer, using regular switched telephone network
Automatic Response Agent Location	Modify actuators and IRR's for this purpose
Special Response Agent Actuators	Modify actuators to provide response agents with several assistance options

END