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Raytheon

1 April 1996

JGD:nt:ESL:96:030

U. S. Department of Justice
National Institute of Justice
633 Indiana Avenue
N. W. Room 866
Washington, DC 20531

Attention: Raymond L. Downs, Staff Contact

Subject: Final Report for Electromagnetic Gun Detection Demonstration System

Reference: Contract Number 95-1J-CX-K008

Gentlemen:

Raytheon Electronic Systems is pleased to submit three (3) copies of the subject report in accordance with the special condition #7 of the referenced contract.

Should you have additional questions, I can be reached directly at (508) 858-5897.

Very truly yours,

RAYTHEON ELECTRONIC SYSTEMS

Joseph G. Doonan

Joseph G. Doonan
Sr. Contract Administrator
Electronic Systems Laboratories

NIJ Contract
Kickoff Meeting

June 2, 1995

G. Milano

Agenda

• Greeting and Introductions - Development History - Program Overview	G. Milano
• Demonstration System - Design Concept - Theory of Operation - Present Design	C. Ciany
• Testing Program - Summary - In-house Testing - Field Testing	C. Ciany
• Project Execution Plan & Schedule - Project Execution Plan - Project Execution Schedule	G. Milano
• Potential Additional Tasks	G. Milano
• Facility Tour	All

Introductions

- Business Area Program Manager - Russ Cardoza
- Project Manager - Gary Milano
- Principal Investigator - Chuck Ciany
- System Engineer - Bob Jordan
- Project Engineer - M. Nadeau

Development History

- Dr. George Keller's invention disclosure submitted to Raytheon - August 17, 1993.
- Raytheon made in-house IR&D investments for years 1993, 1994, and 1995.
- Feasibility demonstrated in Portsmouth - summer of 1994 (Single axis transmit and receive, near field demonstration).
- Weapon orientation dependence highlighted as a problem - summer of 1995.
- Present focus is on building an orientation independent prototype with increased range.

Program Overview

- Award date - April 14, 1995.
- Period of performance - March 1, 1995 to November 1, 1995.
- Objective: Test Raytheon's prototype handgun detection system in an operational but friendly environment in order to determine the performance as a function of probability of detection and false alarm rate.
- Deliverables:
  - Quarterly Progress Reports
  - Final Activity Report

DEMONSTRATION SYSTEM DESIGN CONCEPT

THEORY OF OPERATION

THEORY OF OPERATION

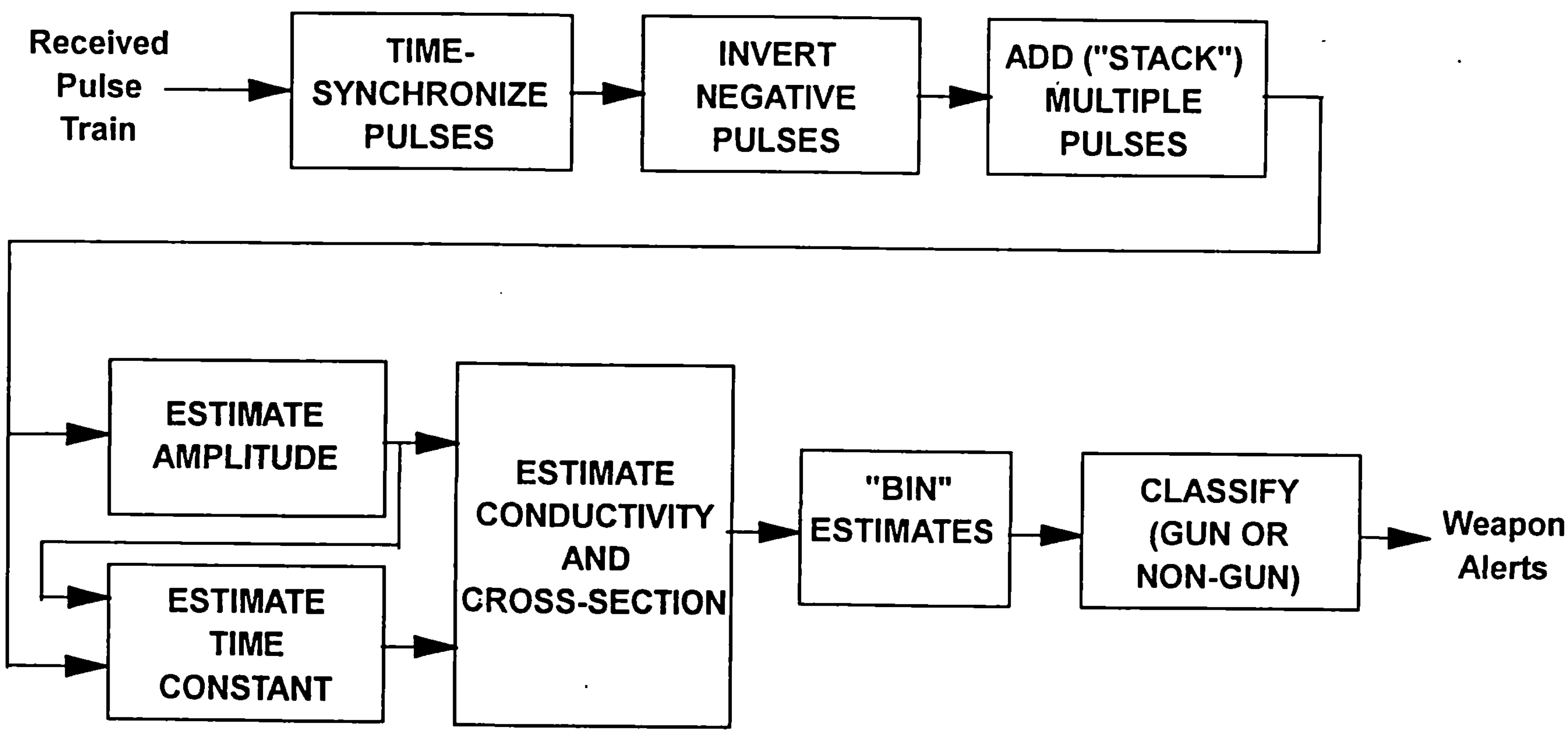
- WEAPONS EXHIBIT PREDICTABLE EM RESPONSE TO INCIDENT EM HEAVISIDE PULSE TRAIN

- RESPONSE CAN BE QUANTIFIED BY ESTIMATING RECEIVED PULSE AMPLITUDE AND EXPONENTIAL DECAY TIME FROM MULTIPLE PULSES ("STACKING")

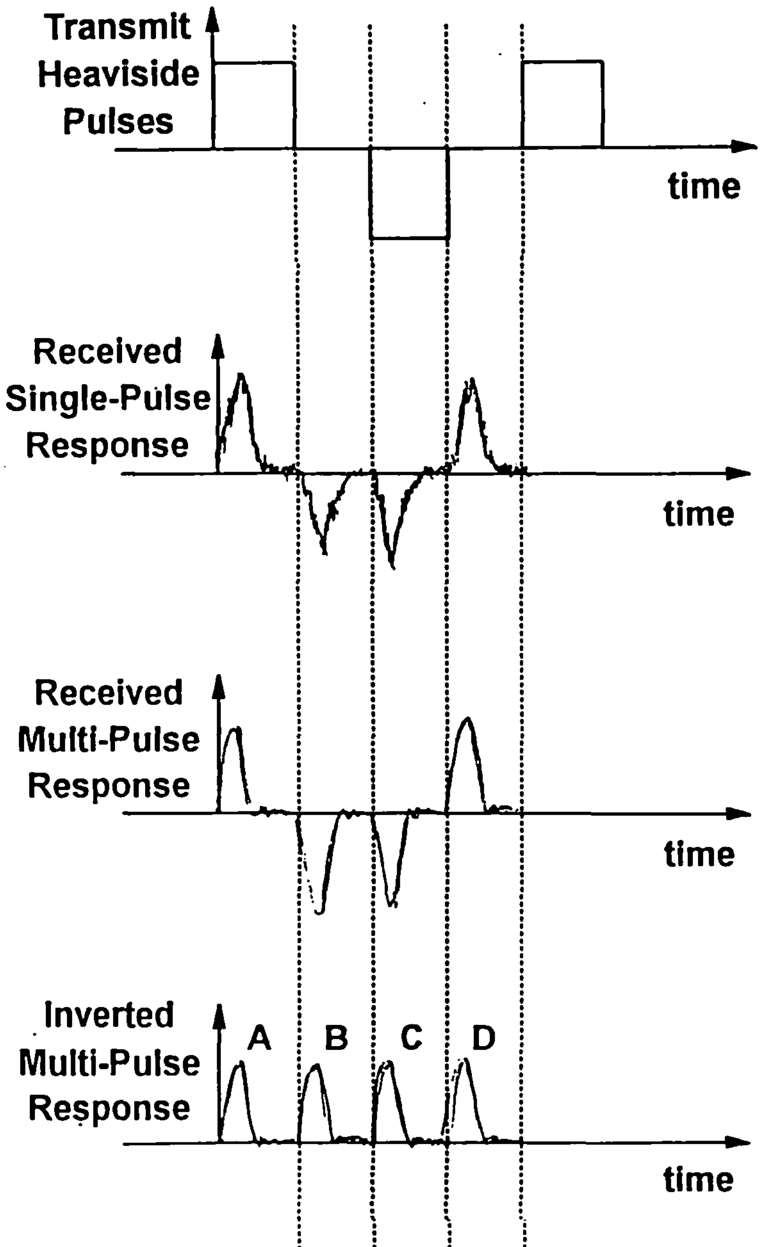
- PULSE AMPLITUDE AND TIME CONSTANT ESTIMATES CAN BE MAPPED INTO CONDUCTIVITY AND CROSS-SECTION ESTIMATES ("BINNING")

- WEAPONS ARE DISTINGUISHED FROM NON-WEAPONS SINCE THEY OCCUPY IDENTIFIABLE REGIONS OF THIS BINNED SPACE ("CLASSIFICATION")

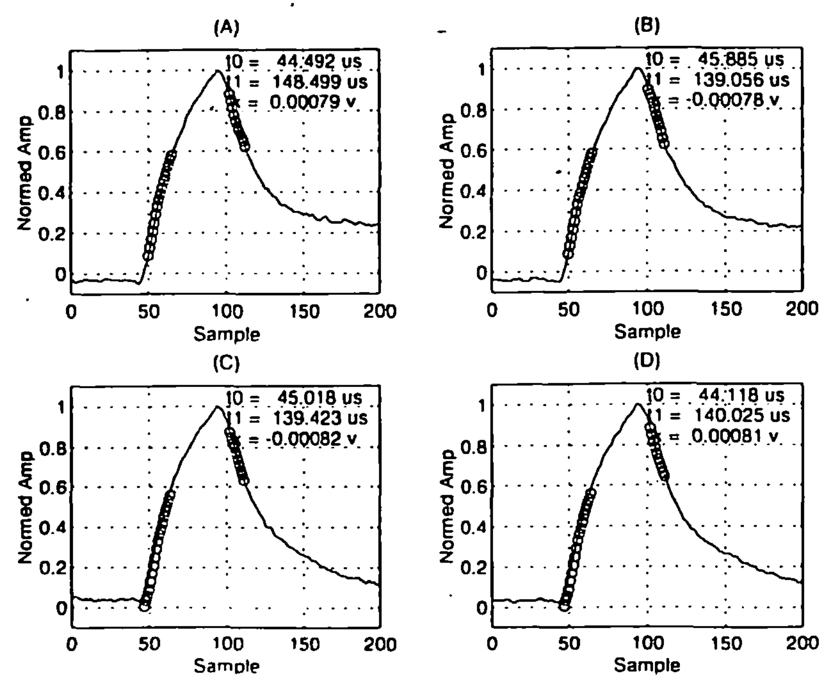
THEORY OF OPERATION:
FUNCTIONAL FLOW DIAGRAM



THEORY OF OPERATION: EXAMPLE OF EXPERIMENTAL STACKING MEASUREMENTS

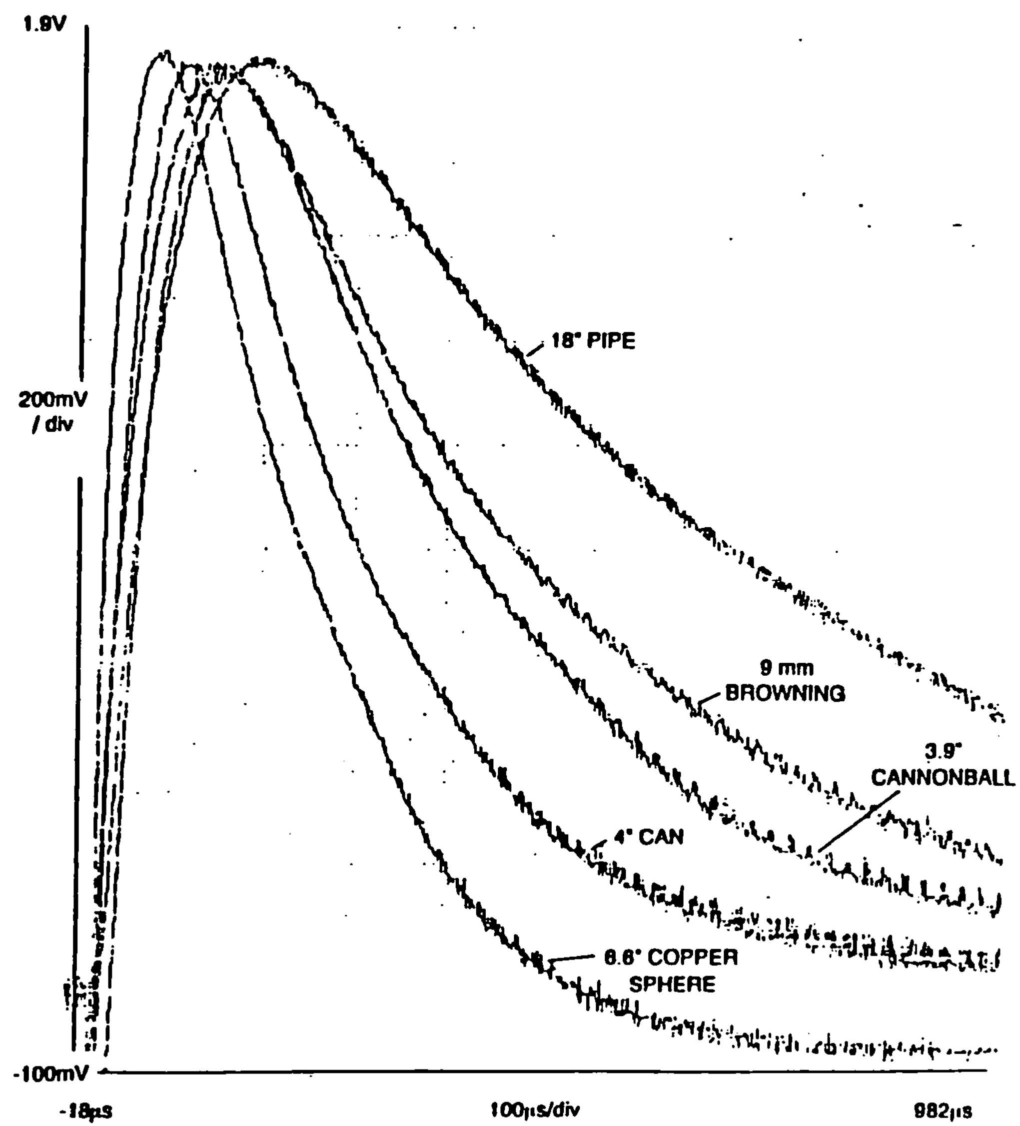


Sample Processed Multi-Pulse Response Showing Time Constant Estimation Intervals:

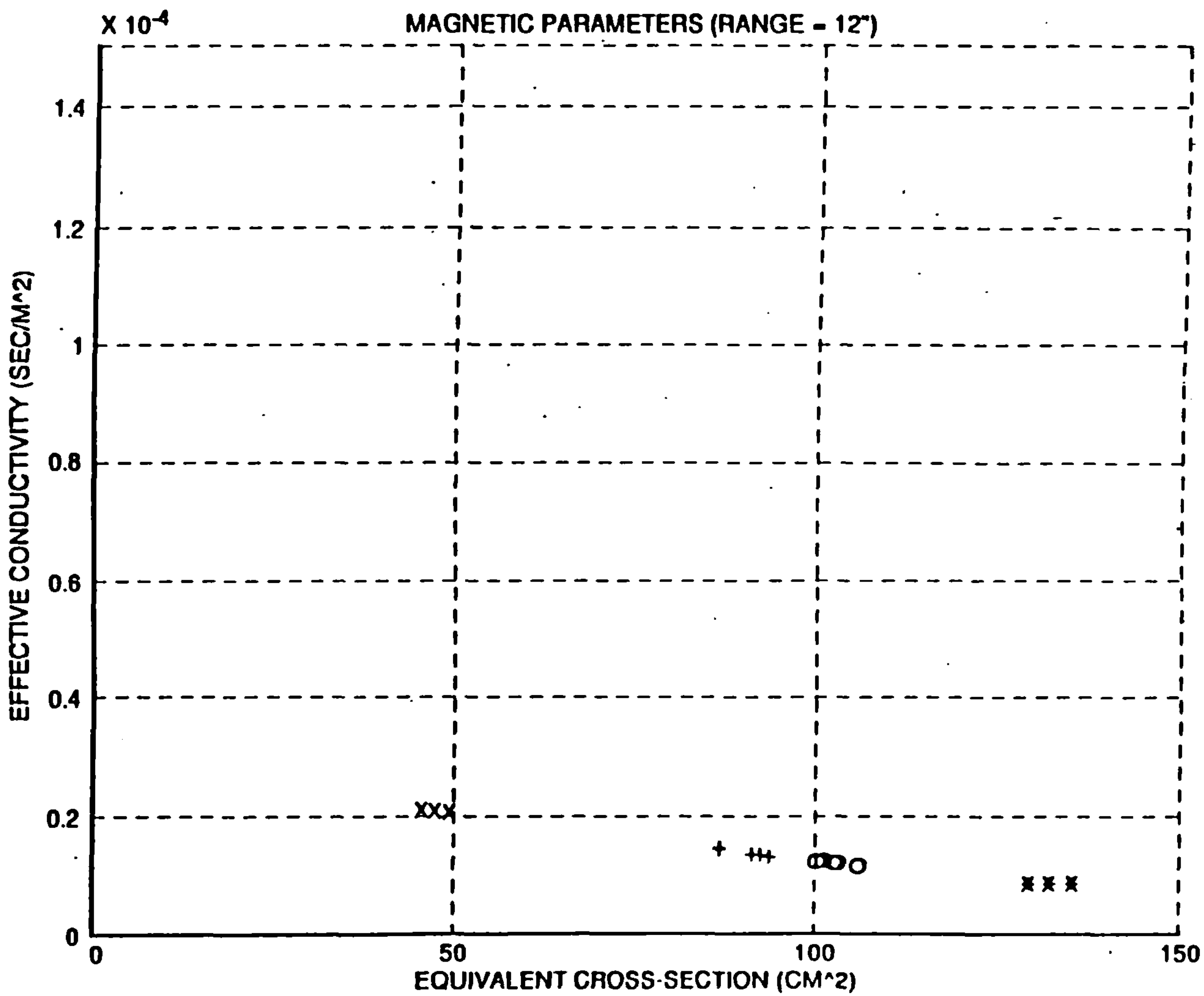


23-Dec-94

THEORY OF OPERATION: SINGLE AXIS EXPERIMENTAL RESULTS FOR TIME CONSTANT ESTIMATES OF VARIOUS OBJECTS



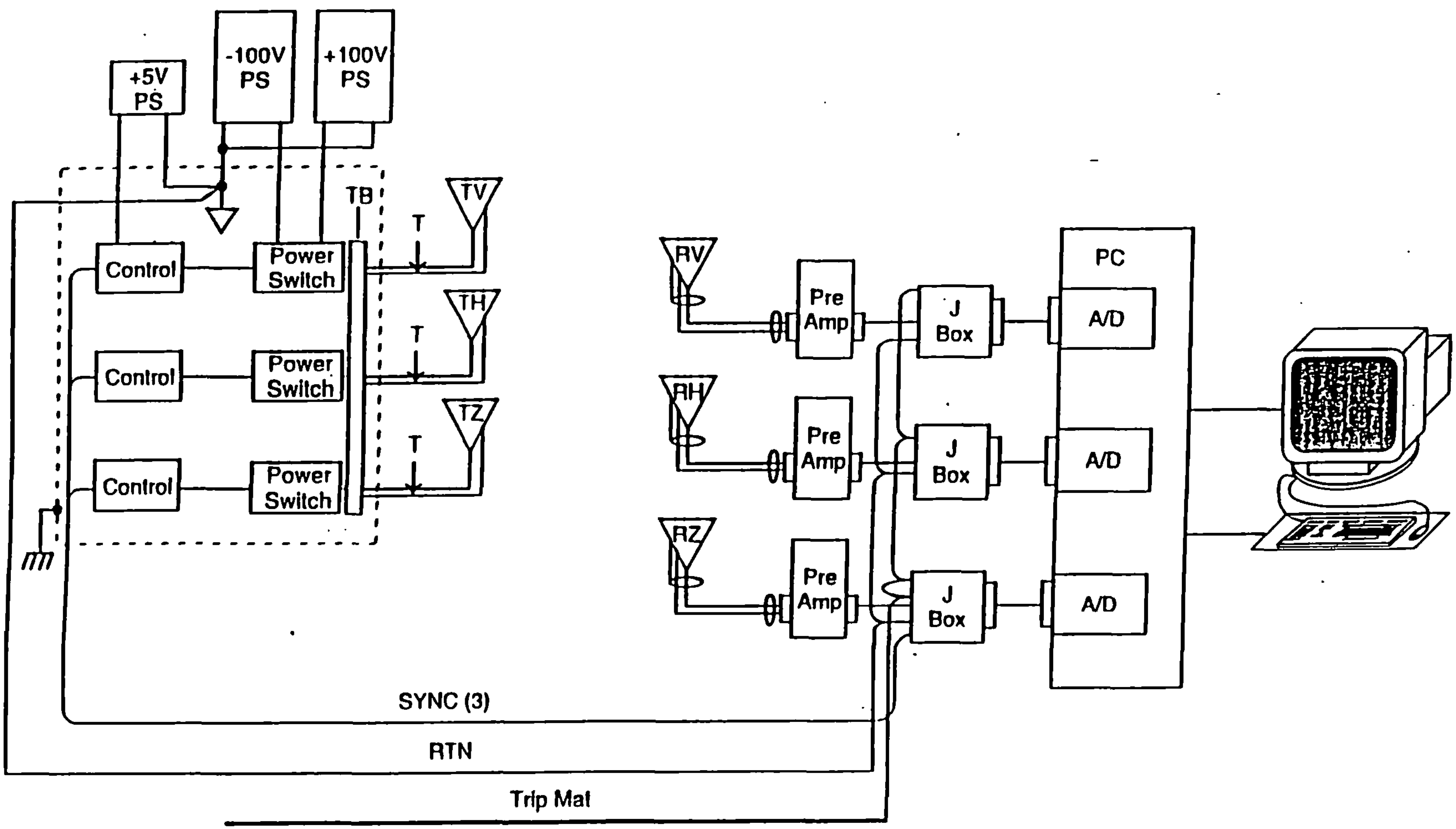
THEORY OF OPERATION: SINGLE-AXIS EXPERIMENTAL RESULTS FOR CONDUCTIVITY/CROSS-SECTION ESTIMATES OF VARIOUS OBJECTS



X = 12" STEEL 3-HOLE PUNCH
+ = 12" ADJUSTABLE WRENCH
REF: 3.9" DIA SOLID IRON SPHERE
O = 10" VICE GRIP WRENCH
✱ = 9mm BROWNING W/O CLIP

PRESENT DESIGN

PRESENT DESIGN: SYSTEM HARDWARE BLOCK DIAGRAM



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PRESENT DESIGN: SYSTEM SOFTWARE BLOCK DIAGRAM

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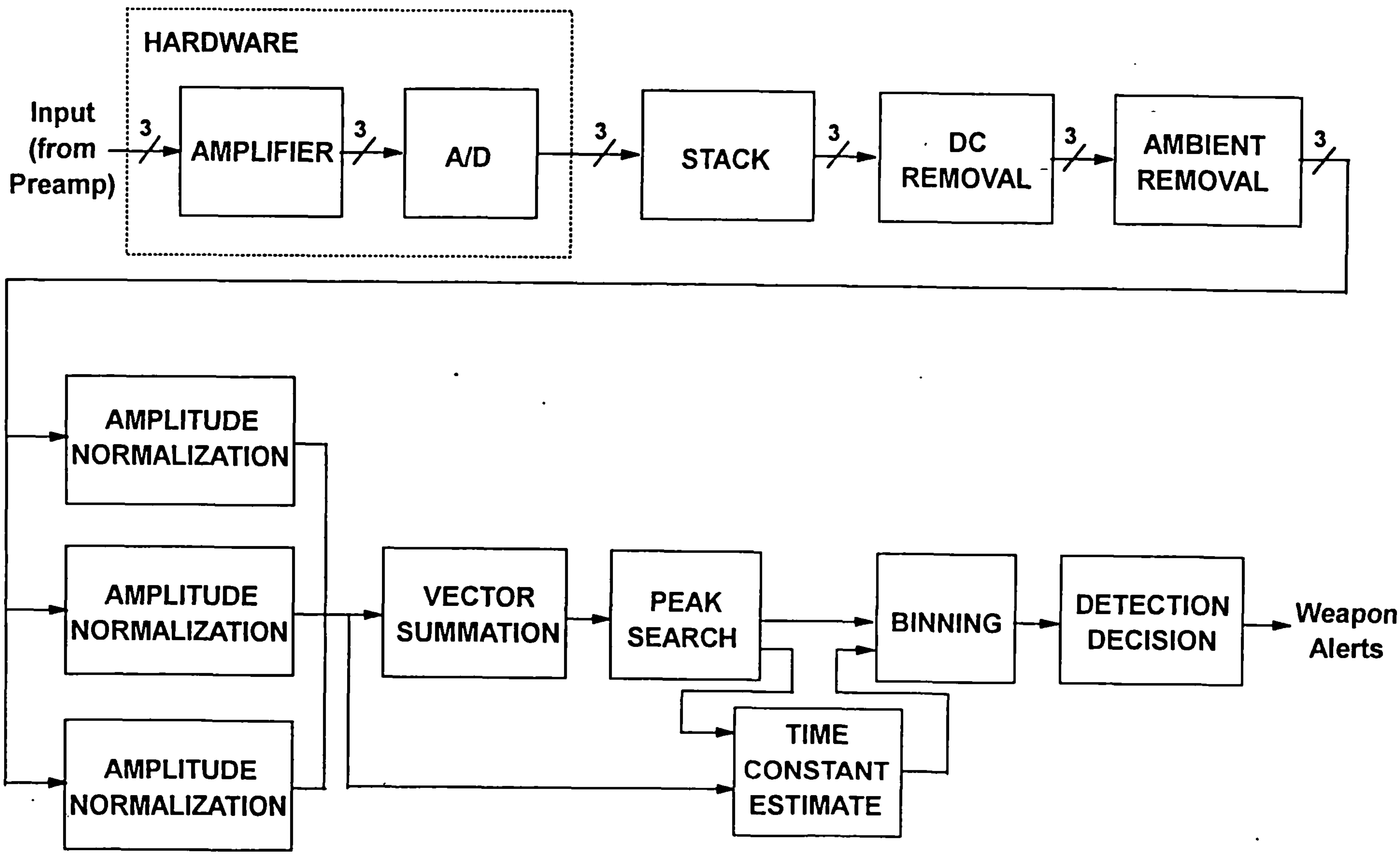

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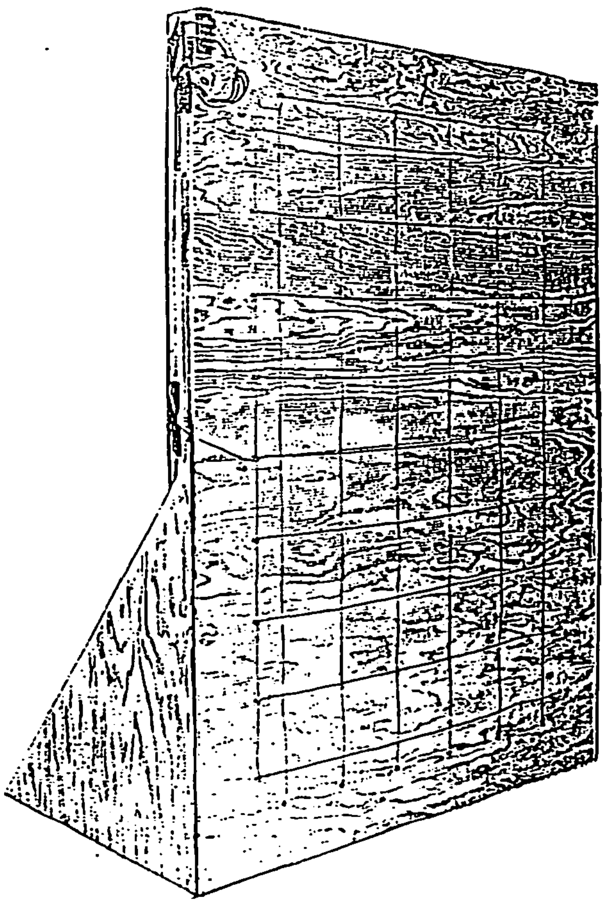
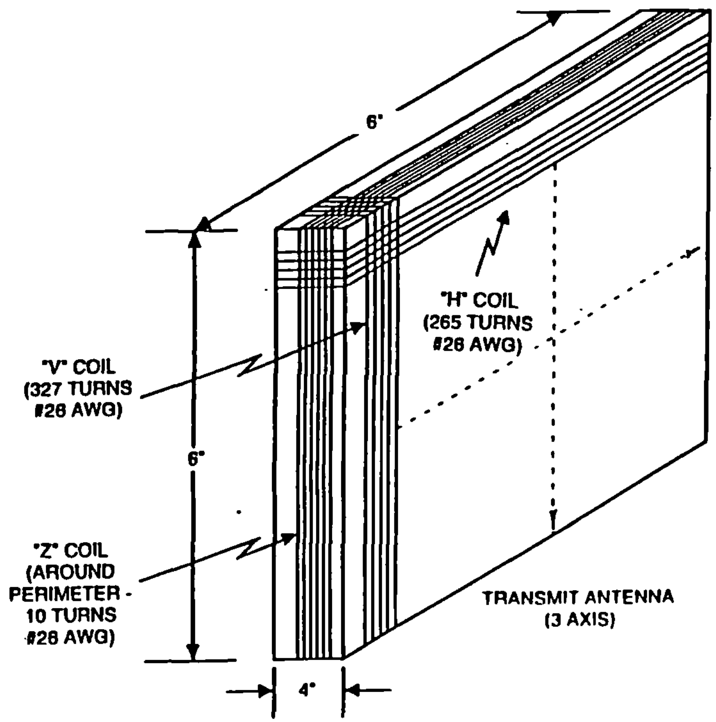
PRESENT DESIGN: EVOLUTION OF TRANSMITTER ANTENNA DESIGN

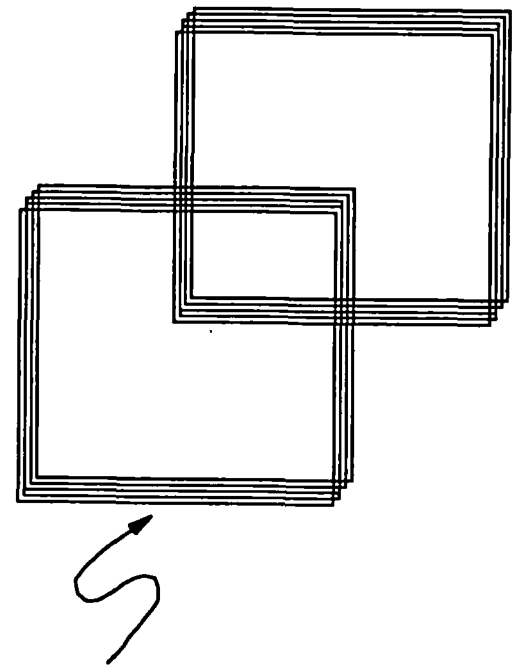
ORIGINAL CONCEPT: ELECTRIC DIPOLE



INTERMEDIATE CONCEPT: MAGNETIC DIPOLE



PRESENT CONCEPT: HELMHOLZ LOOP



~ 10 TURNS
PER LOOP

PRESENT DESIGN: SAFETY STUDY SYNOPSIS

- **DEFINITIONS:**
  MSL = MAXIMUM SAFE RADIATION LEVEL
  MDL = MINIMUM REQUIRED RADIATED LEVEL FOR RELIABLE DETECTION
  ρ = RATIO OF PEAK-TO-MINIMUM RADIATED FIELD LEVEL

- **SAFE LEVELS ARE MAINTAINED IF AND ONLY IF ρ < MSL / MDL**

- **RECOMMENDED SAFE LEVELS FOR PACEMAKERS: MSL = 120 uT AT 250 Hz**

- **MINIMUM RADIATED LEVELS FOR CURRENT DESIGN (250 HZ REP RATE):**
  30 uT FOR PORTAL SIZE PASSAGE (6 ft L x 3 ft W x 7 ft H)
  48 uT FOR CORRIDOR SIZE PASSAGE (7 ft L x 7 ft W x 9 ft H)

- **CORRESPONDING REQUIRED PEAK-TO-MIN RATIO IS ρ < 120 uT / 48 uT = 2.5**

- **SYSTEM SAFETY CONFORMANCE REQUIREMENTS:**
  TRANSMITTER ANTENNA WITH FIELD UNIFORMITY OF ρ < 2.5 , AND/OR
  REDUCTION OF RECEIVER MDL TO < 48 uT TO RELAX REQUIRED FIELD UNIFORMITY

- **RAYTHEON IS INVESTIGATING BOTH OPTIONS IN CURRENT ANTENNA STUDY**

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PRESENT DESIGN: MDL VS HORIZONTAL RANGE FOR INTERMEDIATE RAYTHEON WEAPON DETECTOR SYSTEM

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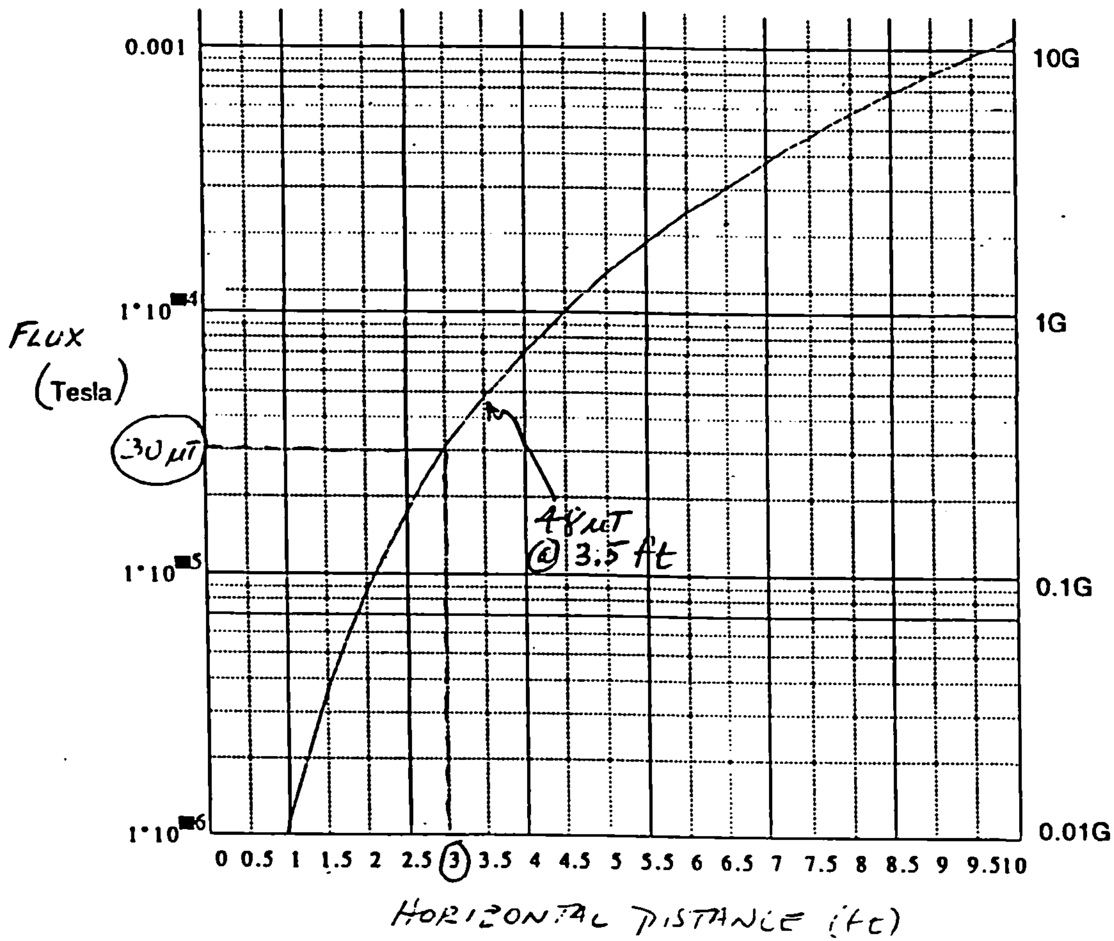
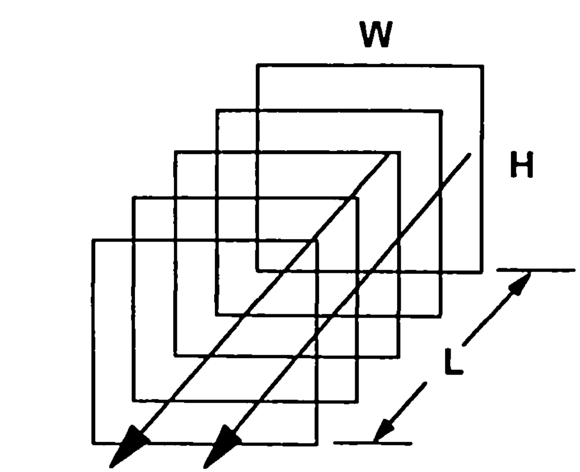
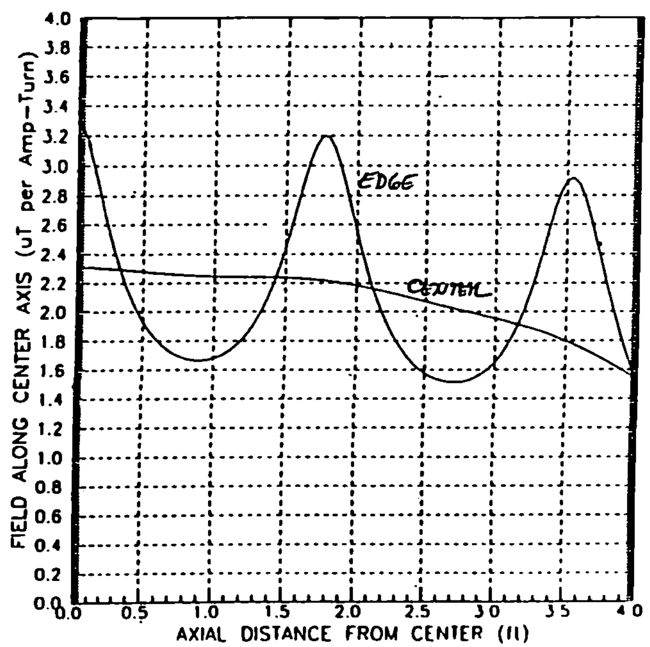


PRESENT DESIGN: EXAMPLE AXIAL ALONG-PASSAGE RADIATION PATTERNS FOR 5 LOOPS

CONFIGURATION

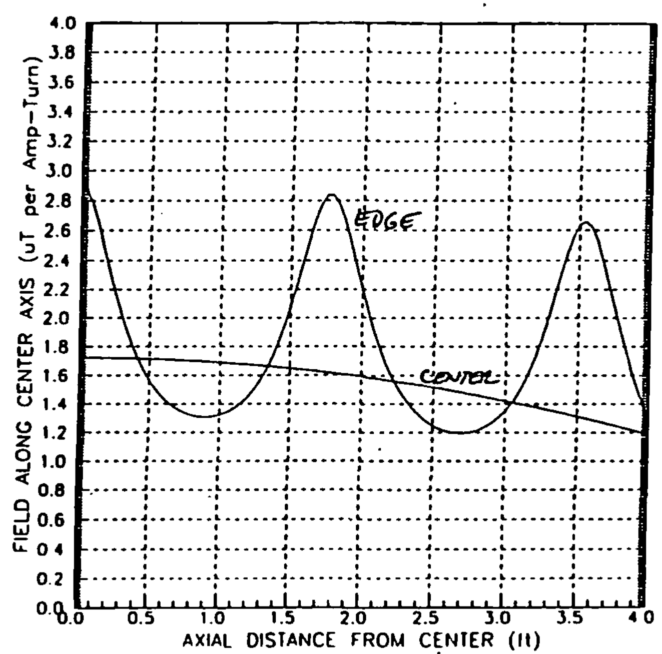


PORTAL APPLICATION (W = 3.3 ft, H = 7 ft, L = 7 ft)



$\rho = 3.26 / 1.52 = 2.1$

CORRIDOR APPLICATION (W = 7 ft, H = 9 ft, L = 7 ft)



$\rho = 2.9 / 1.2 = 2.4$

PRESENT DESIGN: SUMMARY OF SYSTEM DESIGN CHANGES

DIFFERENCE	ORIGINAL PLAN	PRESENT PLAN
1) Detector Configuration	Planar (Monostatic)	Walk-Through Portal (near-field) (Bistatic)
2) Tx Pulse Rep Rate	20 - 50 Hz	250 - 1000 Hz
3) Safety Conformance	Well Below U.S. & European Stds.	Below U.S. Stds.
4) Processor Implementation	Real-Time by mid '95	Off-Line (Matlab-based) by August '95 Demo

TESTING PROGRAM

TESTING PROGRAM SUMMARY

CATEGORY	DATE & PLACE	STATUS
SINGLE-AXIS VALIDATION OF GUN DETECTION	7/94 at RAYTHEON	COMPLETED
MULTI-AXIS VALIDATION OF GUN DETECTION	3/95 INITIATED at RAYTHEON	IN PROCESS
ANTENNA TEST & EVALUATION	6/95 at RAYTHEON	PLANNED
SYSTEM INTEGRATION & WEAPON CALIBRATION	7/95 at RAYTHEON	PLANNED
SYSTEM FIELD TESTING	9/95 at SALVE REGINA	PLANNED

IN-HOUSE TESTING

IN-HOUSE TESTING: ANTENNA TEST & EVALUATION

- **EXPERIMENTAL VALIDATION OF MODEL USED IN SAFETY ANALYSIS**
  - VERIFY ANALYSIS THAT PREDICTS SINGLE-AXIS FIELD UNIFORMITY
  - USE EXISTING HELMHOLZ TRANSMITTER: PAIR OF 4.4 FT x 6.2 FT LOOPS, WITH 10 TURNS PER LOOP

- **SIDE-BY-SIDE RECEIVER COMPARISON**
  - CALIBRATE RECEIVER EMI NOISE FLOOR IN ABSENCE OF TRANSMISSIONS
  - COMPARE EXISTING "SMALL-LOOP" (CUBE) RECEIVER WITH NEWLY FABRICATED "LARGE-LOOP" RECEIVER TO DETERMINE DESIGN WITH LOWEST RECEIVE MINIMUM DETECTABLE LEVEL (MDL)

- **FINALIZATION OF ANTENNA DESIGN**
  - USE VALIDATED MODEL TO COMPUTE REQUIRED AMPERE-TURNS AND GEOMETRIC COIL DIMENSIONS THAT ACHIEVE MINIMUM DETECTABLE LEVELS WITHIN THE CONSTRAINT OF SAFE TRANSMISSION LEVELS
  - "SAFE" IS DEFINED AS WITHIN THE LIMITS OF U.S. RECOMMENDED LEVELS FOR PACEMAKERS

IN-HOUSE TESTING:
SYSTEM INTEGRATION & WEAPON CALIBRATION

- **INTEGRATION OF SYSTEM HW & SW**
  - FINAL TX & RX ANTENNAS
  - DATA COLLECTION & ANALYSIS SW (LABVIEW & MATLAB)
  - SWITCHING AMPLIFIERS FOR MULTI-AXES

- **VALIDATION OF ASPECT-INDEPENDENT DETECTION (MULTI-AXIS)**
  - CALIBRATE SYSTEM USING SPHERE
  - REPEAT TESTING OF 9 mm AUTOMATIC & .38 CALIBER REVOLVER AT MULTIPLE ASPECTS AND AXIAL LOCATIONS WITHIN PASSAGEWAY
  - VERIFY RELIABLE DISCRIMINATION OF NON-GUNS USING AT LEAST 3 TYPICALLY ENCOUNTERED OBJECTS (e.g., CIGARETTE LIGHTERS, LIPSTICK TUBES & KEYS)

- **WEAPON CALIBRATION**
  - DEMONSTRATE ASPECT-INDEPENDENT DETECTION OF AT LEAST 3 OTHER TYPES OF COMMONLY AVAILABLE GUNS
  - COLLECT DETECTION STATISTICS TO FINALIZE RELIABLE RECEIVER DETECTION THRESHOLDS

FIELD TESTING

FIELD TESTING: SITE DEMONSTRATION

- **SUBJECT CANDIDACY**
  - BOTH SEXES
  - VARIABLE HEIGHTS: NOMINALLY BETWEEN 3.5 ft AND 5.5 ft
  - SUBJECTS INTERVIEWED BEFORE PASSING THROUGH DETECTOR
- **SUBJECT MOTION CONSTRAINTS**
  - WALK-THROUGH BETWEEN EDGE AXES OF PASSAGEWAY ("EDGE" DEFINED AS > 4" FROM EACH SIDE OF PASSAGEWAY)
  - WALKING PACE: COMPLETE 6 ft PASSAGE IN 7 SECONDS
- **WEAPON LOCATION**
  - ANYWHERE BETWEEN SHOULDERS AND ANKLES
- **QUANTITY OF DATA**
  - AT LEAST 1000 TRIALS DESIRED FOR STATISTICAL SIGNIFICANCE
  - REQUIRES AT LEAST 25 TRIALS PER DAY FOR 8-WEEK TESTING

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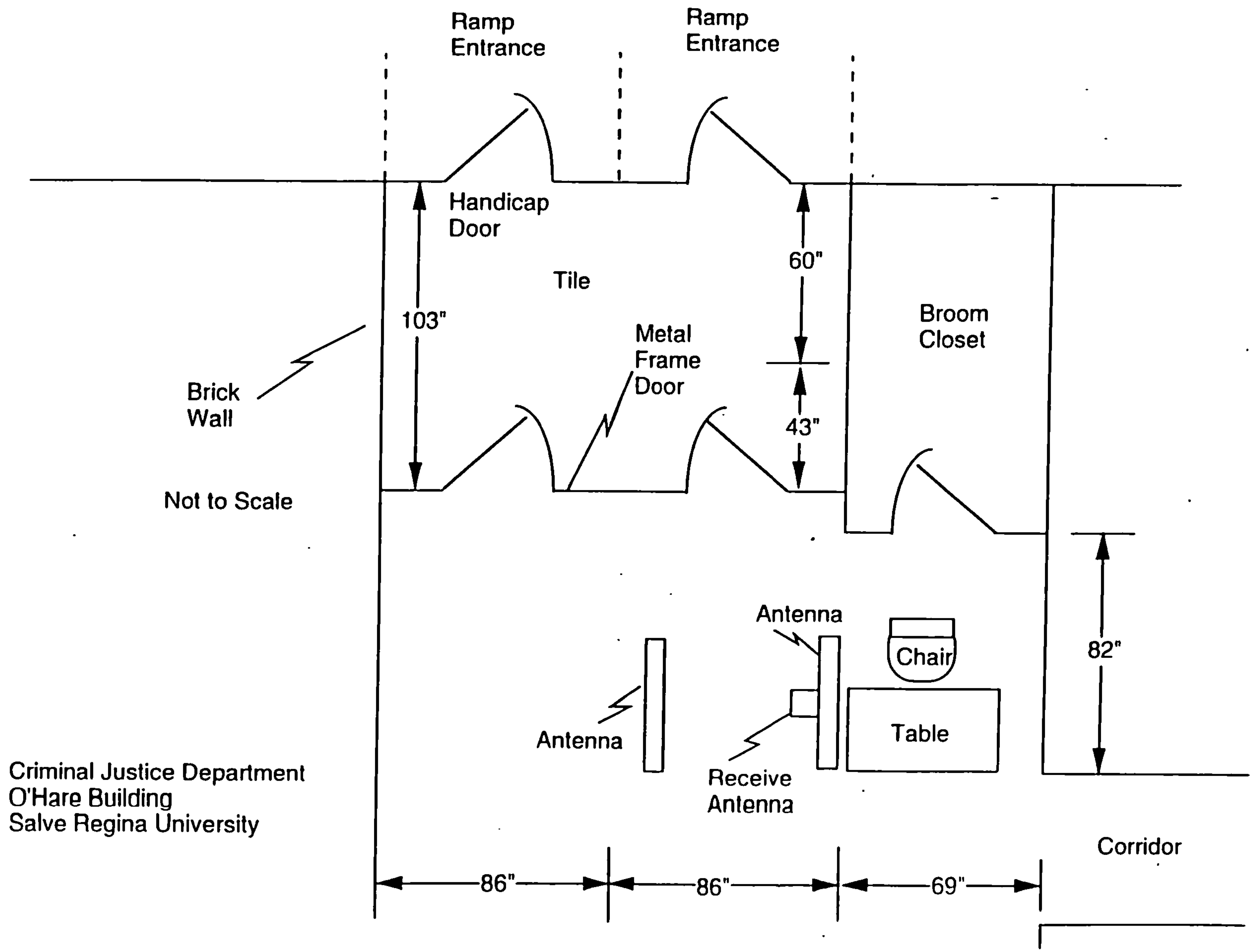
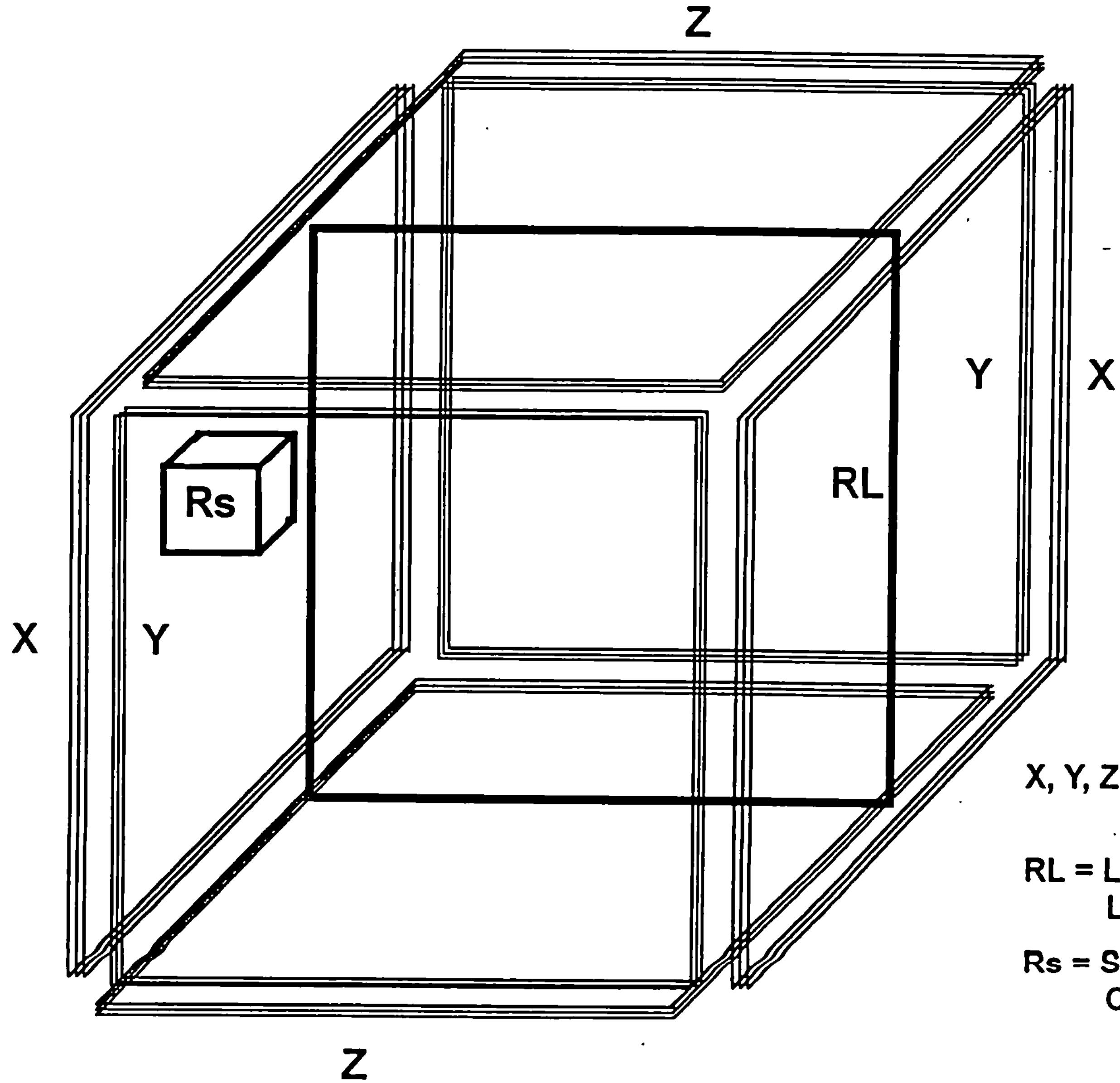
FIELD TESTING LAYOUT



FIELD TESTING:
CANDIDATE ANTENNA CONFIGURATION



X, Y, Z = HELMHOLZ TRANSMIT LOOPS (7' x 7' x 7')

RL = LARGE RECEIVER LOOP (7' x 7')

Rs = SMALL RECEIVER CUBE

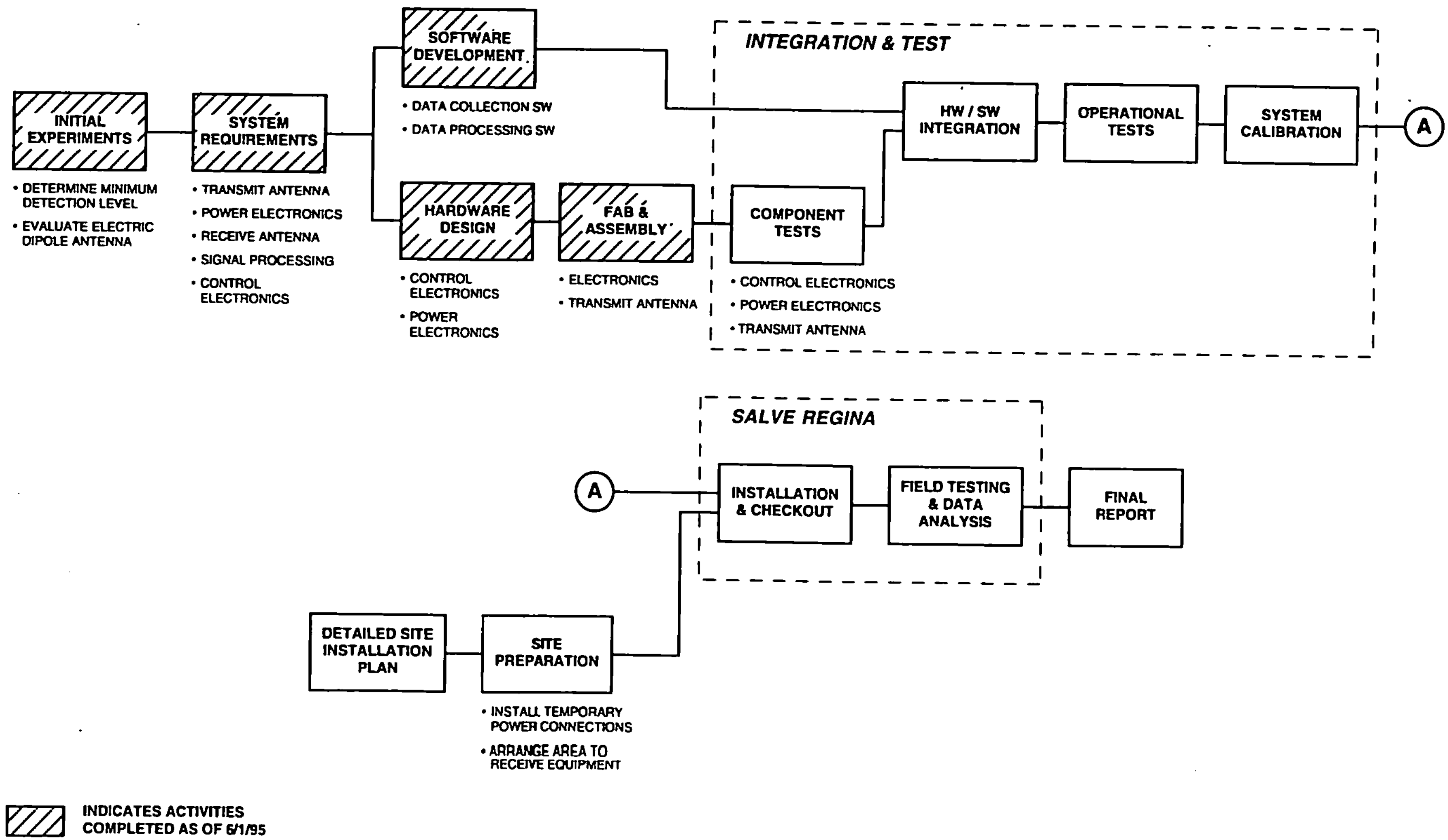
FIELD TESTING: DETECTION STATISTICS

- **EXPERIMENTAL MEASUREMENTS:**
  - Nt: Total # trials with subjects passing through gun detector
  - Ng: # trials in which subject has a handgun
  - Nd: # trials where system correctly detects gun when one is present
  - Nfd: # trials where system fails to detect gun when one is present
  - Ncd: # trials where system correctly decides gun is not present
  - Nfa: # trials where system detects a gun when one is not present
  - Note: Nt = Nd + Nfd + Ncd + Nfa > 1000 for statistical significance

- **DERIVED DETECTION STATISTICS:**
  - Pd = Correct Detection = Nd / Ng
  - Pfd = False Dismissal = Nfd / Ng
  - Pcd = Correct Dismissal = Ncd / (Nt - Ng)
  - Pfa = False Alarm = Nfa / (Nt - Ng)

Project Execution Plan & Schedule

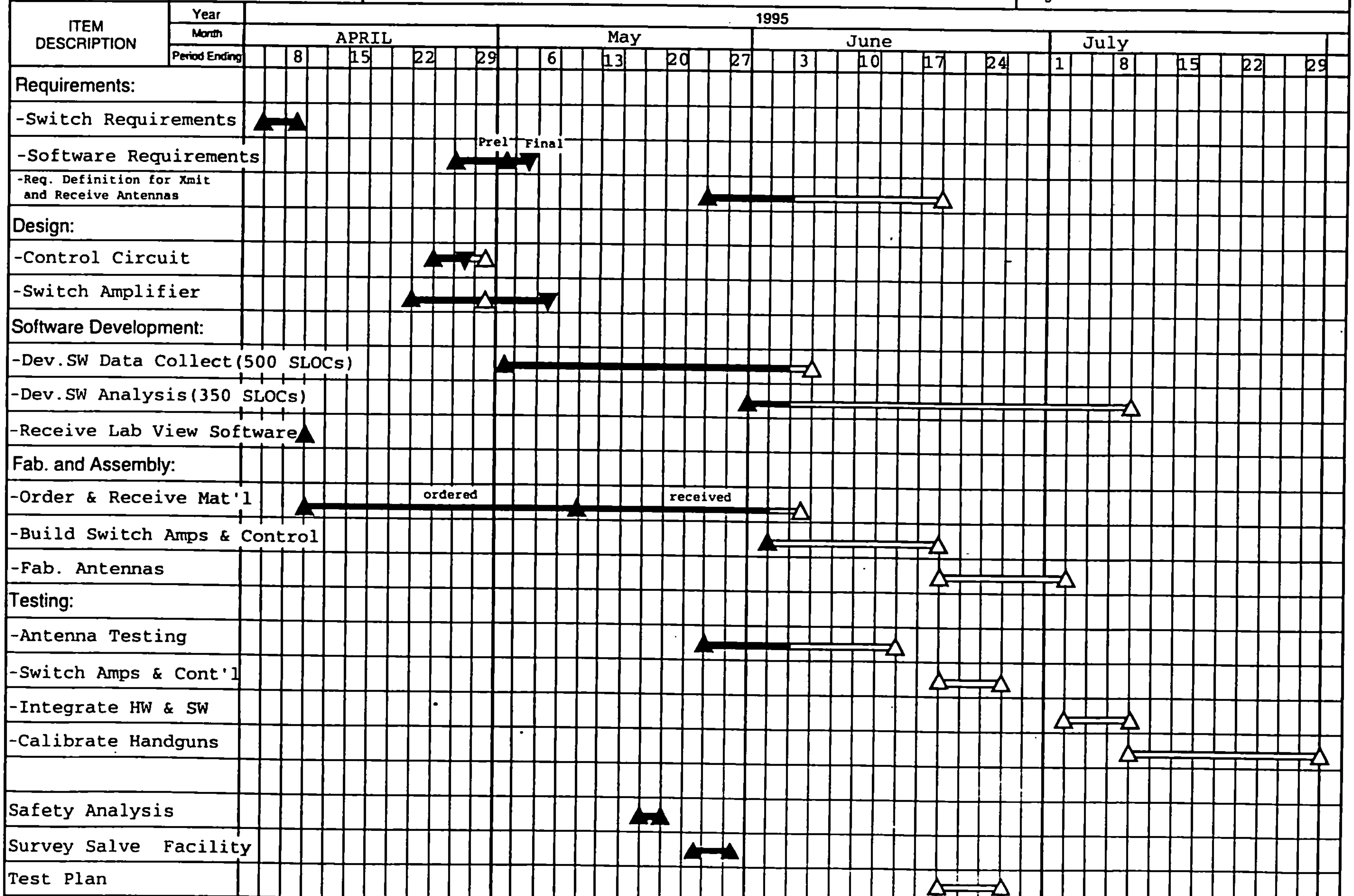
Project Execution Plan



Project Schedule

Raytheon

ORIGINATED BY: M. Nadeau	ORIGINATION DATE: 3/15/95	PROJECT TITLE: EM Weapon Detection Schedule	Rev. # 8	Date: 05/31/95
DEPARTMENT: Project Engineering	SCHEDULE CLASSIFICATION: Unclassified		Page: 1 of 1	



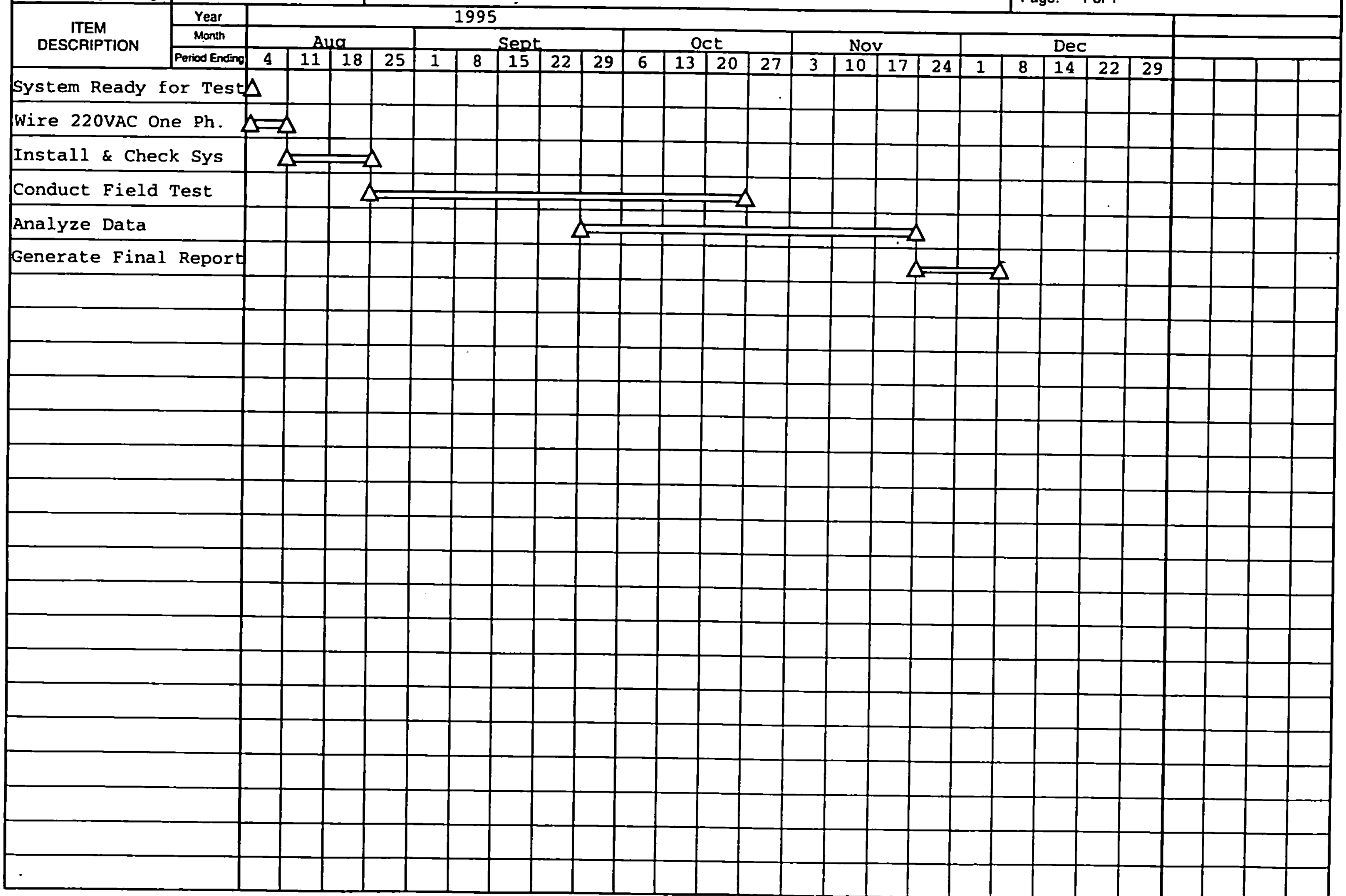
LEGEND: = Plan Schedule Line; = % Complete; = Estimated Start or Completion outside of original schedule; = Actual Start or Completion outside of original schedule

3/15/95MJN-01

Project Schedule

Raytheon

ORIGINATED BY:	ORIGINATION DATE:	PROJECT TITLE:	Rev. # 1	Date: 5/31/95
M. Nadeau	5/04/95	EM Weapon Detection Field Testing Sched.	Page: 1 of 1	
DEPARTMENT: Project Engineering	SCHEDULE CLASSIFICATION: Unclassified			



LEGEND: △—△ = Plan Schedule Line; ▲—△ = % Complete; ▽ = Estimated Start or Completion outside of original schedule; ▼ = Actual Start or Completion outside of original schedule

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Potential Additional Tasks

Potential Additional Tasks

Task	Task Description/Objective	Order of Magnitude Price Range K$
Expanded Testing of Threatening and Non-Threatening Items	Use the confiscated weapon inventory from the local police and a list of plausible non-threatening objects to evaluate the system's performance and find ways to improve it.	60 - 120
Increased Detection Range - Investigation	Investigate frequency domain techniques to improve system signal to noise ratios to enable lower field strengths to be used for detection. Various signal process methods will be examined.	80 - 160
Expand Countermeasures Testing	Develop additional test cases and conduct tests to test countermeasures.	80 - 160
Convert to Real Time Processing	The prototype used for field testing will be converted to a real time system. The current design requires post processing of the data which takes a few minutes.	100 - 200
Feasibility Study - Crowd Control Applications	Determine the feasibility of using Electromagnetic weapon detection technology for large area crowd control. Ways of extending the technology will be investigated.	120 - 240
Feasibility Study - Other System Configurations	Investigate the feasibility of three other useful system configurations. Include attaché case, six-element planar array for overhead or underfoot monitoring and seven-element linear array for mounting on a pillar.	80 - 160

Expanded Testing of Threatening and Non-Threatening Items

Objective: Evaluate the performance of the system on a larger population of metal object.

Approach: Use the confiscated weapon inventory from the local police and a list of plausible non-threatening objects to evaluate the systems performance.

Tasks:

1. Develop a list of non-threatening metal objects that might be carried on ones person by situation (i.e. student, bank customer, etc.). Such items would include metal lunch pails, metal Cains, metal briefcases, etc. Gather these items for testing with the detector.
2. Coordinate with the local police department to gain access to their inventory of confiscated items.
3. Conduct tests with both threatening and non-threatening items and record results for further analysis.
4. Examine the data and propose methods of processing the data to discriminate between threatening and non-threatening items.
5. Experiment with two or three data processing methods and report results.

Increased Detection Range - Investigation

Objective: Investigate using frequency domain methods of magnetic weapon detection to increase the detection range.

Approach: Using SAITO'S results for frequency response at HF as a basis, modify the prototype to enable transmission of modulation frequencies of 10kHz or Greater and receiver demodulation andlow-pass filtering. Test on weapons using tri-axial configuration from the Time Domain experiments.

Tasks:

1. Define System Requirements
2. Modify transmitter hardware for modulation
3. Modify receiver hardware for demodulation and filtering
4. Modify receiver software to perform conductivity calculations
5. Calibrate the system using the iron sphere and conduct testing on weapons

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Expand Countermeasures Testing

Objective: Investigate the feasibility of effective countermeasures against Raytheon's weapon detection system.

Approach: Perform theoretical/experimental investigations to evaluate several potentially effective countermeasure schemes and assess their practical feasibility. Specific countermeasure that will be included in the study are:

- "Masking" of the weapon's time constant by associating another object with a larger time constant.
- Enclosing the weapon in a high-mu, high-sigma metal box.
- "Signal Reversal" by changing the material from a paramagnetic/ferromagnetic to a diamagnetic.

Tasks:

1. Perform tests to determine feasibility of "masking"
2. Construct or purchase a high-mu, high-sigma box and perform tests
3. Construct a mold for the weapon of copper or aluminum impregnated material. Perform tests.

Convert to Real Time Operation

Objective: Develop real time processing hardware and software so that continuous operation of the Weapon Detection System is possible.

Approach: Determine the A/D and DSP resources required to support real time operation. Develop the software required to meet system performance requirements. Test the performance of the real time system.

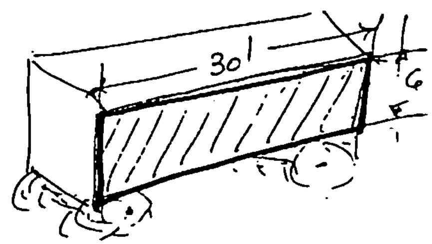
Tasks:

- Evaluate the number of operations required to complete one detection cycle. (3)
- Select final transmit frequency and compute the required throughput. (2)
- Select a suitable A/D and DSP environment, segmenting the operations among processors if required. Decide on make/buy. (15)
- Prepare equipment specifications and purchase. (10)
- Revise software for real time operations. (15)
- Code and test real time software. (30)
- Hardware/Software integration. (15)
- Conduct system testing. (10)

Feasibility Study - Crowd Control Applications

Objective: Investigate the feasibility of using a bistatic electromagnetic weapon detection system for crowd monitoring.

Approach: We envision a van-mounted bistatic system where the van is parked along a curb where a crowd is to monitored for concealed weapons. The transmitting antenna occupied the entire side of the van that faces the crowd. It could either be a planer array or a loop wound all around the same vertical wall. The "depth of illumination" required would be 30'. A few small-size portable, battery-operated, self-contained unmarked receiver/processors would be distributed in the illuminated region and detect the presence of a weapon.



Van-mounted system

Task:

1. Define the system performance in terms of achievable range, volumetric coverage, number of required bistatic receivers, receiver's "volume sensitivity", analysis of radiation safety issues, etc.

2. Perform and engineering study of the required hardware: mechanization of the transmitter electronics and antenna; mechanization of the receiver electronics and antenna; battery system; etc.

Feasibility Study - Other System Configurations

Objective: Investigate the feasibility of other useful system configurations.

Approach: Devote a preliminary effort to the definition of additional system configurations, namely:

(a) Small-size attaché case, self-contained system for individual personal searches;

(b) Six-element planar array for mounting overhead, underfoot, or on the side of a doorway, or other choke points;

(c) Seven-element linear array for mounting on a pillar.

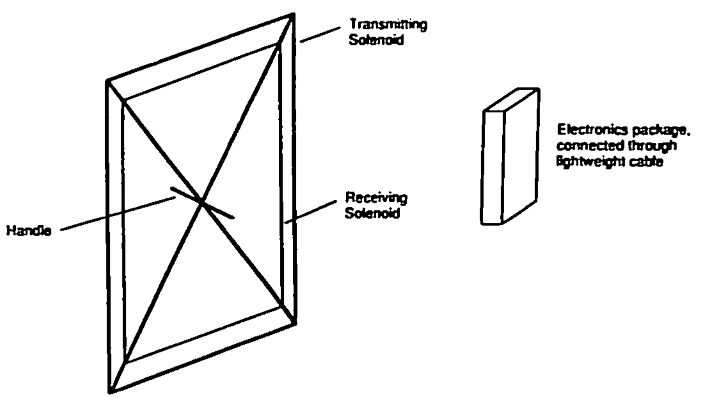
Task:

1. Conduct field strength analysis for each of the proposed configurations.
2. Evaluate the feasibility given the calculated field strength and the minimum detectable level required.

Feasibility Study - Other System Configurations (continued)

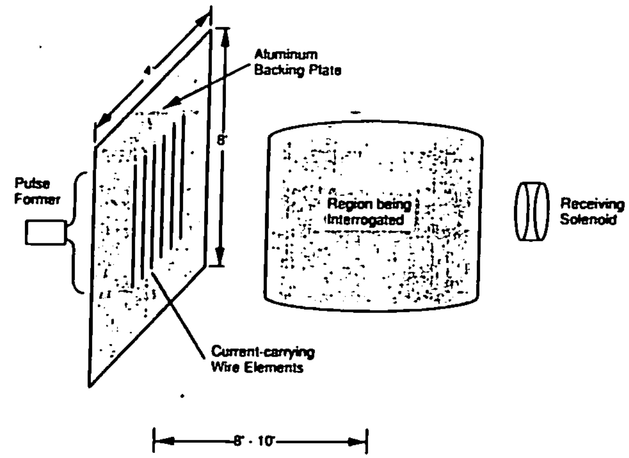
Small Size, Attache' Case Based, Heaviside Pulse Radar

- Small two-element system
  - For hand operation or mounted in attache' case, nominal size 12 x 18 inches
- Detection Range ..... 5 feet

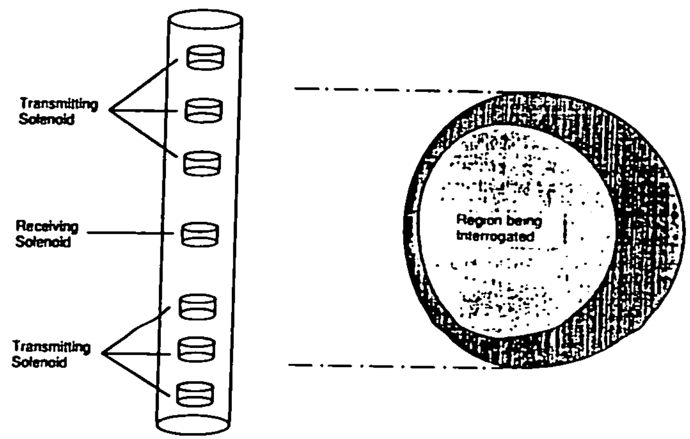


Six Element Planar Array

- For mounting overhead, underfoot, or to the side of doorway or other choke point



Seven Element Linear Array for Mounting in Pillar



Note: Interrogated region is doughnut shaped, centered on pillar

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