AD NUMBER
AD472159
LIMITATION CHANGES
TO: **Approved for public release; distribution is unlimited.**
FROM: **Distribution authorized to U.S. Gov't. agencies and their contractors; Administrative/Operational Use; 15 OCT 1965. Other requests shall be referred to Army Engineer Research and Development Laboratories, Fort Belvoir, VA 22060.**
AUTHORITY
USAMERDC ltr dtd 5 Aug 1974

SECURITY MARKING

The classified or limited status of this report applies to each page, unless otherwise marked.
Separate page printouts MUST be marked accordingly.

THIS DOCUMENT CONTAINS INFORMATION AFFECTING THE NATIONAL DEFENSE OF THE UNITED STATES WITHIN THE MEANING OF THE ESPIONAGE LAWS, TITLE 18, U.S.C., SECTIONS 793 AND 794. THE TRANSMISSION OR THE REVELATION OF ITS CONTENTS IN ANY MANNER TO AN UNAUTHORIZED PERSON IS PROHIBITED BY LAW.

472159

RAILROAD SABOTAGE DETECTION RESEARCH

18 June 1964 — 15 October 1965

FINAL TECHNICAL REPORT

Contract DA-44-009-AMC-657(X)
ARPA Order No. 293/10
Program Code No. 4860

Prepared for:
U.S. Army Engineer Research
and
Development Laboratories, Fort Belvoir, Virginia

GEOSCIENCES OPERATIONS
TEXAS INSTRUMENTS
INCORPORATED
SCIENCE SERVICES DIVISION
6000 LEMMON AVENUE
P O BOX 5621 • DALLAS, TEXAS

RAILROAD SABOTAGE DETECTION RESEARCH

18 June 1964 — 15 October 1965

FINAL TECHNICAL REPORT

Contract DA-44-009-AMC-657(X)
ARPA Order No. 293/10
Program Code No. 4860

Prepared for:
U.S. Army Engineer Research
and
Development Laboratories, Fort Belvoir, Virginia

GEOSCIENCES OPERATIONS

TEXAS INSTRUMENTS
INCORPORATED
SCIENCE SERVICES DIVISION

PREFACE

This report covers research and data analysis conducted since 20 January 1965 in evaluating the feasibility of a system design for detection of railroad sabotage. The work was performed by Texas Instruments Incorporated under Contract DA-44-009-AMC-657(X) issued by the Research and Development Procurement office of the U. S. Army Engineer Research and Development Laboratories. The report includes (a) a review of field tests, results and conclusions discussed in First Interim Technical Report and (b) new information and conclusions based on broader analysis of a larger amount of data.

The following Texas Instruments personnel were engaged in the extended analysis phase of the project:

Mr. E. D. Martin, Jr. — Project Manager

Mr. R. E. Brannian — Project Engineer

Mr. R. G. Baker — Member of Technical Staff

Dr. A. E. Sobey, Jr. — Member of Technical Staff

Mr. A. B. Cvercko — Engineer

TEXAS INSTRUMENTS INCORPORATED

J.R. Van Lopik

J.R. Van Lopik, Manager
Environmental Science Programs

TABLE OF CONTENTS

TABLE OF CONTENTS (CONTD)

APPENDIXES

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS (CONTD)

LIST OF TABLES

SECTION I

SUMMARY

A workable detection system is designed to record sabotage activity on a one-mile section of railroad and discriminate against noise in the rail and pedestrian traffic. Elimination of false alarms and conservation of power in an RF data link are important considerations. The four features of discrimination logic are frequency filtering, amplitude threshold, pulse repetition rate, and aural monitoring. Preliminary conclusions and recommendations in First Interim Technical Report are reviewed herein and are substantiated with specific data and appropriate changes in details derived from an extended analysis of more than 2600 signals.

Field experiments were conducted on railroads with 5- and 6-in. rails. Electromechanical instrumentation capable of detecting seismic and acoustic waves was utilized to determine that 400- to 5000-cps acoustic waves in the rail possessed the best transmission qualities. A third method of detection was the subject of a classified report submitted separately with First Interim Technical Report. The extended analysis of data recorded by a breadboard model of the detector system provide detailed design specifications of the discrimination logic as follows:

- Frequency filtering: 700-1100 cps
- Threshold: 8.8 μv at the 25-mv/g transducer
- Pulse repetition rate (time domain): at least 1 pulse per 15 sec continually for 2 min

A system incorporating the logic described above is shown on the basis of the analyzed data to have a false alarm rate of zero per day per mile of track, except in the case of closely spaced or grouped pedestrian traffic. Inclusion of aural monitoring capabilities is expected to permit discrimination against all pedestrian traffic with minimal training of the operator. In addition, aural monitoring provides the operator with a reasonable judgment as to the type of sabotage act taking place after a detection alarm.

Based on a detection probability of 50 percent or greater, the detection range of the system with the proposed logic is 200 m on both the rail holding the detector and its opposite parallel.

It is therefore concluded that the performance reliability of a system based on the recommended design will be adequately high enough to support the type of operating conditions for which the system is intended. It is not possible to place a precise quantitative value on this type of reliability since this can be done only after consideration of the accumulative influences of electronic component reliability, assembly workmanship and other quality assurance programs.

It is recommended that a prototype system be built incorporating the design specifications set forth in this report. One four-detector system with data link and monitor controls will require 30-35 man-months of labor and materials or components costing about $9360. Additional research should be conducted on transducer coupling, transducer location with respect to rail joints and telemetry requirements of the system.

SECTION II

INTRODUCTION

The objective of contract DA-44-009-AMC-657(X) was to determine optimum design of a system — seismic, acoustic or other — for detecting railroad sabotage. Specified performance criteria are as follows:

- Crew. The detection system shall require not more than one man per mile of railroad for operation and maintenance.
- False Alarms. The system shall not register more than one false alarm per mile per day in the presence of pedestrian traffic. A false alarm is an indication requiring the monitoring crew to respond in the same manner as to a true detected act of sabotage.
- Tampering Resistance. The system must be capable of complete concealment or of incorporating adequate tampering-resistant features. Remote components shall not require attention more often than once a year for each location or once a year per mile of track.

Investigations and findings are reported in two categories: seismic and acoustic.

A. SEISMIC

Five types of vertical- and two types of horizontal-velocity seismometers were subjected to various signals in order to select optimum instruments, compare results with past investigations, and determine feasibility of the seismic technique for detecting railroad sabotage.

B. CLASSIFIED

Reported previously (Reference 1: System Predictions Report, Railroad Sabotage Detection Research, First Interim Technical Report).

C. ACOUSTIC

Acoustic studies were stressed as requested and encompassed about 90 percent of the total program.

Field experiments were made on two different size tracks in the Dallas and Sherman areas of Texas (Figure 1). Permission for track use was obtained from the Dallas Power and Light Company and the Texas and Pacific Railway.

Site 1, at Mountain Creek Lake, near Dallas, was on an unused railroad with 5-in. rails. It was overgrown with weeds and generally, for our work, was not as satisfactory as the second site.

Site 2, near Sherman, Texas, was on an active railroad with 6-in. rails. Best results were obtained here.

Simulated acts of sabotage were removal of spikes and joint-bars and shoveling of ballast under rails. Some acts stipulated in the proposal and work statement were not permitted by the railroads (e.g., weakening of bridges and detonating of explosives as a train passes).

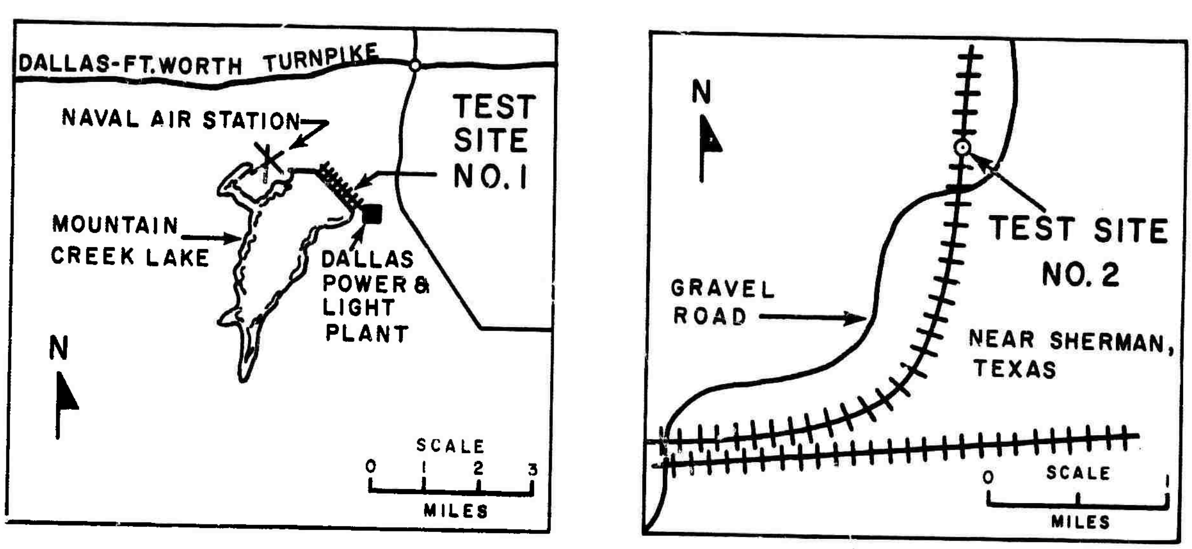


Figure 1. Test Sites

Field results were analyzed by physical measurement of many multichannel filtered trace amplitudes and time intervals between individual pulses (events) to substantiate results obtained by the digital computer analysis reported previously (Reference 1).

Acoustic System Concepts, Section III of First Interim Technical Report (Reference 1), is enclosed with minor changes as Appendix A of this report.

SECTION III

INVESTIGATION

A. SEISMIC

Seismic detection of personnel movement was studied previously (Reference 1),and resultant data were used for this project also. Only limited tests were anticipated in the proposed program to determine if rails, ties and ballast affect detection range. The qualitative system concepts involved only reevaluation of velocity transducers to see if proximity of the rail line affected their response appreciably. This study confirms and extends past conclusions and also yields additional information about seismic detection in proximity to a rail line.

In field experiments at Test Site 1, simultaneous recordings were made from 15 seismometers arranged in three groups of five each. The following instrumentation was used:

- Seismometer: Hall-Sears Model HS-1; peak response — 4.5, 14.0, 20.0, 30.0, and 40.0 cps; standard impedance — 215 ohms each
- Amplifier: HTL 7000 Series; frequency response — 13-200 cps at the three-db-down level
- Recorders: HTL RS-8U, 50-channel oscillograph with 500-cps galvanometer
- Pressure transducer (for comparison): Sensonics Model V25-1 "Variducer"

Test signals were introduced at varying distances. Some tests were as follows:

- Man weighing 170 lb wearing tennis shoes, walking first normally and then stealthily first down center of rail line, then approaching at right angle up grade to the rail line
- Shoveling ballast between ties and under rail
- Prying spike from tie
- Removing bolts from rail-joint bar with wrench
- Striking rail at joint-bar coupling with 16-lb hammer

Vertical and horizontal high-impedance velocity seismometers were coupled to the rail with C-clamps and compared to the Sensonics "Variducer" (pressure transducer) which was coupled mechanically to the top of the rail by a small magnet. Signal sources were calibrated weight drops at four selected distances.

B. ACOUSTIC

Early in the program, USERDL requested that Texas Instruments record and analyze data covering a spectrum up to 20 kc to determine if any high signal frequencies were propagated by simulated acts of sabotage. This investigation seemed desirable because of low noise in the upper part of the spectrum. The request involved a major change in scope of the proposed investigation which indicated the intent to look at spectra up to 5 kc with simple vibration transducers.

The most feasible way to conduct the program appeared to be through evaluation of each basic element and through application of the most desirable elements or methods selected. Total research effort was based on continual revision of the qualitative system concepts and included:

- Transducer evaluation
- Transducer coupling
- Calibrated weight drops
- Electrodynamic driver
- Selected broadband recording of noise and signals (50-20,000 cps)
- Breadboard model detector for attachment to the bottom of the rail
- Selected narrowband recording of noise and signals using the breadboard detector (300-500 cps)
- Continuous recording for false alarm count
- Data analysis

1. Transducer Evaluation (Instrumentation)

- Piezoelectric transducers (Table 1)
  - — Clevite Model 25D21 Accelerometer
  - — Sensonics Model V25-1 Variducer
- Oscilloscope

Comparison tests were made between response of the Variducer and the accelerometer with calibrated weight drops. With the Variducer, both a weight and magnet were used to maintain contact pressure between it and the rail. Transducer response was proportional to acceleration since contact pressure varied because of vibration of the weight or magnet. Frequency response was not determined since the system was used only for qualitative comparison purposes.

Table 1

PIEZOELECTRIC TRANSDUCER SPECIFICATIONS

Clevite Model 25D21 Accelerometer		Sensonics Model V25-1 Variducer (Pressure Transducer)	
Sensitivity, Axial, Open Circuit	25 mv, Peak/g, Peak	Open Circuit Sensitivity	140 mv/psi
Capacitance	1300 pf	Capacitance	150 μμf
Resonant Frequency	30 kc	Resonant Frequency	500 kc
Frequency Response Open Circuit	± 5%, 1 cps-6 kc	Flat Frequency	? cps - 100 kc
Dynamic Range	To 10, 000 g	Maximum Pressure	100 psi
Amplitude Linearity	± 1%	Minimum Pressure	0. 001 psi

The accelerometer is more sensitive than the Variducer when foreign material is inserted between the sensor and contact surface. It was selected as the better transducer for feasibility studies.

2. Transducer Coupling (Table 2)

Pressure transducer seating is critical. The mounting surface and the transducer sensing surface must be cleaned thoroughly, and the transducer must be aligned carefully to obtain optimum sensitivity.

Experiments with calibrated weight drops and an oscilloscope determined optimum seating methods and compared relative outputs of the Variducer and the accelerometer. (See Reference 1, Figure 31.

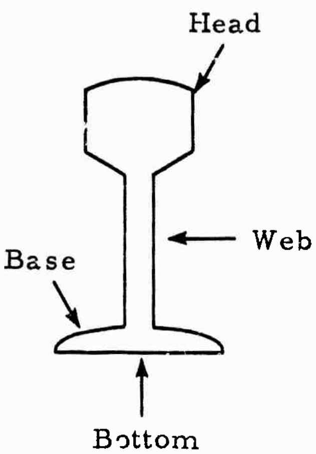
Best results were obtained from seating positions on the head and base of the rail, with the transducers pressure-coupled to a steel plate fastened to the rail with epoxy-resin. A greater loss of sensitivity was apparent when the sensor was fastened directly to the rail. In all cases where epoxy was used, careful cleaning of contact surfaces increased sensitivity of the transducer; however, no appreciable difference could be noted in sensitivity when the transducer and rail were coupled magnetically after carefully sanding and brushing the contact surfaces. The latter method is considered the more practical and was utilized in the breadboard model detection system.

3. Calibrated Weight Drops

A simple experiment determined that calibrated weight drops produce repeatable signals (frequency and amplitude) and could resolve attenuation rates of signals induced into the rail (Reference 1, Figure 32).

Table 2

TRANSDUCER COUPLING METHODS

<table>
<tr><th>Transducer Location</th><th>Transducer Coupling</th></tr>
<tr><td>
</td><td>1. Direct contact-coupling by transducer weight only
2. Double-backed adhesive tape
3. Quick-drying epoxy
4. One mil mylar-lead weight on top of transducer
5. Magnet
6. Transducer coupled mechanically to small steel plate, 1/8-in. thick; plate glued to rail with epoxy
7. Transducer glued to steel plate and plate glued to rail with epoxy
8. Transducer coupled to steel plate with lead weight; plate fastened to rail base with epoxy</td></tr>
<tr><td>Head</td><td>1, 2, 3, 4, 5, 6</td></tr>
<tr><td>Web</td><td>5, 6</td></tr>
<tr><td>Base</td><td>2, 3, 4, 5, 6, 7, 8</td></tr>
<tr><td>Bottom</td><td>5, 6</td></tr>
</table>

4. Electrodynamic Driver

A driver for inducing known frequencies into the rail was constructed; it consisted of a PZT-4 piezoelectric crystal cemented between a magnetic attachment base and a brass inertial load and was driven by a McIntosh Model MC-75 monophonic 75-w amplifier through a matching transformer (Reference 1, Figure 34). The driver provided a source of variable signals over a wide range of frequencies. Tests were made to obtain supporting attenuation data and to confirm results of calibrated weight drops. (Results are shown in Reference 1, Figures 35, 36 and 37 and Table 4.)

5. Broadband Recording of Noise and Signals for Analog and Digital Analyses

a. Instrumentation

- Detector — Clevite Model 25D21 accelerometer
- Preamplifier — Sensonics Model 1000, high-impedance, transducer amplifier; voltage gain, 60 db; frequency response, 5-60 kc (± 1 db); integrated noise level < 10 µv rms (referred to open or shorted input over 100-kc bandwidth)
- Signal line — 150 ft, shielded cable from preamplifier to acoustic amplifier
- Acoustic amplifier — Cubic Model 1300 differential d-c amplifier. Range, dc-20 kc (± 1 db); input noise level, 4 µv rms (0-50 kc)
- Magnetic tape recorders (two) — Precision Instruments Model PI 214 and PS 207A. Direct recording at 30 ips
- Monitoring instruments
  - Oscillograph: Houston Technical Laboratories Model RS-8U, 50-channel
  - Oscilloscopes (two): Hewlett-Packard Model 130B and Dumont 2620 with Polaroid camera

b. Transducer-Rail Coupling

A small steel plate was affixed to the rail base with epoxy-resin, and the transducer was coupled to the plate with a lead weight (Table 2).

6. Breadboard Model Detector (Figure 2)

Detector design was based on revised qualitative system concepts and preliminary analysis of signals and noise recorded with broadband techniques. Magnetic transducer attachment represents a reasonable approach to the functional needs of easy installation and concealment. In addition to the transducer and preamplifier, the detector package contains low- and high-cut filters (for 300-5000 cps passband) and a transformer to isolate conductors from ground and permit use of a shielded cable. This combination, with 150 ft of cable, had a voltage gain of 9.1 at 1000 cps and an attenuation of 24 db/octave outside the passband (Figure 3).

7. Narrowband Recording of Signals and Noise — 300 to 5000 CPS

Preliminary visual analysis showed that most dominant frequencies of induced signals fell within a band of 300-1000 cps; however, a wider passband of 300-5000 cps, which insured good aural monitoring, was selected for detailed study. Analysis was performed on some narrowband signals prepared by digital methods and on other recordings played back at low translation speeds on paper records. Neither method would permit a large number of signals to be analyzed economically. The most feasible method of examining thousands of signals was recording on film and studying on a 20x film viewer. The film presentation was recorded by a Fairchild 16-mm movie camera modified with a TI oscilloscope which had been developed especially for displaying high-frequency signals. Selected sets of signals were isolated for multichannel filtering on a Bruel and Kjaer 1/3-octave filter. Filtered signals were demodulated to d-c pulses by passing them through a peak detector (rectified and integrated) to obtain the rectified pulse envelope. Both the filtered and unfiltered pulses were photographed simultaneously. Three runs of the selected 300-min data set were needed to cover completely the 300-5000 cps range.

Figure 4 is a schematic of the narrowband recording and monitoring instrumentation; Figure 5 is a schematic of the playback instrumentation. Figures 6 and 7 show filter responses, and an example of the filmed system output is shown in Figure 8.

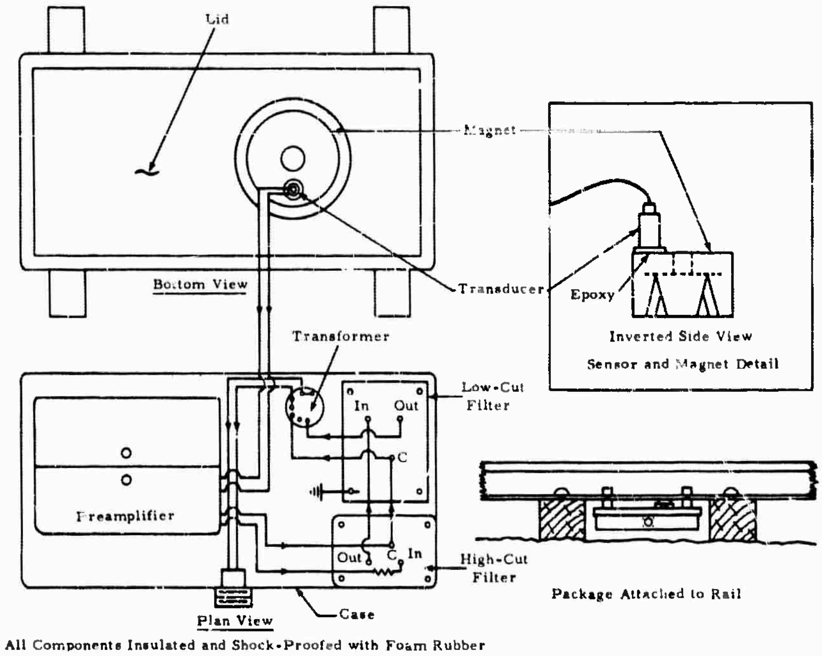


Figure 2. Breadboard Model Detector

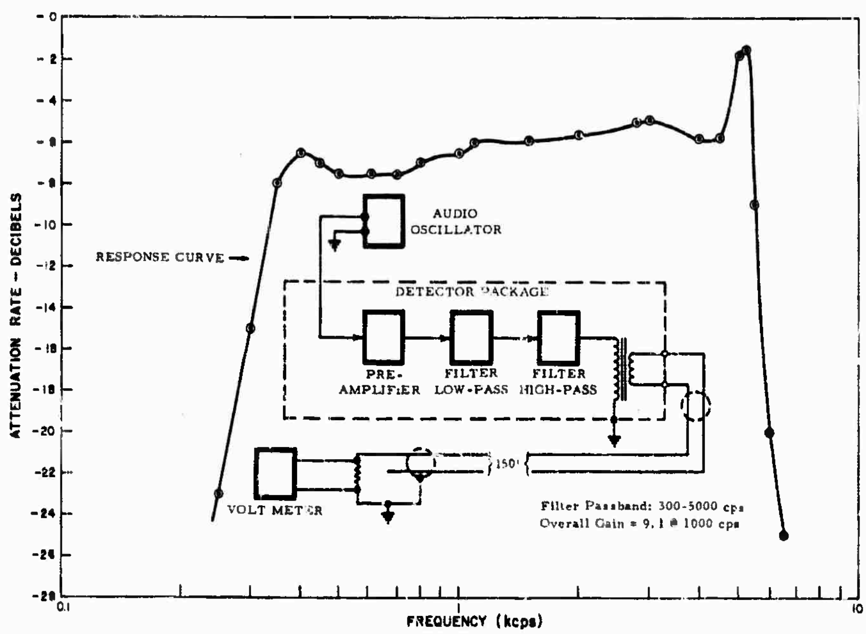


Figure 3. Schematic Diagram and Response Curve of Breadboard Model Detector

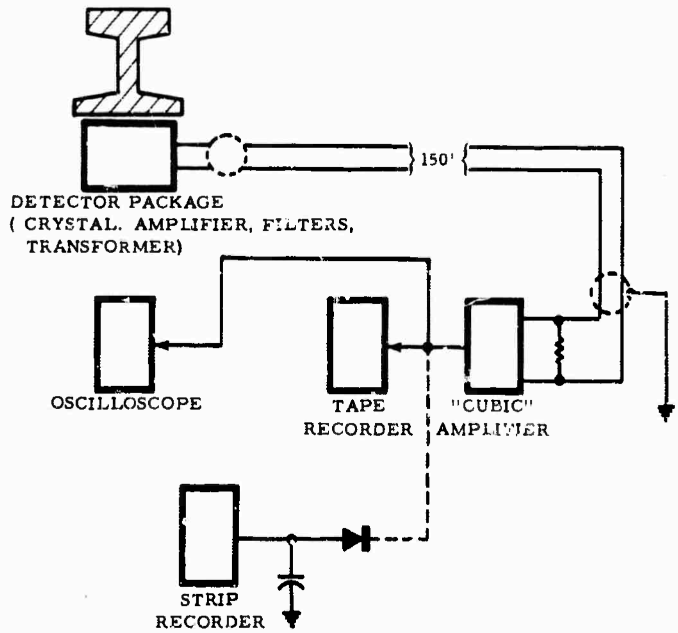


Figure 4. Schematic of Narrowband Instrumentation for Recording Noise, Signatures and False Alarm Count

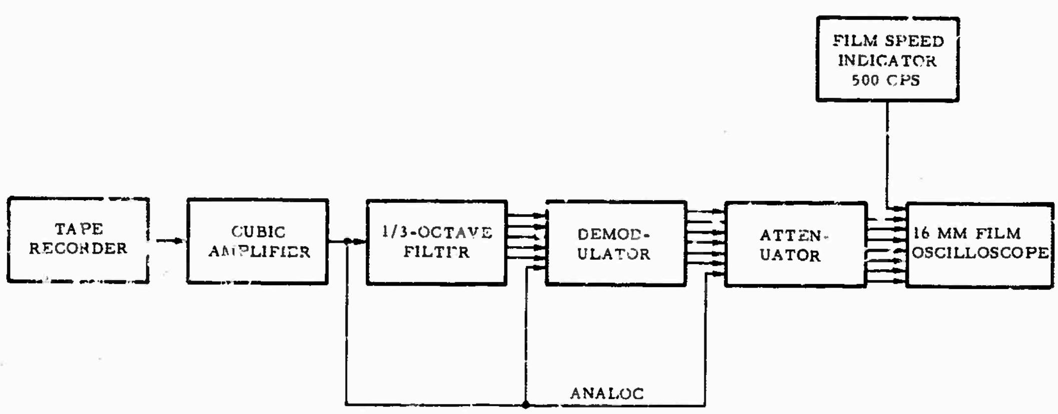
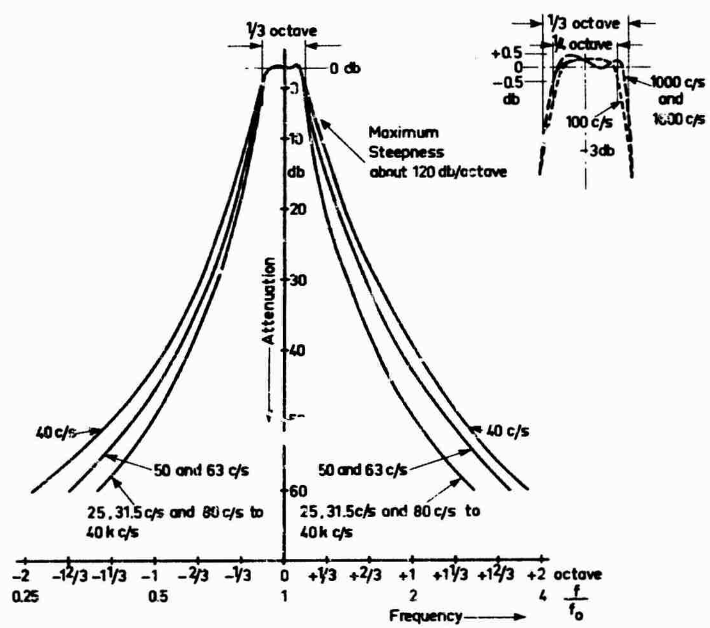


Figure 5. Schematic of Instrumentation Used for Narrowband Playback of Noise, Test Signals, Sabotage Signatures, and False Alarm Count



(a) Detailed 1/3 octave filter characteristic derived from sine-wave signals.

Center Frequency c/s	Bandwidth at 3 dB c/s Approx.	Center Frequency c/s	Bandwidth at 3 dB c/s Approx.
25	5.8	1000	230
31.5	7.3	1250	290
40	9.2	1600	370
50	11.6	2000	460
63	14.5	2500	[illegible]
80	18.3	3150	730
10?	23	4000	920
125	29	5000	1160
160	37	6300	1450
200	46	8000	1830
250	58	10000	2300
315	73	12500	2900
400	92	16000	3700
500	116	20000	4600
630	145	25000	5800
800	183	31500	7300
		40000	9200

(b) Table of bandwidths.

Figure 6. Characteristics of Bruel and Kjaer 1/3-Octave Filters

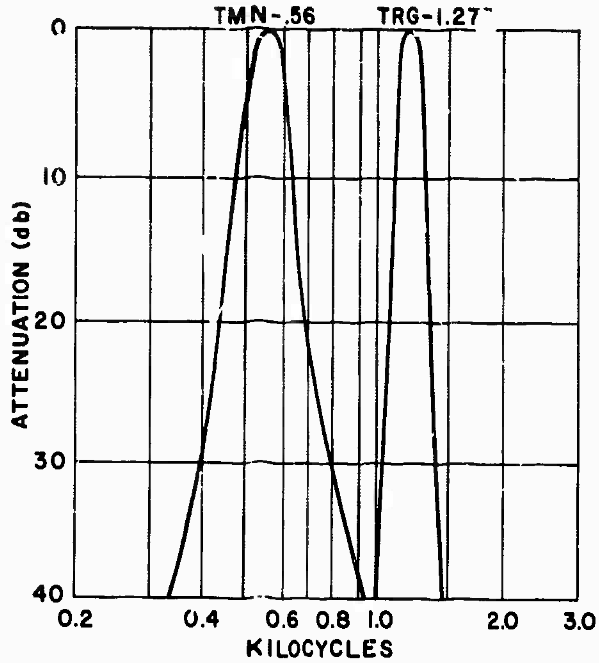


Figure 7. Response Characteristics of Two Narrow Bandwidth UTC Filters, TMN-0.56 and TGR-1.275

Noise was recorded at four intervals during the day — sunrise, noon, sunset, and midnight. Each record set consisted of one 24-min recording, four 6-min recordings and two more 24-min recordings. These were scheduled so that sunrise, noon, sunset, and midnight fell between the second and third 6-min recordings. The 24-min recordings were stored as basic data (24 min is the recording time for one 3600-ft reel of tape at 30 ips). The 6-min recordings were for statistical analyses of false alarms and for amplitude and frequency studies of rail-generated noise. Calibrated weight drops and simulated acts of sabotage were conducted at distances up to 250 m in both directions from the detector and on both rails without moving the detector. Detection range, pulse interval, frequency content, and amplitude criteria required for discrimination logic design were resolved. All signal amplitudes measured on the viewer are convertible into absolute units for threshold evaluation by means of a 1-v, 1000-cps calibration signal on field tape H-1. Significant analog event time-interval measurements were based on the 500-cps square wave time-reference on each film.

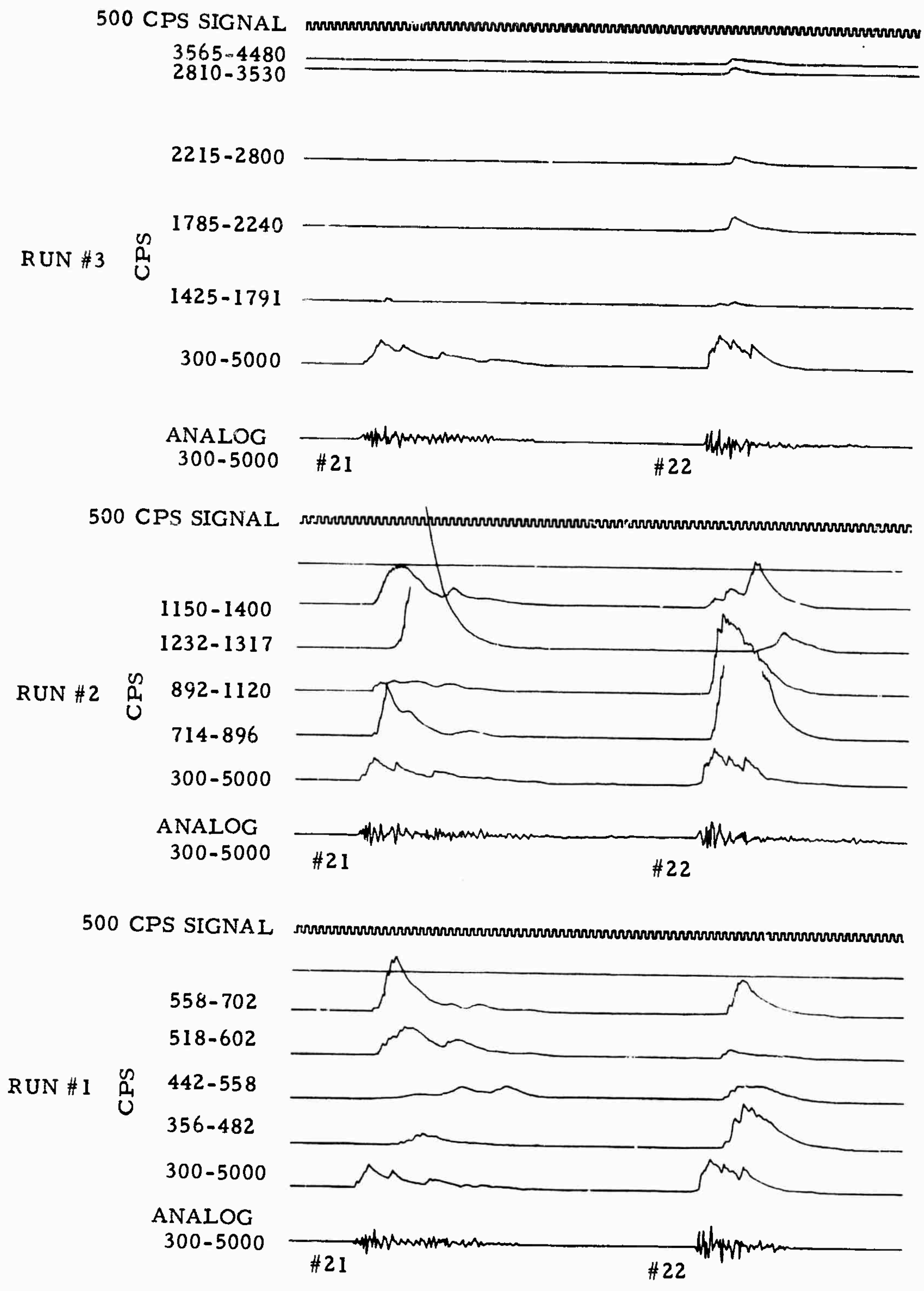


Figure 8. Example of Narrowband Data Playback for Extended Analysis

SECTION IV

DISCUSSION

A. SEISMIC

1. Summary

Ground-transmitted seismic signals in the frequency range of 1-30 cps are not as satisfactory for sabotage detection as rail-transmitted acoustic energy. Maximum effective range of seismic detection is 115 m.

2. Discussion

Vertical velocity seismometers with peak responses at 14 and 20 cps consistently produced the best signal-to-noise (S/N) ratio for ground-transmitted signals. Signals are low-velocity guided waves with frequency, amplitude and rates of attenuation related to boundary conditions in the subsurface layers of soil or rock. Dominant frequencies of all input signals were between 18 and 29 cps.

Maximum detection range was 115 m for ground-transmitted signals of sabotage acts performed on this project. An average detection range for mechanically-induced signals was 75 m when minimum S/N ratio for the 14 and 20 cps records was two. Maximum detection range for a man walking down the center of the track was 59 m (Table 3).

Optimum signal-to-noise ratios were determined by measuring peak-to-peak amplitudes of signals and noise on oscillograph records. Detection ranges of ground-transmitted signals were determined from plots of S/N ratio vs distance for each seismometer type.

Where sabotage energy was coupled directly or indirectly into the rail, the rail-propagated energy was recorded at distances up to 110 m by seismometers buried two feet from the rail. This high-frequency rail-transmitted energy travels at an average velocity of 4000 m/sec vs 150 m/sec for the maximum amplitude

Table 3

SEISMOMETER COMPARISON SUMMARY FOR SELECTED SABOTAGE-ACT SIGNALS

Signal	Ground Transmission Detectable Range (Meters) Seismometer Peak Response (cps)					Dominant Frequency (cps) Seismometer Peak Response	
	4.5	14	20	30	40	14	20
Normal Walking Down Center of Track (One Footstep)	33	59	53	33	28	18	20
Sneak Down Center of Track (One Step)	7	15	21	16	11	27	29
Shoveling Ballast from Under Rail (No Rail Contact)	57	76	90	56	38	19	21
Prying Spike	60	58	70	74	38	22	27
Turning Nut at Joint-Bar	39	39	28	26	27	20	25
Strike Rail with 16-lb Hammer	108	115	115	95	84	20	22

Threshold: Signal-to-Noise Ratio (S/N) = 2 ground wave, and its attenuation rate appears less than that of the latter. Observation of the rail-transmitted energy on seismic records emphasizes the need for more extensive study of this phenomena.

The horizontal seismometer coupled parallel to the rail gave better results than either the horizontal at right angles or the vertical. This shows that longitudinal waves are predominant in the rail-transmitted energy and that any final system design should involve more study of wave propagation modes in order to orient the transducer properly.

B. ACOUSTIC

1. Broadband Analysis

This was reported earlier in First Interim Technical Report Reference 1) and is reviewed here to provide continuity.

Preliminary field data recorded broadband (50-20,000 cps) were analyzed by analog methods and by Markoff power spectrum analysis (Reference 1, p. 68-92). The purpose was to determine if discrimination against unwanted signals would be possible by filtering and threshold logic techniques. Both analog- and power-spectra data were used to determine frequency content and amplitude of signals and noise. Use of the Markoff method was based on superior frequency resolution. Power spectra were plotted in db re unit^2/cps vs frequency (Reference 1, Appendix A).

a. Noise Studies

1) Instrument Noise

Instrument noise level was 0-16 db below 1 μv and was high in the frequency spectrum compared to optimum signal bands.

2) Ambient Rail Noise

Broadband data showed that rail noise greater than 1 μv was primarily in the 430-1600 cps band on the 6-in. rail and in the 150-2500 cps band on the 5-in. rail with the more dominant frequencies in the latter having 4-6 db more power.

3) Thermal Release Noise

Thermal stress signals vary markedly in amplitude and frequency content. The variation may be a function of type and degree of mechanical coupling and distance from the detector; however, substantiation of these conclusions would be difficult except by locating points of thermal bursts with multiple detectors.

b. Induced Rail-Transmitted Signals

Induced signals were analyzed for optimum frequency bands, attenuation rates, detection range, and sensitivity.

Signals were produced by calibrated weight drops, hitting and prying spikes, hitting wrench on joint-bar nut, shoveling under rail, and pedestrian traffic. All sabotage-act signals processed for power spectra were recorded at a distance of 100 m from the transducer and were edited to include only primary or initial pulse signal; the editing excluded signals resulting from reflection at discontinuities near the detector (Reference 1, Figure 55).

1) Optimum Frequency Bands

From broadband data, predominant frequencies of simulated acts of sabotage and pedestrian traffic appear in the 500-800 cps band, although each rail size seemed to have individual characteristics in its ability to propagate acoustic energy.

The 6-in. rail transmitted more frequencies below the 500-800 cps band, and the 5-in. rail transmitted more above, particularly in the 2000-3000 cps band where power level approaches that of lower frequencies.

2) Signal Attenuation

Attenuation rate for each predominant frequency was determined by visual selection of a straight line plot with more weight on values recorded at shorter distances. From tabulated rates, an average of 15 db/100 m was assumed for any frequency between 250 and 2200 cps (Reference 1, Table 6).

Signal output loss due to line capacitance becomes a significant factor at higher frequencies with a 1.5-db loss at 10 kc and a 3.5-db loss at 20 kc. These do not affect appreciably the dominant frequencies below 2000 cps and are not considered at the lower frequencies.

3) Detection Range

From spectral analysis of broadband data where S/N ratio equals 2, the maximum distance at which most sabotage signals could be detected on a rail was 150 m; prying a spike or tapping a wrench on the opposite rail was detectable at 100 m from rail-to-rail coupled energy. These ranges are less than those determined from narrowband data (250 m and 200 m, respectively) because signals analyzed were limited to those with amplitude less than the dynamic range limits of the amplifier.

4) Sensitivity

Absolute values of signal and noise levels were computed from power spectra. The greater values were mainly in the band of 500-900 cps.

The signal from a calibrated weight drop was analyzed spectrally to determine if frequencies were present up to 20 kc. Results show that frequencies above 5 kc are insignificant and need not be considered in a detection system.

2. Narrowband Analysis

Preliminary analysis was covered in First Interim Technical Report (Reference 1, p. 99-116) and is reviewed briefly here to provide continuity.

a. Summary

The 300-5000 cps bandwidth of acoustic signals was selected for detailed analysis because most of the signals due to simulated acts of sabotage were in the 400-1200 cps range. The passband was widened beyond this to insure better aural monitoring. Extended studies showed that a 708-1115 cps passband decreases the number of unwanted signals and is capable of sounding alarms from one detector due to sabotage acts at distances of 200 ft on either of the parallel rails when an 8.8-μv amplitude threshold (at a 25-mv/g transducer) and an 8-pulse (1 pulse/15 sec continuously for 2 min) time-domain logic are used.

b. Preliminary Analysis (A Review)

Selected portions of data up to 20 kc were transcribed for spectral analysis by digital methods. Available digital computers required frequencies less than 500 cps, the aliasing frequency for a 1-msec sampling rate. Steps to overcome this limitation (Reference 1, Table 5) were also needed in reducing data to analog form for visual inspection and analysis.

Narrowband data (300-5000cps) from the breadboard model detector were analyzed initially to determine rail noise and unwanted signals, repeatability of induced signals on more than one rail, and effect of change in transducer-rail coupling.

1) Noise and Unwanted Signals (Thermal Release Noise)

Noise generated by rail expansion and contraction is a major contributor to false alarm rate unless rejected by some form of discrimination.

Frequency of occurrence of thermal release noise depends on temperature value and rate of change. The greatest number of signals occurs at sunset, and the smallest number occurs when rail temperature is constant, e.g., just prior to sunrise and during the hottest part of the day. Light rain or prolonged shade also affect thermal noise.

2) Other Potential Noise Sources

- Pedestrian traffic. Foot traffic is a possible serious source of false alarms in areas where railroad right-of-way is used by pedestrians. Signal amplitude and frequency content vary, but footstep signals are within frequency bands of simulated acts of sabotage; therefore, discrimination against them on the basis of frequency content alone appears infeasible.
- Rainfall and accompanying electrical disturbances. Most noise from rainfall produces signal frequencies greater than those of signals from simulated acts of sabotage (Reference 1, Figure 70). However, enough signal is in the optimum passband (800-1000 cps) that false alarms from heavy rainfall would be objectionable. Detailed spectral analysis of rainfall signals was not made.
- Wind effects. Wind did not affect the rails directly, but indirect effects were apparent. These were caused by blowing sand and movement of vegetation, but they were observed only on the inactive track at Site 1 where the rail rests directly on sand with small vegetation nearby. On a windy day, sand-grain impact could be heard as high-frequency "pinging" when the system was on audio. Wind effects could be serious in a dry, sandy area.
- Vehicular traffic and low-flying aircraft. Low-flying aircraft create noise for short periods of time. Propeller-driven aircraft and helicopters appear to cause stronger signals than jet aircraft,

but none of these signals should be a source of false alarm in a remote area where the system operator would be aware of aircraft in the vicinity.

3) Repeatability of Induced Signals

Tests on both rails and in both directions from the detector at Site 2 determined if previous results were peculiar to a particular section of rail or general for that rail line. Tests showed that for either rail, induced signal amplitude and character was approximately the same in both directions.

4) Effect of Change in Transducer-Rail Coupling

Changes in coupling apparently caused wide discrepancy in system sensitivity. On one rail, measurements were made with the detector package attached to a spot that had been cleaned thoroughly with wire brush and emery cloth; on the other, measurements were made on the same day with the same detector package but after only minimal cleaning. Results indicate that thorough cleaning of the attachment point is mandatory for maintaining system sensitivity.

c. Extended Analysis (New Research)

Signal amplitudes of 2663 acoustic pulses were measured on 13 filtered outputs and 2 wideband outputs, and time intervals were measured between 1045 of the more significant events. These measurements were tabulated on work sheets and are summarized in Tables 4, 5 and 6.

Events listed under "No. of Events" in Table 4 has at least 6.6-μv (rms) amplitude and output through at least one filter and corresponding demodulator. Average amplitude per event (Figure 9) indicated that predominant signal frequencies for detailed study were between 500 and 1300 cps and were primarily in the 800-1000 cps band.

1) Noise and Unwanted Signals (Thermal Release Noise)

Approximately 63 percent of thermal release signals remained after the 8.8-μv threshold was applied to amplitudes of 558-1359 cps frequency recorded on the 6-in. rail at time of maximum

Table 4

SIGNAL AND NOISE COUNT FOR DISCRIMINATION LOGIC EVALUATION

Type of Signal	Field Tape & Channel No.	Rail Size (in.)	Length of Sample (sec)	No. of Events	Average Duration (Analog) (msec)	Average Interval (Analog) (sec)
Sabotage						
Complete Series (including pedestrian traffic)	H-1, 3, 5, & 7	6	3960	1315	84	3.01
	B-7	5	1380	631	54	2.19
On rail with detector attached						
100 m: North	H-1	6	120	106	93	1.13
South	H-1	6	180	135	91	1.33
150 m: North	H-1	6	240	75	76	3.20
South	H-1	6	300	92	79	3.26
200 m: North	H-1	6	240	62	72	3.87
South	H-1, 3	6	360	89	68	4.04
250 m: North	H-1	6	120	9	70	13.33
South	H-3	6	300	32	68	9.38
On oposite rail without detector attached						
100 m: North	H-5	6	240	145	45	1.65
South	H-7	6	240	114	60	2.11
150 m: North	H-5	6	240	86	33	2.79
South	H-7	6	240	108	33	2.22
200 m: North	H-5	6	300	36	16	8.33
South	H-7	6	180	10	21	18.0
Pedestrian Noise	H-7	6	240	218	114	1.10
Two men walking past detector and remaining within range	B-7	5	120	118	62	1.02
Thermal Release Noise						
Sunset	I-1	6	1440	163	52.1	8.83
	C-1	5	1380	158	20.9	8.73
Midnight	J-3	6	1440	4	1.25	360.0
	D-1	5	1440	20	11.6	72.0
Sunrise	K-1	6	1440	114	11.1	12.63
	E-5	5	1440	2	6.5	720.0

Table 5

FILTER AND THRESHOLD LOGIC EVALUATION

Type of Signal	Percentage of Events — Passing Logic										
	Threshold = 8.8 μv (transducer output)*						Threshold = 13.2 μv (transducer output)*				
	300-5000 cps (Analog)	558-702 cps	708-891 cps	885-1115 cps	1105-1395 cps	708-1115 cps (Combined)	300-5000 cps (Analog)	558-703 cps	708-891 cps	885-1115 cps	1105-1395 cps
Sabotage											
Complete series 6-in. rail	90	68	70	72	57	78	71	63	62	62	53
Complete series 5-in. rail	86	57	52	61	63	63	78	54	50	59	61
On rail with detector attached											
100 m	93	70	69	73	71	78	76	66	63	66	66
150 m	95	78	81	78	76	83	81	75	77	76	68
200 m	93	73	75	64	40	80	66	64	62	54	31
250 m	68	46	49	54	59	54	49	46	46	46	49
On opposite rail without detector attached											
100 m	87	71	78	82	70	85	73	[illegible]	66	71	66
150 m	86	69	78	79	44	82	75	64	65	68	42
200 m	85	24	63	50	0	63	22	9	4	0	0
Pedestrian Noise											
Two men walking past detector and remaining in range											
6-in. rail	[illegible]	66	69	61	48	74	67	58	58	53	46
5-in rail	83	50	40	43	34	48	69	45	37	30	42
Thermal Release Noise											
Sunset: 6-in. rail	66	64	60	63	63	63	57	57	54	55	55
Sunset: 5-in. rail	56	8	11	11	21	16	37	7	10	11	19
Midnight: 6-in. rail	0	0	0	0	0	0	0	0	0	0	0
Midnight: 5-in. rail	100	0	0	0	0	0	95	0	0	0	0
Sunrise: 6-in. rail	66	18	27	26	26	30	27	16	23	23	23
Sunrise: 5-in. rail	50	50	0	0	0	0	50	50	0	0	0

*Transducer sensitivity = 25 mv/g

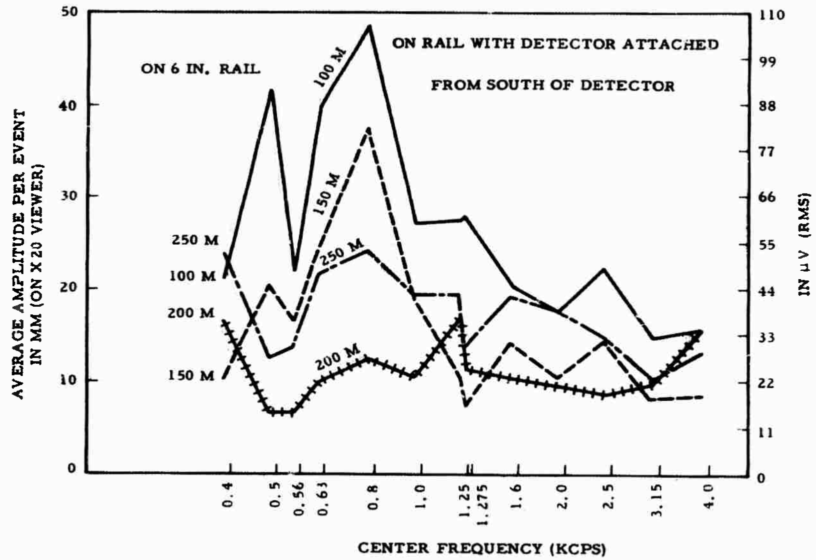
Table 6

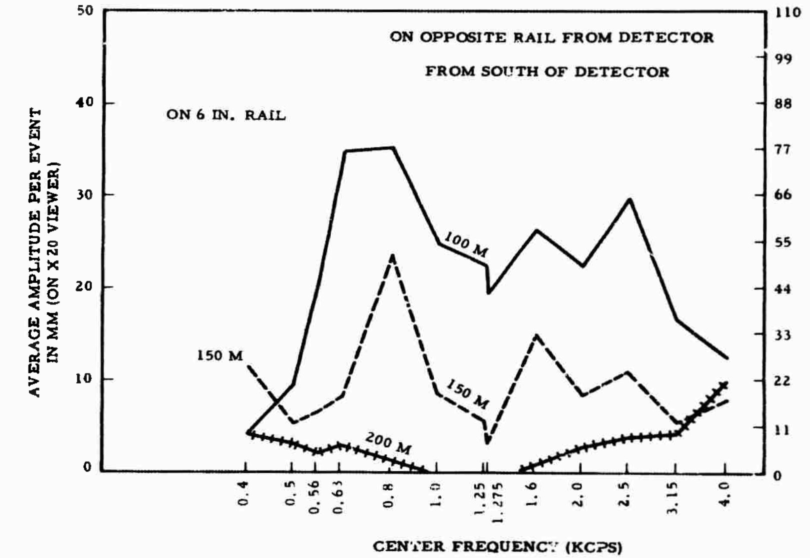
TIME-DOMAIN LOGIC EVALUATION
(With 8.8-μv Threshold and Optimum Filters)

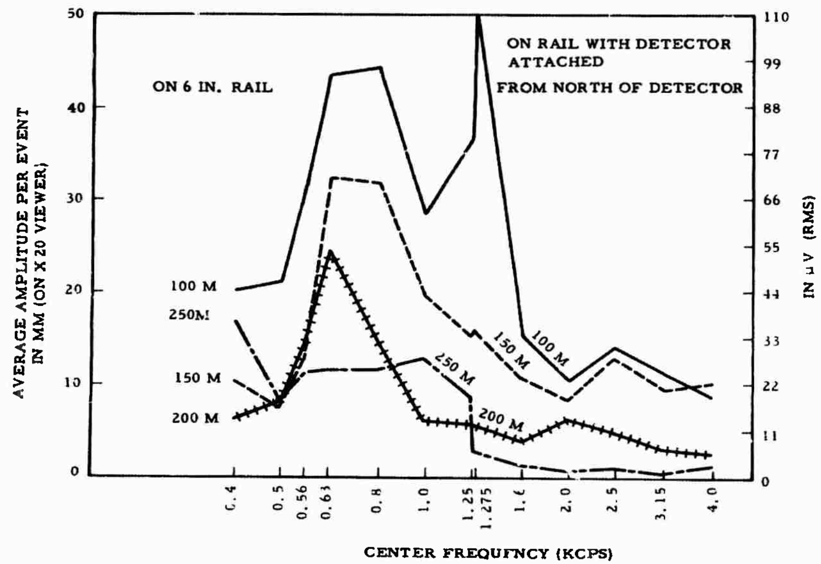
Type of Signal	Percentage of Events Passing Logic and Number of Alarms*							
	No Time Domain		20 Sec-2 Min Logic		15 Sec-2 Min Logic		12 Sec-2 Min Logic	
	300-5000 cps	708-1115 cps	300-5000 cps	708-5000 cps	300-5000 cps	708-1115 cps	300-5000 cps	708-1115 cps
Sabotage Acts								
On rail with detector attached								
200 m: 6-in. rail	93	80	86 (20)	72 (18)	80 (14)	69 (12)	33 (6)	33 (6)
250 m: 6-in. rail	68	54	14 (1)	14 (1)	0 (0)	0 (0)	0 (0)	0 (0)
On opposite rail without detector attached								
150 m: 6-in. rail	86	82	80 (26)	77 (25)	70 (17)	66 (16)	67 (13)	57 (11)
200 m: 6-in. rail	85	63	65 (5)	52 (4)	70 (4)	52 (3)	43 (2)	43 (2)
Pedestrian Noise								
Two men walking past detector and remaining within range								
6-in. rail	91	74	88 (32)	74 (27)	88 (24)	73 (20)	87 (19)	73 (16)
5-in. rail	83	48	76 (15)	46 (9)	75 (11)	41 (6)	76 (9)	42 (5)
Thermal Release Noise								
Sunset: 6-in. rail	66	63	29 (8)	29 (8)	5 (1)	0 (0)	0 (0)	0 (0)
Midnight: 6-in. rail	0	0	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)	0 (0)
Sunrise: 6-in. rail	66	30	32 (6)	0 (0)	28 (4)	0 (0)	26 (3)	0 (0)

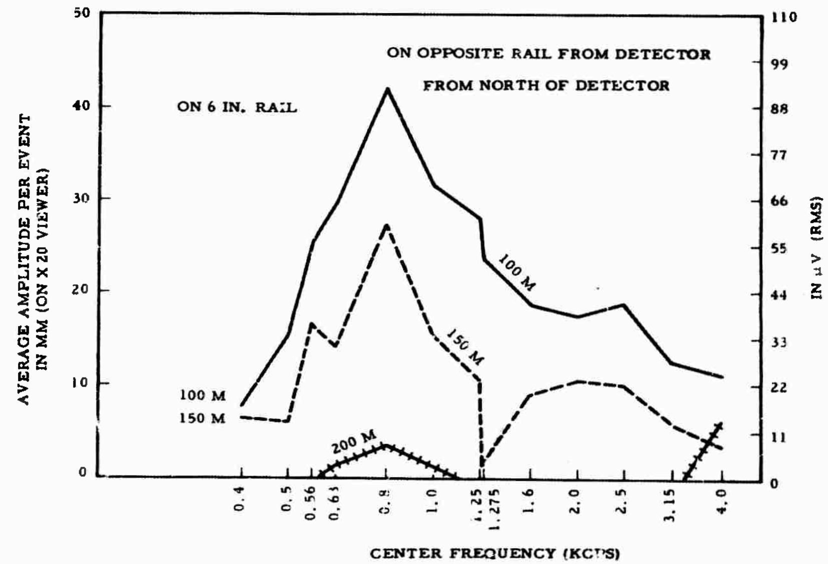
*Alarms in parenthesis

SIMULATED ACTS OF RAILROAD SABOTAGE 6 IN. RAIL

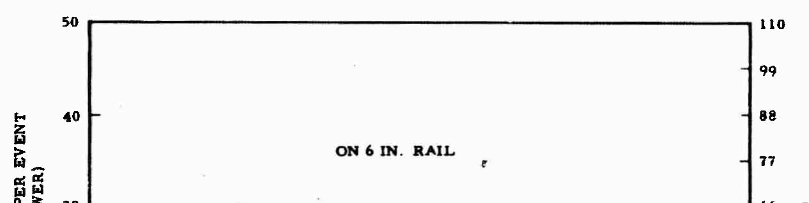




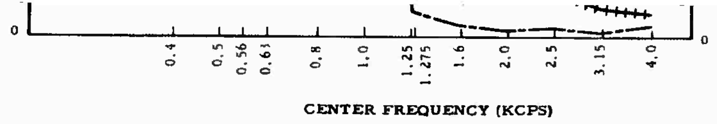


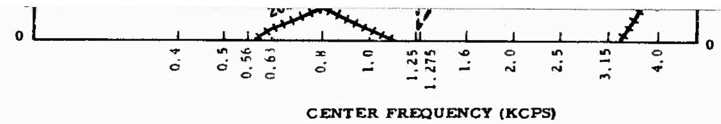


THERMAL RELEASE NOISE

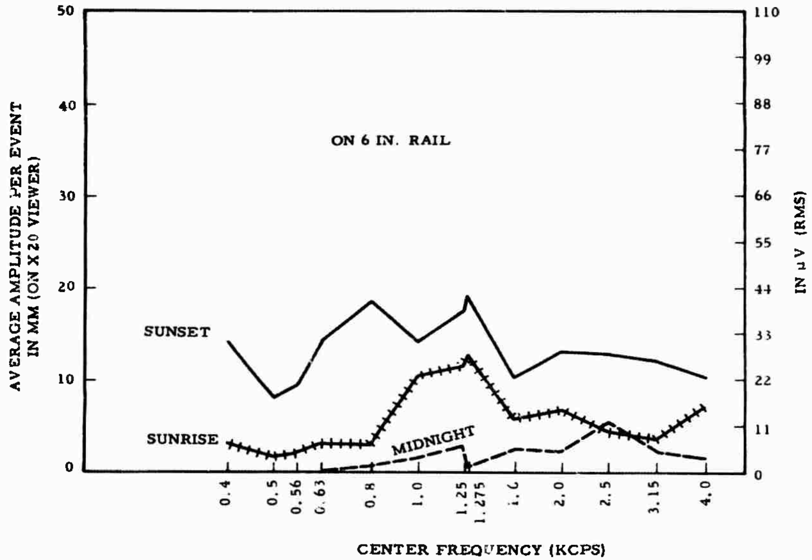


PEDESTRIAN TRAFFIC

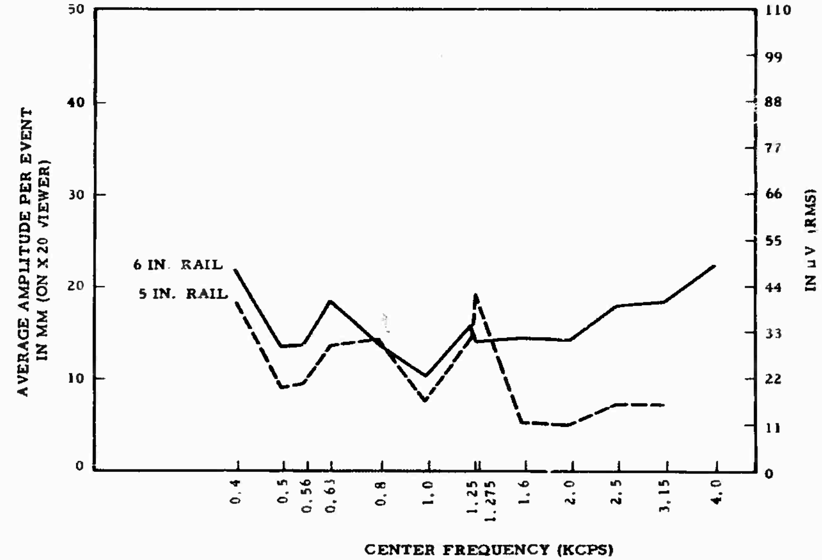


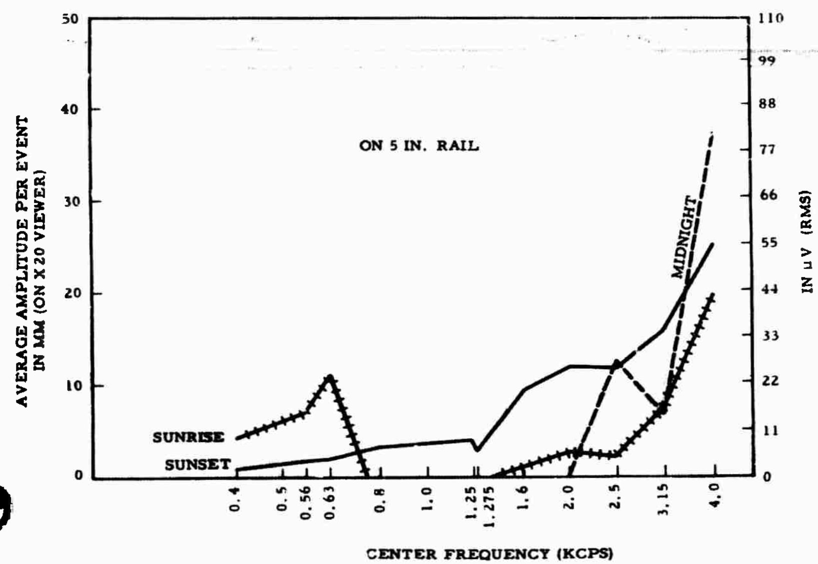


THERMAL RELEASE NOISE



PEDESTRIAN TRAFFIC





2

Figure 9. Average Amplitude per Event Recorded by Breadboard Model Detector, Narrowband Analysis

occurrence, sunset. This percentage was reduced to zero when a 15 sec-2 min time-domain logic was applied to time-interval data; i.e., one pulse occurred every 15 sec continually for 2 min.

2) Occurrence and Effect of Other Potential Noise Sources

a) Pedestrian Traffic

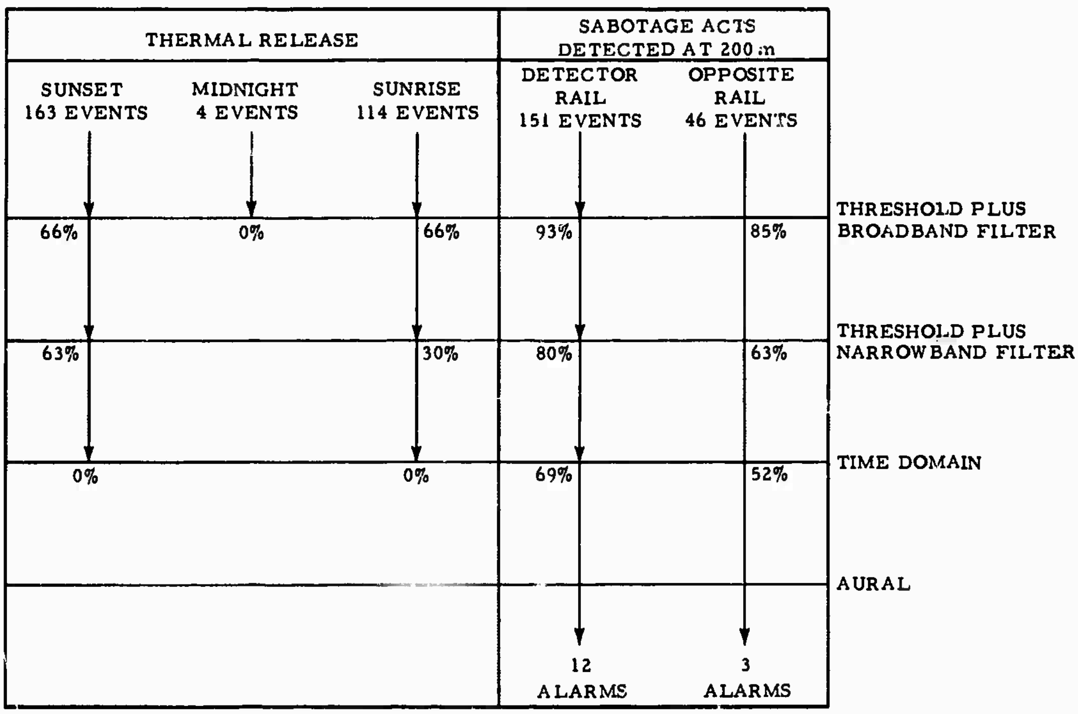
A two-minute event (signal) count accumulation period for discriminating against a solitary pedestrian passing a sensor was selected on the basis of duration times obtained from broadband chart recordings of which Figure 65, Reference 1, is an example. The false alarm rates obtained for pedestrian traffic from the data recorded on film for extended analysis are not considered as reliable estimates of system performance against this signal source. In simulating pedestrian traffic for these data, the signal sources did not proceed beyond detection range before returning toward the sensor; thus, a signal was produced that lasted longer than two minutes. For this reason, the chart recordings are considered to be a more valid measurement of realistically simulated pedestrian traffic. Since they were taken with no filtering, the two-minute period should be more than adequate for the filtered signal.

b) Rainfall and Accompanying Electrical Disturbances

Film from field tape K-3 contains rainfall, thunder and lightning noise. All frequencies within the 300-5000 cps pass-band are present and, as indicated in Reference 1, p. 104, intensity and continuity of signals make time-interval measurements and eventual time-domain and frequency discrimination impossible.

3) Sabotage Signals

Eighty percent of sabotage events conducted on the rail with the detector at 200 m distance and 63 percent on the opposite rail at a similar distance were transmitted to time-domain logic through the 8.8-μv threshold and 708-1115 cps filter passband. An event is considered one pulse; i.e., one hammer tap, one thermal release "pop," etc. Out of 151 events on the disturbed rail and 46 on the opposite, 12 and 3 alarms, respectively, would be triggered by the optimum 15 sec-2 min time logic which eliminated all thermal release noise (Table 6). Figure 10 illustrates the contributive effect of the logic circuitry on thermal release noise and sabotage events. This same logic eliminated all signals originating 250 m from the detector. Since all test sabotage signals were created by one or two men, it could be expected that actual sabotage activity entailing more than two men would cause a proportional increase in number of signals.



PERCENTAGES INDICATE THOSE EVENTS PERMITTED TO PASS THE SPECIFIC LOGIC CIRCUITRY

Figure 10. Contributive Effect of Logic Circuitry

SECTION V

CONCLUSIONS

Results of this research indicate that the most feasible method of detecting railroad sabotage would be detection of acoustic or vibration signals introduced into the rail. Based on results of acoustic investigations, a system can be constructed that meets specified performance criteria. The features of this system are:

1. After the system has been installed, one man can maintain and operate a four-sensor system that covers one mile of railroad. Each remote sensor can be turned on or off and tested by an individual at the centrally-located monitor unit.

2. A false alarm rate less than one per mile per day can be achieved by a three-step logic system with a 700-1100 cps passband filter, 8.8-μv amplitude threshold (at 25-mv/g transducer) and an event repetition rate equal to or exceeding one event per 15 seconds consecutively for 2 minutes. Signals from thermal release noise will be eliminated, yet sabotage signals 200 meters away will create an alarm. The 2-min feature of this logic will discriminate against solitary or widely spaced pedestrian traffic. The aural monitor will be the sole discriminator against a procession of pedestrians or dawdlers.

3. Tampering resistance is fulfilled by concealment of the remote system package in railroad ballast beneath the rail and linking the system to a camouflaged antenna by a buried shielded cable. While not incorporated in any of the block diagrams, a simple pressure-release key could activate continuous transmission of sensor output and provide a homing signal when a system was removed from the rail by unauthorized persons.

SECTION VI

RECOMMENDATIONS

Acoustic investigations have successfully demonstrated the feasibility of a system designed to detect clandestine attempts to sabotage railroads by physically damaging or removing sections of rails and ties. On the basis of the results obtained, the following specific recommendations are made:

- Design and construct a prototype system
- Extended investigations

A. DESIGN AND CONSTRUCT A PROTOTYPE SYSTEM

To utilize results of this study, it is recommended that an operational system be constructed. The system should consist of a monitor unit and sufficient sensor units to give one-mile coverage on a test track. It is understood that Atlantic Research Corporation is undertaking such a project to instrument three kilometers of track under Contract DA-44-009-AMC-1002(T).

The sensor package should contain the transceiver, amplifiers, filter, and all logic and control circuitry and should be made as small as possible to simplify concealment. The only physical requirement for either the sensor or the monitor unit is that it be easily portable and that the entire unit, including power, can be carried by one man. Each unit will be buried — the sensor unit under the rail ties and the power package near the antenna to allow battery changes in more secrecy.

It has been shown that a detection range of 200 m is attainable based on the use of the breadboard model detector. (This range refers to both directions on both rails.) A suitable deployment pattern for the detector units would be a staggered spacing of 800 m on each rail.

Based on the design concepts and detector spacing, the estimated material cost for design and construction of a prototype four-sensor system for 1600 m (one mi) of coverage would be as follows:

FOUR REMOTE UNITS

Transducers	$1000
Amplifiers and preamplifiers	2000
Sensor gates	12
Summers	2
Filters	240
Threshold (Schmitt Trigger) logics	40
Time-domain logics	400
Transmitter ON-OFF logics	2
Transceivers (RF 450 Mc)	2400
Command controls	140
Test function generators	120
Reset generators	12
Function selects and test gates	32
Batteries	30
Power switches	200
Magnets	100
Cases	400
Switching and cabling	40
Subtotal	$7170

ONE MONITOR UNIT

Receivers (4)	$ 400	
Visual indicators (4)	200	
Aural indicator (1)	50	
Transmitter ON-OFF (1)	200	
Reset and switches (4)	240	
Battery pack (1)	100	
Telescoping antenna (1)	300	
Weatherproof console (1)	700	
Subtotal	$2190	
TOTAL		$9360

An estimated 30 to 35 man-months of labor would be required to design and construct a detection system for one mile of coverage. The cost of design and construction of a system with two miles of coverage would probably not exceed 20 percent more than the costs indicated for one mile exclusive of additional materials cost.

B. EXTENDED INVESTIGATIONS

It has been determined that certain areas of the investigation warrant further study since they may lead to improved system capabilities. These tests should be incorporated into any program leading toward construction of a multisensor unit and would include the following:

- Transducer-rail coupling
- Optimum transducer location on rail
- Attenuation rates
- Telemetry

1. Transducer-Rail Coupling

The experiments performed as a part of the qualitative system concepts of this study focus the need for a more detailed study of transducer-rail coupling. It is apparent that thorough cleaning of the contact surface is mandatory and that attachment of the transducer must assure a rigid contact with good alignment. Attachment and alignment do not present a serious problem but cleaning of the contact surface does since ease and speed of emplacement is essential to a workable system. It is believed that a combination of magnetic attachment and epoxy adhesive will yield satisfactory results.

2. Optimum Transducer Location on Rail

The location of the transducer within a section of rail line may have an important bearing on the detection range of a workable system. The experiments which were carried out in this aspect of the program were inconclusive because it was evident that multiple transducers were needed to overcome transducer coupling inconsistencies encountered in transplanting one transducer.

A signal being transmitted down the rail must undergo a complex transformation at the rail joint-bar coupling with an attendant sharp loss in energy at each joint-bar coupling crossover. These effects can be scrutinized closely only by the use of multiple transducers attached at short increments of distance from the center of a rail section to and across a joint-bar coupling and simultaneous recording of a relatively distant input signal. A more detailed study should include the use of transducers sensitive to vertical and horizontal components of rail-transmitted energy.

3. Attenuation Rates

A reasonable estimate of the attenuation rate of induced frequencies has been made with a single transducer and a calibrated weight drop at varying distances. Additional measurements of this factor are desirable, however, using multiple transducers monitoring the same signal. It has been shown that calibrated weight drops produce repeatable signals from one location but that varying the distance and location of weight drops within a section of rail may produce results which are misleading.

4. Telemetry

A remote (wireless) communications link will be mandatory for any operational field system because long cables would be difficult to install and conceal. The power loss due to cable length must also be considered. The tentative conclusions reached in the discussion of the transmission of data, Appendix A, should be carefully restudied prior to incorporating a wireless data transmission link into a prototype system.

APPENDIX A

ACOUSTIC SYSTEM CONCEPTS

APPENDIX A

ACOUSTIC SYSTEM CONCEPTS

This section of the report is a restatement of the acoustic system concepts section of First Interim Technical Report, Reference 1, p. 118. The optimum frequency passbands of the earlier report have been superseded by data from the more extensive sample of the extended analysis. Significant changes made are in the system design factors — false alarm discrimination and detection range.

Basic factors affecting prototype design are:

- System concepts
- Design factors
- Design specifications
- Operation
- Performance estimates

1. System Concepts (Figures A-1 through A-3)

- Adequate sensors for a minimum of one-mile coverage for each monitor unit
- Built-in logic circuitry for discrimination against false alarms
- Rapid sensor attachment
- Data transmitted through logic circuitry for a fixed period of time after receipt of a signal
- Monitor unit with separate receivers and visual indicators for each sensor plus an aural monitor which can receive transmissions from all sensing units simultaneously or can be tuned to any individual sensor

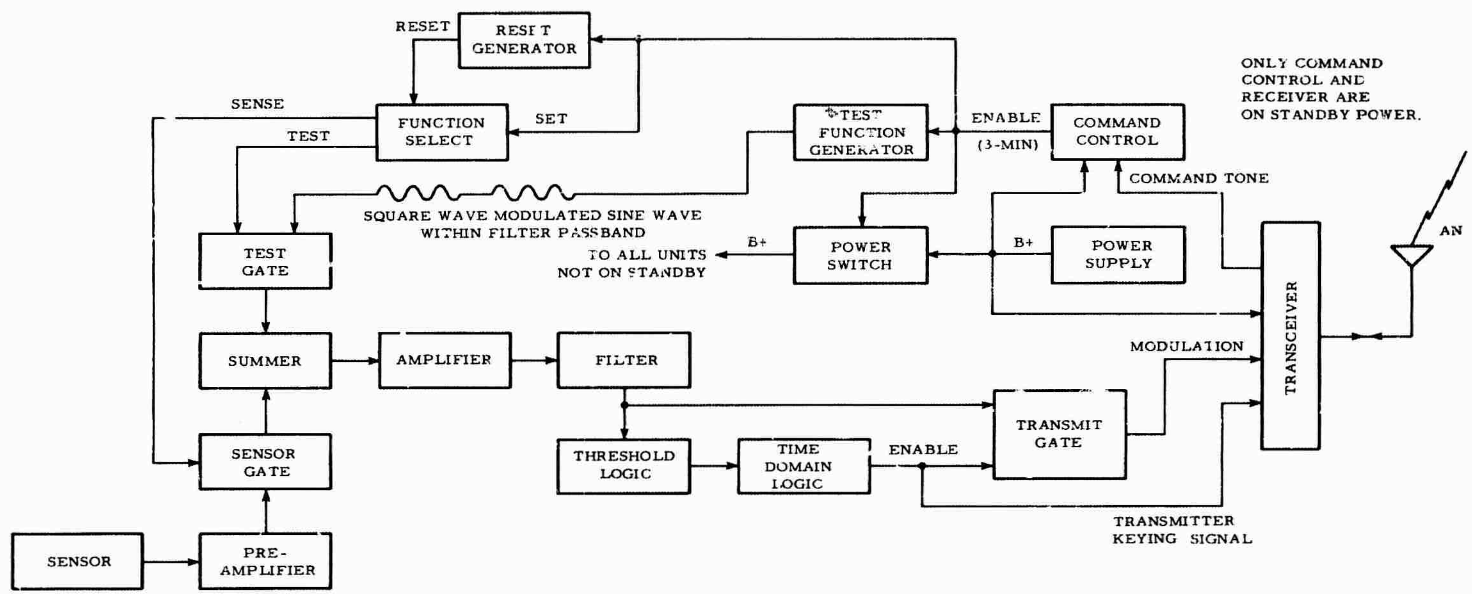


Figure A-1. Sensor Package Block Diagram

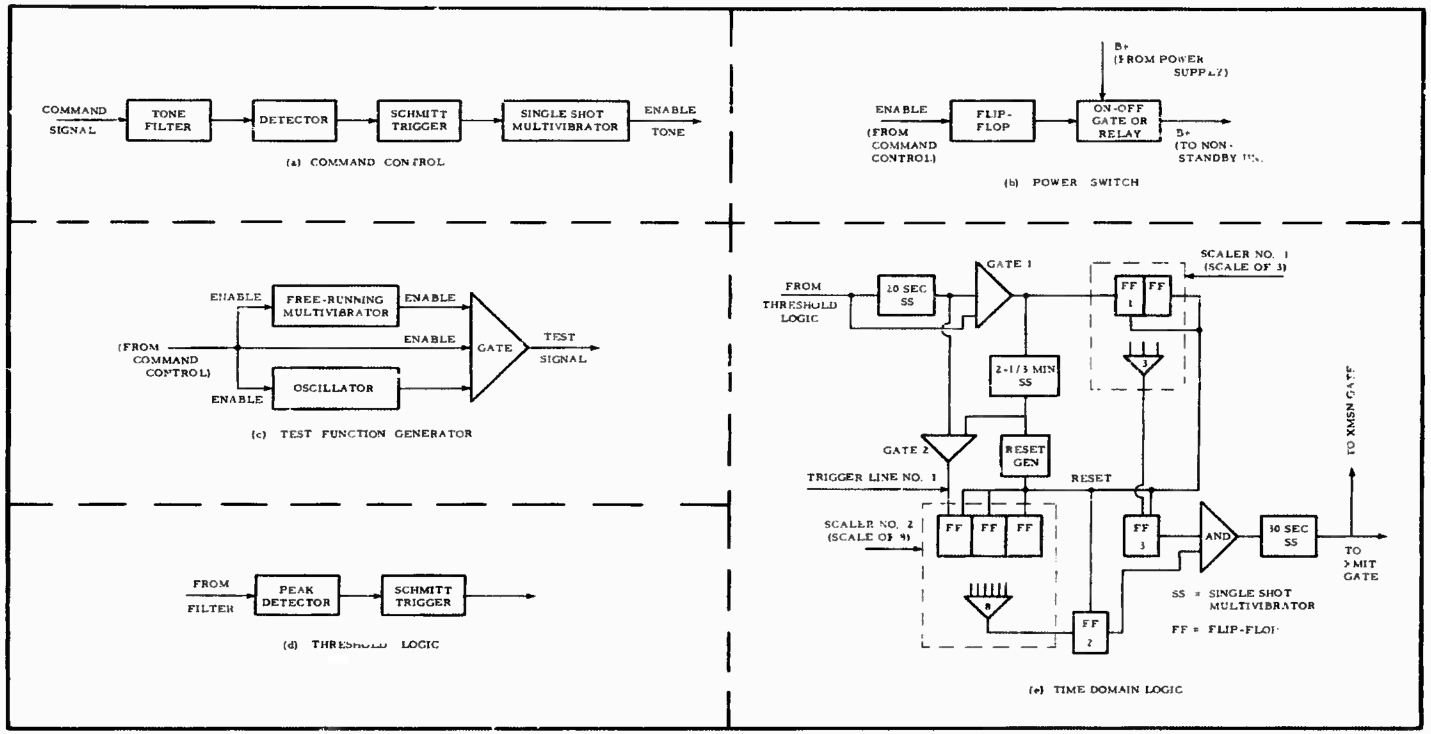


Figure A-2. Detailed Sensor Package Subsystem Block Diagrams

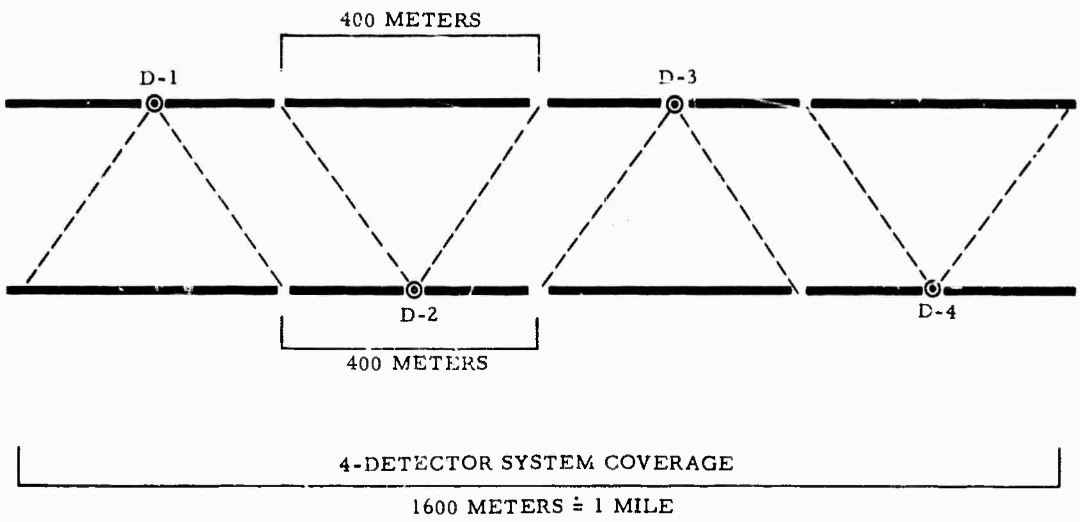


Figure A-3. Detector Spacing and Deployment Pattern

2. Data System Design Factors

Important design factors in a workable system are false alarm discrimination, detection range, data link, and tactical consideration.

a. Discrimination Against False Alarms

This is the primary design factor. The most serious potential sources of false alarms are thermal release and pedestrian traffic. Heavy rainfall, electrical disturbances and high winds under dry conditions could render the system ineffective; therefore, it is anticipated that the system would not be operated under extreme weather conditions when continuous alarm transmission would use power unnecessarily.

Four methods of discrimination which will virtually eliminate false alarms under favorable weather conditions are:

- Frequency filtering
- Threshold logic
- Time-domain logic
- Aural monitoring

1) Frequency Filtering

Spectral analyses of simulated acts of sabotage indicate a majority of the rail-transmitted energy lies within 400-1200 cps. These data are substantiated by extended analysis where a 700-1100 cps passband provides optimum filtering. Narrower passbands could exclude a portion of unwanted signals with frequencies within the same spectral region; however, narrowing the passband further attenuates signals undesirably. Very small or very large rails may prove to have optimum passbands extending slightly beyond these optimum limits, but this should not reduce system capability appreciably. Therefore, the filter section should have a passband of 700-1100 cps with an attenuation rate of about 24 db/octave on either side of this band.

2) Threshold Logic

An 8.8-μv transducer output threshold (transducer sensitivity = 25 mv/g) was selected optimum. It is twice the highest observed ambient noise level on an active rail. At least 85 percent of all sabotage signals from 200 m distance exceed this threshold. Average amplitudes of 110 μv for 100-m distance signals approach dynamic range of instrumentation. The detector system can incorporate an inexpensive Schmitt trigger which will pass only those pulses created by transducer outputs greater than the desired level. For example, maximum noise was recorded during the heat of the day; an optimum threshold for quiet night operations would be lower.

3) Time-Domain Logic

Results of the investigation indicate that a time-domain logic circuit, based on average repetition rate of signals during a specified time period, is the most feasible method for eliminating potential false alarms. Signals produced by thermal release, acts of sabotage and pedestrian traffic occur at rates which permit effective discrimination.

A time-domain logic circuit can be designed which will trigger the transmitter only when pulses are received from the filter and threshold logics at a rate of one or more per 15 sec for a 2-min period. One pulse/15 sec discriminates thermal release signals from sabotage signals, and the 2-min period discriminates against individual pedestrian signals since a pedestrian would normally pass out of detector range within that time period. Sabotage acts could be expected to continue longer; at least 10 min is required to remove sufficient nuts and spikes to spread or remove a single rail. The quick emplacement of explosives could not be detected effectively by this system.

A filter-threshold time-domain logic subsystem for elimination of false alarms meets system concepts. A false alarm could still be sent when one or more pedestrians followed each other at 2- to 4-min intervals and also when the thermal release signal rate exceeded one pulse/15 sec. The aural discrimination stage is necessary to evaluate these alarms.

4) Aural Monitor

a) Alert System

In the open position, the aural monitor serves all sensors. It emits a brief aural alarm to alert the operator when any sensor detects a signal. The visual indicator consists of a lamp for each sensor; the appropriate lamp is lighted when its sensor transmits a signal and remain lighted until reset, thus revealing location of the signal source.

b) Final Discrimination Stage

A selector switch on the aural monitor lets the operator listen to any single sensor and determine how the signal is being produced. Thermal release and footstep signals can be distinguished from simulated acts of sabotage by an operator with very little training or experience.

The monitor also contains an interrogation command control for turning on the sensor subsystems remotely and for use as an intermittent operability check. This control also permits deactivation of the system.

b. Detection Range of Sensor Units

Initial indications of a 250-m detection range were substantiated by extended analysis but must be qualified by the time-domain logic design. A complete study of field results and the application of discrimination stages indicate that a detection range of 200 m on each parallel rail is optimum. A staggered deployment of detectors as indicated in Figure A-3 will permit four units to cover effectively one mile of railroad track.

c. Data Link

Cable was used in the study to transmit signals from the detector to the recording and monitoring units. Data transmission in a workable system would have to be by wireless link to meet requirements of complete concealment and ease of installation.

Three possible means of wireless communication have been considered — acoustic, radio and infrared laser. The laser would be a secure method but requires line-of-sight transmission and precise aiming of the transmitter. A secure acoustic means involves use of ultrasonic frequencies and, while it warrants further investigation, major uncertainties exist with respect to range and power requirements. A radio frequency link appears most feasible for wireless transmission of data.

Factors which must be considered in choosing the operating radio frequency include attenuation, propagation characteristics, antenna size, and noise. An attractive approach would be to use one of the frequency bands in which commercially-available pocket transmitters operate: 25-50 Mc, 130-170 Mc and 450-470 Mc. To choose between these bands, first considerations must be given frequency-dependence of signal attenuation over the transmission path and antenna size.

In Table A-1 are tabulated free-space attenuation for a 2-km path and length of a quarterwave monopole antenna vs frequency. The free-space attenuation factor accounts only for loss from spherical spreading and does not consider other loss factors (such as air moisture content) which are also frequency-dependent. Apparently, requirements of low attenuation and small antenna size conflict.

However, necessary concealability dictates choice of the 150- or 450-Mc region. The monopole antenna at 450 Mc is a stub slightly over six inches long and the 150-Mc antenna can be made reasonable in size by using a rigid loop approximately 4.5 in. in diameter. The quarterwave antenna could be hidden nearby and connected by concealed lead to the sensor package transmitter.

Table A-1

ATTENUATION AND ANTENNA SIZE VS FREQUENCY

Frequency (Mc)	Attenuation (db)	$\lambda/4$ Antenna (ft)
450	91	0.52
150	82	1.66
50	72	4.7
27	67	8.7
3	48	78.0
1	38	234.0

Radio waves at either of these frequencies suffer severe attenuation in dense, high-moisture-content foliage, and such attenuation increases with frequency. However, the surface wave at these frequencies follows curved valleys to achieve communication well beyond line-of-sight. The railway forms a man-made valley through local vegetation, and the surface wave can be expected to follow the railway and along tree tops. A receiving antenna extending above the tree tops would intercept this wave. In regions of sparse vegetation, the surface wave would suffer less attenuation.

Atmospheric static noise ceases to be important above 30 Mc, but thermal receiver noise begins to be significant in this frequency region with a typical value of 1 μv/m at 450 Mc for a receiver bandwidth of 6 kc. Cultural interference levels are considerably reduced in the 150- 450-Mc regions, but this noise source would be insignificant in a remote region.

Transmitter power requirements are affected by all factors discussed above plus the transmitter duty cycle and the bandwidth. The smallest bandwidth requirements will apply if only identification and alarm signals need to be transmitted. With a separate frequency for each transmitter, the carrier could be used as identification. However, presence of any radio frequency source (at the same frequency) in the area could trigger a false alarm. Carrier modulation with a simple tone oscillator would eliminate this source of a false alarm.

Limited duration transmission of the signal to permit aural monitoring should be considered. This would not increase bandwidth requirements significantly, since a band of 200-1400 cps should be adequate for aural identification of the signal cause. A more significant power requirement would be a longer (30-60 sec) transmission to allow the observer adequate time for signal source identification.

Above considerations lead to tentative selection of a radio link in the 450-Mc frequency region. Maximum flexibility, reliability and ease of operation would be afforded by a separate channel for each of the vibration sensor packages with a separate receiver in the monitor unit. If false alarm discrimination meets desired goals, the transmitter would be keyed by output of the logic circuit only for a true sabotage act. Hence, transmitter duty cycle would be very low. Commercially available units provide approximately 80 hr of operation with mercury batteries on a 10 percent duty cycle. With a cycle of one percent or less, which appears reasonable, battery life could be extended.

d. Tactical Considerations

Success of any system for detecting overt acts of sabotage must be based primarily on ability to emplace the system rapidly and surreptitiously and in such manner that it cannot be detected easily. Any system for use on rail lines must meet the following qualifications:

- Sensor packaging requirements
- Easily concealed data link
- Minimum transmission time

1) Sensor Packaging Requirements

Since the sensor package must fit under the rail line and be completely hidden in daylight, the only critical dimension is the magnetic coupling device. Electronics would be buried below the rail ties in any conveniently small package. Recommended dimensions are discussed under system design specifications.

2) Easily Concealed Data Link

A wire data link is not considered practical because of the time necessary for installation and the difficulties of adequate concealment. An RF system may require a short-wire data link to an off-road concealed antenna. Operational tests may show that a hardly noticeable quarterwave stub or a horizontal loop will give adequate transmission range. Either of these could be part of the sensor package and extend from under the rail at ground level. A unit of this kind could be traced easily if it were keyed to transmit when removed from the track by unauthorized persons.

3) Minimum Transmission Time

This is needed to decrease the chance of system detection by RF monitoring systems which may be in the area. Very little transmission time is anticipated with the logic circuitry recommended.

3. System Design Specifications

The contemplated system consists of remote and monitor units. This remote unit can contain both the sensor and data link packages, or the latter can be buried near an external antenna away from the railroad track.

a. Remote Unit

1) Sensor Package

- Accelerometer — Clevite Model 25D21 (or equivalent) with sensitivity of 25 mv/g. Size: 0.62-in. dia x 0.71 in. high; Weight: 0.9 oz

- Filter — 700-1100 cps passband; attenuation slope 24 db/octave above and below passband

- Preamplifier — input impedance equivalent to Sensonics Model 1000; under 1-μv rms integrated noise over 700-1100 cps bandwidth

- Amplifier — 20 db gain; 700-1100 cps bandwidth

- Command control

- Circuitry for false alarm discrimination, test function generation, etc.

- Threshold detector — noise limiter to pass only signals with transducer output > 8.8 μv (transducer sensitivity = 25 mv/g)

- Time-domain logic — circuitry to pass only those signals which average more than 1 pulse/15 sec for a 2-min interval

- Power supply — adequate for one month's operation using rechargeable batteries

- Magnetic mounting — a magnet with less than 4-in. dimensions should be used for rapid attachment and satisfactory transducer coupling to the rail while epoxy is setting. The length lead from the transducer to the buried electronics package would vary according to depth

2) Data Link Package

- Transceiver — 150 or 450 Mc region

- Power supply — batteries adequate for one month's operation with a 1 percent duty cycle

- Antenna — loop or monopole; size determined by frequency

b. Monitor Unit

- Receiver — one per remote unit

- Visual indicators — with resets

- Aural alarm common to all receivers
- Aural monitoring of any receiver by selection
- Sensor activator and operability check — transmitter in a control unit to turn all sensors ON or OFF by means of a tone-modulated carrier signal
- Battery pack.
- Erectable antenna

4. System Operation

System concept requirements are met by preliminary sensor package design shown in Figure A-1. The package consists of an RF transceiver, power supply, command control circuit, test function generator, sensor (accelerometer), amplifiers, filter, and threshold and time-domain logic circuits. Operation of the sensor package system is as follows:

- The receiver and command control circuit are on standby power; all other circuits are off until activated by a command signal.
- A command signal detected by the receiver causes the command control circuit to turn on power to all other circuits, sets the function select circuit to TEST and enables the test function generator.
- The test signal is passed by the test gate into the amplifier-filter-logic circuits. The sensor gate blocks signals from the accelerometer during the test period. The test signal must meet all requirements of the logic control circuitry.
- The test signal satisfies logic requirements, and the final logic stage enables the transmit gate and keys the transmitter. During the period the transmitter is keyed, the signal at the filter output is passed by the transmit gate and modulates the transmitter. The test signal received by the monitor would activate

the visual indicator to show the sensor package on that channel is operating satisfactorily.

- At the end of the enable signal from command control, the test function generator is turned off, and a reset generator sets the function-select circuit to SENSE. Then, any input to the test gate is blocked and the sensor gate is opened.

- Any subsequent command signal (identical to the first) will turn the power switch to OFF. (It would also tend to restart the test cycle but cannot because power is removed from the circuits.)

- While the sensor package is in SENSE, any signal from the accelerometer (or sensor) which satisfies requirements of the logic circuits will key the transmitter for a fixed period of time. During this period the filtered signal from the sensor modulates the transmitter, and the signal can be monitored aurally by the operator at the monitor console.

Detailed block diagrams of the sensor package subsystems are shown in Figure A-2. Operation of these subsystems is as follows:

- The command control signal is a tone-modulated RF carrier which must fall within the tone filter passband. The detector forms the rectified envelope of the tone signal which activates the Schmitt trigger if it is above triggering level. Trigger output initiates the monopulse (single shot) multivibrator, which is set for a 3-min period. This output is an enable signal for the power switch, test function generator and function-select circuit.

- A flip-flop and an ON-OFF power gate or relay comprise the power switch. The enable signal from command control switches the flip-flop to ON, which turns on the power gate. It remains on until another positive pulse is received from command control which resets the flip-flop to OFF. When the command-control enable signal ceases, the negative pulse does not affect the flip-flop.

- A free-running multivibrator, an oscillator and a gate comprise the test function generator circuit. Oscillator frequency is centered in the passband of the sense circuit filter. The gate passes the oscillator signal only when the enable signal from command control and the positive (or negative) polarity of the square wave from the multivibrator are present. The result is a 100-percent square wave modulated sinusoid. The square wave frequency is set to ≥ 4 cycles/min; i.e., the multivibrator period is < 15 sec.

- The threshold logic circuit contains a peak detector which forms a rectified envelope of any signal passed by the filter. If the pulse envelope exceeds trigger level amplitude of the Schmitt trigger, the latter puts out a pulse to the time-domain logic circuit.

- Time-domain logic — A pulse from the threshold logic circuit initiates a 15-sec single shot multivibrator whose output enables gate 1 and is the input to gate 2. If a second pulse arrives during the 15-sec period of the single shot, it is passed by gate 1 and enters as one count in scaler 1. It also initiates a single-shot multivibrator with a period of 2-1/4 min. Output of this single shot enables gate 2. The trailing edge of the 15-sec single shot pulse triggers an output pulse from gate 2 on trigger line 1. Scaler 2 can receive triggers only at the rate of 4/min since the trigger line is controlled by gate 2 whose input consists of 15-sec pulses from the 15-sec single shot. If input pulses arrive at a rate >4 min and persist for 2-1/4 min, scaler 2 will be brought to a full count of eight and will put out a pulse to flip-flop 2 whose output provides one enabling signal to the AND gate.

Scaler 1 receives counts only during the enable period of gate 1. If the rate of pulse arrival is just $>$ 4/min, it would count only three pulses since the first, third and fifth pulses would enable the gate and the second, fourth and sixth would be passed by the gate. Scaler 1 then needs to be only a scale of three, and a full count in this scaler establishes a pulse arrival rate $>$ 4/min during the 2-min test period. When scaler 1 reaches a full count, it puts out a pulse to flip-flop 3 whose output provides the second enabling signal to the AND gate. Since both inputs to this gate are now ON, the gate triggers a 30-sec single shot multivibrator which provides the enabling signal for the transmit gate and the keying pulse for the transmitter.

If the initial pulse is not followed by another within 15 sec, the next pulse is blocked by gate 1. Thus, pulses which arrive at a rate $<$ 4/min (such as from thermal release signals) do not initiate the count cycle.

If the count cycle is initiated by arrival of two pulses within a 15-sec period, but this rate does not persist for 2-1/4 min, scaler 2 will not reach a full count and one of the necessary ON signals to the AND gate will be missing. The trailing edge of the 2-1/4-min single shot pulse triggers the reset generator, and all flip-flops are returned to their initial state.

The 2-1/4-min period for the second single shot multivibrator is needed for a 2-min test period since scaler 2 only receives counts on the trailing edge of the 15-sec single shot pulse. Since there must be some interval between the 15-sec pulses, the trailing edge of the eighth pulse cannot arrive within 2 min.

In summary, the time-domain logic requires that the pulse arrival rate exceed 4/min and that this rate of arrival persist for 2 min.

The monitor unit design provides for one receiver for each sensor package. The output of all receivers is coupled to a common audio alarm to alert the operator when any sensor package is transmitting. The output of each receiver has its own visual indicator which is turned on by the presence of an output and remains on until reset manually. A transmitter for command control of all sensor packages transmits an RF carrier modulated by a single tone. In addition, an erectable antenna, battery pack, and appropriate circuits and switches for battery checks and operability checks are provided.

5. System Performance

Experimental research yielded sufficient data for design of a system meeting the performance criteria given in the purchase description. These criteria are:

- Operation maintenance (one man/mile)
- False alarm rate (one/mile/day)
- Tampering resistance (or concealability)
- Performance reliability

a. Operation Maintenance (One Man/Mile)

One man per mile of operation and maintenance is feasible after installation of the system. Figure A-3 shows that four sensor packages will give one mile of coverage, and the monitoring unit for four sensors can be designed so that one man can transport it easily. Operation and maintenance of the unit can be done by one man with only a small amount of training.

b. False Alarm Rate (One/Mile/Day)

False alarm rate limit of one per mile per day can be achieved by utilizing the above design features except in the case of grouped or closely spaced pedestrian traffic. The chances of premature military action due to false alarms caused by pedestrian traffic are greatly reduced with provision for aural monitoring.

c. Tampering Resistance (or Concealability)

The sensor package meets this concealability requirement. Command control permits regular operability checks for each sensor.

d. Periodic Attention

The requirement for remote components to need attention less frequently than once per year per location or once per year per mile of track is not considered realistic or feasible for these reasons:

- Battery power requirements
- Greater system costs due to higher cost components and extensive testing program
- Probable detection of at least one unit within a period of one year

e. Performance Reliability

A system incorporating filter-threshold time-logic circuitry and aural monitoring capabilities should be completely reliable for sabotage detection purposes when constructed of thoroughly tested components and assembled by high quality workmanship.

APPENDIX B

REFERENCES

APPENDIX B

REFERENCES

1. Texas Instruments Incorporated, 1965, First Interim Report, System Predictions Report, Railroad Sabotage Detection Research (U), Contract DA-44-009-AMC-657(X), Apr., 148 p.

AD______________________ Accession No. ______________

Texas Instruments Incorporated, Dallas, Texas — RAILROAD SABOTAGE DETECTION RESEARCH R.E. Brannian, R.G. Baker, A.E. Sobey, Jr.

Final Technical Report, 15 October 1965
62 p., 13 illustrations, 6 tables.
DA Project 44-009-AMC-657(X) Unclassified Report

This is a final technical report on feasibility studies for detection of railroad sabotage. The study of acoustic rail-transmitted signals induced into the rail by simulated acts of sabotage is emphasized; however, some attention was devoted to seismic and other classified modes of energy transmission. Descriptions of tests and results presented in First Interim Technical Report, April 1965, are reviewed and new results, conclusions and system design specifications are included. The latter are based on a much larger sample of data and, with detail changes, substantiate system concepts of the preceding report.

UNCLASSIFIED

1. Seismic, Acoustic Experiments, Data Analysis, System Design
2. Contract DA-44-009-AMC-657(X)

AD______________________ Accession No. ______________

Texas Instruments Incorporated, Dallas, Texas — RAILROAD SABOTAGE DETECTION RESEARCH R.E. Brannian, R.G. Baker, A.E. Sobey, Jr.

Final Technical Report, 15 October 1965
62 p., 13 illustrations, 6 tables.
DA Project 44-009-AMC-657(X) Unclassified Report

This is a final technical report on feasibility studies for detection of railroad sabotage. The study of acoustic rail-transmitted signals induced into the rail by simulated acts of sabotage is emphasized; however, some attention was devoted to seismic and other classified modes of energy transmission. Descriptions of tests and results presented in First Interim Technical Report, April 1965, are reviewed and new results, conclusions and system design specifications are included. The latter are based on a much larger sample of data and, with detail changes, substantiate system concepts of the preceding report.

UNCLASSIFIED

1. Seismic, Acoustic Experiments, Data Analysis, System Design
2. Contract DA-44-009-AMC-657(X)

AD______________________ Accession No. ______________

Texas Instruments Incorporated, Dallas, Texas — RAILROAD SABOTAGE DETECTION RESEARCH R.E. Brannian, R.G. Baker, A.E. Sobey, Jr.

Final Technical Report, 15 October 1965
62 p., 13 illustrations, 6 tables.
DA Project 44-009-AMC-657(X) Unclassified Report

This is a final technical report on feasibility studies for detection of railroad sabotage. The study of acoustic rail-transmitted signals induced into the rail by simulated acts of sabotage is emphasized; however, some attention was devoted to seismic and other classified modes of energy transmission. Descriptions of tests and results presented in First Interim Technical Report, April 1965, are reviewed and new results, conclusions and system design specifications are included. The latter are based on a much larger sample of data and, with detail changes, substantiate system concepts of the preceding report.

UNCLASSIFIED

1. Seismic, Acoustic Experiments, Data Analysis, System Design
2. Contract DA-44-009-AMC-657(X)

AD______________________ Accession No. ______________

Texas Instruments Incorporated, Dallas, Texas — RAILROAD SABOTAGE DETECTION RESEARCH R.E. Brannian, R.G. Baker, A.E. Sobey, Jr.

Final Technical Report, 15 October 1965
62 p., 13 illustrations, 6 tables.
DA Project 44-009-AMC-657(X) Unclassified Report

This is a final technical report on feasibility studies for detection of railroad sabotage. The study of acoustic rail-transmitted signals induced into the rail by simulated acts of sabotage is emphasized; however, some attention was devoted to seismic and other classified modes of energy transmission. Descriptions of tests and results presented in First Interim Technical Report, April 1965, are reviewed and new results, conclusions and system design specifications are included. The latter are based on a much larger sample of data and, with detail changes, substantiate system concepts of the preceding report.

UNCLASSIFIED

1. Seismic, Acoustic Experiments, Data Analysis, System Design
2. Contract DA-44-009-AMC-657(X)

AD ____________ Accession No. ____________

Texas Instruments Incorporated, Dallas, Texas — RAILROAD
SABOTAGE DETECTION RESEARCH R.E. Brannian, R.G. Baker, A.E. Sobey, Jr.

Final Technical Report, 15 October 1965
62 p., 13 illustrations, 6 tables.
DA Project 44-009-AMC-657(X) Unclassified Report

This is a final technical report on feasibility studies for detection of railroad sabotage. The study of acoustic rail-transmitted signals induced into the rail by simulated acts of sabotage is emphasized; however, some attention was devoted to seismic and other classified modes of energy transmission. Descriptions of tests and results presented in First Interim Technical Report, April 1965, are reviewed and new results, conclusions and system design specifications are included. The latter are based on a much larger sample of data and, with detail changes, substantiate system concepts of the preceding report.

UNCLASSIFIED

1. Seismic, Acoustic Experiments, Data Analysis, System Design
2. Contract DA-44-009-AMC-657(X)

AD ____________ Accession No. ____________

Texas Instruments Incorporated, Dallas, Texas — RAILROAD
SABOTAGE DETECTION RESEARCH R.E. Brannian, R.G. Baker, A.E. Sobey, Jr.

Final Technical Report, 15 October 1965
62 p., 13 illustrations, 6 tables.
DA Project 44-009-AMC-657(X) Unclassified Report

This is a final technical report on feasibility studies for detection of railroad sabotage. The study of acoustic rail-transmitted signals induced into the rail by simulated acts of sabotage is emphasized; however, some attention was devoted to seismic and other classified modes of energy transmission. Descriptions of tests and results presented in First Interim Technical Report, April 1965, are reviewed and new results, conclusions and system design specifications are included. The latter are based on a much larger sample of data and, with detail changes, substantiate system concepts of the preceding report.

UNCLASSIFIED

1. Seismic, Acoustic Experiments, Data Analysis, System Desigo
2. Contract DA-44-009-AMC-657(X)

AD ____________ Accession No. ____________

Texas Instruments Incorporated, Dallas, Texas — RAILROAD
SABOTAGE DETECTION RESEARCH R.E. Brannian, R.G. Baker, A.E. Sobey, Jr.

Final Technical Report, 15 October 1965
62 p., 13 illustrations, 6 tables.
DA Project 44-009-AMC-657(X) Unclassified Report

This is a final technical report on feasibility studies for detection of railroad sabotage. The study of acoustic rail-transmitted signals induced into the rail by simulated acts of sabotage is emphasized; however, some attention was devoted to seismic and other classified modes of energy transmission. Descriptions of tests and results presented in First Interim Technical Report, April 1965, are reviewed and new results, conclusions and system design specifications are included. The latter are based on a much larger sample of data and, with detail changes, substantiate system concepts of the preceding report.

UNCLASSIFIED

1. Seismic, Acoustic Experiments, Data Analysis, System Desigo
2. Contract DA-44-009-AMC-657(X)

AD ____________ Accession No. ____________

Texas Instruments Incorporated, Dallas, Texas — RAILROAD
SABOTAGE DETECTION RESEARCH R.E. Brannian, R.G. Baker, A.E. Sobey, Jr.

Final Technical Report, 15 October 1965
62 p., 13 illustrations, 6 tables.
DA Project 44-009-AMC-657(X) Unclassified Report

This is a final technical report on feasibility studies for detection of railroad sabotage. The study of acoustic rail-transmitted signals induced into the rail by simulated acts of sabotage is emphasized; however, some attention was devoted to seismic and other classified modes of energy transmission. Descriptions of tests and results presented in First Interim Technical Report, April 1965, are reviewed and new results, conclusions and system design specifications are included. The latter are based on a much larger sample of data and, with detail changes, substantiate system concepts of the preceding report.

UNCLASSIFIED

1. Seismic, Acoustic Experiments, Data Analysis, System Design
2. Contract DA-44-009-AMC-657(X)

SUPPLEMENTARY

INFORMATION

ERRATA

for

RAILROAD SABOTAGE DETECTION RESEARCH
FINAL TECHNICAL REPORT

ARPA Order No. 293/10
Contract DA-44-009-AMC-657(X)
Published 15 October 1965

Appendix A — Remove existing p. A-13 through A-17 and replace with the attached revised pages, A-13 through A-22.

Appendix A — Figure A-2(e), Time Domain Logic, in lower right-hand corner of p. A-3 has been superseded by the revised Figure A-2(e), p. A-15/16. Affix enclosed paste-over sheet to Figure A-2(e), p. A-3.

Figure A-2(e) has been superseded. Refer to revised Figure A-2(e) on p. A-15/16.

the visual indicator to show the sensor package on that channel is operating satisfactorily.

- At the end of the enable signal from command control, the test function generator is turned off, and a reset generator sets the function-select circuit to SENSE. Then, any input to the test gate is blocked and the sensor gate is opened.
- Any subsequent command signal (identical to the first) will turn the power switch to OFF. (It would also tend to restart the test cycle but cannot because power is removed from the circuits.)
- While the sensor package is in SENSE, any signal from the accelerometer (or sensor) which satisfies requirements of the logic circuits will key the transmitter for a fixed period of time. During this period the filtered signal from the sensor modulates the transmitter, and the signal can be monitored aurally by the operator at the monitor console.

Detailed block diagrams of the sensor package subsystems are shown in Figure A-2. Operation of these subsystems is as follows:

- The command control signal is a tone-modulated RF carrier which must fall within the tone filter passband. The detector forms the rectified envelope of the tone signal which activates the Schmitt trigger if it is above triggering level. Trigger output initiates the monopulse (single shot) multivibrator, which is set for a 3-min period. This output is an enable signal for the power switch, test function generator and function-select circuit.

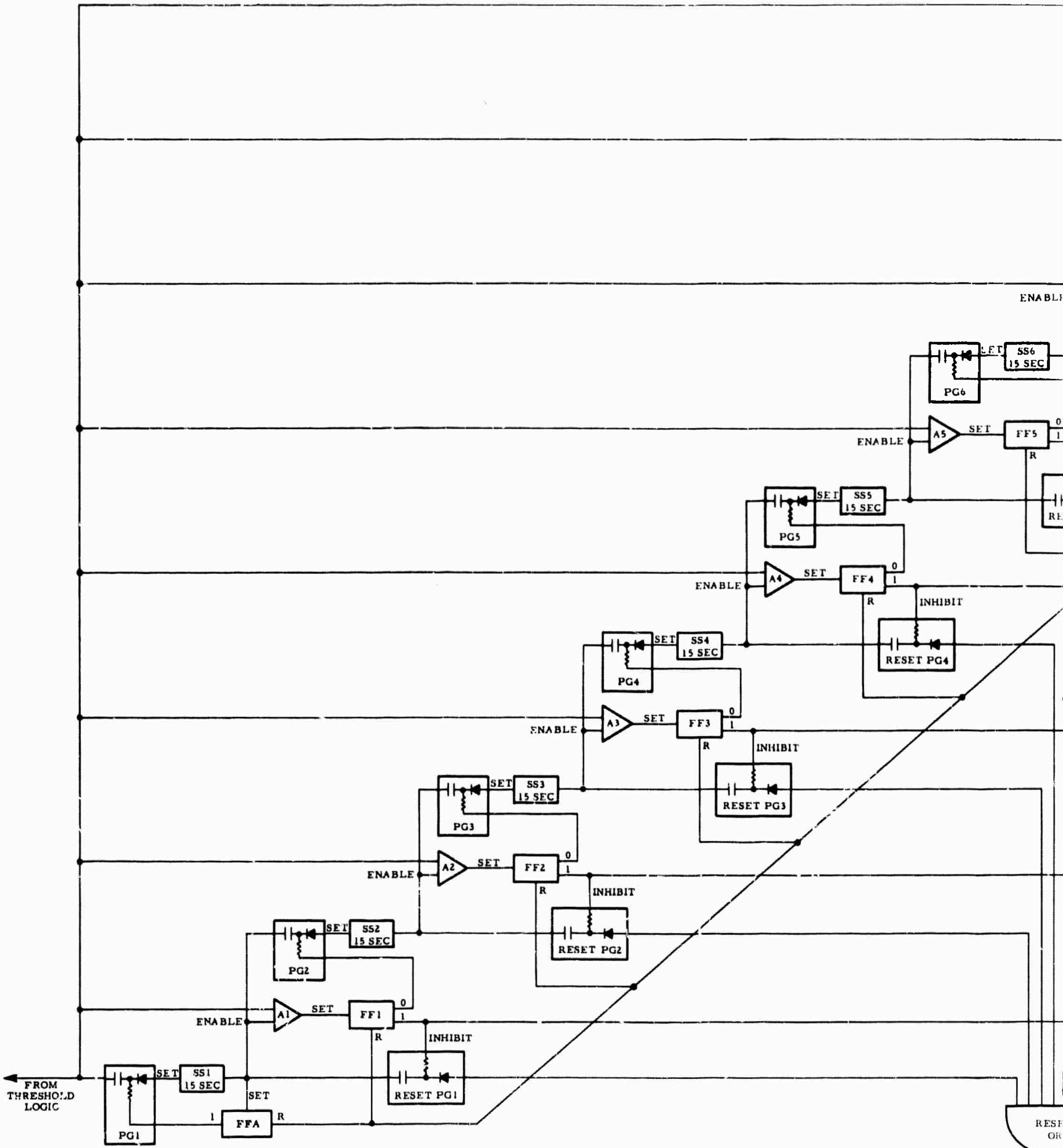
- A flip-flop and an ON-OFF power gate or relay comprise the power switch. The enable signal from command control switches the flip-flop to ON, which turns on the power gate. It remains on until another positive pulse is received from command control which resets the flip-flop to OFF. When the command-control enable signal ceases, the negative pulse does not affect the flip-flop.

- A free-running multivibrator, an oscillator and a gate comprise the test function generator circuit. Oscillator frequency is centered in the passband of the sense circuit filter. The gate passes the oscillator signal only when the enable signal from command control and the positive (or negative) polarity of the square wave from the multivibrator are present. The result is a 100-percent square wave modulated sinusoid. The square wave frequency is set to ≥ 4 cycles/min; i. e., the multivibrator period is < 15 sec.

- The threshold logic circuit contains a peak detector which forms a rectified envelope of any signal passed by the filter. If the pulse envelope exceeds trigger level amplitude of the Schmitt trigger, the latter puts out a pulse to the time-domain logic circuit.

- Time-domain logic — The time-domain logic circuitry is shown in simplified block diagram form in Figure A-2(e), Revised. The theory of operation is to sample the output of the threshold logic circuitry for the presence of pulses occurring at a rate of 4/min and persisting as a pulse train from a minimum of 2 min. If these conditions are met, the transmitter then is turned on for a 30-sec period to indicate that a detection has been registered. The time-domain logic circuitry then is reset, and a detection cycle may be restarted.

(Revised - D. M. Metcalfe, 2/12/65)



FROM THRESHOLD LOGIC
PG1
SET
SS1 15 SEC
FFA
1
R
SET
ENABLE
A1
SET
FF1
0
1
R
INHIBIT
RESET PG1
PG2
SS2 15 SEC
ENABLE
A2
FF2
INHIBIT
RESET PG2
PG3
SS3 15 SEC
ENABLE
A3
FF3
INHIBIT
RESET PG3
PG4
SS4 15 SEC
ENABLE
A4
FF4
INHIBIT
RESET PG4
PG5
SS5 15 SEC
ENABLE
A5
FF5
PG6
SS6 15 SEC
ENABLE

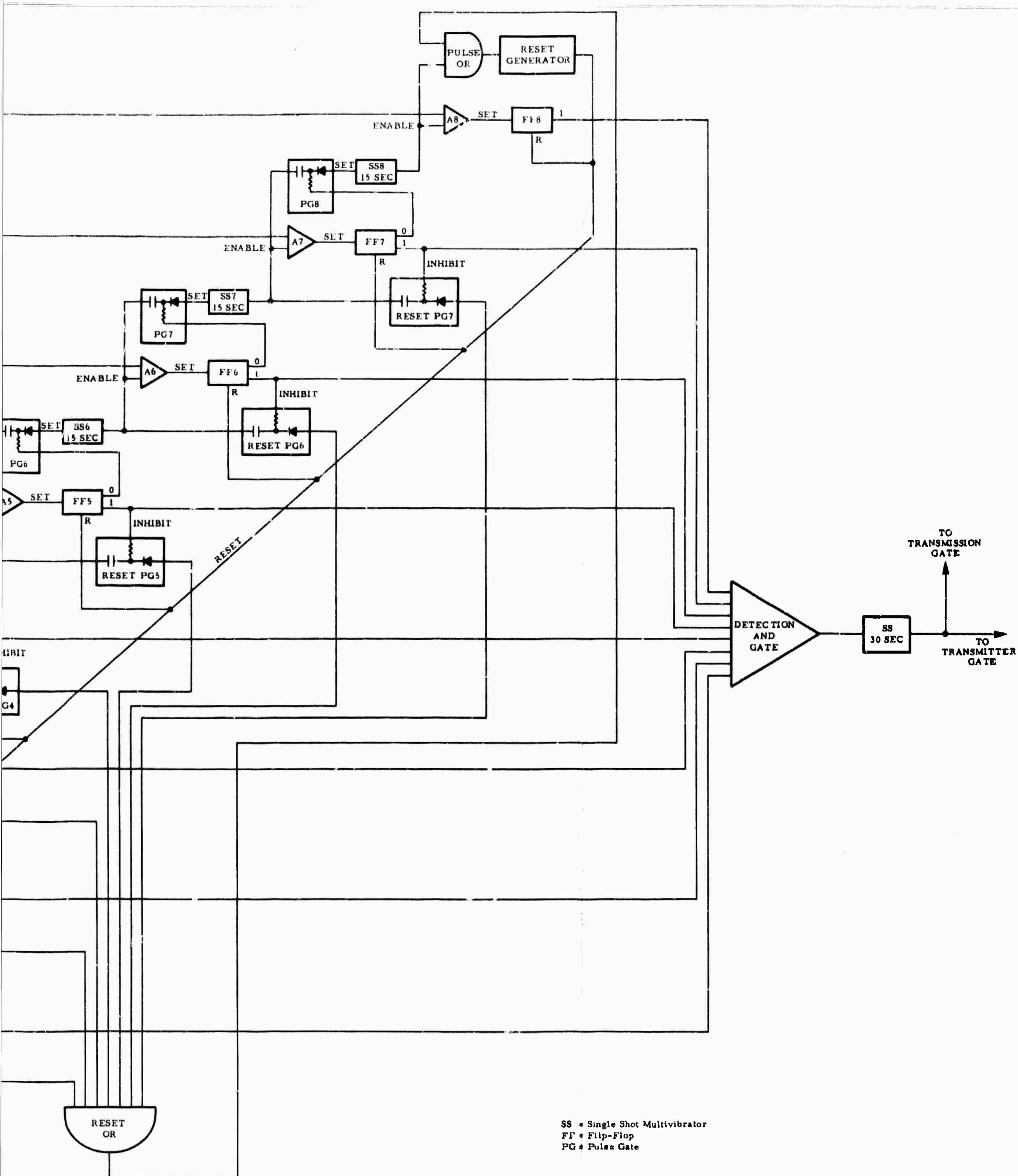


Figure A-2(e). Revised Block Diagram of Time-Domain Logic Circuitry (Revised - D. M. Metcalfe, 2/12/65)

The proposed circuitry possesses the ability to recycle at any time after the start of a detection cycle when the first detection criteria (at least a single pulse every 15 sec) has not been met. This ability does not require that an entire 2-min period be wasted when a detection cannot be registered because of, perhaps, a single interval of time during which no pulses occur. The consequence of this ability allows the circuitry to always be on-line, ready to complete a detection cycle rather than having to complete a cycle where a failure of detection criteria already has occurred.

In revised Figure A-2(e), inputs from the threshold logic circuitry are coupled through Pulse Gate (PG)1 to the associated 15-sec single-shot multivibrator. The single-shot output then is driven up, which acts as an enable signal to the AND gate, A1. During the presence of the enable signal, if a second input from the threshold logic circuit is received at the detection gate, it is coupled through the AND gate into the set line of the flip-flop. Operation of the flip-flop will drive the 0 line down and allow the trailing edge of SS1 to cause operation (enable) of the next detection gate and allow the detection phase to continue. If a second pulse is not received during the enable period of SS1, the trailing edge of the waveform cannot be passed through PG2, and the enable command cannot be passed from detection gate to detection gate. However, since a detection has not been registered, line 1 of FF1 still is down and the trailing edge of the SS1 waveform will be passed through the reset pulse gate, causing operation of the reset generator; this, in turn, will clear all flip-flops and allow the next pulse to start a new detection cycle.

(Revised - D. M. Metcalfe, 2/12/65)

A total of eight detection gates are used. Six detection gates are identical. The first and last detection gates differ slightly from the others. The last gate, 8, has no pulse gate which can cause inhibit of the trailing edge of the associated single shot. This is because the completion of a detection cycle has occurred and a reset command always must be allowed to pass through this gate into the reset generator.

The first detection gate required an additional flip-flop (shown as FFA). The purpose of this additional flip-flop is to allow the enable signal to the AND gates to be generated and propagated through the remaining detection gates only once per cycle. Without the inhibit signal on PG1, each input signal would cause operation of SS1 and propagation of additional enable signals. Special cases where two (or several) enable signals exist on different gates could result in a single input pulse being accepted by several AND gates at once. This is not allowed.

The first input pulse that operates SS1 causes FFA to be set immediately. The 1 line (which was down) then is driven positive and inhibits all remaining input pulses from the set line of SS1. The remaining detection gates do not require this flip-flop since their set lines are operated from the preceding single shot and, consequently, can be set only once per cycle. Any time a detection within the individual gate is not registered or a detection cycle is completed, the reset signal will remove the inhibit signal, allowing the next input pulse to cause operation of SS1 and start a new detection cycle.

(Revised - D. M. Metcalfe, 2/12/65)

A detection is registered when all flip-flops (1 through 8) are operated. The 1 line from each flip-flop is combined at the detection AND gate. A signal on each input line will result in the operation of the 30-sec single shot and, consequently, turn on the transmitter.

Interesting innovations are possible on this design without requiring extensive redesign for future units of more-sophisticated signal processing. An immediately apparent approach would be to count the number of input pulses occurring during each 15-sec interval and use weighting functions to determine when it might be worthwhile to turn on the transmitter, even though no pulse was received during any one interval. This type of design would require that FF1 through FF8 be replaced with counter circuits, require addition of weighting circuits and allow statistical approaches.

The monitor unit design provides for one receiver for each sensor package. The output of all receivers is coupled to a common audio alarm to alert the operator when any sensor package is transmitting. The output of each receiver has its own visual indicator which is turned on by the presence of an output and remains on until reset manually. A transmitter for command control of all sensor packages transmits an RF carrier modulated by a single tone. In addition, an erectable antenna, battery pack, and appropriate circuits and switches for battery checks and operability checks are provided.

5. System Performance

Experimental research yielded sufficient data for design of a system meeting the performance criteria given in the purchase description. These criteria are:

- Operation maintenance (one man/mile)
- False alarm rate (one/mile/day)
- Tampering resistance (or concealability)
- Performance reliability

(Revised - D. M. Metcalfe, 2/12/65)

a. Operation Maintenance (One Man/Mile)

One man per mile of operation and maintenance is feasible after installation of the system. Figure A-3 shows that four sensor packages will give one mile of coverage, and the monitoring unit for four sensors can be designed so that one man can transport it easily. Operation and maintenance of the unit can be done by one man with only a small amount of training.

b. False Alarm Rate (One/Mile/Day)

False alarm rate limit of one per mile per day can be achieved by utilizing the above design features except in the case of grouped or closely spaced pedestrian traffic. The chances of premature military action due to false alarms caused by pedestrian traffic are greatly reduced with provision for aural monitoring.

c. Tampering Resistance (or Concealability)

The sensor package meets this concealability requirement. Command control permits regular operability checks for each sensor.

d. Periodic Attention

The requirement for remote components to need attention less frequently than once per year per location or once per year per mile of track is not considered realistic or feasible for these reasons:

- Battery power requirements
- Greater system costs due to higher cost components and extensive testing program
- Probable detection of at least one unit within a period of one year

e. Performance Reliability

A system incorporating filter-threshold time-logic circuitry and aural monitoring capabilities should be completely reliable for sabotage detection purposes when constructed of thoroughly tested components and assembled by high quality workmanship.