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SEISMIC AND ELECTROMAGNETIC TUNNEL DETECTION INVESTIGATION

July 1975

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This report describes the major areas of tunnel detection investigations conducted by USAMERDC during the period December 1966 through December 1969. A short discussion of the tunnel problem is presented, and two technical approaches, seismic and electromagnetic, are discussed. Both seismic and electromagnetic detector systems were developed and evaluation tests were conducted to determine capabilities and limitations of the devices. The nature of the problem addressed, i.e., detection of subsurface voids located in vegetative areas, does not lend

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itself to the successful deployment of the systems developed; however, the basis for future development has been established. Operational parameters of the systems are presented in the appendices.

PREFACE

This work was conducted in support of the "Guerrilla Countermeasures Techniques," Project and Task Number 1J662708A6206, "Tunnel Detection Research."

The following USAMERDC personnel have contributed to the conduct of tunnel detection investigations: James Wallen, Chief, Guerrilla Countermeasures Techniques Branch; Charles N. Johnson, Jr., Chief, Physical Sciences Branch; Andrew Cuneo; Robert A. Falls; Henry F. Knauf; Donald Granahan; Charles French; CPT Richard Van Konynenberg; Sp-4 Benjamin Fletcher; and Sp-4 Walter Scott. The pictures contained in this report were provided by the MERDC RD&E Pictorial Support Division. Robert Brooke reviewed the report manuscript and suggested material content. Louis Mittleman was the technical coordinator for tunnel detection since 1970.

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I. INTRODUCTION

The detection and identification of subsurface voids, such as tunnels and weapons caches, involve three primary problems. First, the transmitter energy must be coupled into and through the soil to the target and the return signal detected. Second, environmental clutter must be reduced to an acceptable level. Third, the return signal from the target must be enhanced to discriminate it from clutter effects.

Two techniques were investigated by USAMERDC to combat the problem posed by tunneling activities. One was development of a seismic tunnel detector and the other was development of an electromagnetic tunnel detector. The seismic tunnel detection system operates on an active pulse-echo seismic principle whereby a portable seismic wave pulse generator induces a vibratory pulse of short-time duration into the soil, and subsurface voids are detected either by the seismic echoes returning to the surface or the velocity change induced in the seismic wave when a void is being traversed. The electromagnetic tunnel detection system operates on a like pulse-echo principle. A short-time electromagnetic pulse is generated and coupled into the soil and the void is detected by the echo returning to the surface.

The following sections present the experimental techniques and results of the investigations.

II. BACKGROUND

Tunnels, although neither a major offensive nor defensive threat in earlier recorded conflicts (except for the South Pacific Theatre of Operations during WWII), posed a serious menace during the Vietnam hostilities. The Viet Cong and North Vietnamese forces used tunnels for weapons and food supply caches and as mechanisms to interdict friendly forces. Casualities to personnel and equipment as a result of tunnel activities induced the U.S. Army, Republic of Vietnam (USARV) to submit an ENSURE request to Headquarters, Department of the Army (HQDA), in December 1966. The request specified certain essential characteristics and features of a system to be addressed during the development phase of tunnel detection equipment to counteract the threat posed by tunneling activities. Research into tunnel detectors had been initiated in June 1964 under ARPA order 29318, but the ENSURE action required development of systems for test and evaluation in Southeast Asia (SEA) on a quick-reaction basis.

The ENSURE request was validated by the Assistant Chief of Staff Force Development (ACSFOR) on 21 December 1966 under the title "Tunnel Detection Equipment

ENSURE #144." Approval to initiate development of tunnel detectors was specified in CRDPES memorandum for CRD dated 11 January 1968.

Correspondence from USARV to USAMERDC requesting available equipment had been received and letter, SMEFB-IR (now STSFB-XR) to CG, USARV, 2 April 1968, subject: "Tunnel Detection Equipment (ENSURE #144)," was submitted in reply. This letter generated a meeting between representatives of OCRD, USAMERDC, WES, et al at General Ostram's office on 25 April 1968. The context of the meeting was to negate direct coordination between USAMERDC and USARV. In the future, all data exchange between CONUS and SEA was to be coordinated through General Ostram's office.

Letters, CRCMR-O, HQ, USACDC, 31 May 1968, and CSGM-F, 24 June 1968, subject: "Tunnel Detection and Neutralization," tasked USACDCCSG and USACDCINTA to prepare a QMDO which would allow research effort to continue toward development of systems, techniques, and material for airborne and manpack detection of tunnels. A DPQMDO for a tunnel detection system was submitted to DA on 1 October 1968. Reference was made that the action would probably be assigned to USAMERDC as prime developer upon completion of staffing and approval by DA.

In the interim, USAMERDC was conducting research into tunnel detection systems as part of "Cargo Detectors." The effort was pursued in the 6.21 category under the Guerrilla Countermeasures Techniques Project, Task 02, "Concealed Munitions Detectors."

Letter, AMCRD-JG, 24 June 1968, Subject: "Tunnel Detection Research," effected coordination of USAMERDC with other Army Agencies to prepare a consolidated Tunnel Detection Research Plan. The plan called for an improved man-portable tunnel detector and required development of vehicular-mounted and airborne systems. This was initiated by letter, AMCRD-JG, 1 August 1968, same subject, which proposed establishment of Task Number 1J662708A46206, "Tunnel Detection Research."

The effort was continued under USAMERDC guidance until the ENSURE action was cancelled in letter, SMEFB-XR, 22 December 1969, subject: "Cancellation of ENSURE #144 (Tunnel Detection Equipment)." Further tunnel detection effort was to be continued in the normal R&D cycle if funded.

III. THE TUNNEL PROBLEM

Allied forces encountered a serious problem in Vietnam as a result of the use of tunnels by the Viet Cong and North Vietnamese forces. This problem was the ability of the enemy to conduct military operations utilizing bases consisting of elaborate systems of tunnels which were extremely difficult, if not impossible, to locate using existing detection systems.

Tunnels were used for hiding places, supply and equipment caches, and headquarters complexes. Interconnected with fortified bunkers, the tunnels served as firing areas and protection against artillery fire and air attacks.

Villages were fortified by extensive tunnel systems containing conference, storage, and hiding rooms, in addition to firing areas and escape routes. A typical Viet Cong stronghold (village) tunnel system may consist of a central hub with as many as 10 legs emanating from the central point. Each leg may be as long as 5000 feet and vary from 3 to 16 feet below the ground surface. Usually each leg will have numerous 90-degree turns and will contain various mechanisms to deter pursuit of escaping personnel. These mechanisms, or ambushes, are: points strategically located in the tunnel which contain sharpened bamboo stakes to maim or kill pursuing forces, command-actuated explosive devices, or booby-trap firing devices located to inflict injury on members of the pursuing force as they attempt to negotiate the bend in the tunnel. At other times, the bend may harbor a sniper whose fire slows the attacker and allows the main force sufficient time to escape. Deterrents also serve to intimidate search parties whose mission is to explore the tunnels for arms and supplies and to map the tunnel course so that measures can be taken to immobilize its usefulness to the enemy by destroying it or making it uninhabitable by chemical agents.

Tunnel construction, in general, is dependent upon the terrain and environmental considerations. Typically, the tunnels are unsupported structures approximately 5 feet high by 2.5 feet wide. They are ventilated by bamboo tubes, 1 to 4 inches in diameter, which connect the tunnel roof to the surface.

Cache tunnels are constructed for the purpose of storing equipment and take advantage of the hills and other natural obstacles which provide heavy overburdens varying up to 20 feet deep. Entrances are about 6 feet in diameter, and the rooms measure a minimum of 12 feet long by 9 feet high. These structures are shored by beams and roof supports. Air vents in cache tunnels may consist of a bundle of bamboo tubes rather than a single tube.

Tunnel construction and depth are also dependent on local conditions. In the northern region of Vietnam, the canopy of extensive jungle vegetation provides sufficient cover so that tunnels are unnecessary. In the delta region to the south, the high water table and seasonably wet climate dictates very shallow tunnel construction. Additionally, the wet soil will not support more than the weight of a man.

Most tunnels are located in areas where there is suitable camouflage to conceal the entrances, exits, and firing bunkers. Usually the first indication of a tunnel system, except in villages which in general are suspect areas, is enemy fire from a concealed bunker that might have otherwise gone undetected.

Systems for detection of tunnel networks must be easy to use and capable of rapid search since it may become necessary to vacate the area quickly. Many of the villages, and other enemy strongholds, are located in areas inaccessible to mobilized attack. Trails serve to connect these areas with other villages or urban transportation systems. Allied forces may be air lifted to the vicinity of target zones, but are then forced to approach the villages by using the trails. Thus, the detection equipment must be easily transported because the operator will be further burdened with heavy loads of food and ammunition necessary to carry out the mission. Further, the equipment must be easily maintained and operated since it will not be used by highly skilled operators. Camouflaged networks of tunnels further mandate that the equipment not be dependent on extensive brush or tree-clearing operations.

Tunnels are most likely to be located in areas of strategic importance to the enemy. These are coastal lands bordered by dense vegetation and the delta regions, since readily accessible food supplies are necessary to conduct military operations. These areas are particularly vulnerable because they house much of the Vietnamese population which the enemy must subjugate to dominate the country. Areas bordering neutral countries are also vulnerable to tunnel construction since clandestine convoys of military supplies are routed through these countries, and the supplies must be stored so that they are not destroyed by air strikes.

In summary, the problems posed by the tunnels affect not only the design of detection systems but also operational use. The design must be addressed to the fact that much of the soil where tunnels are located is lateritic in nature; that is, the soil is a product of rock decay, red in color, with a high content of the oxides of iron and hydroxide of aluminum. The country experiences monsoons which implies a high water content in the soil during part of the year. Depth of the tunnel overburden and vegetation cover also thwart detection techniques. Trees and brush oppose rapid search of suspect areas or render some detection devices useless. An optimum system must circumvent these problems.

IV. TECHNICAL APPROACHES

The USAMERDC emphasis was directed towards two approaches as a solution to the tunnel detection problem in response to ENSURE #144. One approach was utilization of seismic devices, and the other was to develop electromagnetic techniques.

1. **Seismic Detection Systems.** The seismic approach required a mechanism to generate and couple an acoustic energy pulse into the earth surface and a receiving

device placed some distance from the transmitter. The receiver was either a geophone or an accelerometer with the associated electronics. An "A" scan (oscilloscope) was used to display the received signal. Its sweep was syncronized with (triggered by) the transmitted pulse.

Several variations of transmitters were tested in addition to different methods for coupling the energy into the soil. One method was generation of an electro-acoustic shock. A second method consisted of a weight contained in a sealed tubular shaft. The weight was command-dropped and generated a shock wave when it struck the tube bottom. A third method, tested on a limited basis, was to generate a shock wave from the concussion produced by an exploding blank-loaded cartridge detonated in a rifle. The shock wave was directed at the ground by inserting the rifle barrel into the truncated apex of an insulated metal cone.

Synchronization of the receiver and display units to the transmitted pulse was achieved for the above three methods as follows. In the electro-acoustic system, part of the transmitter energy is coupled to the receiver and display units to initiate the display sweep. Synchronization of the receiver and display unit to the weight-drop unit is achieved by closing a microswitch in the transmitter unit. The switch is actuated when the weight is command-dropped. A trigger pulse is generated with the exploding cartridge method by placing a geophone under the cone. The shock wave registered by this geophone develops an energy pulse which is coupled to the receiver and display units.

Coupling of the transmitter pulse to the earth is accomplished in two ways for the electro-acoustic method. The transmitter unit used in the initial tests was shock-mounted in a long cylindrical tube. One end of the tube was permanently attached to a sharply pointed cone. The energy is coupled to the ground from the cone which was forcefully driven into the ground by "brute force." The tube was held in both hands and swung in an arc so that the cone would penetrate the surface. This was extremely time-consuming, especially in a densely packed environment since it could take several "swings" to assure that the cone was sufficiently buried in the soil to attain good coupling. The later version was constructed in the following manner. One end of the tube containing the transmitter unit was enclosed in a larger cylinder having a ring base and containing a spring. The operator placed the unit on the ground and stood on the ring base. The force of the spring pressed the transmitter unit into close contact with the earth surface to couple the energy pulse into the ground.

In the weight-drop system, the tube containing the weight was held vertically and pressed against the earth surface by the operator. A shock wave was generated when the weight struck the tube bottom.

In the third method, the shock wave was produced by the blast from the exploding cartridge.

Two methods of detection of a subterranean void are theoretically feasible. One method is detection of energy reflected from the soil-void interface, and the second is refraction of the energy in the void overburden. In either case, the Rayleigh or surface wave is present but arrives at the receiving unit in less time than the wave propagating in the soil.

Detection of subterranean voids by the reflective method implies that the transmitting and receiving units must be located such that they straddle the tunnel in order that the seismic pulse will be reflected from the void-soil interface. The waveform observed on the display unit is a relatively large deflection caused by the Rayleigh wave and its associated ring-down time followed by a smaller deflection of the "A" scan trace at a later time due to the energy from the reflected wave. The depth of the void can be determined from the time elapsed between the transmitted pulse and the received echo. Since the pulse is not a well confined wave train, a second echo should also be observed from the soil-air interface at the bottom of the cavity. If the two echos are distinguishable separately, the size of the cavity can be determined.

When a cavity (tunnel) is bored beneath the soil surface, certain stresses occur in the overburden due to the discontinuity of soil density caused by the presence of the void. If the transmitter and receiver transect this void, then the acoustic pulse launched by the transmitter undergoes a velocity change (refracted) as it is propagated through the stressed soil. As the system is traversed across the void, the time of arrival of the energy pulse will change. The maximum change should occur where the greatest stress occurs, presumably directly over the void. Thus it should be possible to map the direction of the void by plotting, on a predetermined grid, the points where maximum change in time of arrival of the energy pulse occur.

This writer has no conception of the duration of time before natural forces will relieve the stress in the overburden or if the stresses remain indefinitely. Since the earth is neither homogeneous nor an isotropic medium, density variations exist in the soil which can also refract or reflect a measurable quantity of the transmitted energy which gives rise to false signals. False signals of sufficient magnitude would necessarily obscure detection of tunnels.

Although both methods of seismic detection, reflective and refractive, have been presented separately, these phenomena occur interdependently. The transmitted pulse is refracted not only by the stress due to the presence of a tunnel but also by naturally occurring density variations in the soil. Both result in changes in the time of arrival of energy at the receiver. Energy reflected from the tunnel air-soil interfaces is affected similarly, that is, the velocity and direction of wave propagation is a function of the density of, and stresses in, the soil.

Two facilities located on the Engineer Proving Ground (EPG), Fort Belvoir, Virginia were available for evaluation tests on the seismic devices. One is a hole (tunnel) bored into the side of a hill of dimensions 3 feet in diameter, 100 feet long, with approximately 5 feet overburden. The overburden is layers of sand, gravel, and quartz patches. Vegetative cover is moderate.

The second site was a wooden box, 4 feet square in cross-section and 8 feet long. The overburden was 3.5 feet of uniform-density sand with no vegetative cover.

The author participated in many of the experimental tests conducted with the seismic device at EPG but was never able to discern any recognizable target return on the "A" scan display or from photographs of the display when the device was operated over the box or tunnel. Magnetic tape was used to record the receiver output to the "A" scan display for laboratory signal processing to determine whether characteristic pattern recognition could be established. Records of the received signal were made over the tunnel and box by mapping across them and in areas semi-remote from the targets. The tape recordings were replayed in the laboratory using frequency filters and other processing techniques to determine recognizable changes in the received signal over the targets as compared to the received signal in the absence of the target. Attempts to isolate characteristics of the received signal waveshape as representative of target location were unsuccessful.

Experiments were also conducted to determine whether density changes in the soil would cause a change in the time of arrival of the transmitted signal. In one attempt, the signal in undisturbed soil was recorded and then an M-60 tank was moved into the area to compact the soil. The transmitter was placed on one side of the track and the receiver on the opposite side. No change was noted. It is probable that the weight of the tank was insufficient to increase the density of the soil in the area where the measurements were conducted.

In another experiment, two parallel trenches separated by several feet were excavated. The transmitter was implanted in the wall of one trench, and the geophone was placed in the laterally opposite wall of the second trench. The level of implant was about 2 feet below the soil surface. A recording of the signal propagating through the soil was taken. Concrete weights were then placed on the surface to compact the soil. The received signal with the weights in place was indistinguishable from the signal in the absence of the weights.

The system was also tested at a tunnel complex located in the San Antonio, Texas area which was maintained by the Southwest Research Institute under contract to MERDC. Measurements on soil samples taken from this area show that it is very lossy for electromagnetic propagation, but appears to be a good medium for propagating seismic waves. The project engineer who conducted tests at this tunnel complex reported excellent results. Photographs taken of the received signal as displayed on the "A" scan display indicated a change in time of arrival as the system was traversed over the tunnel. Figure 1 is a plot of the change in time of arrival of the pulse resulting from the pass over the tunnel. Figure 2 is a photograph portraying operational use of the first version of the electro-acoustic system.

The earlier version of the electro-acoustic system was tested in the Republic of Vietnam. The system appeared to be successful in mapping the tunnels at the USARV tunnel/minefield training camp but was unsuccessful during tactical field use. No results are available from this test.

The system is cumbersome for practical field use since the transmitter/receiver units are connected by an umbilical cord which limits the displacement distance of the geophone receiver from the transponder and each must be individually coupled to the ground. This limits the speed and mobility for mapping unknown areas.

The spring-loaded transmitter system eliminated some of the difficulty with transmitter coupling; however, the geophone has to be inserted into the ground at each point of the mapping grid.

A seismic system is essentially limited by the terrain, extreme difficulty in interpreting the target signatures, and adaptation to mapping small, elongated subsurface voids. Research was suspended, probably as a result of the advances in electromagnetic detection of tunnels which offered greater promise and rapid search speeds of suspected tunneling activities.

2. **Electromagnetic Detection Systems.** The electromagnetic tunnel detection system is based on the pulse-echo principle common to most radar systems. The antenna, a bidirectional radiator, is used for both transmit and receive modes. It is a planar, folded dipole which was developed by Dr. Lehrner of M.I.T. Figure 3 shows the antenna mounted on a sled. The radiated energy is a short-duration, low-voltage pulse. The pulse repetition frequency (PRF) is several megahertz which allows sufficient relaxation time for echos (reflected energy) to be observed. An STC (sensitivity time control) gain is used to regulate amplification of the received energy. This is basically a ramp voltage applied to the amplifier to linearly increase the amplification of the reflected energy as a function of time after the transmitted pulse.

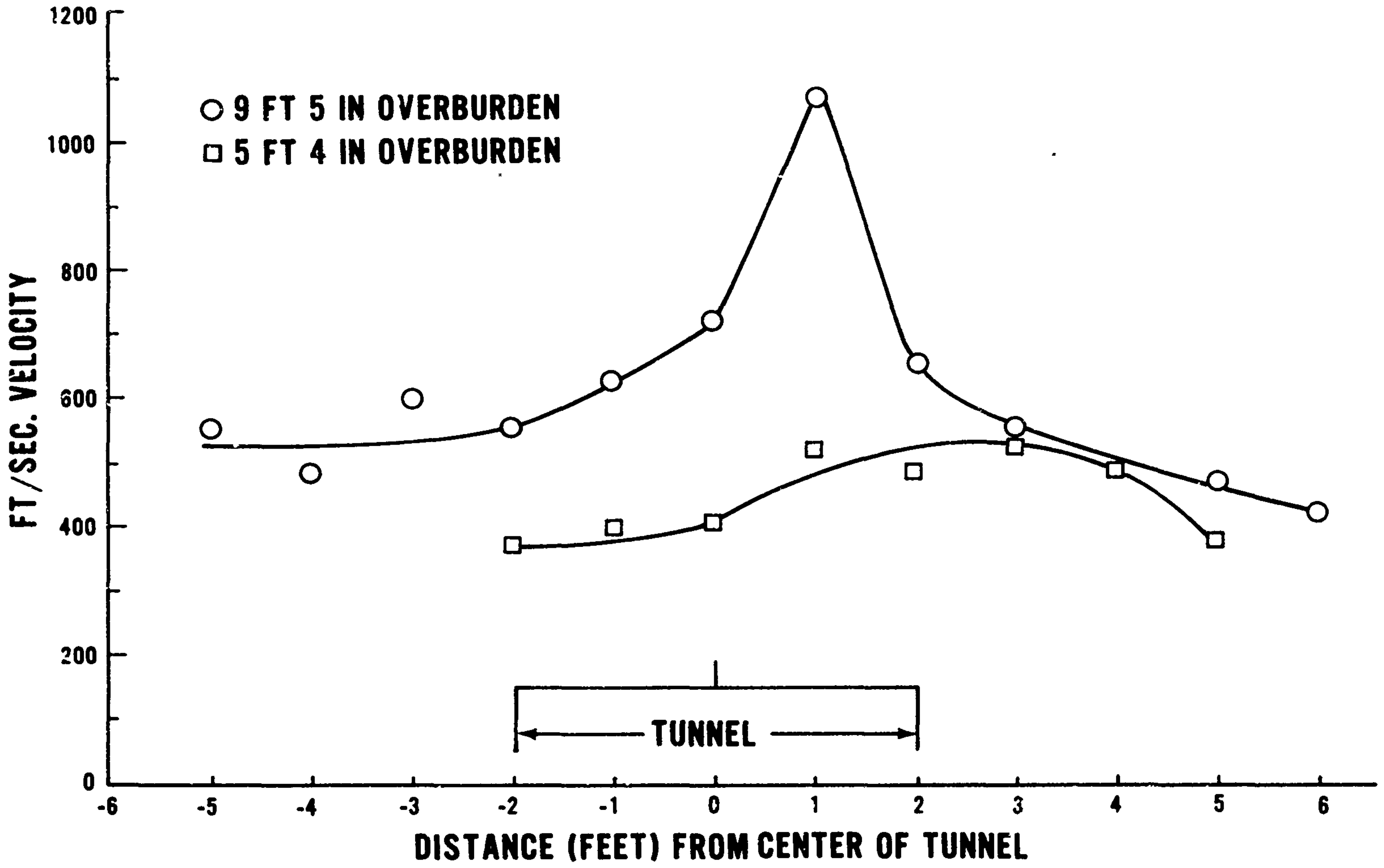

Figure 1. Change in time of arrival of seismic pulse over a tunnel.

Figure 2. Seismic Tunnel Detector – operational view.

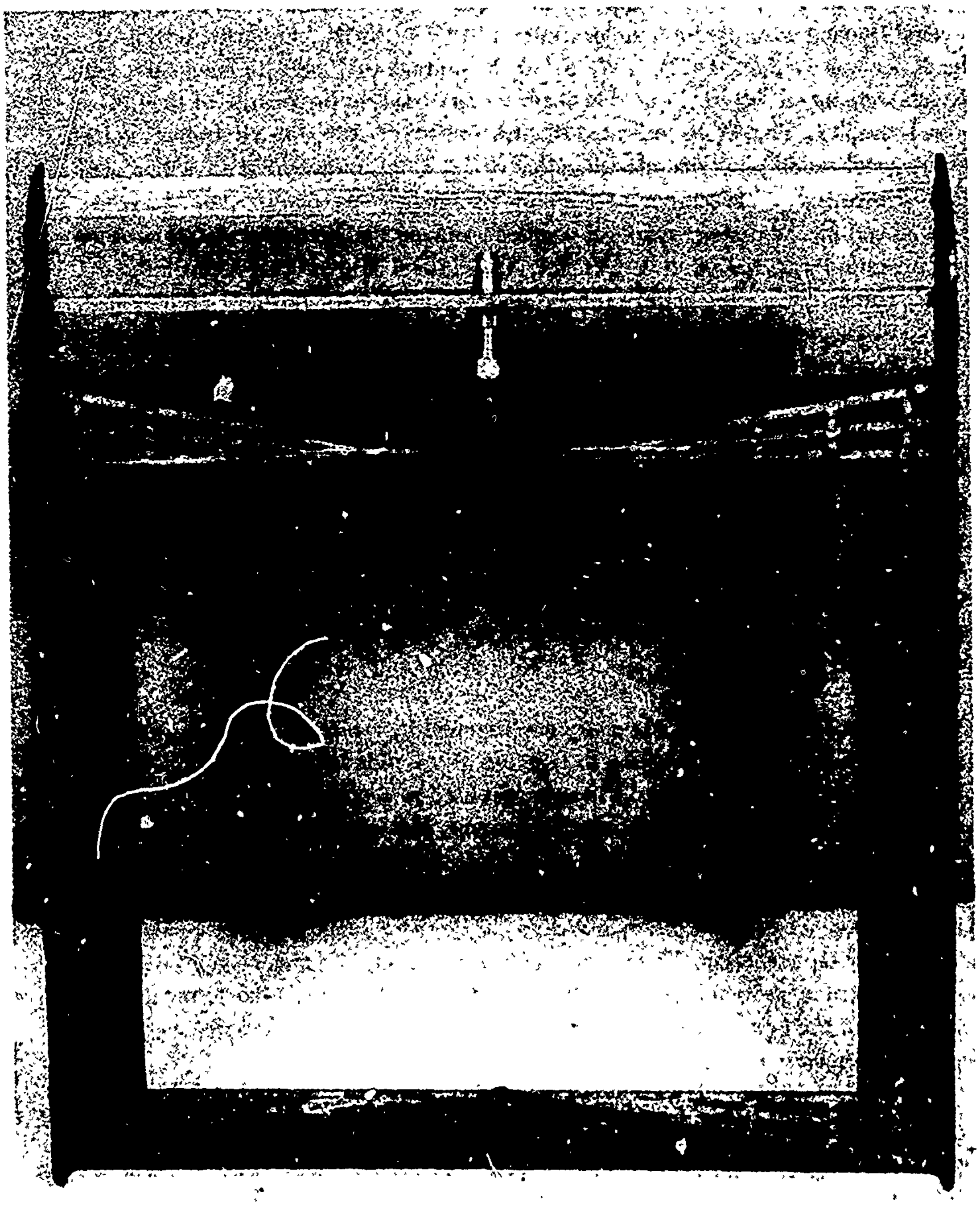

Figure 3. VHF tunnel detector antenna. S4893

A prototype man-portable electromagnetic tunnel detector was developed by General Dynamics Corporation under contract to USAMERDC. Extensive testing of the device was conducted at the EPG during the summer of 1968 with marginal results. Targets were metal culverts located beneath tertiary roads in the vicinity of the EPG tunnel complex. The results indicated that the prototype system was extremely voltage sensitive and would function only when the battery voltage was within a few tenths of the design voltage. Fabrication of the system parameters was conducted using a regulated 24-volt d.c. laboratory supply as a voltage source. The battery normally used for field operation was charged to 28 volts d.c. Operational current drain reduced the battery voltage. When the battery voltage approached 24 volts, the device functioned, but did not necessarily detect the target. As the battery voltage decreased below 24 volts, the system ceased operation.

An oscilloscope was incorporated into the system to display the waveshape of the received signal.

Tests consisted of traversing the system over a metal culvert with approximately 2.5-foot fill-dirt overburden. The results were inconclusive until the system was powered from an inverter-equipped military vehicle. After adjustment of the supply voltage to 24 volts d.c., the system functioned and echos from the metal culvert were identified.

An advance system was under development by General Dynamics during this time. This system was designed to function over a wide range of battery voltage and was ruggedized for field use. A harness was used to support the unit on the operator's chest, freeing his hands to operate the controls and pull the antenna sled (Figure 4).

A control enabled the operator to select either a 5-kHz or a 30-HZ PRF display on the oscilloscope. A BNC jack coupled the 30-Hz signal to ancillary equipment such as a magnetic tape recorder. Tapes were made of the received signal, both over the void and in adjacent areas to aid the operator in distinguishing target returns during laboratory replay of the tapes. Signal processing was also conducted to determine mechanisms for signal-to-noise enhancement.

The received signal was also recorded on an Alden recorder for histographic display. This instrument is not suitable for field use as it requires a 120-volt, 60-cycle power supply for operation. However, target returns presented as a histogram display are not only easier to recognize, they provide a hard-copy presentation of areas searched. Target returns can be investigated immediately or the suspect voids can be validated at a later time. This need prompted MERDC to solicit a contract with Southwest Research Institute to develop a portable histogram recorder. This was used in further field evaluations.

Figure 4. VHF Tunnel Detector System.

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Tests conducted by traversing the tunnels at EPG were unsuccessful in that no recognizable signal from the tunnels was observed either directly or when the tape recordings were replayed in the laboratory with and without application of signal processing techniques.

As was stated in the section on seismic detectors, the tunnel overburden was inhomogeneous with considerable vegetative cover. It was decided to fabricate a void in an adjacent area, free of vegetative cover, consisting of a fairly homogeneous soil. The electromagnetic attenuation of this soil is about 8 db per meter in the range of frequencies of interest. The attenuation was determined by laboratory measurements of selected soil samples taken from this area. The void was formed by the 4-foot in cross-section by 8-foot long box described previously.

A second detector system incorporating a signal processor was also fabricated by the contractor. The processor would "store" a received signal waveshape and compare it to subsequent waveshapes. Operationally, if the waveshape did not change during a run, the output would be zero or a small d.c. potential. The stored waveshape could be updated manually or automatically at 30-second intervals. In practice, the d.c. level was never achieved since the stored signal underwent a perturbation during comparison with each subsequent signal. Each signal return is modified by orientation of the antenna with the ground, the changing distances between the antenna and the ground surface, and reflections from above-surface objects, such as trees. Thus, the signal processor was not sufficiently sophisticated to enhance signal discrimination.

Signal returns obtained by traversing the wooden box and metal culverts with the tunnel detectors developed by General Dynamics Corporation proved the feasibility of detecting subterranean voids by electromagnetic techniques. The major drawback was the "A" scan display, since the operator had to monitor the oscilloscope constantly and interpret the visual display for target returns. In addition, reflections from overhanging tree branches tended to obscure signal returns from deeper voids. Near surface voids located in areas where the electromagnetic attenuation of the soil was relatively high were also difficult to discern due to the clutter from above-surface anomalies. This arises since the velocity in the soil is about one third that in air. Reflections from tree branches arrived at the same time as reflections from the void and were of the same magnitude.

The hard-copy (histogram) recorder when used in conjunction with the detector system alleviated much of the operator monitor and discrimination problems, but it was cumbersome to use. It required a minimum of two people for operation, and since the recorder and transmitter were not slaved to the transverse displacement of the antenna, the system was not optimally useful for mapping suspect areas.

The results attained from the evaluation tests of the tunnel detector system led to the development of a one-man portable system with a histogram display. This system was developed by Southwest Research Institute under contract to USAMERDC.

The transmitter, receiver and display units were housed in a single package. This package was carried on the chest of the operator by means of a shoulder harness, with the power supply attached to the back of the harness. The antenna sled was mounted on wheels for ease of traversing a suspect area. The transmitter and display units were slaved to the transverse displacement of the antenna but could be operated independent of antenna movement by switching to automatic sync.

A microswitch was closed twice during each revolution of the sync wheel attached to the antenna sled. Closing the switch grounded the emitter of one of the transistors in the transmitter trigger circuit causing a single pulse of energy to be launched to the antenna. This also caused the chart paper in the recorder to be advanced a small distance. The received energy was amplified and transmitted to the styli as independent voltages corresponding to the amplitude of the return signal waveshape.

The presentation on the chart paper was varying shades of gray. White corresponded to the most negative portion of the waveshape and a dark gray to the most positive. Figure 5 is a typical histogram recording from a subsurface void, using the system developed by Southwest Research Institute. Figure 6 is a histogram recording taken with the Alden recorder. It shows the clutter effects due to trees. Figure 7 displays the system during a tactical search.

The system was evaluated, to a limited extent, at EPG during the spring of 1969. Extended testing to determine capabilities and limitations of the system were not conducted because of the cancellation of ENSURE #144, which reduced the priority for development of tunnel detection equipment.

V. DISCUSSION

1. Detection:

a. Seismic detection of voids appears to be limited by the size and extent of the cavity, density variations in the soil, stresses occurring in the soil overburden, and interpretation of the received signal. Amplitude variations in the received signal caused by reflections from the soil-void interface were not distinguishable when the detector was used to locate tunnels. It is assumed that the seismic technique would not merit further consideration in any future exploration of tunnel detection investigations based on the success achieved with the electromagnetic approach.

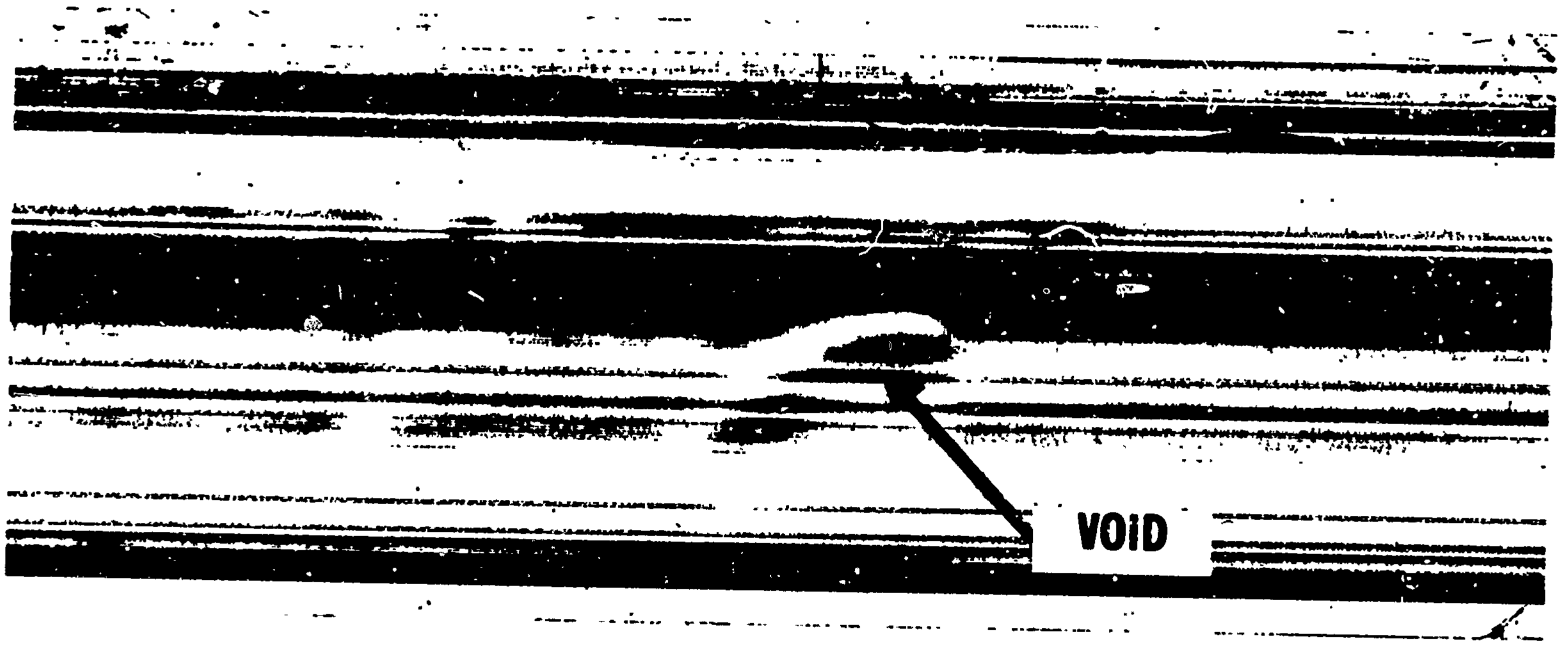

Figure 5. Histogram recording of signal return from a void.

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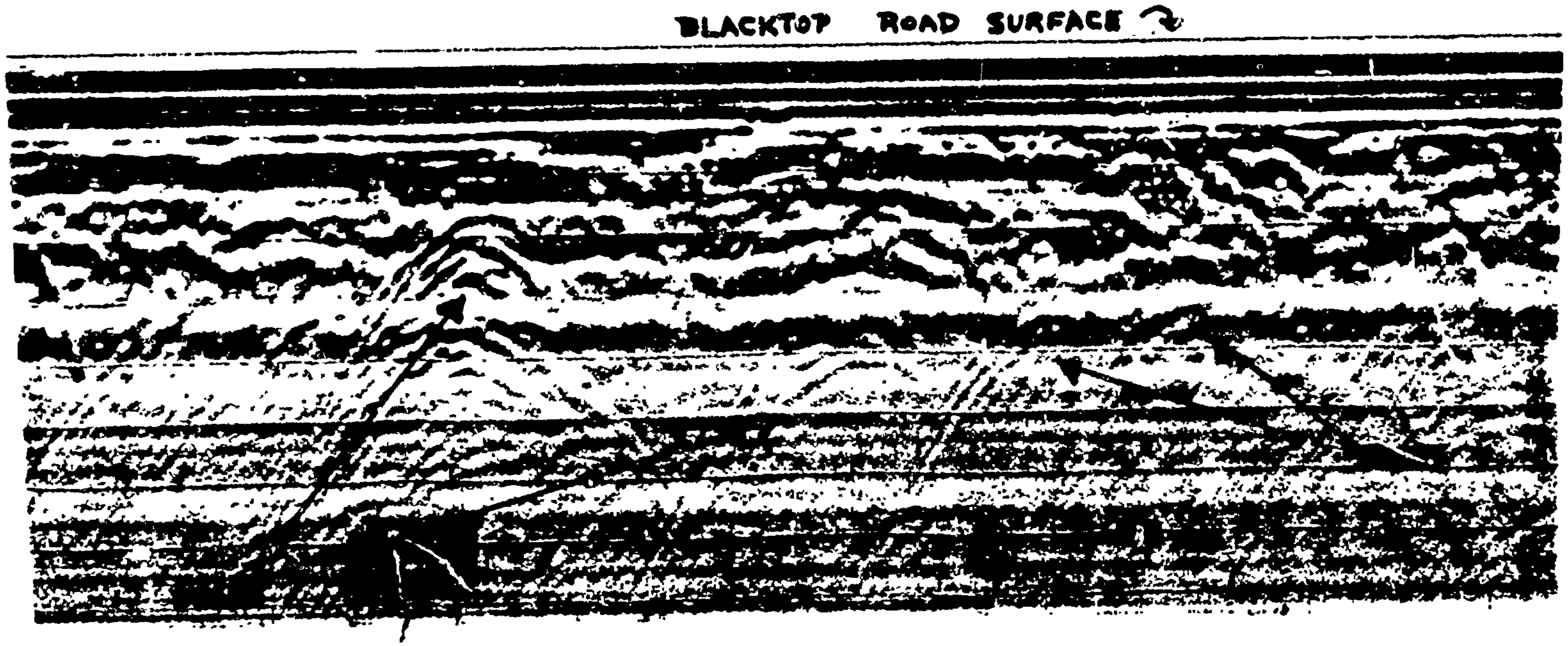

Figure 6. Typical geodar recording taken along a void-free road.

Figure 7. VHF Tunnel Detector – operational view.

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b. The electromagnetic approach resulted in recognizable target signatures in the form of amplitude versus time changes due to reflections of the transmitted pulse when the system was operated across the buried box and metal culverts. Evaluation tests were limited to areas where the soil was fairly homogeneous and electromagnetic attenuation was minimal, in the range of 3 to 8 db per meter.

2. **Display:**

a. Received signals from the seismic device were presented as an amplitude versus time display on the cathode ray tube (CRT) of an oscilloscope. Photographic records of the display were necessary in order to determine if any change occurred in the time of arrival of the received energy thereby indicating the presence of a tunnel. Mechanisms to correlate and present only the change in arrival time were not pursued.

b. Received signals from the electromagnetic system were also presented as an amplitude versus time display. In addition, a histographic recorder was available for use with the system. Pattern recognition was enhanced by this device and resulted in a permanent record of the traverse.

3. **Data:**

a. The constraint imposed by the seismic device was a point-by-point search. The transmitter and receiver would be implanted with about a 3-foot separation. The pulse would be launched and a photograph or magnetic tape recording taken of the received energy as presented on the CRT. The two units would then be displaced 1 foot and the signal again recorded. Additional pulses could be propagated at each location, but were not warranted. Energy received due to extraneous seismic disturbances (vehicular traffic, etc.) did not appear to alter the received signal drastically.

b. The transmitter used for the electromagnetic system operated at a PRF of several megahertz. Usually, the antenna was traversed over the target at speeds varying from 10 to 20 paces per minute to 5 miles per hour when operated from a vehicle. Point-by-point measurements were also taken by recording the received signal as the antenna was moved in 1-foot increments across a known void. During a continuous traverse, the signal was displayed on the histogram recorder and also was recorded on magnetic tape for future processing.

4. **Problem Areas:** There are many unsolved or marginally investigated problem areas–such as coupling the energy (acoustic or electromagnetic) from the transmitter into the soil, retrieving the signal at the receiver, interpretation of the signal, and effects of the earth as a medium for propagating the transmitted energy. Basic to the problem is the need to identify soil characteristics by categorizing strata, density variations, and moisture and salt content in various geographic areas. This data could be used to determine electromagnetic attenuation in the soil which limits system capability.

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   Contract No. DA-44-009-AMC-1755(T)
   Prepared for USAERDL by Melpar Inc.
   July 1967
3. A Strip Chart Recorder for Use with Tunnel Detectors
   Contract No. DAAK02-68-C-0033
   Prepared by USAMERDC by Southwest Research Institute
   May 1969
4. An Exploratory Investigation of Shallow Tunnel Detection by Seismic Methods
   Contract No. DA-44-009-AMC-1639(T)
   Prepared by Southwest Research Institute
5. Underground Tunnel Detection Tests in a Borax Mine
   Contract No. S0230038
   Prepared for Denver Mining Research Center, US Bureau of Mines by Southwest Research Institute
   30 May 1973
6. Development of an Advanced Prototype VHF Tunnel Detector
   Contract No. DAAK02-70-C-0101
   Prepared for USAMERDC by Southwest Research Institute
   30 June 1970
7. Millimeter Wave Radiometer Tunnel Detector
   Memo Report No. 1922
   BRL, APG, MD
   April 1968
8. Portable Tunnel Detection Differential Magnetometer
   Prepared by Varian Associates
   July 1971.
9. Experimental Portable Hole and Tunnel Detector
   Contract No. DA-44-009-AMC-811(T)
   Prepared by Advanced Technology Corporation for A [illegible]
   November 1965
10. Electromagnetic Tunnel Detector, Model 197-2
    Contract No. DAAK02-68-C-0143
    Prepared for USAMERDC by General Dynamics Corporation
    February 1970
11. Soil Penetrating Radar for Tunnel Detection
    Prepared by General Dynamics Corporation
    19 March 1969
12. Soil Penetrating Radar for Detection of Tunnels
    Prepared by Wheeler Labs Inc.
    6 September 1967

APPENDIX A

VHF TUNNEL DETECTOR PARAMETERS

1. THEORY OF OPERATION

a. General

The VHF Tunnel Detector System comprises an electro-magnetic radar and a strip chart display section both controlled by a common digital logic section. The radar transmits a single pulse, approximately 4 nanoseconds in duration, at a rate of 3.12×10^6 p.p.s. The received echoes are sampled down in time, amplified, and directed to the recorder input. The display section is a multistylus strip chart recorder, marking on 3-inch-wide electrosensitive paper.

Figure A-1 is a simplified block diagram of the system presenting the basic modules and their interconnections. Figure A-2 shows the detector electronics package.

b. Radar

(1) Transmitter

The radar transmitter consists of a 3.12 MHz crystal controlled oscillator, a gated buffer, a class C radio frequency amplifier and a step recovery diode pulse generator. The gated buffer is turned off or on by the control logic. In the "on" state, 50-volt peak amplitude, 4-nanosecond-wide, pulses are generated by the transmitter diode at a 3.12 MHz rate. The pulses are connected to the antenna by the antenna hybrid or directional coupler.

(2) Receiver

Signals arriving back at the hybrid from the antenna are directed into the receiver preamp. The preamplifier contains two commercial broadband unit amplifiers. In addition, the input to each amplifier is protected by series and shunt signal limiters.

The output of the preamplifier is connected to a sampling circuit. The purpose of the sampling circuit is to translate the high-frequency video echoes down to a low audio frequency so they can be recorded. In the sampler, the first 180

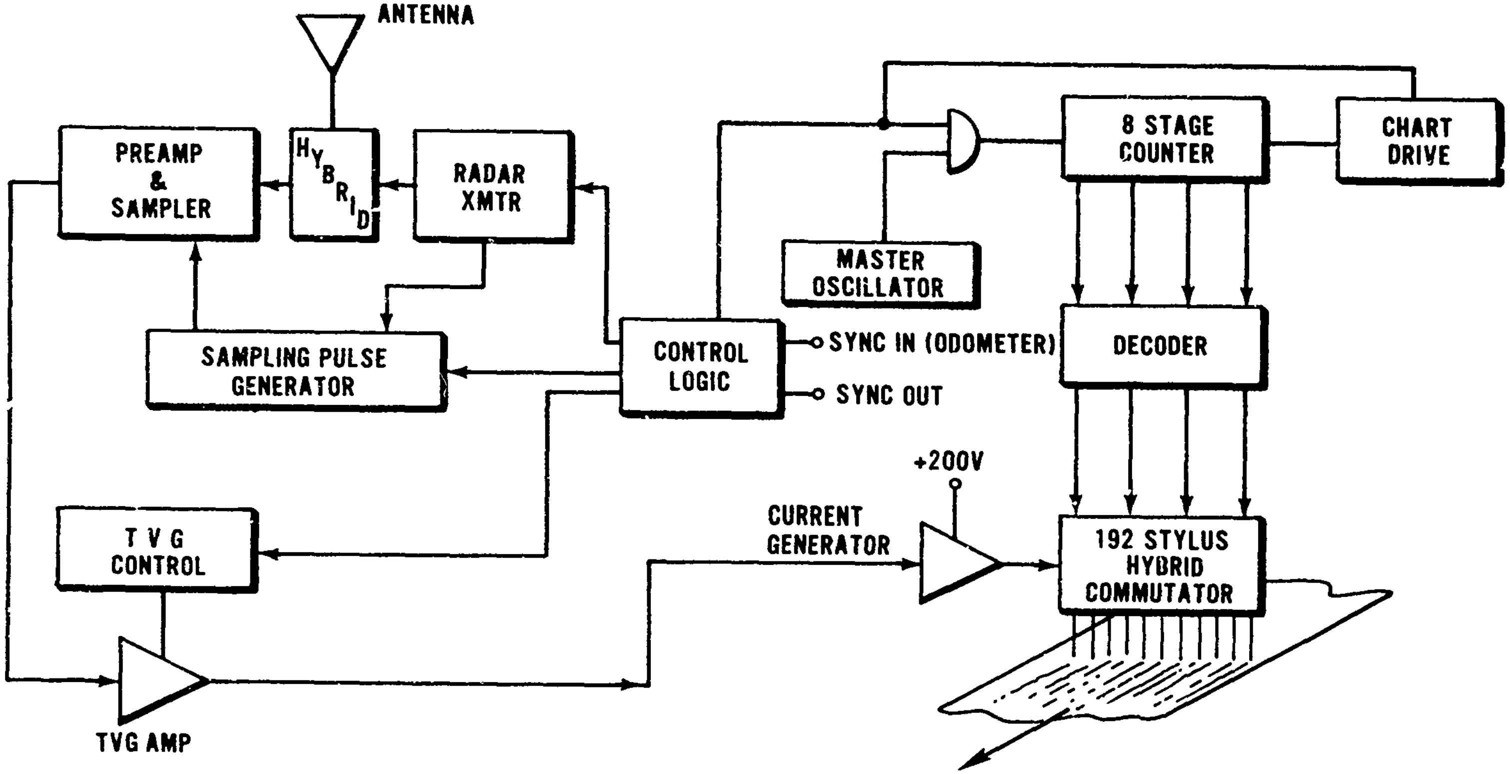

Figure A-1. VHF System Block Diagram.

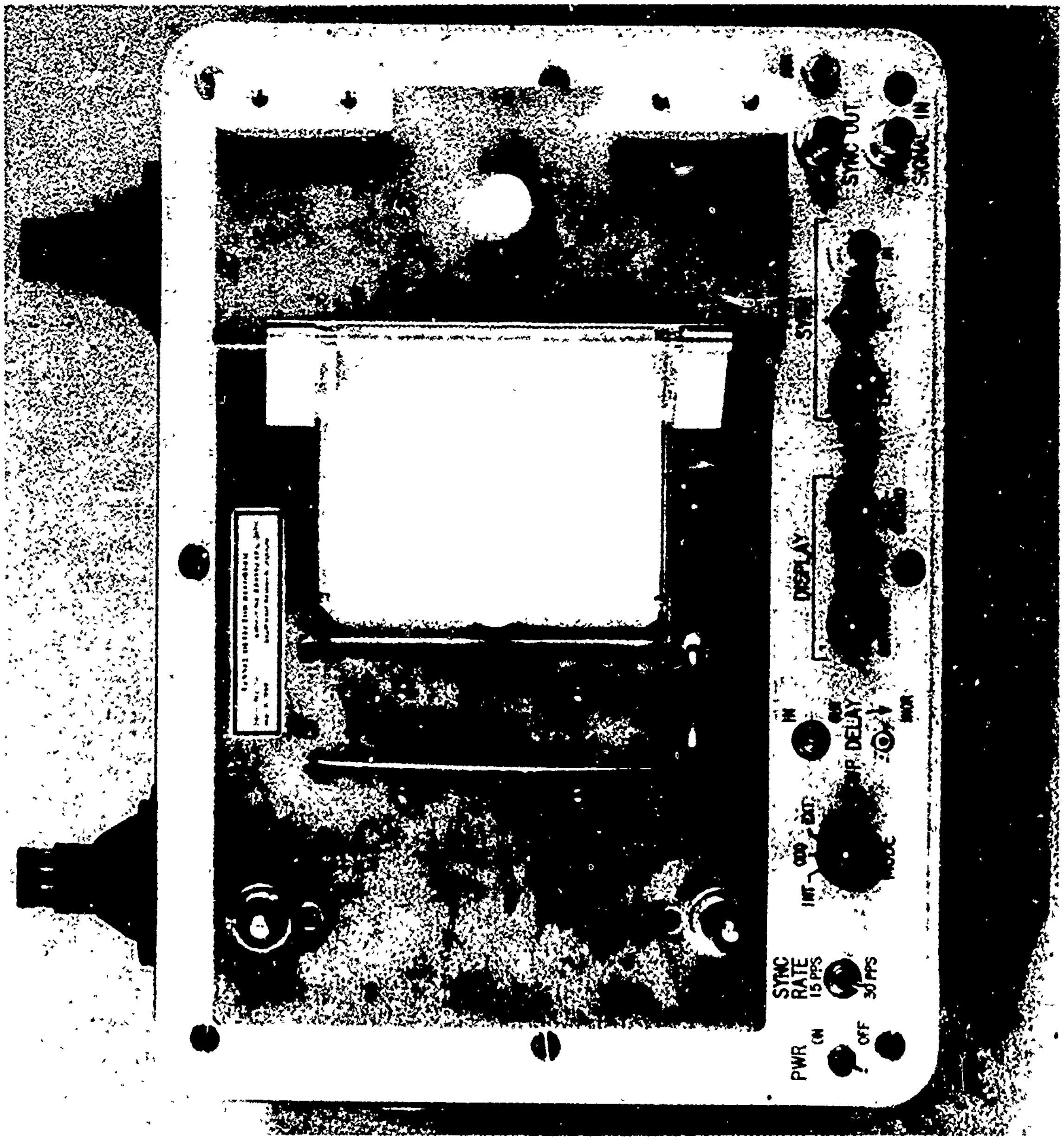

Figure A-2. VHF Tunnel Detector – electronics package. S7030 nanoseconds following the transmit pulse is transformed to 25 milliseconds recorder time, the time for one sweep across the chart.

The sampler output is amplified by the Time Varying Gain (TVG) amplifier. The TVG control circuit is synchronized with the sweep across the chart by the system control logic. The time varying gain can be set by three controls: (a) the Early Gain control sets the gain of the TVG amplifier at the start of the sweep; (b) the DELAY control sets the time period for which the gain remains at the early gain level; and (c) the TVG SLOPE control sets the rate at which the gain of the amplifier increases after the TVG delay time. The output of the TVG amplifier is directed to the recorder current source amplifier.

c. Recorder

(1) Signal Circuits

Echo signal voltages are converted to chart marking current by the marking current amplifier. This amplifier consists of: (a) an operational amplifier in which are summed the signal voltage and a dc voltage for an over-all background level; (b) a voltage to current converter with a 200-volt power supply; and (c) a 192-position single-pole commutator which connects the individual marking wire styli to the current source one at a time in sequence. The marking current flows through the wire styli into the electrosensitive chart paper and then to circuit ground. Each stylus is connected for about 130 microseconds during each sweep across the chart and a black dot is marked on the paper under each wire, the size of the dot depending on the amount of current.

(2) Switching Circuits

These circuits, operating under the control of the system control logic, produce the switching voltages for the 192-position commutator and the drive voltages for the chart drive stepper motor.

The heart of the switching circuit is the crystal controlled 7.68-kHz oscillator. The output of the oscillator is counted down by an eight-stage binary counter. The eight outputs of the counter are decoded to produce a switching voltage for each of the 192 segments in the commutator.

The chart drive motor obtains supply voltage control from the counter. In addition, the control logic supplies an "off-on" signal to the chart drive circuit.

d. Control Logic Circuits

The control logic circuits are integrated circuit, digital logic elements. These circuits provide the necessary gating and control functions to accept external synchronizing signals and cause the system to record one line for each external pulse or to cause the system to free run at a 30-line-per-second rate and generate Sync Out pulses at this rate. It also controls the radar transmitter, the sampling circuit, and the TVG circuit.

e. System Power

Power to operate the system is supplied by a battery attached to the harness on the operator's back. Two types of battery are available: (1) a silver-zinc rechargeable battery, and (2) a mercury battery with replaceable cells.

The 24-volt d.c. from the battery is converted to ± 12 volts unregulated, + 12 volts regulated, + 5 volts regulated, and + 200 volts regulated by d.c. to d.c. converters in the electronics unit.

APPENDIX B

SEISMIC TUNNEL DETECTOR PARAMETERS

1. THEORY OF OPERATION

a. General

The seismic tunnel detector is a portable device designed to locate shallow subterranean man-made or natural tunnels and caves. It is a sound-ranging system which functions on a principle similar to SONAR. The detector system consists of three components: a transmitting transducer, a receiving transducer, and an electronics package.

b. Detector Electronics System

(1) Transmitter

The transmitter section of the tunnel detector system has a fixed-pulse repetition rate of one pulse per second. It is illustrated by the simplified block diagram of Figure B-1. Signal flow through this portion of the system can be followed by starting with the Master Oscillator. In the Internal Sync mode of operation, timing pulses are generated by the oscillator at a rate of one pulse per second. In the External Sync mode of operation, the master oscillator produces timing pulses at a rate determined by the frequency of the external synchronization source or whenever the Single Pulse switch is operated.

The master oscillator pulses are delivered directly to the receiver blanking circuits to reduce receiver gain during transmit time and for an adjustable period following transmit time. The oscillator output is delayed approximately 50 microseconds before being delivered to the display circuits to start the scope trace and to the transmit trigger shaping circuit used to fire the high-voltage switch. The delay time between the receiver gating and transmitter trigger reduces the possibility of transmitter signals overloading and blocking the receiver circuits.

The transmit trigger shaping circuit is a one-shot multivibrator which delivers a fixed-amplitude, fixed-duration pulse to the high-voltage switch.

The high-voltage switch consists of six silicon controlled rectifiers series-connected across the terminals of the transmitter transducer and damper network. In

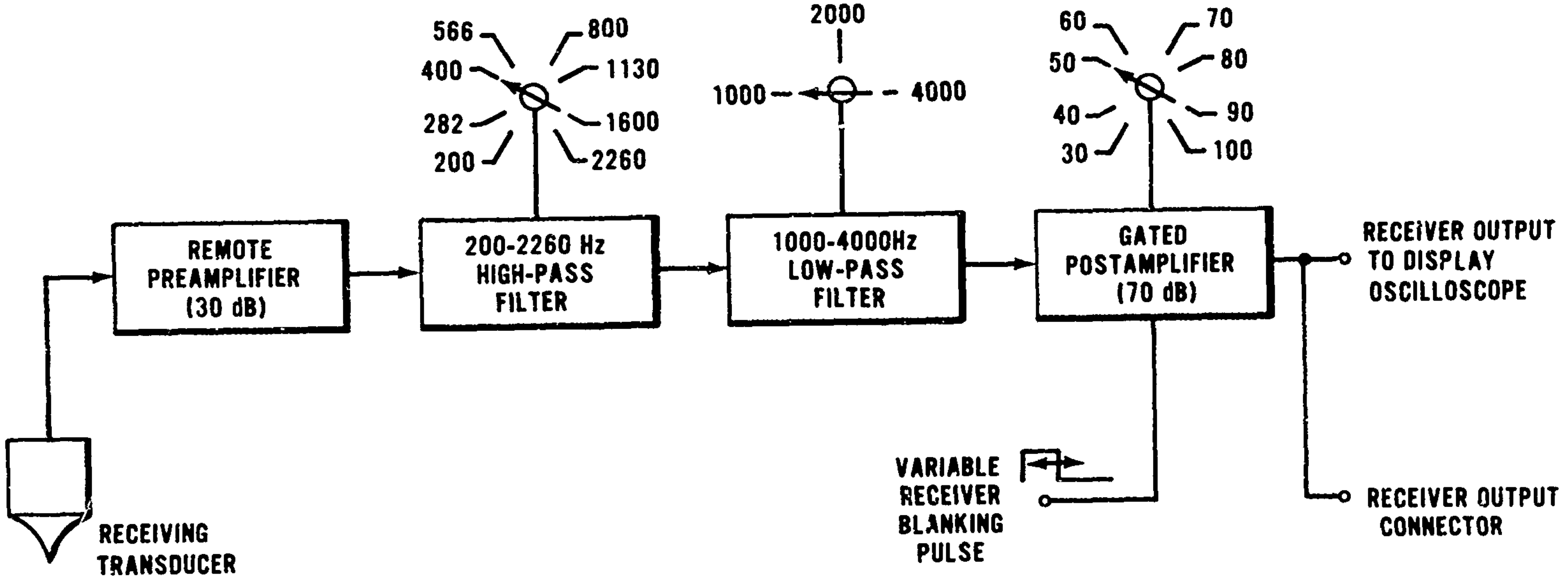

Figure B-1. Seismic Receiver Block Diagram.

the "off," or blocking, state the switch is a very high impedance.

While the high-voltage switch is in the "off" state, the high-voltage power supply is charging the capacitive transmitting transducer element through the charging resistor and the tuning inductor. When the high-voltage switch is triggered to the "on" state by the transmit trigger pulse, the transmitting transducer discharges rapidly through the tuning inductor and the switch. The controlled rectifiers in the switch remain in the "on", or low, impedance state until the discharge current passes through zero, at which time they revert to the blocking state. Reverse current then flows through the damping network until the current again reaches zero. This completes the transmit cycle, and the transmitting transducer begins to recharge until the next transmit time.

The high-voltage power supply used in the modified tunnel detector was a miniature 6,000-volt (peak-to-peak), 10-kHz square wave inverter followed by a high-voltage diode bridge rectifier. This power supply, procured as a special design from Austron, Inc., Austin, Texas measured 2 inches in diameter and 4 inches in length and was capable of delivering 5 milliamperes output current into a 600 K-ohm load. The power supply, diode bridge, high-voltage switch, and damper network were mounted in the transmitting transducer housing to reduce the size of the electronics package.

(2) Receiver

The seismic receiver section of the electronic system consists of a remote preamplifier, a step-variable high-pass filter, a step-variable low-pass filter, and a pulse-gated variable gain postamplifier as shown in the block diagram of Figure B-2. The remote preamplifier is a 30-dB FET amplifier comprising Q19 and Q20 in the schematic diagram of Figure B-3. This preamplifier has special features of low noise, high-input impedance, low-output impedance, and protective limiter circuits at both input and output terminals. The preamplifier is connected to the transmitting transducer by means of a lightweight 10-foot, multiconductor shielded cable which is, in turn, connected to the electronics unit by a 10-foot interconnecting cable.

The high- and low-pass filters are conventional three-stage unity gain active resistive capacitive (RC) circuits. The high-pass circuit is variable in half-octave steps from 200 Hz to 2260 Hz, and the low-pass circuit is variable in one-octave steps from 1000 Hz to 4000 Hz. Both filter sections have 30 dB/octave asymptotic stop band attenuation rates.

The 70-dB gain gated postamplifier is made up of two operational amplifier stages (40 dB and 30 dB), each having 10-dB step-variable feedback networks with a continuously variable 10-dB gain control in the second stage. Gating of the postamplifier is accomplished by means of pulse-controlled FET devices in the operational

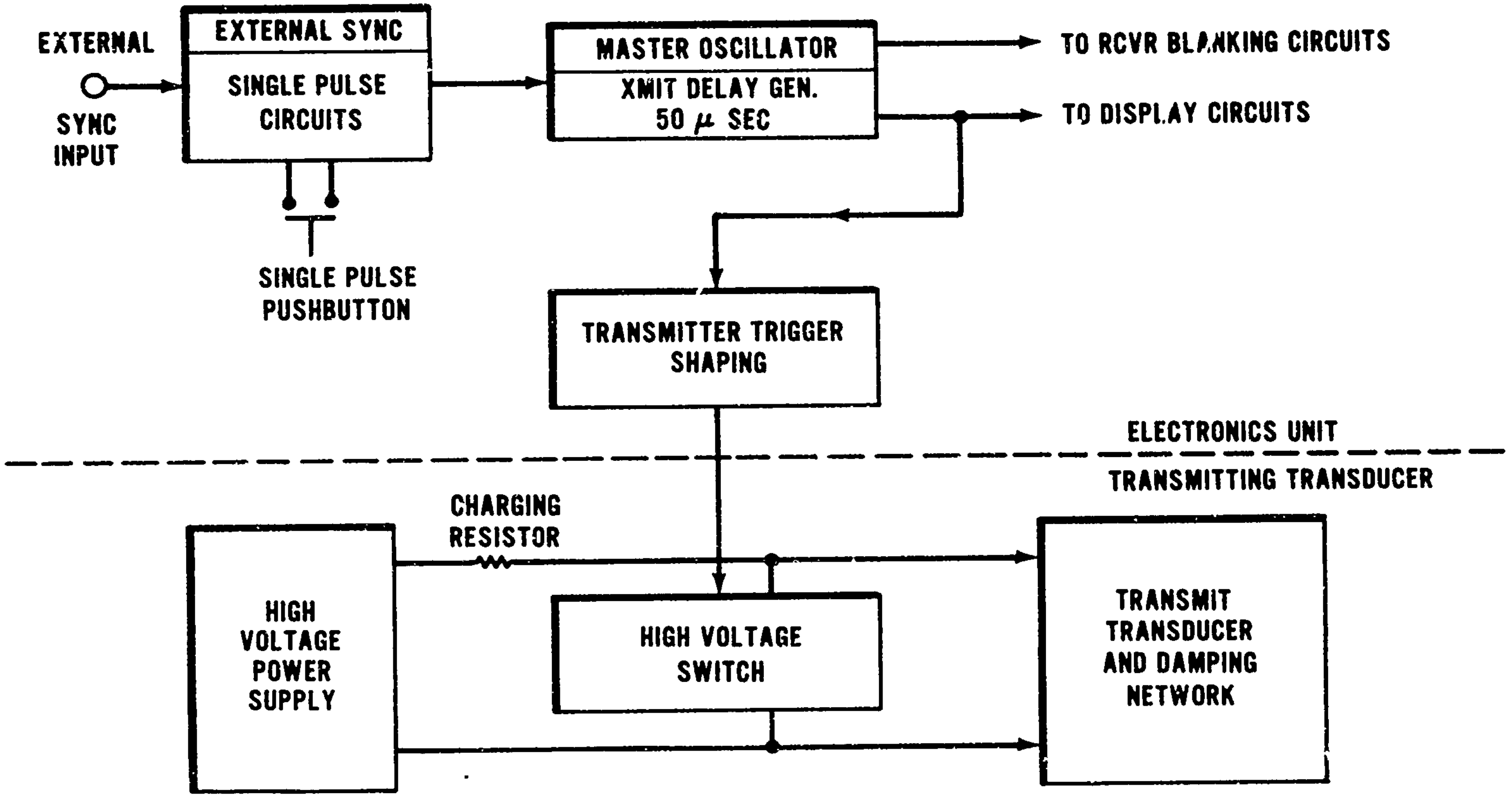

Figure B-2. Seismic Transmitter Block Diagram.

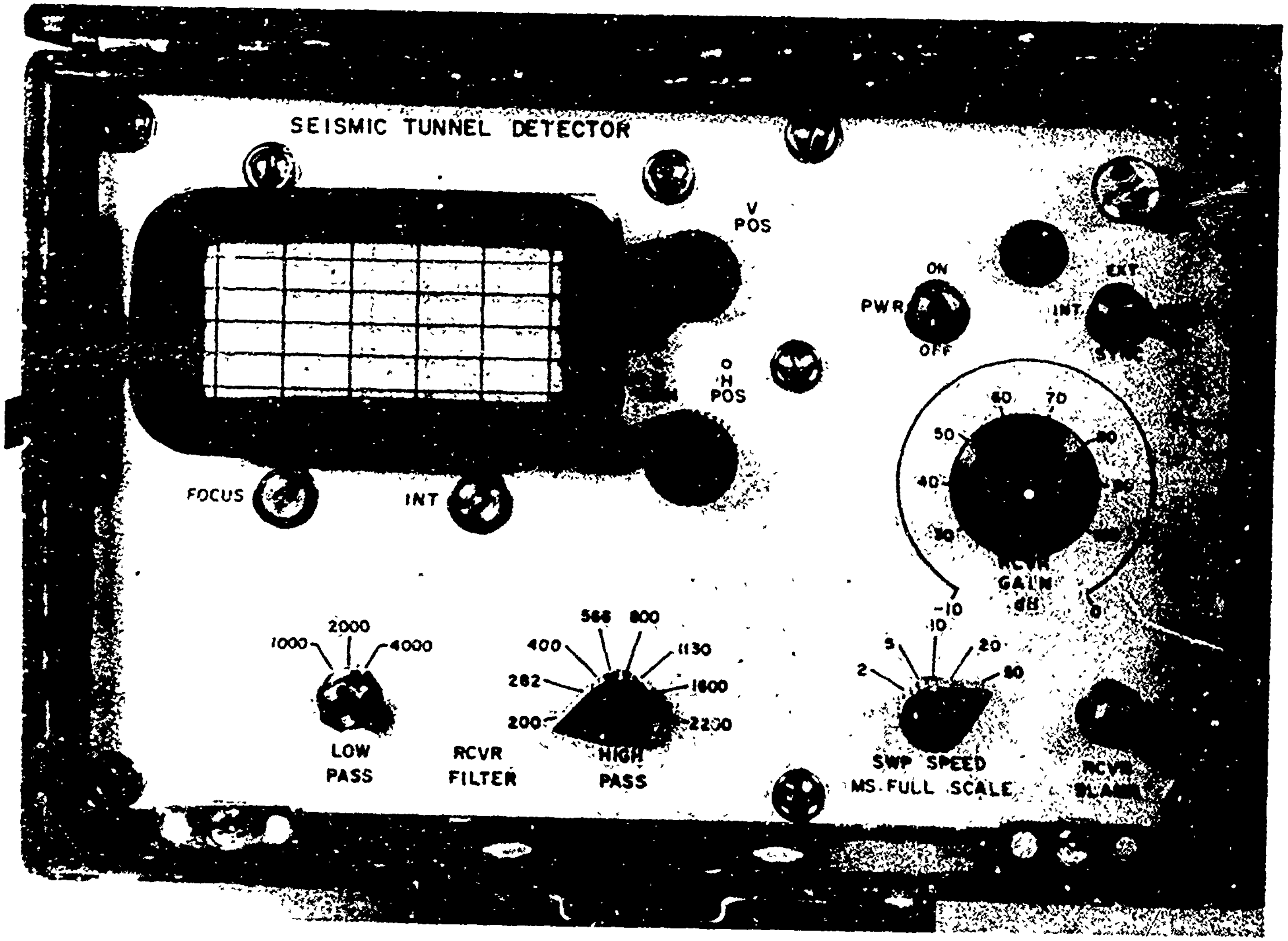

Figure B-3. Seismic Tunnel Detector — control panel.

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amplifier feedback networks which reduce the gain of each circuit to unity together with a shunt FET gate at the output terminals. Gating occurs during the receiver blanking cycle controlled by the receiver blanking circuit. The postamplifier output signal is made available at the RCVR OUTPUT connector inside the battery compartment and is also fed to the vertical deflection input terminals of the display oscilloscope.

The seismic receiving transducer is a basic Columbia Research Corporation Model 302-4 accelerometer modified to have a smaller mounting base and supplied without the usual metal case enclosure. The specifications of this accelerometer are as follows:

Open circuit voltage sensitivity:	783 pk mV/pk g
Crystal capacitance:	80 pF
Resonant frequency:	18 kHz
Weight:	49 g

(3) CRT Display

The essential requirement of the display system is to present the received signals in an "A-Scan" form. The trace length (sweep speed) is adjustable in steps to 2, 5, 10, 20, and 50 milliseconds full scale.

The sweep generator consists of a bistable sweep-enabling circuit controlling a transistor switch, a constant current circuit which charges a capacitor, and an output amplifier with feedback through a diode to the enabling circuit.

The oscilloscope employed in the system is a Benrus Model RA-840C unit, modified for minimum total power consumption. Standard models of the oscilloscope consume approximately 24 watts at 115 volts, 50 to 400 Hz. Modification of the vertical and horizontal amplifiers reduced this power consumption to slightly less than 12 watts.

Power for the oscilloscope is supplied by a specially designed d.c.-to-a.c. inverter obtained from Austron, Inc., Austin, Texas. This power supply was miniaturized to be installed in the Benrus oscilloscope in place of the original a.c. power transformer. The power supply RMS output voltages were nominally 1100 volts, 6.3 volts, 220 volts, 25 volts, and 11.4 volts at 1,000 Hz. These voltages were fed to the existing oscilloscope rectifier circuits to provide the necessary internal d.c. voltages. The dimensions of this power supply were 2-3/4 in. by 3-1/16 in. by 2-5/32 in., with mounting studs designed to fit the oscilloscope power transformer mounting.

Outdoor viewing of the CRT display was facilitated by a specially formed collapsible polymer rubber hood designed to fit the CRT bezel when in use. The viewing hood is stored in the storage compartment of the electronics unit for transport. Figure B-3 shows the electronics unit control panel.

(4) Internal Battery Power Supply

The internal battery supply for the system consists of eight type BA1100/U mercury batteries. They are series connected to provide a centertapped nominal 24-volt supply.

The two d.c.-to-a.c. power inverters operate from the full supply voltage, and the electronic sections make use of the ± 12 volts with respect to the battery centertap. The centertap is connected to circuit common and chassis.