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EDGERTON, GERMESHAUSEN & GRIER, INC.

ELECTROMAGNETIC MEASUREMENTS ON CANADIAN 100 TON TNT EXPLOSION

by

Clyde B. Dobbie

Stuart R. Hamilton

Edgerton, Germeshausen & Grier, Inc.

Boston, Massachusetts

EG&G Report No. B-2572

Contract No. AF30(602)-2546

This effort is supported by The Advanced Research Projects Agency and directed by Rome Air Development Center under ARPA Order 180-60 as amended.

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Rome Air Development Center
Research And Technology Division
Air Force Systems Command
United States Air Force
Griffis Air Force Base
New York

BOSTON AND SALEM, MASSACHUSETTS
LAS VEGAS, NEVADA · SANTA BARBARA, CALIFORNIA

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ABSTRACT

The detonation of a 100-ton TNT charge took place on 3 August 1961 at the Suffield Experimental Station in Ralston, Alberta Province, Canada. The EG&G effort on the explosion was intended to (1) measure the electromagnetic (EM) signals, (2) perform high speed photographic measurements to assist in the analysis of the EM data. This report contains a description of the EM detection phase of the effort.

Detection and recording of the EM signal was attempted using loop antennas pre-amplifiers, and a tape recorder. Time correlation between film records and EM records was provided by EG&G Fiducial Marker Generators.

No EM signal was detected. It is believed that this was due to the fact that the charge was hemispherical, and was on the surface of the earth.

Title of Report RADC-TDR-63-193

PUBLICATION REVIEW

This report has been reviewed and is approved.

Approved: John N Entzminger
JOHN N. ENTZMINGER
Project Engineer

Approved: for Geo. E. Brunetti
TODD G. WILLIAMS, Lt. Col., USAF
Chief, Equipment Laboratory
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SECTION I

INTRODUCTION

1. The objectives of the EG&G Electromagnetic Measurement effort on the Canadian experiment were as follows:

(1) To design, procure, and assemble a self contained dB/dt detection and recording system, directional in three planes, and capable of recording pulses between 0.1 V/M and 20 V/M (measured at 1 kc) over the frequency range from 200 cps to approximately 12 kc.

(2) To transport this equipment and personnel to Suffield Experimental Station in Ralston, Alberta, Canada, to monitor a 100-ton TNT explosion.

(3) To calibrate the system with regard to polarity, frequency response, and sensitivity in the field prior to monitoring the shot.

(4) To obtain the magnetic bearings and position of the antenna relative to ground zero.

(5) To analyze and report on the results of the experiment.

1.1 BACKGROUND

1.2 Part of the work being carried out in the theoretical investigations portion of this contract is a study of the various mechanisms by which nuclear explosions can generate and radiate significant quantities of Electromagnetic (EM) energy. Be cause of the moratorium on nuclear testing which was in effect at the time, it was

believed that the study of large chemical explosions might yield useful information on EM mechanisms.

1.3 In May of 1961 during the Banshee project, EG&G measured the EM field produced by a 500 pound center-detonated spherical charge of HE detonated in the air. The EM field approximately 1000 feet from the explosion was on the order of 1.0 V/M with 1 kc components predominating. The field strength and wave-shape agreed quite well with that which could be predicted using the "magnetic bubble" model.

1.4 In July of 1961 RADC informed EG&G that the Canadian Government was about to detonate 100 tons of TNT on the surface of the earth at the Suffield Experimental Station, at Ralston, Alberta, Canada. On the basis of the "magnetic bubble" model, calculations indicated that essentially the same EM field (1 V/M) which occurred a distance of 1000 feet from the Banshee shot would exist 7000 feet from the 100 ton explosion; but that the EM energy would be concentrated at approximately 1/7 the frequency. These large explosions appeared to afford an excellent opportunity to test the "magnetic bubble" mechanism for HE on a large scale.

1.5 RADC requested EG&G to assemble a field team and the necessary equipment to monitor the EM output from the 100 ton explosion and to simultaneously take high speed pictures of the explosion. The EM and photographic data were to be time correlated by means of a fiducial signal obtained from an EG&G fiducial generator. It was believed that a great deal of information could be obtained on the basic EM generating mechanism by correlating the EM data with the rate of growth and decay of the fireball as recorded by high speed photography.

SECTION II

SYSTEM DESCRIPTION

2. GENERAL. The EM detection system consisted of three orthogonal 30-inch loop antennas, each consisting of 11 turns. A block diagram of the system is shown in Figure 1. Each antenna fed two channels of an Ampex FR1100 seven-channel tape transport through an antenna matching transformer, preamplifier, two parallel direct-record amplifiers set to provide the desired dynamic range, and head-matching transformers. The tape recorder was operated at 15 ips with 1/2-inch magnetic tape.

2.1 LOOP ANTENNAS

2.2 Stoddard Aircraft Corporation Model 90117-3 loop antennas were used. They were 30 inches in diameter and contained 11 turns of wire surrounded by an aluminum electrostatic shield. The manner in which the three loop antennas were mounted in an orthogonal array is shown in Figure 2. The location and alignment of the antennas and the recording system, relative to the explosion, are shown in Figure 3. The antennas were located on a hill 134 feet above ground zero.

2.3 In order to determine the system sensitivity, a calculation of the effective height of the loops is necessary. The expression for the effective height is shown in Equation 1.

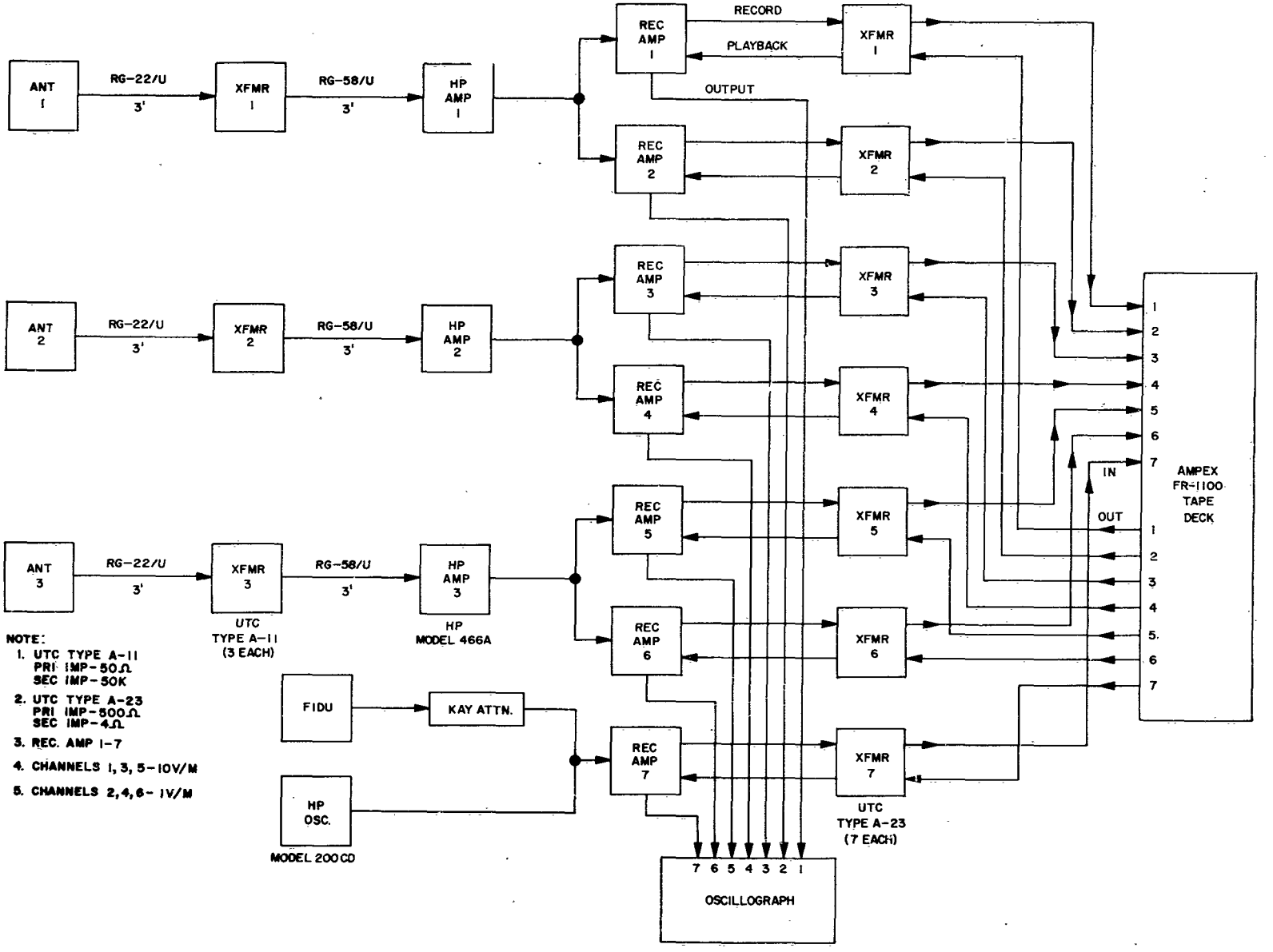


Figure 1. Detection System Block Diagram

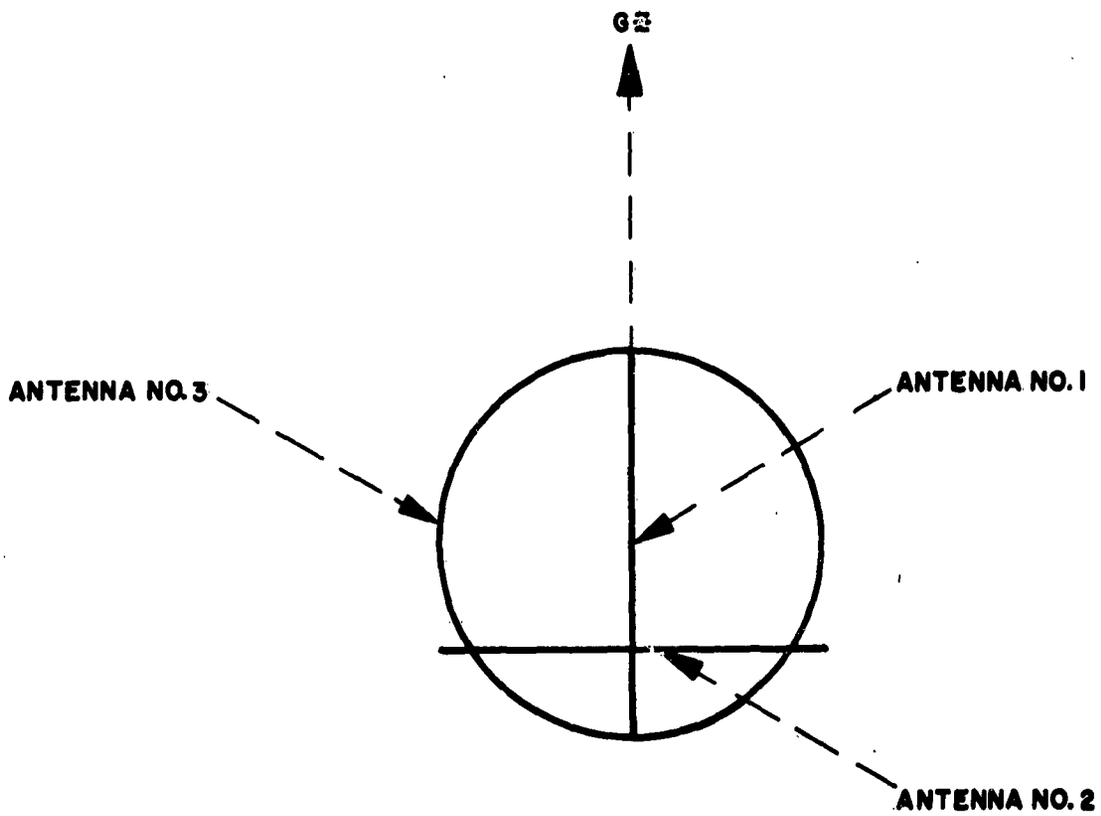


Figure 2. Antennas Used For Detection Of EM Signal

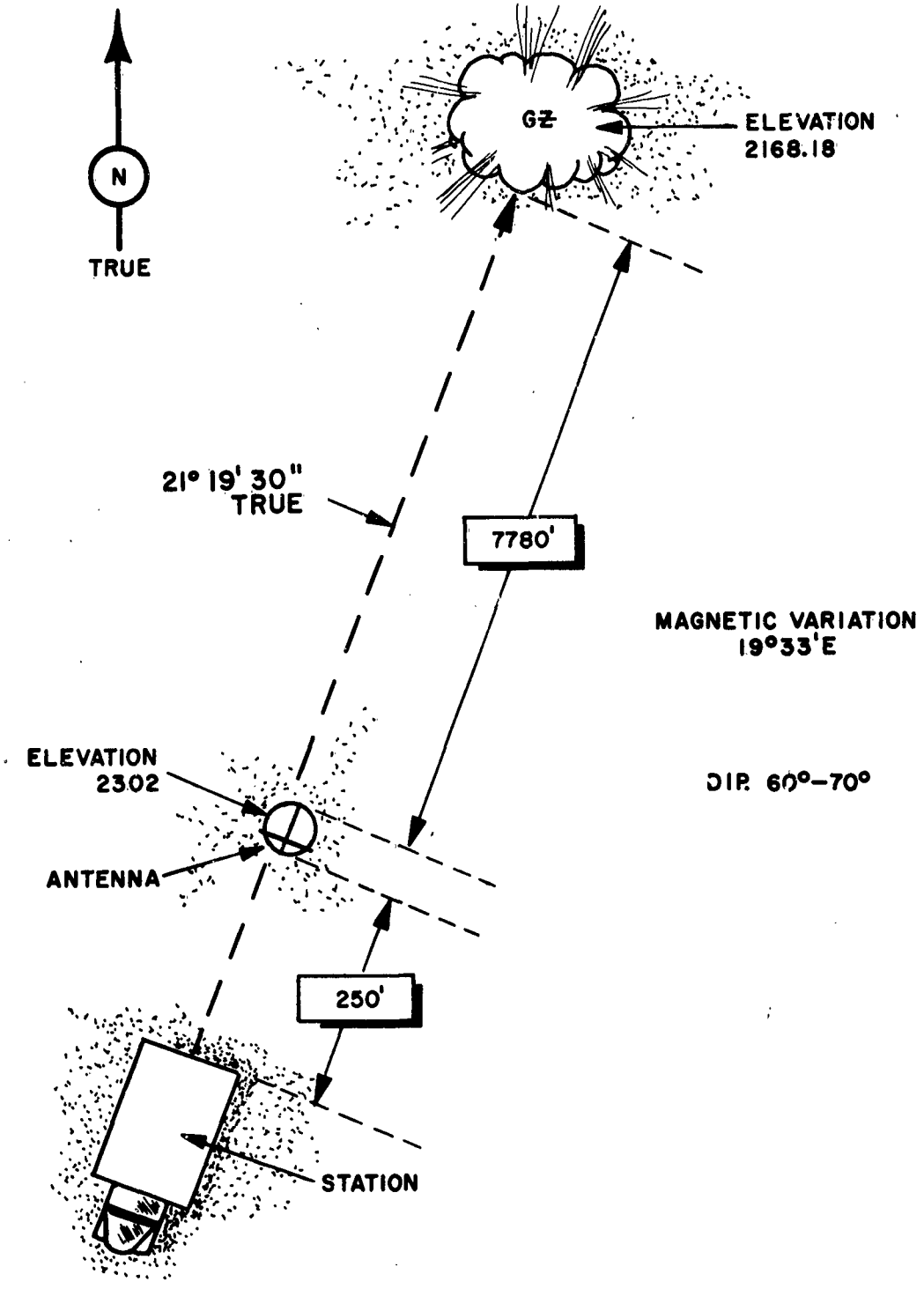


Figure 3. Antenna Location And Alignment

$$H_e = 2\pi N \frac{A}{\lambda} \cos\theta \qquad (1)$$

where: H_e = effective height in meters

N = 11 (number of turns in loop)

A = area of loop in meters^2 = $0.456M^2$

λ = wavelength in meters = $\frac{c}{f} = \frac{3 \times 10^8}{f}$

f = frequency in cycles per second.

Substituting the values for the Stoddart loop in Equation 1 gives:

$$H_e = 10.5 \times 10^{-8} f \cos\theta \qquad (2)$$

The voltage induced in an antenna (V_a) is related to the effective height of the antenna (H_e) by the following expression:

$$V_a = \epsilon H_e \text{ Volts}$$

Where ϵ is the electric field in volts per meter.

2.4 The antenna output voltage over the range of field strengths from 0.1 V/M to 20 V/M (at 1 kc) is from 10.5 μv to 2.1 mv.

2.5 ANTENNA MATCHING TRANSFORMER

2.6 The antenna was connected through a 3 foot cable to the 50 Ω primary winding of a matching transformer. The antenna matching transformer used was a United Transformer Corp. type A-11. The primary impedance (to the antenna) was 50 Ω; the secondary impedance (to the pre-amplifiers) was 50,000 Ω. These transformers have a frequency response of ± 2 db over the range of 20 cps to 20,000 cps. The

transformers are shielded against hum pick-up and are designed for low signal-level operation. The turns ratio (voltage gain) is 31.6.

2.7 The voltage at the output of the transformer is 31.6 times greater than the voltage out of the antenna and can be expressed as:

$$V_T = 31.6V_a = 3.32 \times 10^{-6} \epsilon f \cos\theta \text{ Volts} \qquad (3)$$

2.8 PRE-AMPLIFIERS

2.9 The transformer output was applied to the input of a Hewlett-Packard 466A pre-amplifier. The pre-amplifiers used were self-contained, battery-operated, transistorized units manufactured by Hewlett-Packard. They have a selectable voltage gain of either 20 db (x 10) or 40 db (x 100)±0.2 db at 1,000 cps. The response is ±0.5 db from 10 cps to 1 mc. The noise level is 75 μv rms referred to the input. Input impedance is 1 Megohm shunted by 25 pf. Output impedance is 50Ω in series with 100 μf. These amplifiers were operated in the 40 db mode giving a voltage gain of 100. The voltage from the pre-amplifiers (V_P) is then:

$$V_P = 100\ V_T = 3.32 \times 10^{-4} \epsilon f \cos\theta \text{ Volts} \qquad (4)$$

The output voltage of the pre-amplifiers was applied to the high-gain input of the recording amplifier.

2.10 RECORDING AMPLIFIERS

2.11 The recording amplifiers were Viking Model RP-62VU. They employ a VU meter and variable bias and signal level adjustments to obtain maximum recording efficiency. The amplifier has two inputs: a low level (62 db gain) and a high level (32 db) gain. The low level input was used in order to obtain maximum sensitivity.

This input requires a minimum of 10 mv to achieve a 100% recording level (to cover the desired dynamic range). Each antenna fed two tape channels through separate recording amplifiers. The gain of these amplifiers was set so that one channel covered 1 V/M to 20 V/M and the second covered from 0.1 V/M to 2 V/M.

2.12 The output impedance of the RP 62VU amplifier is 500 ohms; however, the impedance of the recording heads on the Ampex tape recorder is 3.2 ohms. To compensate for this mismatch it was necessary to install a transformer between the amplifier and each of the recording heads.

2.13 HEAD MATCHING TRANSFORMERS

2.14 United Transformer Corp. Model A-23 transformers were used to match the impedance of the recording heads to the amplifier output impedance. The transformer has an input impedance of 500 ohms and an output impedance of 4 ohms. The frequency response is ± 2 db from 40 to 20,000 cps. Tests were made to insure that this transformer would pass the 60 kc bias frequency. Since the load is highly inductive, the losses were low enough that the record amplifier was able to drive the 60 kc bias to the recording heads. The system was optimized by recording a 1 kc tone while simultaneously monitoring the reproducing head for that channel. The signal and bias levels were adjusted individually to produce the maximum undistorted output on each channel.

2.15 TAPE TRANSPORT

2.16 The tape transport was an Ampex FR1100, set to run at 15 inches per second using 1/2 inch tape. It employs separate recording and playback heads and records and plays back on seven channels. The Viking amplifiers are designed

to operate with combination recording and playback heads, so a switch panel was installed to allow selection between recording and playback heads as desired. The frequency response of the reproduce heads is 100 cps to 20,000 cps. The cumulative flutter (peak to peak) of the transport is 0.9% measured at 500 cycles. The timing accuracy of the transport is better than ± 120 ms per minute, assuming a stable 60-cycle power source. During operation, power was provided by an isolated portable generator, which may have affected the recording speed. To offset this, a 1000-cycle sine wave was recorded on one channel for use as a timing reference. A great deal of care was taken to establish a single ground for the entire system, including the truck body, so as to minimize the effect of hum or other interferring signal pickup.

2.17 All recordings were made on 1/2 inch instrumentation tape, 1.5 mils thick, 2,500 feet long. This gave a running time of approximately 33 minutes at the 15 ips speed which was used. On the shot run, the transport was started at minus 5 minutes by hand. This allowed ample time for the speed to stabilize before the shot.

2.18 FIDUCIAL MARKER GENERATOR

2.19 This unit was used to generate an electrical output signal synchronized as nearly as possible to the initial light output from the explosion. The output signal was mixed with a 1 kc output of an audio oscillator then applied to channel number seven on the tape. The fiducial signal provided a zero mark, and the 1 kc signal provided a time base as an aid in reducing the data on the six information channels.

2.20 The Fiducial Marker Generator employs a telescope as a collimating and aiming device with a mirror reflecting half the light from the telescope to a

photomultiplier. The field angle of the telescope is 7 degrees. The generator requires a light pulse with a rise time of less than 1 μsec to generate a trigger. The generator provides four parallel outputs, only one of which was used in this system. The output pulse has an amplitude of 350 to 400 volts with a rise time of 0.05 μsec. The reaction time is 0.02 μsec.

2.21 CALIBRATION PROCEDURE

2.22 The overall system was calibrated by inducing known signals into the loop antennas by the shield injection method. This is based on driving a known current around the shield as a means of generating a signal in the loop. Calculations showing the relationship between the shield current and the induced voltage appear in Appendix 1. From the derived equation it can be seen that a current of 0.912 ma rms at 1 kc can be used to simulate a field equivalent to 1 V/M in the Stoddart antenna. Calibration was accomplished using the calibrator shown in Figure 4. This unit generates the proper current in the shield to simulate 0.01 V/M, 0.1 V/M, 1.0 V/M, or 3.03 V/M, based on 1 kc. Using this calibrator, recordings were made of various frequencies at various simulated signal levels in order to obtain a record of the overall system frequency response characteristics. These recordings were observed on the oscillograph in the same manner as the shot records themselves. A plot of the peak to peak response in inches, verses frequency at the various levels can be seen in Figure 5.

2.23 The 1 V/M calibrations were not carried above 5 kc since this saturated the system and would have overloaded the pre-amplifiers. The cutoff of the oscillograph galvanometers is 3 kc. Signals above this frequency were studied using an oscilloscope which did not have the 3 kc limitation of the Visicorder.

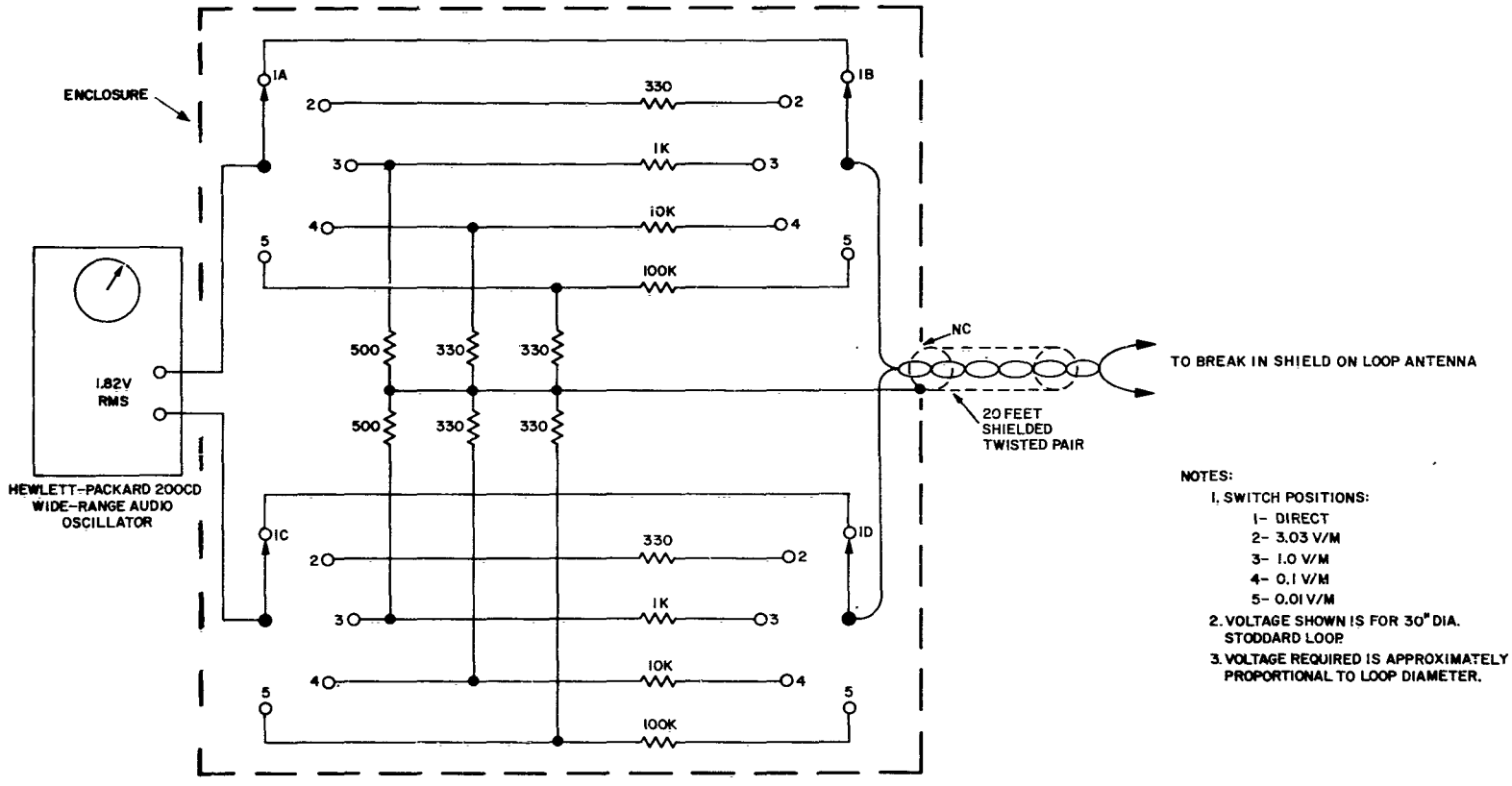


Figure 4. System Calibration Circuit

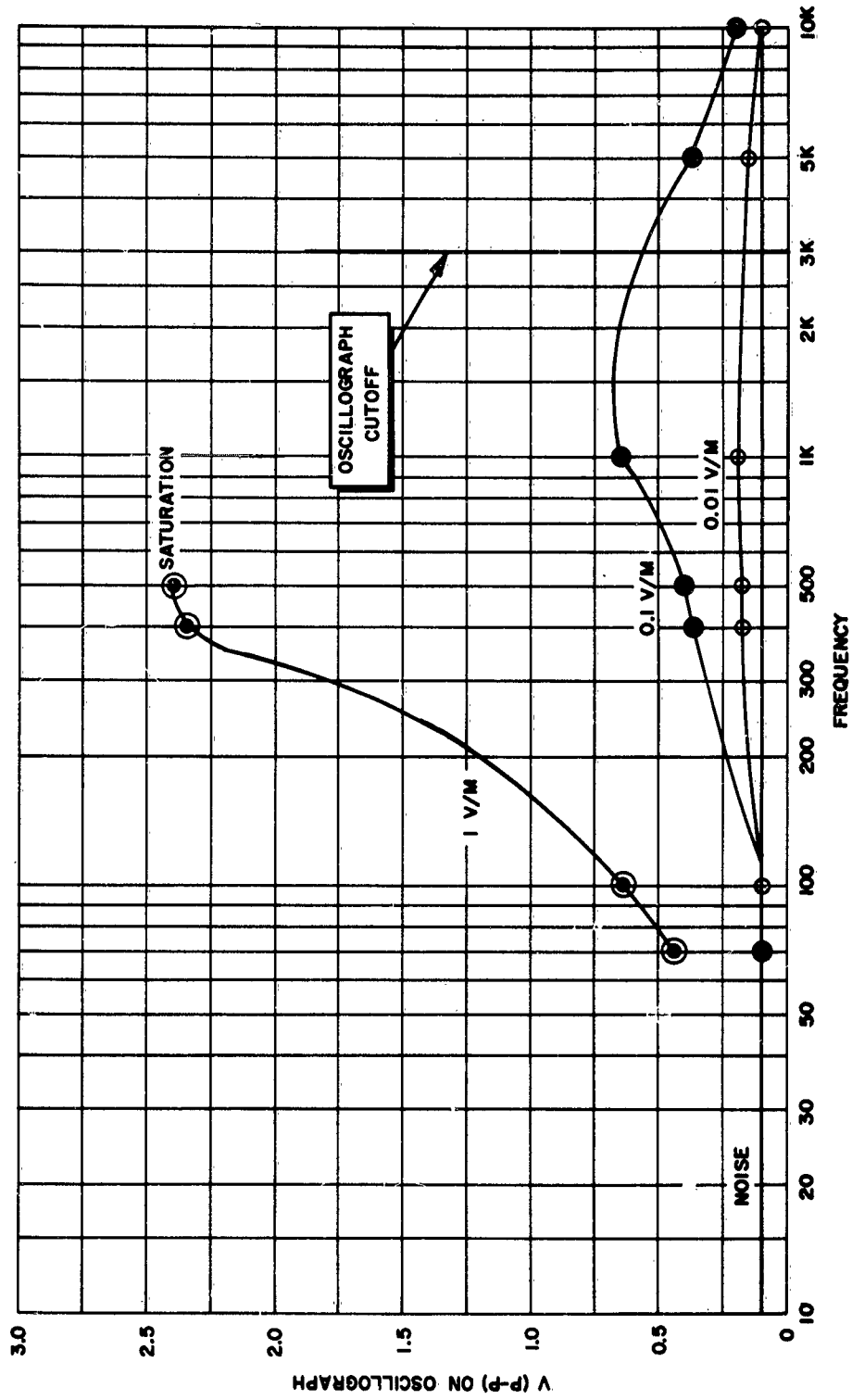


Figure 5. Amplitude Response Vs Frequency Curves

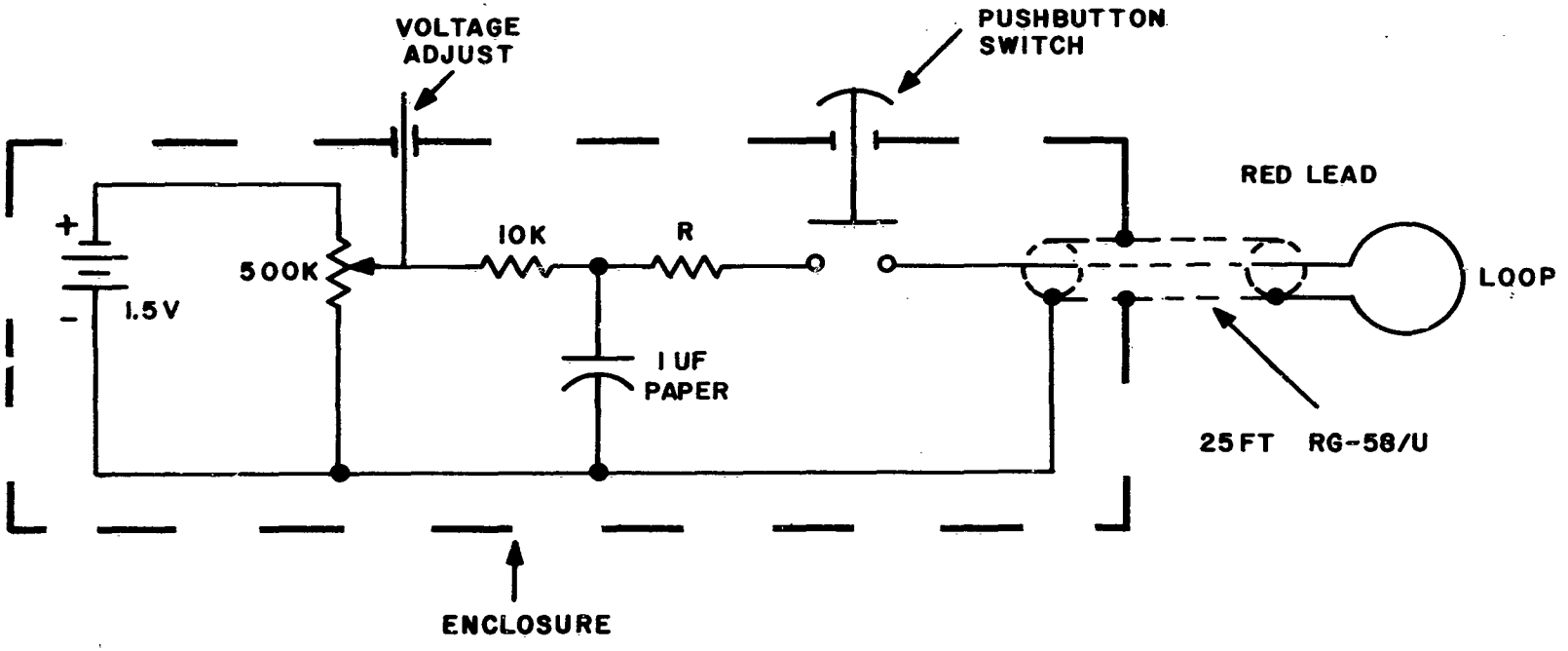
2. 24 Figure 6 shows the polarity calibrator used in this system. In this calibrator, a capacitor is charged with a known voltage of known polarity, and then discharged into a disk-shaped coil. Knowing the direction of the current through the coil windings, it is possible to simulate an EM pulse with known polarity. The disk was held in the vicinity of each loop antenna and pulsed several times. The signal detected by the antenna was recorded on tape for use in conjunction with the data reduction.

SECTION III

DATA REDUCTION

3. Figure 7 shows the setup used for reducing the data. The output of the tape deck was applied to a variable pass filter through a galvanometer amplifier into an oscillograph. The oscillograph used galvanometers with a response of dc to 3 kc. For frequencies above 3 kc, the data was examined with oscilloscopes both with and without filtering, and at a variety of sweep speeds. This was done to expand the data as much as possible, and to optimize the frequency response.

3. 1 We observed what is believed to be such things as rocket ignitors a few seconds before zero time, the spark markers and electric motor noise from the high speed cameras located in our station. Also, signals were recorded when the



NOTE: Loop consists of 200 turns on 12 inch diameter form with 1 inch radius. One face of loop is painted red. Loop is wound so that the red face is a north magnetic pole when a positive voltage is applied to the red head.

gure 6. Polarity Calibrator

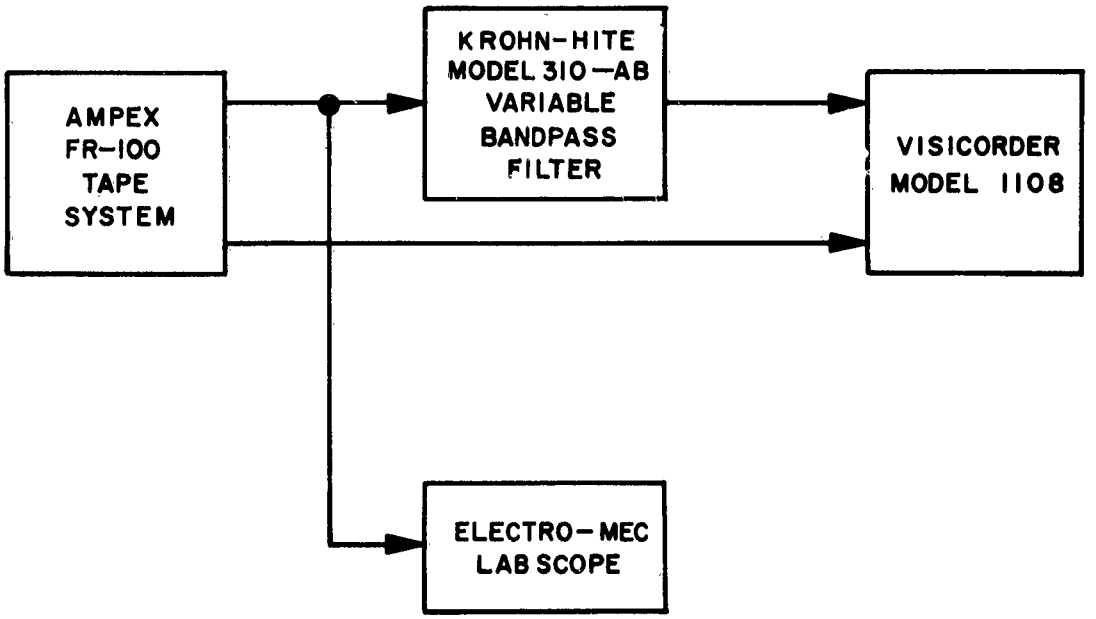


Figure 7. Data Reduction System Block Diagram

antennas were disturbed by both the seismic and air shock pulses. However, no significant electromagnetic data was observed near zero time. The probable reason for this is discussed in the following section.

SECTION IV

CONCLUSIONS

4. It is of interest to speculate on possible reasons why no significant electromagnetic signal was observed from this particular explosion. As part of Project Banshee, it was shown in a calibration shot at Aberdeen Proving Grounds that a centrally detonated 500-lb sphere of high explosive suspended above the ground apparently produced a unique electromagnetic signal. One reasonable way to explain such a signal (assuming it was not related to lightning) is to invoke the idea of a "magnetic bubble." The expanding "fireball" or strong shock wave is a conducting surface when the temperature is sufficiently high. The earth's magnetic field, H_o, will be expelled from the interior of this expanding volume as long as the conductivity remains high. An external observer then sees a certain surface current distribution on the expanding "fireball." The fields measured by a distant observer are essentially those of a quasi-static magnetic dipole; i.e., in polar coordinates,

$$H_r(t) = H_o \left[\frac{R(t)}{D}\right]^3 \text{Cos}\,\theta$$

$$H_\theta(t) = \frac{1}{2} H_o \left[\frac{R(t)}{D}\right]^3 \mathrm{Sin}\theta$$

where R(t) is the radius of the fireball at time t and D is the distance to the observer. Such expressions were used to estimate the signal strength to be expected from the Canadian explosion and in adjusting the system sensitivity.

4.1 No EM signal was detected during this experiment. The 100-ton hemisphere of high explosive used in this Canadian test was placed on the ground and centrally detonated. It is now realized that the temperature (and therefore the conductivity) everywhere inside the hemispherical shock wave (especially on the surface of the ground) was not sufficiently high to produce a closed (expanding) volume of high conductivity fluid. This would not be the case for a nuclear explosion where the temperatures everywhere, inside even a surface explosion, are very much higher. The nuclear explosion and Banshee situation, are shown in Figure 8. There may be, of course, very weak fields associated with the hemispherical ground burst of high explosives (see Figure 9) which were not detected. The energy stored inductively for an air burst is,

$$\frac{H_o^2}{8\pi} \text{ x Volume of Hemisphere at time t,}$$

whereas for a ground burst the volume is not that of the hemisphere but of a very much smaller shell at the shock front whose thickness at time t is of the order of the distance the current can diffuse into the conducting fluid in time t, assuming initially it was all on the surface (transient skin analysis).

4.2 Definitive conclusions cannot be made, of course, on the basis of only one experiment.

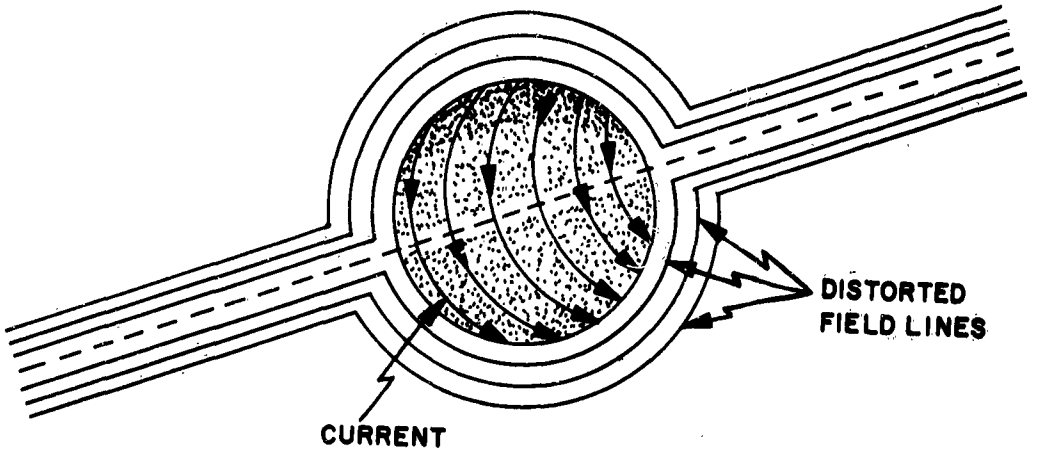


Figure 8. Air Burst Cross Sectional View

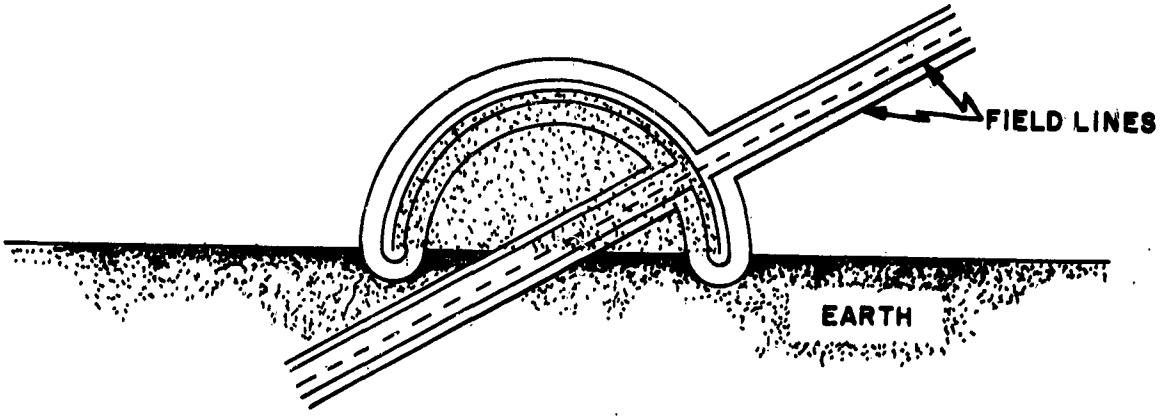


Figure 9. Ground Burst Cross Sectional View

APPENDIX 1

It is desired to establish a known magnetic field within the shield of the Stoddart Loop Antenna for purposes of system calibration.

The inductance of the loop antenna can be expressed as:

$$L = \frac{\phi}{I} \times 10^{-4} \quad (1)$$

$$\phi = BA \quad (2)$$

$$L = 10^{-4} \frac{BA}{I} \quad (3)$$

so:

$$I = 10^{-4} \frac{BA}{L} \quad (4)$$

where: L = Inductance in Henries

I = Current in amperes

B = Flux density in Gauss

A = Area in meters^2

From Terman, Radio Engineers Handbook, p52, McGraw-Hill, New York, 1943, inductance L, of a circular ring of tubular cross-section can be calculated as follows:

$$L = 0.01595D \left(2.303 \operatorname{Log}_{10} \frac{8D}{d_2} - 2\right)$$

where: L = Inductance in microhenries

D = Diameter of circular ring in inches (30 in.)

d_2 = Outer diameter of tube in inches (1 in.)

therefore:

$$L = 1.665 \times 10^{-6}$$

Substituting this value of L in the loop inductance equation (4) gives:

$$I = \frac{BA}{1.666} \times 10^{2} \qquad (5)$$

In a radiation field the relationship between the electric field ϵ and the magnetic field B is given by:

$$\epsilon \text{ (Volts/Meter)} = B\text{(Gauss)} \times 3 \times 10^{-4} \qquad (6)$$

Substituting the relationship of equation (6) into equation (5) gives:

$$I = \frac{\epsilon A}{4.998} \times 10^{-2}$$

when:

$$A = 0.456 \text{ M}^2$$

$$\epsilon = \text{Volts/Meter}$$

then:

$$I = 0.912 \times 10^{-3} \epsilon \qquad (7)$$