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PRELIMINARY

ASTIA Document No. AD- APRIL 1962

FINAL TECHNICAL REPORT

ON

RADIOMETRIC SIGNATURES OF BATTLEFIELD TARGETS

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GPL DIVISION
GENERAL PRECISION, INC.
63 Bedford Road
Pleasantville, New York

Contract No. DA-30-069-ORD-3507

BALLISTIC RESEARCH LABORATORY

ABERDEEN PROVING GROUND

ABERDEEN, MARYLAND

PRELIMINARY

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NOTICES

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GPL SECURITY NO. P-0429-AL

RADIOMETRIC SIGNATURES OF BATTLEFIELD TARGETS

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GPL DIVISION

GENERAL PRECISION, INC.

63 BEDFORD ROAD

PLEASANTVILLE, NEW YORK

GPL FINAL ENGINEERING REPORT

ON FIELD TEST PROGRAM

APRIL 1962

CONTRACT DA-30-069-ORD-3507

BALLISTIC RESEARCH LABORATORY

ABERDEEN PROVING GROUND

ABERDEEN, MARYLAND

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FOREWORD

This report was prepared by GPL Division - General Precision, Inc., Pleasantville, New York on Army Contract No. DA-30-069-ORD-3507, Radiometric Signatures of Battlefield Targets. The work was administered under the direction of Ballistic Research Laboratory, Aberdeen Proving Ground. Mr. Victor Richard administered the project for the laboratory.

The field program began on January 3, 1962 and was concluded March 23, 1962. Thomas W. Odell was the project engineer and Seaman M. Seelig was the assignment engineer for GPL.

The cooperation of the Ballistic Research Laboratory is gratefully acknowledged. GPL is especially grateful for the invaluable assistance of Dr. Alfred A. Hodge of BRL in the conduct of the field program.

This report concludes the work on Contract No. DA-30-069-ORD-3507.

This report is classified Confidential because of the measurements of apparent temperatures and apparent temperature differentials of battlefield targets listed throughout. Also, any discussions, conclusions or recommendations concerning these temperatures are similarly classified.

ABSTRACT

This report comprises the results of a field study on the microwave radiometric temperature differentials between typical battlefield targets and their backgrounds under various climatic and terrain conditions.

The targets viewed include personnel, tanks, trucks, jeeps and napalm fires. Data was obtained during night and day conditions as well as during fog, rain and snow. Also, target signatures were taken when the tank was obscured by smoke, camouflage and vegetation. To simulate observations of a missile borne guidance seeker, tank targets were viewed with the radiometer at elevation angles approaching 45°.

This report includes the test data, a discussion of results, conclusions and recommendations for further research and development.

TABLE OF CONTENTS

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF ILLUSTRATIONS

LIST OF TABLES

1. INTRODUCTION

This is the final report covering the accomplishments and results of the signature study program conducted under Contract No. DA-30-069-ORD-3507. The program involved field measurement at the Spesutie Island facility of the Ballistic Research Laboratory, Aberdeen, Maryland and utilized a GPL owned radiometric instrument as the basic measuring device. Field measurements commenced on January 3, 1962 and were concluded on March 23, 1962.

The test program was directed toward determination of radiometric temperature differentials between typical battlefield targets and their backgrounds under various climatic and terrain conditions. The resultant data is intended for Army use in evaluating feasibility and desirable characteristics of future passive detection and guidance systems.

Targets used during the test program included tanks, trucks, jeeps and personnel. Data was obtained during night and day conditions as well as during rain, fog and snow. Also included are tank signature data when camouflaged and when obscured by smoke, fire and vegetation. To simulate observations of a missile borne guidance seeker, a cherry-picker vehicle was used to elevate the radiometric instrument to heights up to fifty feet above terrain.

The contract was executed by the GPL Division, General Precision, Inc. under the direction and cognizance of the Ballistic Research Laboratory, Aberdeen Proving Ground, Maryland. The personnel involved in the test program are shown in Figure 1-1 [Left to right: A.G. Kelly (BRL), D. Stevens (GPL), D.L. Barnhouse (U.S. Army), Dr. A.A. Hodge (BRL), S.M. Seelig (GPL)].

This report includes a description of the field program, a discussion of the results, conclusions and recommendations. Also included are appendices containing the test data, a discussion of the theory of microwave radiometry, derivations of the antenna temperature and range equations and a bibliography of reports applicable to this program.

2. FIELD PROGRAM

On January 3, 1962 the field test portion of the radiometer signature study was initiated at the Aberdeen Proving Grounds. For the initial measurements the radiometer and associated test equipment were placed in a portable instrument trailer. (See Figure 2-1 and 2-2). The receiver and dish were secured to a mount steerable in both azimuth and elevation. On the same mount, adjacent to the dish was placed a telescopic sight. Collimation between the dish and the sight was accomplished by placing a 35 GCS signal generator 25 yards from the dish, pointing the dish for maximum signal and offsetting the sight cross hairs the proper distance from the signal generator. Additional procedures included measurement and marking off of the test range, set-up and calibration of thermocouples on the tank, and familiarization with measurement techniques on the light meter, psychrometer, and thermocouple potentiometer.

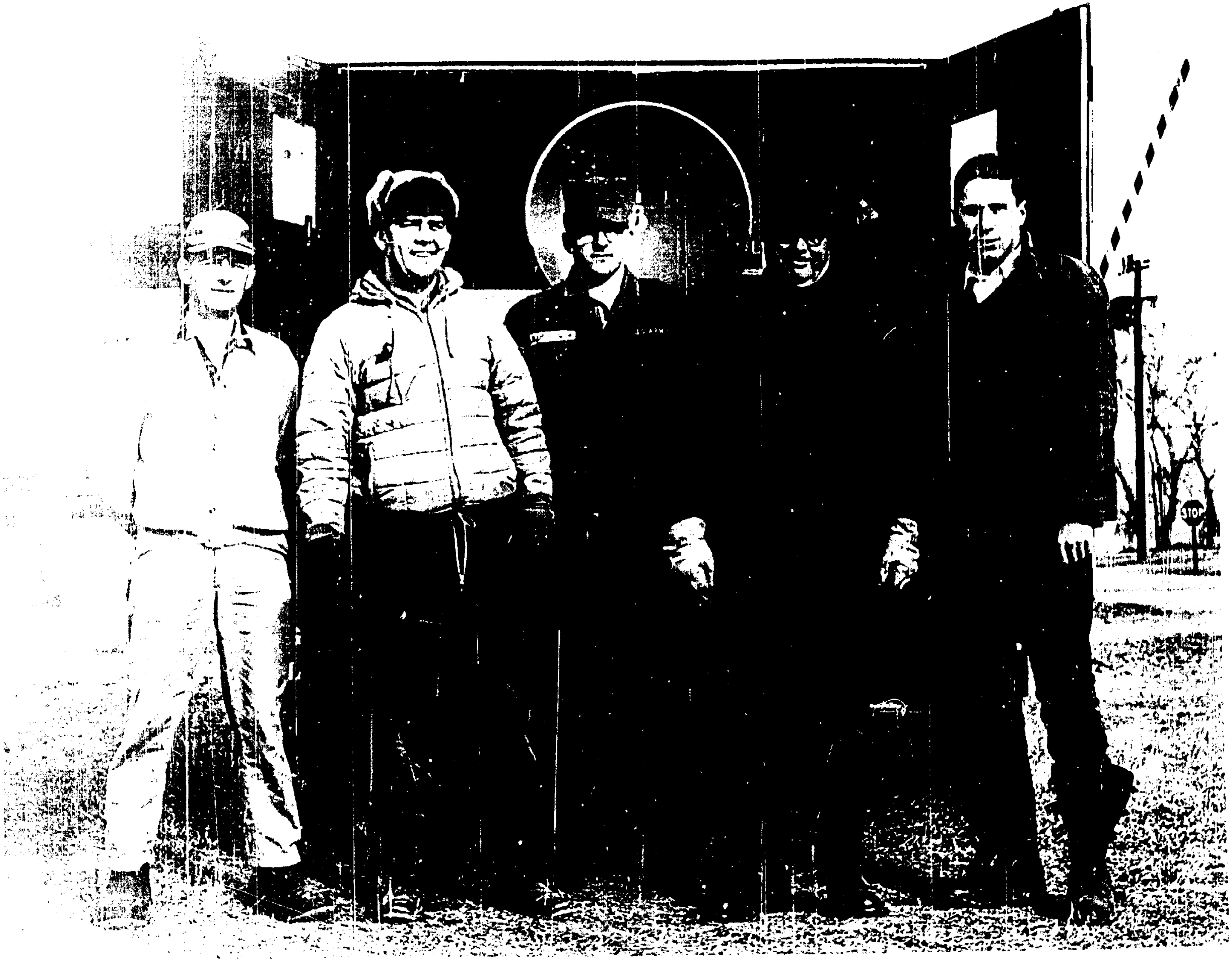


FIGURE 1-1. RADIOMETER FIELD TEAM

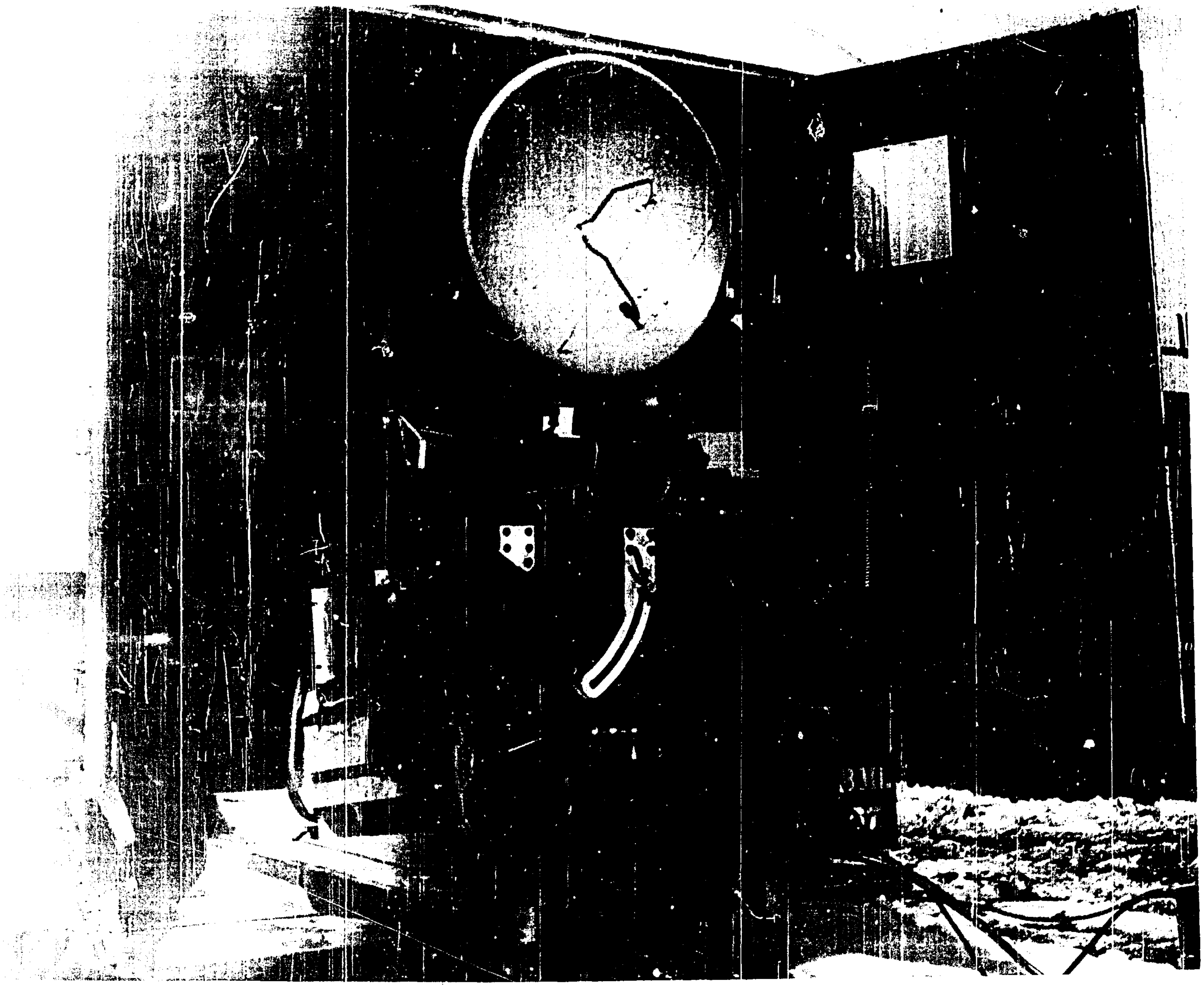


FIGURE 2-1. RADIOMETER RECEIVER IN TRAILER

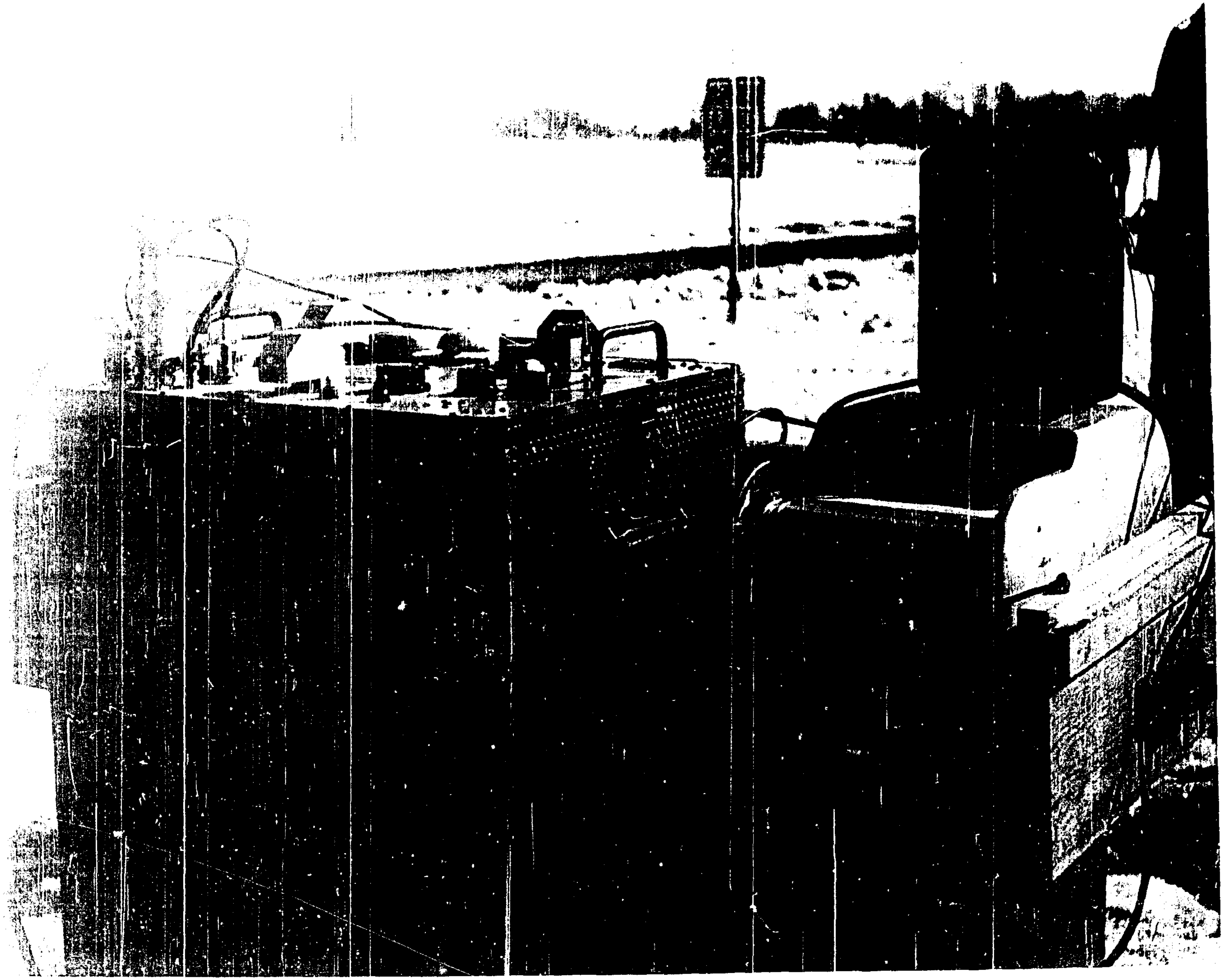


FIGURE 2-2. RADIOMETER CONTROL AND OUTPUT EQUIPMENT OUTSIDE FOR DEMONSTRATION

The swivel mount containing the radiometer was placed on tracks enabling the entire unit to be moved outside the trailer. This allowed the radiometer to be pointed at the sky for calibration purposes. A sky angle of about 32.5° (angle above the horizon) was chosen and the elevation of the dish moved to this angle for each calibration run.

The equipment trailer was heated and controlled with a thermostat so as to keep the equipment at a constant temperature and free from dampness during overnight and weekend storage.

Throughout the entire field program certain additional measurements were taken in order to specify carefully the environmental conditions under which the apparent temperatures were taken. As explained in Appendix "A" these conditions play an important part in determining the apparent temperature of a target. The following readings were taken in conjunction with the measured temperatures:

1. reflected light from target
2. incident and reflected light on radiometer dish
3. degree of cloud cover and type of weather
4. time of day
5. temperature and relative humidity
6. thermometric temperature of tank target
7. radiometric temperature of two reference surfaces of aluminum and microwave absorbing material

2.1 Characteristics of Radiometer

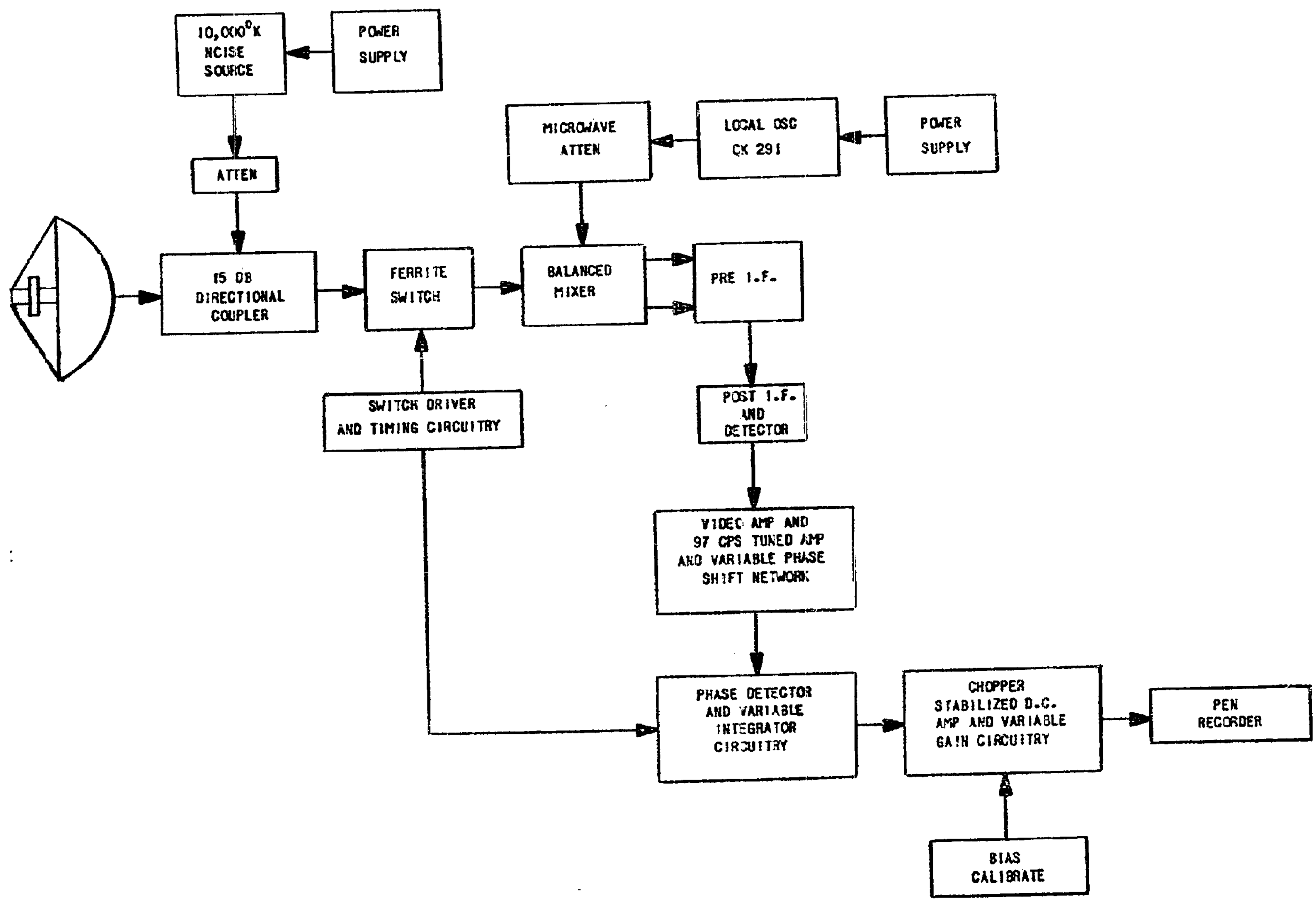
2.1.1 Physical Characteristics

The radiometric package, excluding separate power units and a control box, comprises an antenna-receiver which is mounted on a scanning head. The antenna consists of a parabolic reflector two feet in diameter with a feed system to provide broad bandwidth and low sidelobe levels. The receiver is a superheterodyne configuration with connections for use with separate power units. The separate power units are used to permit remote mounting of the radiometer up to a maximum of 100 feet from the antenna.

2.1.2 Electrical Characteristics

2.1.2.1 Receiver Operation

The radiometer functional diagram is shown in Figure 2-3. The unit is basically a microwave superheterodyne receiver (.86 cm) with special signal processing circuitry. The noise signal received by the antenna is mixed in a balanced mixer with the output of a Ka band klystron oscillator to produce a 30 MC I.F. signal. Alternately, at a 97 cps rate, the mixer input port is connected to a fixed reference source. The resultant I.F. signal is amplified and the 97 cps envelope is detected.



RADIOMETER BLOCK DIAGRAM
FIGURE 2-3

Phase detection and integration are then performed. After further D.C. amplification, the resultant signal passes on to the alarm and memory circuits. The output of the radiometer drives a D.C. pen recorder. Provisions are made for both absolute and relative calibration.

2.1.2.2 Equipment Description

The radiometer used in the Field Test Program had the following parameters:

TABLE 2-1

Item	Characteristic
Operating Frequency	8.6 m.m. region
Receiver Type	Superheterodyne
Polarization	Vertical
Noise Figure (double channel)	9.4 db
I.F. Center Frequency	30 m.c.
I-F Bandwidth	15 m.c.
Antenna	Parabolic dish - 2 ft. in diameter
Azimuth Scan Rate	0 - 18°/sec
Field of View	30° azimuth, 90° elevation
Spatial Resolution	1.1° (3 db points)
Receiver Temperature Resolution	2.47°K τ = .05 sec. 0.554°K τ = 1 sec. 0.247°K τ = 5 sec.
Output Data Form	D-C Voltage (0 - 6 v) Z - out = 600 Ω
Readout	Pen Recorder and D.C. Meter
Input Power	115 v, 60 cps, 345 v.a.
Dynamic Range	500°K

2.2 Personnel Measurements

Initial measurements indicated that the amount of metal on a target is the decisive factor in its apparent temperature. Hence, a soldier in full battle dress, including field pack, rifle, and helmet was used as the personnel target (See Figure 2-4). The range for all personnel measurements was 50 yards from the radiometer. Eight runs were taken: 1 each of the three basic positions - front, side and prone, both day and night; and front and prone in the daytime during rain (See Figure 2-5, 2-6).

NOTE: Explanation of Taped Data

The measured temperature differential between a target and the background appears as a D.C. voltage at the output of the system. The larger the temperature difference the larger the voltage. If the voltage is positive the target is "hotter" than the background, if negative it is "colder". To obtain the differential in degrees Kelvin, the measured

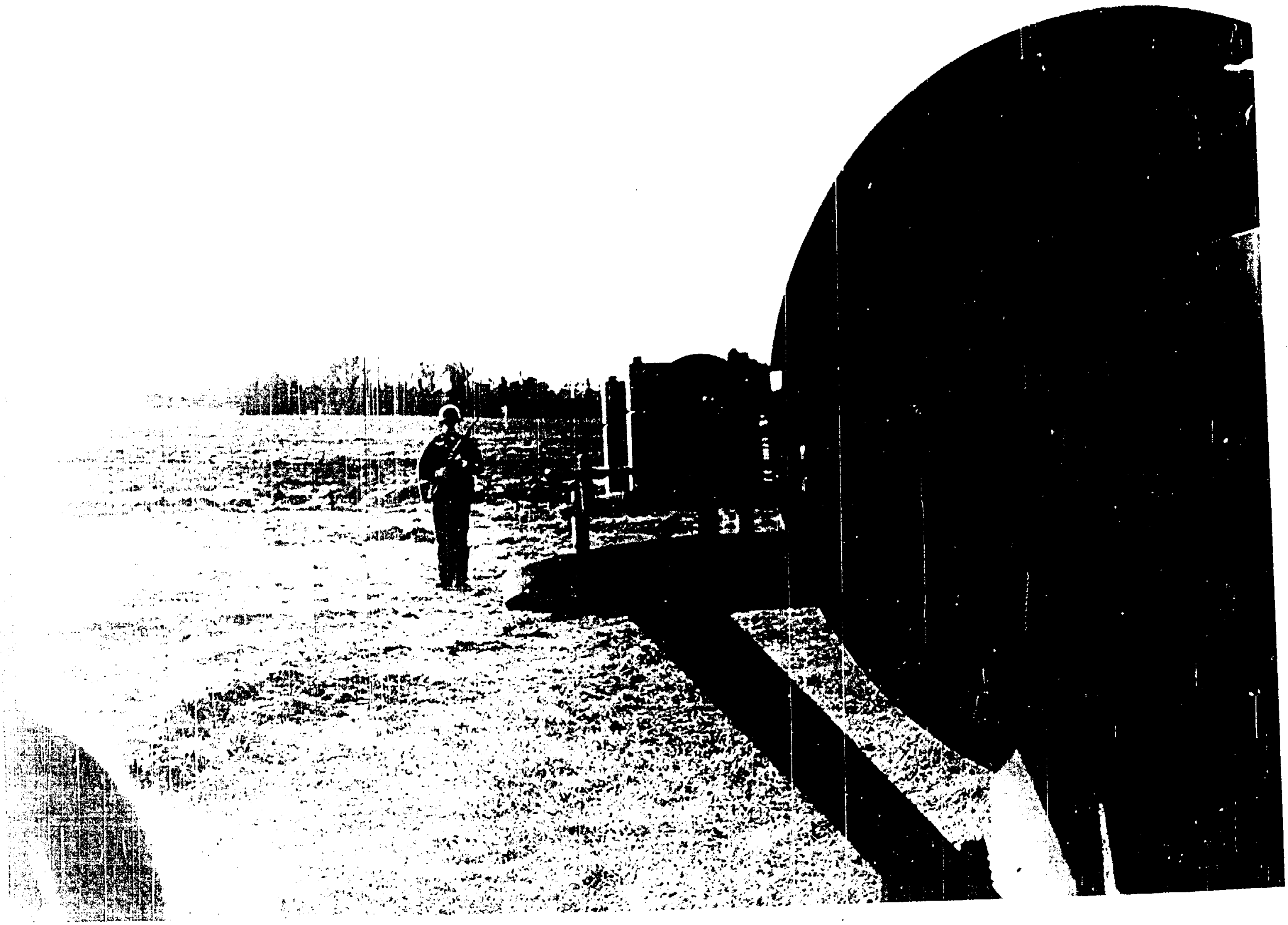


FIGURE 2-4. PERSONNEL TARGET - FRONT VIEW, R=25 YDS.

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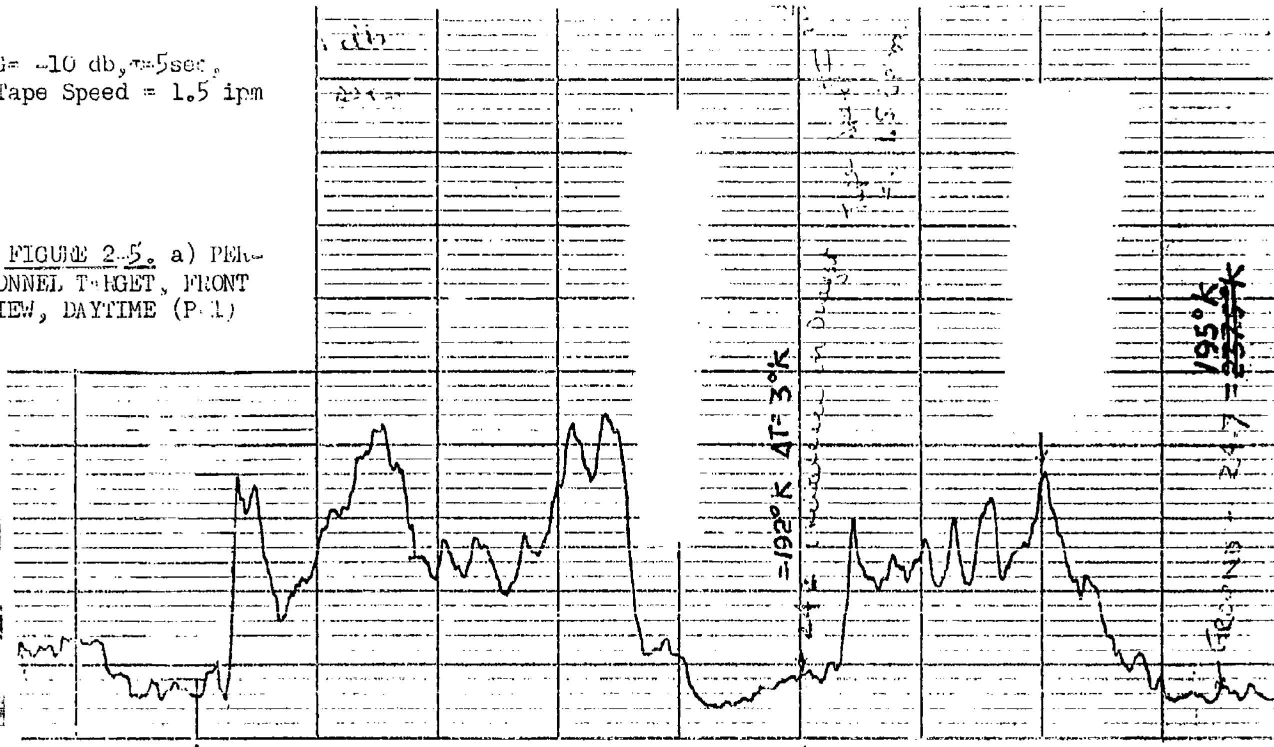
G= -10 db, τ=5sec,
Tape Speed = 1.5 ipm

FIGURE 2-5. a) PERSONNEL TARGET, FRONT VIEW, DAYTIME (P-1)



[illegible] 10 db, τ=5sec,
Tape Speed = 1.5 ipm

FIGURE 2-5. b) PERSONNEL TARGET, FRONT VIEW, NIGHTTIME (P-2)

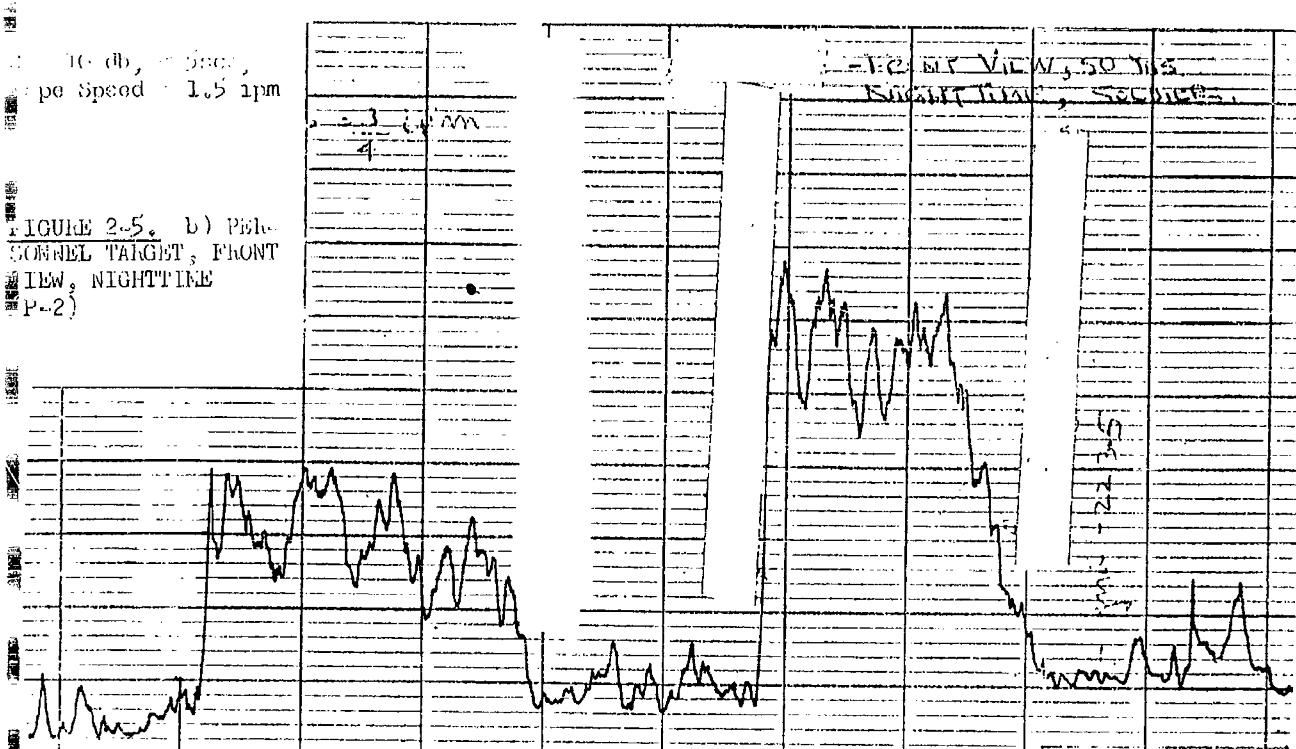


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FIG 2.5
P-1, P-2

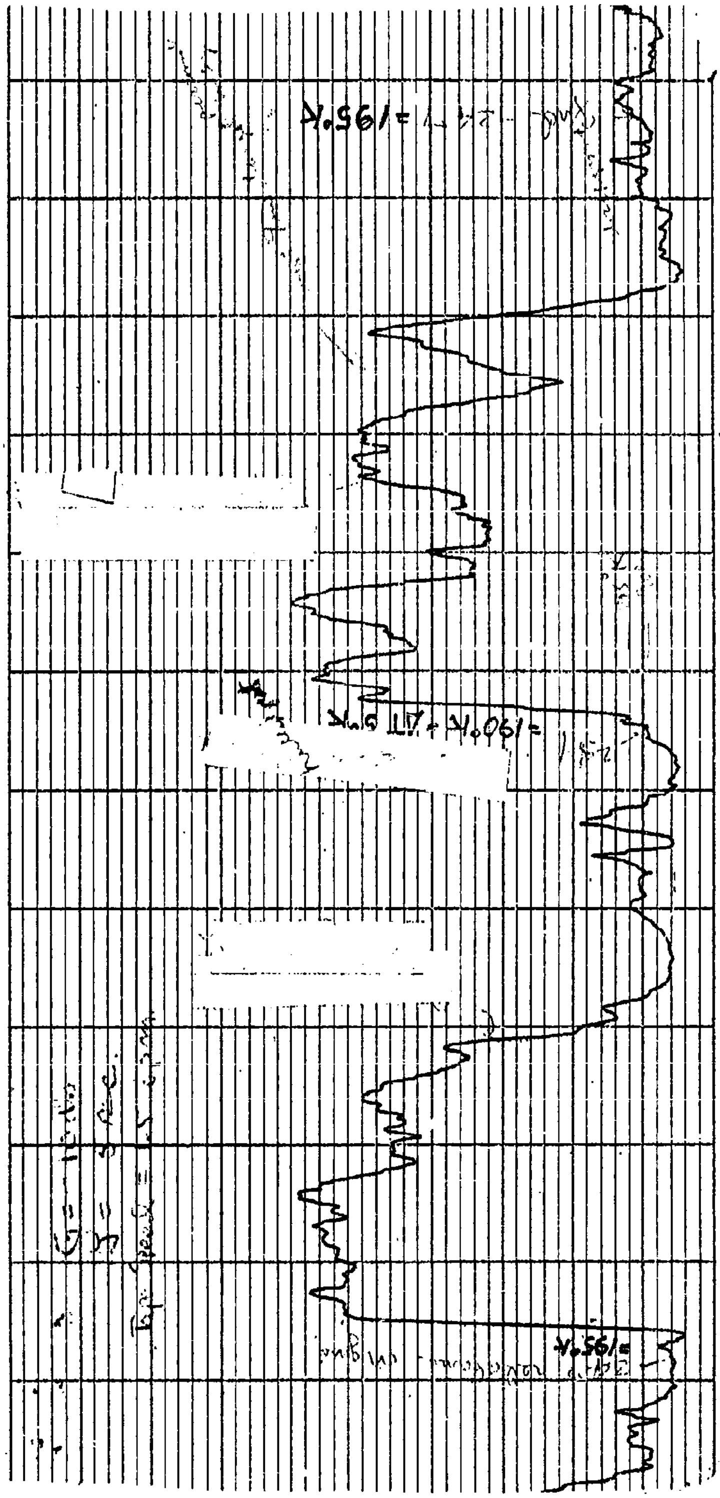


FIGURE 2-6. PERSONNEL TARGET, SIDE VIEW, DAYTIME (P-3)

G= - 10 DB, τ = 5 SEC, TAPE SPEED = 1.5 IPM voltage is nulled out with a reference battery voltage calibrated in degrees.

The target was first sighted through the scope, and then the mount containing both dish and scope, was adjusted for the proper elevation. The mount was then moved in azimuth off to the side of the target and the voltage representing the temperature of the background at this elevation was nulled out using the calibrated dial. The mount was then swept through the target in azimuth from one side to the other to obtain its profile and its point of maximum signal. This sweep represents the first deflection on each tape (See Figure 2-6). The radiometer was then swept back on the target and left pointing at the position of maximum signal. This represents the second deflection on each tape. This signal was then nulled out using the calibrated dial. The difference between the new dial setting and the original one represented the difference between the target and background temperature (for the beam filled case).

2.3 Tank Measurements

Tank runs were performed for four basic views (front, back, side and 3/4 rear), three ranges (50, 300, and 500 yds), and with a number of different environmental conditions. The target tank used was an M-48A2 full tracked combat tank (See Figure 2-7).

At 50 yds from the radiometer its beam is 2 1/2 feet in diameter. Hence at this range a thermal profile of the tank was "painted" by taking azimuth runs across it at three different values of elevation angle (See Figure 2-9). The apparent temperature of significant features was measured and recorded (See Figures 2-8 through 2-13). At the 300 and 500 yd ranges the beam diameter is greater than the height of the tank and with the horizontal cross-hair centered on the base of the turret, only one azimuth sweep was necessary (See Figures 2-14, 2-15). Measurements were taken at all positions and ranges mentioned above with the tank engine on and off. In addition to the runs mentioned, measurements were taken of a camouflaged tank,* Figures 2-16 through 2-19, a tank against a sky background, Figures 2-20, 2-21, a tank in shade and behind trees, Figures 2-22, 2-23, and a tank at night, Figure 2-24.

During the shade runs the tank was hidden by shrubbery directly between it and the radiometer as seen in Figure 2-22. For the night runs the tank was illuminated with searchlights so that the horizontal cross-hairs could be accurately placed in elevation at the base of the turret. Then the sweep procedure previously described was performed.

2.4 Supplementary Measurements

The contractual requirements of the field program were completed sufficiently ahead of schedule to allow a large number of supplementary runs. These runs in part served to resolve questions raised during the first part of the program, such as tank warm-up temperatures and the effects of mud, rain, snow and fog on apparent temperature measurements. They also allowed

* See Addendum, page 115

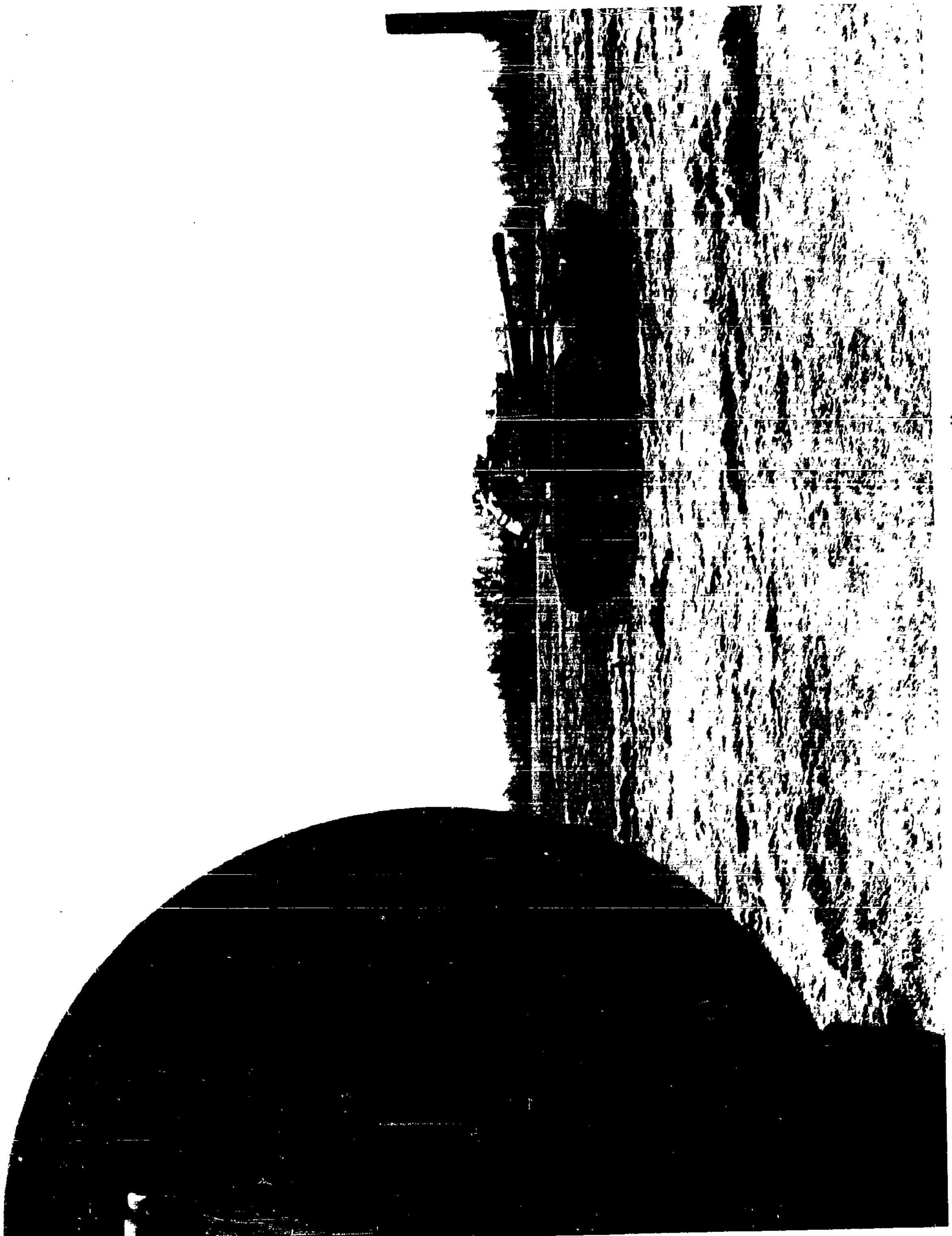


FIGURE 2-7. TANK TARGET - 3/4 REAR VIEW - R = 50 YARDS (T-15)

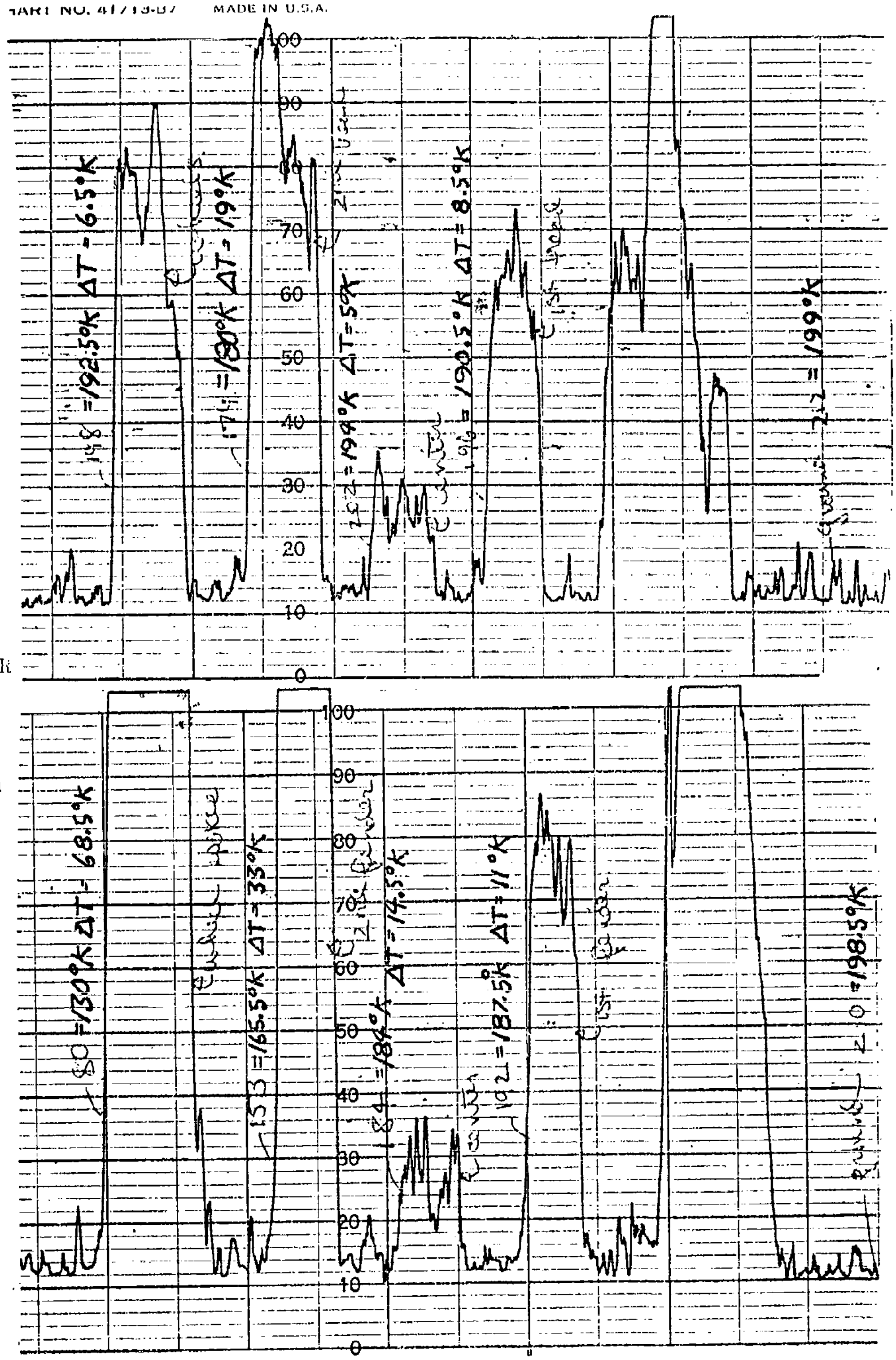


FIGURE 2-8

[illegible] TARGET, 3/4 REAR [illegible], R=50 YDS, [illegible] A, B (T-15)

G= -20 db, τ=1 sec, Tape Speed = 3/4 ipm

FIG 2-8
T-159,b

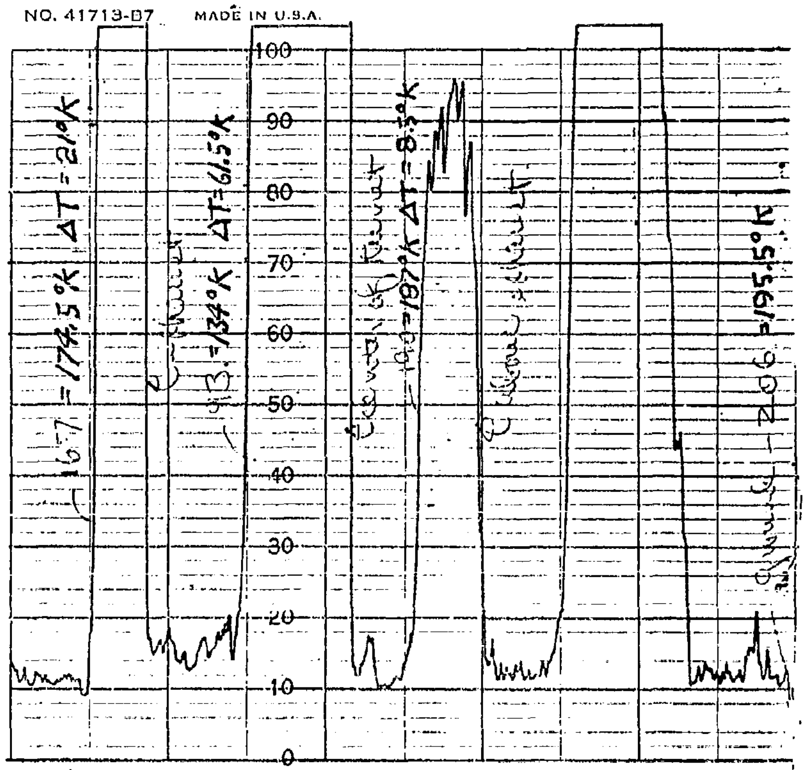


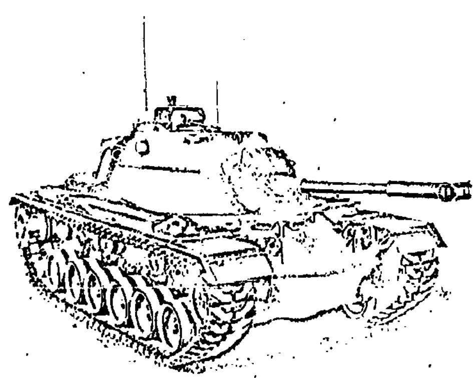
FIGURE 2-9. TANK TARGET, 3/4 REAR VIEW, R=50 YARDS SWEEP C (T-15)

G = - 20 db, τ=5 sec
Tape Speed = 1.5 ipm

CHARACTERISTIC DATA — **ORDNANCE TANK-AUTOMOTIVE COMMAND**

VEHICLE: TANK, COMBAT, FULL TRACKED, 90MM GUN, M48A2
TYPE

SECTION: STV-1
CODE: STV-8
STATUS: STANDARD
DATE: 22 DECEMBER 1958



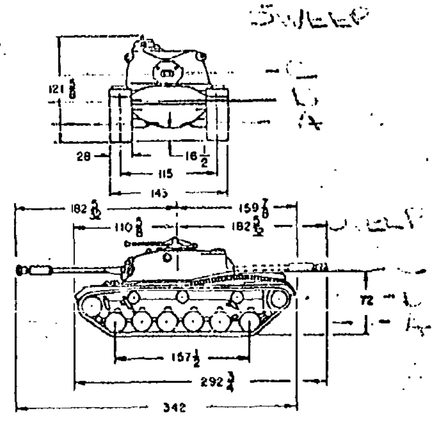
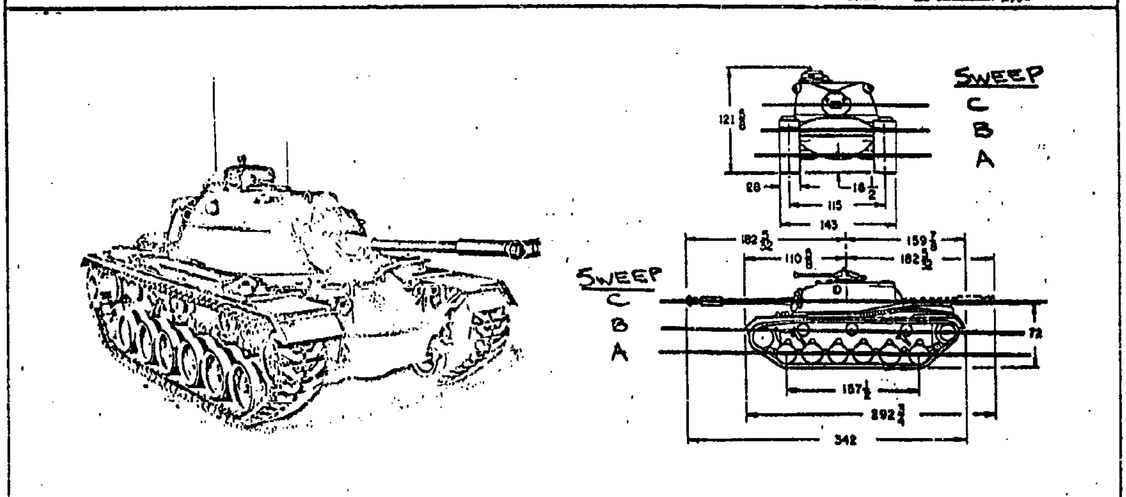


Fig 2-9
T-15 C

FIGURE 2-10. TANK TARGET - FRONT VIEW, R = 50 YARDS (T-1)

CHARACTERISTIC DATA	ORDNANCE TANK-AUTOMOTIVE COMMAND
VEHICLE: TANK, COMBAT, FULL TRACKED, 90MM GUN, M48A2 TYPE	SECTION: STV-1 CODE: STV-6 STATUS: STANDARD DATE 22 DECEMBER 1958



G= 20 db, τ=1 sec,
Tape Speed = 3/4 ipm

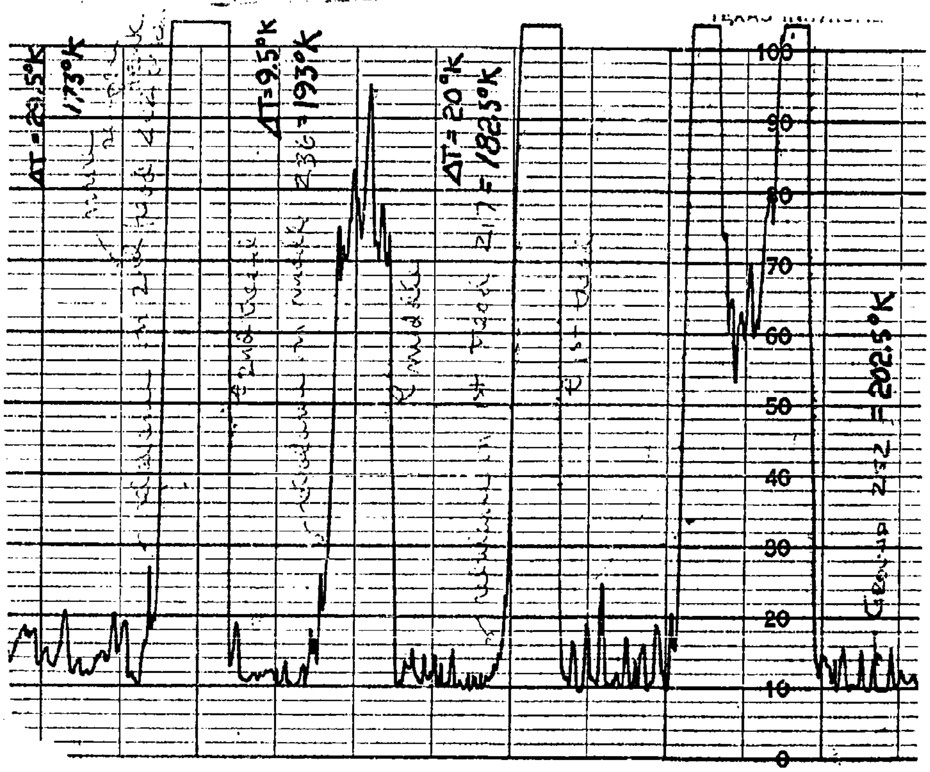


FIGURE 2.11. TANK TARGET, BACK VIEW, R=50 YARDS, SWEEP A (T-7)

Fig 2-11
T-7a

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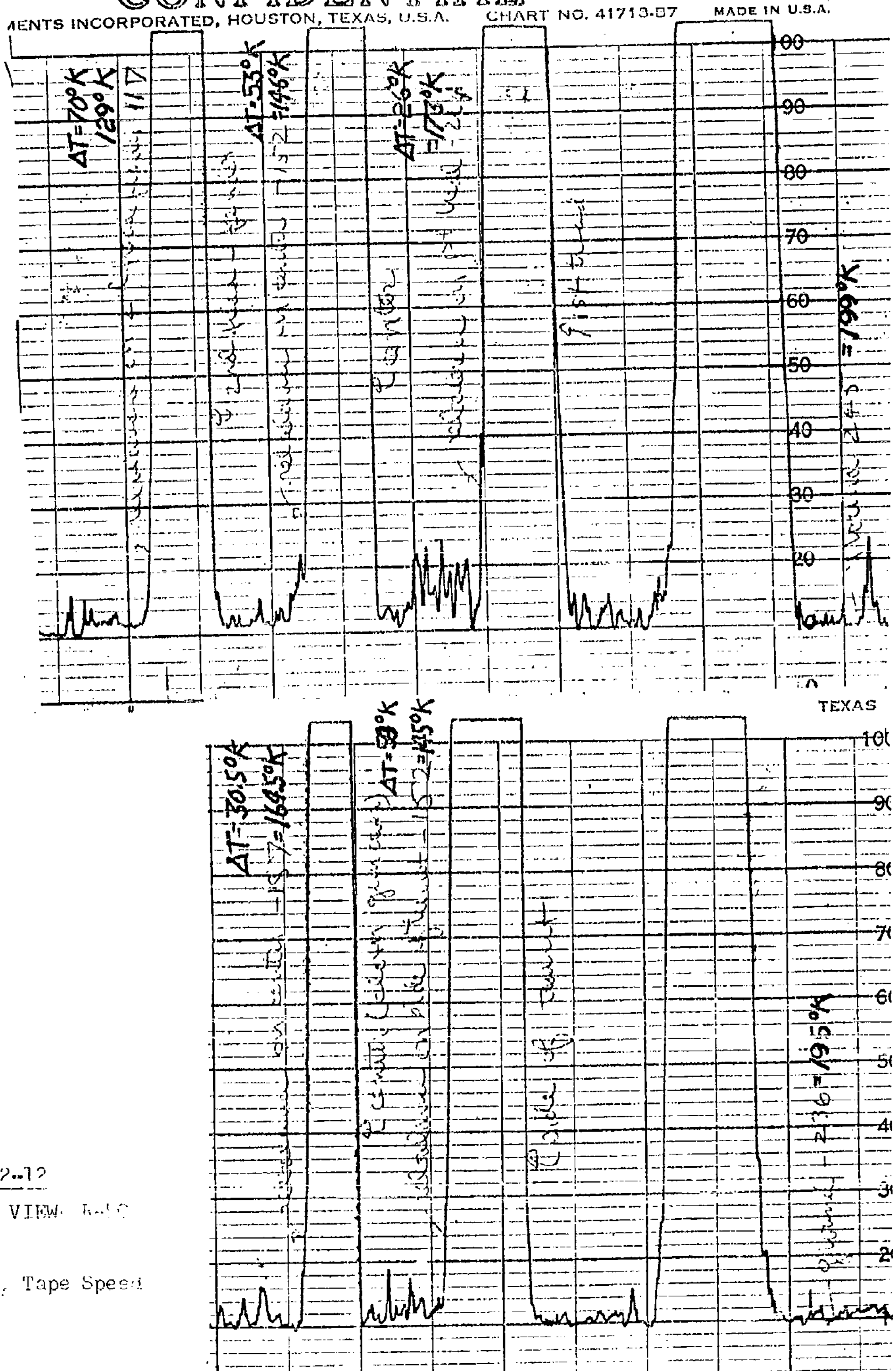

FIGURE 2-12

TANK TARGET, BACK VIEW, [illegible] YARDS, SWEEP B, C

G= 20 db, τ=1 sec, Tape Speed = 3/4 ipm

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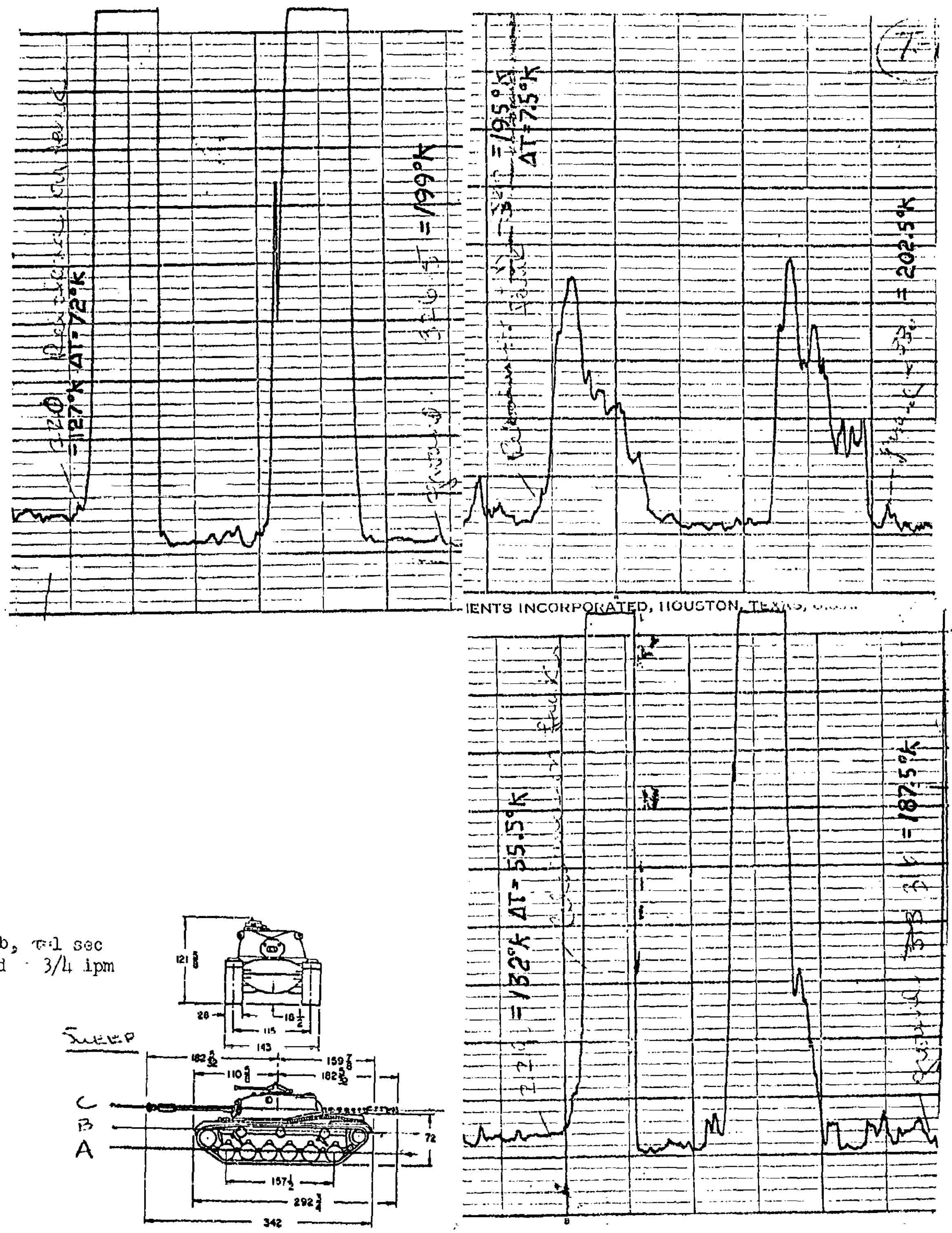
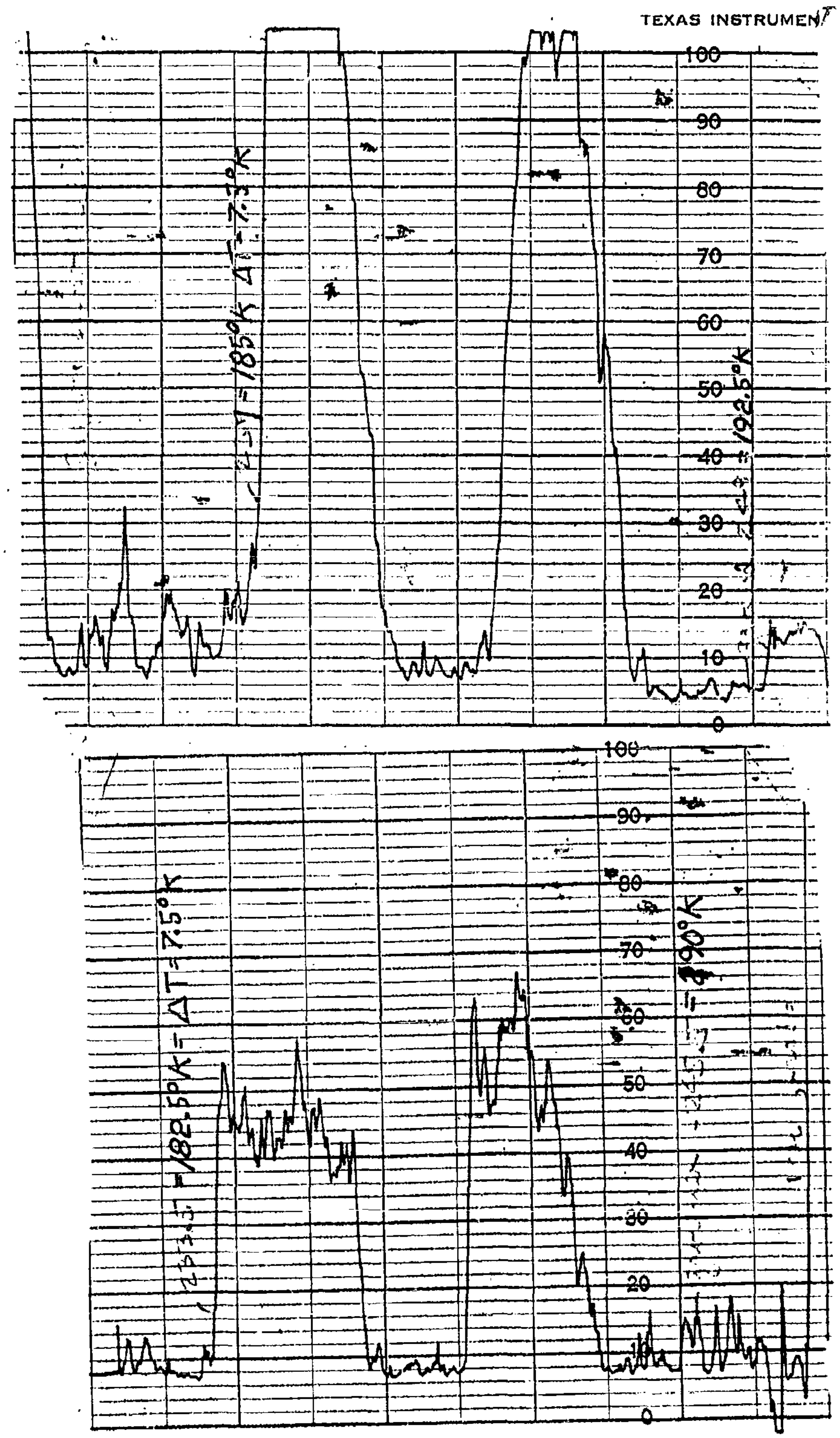
FIG 2-12
T-7 b, c



G = 20 db, τ=1 sec
Tape Speed = 3/4 ipm

FIGURE 2-13. TANK TARGET, SIDE VIEW
R=50 YDS, SWEEPS A,B,C. (T-13)

FIG 2-13
T-13

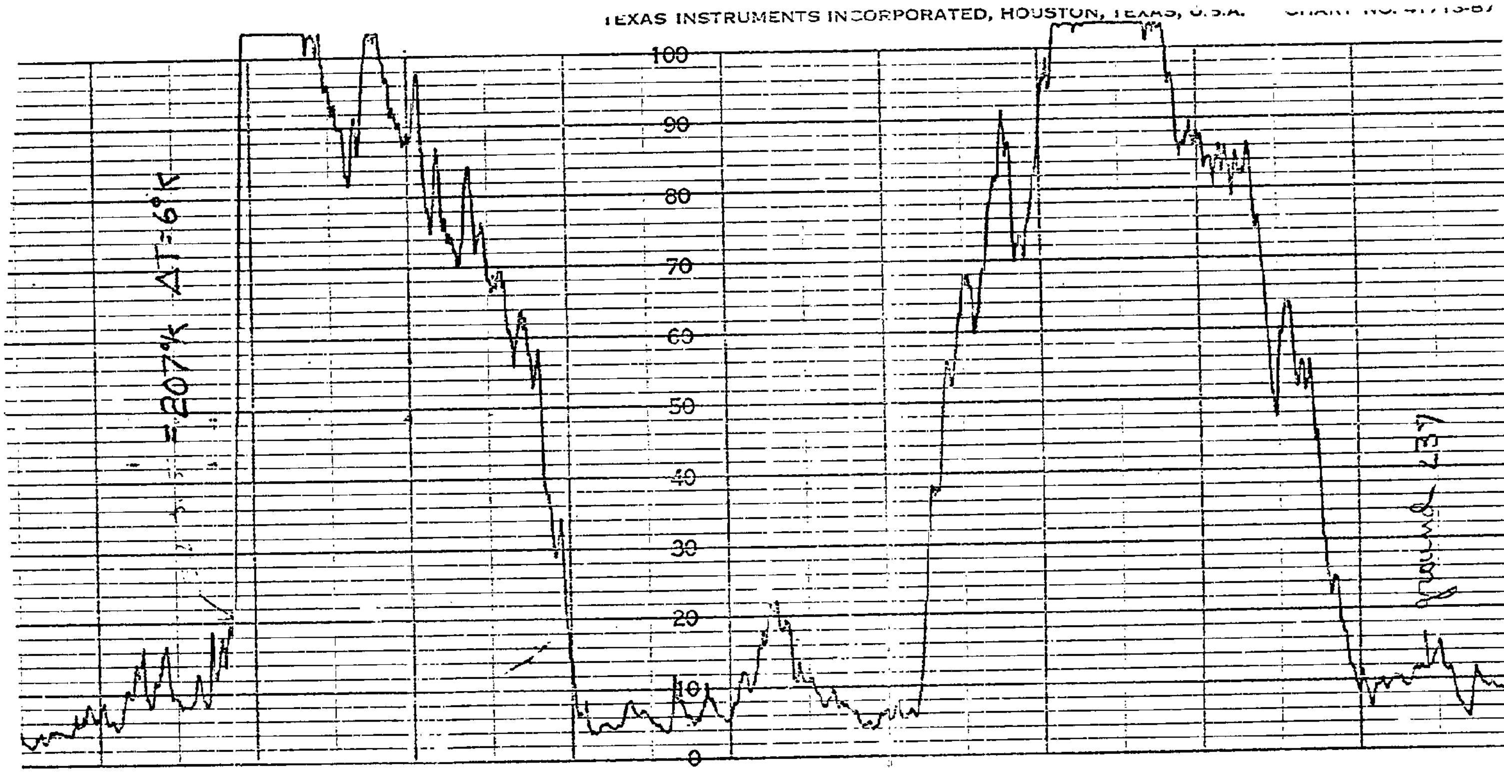


a) G=10 db, τ = 5 sec
Tape Speed 3/4 ipm

b) G=20 db, τ=1 sec,
Tape Speed = 3/4 ipm

FIGURE 2-14. TANK TARGET, FRONT VIEW, R=300 YDS. (T-3)

FIG. 14
T-3 1,2



G=10 DB, τ=5 SEC. TAPE SPEED = 3/4 IPM

FIGURE 2-15. TANK TARGET, BACK VIEW, R=500 YDS (T-12)

Fig 2-15 T-12

FIGURE 2-16. TANK TARGET, CAMOUFLAGED, BACK VIEW, R = 50 YARDS (T-22)

G= - 20 db
τ=1 sec, Tape
Speed = 3/4 ipm

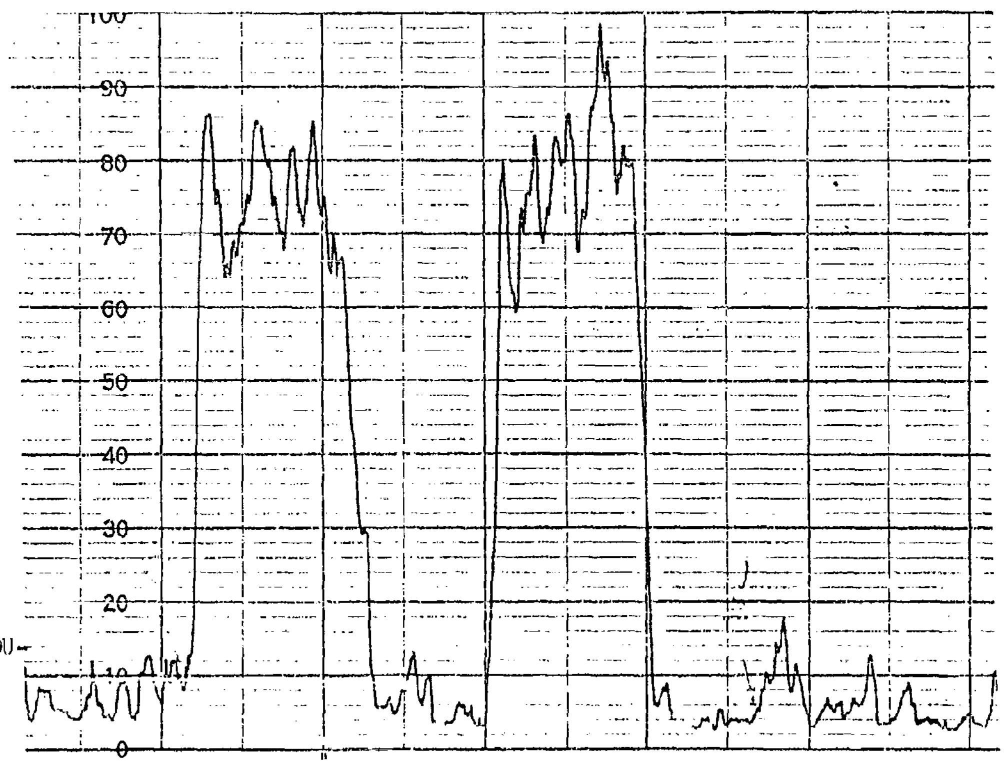


FIGURE 2-17
TANK TARGET, CAMOUFLAGE ON AND OFF, BACK VIEW R=50 YARDS, SWEEP A (T-22, T-23)

G= - 20 db,
τ= 1 sec,
Tape
Speed = 3/4
ipm

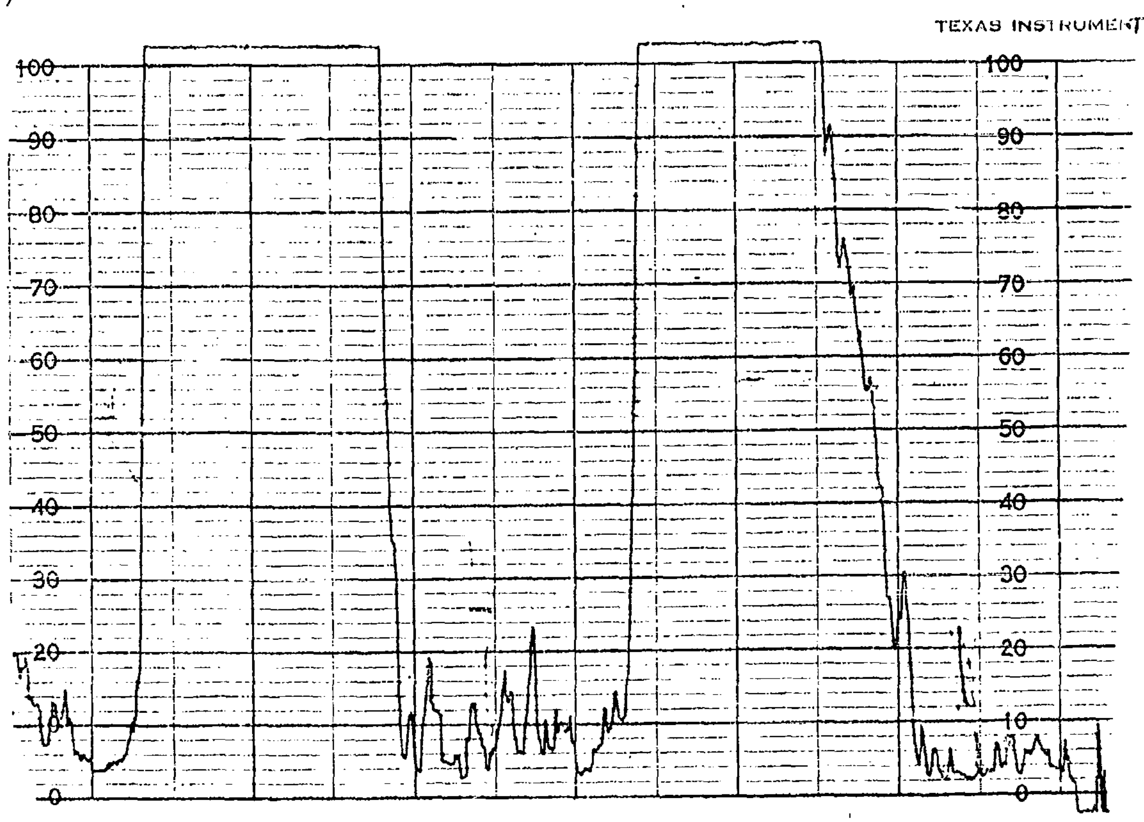
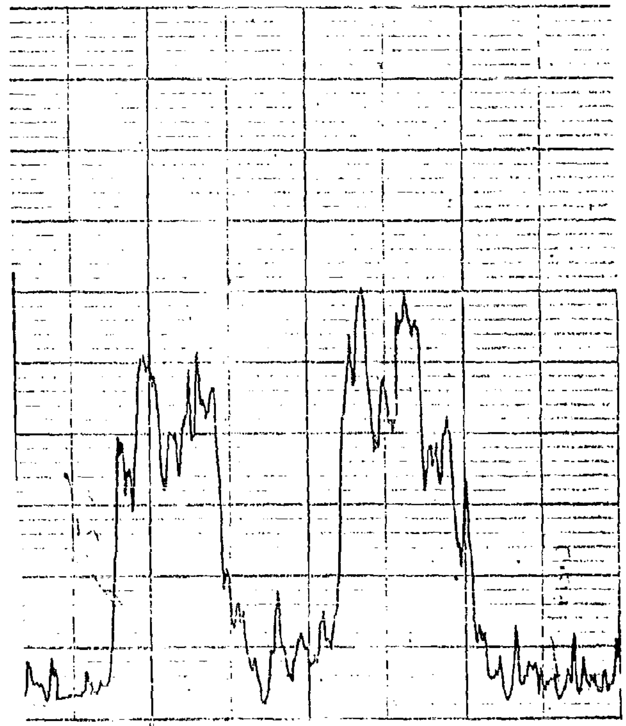


Fig 2-17
T-23, T-22 (A)

G= - 10 db, τ=5sec, Tape Speed = 3/4 ipm



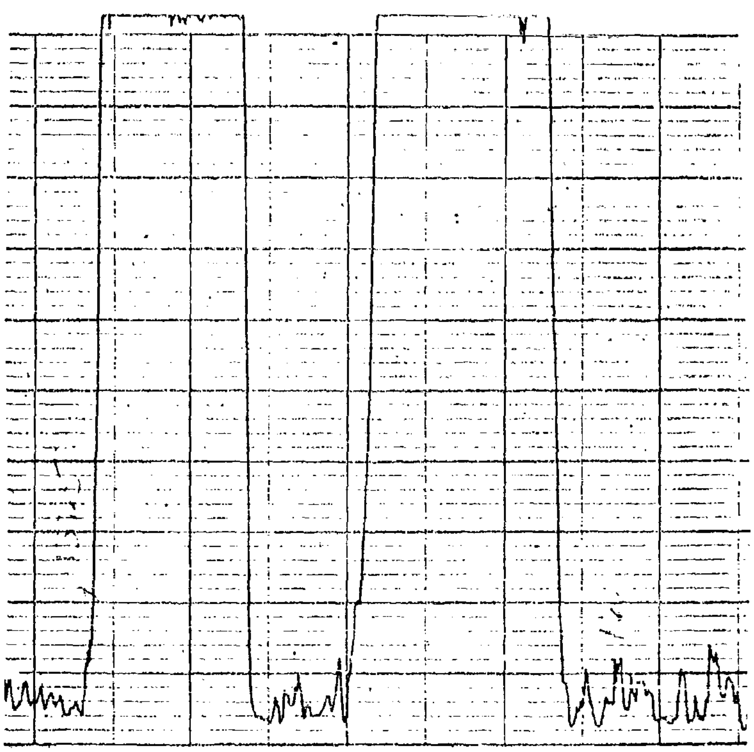
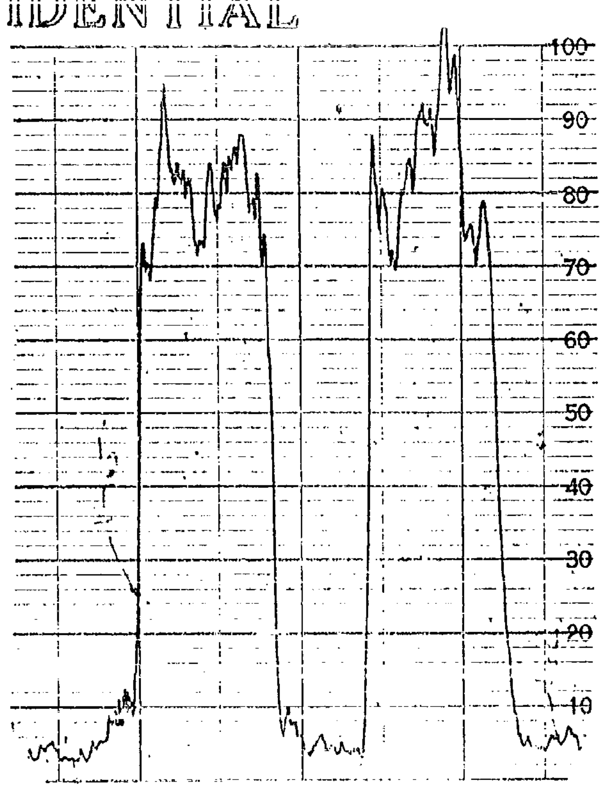


FIGURE 2-18

TANK TARGET, CAMOUFLAGE ON AND OFF, BACK VIEW, R=50 YARDS, SWEEP B (T-22,T-23)

FIG 2-18
T-23,22 B



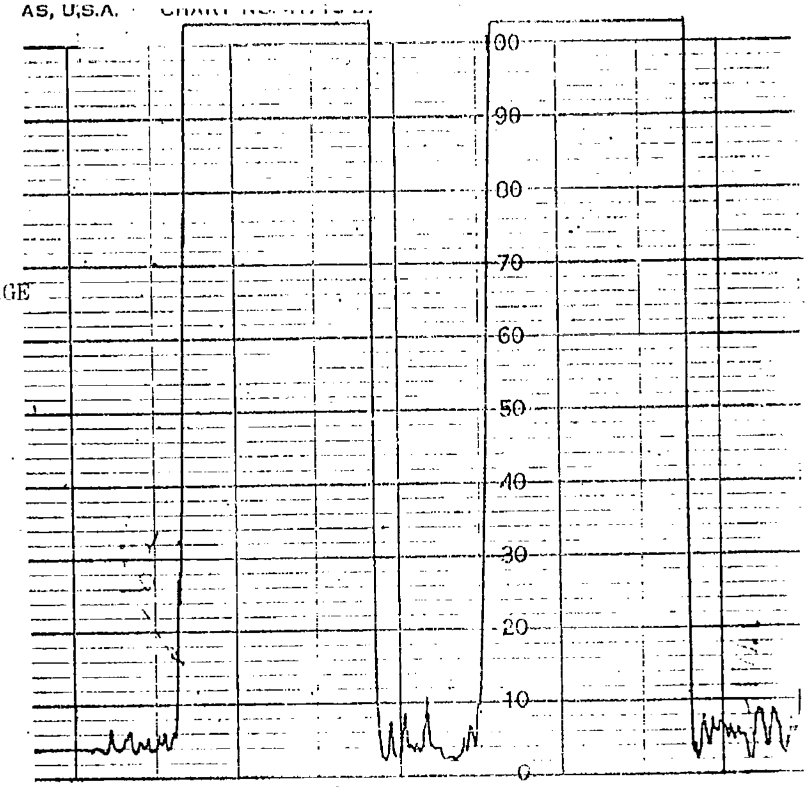


FIGURE 2-19. TANK TARGET, CAMOUFLAGE ON AND OFF, BACK VIEW, R=50 YDS, SWEEP C, (T-22, T-23)

G= - 20 db, τ=1 sec, Tape Speed = 3/4 ipm

FIG 2-19
T-23, 22 C

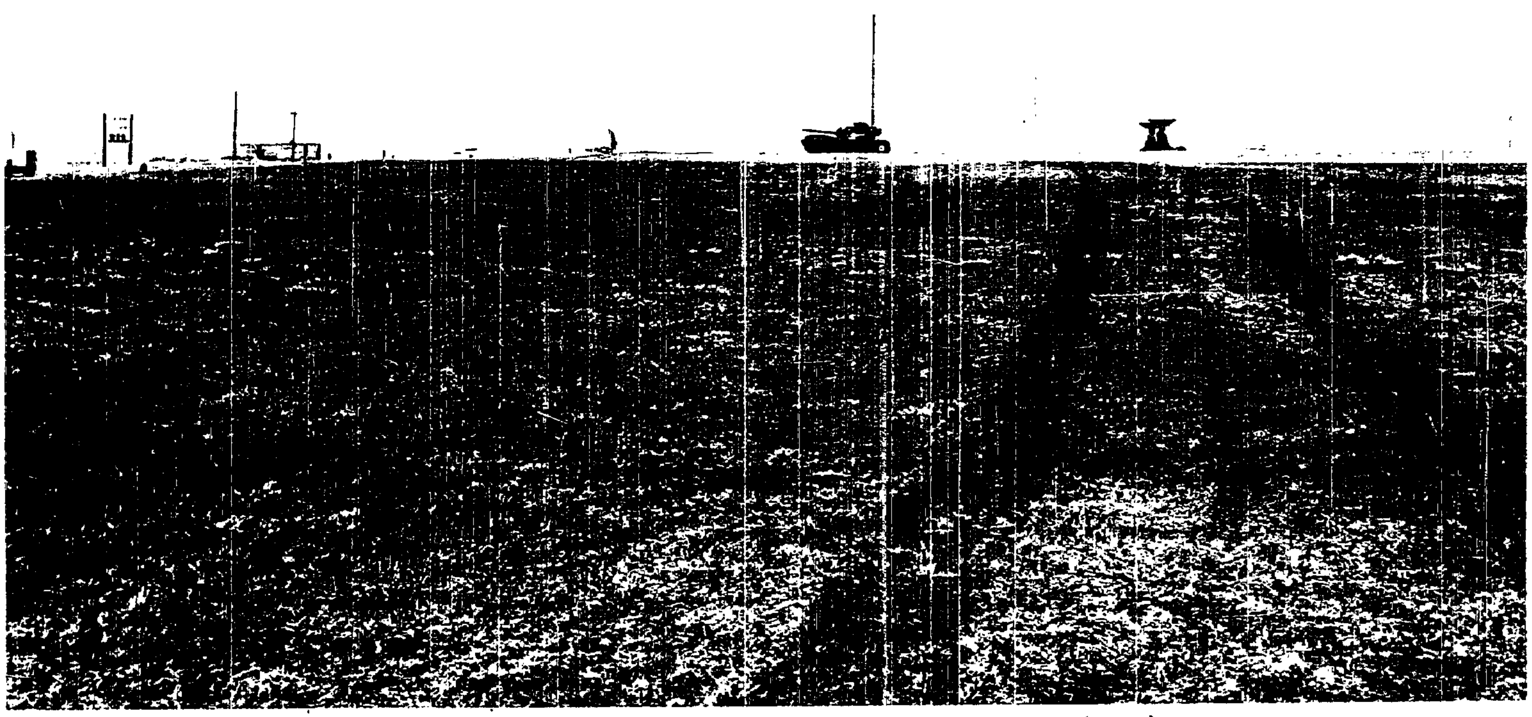
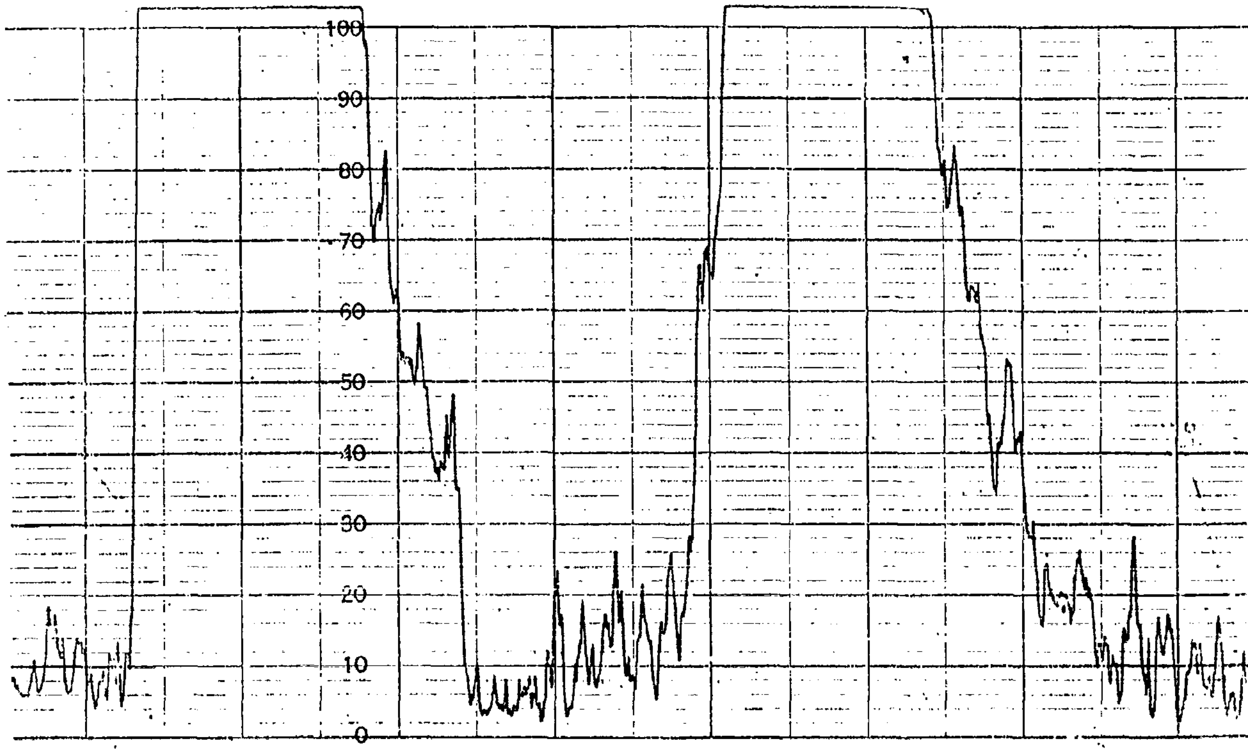


FIGURE 2-20. TANK TARGET, SKY BACKGROUND, SIDE VIEW, R = 200 YARDS, (T-31)



G= - 20 db, τ=1 sec,
Tape Speed =3/4 ipm

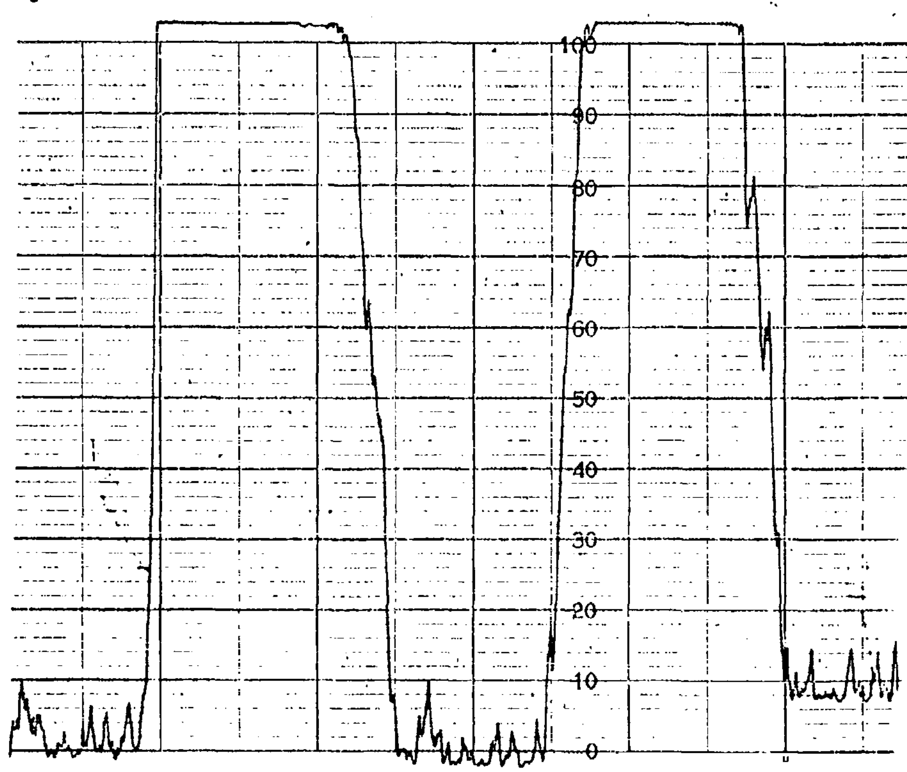


FIGURE 2-21

TANK TARGET, SKY BACKGROUND, SIDE VIEW, R=100 YARDS, (T-31)

FIG. 2-21
T-31, 30

FIGURE 2-22. TANK TARGET IN SHADE AND BEHIND TREES, 3/4 REAR VIEW, R = 150 YARDS (T-34)

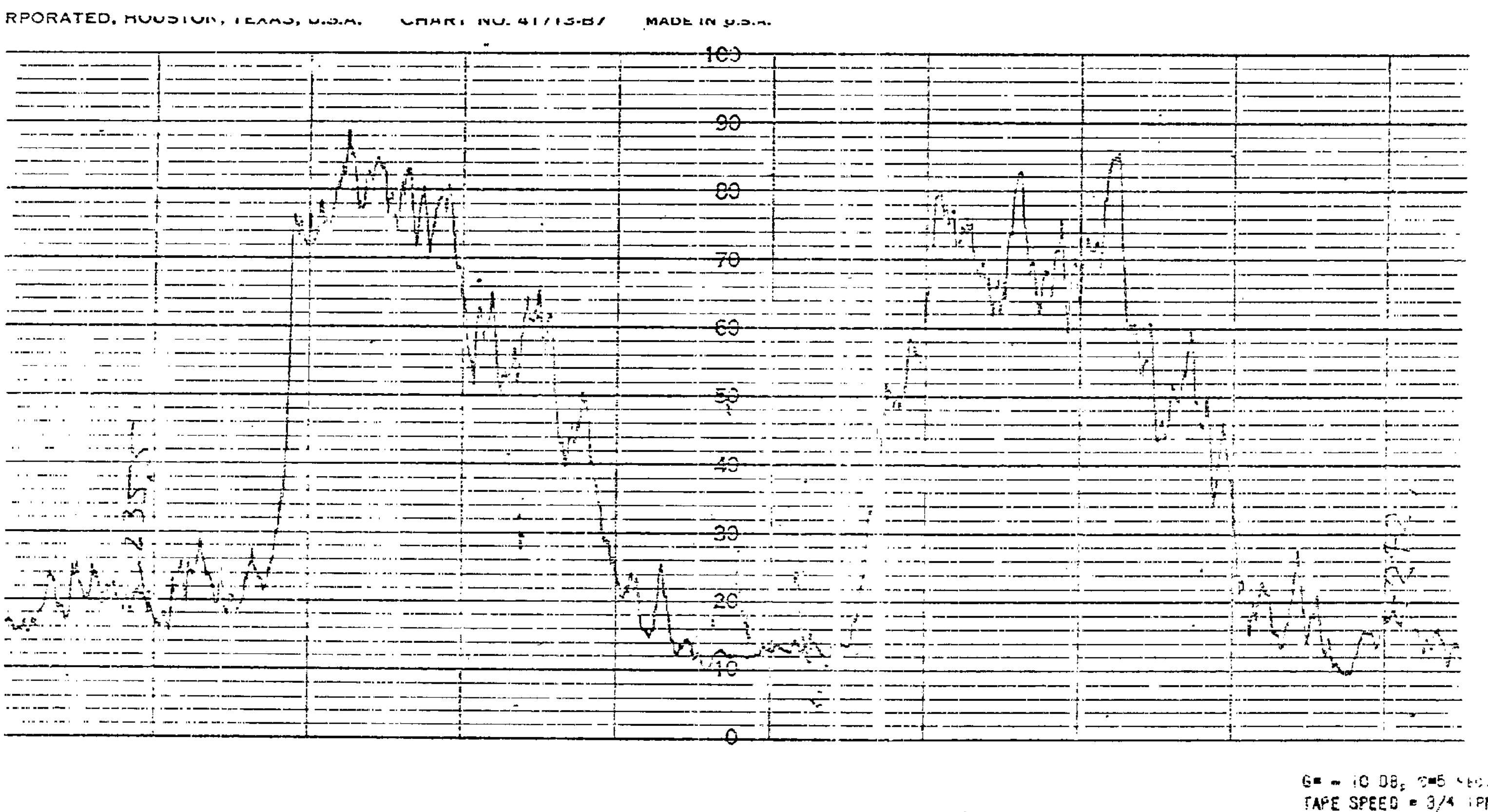


FIGURE 2-23. TANK TARGET IN SHADE AND BEHIND TREES, 3/4 REAR VIEW, R=150 YDS (T-34)

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FIG 2-23
T-34

FIGURE 2-24

a)
TANK TARGET AT NIGHT,
SIDE VIEW, R=300 YDS,
(T-37)

G= - 20 db, τ=5 sec,
Tape Speed =3/4 ipm

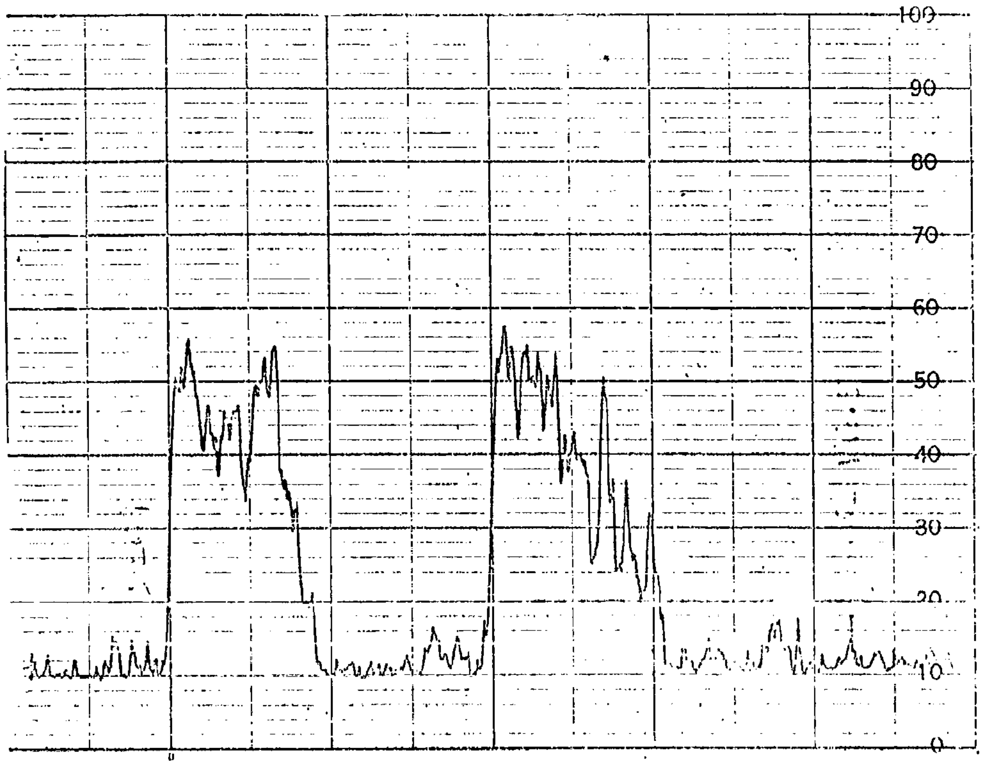
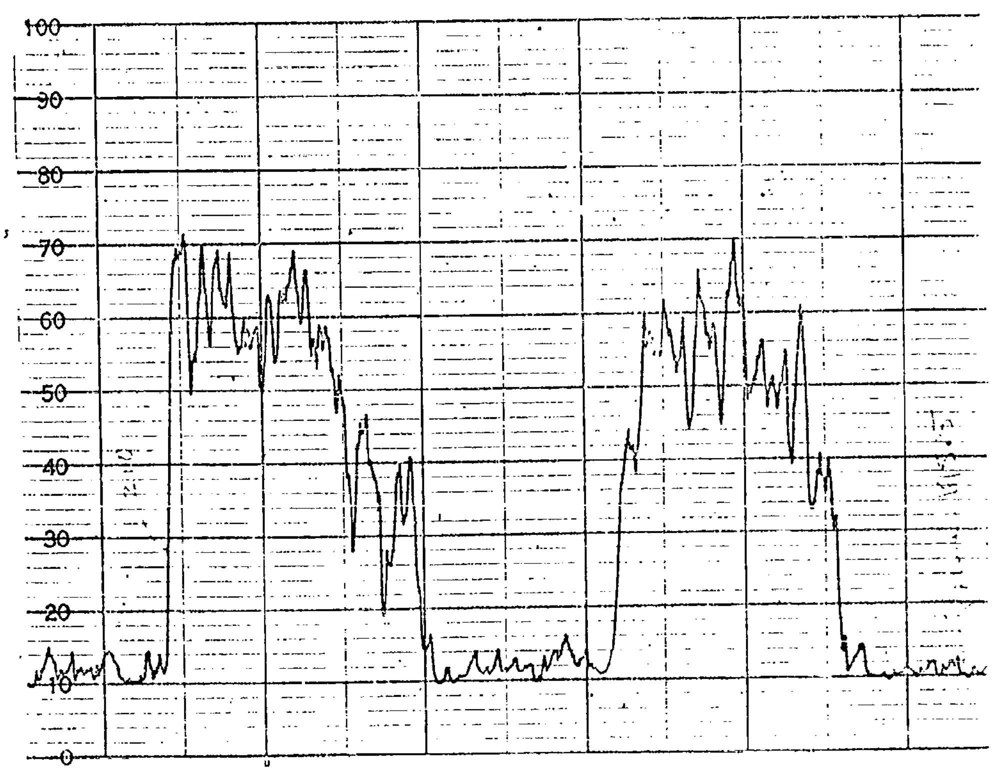


FIGURE 2-24

b)
TANK TARGET AT NIGHT,
SIDE VIEW, R=300 YARDS,
(T-38)

G= - 20 db, τ=5 sec,
Tape Speed =3/4 ipm



the use of other targets, such as trucks, jeeps, and napalm fires. In addition the radiometer was mounted in a 50 foot high cherry-picker to enable a view of the tank from the angle of an incoming missile.

2.4.1 Tank Warm-up

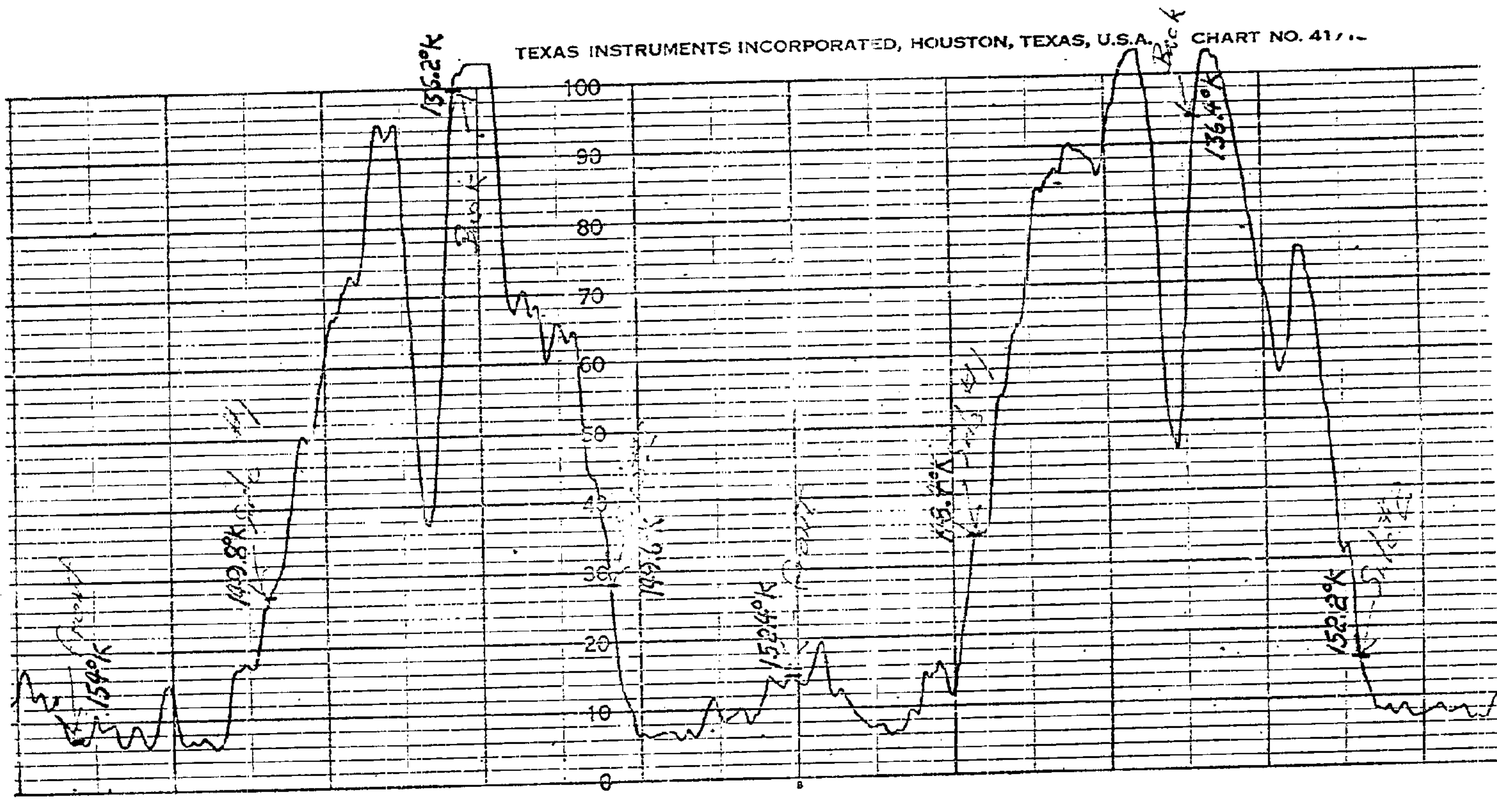
The purpose of this run was to see if tank engine temperature had an effect on its apparent temperature. To determine this the rear of the tank was moved to within 25 yds. of the dish, the cross-hairs centered on the exhaust and the tank allowed to cool for over 4 hours. The signal from the cold engine compartment was then nulled out, the engine turned on, and the subsequent change in the null condition, indicating a change in apparent temperature, duly noted on the pen recorder. In addition, the thermodynamic temperatures of the tank exhaust and engine compartments, both before and after engine turn on, were measured with the aid of thermocouples. The tank was allowed to run until its apparent temperature stabilized (about 45 minutes). During this time the unbalance created by the increased engine temperature was nulled out, the new dial reading noted, and the dial returned to its original setting. After engine turn off the radiometer remained pointed at the tank, to record the cooling-off curve, until a new stable radiometric temperature was reached. This took approximately one hour, thus completing the run. A number of such measurements were taken to determine data repeatibility. Table 3-2 contains a summary of data from all the tank runs.

2.4.2 Tank Rotation Runs

Rotation runs were taken in order to find out which tank aspect angles provided the maximum and minimum temperature differential with the background. The radiometer cross-hairs were maintained on the base of the turret as the tank was slowly rotated in a tight circle at 100 and 300 yds. In order to include all views of the tank on the limited dynamic range of the pen recorder, the radiometer was initially nulled out on the front view, which gave the minimum signal. Thus peaks in the data curve (see Figure 2-25) representing signals from other aspect angles, signify colder temperatures than the front view base line.

2.4.3, 2.4.4 Truck and Jeep Runs

The apparent temperatures of a 2 1/2 ton truck and a jeep were taken for both front and side views. Measurements of the truck T_a were made at 50, 300 and 500 yds. while those of the jeep were at 50 yds. The heights of the azimuth sweeps made at 50 yds are illustrated in Figures 2-26 and 2-32. In addition, rotation runs of both targets were made in a manner similar to that described previously for the tank. See Figures 2-26 through 2-33.



G = - 20 DB, τ = 1 SEC, TAPE SPEED = 3/4 IPM

FIGURE 2-25. TANK ROTATION RUNS, R=100 YDS (S-2)

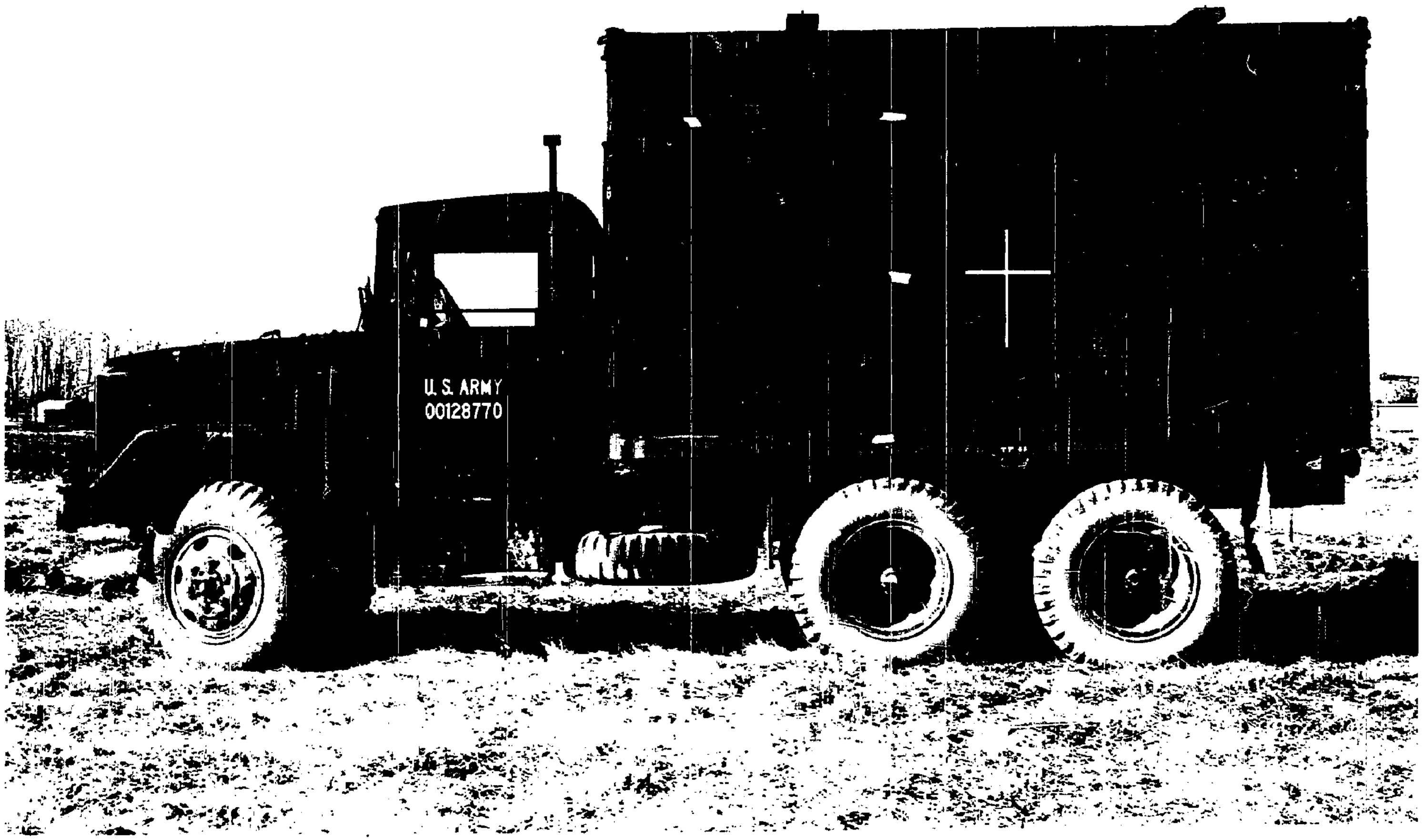
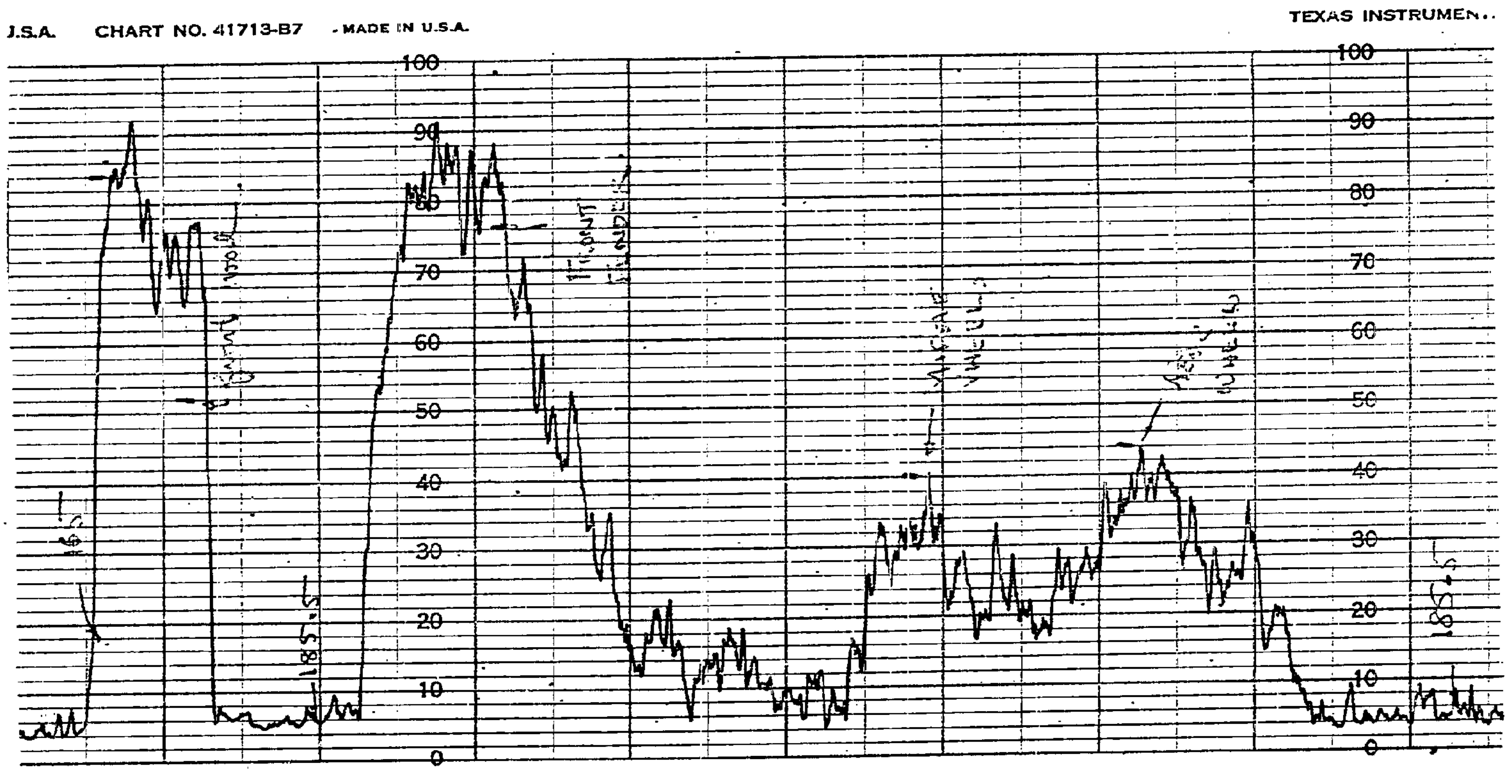


FIGURE 2-26. TRUCK TARGET - SHOWING POSITION OF AZIMUTH SWEEPS.



G = - 20 DB, τ = 1 SEC, TAPE SPEED = 3/4 IPM

FIGURE 2-27. TRUCK TARGET, SIDE VIEW, R=50 YDS, SWEEP A (S-3)

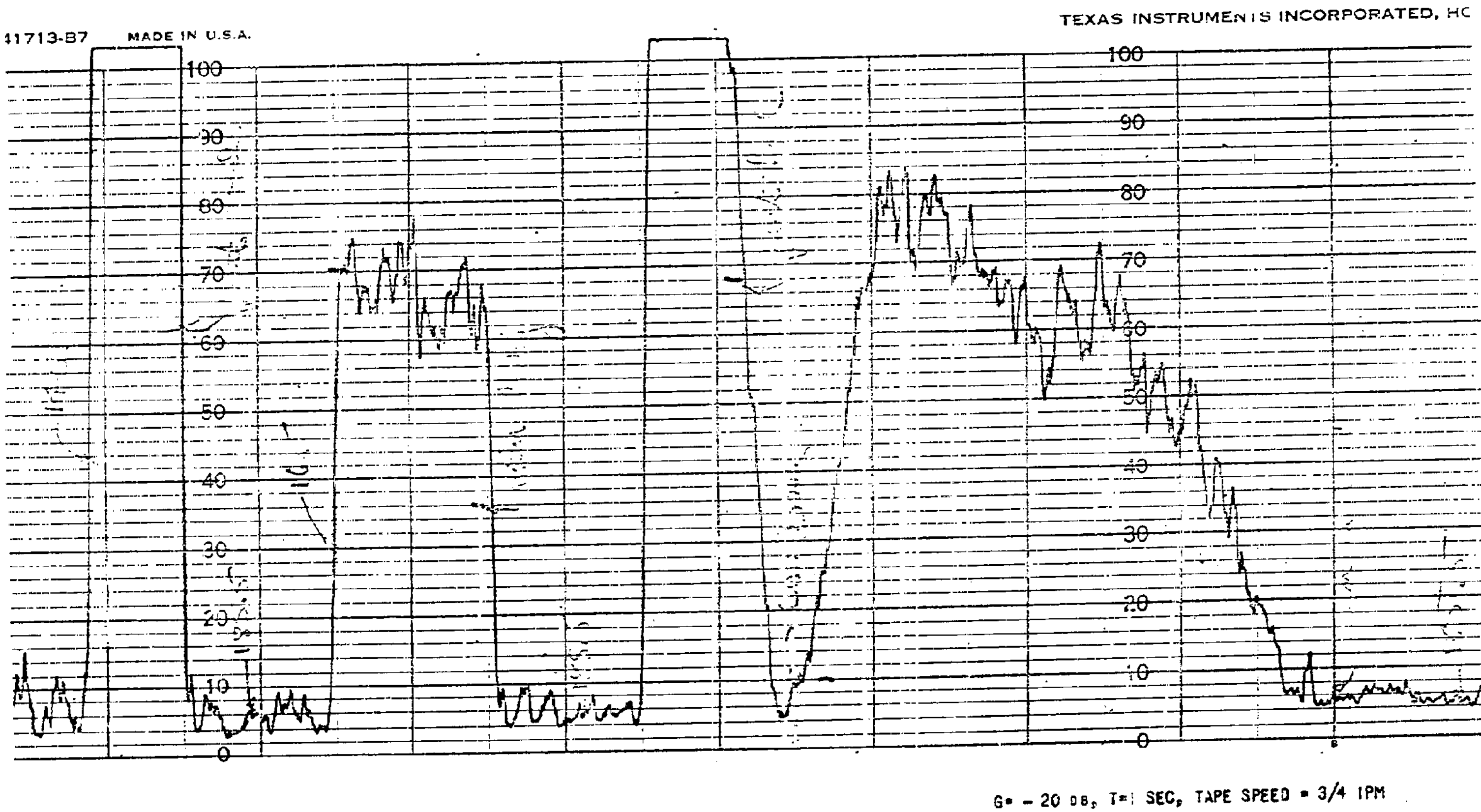


FIGURE 2-28. TRUCK TARGET, SIDE VIEW, R=50 YDS, SWEEP B (3-3)

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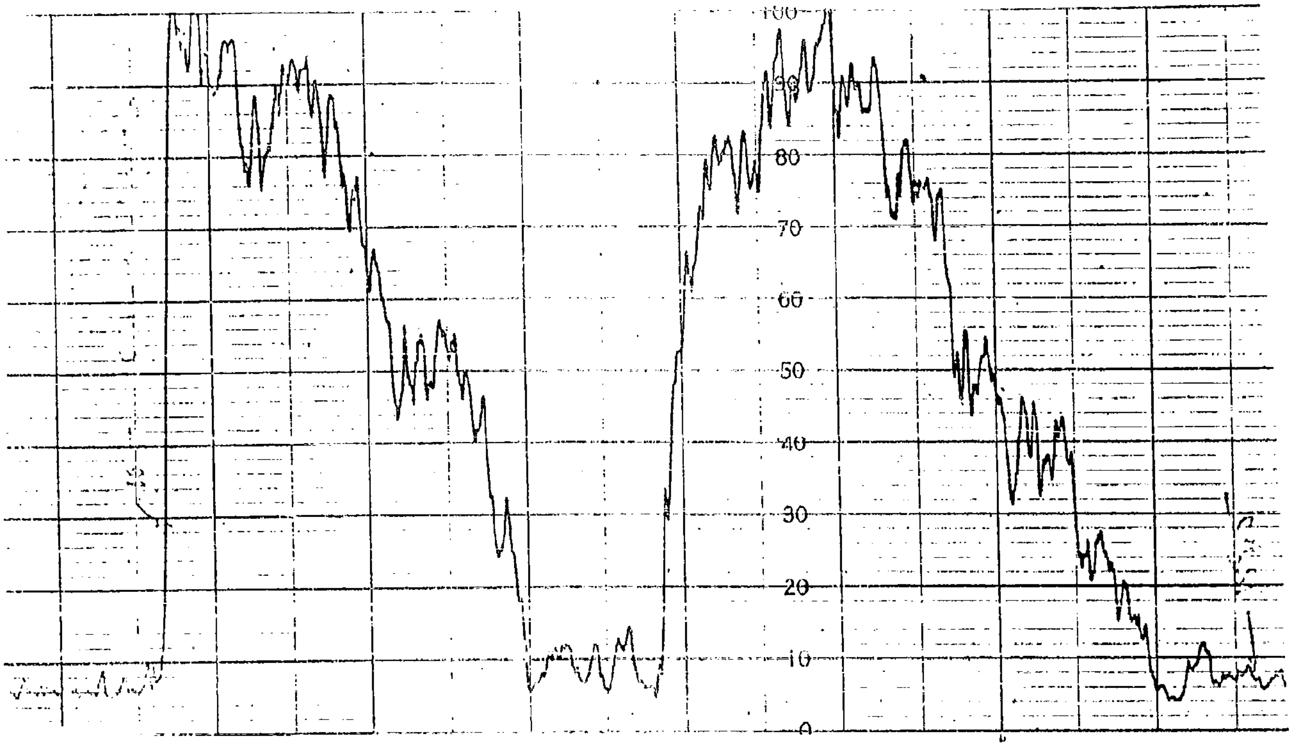

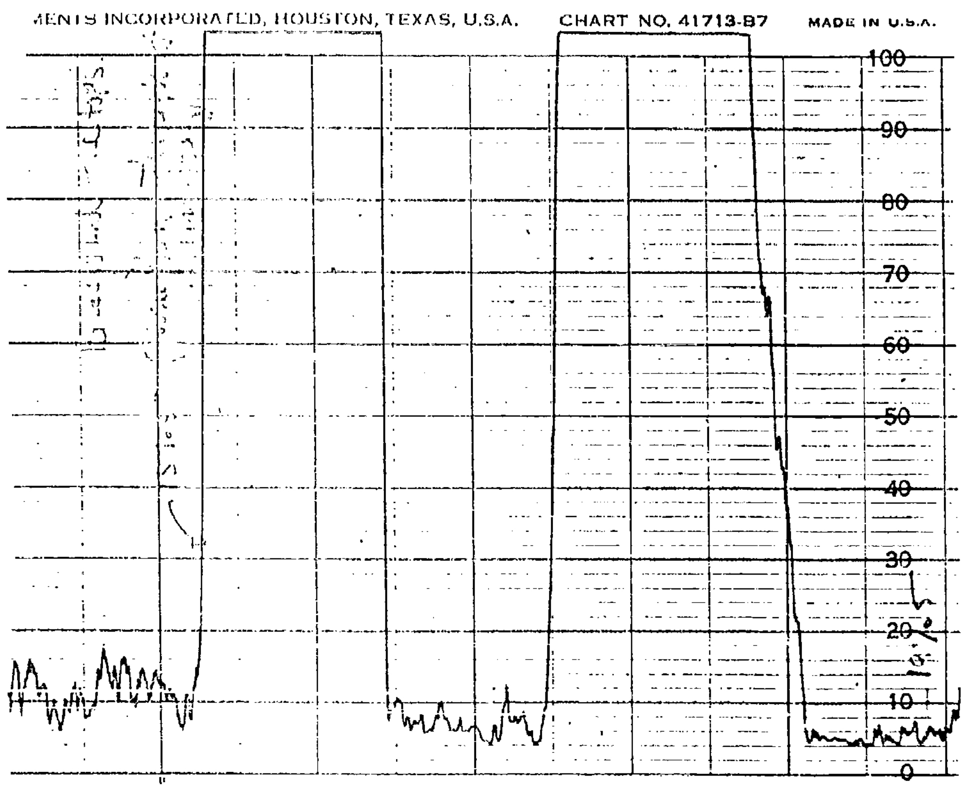

FIGURE 2-29. TRUCK TARGET, SIDE VIEW, R=50 YDS, SWEEP C,D (S-3)

G= - 20 db, τ=1 sec.,
Tape Speed =3/4 ipm

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FIG 2-29

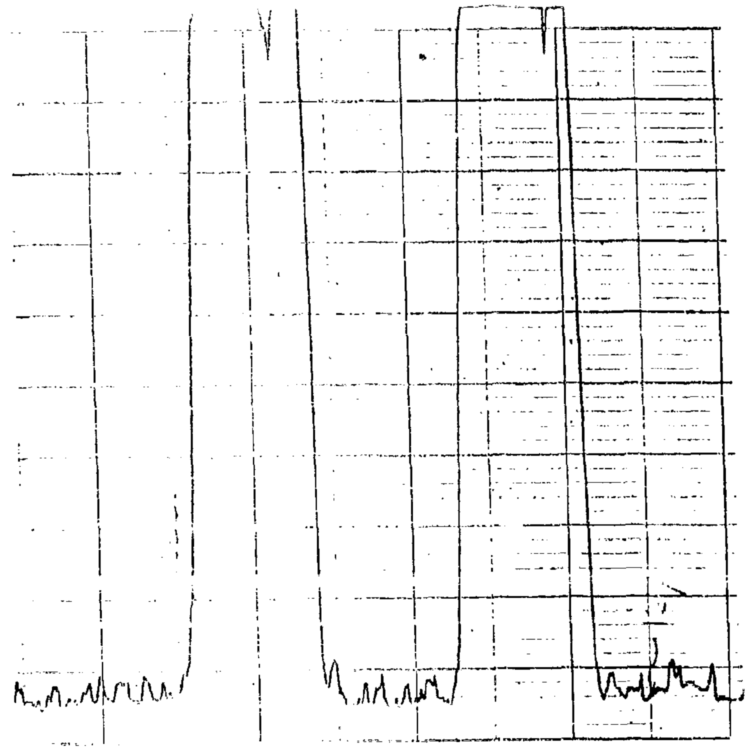


FIGURE 2-30. a) TRUCK TARGET, SIDE VIEW, R=300 YARDS (S-5)

G= - 20 db, τ=1 sec,
Tape Speed = 3/4 ipm

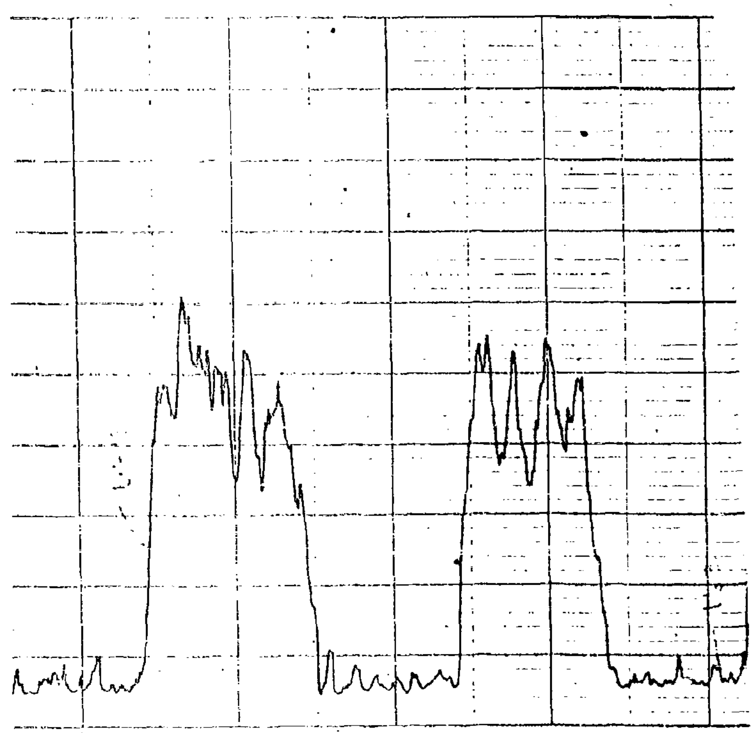
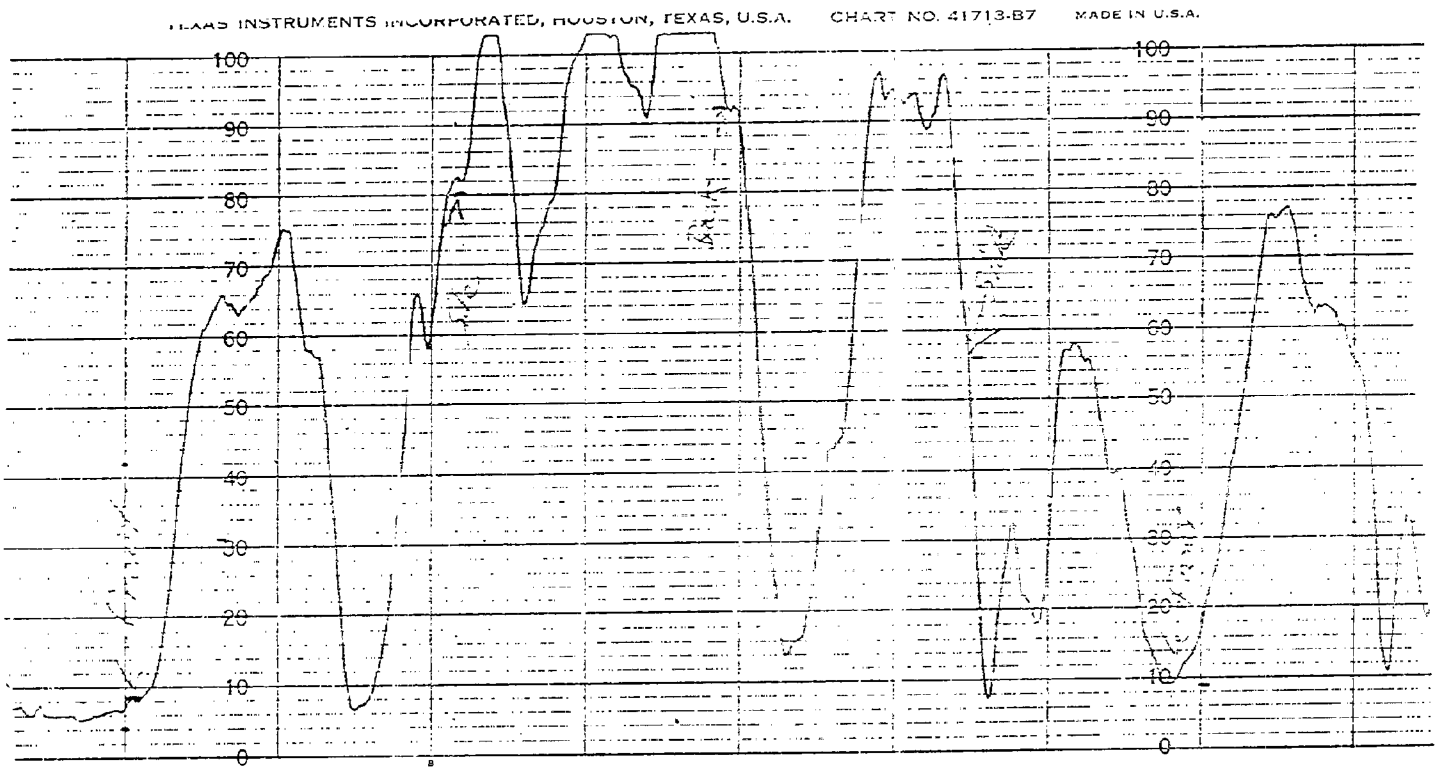


FIGURE 2-30. b) TRUCK TARGET, FRONT VIEW, R=300 YARDS (S-6)

G= - 20 db, τ=1 sec,
Tape Speed = 3/4 ipm

Fig 2-31
S-5, S-6



G = – 20 DB; τ = SEC; TAPE SPEED = 3/4 IPM

FIGURE 2-31. TRUCK ROTATION RUN, R=100 YARDS (S-8)

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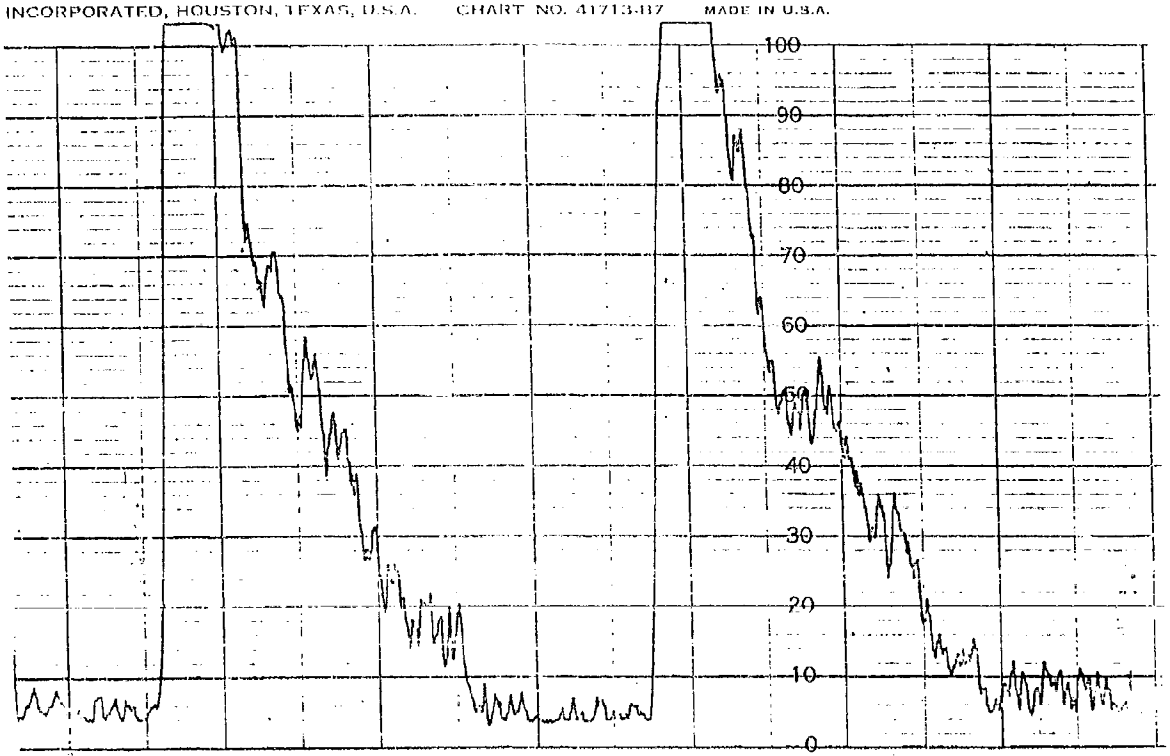
FIGURE 2-32. JEEP TARGET - SHOWING POSITION OF AZIMUTH SWEEPS



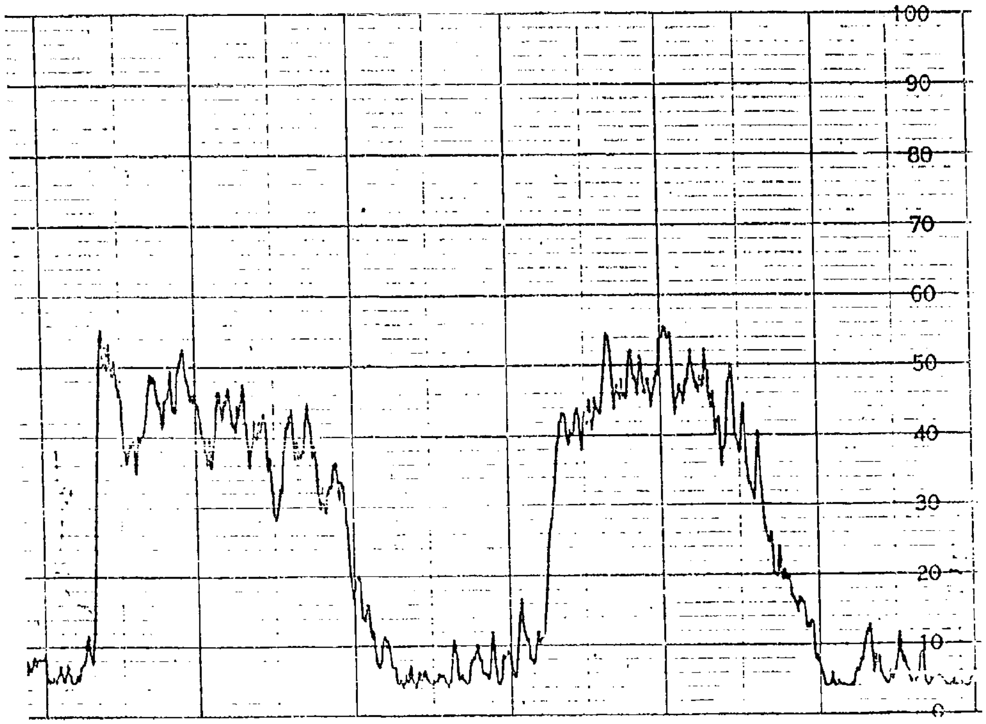


FIGURE 2-33. JEEP TARGET, SIDE VIEW, R=50 YDS, SWEEPS A, B, (S-16)

C= -20 db,
τ= 1 sec, Tape
Speed = 3/4 ipm

Fig. 2-33
S-16 A, B.

2.4.5 Napalm Fire Runs

Up until this point in the program, all targets viewed have been detected by virtue of their reflection of radiation from the "cold" sky, thus making them appear, to the radiometer, cooler than the background. Now it was desirable to see how well the instrument could detect targets that were hotter than the background. To assist in this part of the program a team from the Army Chemical Center at Edgewood, Md. was called in to provide napalm and flame thrower equipment.

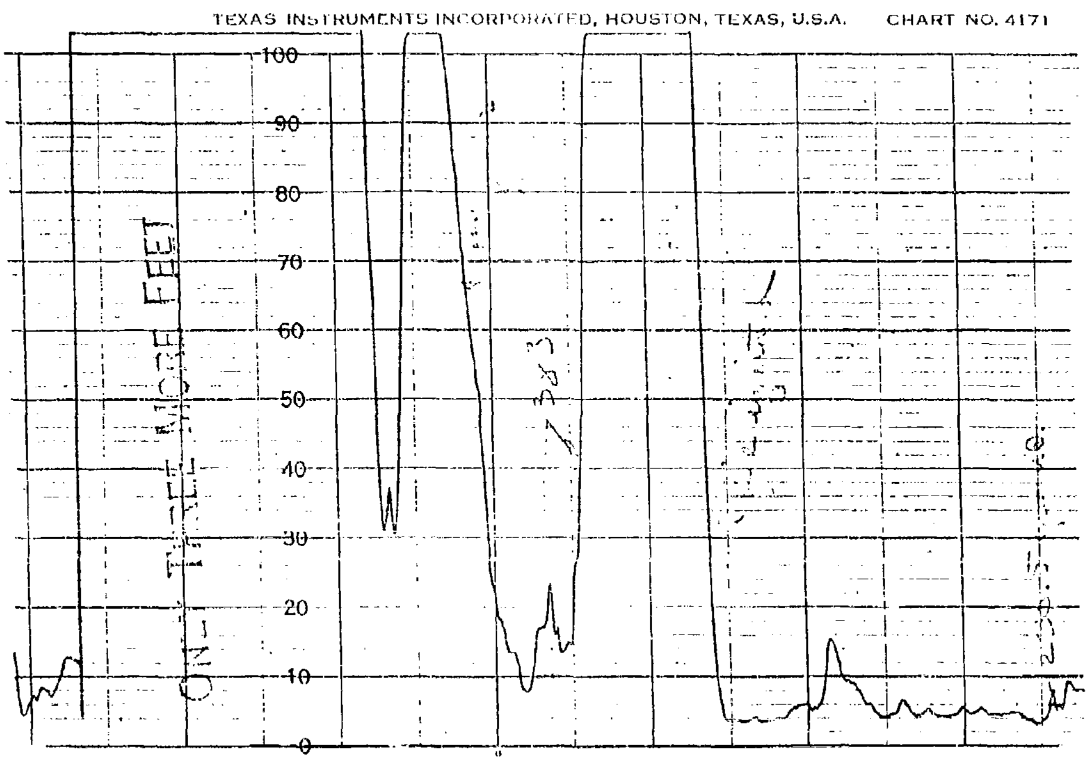
At first the napalm was placed in a 2 foot diameter puddle 25 yds. from the radiometer and ignited. The radiometer which had initially been nulled out on the temperature of the unlit napalm was now rebalanced on the burning chemical and the new dial reading noted, thus indicating its apparent temperature (see Figure 2-34). This was repeated at 100 yds. with a larger fire. A third run was conducted to examine the effect of having burning napalm between the tank and the radiometer. To accomplish this, the napalm was spread in a 30 foot strip at the 25 yd. point and the tank placed at the 50 yd. point. The radiometer was focused on the tank, nulled out, and the napalm was ignited. Unfortunately, the flame never climbed high enough to obscure the tank. However, the smoke from the fire completely blotted out the tank and this in itself provided a useful test (see Figures 2-35, 2-36). The final test involved measuring the apparent temperature of bursts from a flame thrower (Figure 2-37). A technician with a flame thrower was placed 5 yds. in front of the radiometer with the nozzle pointing at a small angle from the dish axis. The radiometer was initially nulled out on this background, a six second burst was fired and a new null reading made during the burst.

2.4.6 Snow, Fog and Rain Runs

Winter in the Chesapeake Bay area of Maryland is a good time of the year to determine the effects of various weather conditions on the apparent target temperatures. All of these measurements were made of the front and side views of a tank at a range of 300 yds (see Figures 2-38 through 2-41). In the case of the snow and fog runs the tank was completely obscured visually. In order to place the horizontal cross-hairs at correct elevation on the base of the turret, it was necessary to wait for a temporary break in the fog and snow. The actual runs were then made when the target was once again completely obscured.

2.4.7 Tank Views from Cherrypicker

One of the most interesting and useful parts of the field test came from viewing the tank with the radiometer from the angle of an incoming missile. This was accomplished by placing the radiometer and associated equipment in the basket of a "cherrypicker", Figure 2-42. Through the use of this device the height of the radiometer could be varied continuously between 0 and 50 feet thus enabling the tank to be viewed from various aspect angles from 0° to 40°. (Figures 2-43, 2-44, 2-45). Inability to further reduce the elevation angle of the radiometer



[illegible] Tape Speed 3/4 ipm

FIGURE 2-34. MEAS[illegible] 25 YDS. (S-[illegible])

FIG 2-34
S-11

FIGURE 2-35. NAPAIM WALL OF FIRE, R=25 YDS, TANK- R=50 YDS (S-12)

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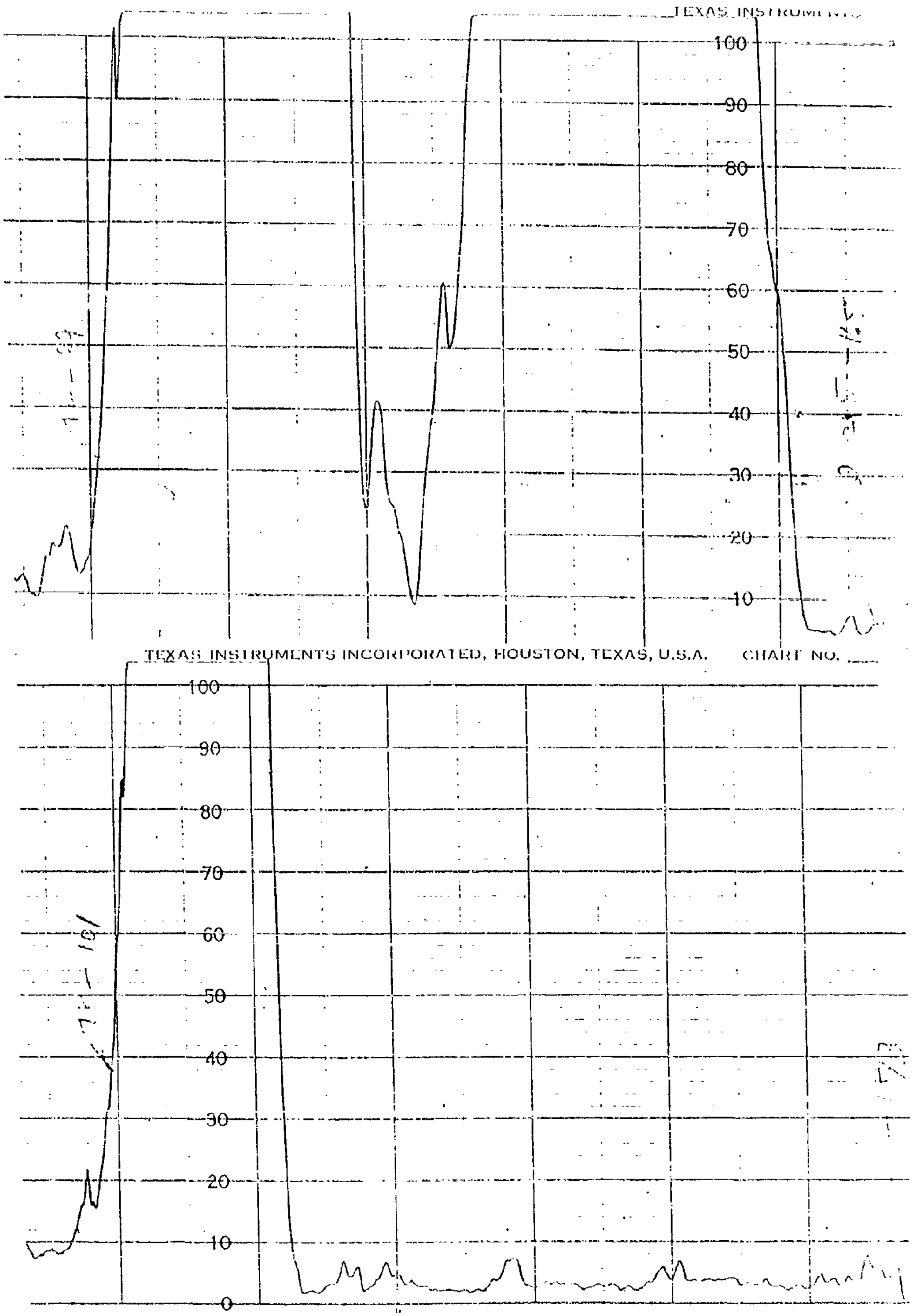

FIGURE 2-36. NAPALM WALL OF FIRE RUNS, [illegible] YDS, TANK R=50 YDS

G = - 20 db, τ= 1 sec, Tape Speed = 3/4 ipm

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FIGURE 2-37. MEASUREMENT OF T_a OF FLAMES FROM FLAME THROWER (S-13)

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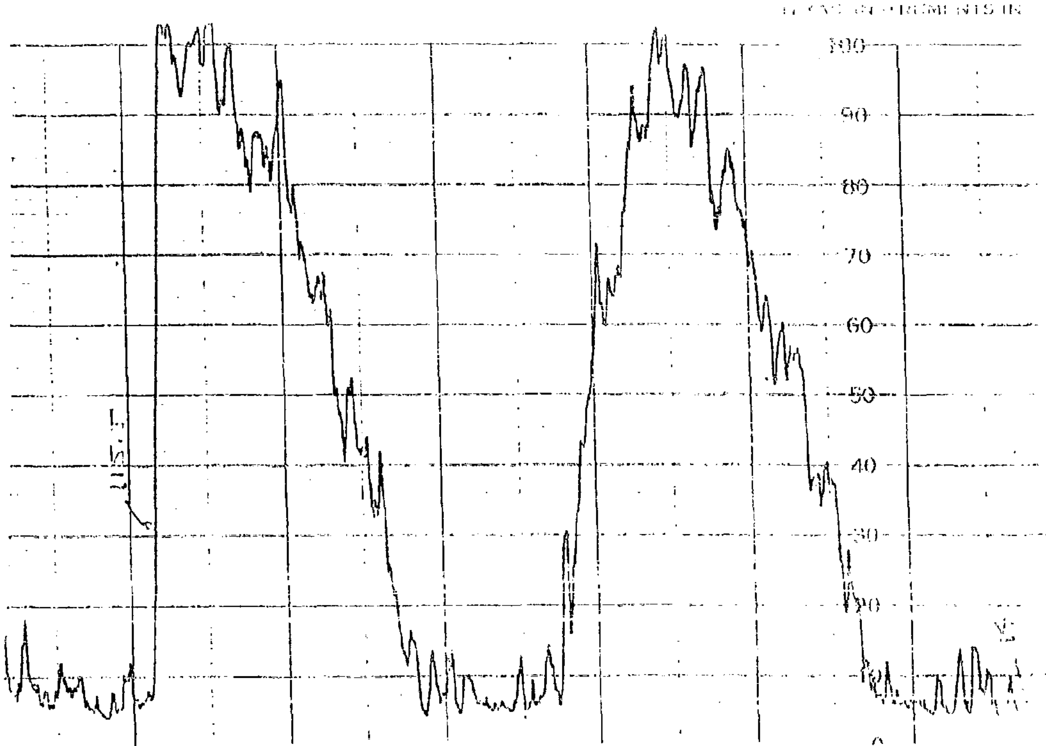

FIGURE 2-38

(a) TANK TARGET, SNOW, [illegible], R=300 YDS

G= -20 db, τ=1 sec, Tape Speed = 3/4 ipm

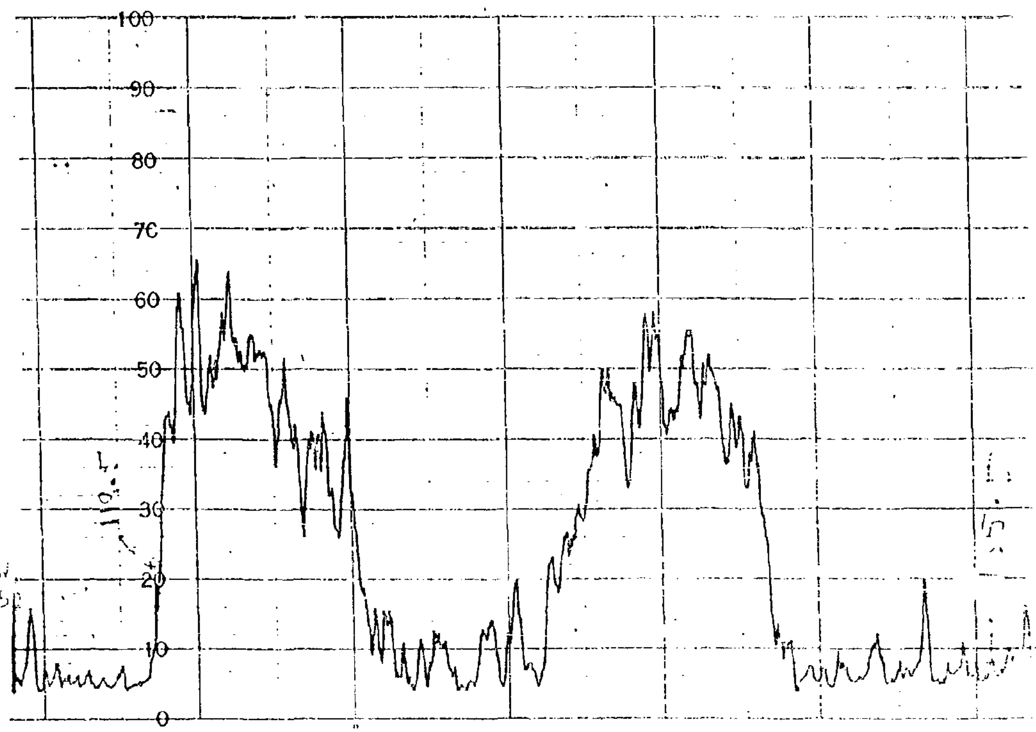

FIGURE 2-38

b) TANK TARGET SNOW, FRONT VIEW, R=300 YARDS(S-35)

G= -20 db, τ=1 sec, Tape Speed = 3/4 ipm

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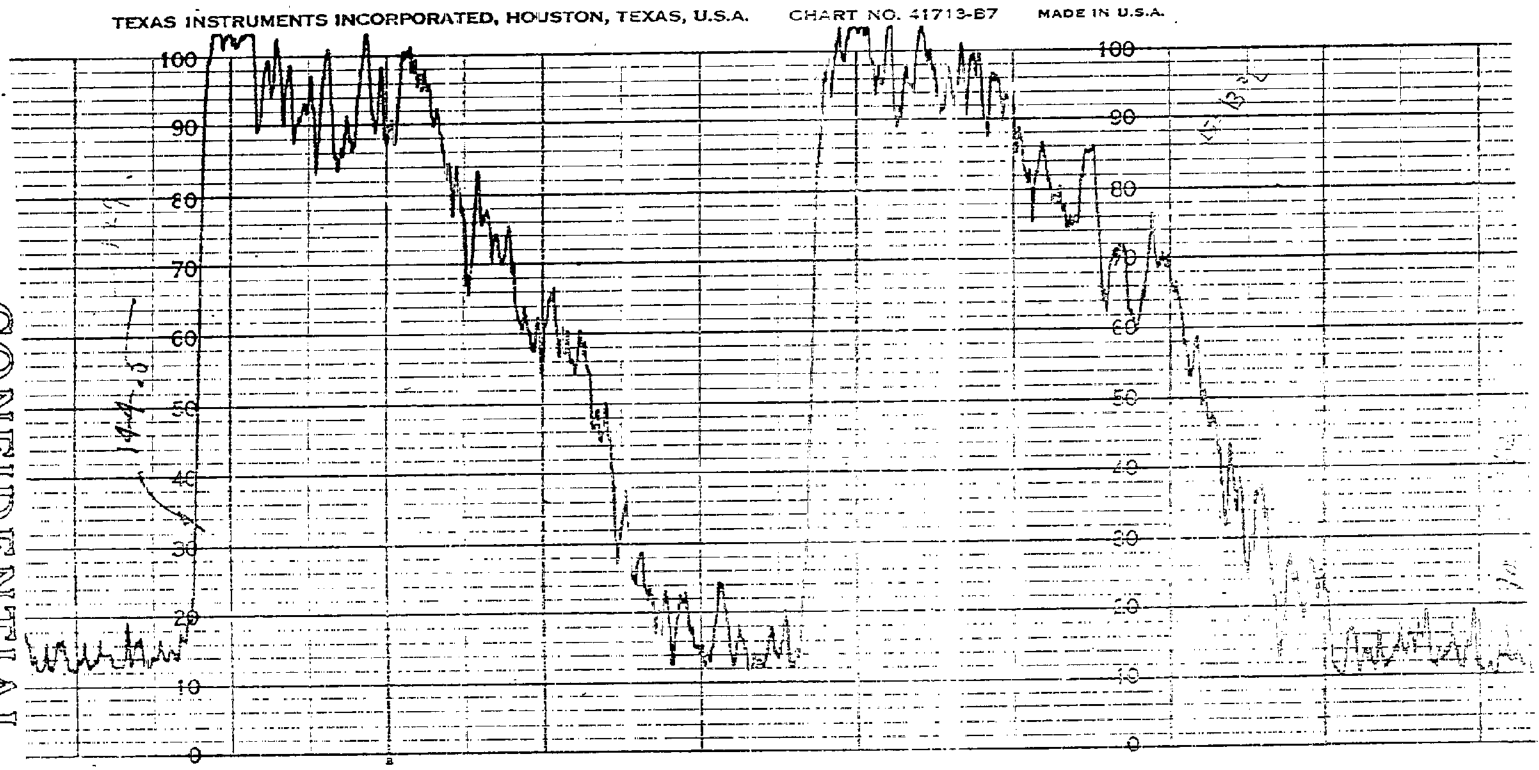

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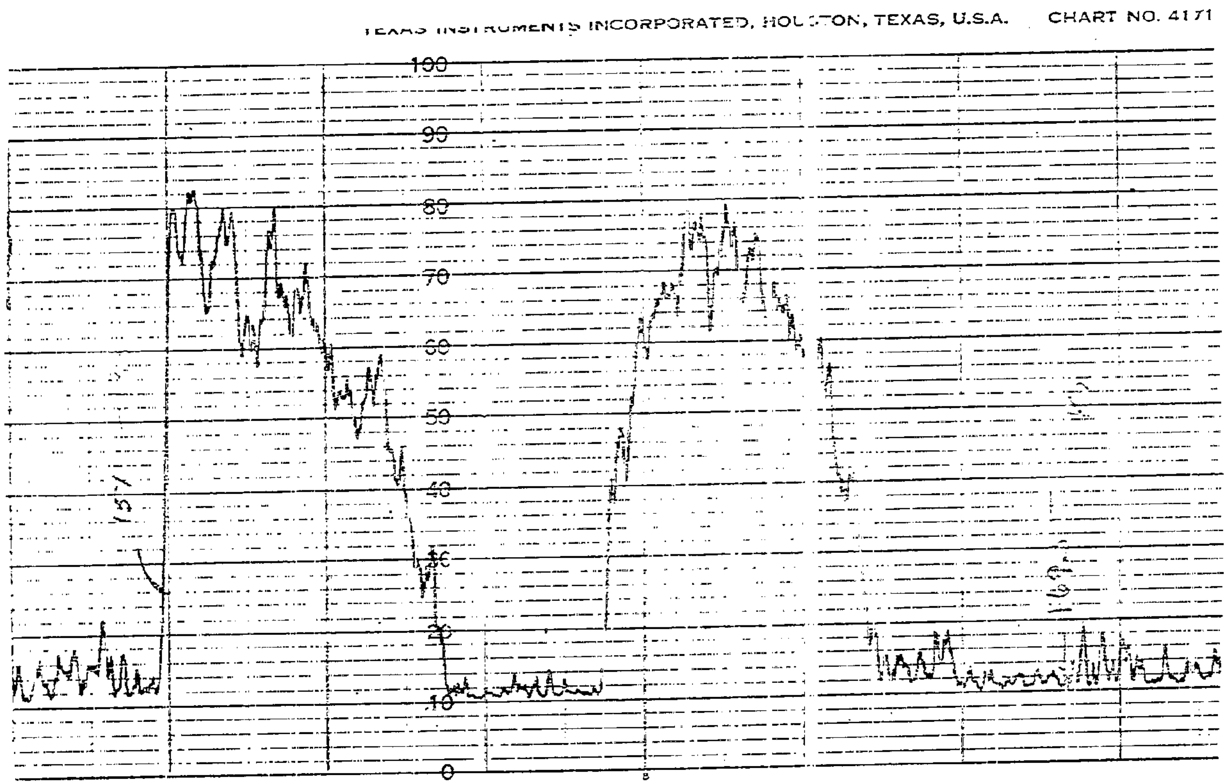
FIG 2-39



TAPE SPEED = 3/4

FIGURE 2-40. TANK TARGET, FOG, FRONT VIEW, R=300 YARDS (S-18)

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FIGURE 2-41. TANK TARGET, RAIN, SIDE AND FRONT VIEWS, R=300 YDS (S-25)

G= - 20 db. τ=1 sec.
Tape Speed 3/4 ipm

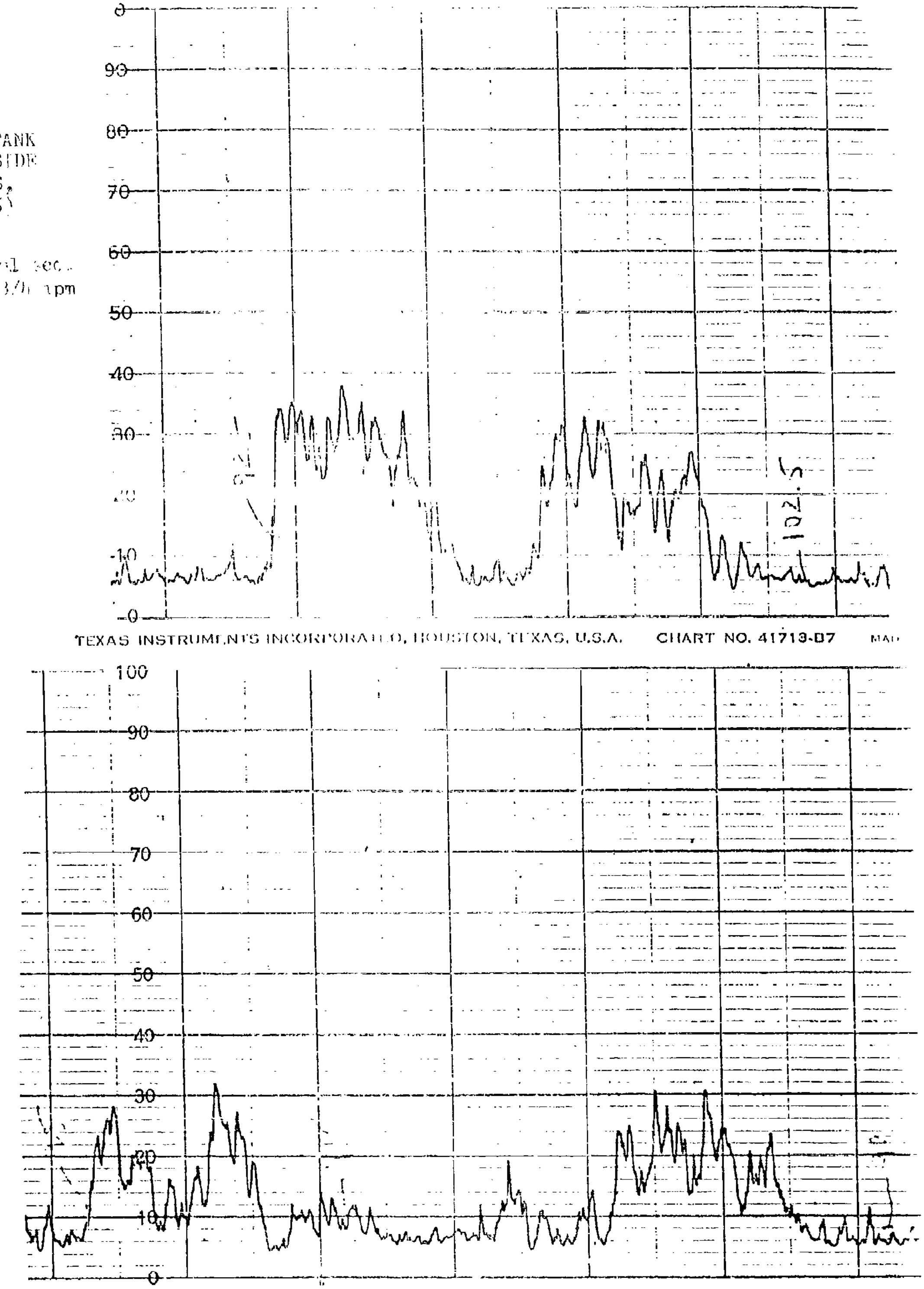

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FIG. 2-41
5-25 SIDE, FRONT

FIGURE 2-42. RADIOMETER EQUIPMENT BEING MONITORED IN CHERRYPICKER BASKET

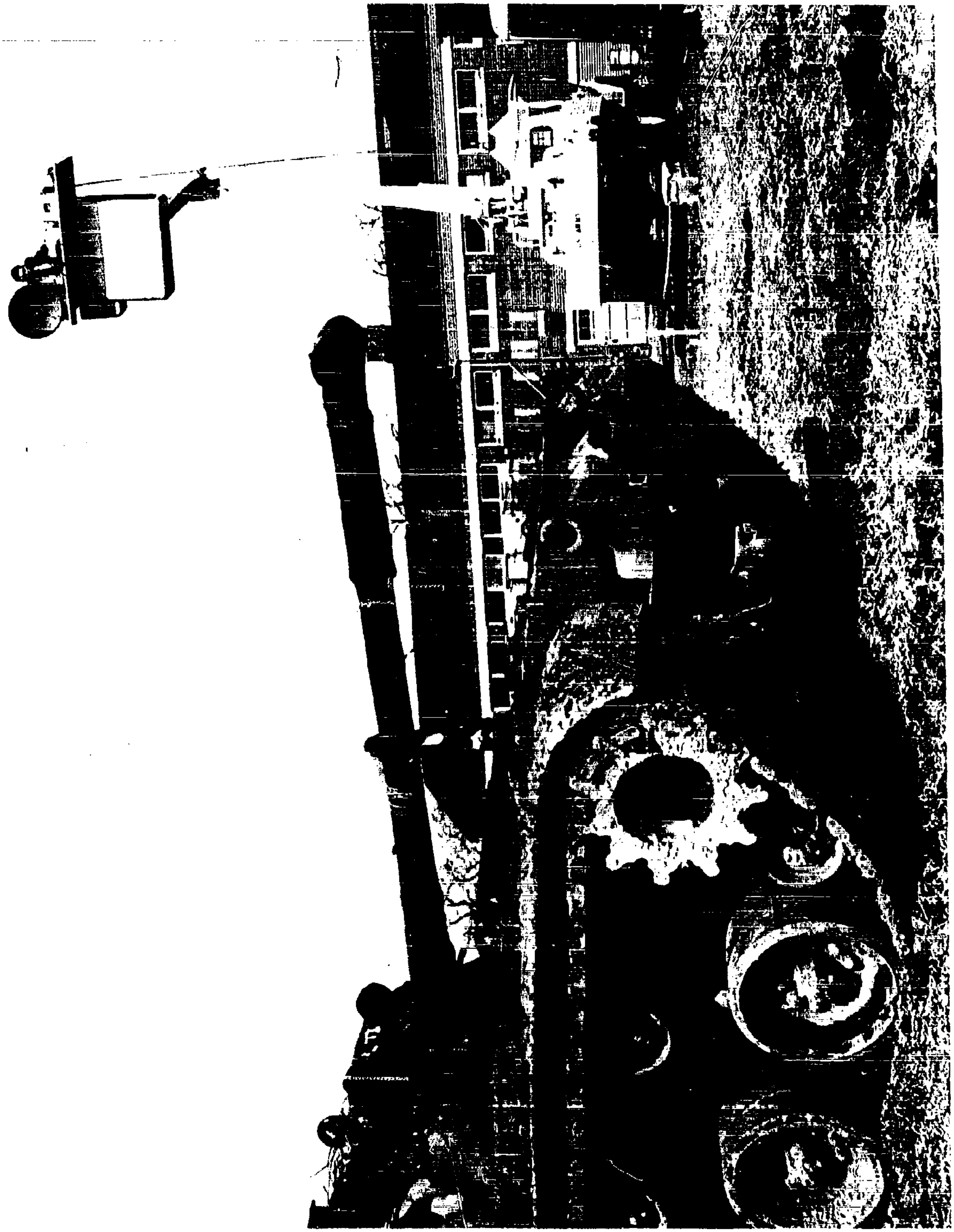

FIGURE 2-43. CHERRYPICKER AT HALF ELEVATION

FIGURE 2-44. CHERRYPICKER AT FULL ELEVATION

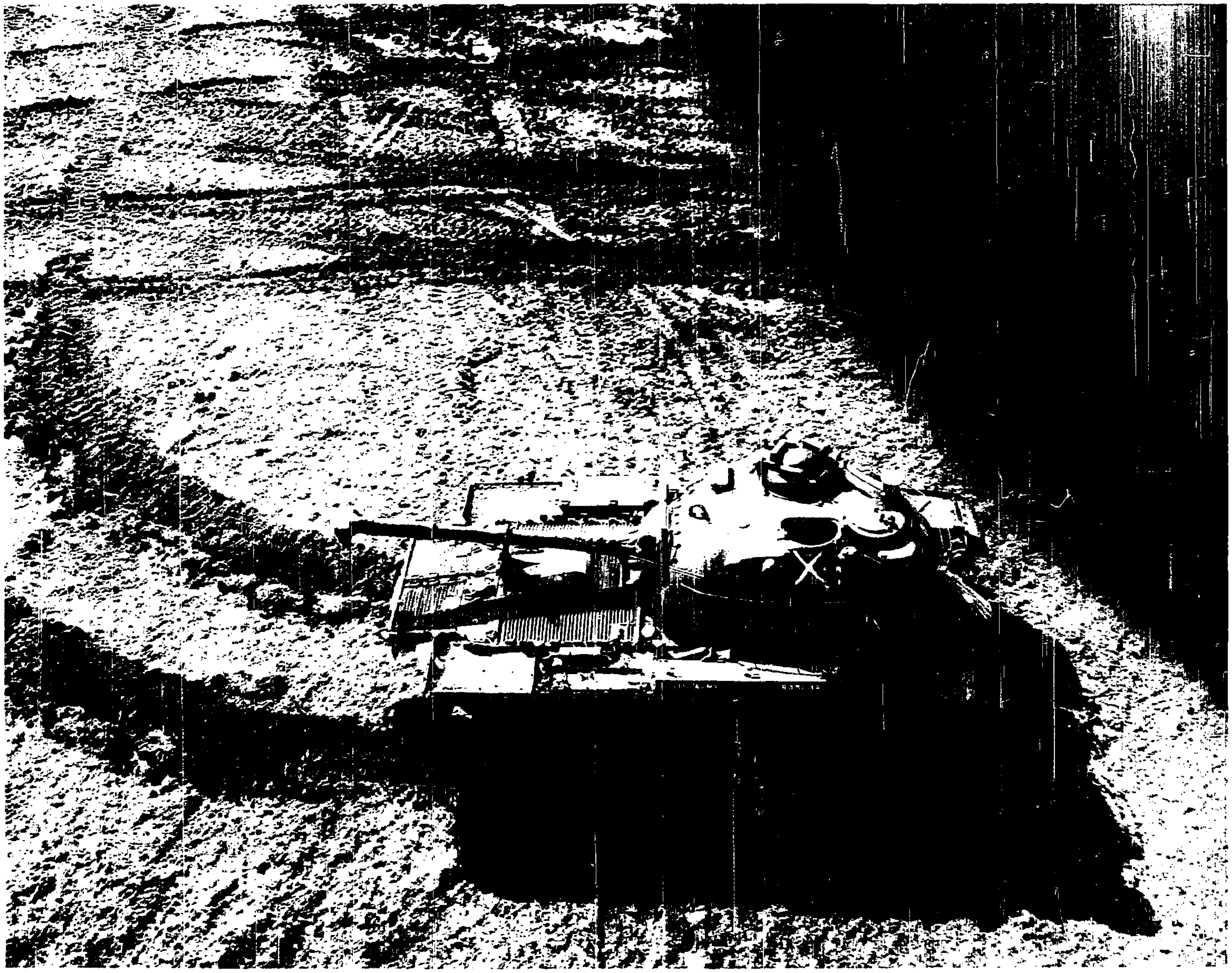

FIGURE 2-45. 40° ANGLE VIEW OF TANK FROM CHERRYPICKER

dish prevented viewing the tank at angles greater than 40°. Apparent temperatures were taken in 10° intervals with the tank at a distance of 47 feet from the base of the cherrypicker (Figure 2-46). In addition, use of the cherrypicker permitted the determination of the greatest distance at which a tank could be detected from elevations other than ground level (Figure 2-47).

2.4.8 Reference Surface Runs

Two reference surfaces were periodically viewed by the radiometer in order to relate easily the apparent temperatures determined in this experiment with those measured in future ones. Any future experimenter can readily relate his readings with those in this report by duplicating the reference surface set-up described and comparing the two sets of temperatures. The surfaces were 4 by 8 feet in area and placed at an angle of 45° with the ground 25 yds. from the radiometer dish. The first reference surface was a sheet microwave absorbing material* which gave a temperature reading hotter than the background. A temperature reading colder than the background was given by a sheet of unpolished aluminum, the second reference surface. In addition to measuring the apparent temperatures of these surfaces periodically, they were employed in certain other tests. The apparent temperature of the aluminum was measured when covered with layers of wet and dry mud in an effort to simulate the effects these coatings would have on the apparent temperature of a tank. Also measured was the apparent temperature of the aluminum as a function of its angle with the ground. This helped to determine from which angular surfaces on a target the largest signal return might be expected.

2.4.9 Audio Modulation of the Microwave Signal

In an effort to determine if the microwave signal from the tank is being modulated by the sound from the tanks engines, the rear of the tank was placed 25 yds. from the radiometer and the dish trained on the engine compartment. The output of the 97 cps detector was fed into an audio amplifier and loudspeaker assembly and the tank was turned on.

* See Addendum, page 115

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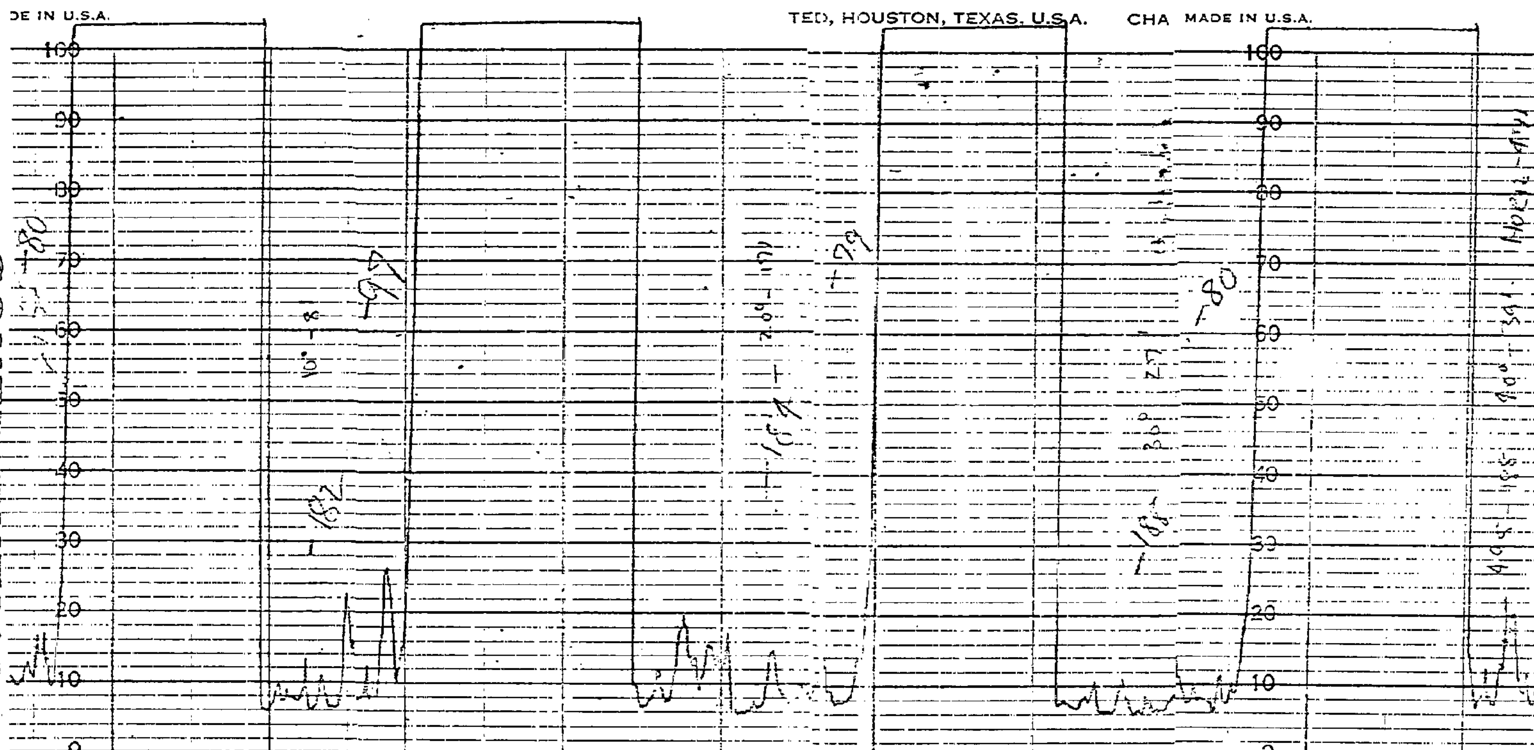

G = - 20 08, τ = 1 SEC, TAPE SPEED = 3/4

FIGURE 2-46. TANK TARGET-T's FROM THE DIFFERENT HEIGHTS FROM CHERRYPICKER (S-10A)

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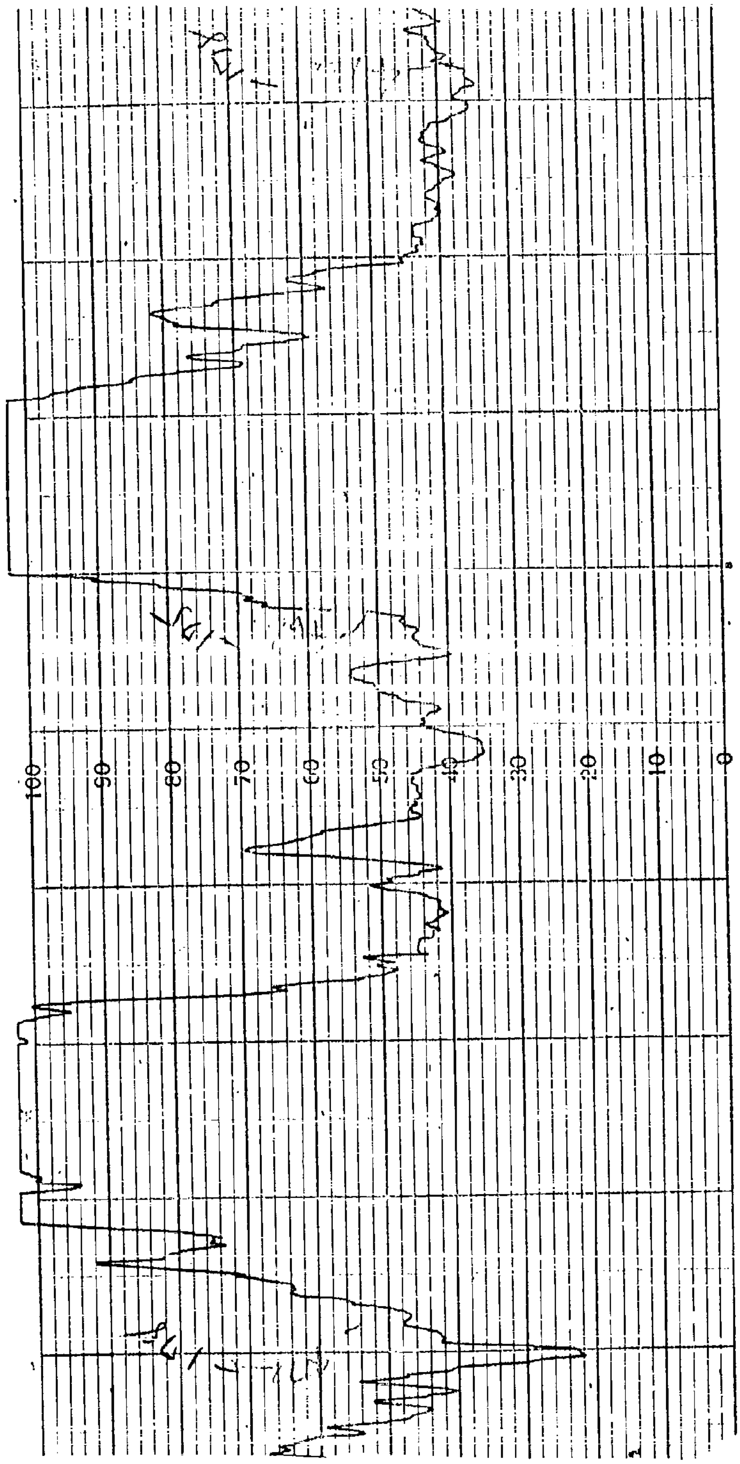

G = 0 DB, τ = 5 SEC, TAPE SPEED = 3 IPM

FIGURE 2-47. TANK TARGET, GREATEST DETECTABLE DISTANCE FROM CHERRYPICKER (S-20-4)

3. DISCUSSION OF RESULTS

3.1 Calibration Procedure

In order to determine the absolute apparent temperatures of the targets viewed, calibration runs were performed each day and sometimes twice a day. Reference to the radiometer block diagram, Figure 2-3, will aid in understanding the procedure used.

As in all Dicke type radiometers in order to eliminate the effects of slow changes in receiver gain, the microwave input to the mixer was switched between the antenna and a source of constant temperature, in this case, the termination of the ferrite switch. Any difference between the antenna temperature and the temperature of the termination results in a D.C. voltage at the output of the integrating circuit. The magnitude and sign of this voltage represents the magnitude and sense of the temperature differential. The chopper of the D.C. amplifier alternately samples this voltage and a calibrated reference voltage. In the measurement procedure, the reference voltage is adjusted until a null reading is obtained from the output of the D.C. amplifier signifying that the integrator voltage was matched in both amplitude and sign by the reference voltage. The dial reading for the reference source is then noted. The calibration procedure relates this dial reading to the temperature in the main guide of the antenna by inserting in the main guide known temperatures from a noise source and balancing them out with the reference source.

During calibration the antenna is pointed at the sky at a 32.5° angle with the horizontal. The antenna temperature contribution to the main guide temperature is known from the sky curves given in Figure 3-1. These show sky temperatures for three different types of weather conditions as a function of angle. For 32.5° from the horizontal these temperatures are 36°K - clear, 51°K - cloudy and 128°K - rain (4m.m./hr). The other contribution to the main guide temperature comes from a 10,100°K noise source which is passed through a calibrated microwave attenuator and coupled into the main guide via a 9.4 db directional coupler. By varying the microwave attenuator, accurately known noise temperatures are introduced into the main guide where they combine with the temperature contribution from the antenna. The resulting integrator voltage representing the resultant main guide temperature is nulled out with the reference voltages and the dial reading noted. Hence the corresponding calibration curve is a plot of main guide temperature versus reference voltage dial reading.

During the measurement process, maximum attenuation (greater than 50 db) is placed in the calibrated attenuator in order to negate the effect of the noise source contribution to the main guide temperature. Appendix B derives an equation for antenna temperature which takes into account this contribution from the noise source along with the effects of noisy and lossy components on the main guide temperature. The resulting equation modifies the existing calibration curves. To take account of this, the forty-seven original calibration runs were separated into three groups on the basis of similarity (less than 10% deviation). While the groups themselves are separated by more than 50°K, no curve in any one group differs from another by more than a few degrees. In each group there is a preponderance of one of the three

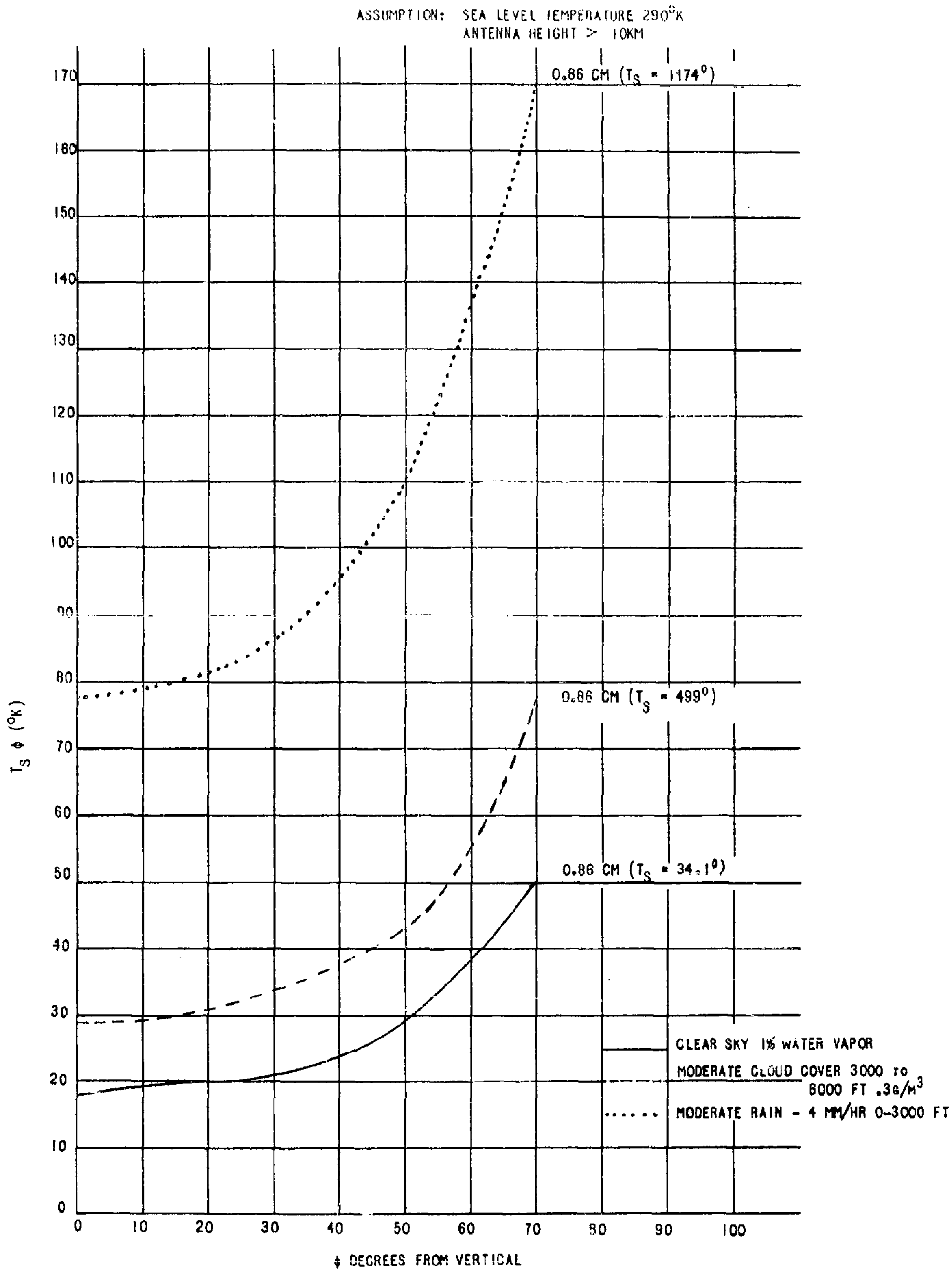

FIGURE 3-1

SKY TEMPERATURE

types of weather conditions mentioned earlier. The fair weather group is composed of 40% fair weather calibration runs; the cloudy group of 65% cloudy runs; and the rainy group of 75% rainy runs. A representative curve from each group was chosen and replotted using the derived antenna temperature equation (See Figures 3-2, 3-3, and 3-4). If there were only three distinct types of weather during the field program, and the sky temperature for each type were accurately known and included in the calibration calculations, one might expect only one universal calibration curve. However, gradations in the degree of cloud cover and the resulting deviations introduced by trying to classify them into three types of weather produced the three separate calibration curves. These curves do not differ in slope but only in intercept on the Y-axis. This difference is not a source of error since each curve represents a calibration that is accurate in itself and the shift of intercept is compensated for in the data when the same temperature is represented by different dial readings for the three groups.

In order to obtain the target temperature corresponding to a given dial reading, the value of 1264 L_{AT} for that reading is picked off the applicable curve and the sky temperature at time of measurement added to it.

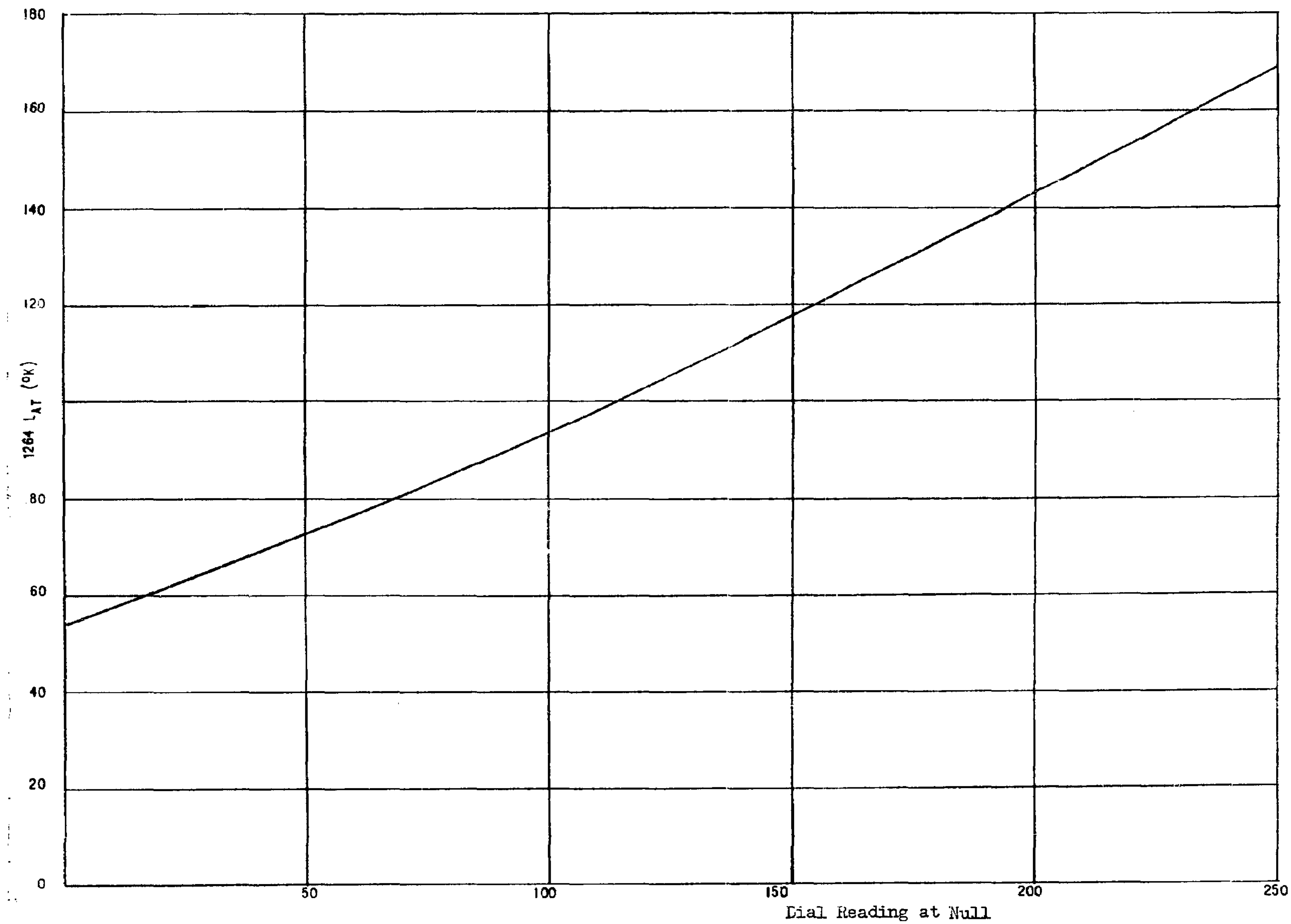

FIGURE 3-2

FAIR CALIBRATION CURVE

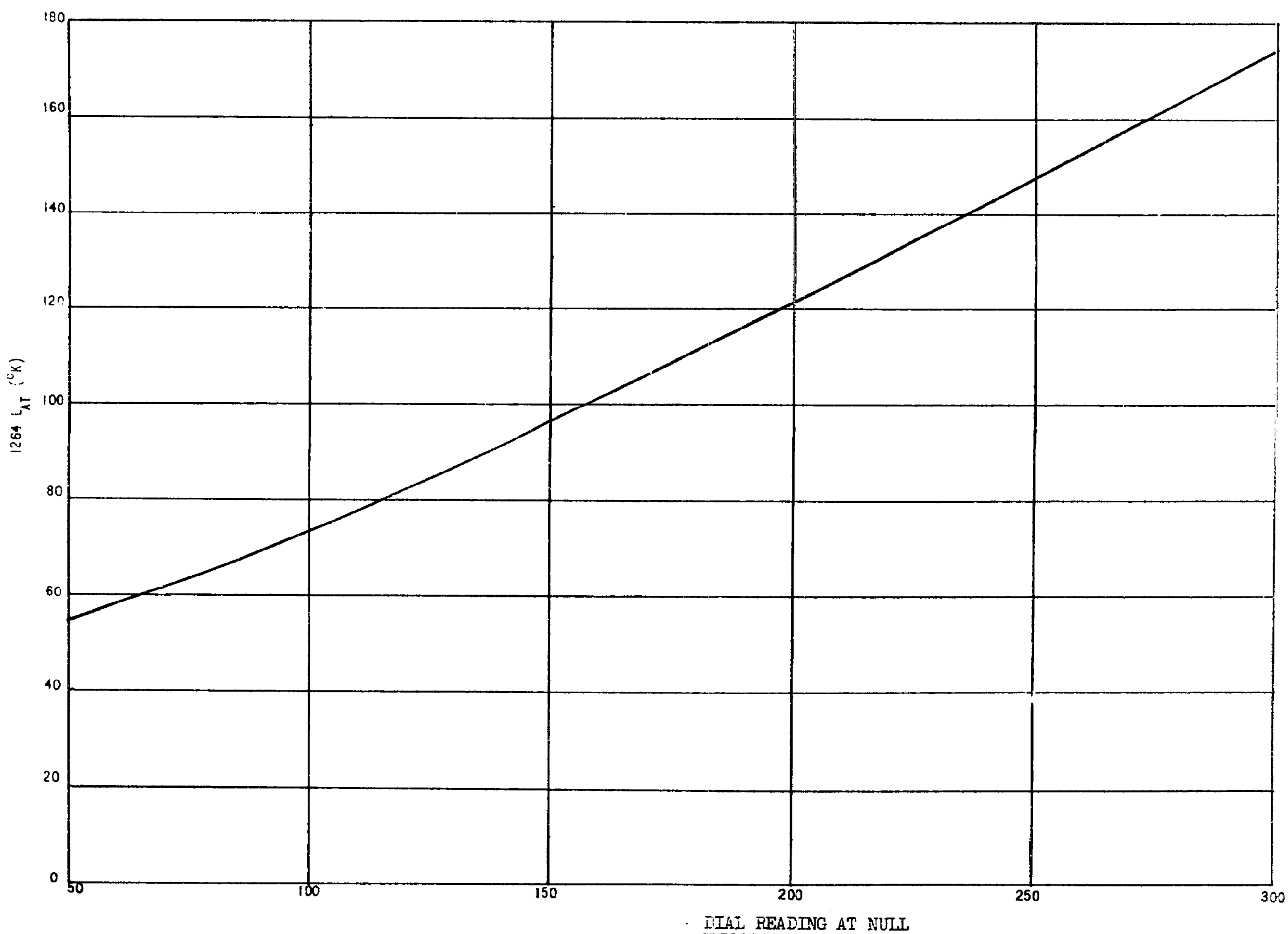

FIGURE 3-3. CLOUDY CALIBRATION CURVE

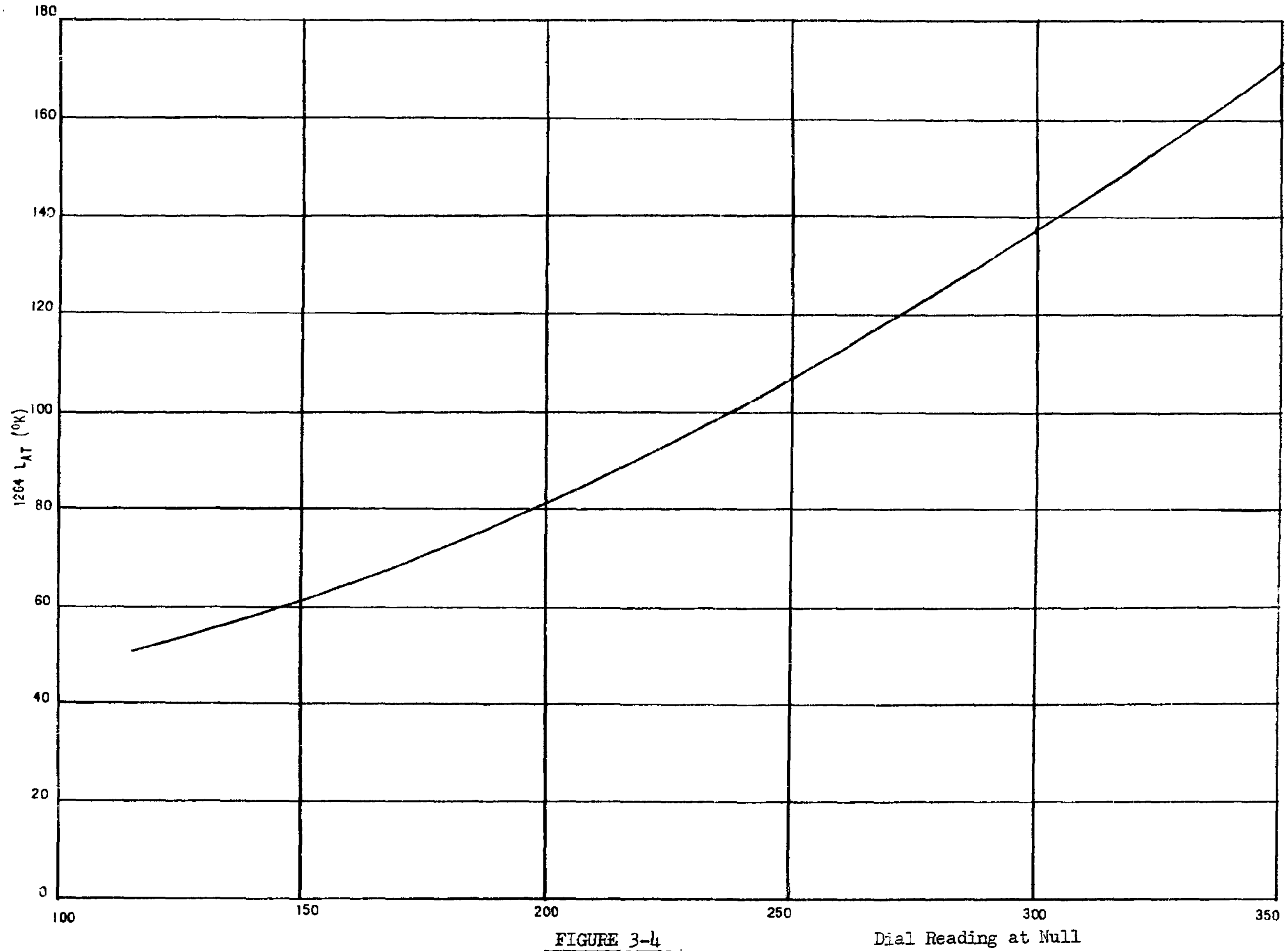

FIGURE 3-4

RAINY CALIBRATION CURVE

3.2 Personnel Measurements

Of all targets used in the field program, personnel provided the least contrast with the background and hence were the most difficult to detect. Table 3-1 lists the measured temperature (T_M) for each target viewed along with its measured temperature differential (ΔT_M). ΔT_M is the difference between the measured temperature of a target with its background and the measured temperature of the background alone. The radiometric temperature of a target has significance only when related to the environmental conditions surrounding it at the time of measurement. These environmental conditions include air temperature, type of cloud cover, degree of shade as well as the apparent temperature of the ground and the target position. Apparent ground temperature is also a function of the environmental conditions just mentioned. In view of this, and in consideration of the fact that most range equations are in terms of target-background temperature differential, the most significant term presented in the tables is that of ΔT_M.

At the ranges of personnel measurements (less than 50 yards) the beam subtends a two foot diameter circle. It was centered on the upper portion of the soldiers chest so that his helmet would be included in the beam area. Because the physical shape of the target prevented it from filling a two foot diameter circle, the temperature measured (T_M) does not correspond to the apparent temperature discussed in Appendix A. For certain ranges in the tank runs, however, the target does completely fill the beam and the measured temperature, T_M is equal to the apparent temperature, T_a.

In comparing the three different views (Table 3-1), it can be seen that the side view resulted in the largest ΔT_M, the front view the next largest, and the prone view the smallest. This can be understood by considering the target temperature measured by the radiometer is heavily dependent upon the amount of metal on the target, specifically the helmet, which is reflecting colder radiation from the sky. This creates a temperature differential when viewed by the radiometer against a hot background of earth. In the side view, a greater helmet area is exposed to the dish than in a front view, thus the larger ΔT_M. The prone position has a smaller ΔT_M than the front view because the reflection of sky radiation by the helmet is the only contribution to the total measured ΔT_M. In the front position other contributions are made by other portions of the target as well as the helmet.

Repeat of the three basic views at night showed almost exact correlation with the ΔT_M's of the same views taken during the day. During rain runs, the greater ΔT_M of the prone view over the front view is a probable result of the solider lying in a large puddle of water. Hence the ΔT_M of the prone view was increased by the sky reflection off the water.

TABLE 3-1

PERSONNEL MEASUREMENTS

TARGET - SOLDIER IN FULL BATTLE DRESS, R = 50 YARDS

RUN NO.	TARGET CONDITION	TIME OF DAY	WEATHER CONDITIONS: TYPE OF DAY	TEMP. (°C)	REL. HUM. (%)	LIGHT CONDITIONS: INCIDENT ON DISH	REFLECTED FROM TARGET	T_M (°K)	T_B (°K)	ΔT_M (°K)
P-1	FRONT VIEW, DAYTIME	9 AM	OVERCAST	+4	[illegible]	22	FACE = 50 BODY = 25	194	197	3
P-3	SIDEVIEW, DAYTIME	9 AM	OVERCAST	+4	[illegible]	22	FACE = 50 BODY = 25	192.5	197	4.5
P-7	PRONE, VIEW, DAYTIME	[illegible] PM	FAIR	+[illegible]	[illegible]	[illegible]	HELMET = 75 FACE = 25	195.5	197.5	2
P-2	FRONT VIEW, NIGHTTIME	7 PM	CLEAR SKY	+1.5	[illegible]	--	--	203	205.5	2.5
P-4	SIDE VIEW, NIGHTTIME	7 PM	CLEAR SKY	+1.5	56	--	--	201	205.5	4.5
P-8	PRONE VIEW, NIGHTTIME	7 PM	CLEAR SKY	+[illegible]	[illegible]	--	--	207.5	209.5	2
P-5	FRONT VIEW,* DAYTIME	[illegible] AM	[illegible] RAIN	+[illegible]	[illegible]	[illegible]	FACE = 20 BODY = 15	202	204	2
P-9	PRONE VIEW,* DAYTIME	[illegible]:30 AM	[illegible] RAIN	+[illegible]	[illegible]	[illegible]	FACE = 20 BODY = 15	197	200	3

* TAKEN AT 25 YDS.

None of the ΔT_M's of the soldier target exceeded $5^{\circ}K$. The target filled more than 75% of beam area and it may be assumed that if the beam were completely filled the ΔT_a would not be more than $7^{\circ}K$ for even the most favorable position.

3.3 Tank Measurements

The tank targets, due to a large mass of relatively high reflectivity metal, provided sizable thermal contrasts with their backgrounds of low reflectivity ground and trees. These contrasts are largest when the tank completely fills the radiometer beam at the shorter ranges and get progressively smaller as the beam area becomes larger than the tank at greater ranges and the background temperature is integrated into the radiometer output along with the tank temperature.

Even though a large number of runs were taken (1/2 total number of tank measurements) with the tank engine on, there was no noticeable effect on its apparent temperature from that of the engine off condition. This may be seen by comparing runs (T-3, T-4), (T-5, T-6), and (T-9, T-10) to cite just a few representative runs. In addition to data supporting this fact obtained during the regular tank measurements, special supplementary runs were taken to investigate it further. The results of these are described in Section 3.4.1. In the few instances where there are substantial differences between the engine on-engine off condition, the runs were taken on different days and a variation in weather conditions explains the difference in the ΔT_M's. Since the engine on condition had no effect, the runs where this was the only parameter changed will be used to reinforce data taken in the corresponding engine-off condition if the data was taken on the same day, and to study the effects of weather on the ΔT_M's if the data for the engine on-engine off conditions were taken on different days.

The measured temperatures (T_M), apparent background temperatures (T_B), and measured temperature differentials (ΔT_M) are listed for all tank targets in Table 3-2. In cases where the target completely fills the beam, primarily at 50 yds, T_M and ΔT_M are equal respectively, to the apparent temperature (T_a), and the difference between the apparent temperatures of target and background (ΔT_a). This is indicated as such in the table. In addition, the environmental conditions accompanying each temperature measurement are also listed.

3.3.1 Apparent Tank Temperatures and Differentials, R= 50 yds.

At the 50 yard range the temperatures measured on the pen recorder (T_M) are equal to the apparent temperatures (T_a) since the targets completely fill the radiometer beam. Hence the term ΔT_M^a becomes ΔT_a signifying the difference in apparent temperatures between the target and its background. Table 3-3 lists the ΔT_a's of all the 50 yd runs together for the purpose of comparison. At 50 yds the radiometer beam is 2-1/2 feet in diameter so that three separate azimuth sweeps across the tank at 3 values of elevation were taken. The positions of these sweeps may be seen by referring to figures 2-7 and 2-10 where the centers of the sweeps are marked by white dots on the photographs, or to Figure 2-9 where the sweeps are marked clearly on a line drawing of the tank.

TABLE 3-2

TANK MEASUREMENTS

TARGET M48A2 FULL TRACKED COMBAT TANK

RUN NO.	TARGET CONDITION	TIME OF DAY	WEATHER CONDITIONS: TYPE OF DAY	WEATHER CONDITIONS: TEMP. (°C)	WEATHER CONDITIONS: REL. HUM. (%)	LIGHT CONDITIONS (CANDLES PER SQ. FT): INCIDENT ON DISH	LIGHT CONDITIONS (CANDLES PER SQ. FT): REFLECTED FROM TARGET	T_M (°K)	T_B (°K)	ΔT_M (°K)
T-1	FRONT VIEW, 50 YDS, ENGINE OFF. SWEEP "A" SWEEP "B" SWEEP "C"	2 PM	OVERCAST, RAINY	+7.3	31	10	TURRET=10 THREADS=15	213.5 199 191.5	221.5 222.5 223	8 23.5 31.5
T-2	FRONT VIEW, 50YDS, ENGINE ON. SWEEP "A" SWEEP "B" SWEEP "C"	11:15 AM	LIGHT CLOUDS, BRIGHT	+0.4	51	70	TURRET=150 TREADS=20	144 119.5 129	181 177.5 172	37 58 43
T-3	FRONT VIEW, 300 YDS, ENGINE OFF	9 AM	HEAVY CLOUDS	-1.3	75	10	TURRET=10 TREADS=5	191.5	197.5	6
T-4	FRONT VIEW, 300 YDS, ENGINE ON	9 AM	HEAVY CLOUDS	-1.3	75	10	TURRET=10 TREADS=5	190.5	196.5	6
T-5	FRONT VIEW, 500 YDS, ENGINE OFF	[illegible] PM	CLOUDY, OVERCAST	+2.1	81%	50	TURRET=25 TREADS=10	124.5	129.5	5
T-6	FRONT VIEW, 500 YDS, ENGINE ON	[illegible] PM	CLOUDY, OVERCAST	+2.1	81%	50	TURRET=25 TREADS=10	124	129.5	5.5
T-7	BACK VIEW, 50 YDS, ENGINE OFF. SWEEP "A" SWEEP "B" SWEEP "C"	9 AM	CLOUDY, OVERCAST	+3.6	73		TURRET=60 TREADS=10	173 132 148	199.5 195.5 191	26.5 63.5 43
T-8	BACK VIEW, 50 YDS, ENGINE ON. SWEEP "A" SWEEP "B" SWEEP "C"	2:30 PM	LIGHT CLOUDS, BRIGHT	+0.3	51		TURRET=100 TREADS=5	146 118.5 132.5	181 177.5 172	35 59 39.5

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TABLE 3-2 (CONT.)

TANK MEASUREMENTS

TARGET M48A2 FULL TRACKED COMBAT TANK

RUN NO.	TARGET CONDITION	TIME OF DAY	WEATHER CONDITIONS TYPE OF DAY	WEATHER CONDITIONS TEMP. (°C)	REL. HUM. (%)	LIGHT CONDITIONS CANDLES PER SQ.FT INCIDENT ON DISH	LIGHT CONDITIONS CANDLES PER SQ.FT REFLECTED FROM TARGET	T_M (°K)	T_B (°K)	ΔT_M (°K)
T-9	BACK VIEW, 300 YDS, ENGINE OFF	2:45 PM	SNOW, OVERCAST	+1.5	64	20	TURRET=20 TREADS=5	178.5	180.5	2
T-10	BACK VIEW, 300 YDS, ENGINE ON	2:45 PM	SNOW, OVERCAST	+1.5	64	20	TURRET=20 TREADS=5	178.5	180.5	2
T-11	BACK VIEW, 500 YDS, ENGINE OFF	8:45 AM	CLOUDY, OVERCAST	-0.3	57	25	TURRET=100 TREADS=10	183.5	190.5	7
T-12	BACK VIEW, 500 YDS, ENGINE ON	9:45 AM	CLOUDY, OVERCAST	-0.3	57	25	TURRET=100 TREADS =10	184.5	191	6.5
T-13	SIDE VIEW, 50 YDS, ENGINE OFF.	3:10 PM	BRIGHT SUN, CLEAR	+14	32		TURRET=35 TREADS=15			
	SWEEP "A"							186.5	193	6.5
	SWEEP "B"							127	190.5	63.5
	SWEEP "C"							131.5	183.5	52
T-14	SIDE VIEW, 50 YDS, ENGINE ON.	10:00 AM	OVERCAST, RAIN	+8.2	75		TURRET=15 TREADS=10			
	SWEEP "A"							251	256	5
	SWEEP "B"							219	257.5	38.5
	SWEEP "C"							231	258	27
T-15	3/4 REAR VIEW, 50 YDS, ENGINE OFF.	3:00 PM	HIGHLY OVERCAST	+5.5	58%	15	TURRET=10 TREADS=10			
	SWEEP "A"							166.5	178.5	12
	SWEEP "B"							116.5	177.5	61
	SWEEP "C"							122	175	53
T-16	3/4 REAR VIEW, 50 YDS. ENGINE ON.	2:00 PM	CLOUDY, OVERCAST	+3.8	73	15	TURRET=35 TREADS=15			
	SWEEP "A"							179	196	17
	SWEEP "B"							128.5	194	65.5
	SWEEP "C"							140	188	48

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TABLE 3-2 (CONT.)

TANK MEASUREMENTS

TARGET M48A2 FULL TRACKED COMBAT TANK

RLN NO.	TARGET CONDITION	TIME OF DAY	WEATHER CONDITIONS: TYPE OF DAY	WEATHER CONDITIONS: TEMP. (°C)	WEATHER CONDITIONS: REL. HUM. (%)	LIGHT CONDITIONS CANDLES PER SQ. FT: INCIDENT ON DISH	LIGHT CONDITIONS CANDLES PER SQ. FT: REFLECTED FROM TARGET	T_M (°K)	T_B (°K)	ΔT_M (°K)
T-17	3/4 REAR VIEW, 300 YDS, ENGINE OFF	9:30 AM	CLOUDY, OVERCAST	+2.2	47	15	TURRET=35 TREADS=20	194.5	203.5	9
T-18	3/4 REAR VIEW, 300 YDS, ENGINE ON	1:00 PM	SUNNY, NO CLOUDS	-3.8	31	140	TURRET=50 TREADS=20	161	154	+7
T-19	3/4 REAR VIEW, 500 YDS, ENGINE OFF	3:45 PM	SUNNY, NO CLOUDS	-3.0	32	10	TURRET=25 TREADS=5	144.5	150	5.5
T-20	3/4 REAR VIEW, 500 YDS, ENGINE ON	3:45 PM	SUNNY, NO CLOUDS	-3.0	32	110	TURRET=25 TREADS=5	128	133.5	5.5
T-22	BACK VIEW, 50 YDS, CAMOUFLAGE OFF. SWEEP "A" SWEEP "B" SWEEP "C"	8:45 AM	CLOUDY, OVERCAST	+3.5	79	50		137 141 110	155.0 155 157.5	18 14 47.5
T-23	BACK VIEW, 50 YDS, CAMOUFLAGE ON. SWEEP "A" SWEEP "B" SWEEP "C"	8:45 AM	CLOUDY, OVERCAST	+3.5	79	50	---	142 149.5 143	153 155.5 153	11.0 6.0 10.0
T-24	BACK VIEW, 300 YDS, CAMOUFLAGE OFF	8:45 AM	CLOUDY, OVERCAST	+3.5	79	50	---	152.5	149.5	+3.
T-25	BACK VIEW, 300 YDS, CAMOUFLAGE ON	8:45 AM	CLOUDY, OVERCAST	+3.5	79	50	---	148	144	+4
T-26	BACK VIEW, 500 YDS, CAMOUFLAGE OFF	8:45 AM	CLOUDY, OVERCAST	+3.5	79	50	---	198.5	201	2.5
T-27	BACK VIEW, 500 YDS, CAMOUFLAGE ON	8:45 AM	CLOUDY, OVERCAST	+3.5	79	50	---	198.5	200.5	2

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TABLE 3-2 (CONT.)

TANK MEASUREMENTS

TARGET M48A2 FULL TRACKED COMBAT TANK

RUN NO.	TARGET CONDITION	TIME OF DAY	WEATHER CONDITIONS: TYPE OF DAY	WEATHER CONDITIONS: TEMP. (°C)	WEATHER CONDITIONS: REL. HUM (%)	LIGHT CONDITIONS CANDLES PER SQ. FT: INCIDENT ON DISH	LIGHT CONDITIONS CANDLES PER SQ. FT: REFLECTED FROM TARGET	T_M (°K)	T_B (°K)	ΔT_M (°K)
T-29	FRONT VIEW, 100 YDS, ENGINE OFF, SKY BACKGROUND.	2:00 PM	CLOUDY, OVERCAST	+5	63	10	TURRET=5 TREADS=5	118	129.5	11.5
T-30	FRONT VIEW, 100 YDS, ENGINE ON, SKYBACKGROUND .	2:00 PM	CLOUDY, OVERCAST	+5	63	10	TURRET=5 TREADS=5	118.5	130	11.5
T-31	SIDE VIEW, 100 YDS, ENGINE OFF, SKY BACKGROUND.	2:00 PM	CLOUDY, OVERCAST	+5	63	10	TURRET=5 TREADS=5	106.5	122	15.5
T-32	SIDE VIEW, 100 YDS, ENGINE ON, SKY BACKGROUND.	2:00 PM	CLOUDY, OVERCAST	+5	63	10	TURRET=5 TREADS=5	107.5	123.5	16
T-34	3/4 REAR VIEW, 150 YDS, ENGINE OFF, SHADE.	8:45 AM	SUNNY, CLEAR	+3	36	270	TURRET=20 TREADS=10	196.5	200.5	4
T-35	3/4 REAR VIEW, 150 YDS, ENGINE ON, SHADE.	8:45 AM	SUNNY, CLEAR	+3	36	270	TURRET=20 TREADS=10	196.5	201	4.5
T-36	SIDE VIEW, 300 YDS, ENGINE OFF, NIGHT	6:30 PM	CLEAR NIGHT	-4.1	41	——	——	164.5	158	+6.5
T-37	SIDE VIEW, 300 YDS, ENGINE ON, NIGHT	6:30 PM	CLEAR NIGHT	-4.1	41	——	——	161.5	155.5	+6
T-38	BACK VIEW, 300 YDS, ENGINE OFF, NIGHT	6:30 PM	CLEAR NIGHT	-4.1	41	——	——	162	154.5	+7.5
T-39	BACK VIEW, 300 YDS, ENGINE ON, NIGHT	6:30 PM	CLEAR NIGHT	-4.1	41	——	——	162.5	155	+7.5

* These runs made at ranges such that $T_M = T_a$ and $\Delta T_M = \Delta T_A$.

<u>KEY</u> (Applies to Tables 3-1 and 3-2)

T_M = Measured Temperature. Actual temperature measured by radiometer, representing combined temperature of all objects, target and background, included in radiometer beam.

T_B = Background temperature. Temperature of the background

ΔT_M = Measured Temperature Differential. Difference between background temperature (T_B) and combined target and background temperature (T_M).

T_a = Apparent Temperature. Special case of T_M where beam is completely filled by target.

ΔT_a = Apparent Temperature Differential. Difference between background temperature and apparent temperature of target.

Apparent Temperature Differentials (ΔT_a), (^oK)

	Front		Back		Side		3/4 Rear	
	*T-1	T-2	T-7	T-8	T-13	*T-14	T-15	T-16
Sweep "A"	8	37	26.5	35	6.5	5	12	17
Sweep "B"	23.5	58	63.5	59	63.5	38.5	61	65.5
Sweep "C"	31.5	43	43	39.5	52	27	53	48
Average	21	45	44.4	44.5	40.6	23.5	42	43.5
	Rain					Rain		

TABLE 3-3

TANK APPARENT TEMPERATURE DIFFERENTIALS, R=50 yds.

*NOTE: It can be clearly seen from Table 3-3 that Runs T-1 and T-14 have considerably lower ΔT_a's for each sweep than the remaining runs. This is because T-1 and T-14 were taken during a moderate rain (4mm/hr) while the other runs were taken either in fair or moderately cloudy weather. Therefore, since they represent a special weather condition they are only included in this table for the purpose of completeness. The discussion of the results listed in Table 3-3, that follows, will be exclusive of these two runs. They will be considered under a later Section (3.3.8), weather effects.

Reference to Table 3-3 shows that the ΔT_a's of each sweep for the front and back views correspond closely, as do those of side and 3/4 rear views. This is explained by the similarity in physical appearance between views: the back-view roughly resembling the front, and the 3/4 rear view being but a slight modification of the side view. It is also interesting to note that the ΔT_a's for sweep "B" through the center of the tank, are the largest of the three sweeps and almost identical for all four views. In addition, the ΔT_a's of sweep "A" for the side and 3/4 rear views are smaller than the corresponding ones for the front and back views. This is to be expected since the bogey wheels of the side view do not have as smooth a reflecting surface as the front of the treads. However, the sweep "C" values for the side and 3/4 rear views are higher than those of the front and back because of the larger area of smooth turret surface. Thus, we see in general that smooth surfaces at an angle approximately 45° with the horizontal (see Section 3.4.8) better reflect the cold sky temperatures and hence provide larger contrasts with the background than surfaces that are irregular and at oblique angles. The relative difference in ΔT_a's between different sweeps and views may be explained solely by the presence or absence of such surfaces.

To obtain the average apparent temperature differential over the entire tank the values of ΔT_a for the three sweeps are numerically averaged for each view. These are presented in the last column of Table 3-3 and form the most important part of the table since they represent the "apparent temperature differentials of a tank". They vary in value from 40.6°K to 45°K a spread of only 4.4°K. The close grouping indicates that high and low contrast sweeps for different views averaged out to the same value. It may also be stated that the temperature differential between the tank and its background is essentially constant for all viewing angles of the tank, the value being 43°K for this grouping of data.

The apparent temperatures of the tank target for all 4 views are listed in Table 3-4. The averages of the three sweeps, found in the last column of the table, range from 130.8° to 151°K exclusive of the rain runs. The total range of apparent temperatures for all weather conditions from fair to moderate rain (4 m.m./hr) is from 130.8°K to 233.6°K or about 100°K. This agrees with the increase in sky temperature of 100°K due to moderate rain as reported in Ref. 13. Reference to the weather data in Table 3-2 shows that the fairest days produced the lowest T_a's while the rainy days produced the highest T_a's. This is to be expected with a target of high reflectivity. It may also be noted that the background temperature decreases from sweeps A to C as the radiometer is raised in height since more of the horizon is included in the beam.

Apparent Tank Temperatures (T_a) (°K)

	Front		Back		Side		3/4 Rear	
	T-1	T-2	T-7	T-8	T-13	T-14	T-15	T-16
Sweep "A"	213.5	144	173	146	186.5	251	166.5	179
Sweep "B"	199	119.5	132	118.5	127	219	116.5	128.5
Sweep "C"	191.5	129	148	132.5	131.5	23[illegible]	122	140
Average	201.3	130.8	151	132.3	148.3	233.6	135	150.3
	Rain					Rain		

TABLE 3-4

TANK APPARENT TEMPERATURES R = 50 yards

3.3.2 Measured Tank Temperature Differentials at Other Ranges R = 300, 500 yards

Tanks were placed at ranges greater than 50 yds to see if they were detectable and if so the magnitude of their temperature differential. In addition, the data obtained from these runs permitted verification and check of the range equation, derived in Appendix D, once the value of tank apparent temperature was known from the runs made at 50 yds.

The ΔT_M's for the 300 and 500 yard runs are listed in Table 3-5. A sample calculation on the data from T-11 using eq. 4 Appendix D, yields a measured temperature differential of $8^{\circ}K$ with the background. This compares favorably with the ΔT_M of $7^{\circ}K$ actually measured.

Measured Temperature Differentials ΔT_M, ($^{\circ}K$)

Range	Front		Back		3/4 Rear	
	T-3	T-4	T-9	T-10	T-17	T-18
300 (yards)	6	6	2	2	9	+7
	T-5	T-6	T-11	T-12	T-19	T-20
500 (yards)	5	5.5	7	6.5	5.5	5.5

TABLE 3-5

MEASURED TANK TEMPERATURE DIFFERENTIAL R=300,500 yards

The ΔT_M's for the 300 yard runs are much smaller than those predicted by the equation. In fact, the measured temperature of the tank in run T-18 was actually hotter than the background. Reference to Table 3-2 shows that all the remaining 300 yard runs including those with camouflage (T-24, T-25) and the night runs (T-36 through T-39) indicate measured temperatures that are also hotter than the background. Hence, we are faced with the unusual result that all the 300 yd tank measurements taken show either a ΔT_M smaller than it should be or even a positive ΔT_M that shows the tank to be hotter than the background. Measurements taken at every other range, even on the same day and under exactly the same conditions as the 300 yd runs, indicate the tank to be colder than the background by a ΔT_M predictable from the range equation. Careful study of all 300 yd data and photographs of the test range revealed the cause of these unusual results. The test procedure used to obtain the tank measurements (described in Section 2.2) involves first balancing the radiometer out on the target. The difference between the two resulting dial readings on the reference potentiometer being proportional to the difference in temperature between the background to the right of the target and the combined temperature of the target and that portion of the background immediately behind it that is included in the beam. Apparently, at the radiometer elevation needed to center the beam on the 300 yd target, there is a change in background temperature as a function of azimuth angle which does not exist at either of the dish elevations corresponding to the 50 or 500 yd ranges. This irregularity, which might be caused by the dip in the tree line illustrated in Figure 2-16, provides a background temperature to the right of the target that is somewhat lower than the temperature of the background immediately behind it. Hence, after balancing out on this cold portion of the background the tank with its hotter background provided a less negative ΔT_M than might be expected and in some runs even a positive one.

3.3.3 Camouflage Runs

The effect of placing a comouflage net on the tank was to increase its apparent temperature. Reference to Table 3-2, runs T-22 and T-23, shows that the average ΔT_a was reduced by two-thirds, from a $\Delta T_a = 27^oK$ to a $\Delta T_a = 9^oK$, by the introduction of the camouflage. This decrease in temperature differential is a result of the net shielding the tank from the incident sky radiation (See Figure 2-16). The positive ΔT_M's obtained at the 300 yard range (T-24, T-25) are explained in the preceding section. However, the relative differentials still indicate the "camouflage on" condition to be the warmer of the two. At the 500 yd range the targets are still detectable with camouflage.

3.3.4 Sky Background Runs

Reference to runs T-29 through T-32 in Table 3-2 indicates that the apparent temperatures of the tank were lower than the background even when the background was the sky at the horizon (See Figure 2-20). This is a result of apparent sky temperature being warmest at the horizon. The tank reflected an integrated temperature from the entire sky, which was colder than that at the horizon, and hence, it appeared colder than its horizon background. The temperature differentials measured are not as great as those obtained when the background was earth or trees whose temperatures are considerably warmer than the horizon. Therefore, on a rainy day when the entire sky is warmer, one might expect more difficulty detecting a tank against a sky background than against one of trees or hills. The side view, with its greater area of smooth reflecting surfaces, produced a slightly larger ΔT_a than did the front view.

3.3.5 Shade Runs

A smaller ΔT_M is to be expected between the tank and its background if the former is in any way shielded from the cold radiation of the sky. A natural shielding effect of this sort takes place when the tank is in a shaded environment. Since the field test was performed during the winter months, not much shading was available. Nevertheless, the tank was placed in a wooded area and in addition, behind an amount of foliage such that it was difficult to visually view. (Figure 2-22 pictures the target condition. The tank, with its driver standing atop it, is just barely discernible at the left of center). Table 3-2, Runs T-34, T-35, indicates a ΔT_a of about 4.5°K which is considerably smaller than one would expect if the target were in an open field at the same range. However, it is still significant to note that the tank may be detected radiometrically even when it is all but invisible to the naked eye.

3.3.6 Night Runs

Because of the unusual background condition at 300 yds, described in Section 3.3.2, the night runs, which were all made at this distance, provided positive temperature differentials and appeared warmer than their background. Since the degree of background irregularity is unknown and the lateral postion of the tank with respect to it variable on each occasion, it is not possible to compare the night measurements with those taken during the day at other ranges. However, one may note (Table 3-2 Runs T-36 through T-39) that they are consistent among themselves and the ΔT_M's compare in magnitude with those of some of the 300 yd measurements taken during the day. From the results of the night personnel runs (Section 3-2) one might expect little change in the ΔT_M's of a tank between day and night conditions provided the amount of cloud cover remained the same.

3.3.7 Target Identification

Throughout the course of the field test program, it was noticed that on certain of the data tapes obtained there was a correlation between the physical properties of the tank and the shape of the resulting curve. This is clearly indicated in Figure 2-11 which shows sweep "A" across the back view of a tank. The presence of the treads on either side of the open space in the bottom center of the tank is reflected in the corresponding curve. This occurred at a range of 50 yds where the beam is only 2-1/2 feet in diameter. At 500 yds, where the beam is considerably larger than the tank, Figure 2-15 shows that the same back view gives another characteristic indication on the tape. Here, an observer might note that the target he is viewing is symmetrical because of the symmetry indicated on the curve. Note: The curve on the left of Figure 2-15 is asymmetrical because the signal peak was nulled out to obtain its temperature as explained in Section 2-2.

A side view at the 300 yd range generates a different shaped curve (Figures 2-21, 2-24). The sweep is made from the back to the front(gun points to the rear in all measurements made) of the tank. The curve builds up to a peak slowly and then falls off sharply. This corresponds to the shape of the tank whose cross-sectional area is small over the back, increases to a maximum at the turrets and then falls off to nothing at the front.

Thus, not only may we obtain information about the location of target from its measured temperature but also to some extent, identification by examining the shape of its temperature curve. The instrument used in the field program was not designed specifically for target identification purposes. However, some of the data obtained from it indicates that identification capabilities might be realized from future passive radiometric systems which have appropriate beam widths, uniform azimuth sweeps and other features which lend themselves to this application.

3.3.8 Weather Effects

According to radiometric theory, the apparent temperature of a target is affected by the environmental conditions surrounding it. If the object is of high reflectivity, the illumination condition of the sky becomes the significant factor in determining its temperature. The temperatures of objects of low reflectivity are not affected by the sky condition but are a function of their thermodynamic temperatures. During the field program, measurements were obtained over a variety of climatic conditions to enable study of the effect of various weather states upon detection range.

The results listed in Table 3-2 show that changes in air temperature, relative humidity, light conditions, time of day, and the thermometric temperature of the tank all played a relatively minor role in determining apparent temperature differentials between the tank and its background. In addition, it is important to note that normal changes in cloud cover from clear skys to heavy clouds did not appreciably change the sky temperature so that the ΔT_a's taken during these conditions did not vary significantly. This is illustrated in Table 3-3. The weather conditions for the 6 runs (excluding the rain runs) vary from fair to heavily overcast and yet there is a spread in the average apparent temperature differentials of only $4.4^{\circ}K$. The only climatic condition that was found to play a major role in changing target background temperature differentials was rain. As illustrated in Table 3-3, a moderate rain (4m.m./hr) reduced the average ΔT_a from $43^{\circ}K$ to $22^{\circ}K$, or about 51% of its original value. This reduction in contrast is predominately caused by the increased sky temperature due to the rainfall. Only a small portion of the reduction is caused by attenuation by the rain of the microwave signal between the target and the radiometer. The fact that the target-background differential is hardly affected by a change from fair to cloudy weather and is largely reduced when the weather turns to moderate rain, may be explained through reference to the sky temperature curves in Figure 3-1. It may be seen that there is but a small difference in sky temperature between the clear and moderately cloudy states but quite a large increase in temperature for the moderate rain condition.

3.4 Supplementary Measurements

3.4.1 Tank Warm-Up

Examination of the initial data from the tank runs indicated that engine temperature had no effect on the apparent temperature of the tank. To substantiate this result, the conditions described in Section 2.4.1 were set up. The tank used was one that had a distributed type exhaust with the combustion gasses passing through a finned area of about 9 square feet. At the 25 yd tank range the radiometer beam was only 2 feet in diameter, and was directed so that the entire beam was subtended by the finned area. If there was any effect on T_a due to engine temperature, it would certainly be detected under these circumstances. Thermocouples placed on the side of the engine compartment and on other parts of the tank indicated that the "engine on" condition produced little if any temperature rise in these areas. There were four runs taken of this target condition. Each of them showed stable and constant radiometer outputs before the tank engine was turned on, and an immediate rise of between 3°K and 7°K, above the balance point for a cold tank, after engine ignition. This small rise in temperature distributed over the exhaust area (only 9 square feet) was not of sufficient magnitude to effect the apparent tank temperature at ranges greater than 25 yds and did not have a noticeable effect on the regular tank measurements. Theoretically, this temperature rise should disappear after the tank engines have been turned off. However the two hour period of time required for this cool-off was longer than the stability period of the radiometer, and shifts in the balance point prevented the verification of this expected result.

3.4.2 Tank Rotation Runs

Rotation of the tank at a range of 100 and 300 yds indicated that both front and back views gave similar contrasts with their background and were the minimum of any view. The 3/4 view gave the greatest contrast being about 14°K larger than either the front or the back. Figure 2-25 indicates the profile obtained at the 100 yd range. The signal from the back view does not drop to the front view level in this tape, because the speed of rotation had to be increased in that position in order to prevent stalling. This tape clearly indicates that the signal from the 3/4 view is the largest while the returns from the sides are intermediate between the front and 3/4 view signals. The 300 yd rotation run, (Figure C-6) was taken at a constant tank rotation speed and clearly indicates identical temperatures for the front and back tank views.

3.4.3 Truck Runs

The 2 1/2 ton truck was the largest target viewed with the radiometer. It had vertical sides and its only curved surfaces were the front hood and the front fenders. Table 3-6 shows the T_M, T_B, and ΔT_M for this target. Reference to Figures 2-27, 2-28 and 2-29 shows that the truck apparent temperature differentials at 50 yds varied widely with the surface within the beam. In the side view, large signals were obtained from the curved front hood and front fender while smaller differentials resulted from the wheels and the vertical main body. The front view, with its large proportion of curved surfaces, produced uniformly high ΔT_a's. The elevation positions of the four azimuth sweeps are indicated by the tape marks in Figure 2-26.

Run No.	Target Condition	T_M (°K)	T_B (°K)	ΔT_M (°K)	Weather
S-3	Side View, R=50 yds, *Sweep "A"	176	186	10	Cloudy
	Sweep "B"	166	186	20	Overcast
	Sweep "C"	176	188.5	12.5	
	Sweep "D"	169.5	192.5	23	
S-4	Front View, R=50 yds *Sweep "A"	176.5	186.5	10	Cloudy
	Sweep "B"	157.5	186.5	28.5	Overcast
	Sweep "C"	165	189.5	22.5	
	Sweep "D"	168.5	189	20.5	
S-5	Side View, R=300 yds	145	162	17	Sunny, Clear
S-6	Front View, R=300 yds	153	160	7	4" of
S-7	Side View, R=500 yds	152.5	161	8.5	Snow on
S-8	Front View, R=500 yds	156.5	162	5.5	Ground

TABLE 3-6

TRUCK MEASUREMENTS

* For these runs, range is such that $T_M = T_A$ and $\Delta T_M = \Delta T_A$.

At 50 yds, the average ΔT_a for the side view is 16.4°K and that for the front view is 20.7°K. For the 300 and 500 yd ranges, however, the side view gives a larger measured temperature differential because of its increased surface area (See Figure 2-30).

In the truck rotation runs, performed at 100 and 300 yds, the 3/4 rear view made the greatest contrast with the background, exceeding the front and back views by 20°K (Figure 2-31, C-6). The side view gives a ΔT_M about half-way between the maximum of the 3/4 rear view and the minimum of the front and back views.

3.4.4 Jeep Runs

Table 3-7 lists the T_a, ΔT_a and T_B of the jeep target at the 50 yd range. The elevation positions of the azimuth sweeps are shown in Figure 2-32.

Run No.	Target Condition	T_a (°K)	T_B (°K)	ΔT_a (°K)	Weather
S-16	Side View, Sweep "A"	164	181.5	17.5	Cloudy
	Sweep "B"	175.5	181.5	6	Overcast
S-17	Front View, Sweep "A"	157.2	178.5	21.3	Cloudy,
	Sweep "B"	159.5	181	21.5	Overcast

TABLE 3-7

JEEP MEASUREMENTS, R= 50 yds

As in the truck runs, the views with the greatest amount of curved surface provided the largest contrast with their background. Hence Sweep "A" of the side view and both sweeps of the front view have large ΔT_a's. Figure 2-33 shows the signal, which is at a low level along the canvas portion of the body, rise to a peak when the curved front hood is reached. The rotation runs, performed at 100 yds, indicate the largest ΔT_M to come from the front of the jeep, the smallest from the rear, with the sides occupying a position midway between the two extremes. The differential between front and back views is 10°K (See Figure C-8).

3.4.5 Napalm Fire Runs

The apparent temperature of burning napalm was found to be 320°K, or 147°K hotter than the background temperature of 173°K (Figure 2-34). This measurement was obtained at a range of 25 yds from a burning puddle of napalm. It is interesting to note that as the fire reduced in intensity the radiometer reflected this by gradually drifting to a cooler unbalanced condition after being balanced out originally on the hotter fire. A larger fire at a range of 100 yds from the radiometer gave a ΔT_M of + 15°K. The smoke from the burning napalm had no effect on the ΔT_a of a tank placed behind it. The ΔT_a from the tank was 66°K both before and after it had been completely obscured by the smoke (Figure 2-35, 2-36). A six second burst from a flame thrower was detected by the radiometer and found to have a ΔT_M of 7°K (Figure 2-37). However, the beam was not filled by the fire and therefore this is lower than it would be for an apparent temperature differential.

In addition to indicating the apparent temperature of napalm, these measurements served to show that targets which are hotter than their background are detectable with the radiometer.

3.4.6 Snow, Fog and Rain Runs

The effects of snow, fog and rain on the measured temperature differential of a tank target at a range of 300 yds are listed in Table 3-8. It can readily be seen that of all adverse weather conditions, rain reduces the ΔT_M of a tank the most. Snowfall and fog raise the sky temperature very little and hence do not have an important effect on the contrast between the tank and the background. Because of the relatively short target distances, the predominant cause of contrast reduction is an increased sky temperature rather than attenuation of the microwave signal over the detection range. See Figures 2-38 through 2-4[illegible].

Weather	Tank Target Condition	T_M (°K)	T_B (°K)	ΔT_M (°K)
Snow	Side View	131	143	12
(Moderate)	Front View	133	140	7
Fog	Side View	129	142	13
(Visibility = 150 yds)	Front View	133	142	9
Rain	Side View	198.5	202.5	4
(4mm/hr)	Front View	199.5	201.2	1.7

TABLE 3-8

SNOW, FOG AND RAIN MEASUREMENTS, R=300 yds

TANK TARGET

3.4.7 Tank Views From Cherrypicker

The results of viewing a tank target from above ground level at angles approaching 45° are significantly different from those obtained at ground level. The physical properties of this new situation provide an explanation for the difference. A much greater tank surface area is now exposed, 25 M^2 as compared to 10 M^2 from the ground. A large percentage of this area is flat and smooth and any energy reflections from it to the radiometer come exclusively from the sky. On the ground, however, the tank aspect angle presented many vertical and irregular surfaces which could reflect ground radiation into the radiometer as well as radiation from the sky. Also, from an elevated position the background is comprised entirely of ground whereas previously it contained part of the horizon. All these factors lead to prediction of a greater target-background contrast when the radiometer is in an elevated position than when it is at ground level. The measurements listed in Table 3-9 indicate this to be the case.

	SIDE VIEW			FRONT VIEW		
Aspect Angle (Deg)	T_A (°K)	T_B (°K)	ΔT_A (°K)	T_A (°K)	T_B (°K)	ΔT_A (°K)
10	80	182	102	97	173	76
20	97	184	87	56	172	116
30	79	188	109	86	182	96
40	80	188	108	59	182	123

TABLE 3-9

TANK TEMPERATURES FROM CHERRYPICKER

Pictures of the equipment set-up and a view of the tank from an elevation angle of 45° are found in Figures 2-42 through 2-45. The temperature differentials listed in Table 3-9 do not represent an average over the entire tank but only one particular spot. Lack of field test time prevented use of the sweep procedure employed when the radiometer was on the ground. However, it is interesting to note that the highest ΔT_a obtained from the ground measurements was 65°K, whereas the largest reading of the measurements taken from the air was 123°K. The results described in the next section lead to the expectation of even greater differentials when the radiometer is at a 45°

elevation angle with respect to the tank. During elevated measurements, fluctuations in ground temperature were noticeably less than those encountered at ground level. This quieter emission is a probable result of more uniformity of background due to a smaller intercepted area than at ground level and also the absence of variations along the horizon due to vegetation and sky conditions.

The cherrypicker was also used to determine the maximum detection distance of a tank target. The tank was detectable to a range of 1150 yds. The day that this measurement was taken was quite windy and the cherrypicker basket was blown about considerably thus causing difficulty in taking the measurement. It is expected that greater detection ranges could have been obtained under more favorable weather conditions.

3.4.8 Reference Surface Runs

The apparent temperatures of the microwave absorbing material reference surface taken at varying intervals during the program are listed in Table 3-10.

Run No.	T_B (°K)	Ref. Temp. (°K)	Weather
T-17	208.5	219.5	Cloudy, Overcast
T-9, T-10	186.5	197.5	Cloudy, Overcast
T-19, T-20	157	164	Sunny
T-5, T-6	136.5	145	Cloudy, Overcast
T-11, T-12	195.5	205	Cloudy, Overcast

Table 3-10

SOME REFERENCE SURFACE TEMPERATURES

The effects of wet and dry mud on the T_a of the aluminum reference are shown in Table 3-11.

Target - Condition - Weather - Clear	T_a (°K)
Microwave Absorbing Material	195
Plain Aluminum	88
Aluminum with 1/16" thick dry mud coating	96
Aluminum with 1/4 " wet mud coating	168
Ground	179

TABLE 3-11

EFFECTS OF MUD ON REFERENCE SURFACE TEMPERATURE

Both wet and dry mud reduce the reflected radiation from the sky.

Varying the angle between the aluminum reference surface and ground indicated that the greatest sky reflection occurred at an angle of 45°.

3.4.9 Audio Modulation Run

The set-up described in Section 2.4.9 indicated that there was no apparent audio modulation of the microwave signal from the tank caused by the vibrations of the engines.

4. CONCLUSIONS

at 35 KMC

1. It is possible to detect most battlefield objects with a microwave radiometer. This is true because the targets have a higher reflectivity than their background. They present a contrast with the hot background by reflecting the cold radiation from the sky. Targets included in this group are tanks, personnel, trucks and jeeps.

2. Most weather conditions have little effect on the capabilities of a microwave radiometer to detect battlefield targets. Fog, snow, and heavy clouds do not appreciably effect the target-background contrast. Moderate to heavy rain, does, however, degrade the performance of the unit due to a large increase in sky temperature.

3. Tank targets are still detectable by the radiometer even when covered with camouflage; obscured by smoke, hidden by vegetation or against a sky background. However, the contrast between target and background is reduced from that of an unobstructed view.

4. Some typical target-background apparent temperature differentials are:

	ΔT_a	
Soldier - full battle dress	7°K	colder than background
Tank	43°K	colder than background
Truck	20°K	colder than background
Jeep	21°K	colder than background
Napalm Fire	147°K	hotter than background

The engine temperature of a tank has no significant effect on its apparent temperature.

5. Use of the above figure for a tank in conjunction with the radiometer range equation and the state-of-art in equipment, indicates a tank detection range in excess of 3000 yards for a ground based radiometer.

6. Preliminary measurements indicate the distinct possibility of using passive microwave radiometry for short range homing missile guidance or for terminal guidance at longer ranges. A large increase in target-background contrast over that for a ground based system was observed when the radiometer was placed in a cherrypicker vehicle at elevation angles approaching 45° above the tank. In addition to contrasts up to 123°K obtained in the elevated position, fluctuations in ground temperature are less than those encountered at a ground level.

7. The field program indicated that target identification through radiometric means is possible. Correlation between the physical shape of the

target and the shape of its temperature curve showed the identification as well as the detection potential of a passive microwave system. An increased capability in this area might be realized from future systems which have appropriate beam widths, uniform azimuth sweeps and other features which lend themselves to this application.

8. Passive guidance studies conducted at GPL indicate that a microwave radiometer has a slight advantage over a similar IR device for the detection of vehicles on a clear day, and would have a much larger advantage under more severe weather conditions.

Report does not substantiate positive lock on - Doubt whether this should be claimed until proven -

5. RECOMMENDATIONS

1. Passive Guidance

Line-of-Sight (LOS) - Tank background contrasts measured in the field program indicate that use of radiometric line-of-sight guidance for a short range anti-tank missile is feasible. Kill ranges up to 800 yards could be expected with a system using state-of-the-art components. The missile would employ the radiometer for homing guidance and need only be aimed visually at the target to insure lock-on within the 800 yard range. While the data on hand indicates basic system feasibility, further study of tactical requirements and technical trade-offs would be needed.

Out of Line-Of-Sight (OLOS) - For tactical situations where the tank target is beyond the direct line-of-sight, preliminary data suggests that radiometric means could be used for terminal missile guidance. Target-background contrasts, which measurements indicate a double in magnitude to those obtainable in a line-of-sight situation, show that a missile launched on a ballistic path would be able to use these contrasts to enable course correction in the final phase of guidance. The increase in contrast is due to the greater elevation angle associated with a long range ballistic path missile as opposed to the small attack angle associated with a short range flat trajectory missile. To further investigate the contrasts that would be presented by targets to a missile borne radiometer, it is recommended that additional field tests be performed with the radiometer in an elevated position.

Recommended Field Program - The field program just completed has indicated that there are large contrasts between tanks and their backgrounds, and has measured the corresponding apparent temperature differentials. Calculations using these differentials in the radar range equation indicate the feasibility of both LOS and OLOS missile guidance using radiometric means. However, the field test described herein only provided the basic temperature contrasts and indicated the desireability of further study. Now that this first general step has been taken, additional tests are needed to investigate field conditions specifically related to the missile guidance problem. Hence it is recommended that a twelve week field study be instituted to obtain data that will be required for a detailed evaluation of the passive guidance concept. The program will be planned so as to combine investigations of field conditions pertinent to both LOS and OLOS guidance modes.

Some suggested areas of investigation with the radiometer mounted in the cherrypicker follow:

Measurement of apparent target - background contrasts at elevation angles appropriate to simulate the angle-of-attack of both a "flat" trajectory LOS missile and a "ballistic" trajectory OLOS missile. Targets would be viewed from different aspect angles (e.g. front, side, 3/4 rear). Measurements would be made of tanks, trucks, bunkers, buildings, roads, and concentration of troops.

Use of multiple targets, such as two adjacent tanks, to see the result of the combined contrasts in an effort to determine the ability of the missile to discriminate between them.

Rain has been shown to be the only atmospheric condition to have a serious effect on target-background contrasts. Hence, detailed measurements under this weather condition should be taken to specify exactly its bearing on the effectiveness of any future guidance system.

Various reports suggest an increase in target-background contrasts through the use of horizontal polarization. Therefore, part of the field program should study the comparative merits of each type of polarization. This data would be essential if the missile were not roll stabilized and the polarization were to change continually.

The effects of countermeasures and spoofing would be studied in the course of the field test. Water puddles, wire mesh and microwave absorbing material, would be used to simulate the effects of natural and man-made conditions on the effectiveness of a passive guidance system.

A detailed study of the natural contrasts inherent in any background situation would be needed in evaluating a passive guidance system. The magnitude of the natural contrasts between land, water, hard packed earth, grass and trees compared to the target-background contrasts in each of these environments should be determined through field test measurements.

The points on a target from which the coldest signal is seen in each of the attack angles for a LOS and OLOS should be determined.

In conjunction with the Army, various realistic tactical situations should be established, such as field measurements for a tank under conditions of complete and partial shade, or with a tank in woods and under shrubbery, so that the resulting contrasts could be considered in determining guidance system effectiveness.

2. <u>Passive Surveilance and Detection</u>

The data obtained from the field program just completed has also indicated the feasibility of passive target detection. Calculations indicate that tank detection ranges in excess of 3000 yards could be achieved with a system furnished with state-of-the-art components. Such a unit would be at its best advantage when maximum security from enemy detection is desired and/or when operating under adverse climatic conditions (snow, fog, rain, etc.). It is recommended that further study be given to this application to examine the operational requirements of such a detection system in conjunction with the tactical situations involved.

3. Procedure for Future Field Programs

Tank targets should be driven into and out of the beam in order to determine their ΔT_a instead of the beam being swept through a stationary target. This will prevent a background with temperature variations as a function of azimuth angle from causing erroneous contrast readings.

The method of calibration should be changed to one that uses both a hot and cold reference source. While no errors in ΔT_a were introduced by the sky calibration used in this field program, uncertainties in sky temperature created errors in the determination of absolute apparent temperature.

APPENDIX A

BASIC RELATIONSHIPS IN MICROWAVE RADIOMETRY

1. APPARENT TEMPERATURES

Energy emanates from all objects in the universe that are above a temperature of absolute zero. This release of energy is due to the random motion of the objects particles. If the temperature of the body is raised, the particles move more violently and more energy is emitted. Hence, a body at a particular temperature will emit more energy than the same body at a lower temperature.

The energy released takes the form of electromagnetic waves, which in the case of solids and liquids, are of every frequency in the spectrum. In our application, only the microwave portion of this frequency spectrum is of interest.

No perfect emitter (black body) exists in nature; all are imperfect to some extent because they reflect some of the energy incident upon them. The quality of the emitter is measured in terms of its emissivity ε. Emissivity is mainly a function of the surface properties of the object. It may be defined as the ratio of the energy emitted by the body to the energy emitted by a perfect emitter (black body) at the same temperature. To a first approximation, ε is constant independent of frequency or temperature.

Measurements have indicated that the microwave signal from a target depends not only on its self-emission, dependent on ε, but on the reflection by the target of the energy emitted by its surroundings which is dependent on its reflectivity, ρ. ρ is defined as the ratio of reflected energy to incident energy.

Thus, the microwave signal coming from a target consists of two parts; namely, that emitted by the target due to the thermal motions of its own molecules, and composed of radiation from surrounding objects reflected by the target. The magnitude of the first of these two signals depends upon the temperature of the target surface and upon its emissivity, as explained previously. The magnitude of the second signal depends upon the target's reflectivity, and upon the effective integrated temperature of the target's surroundings. This may be expressed in equation form as follows:

$$T_a = \varepsilon T_t + \rho T_s$$

where: T_a is the apparent temperature of the target

ε is its emissivity

T_t is its thermometric temperature

ρ is its reflectivity and

T_s is the integrated temperature of the surroundings

Thus, to obtain the apparent temperature of an object experimentally, careful consideration must be taken of the atmospheric and environmental conditions around it, since these determine T_s, the integrated temperature of the surroundings, in the above equation.

2. SENSITIVITY OF THE SWITCHED RADIOMETER

The form of the signal emitted by a gray body is, over practical bandwidths, flat, random noise, the average level of which depends upon the equivalent black body temperature of the source. The level of this noise is quite low for most terrestrial targets being in the order of 4×10^{-15} watts per megacycle. The noise generated by the detection and amplification portion of typical microwave receivers is many times larger than this number. Thus, the detection of noise type signals at the antenna is limited by the noise figure of the receiver. Furthermore, to be of practical use a radiometer should have the capability of detecting small changes in antenna noise temperature (less than 1^oK). Since the value of FT_o (F-receiver noise figure, $T_o = 290^oK$) is generally above 2500, amplification within the receiver must be stable to one part in several thousand to detect a change of 1^oK in the antenna temperature. This limitation is overcome through use of a switched radiometer at the expense of a decrease in sensitivity (normally 3 db).

A block diagram of a switched radiometer is shown in Figure A-1.

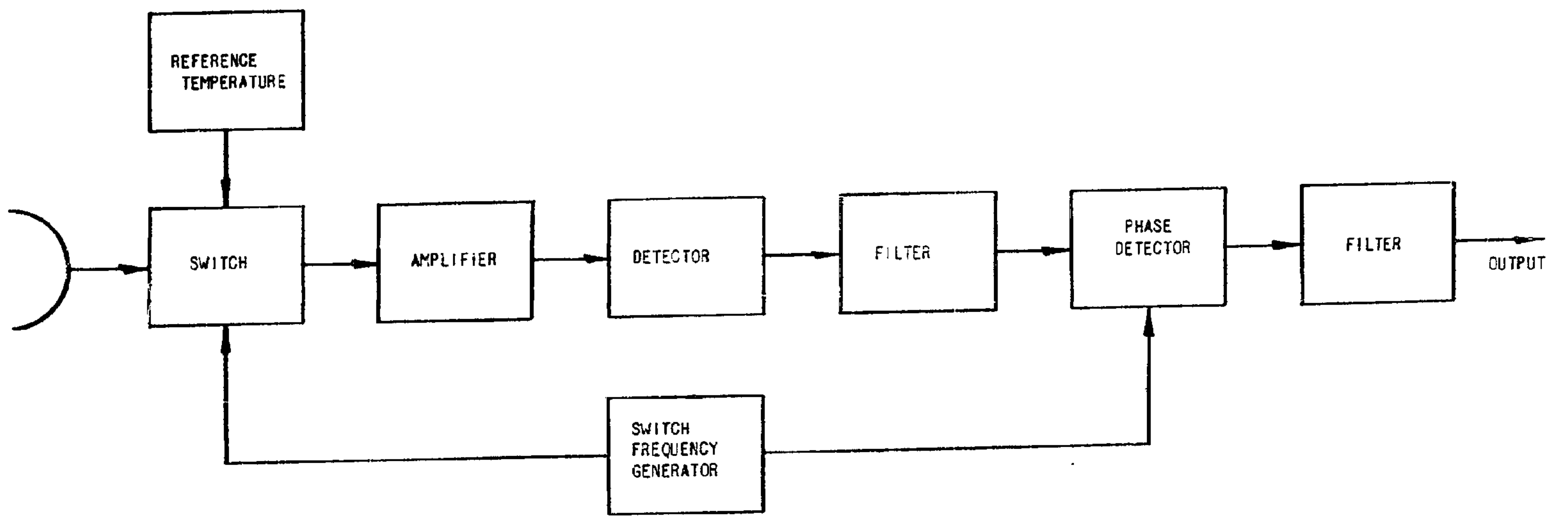


FIGURE A-1

SWITCHED RADIOMETER BLOCK DIAGRAM

As previously mentioned the input to the detector is normally subject to considerable fluctuation due to random variations in amplifier gain and also systematic variations due to power fluctuations, ripple, etc. To make the receiver insensitive to these variations, a convenient method is to rapidly switch the receiver between the antenna and a source of stable temperature at a frequency higher than that of the gain variation and fluctuation spectrum.

The output of the detector is then passed through a bandpass amplifier and a synchronous detector; the output then being applied to a low-pass filter. The difference between the received and reference signal is then not affected by low-frequency gain fluctuations. This technique was first used in a radiometer by R.H. Dicke, in 1946. If the signal is switched (or amplitude modulated), with the switching frequency low compared to the bandwidth of the signal, half of the signal power is lost when the modulating function has a 50 percent duty ratio. Therefore, when the antenna is connected to the receiver, the input to the detector becomes $S_o/2 + N_o$. When the antenna is disconnected, the input to the detector is simply N_o.

The temperature resolution ΔT min for the square wave switched radiometer is developed below.

The peak-to-peak square wave signal output from the microwave detector is $KB\Delta T$ where ΔT is the temperature difference between the antenna and the reference source and B is the acceptance bandwidth of the amplifier. Upon filtering this system at the fundamental switching frequency, a sine wave is obtained with an rms amplitude equal to:

$$\frac{KB\Delta T}{2} \times \frac{4}{\pi} \times \frac{1}{\sqrt{2}} = \frac{\sqrt{2}}{\pi} KB\Delta T$$

The output current of the detector is given by Rice* and for a one ohm impedance level is equal to

$$I = KB\left(T_o(F-1)+T\right) \quad (d-c)$$

$$+ K\left[T_o(F-1)+T\right]\sqrt{2bB} \quad (a-c)$$

The a-c term is the rms current corresponding to the noise power in the post detector bandwidth b. Allowing T to equal $T_o + \Delta T$ (assumes the reference temperature at T_o as was the case in the field program):

$$I_{a-c} = K[F\,T_o + \Delta T]\sqrt{2bB}$$

Since $F\ T_o \gg \Delta T$

$$I_{a-c} \cong KF\ T_o \sqrt{2bB}$$

The ratio of signal to noise power at the filter output is therefore:

$$S/N = \left(\frac{2K^2\ B^2\ \Delta\ T^2}{\pi^2} \right) \left(\frac{1}{2K^2\ F^2 T_o^{\ 2}\ bB} \right) = \frac{B \Delta T^2}{\pi^2\ F^2 T_o^{\ 2} b}$$

The d-c signal-to-noise ratio at the output of the phase detector is twice that of the input due to the presence of a larger carrier signal at the switching frequency. The resultant signal-to-noise ratio is twice that above. Allowing for this and setting the S/N ratio equal to unity the following result is obtained for ΔT, the system sensitivity:

$$\Delta T = \frac{\pi}{\sqrt{2}}\ FT_o \sqrt{\frac{b}{B}}$$

Since the receiver is a superhetrodyne type and accepts input radiation above and below the local oscillator frequency the input signal power is twice that of a single channel receiver. Hence,

$$\Delta T = \frac{\pi}{2\sqrt{2}} FT_o \sqrt{\frac{b}{B}}$$

where F is the single channel noise figure, b is the post detector band-width $\left(\frac{1}{2Rc}\right)$ and B is the r-f bandwidth. Substituting for b:

$$\Delta T = \frac{\pi}{4}\ F\ T_o \sqrt{\frac{1}{B\tau}}$$

where $\tau = RC$, the post detection time constant.

---

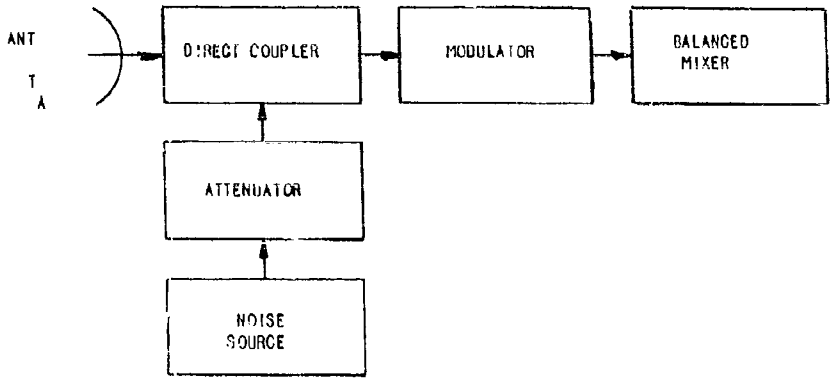
* S.R. Rice, "Mathematical Analysis of Random Noise", Bell System Technical Journal, January 1945.

APPENDIX B

DERIVATION OF THE ANTENNA TEMPERATURE EQUATION

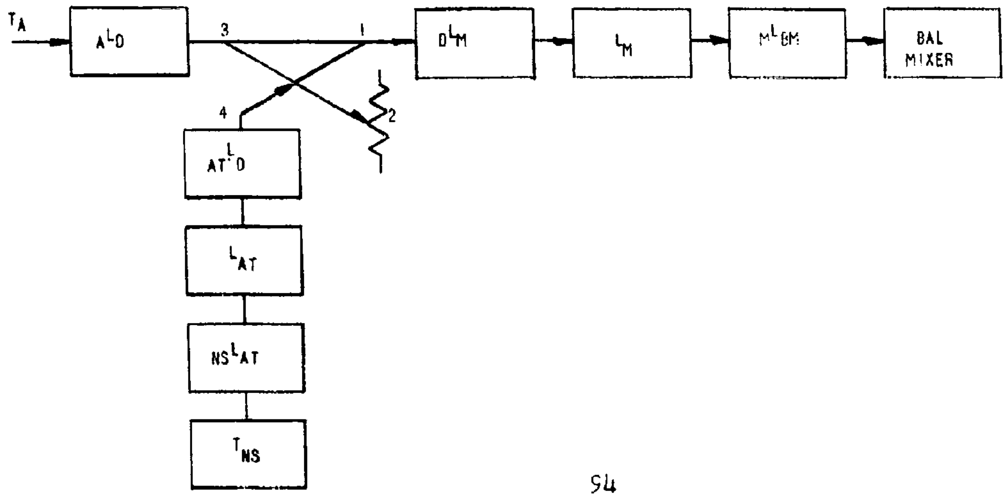
1. INTRODUCTION

This appendix will be concerned with the equation to be used in determing apparent temperature with consideration given to noisy and lossy components within the radiometer instrument. These include all components prior to the balanced mixer and are shown in the block diagram below.



All components with the exception of the noise source and antenna will be assumed at a temperature of 290°K. The antenna temperature will be denoted by T_A and the noise source temperature will be taken as 10,100 K since it was always on during the measurement process.

The block diagram shown above will be broken down into terms of losses and temperatures as shown below.



The following terms will be used in the equations to be derived:

TA - antenna noise temperature

${}_{A}L_{D}$ - Loss between the antenna and directional coupler

${}_{AT}L_{D}$ - Loss between the attenuator and directional coupler

L_{AT} - Attenuator loss

${}_{NS}L_{AT}$ - Loss between the noise source and the attenuator

T_{NS} - Noise source temperature

${}_{D}L_{M}$ - Loss between the directional coupler and modulator

LM - Modulator Loss

${}_{M}L_{BM}$ - Loss between the modulator and the mixer

2. CALCULATION OF NOISE CONTRIBUTIONS

The contribution of noise at the mixer input due to the various sources shown above will be calculated. Assuming all components are linear, the controlling bandwidth will be that of the balanced mixer.

2.1 Noise at Input 4 of the Directional Coupler

The noise power from the noise source is:

$$P_{NS} = KT_{NS} \text{ watts/cps}$$

The noise power at the input to the attenuator is:

$$P_1 = P_{NS} \; {}_{NS}L_{AT} + K (290) (1 - {}_{NS}L_{AT})$$

At the output of the attenuator the noise power is:

$$P_2 = P_1 L_{AT} + K(290) (1 - L_{AT})$$

The noise power at input 4 of the directional coupler is:

$$P_3 = P_2 \, {}_{AT}L_D + K(290)\,(1 - {}_{AT}L_D)$$

$$= \left\{ [K\,T_{NS}\,{}_{NS}L_{AT} + K(290)\,(1 - {}_{NS}L_{AT})]\,L_{AT} + K(290)\,(1 - L_{AT}) \right\} {}_{AT}L_D + K(290)\,(1 - {}_{AT}L_D)$$

$$P_3 = KT_{NS}\,{}_{NS}L_{AT}\,L_{AT}\,{}_{AT}L_D + K(290)\,(1 - {}_{NS}L_{AT})\,L_{AT}\,{}_{AT}L_D$$

$$+ K(290)\,(1 - L_{AT})\,{}_{AT}L_D + K(290)\,(1 - {}_{AT}L_D)$$

2.2 Noise at Input 3 of the Directional Coupler

The noise power at the antenna input terminals is

$$P_A = KT_A$$

The noise power at input 3 of the directional coupler is:

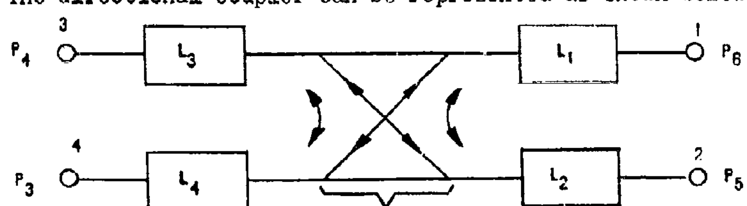
$$P_4 = KT_A \, {}_{A}L_D + K\,(290)\,(1 - {}_{A}L_D)$$

2.3 Noise at Input 2 of the Directional Coupler

$$P_5 = K\,(290)$$

2.4 Noise at Output 1 of the Directional Coupler

The directional coupler can be represented as shown below:



The coupling factor (lossless) between terminals 4 and 1 will be denoted by C and the directivity between terminals 2 and 1 will be denoted by D.

The noise power at output 1 of the directional coupler is therefore:

$$P_6 = [P_4 L_3 (1-c) + K(290) (1-L_3) (1-C)] L_1 +$$
$$[P_3 L_4 + K (290) (1-L_4)] CL_1 +$$
$$[P_5 L_2 + K(290) (1-L_2)] DL_1 + K(290) (1-L_1)$$

$$P_6 = KT_A \, {}_A L_D \, L_3 L_1 (1-C) + K(290) (1-{}_A L_D) L_3 L_1 (1-C) + K(290) (1-L_3)(1-C)L_1$$
$$+ KT_{NS} \, {}_{NS}L_{AT} \, L_{AT} \, {}_{AT}L_D \, L_4 \, CL_1 + K(290) (1-{}_{NS}L_{AT}) L_{AT} \, {}_{AT}L_D \, L_4 \, CL_1 +$$
$$K(290) (1-L_4) CL_1 + K(290) (1-L_{AT}) \, {}_{AT}L_D \, L_4 \, CL_1 +$$
$$K(290) (1-{}_{AT}L_D) L_4 CL_1$$
$$+ K(290) L_2 DL_1 + K(290) (1-L_2) DL_1$$
$$+ K(290) (1-L_1)$$

2.5 Noise at the Input to the Modulator

$$P_7 = P_6 \, {}_D L_M + K(290) (1-{}_D L_M)$$

2.6 Noise at the Output of the Modulator

$$P_8 = P_7 L_M + K(290) (1-L_M)$$
$$= P_6 \, {}_D L_M \, L_M + K(290) (1-{}_D L_M) L_M + K (290) (1-L_M)$$

Since the noise contributions after the modulator are common to both the antenna and reference temperatures during measurements they may be considered part of the receiver noise and need not be considered here.

3. CALCULATION OF LOSSES

The theoretical attenuation of RG 96/U is approximately 18db/100 feet. In practice the attenuation will be somewhat greater, therefore a value of 20 db/100 feet or 0.2db/ft will be used.

$$_{NS}L_{AT} = \frac{.2 \times 3.5}{12} = 0.06 \text{ db} = .9863$$

$$_{AT}L_{D} = \frac{.2 \times 11}{12} = 0.19 \text{ db} = .9572$$

$$_{A}L_{D} = \frac{.2 \times 15}{12} = 0.25 \text{ db} = .9441$$

$$L_4 = \frac{.2 \times 1.5}{12} = 0.025 \text{ db} = .9943$$

$$L_1 = \frac{.2 \times 1.0}{12} = .017 \text{ db} = .9961$$

$$L_2 = \frac{.2 \times .5}{12} = .008 \text{ db} = .9982$$

$$L_3 = \frac{.2 \times 1.0}{12} = .017 \text{ db} = .9961$$

$$_{D}L_{M} = 0\text{db} = 1.0$$

$$C = 9.4 \text{ db} = .1148$$

$$D = 25 \text{ db} = .00316$$

$$T_{NS} = 10,100^{\circ}K$$

Substituting these values into the equation for P_8 the following equation is obtained:

$$P_8 = K\,[0.83\,T_A + 1050\,L_{AT} - 239.5]\,L_M + 290\,K$$

When measurements were taken during the field program the attenuation (L_{AT}) was set at 50 db. The value of P_8 for this condition becomes:

$$P_{8_M} = K\,[0.83\,T_A - 239.5\,]\,L_M + 290\,K$$

The modulator is alternately switched between an on and off state, L_M being 0.8 db in the on state and 38 db in the off state. The value of P_{8_M} for these two conditions is given below:

$$P_{8_M} \text{ (on)} = K \; [.69 \; T_A + 91]$$

$$P_{8_M} \text{ (off)} = K \; [.00013 \; T_A + 290]$$

The receiver output is a measure of the difference in these two quantities and is therefore proportional to

$$\Delta P_{8_M} = K \; (.69 T_A - 199)$$

During calibration the modulator of course is also switched between an L_M of 0.8 db and 38.0 db. The value of P_8 during calibration for these two conditions is accordingly:

$$P_{8_C} \text{(on)} = K \; [0.69 \; T_A + 873 \; L_{AT} + 91$$

$$P_{8_C} \text{(Off)} = K \; [.00013 \; T_A + .17 \; L_{AT} + 290]$$

The difference measured by the receiver is therefore:

$$\Delta P_{8_C} = K \; [.69 \; T_A + 873 \; L_{AT} - 199]$$

4. <u>APPARENT TEMPERATURE EQUATION</u>

During the test program, the antenna was pointed at the sky during calibration and at the target object during measurement. The temperature difference was obtained by effectively changing the setting of L_{AT} to null out the difference in noise power to obtain:

$$\Delta P_{8C} = \Delta P_{8M}$$

or

$$.69 \; T_S + 873 \; L_{AT} = .69 \; T_A$$

when T_S = sky temperature during calibration

T_A = antenna temperature during measurement

$$T_A = T_S + \frac{873}{.69} \quad L_{AT}$$

$$T_A = T_S + 1264\ L_{AT}$$

In practise, L_{AT} was not varied but instead a DC voltage was used to null out the output of the phase detector. Calibration runs of a dial reading corresponding to the null voltage versus settings of L_{AT} were therefore taken to enable calculation of T_A in the above equation.

APPENDIX C

Additional Data

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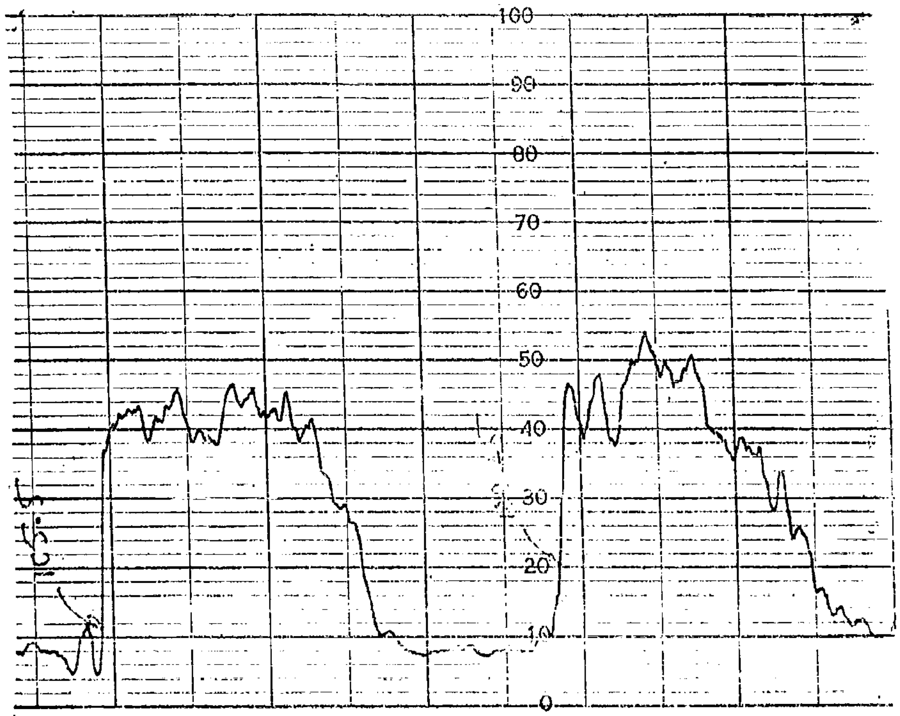

FIGURE C-1a

a) PERSONNEL TARGET, [illegible] VIEW, [illegible]IN, DAY- [illegible] (P-5)

[illegible]= - 10 db, τ=5 sec, [illegible] speed = 3/4 ipm

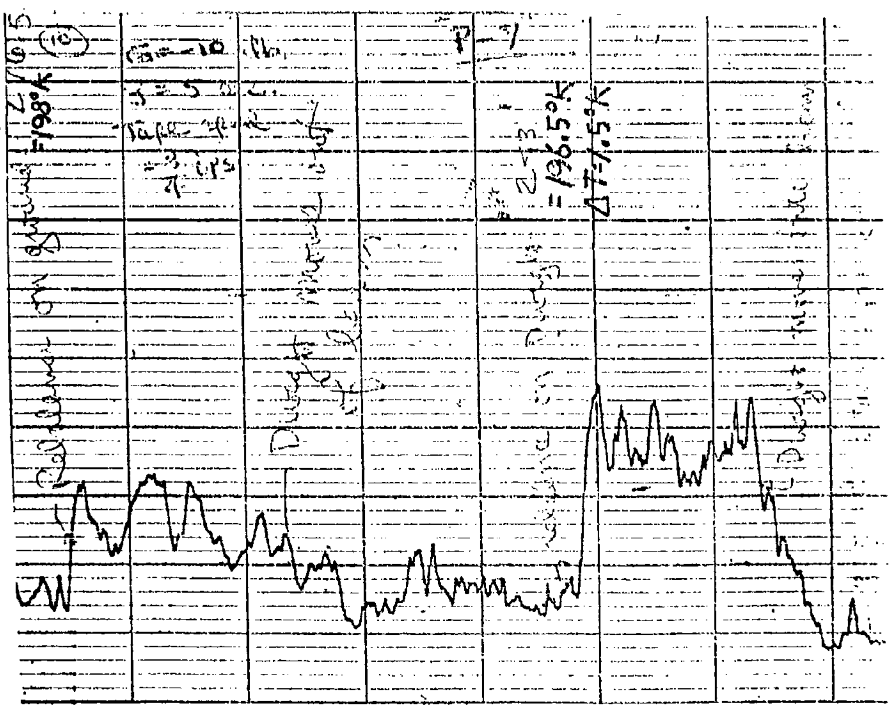

FIGURE C-1b

b) PERSONNEL TARGET, PRONE [illegible], [illegible]TIME (P-7)

[illegible] - 10 [illegible], [illegible] sec, [illegible] speed = [illegible]

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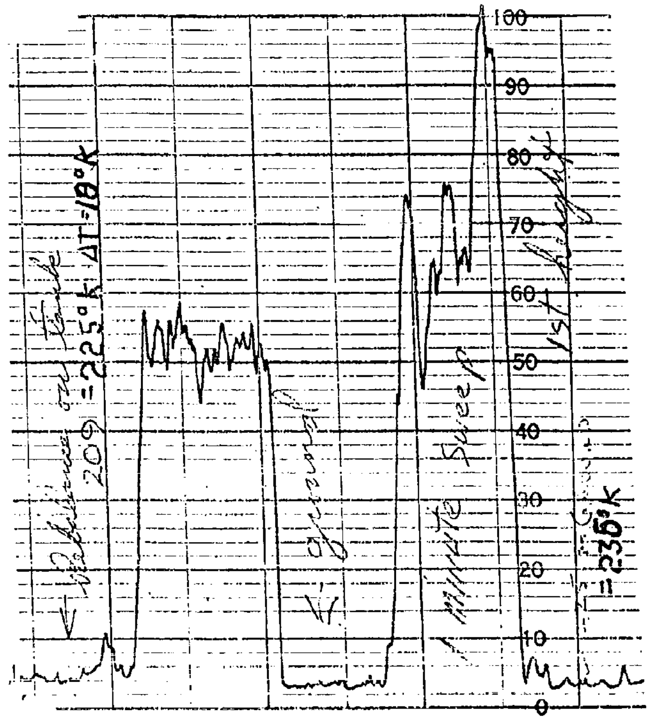
FIG. C-1
P-5, P-7

FIGURE C-2

TANK TARGET; FRONT VIEW, R=50 YDS
(T-1)

G= -20 db, τ=1 sec,
Tape Speed =3/4 ipm



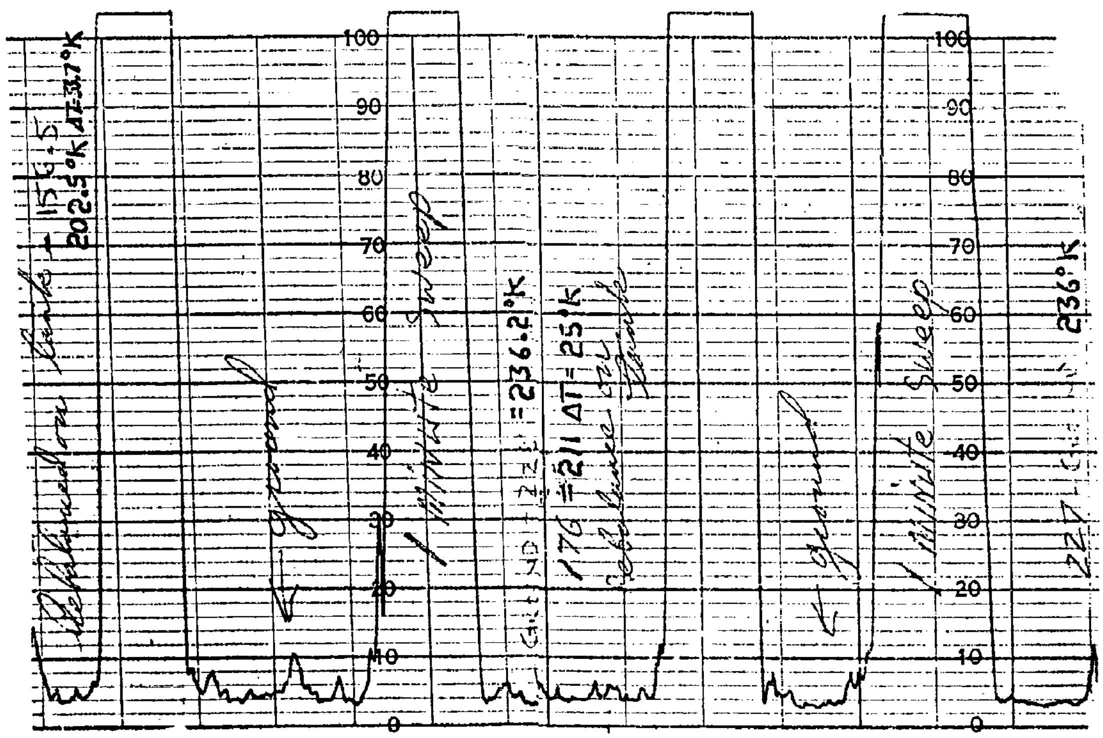


Fig. C-2
T-1

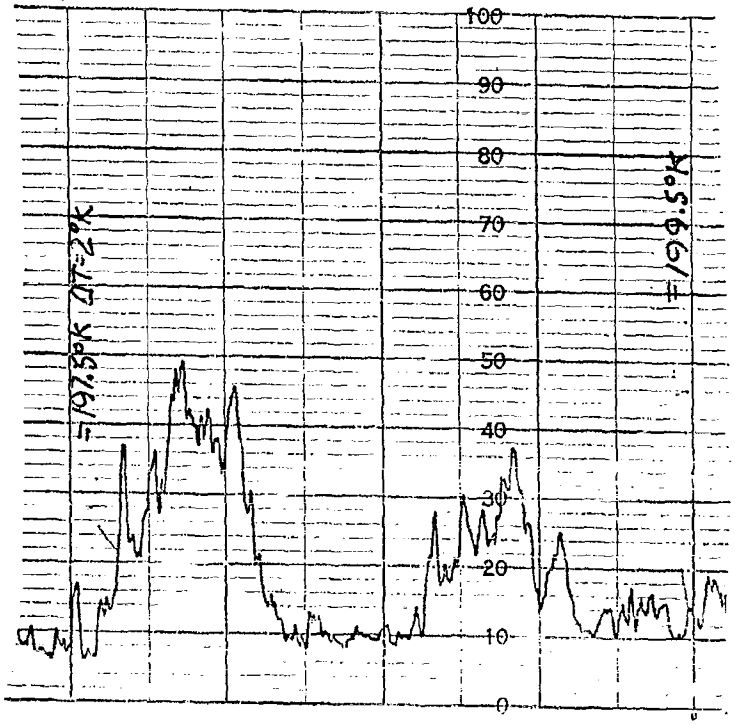


FIGURE C-3. a) TANK TARGET, BACK VIEW
R=300 YDS, ENGINE OFF (T-9)

G=- 10 db, τ=5 sec, Tape Speed
- 3/4 ipm

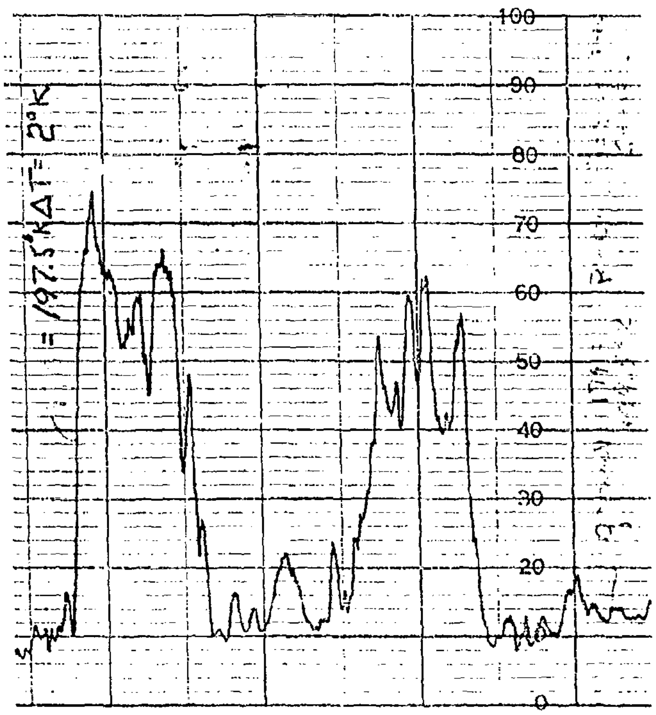


FIGURE C-3. b) TANK TARGET, BACK VIEW,
R=300 YDS, ENGINE ON (T-10)

G= - 10 db, τ=5 sec, Tape Speed
= 3/4 ipm

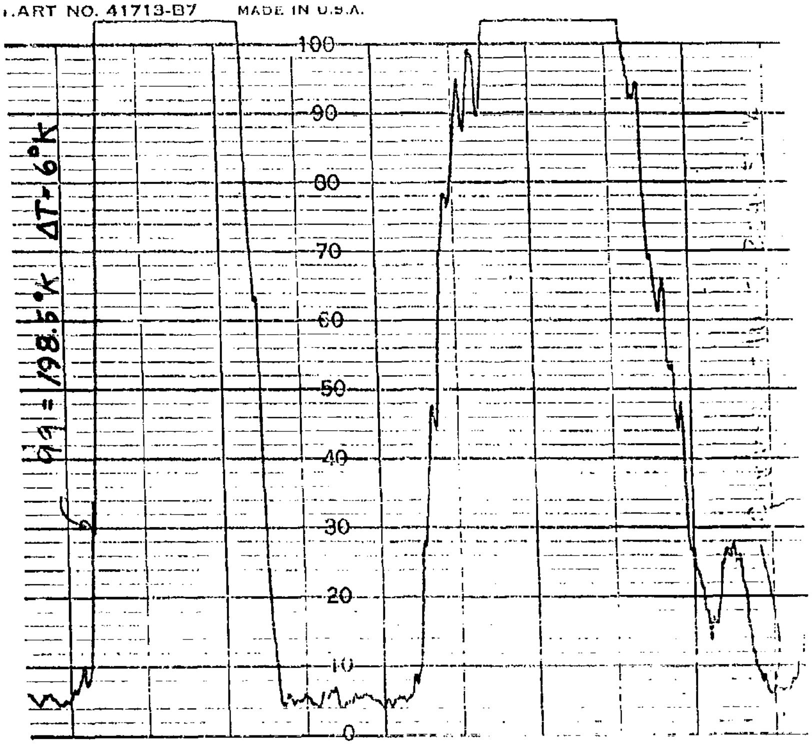


FIGURE C-4. a) TANK TARGET FRONT VIEW, R=500 YDS, DAYTIME (T-6)

a) G= - 10 db, τ=1 sec, Tape speed = 3/4 ipm

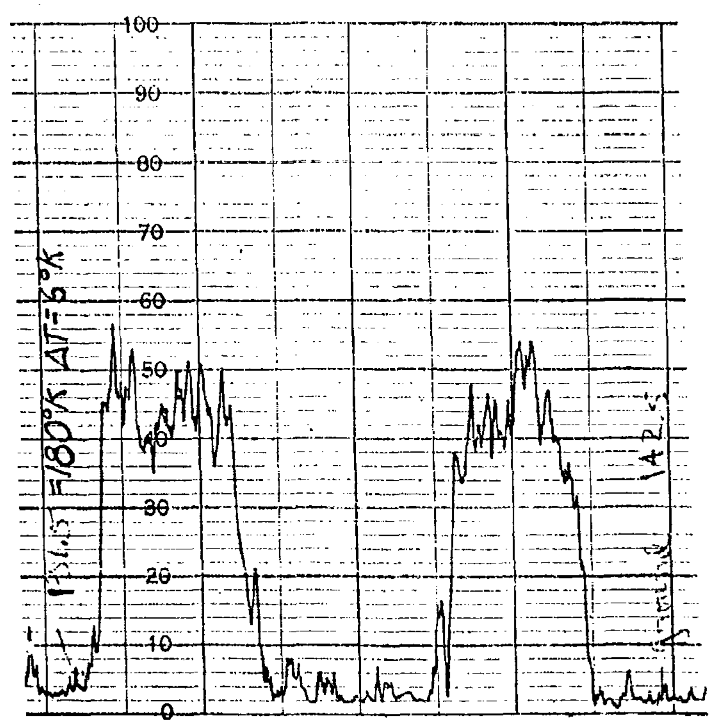


FIGURE C-4. (b) TANK TARGET, 3/4 REAR VIEW, R=500 YDS, DAYTIME (T-19)

G= 20 db, τ=1 sec, Tape Speed = 3/4 ipm

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GURE C-5. a) TANK TARGET, BACK
EW, R=500 YDS, CAMOUFLAGE ON (T-27)

= 10 db, τ=5 sec, Tape Speed
3/4 ipm

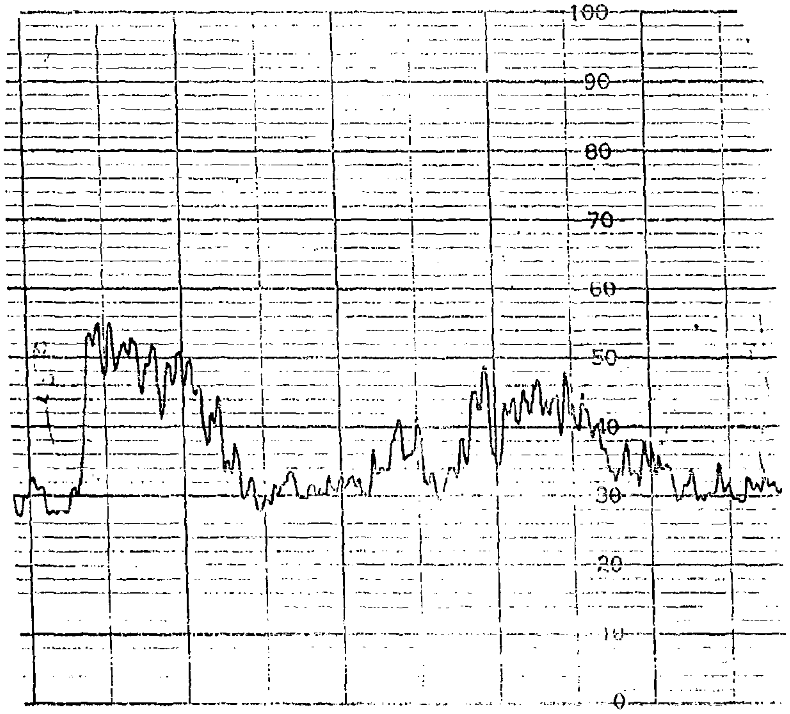
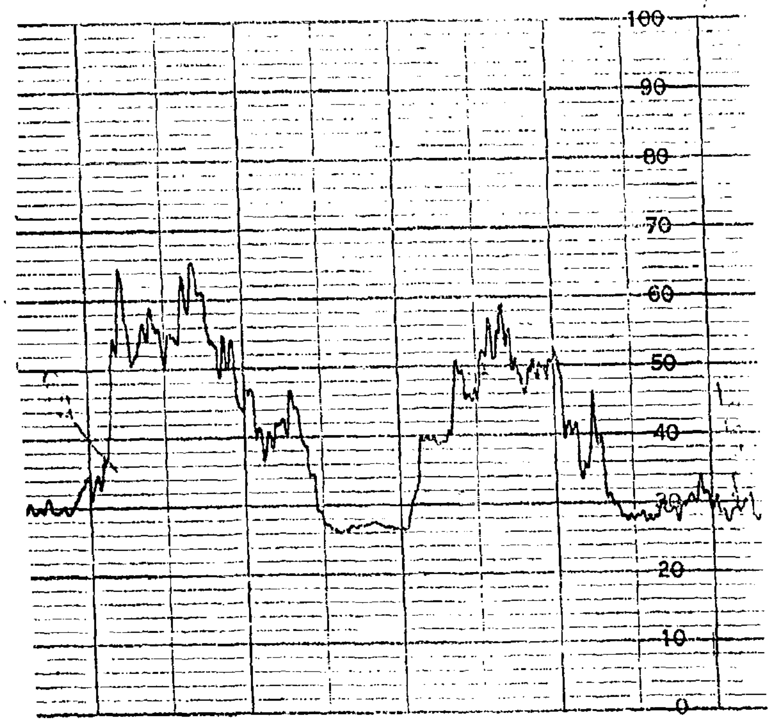


FIGURE C-5. b) TANK TARGET, BACK VIEW
500 YARDS, CAMOUFLAGE OFF T-26

- 10 db, τ=5 sec, Tape Speed
= 3/4 ipm



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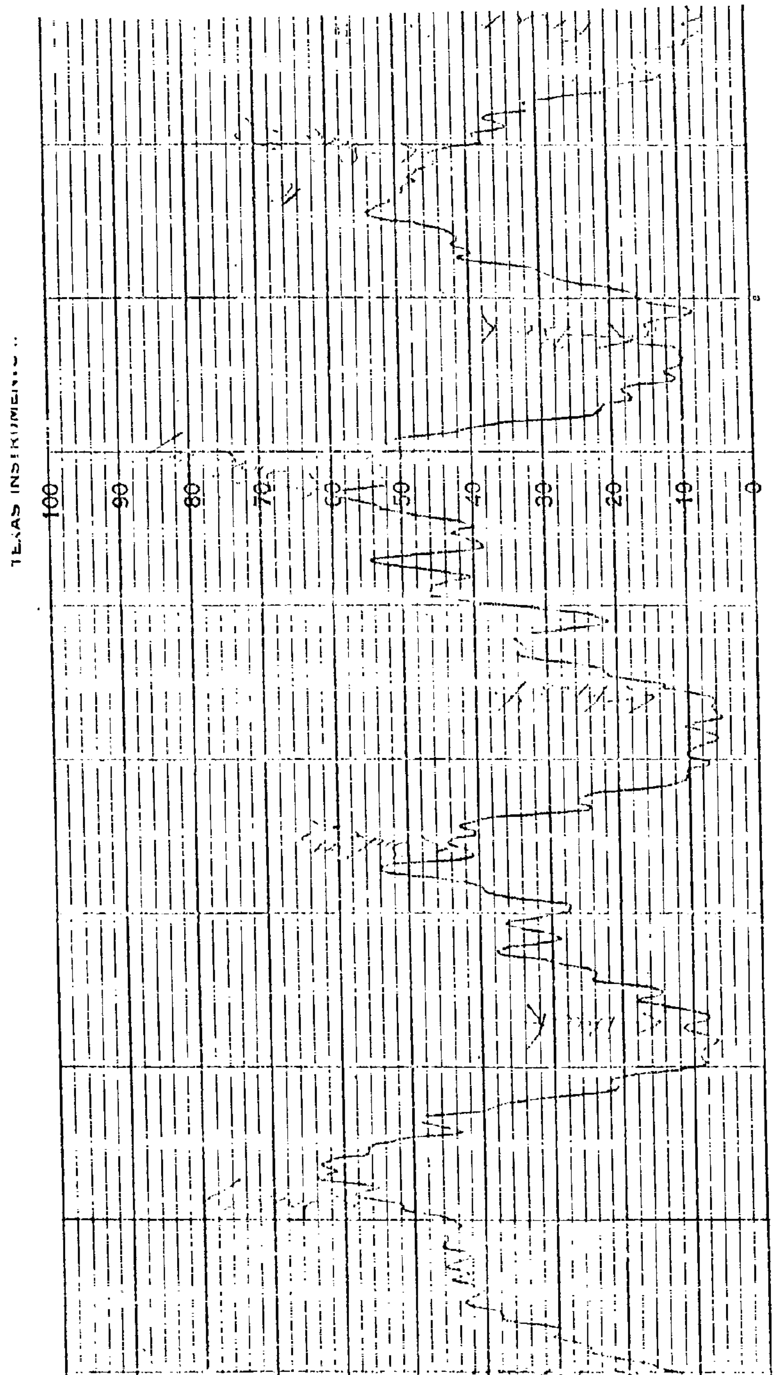
C-5
T-27, T-26



G = -20, τ = 1 SEC, TAPE SPEED = 3/4 IPM

FIGURE C-6. TANK ROTATION RUN, R=300 YARDS, (S-2)

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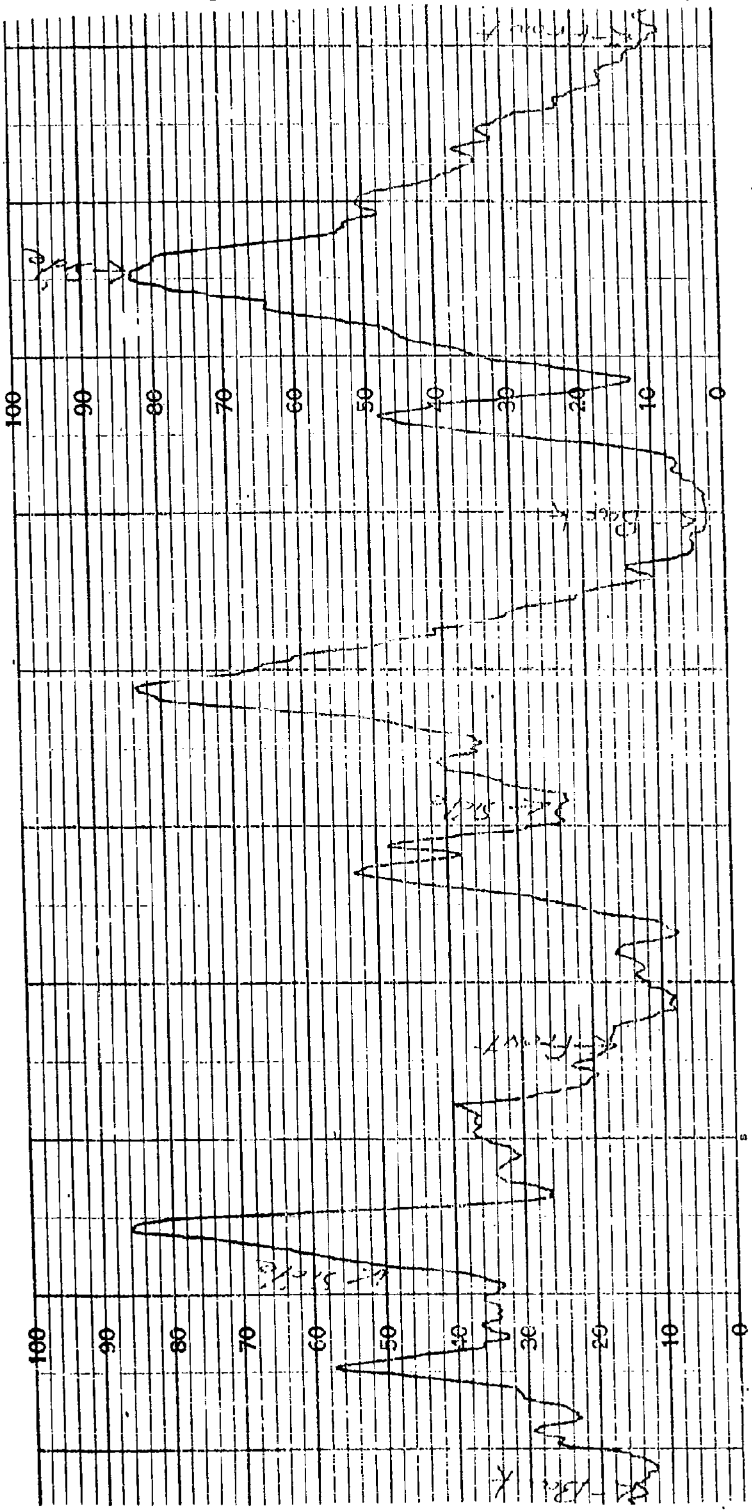
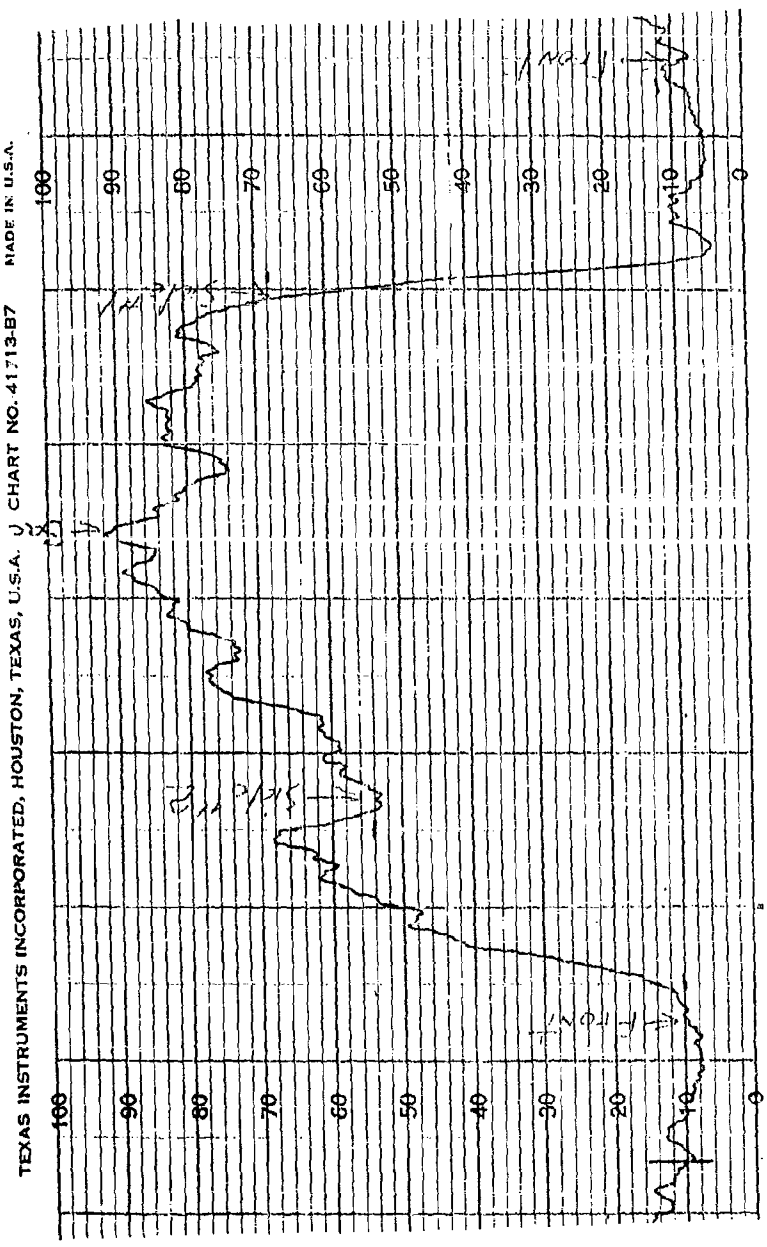


FIGURE C-7. TRUCK ROTAT ON RUN, R=100 YARDS (3-2)
GF = 20 ... TAPE SPEED = 3/4 IPM

CONFIDENTIAL



TAPE SPEED=3/4 IPM

F GURE C-8. JEEP ROTA[illegible] ON RUN, R= [illegible] YARDS (S-8)

APPENDIX D

DERIVATION OF RANGE EQUATIONS

A range equation may be derived from the proper combination of fundamental relationships to show the range performance of a given radiometer for an assumed target.

From fundamental radiometer theory:

$$\Delta T \text{ min.} = KFT_o \sqrt{\frac{b}{B}} \qquad \text{(Eq 1)}$$

Where: ΔT min. - the minimum detectable temperature differential (^oK)

T_o - 290^oK

F - receiver noise figure (single channel)

b - post detection bandwidth (cps)

B - I-F bandwidth prior to detection (cps)

Where: T_a - target apparent temperature

A_t - target cross sectional area

A_b - beam cross sectional area.

The effective temperature of a target against a background with temperature T_b is given by

$$T_{eq} = T_a\left(\frac{A_t}{A_b}\right) + T_b \frac{(A_b - A_t)}{A_b} \qquad \text{(Eq 2)}$$

The temperature difference between T_{eq} and T_b is defined as Δ T.

$$\Delta T = (T_{eq} - T_b) \qquad \text{(Eq 3)}$$

Thus:

$$\Delta T = \frac{A_t}{A_b} (T_a - T_b) \qquad \text{(Eq 4)}$$

Rearranging:

$$A_b = \frac{A_t}{\Delta T} (T_a - T_b) \qquad \text{(Eq 5)}$$

The area A_b at range R is given by:

$$A_b = \frac{\pi R^2 \theta^2}{4} \qquad \text{(Eq 6)}$$

Rearranging:

$$R = \frac{4\sqrt{A_b}}{\sqrt{\pi \theta^2}} \qquad \text{(Eq 7)}$$

Where θ is the 3 db antenna beamwidth in radians and is generally small so that $\tan \theta \cong \theta$.

Combining Eqs 5 and 7

$$R = \sqrt{\frac{4 A_t (|T_a - T_b|)}{\pi \theta^2 \Delta T}} \qquad \text{(Eq 8)}$$

If ΔT is made equal to ΔT min., then

$$R = \sqrt{\frac{4 A_t (|T_a - T_b|)}{\pi \theta^2 KF T_o \sqrt{\frac{b}{B}}}} \qquad \text{(Eq 9)}$$

Rearranging the equation,

$$R = \frac{1}{\theta} \left[\frac{4}{K\pi T_o} \right]^{1/2} \cdot \left[\frac{A_t |T_a - T_b|}{F} \right]^{1/2} \cdot \left[\frac{B}{b} \right]^{1/4} \qquad \text{(Eq 10)}$$

If an R-C filter is used, the post detection bandwidth b is equal to $\frac{1}{4\tau}$ (Reference 8),

where τ is the time constant of the low pass RC circuit.

For a square wave switched radiometer of the type used in the field program K = 1.57 (Reference 8).

Therefore: $$R = \frac{7.48 \times 10^{-2}}{\theta} \left[\frac{A_t |T_a - T_b|}{F} \right]^{1/2} \cdot [B_\tau]^{1/4} \qquad \text{(Eq 11)}$$

Converting: A_t from square yds. to sq. meters

θ from radians to degrees

B from cps to mc.

$$R = \frac{148}{\theta} \left[\frac{A_t |T_a - T_b|}{F} \right]^{1/2} [B_\tau]^{1/4} \qquad \text{(Eq 12)}$$

Where: R = range in yds.

A_t = target area in square meters

T_a = apparent target temperature in degrees Kelvin

T_b = background temperature in degrees Kelvin

θ = antenna beamwidth in degrees

F = receiver noise figure (single channel)

B = pre-detection I-F bandwidth in m.c.

τ = time constant of low pass R-C filter in sec.

APPENDIX E

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ADDENDUM

Type of Camouflage Net.

1080-252-7834
Net Camouf. Ctn. Twn.
Net Set 2 M2 Main 29x29 Desert
1 each
A/A-111-2/62
Wt. 70 Cf 7

Type of Microwave Absorbing Material

Emerson and Cuming, Inc.
869 Washington Street
Canton, Massachusetts

Eccosorb CV - 40 db down microwave absorber - .01% reflection
ref. tech. bulletin 8-2-14
below 40 db from lower end of S band thru K_a band insensitive to incident angle.
light weight artifical dielectric loaded flexible foam - rippled.

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