NATIONAL BUREAU OF STANDARDS REPORT

8596

Guide to Use of the AN/TSM-11 Cable Test-Detecting Set

By

James E. Davis and J. W. Simeroth

NBS

U.S. DEPARTMENT OF COMMERCE

NATIONAL BUREAU OF STANDARDS

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U.S. DEPARTMENT OF COMMERCE
NATIONAL BUREAU OF STANDARDS

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Guide to Use of the AN/TSM-11 Cable Test - Detecting Set

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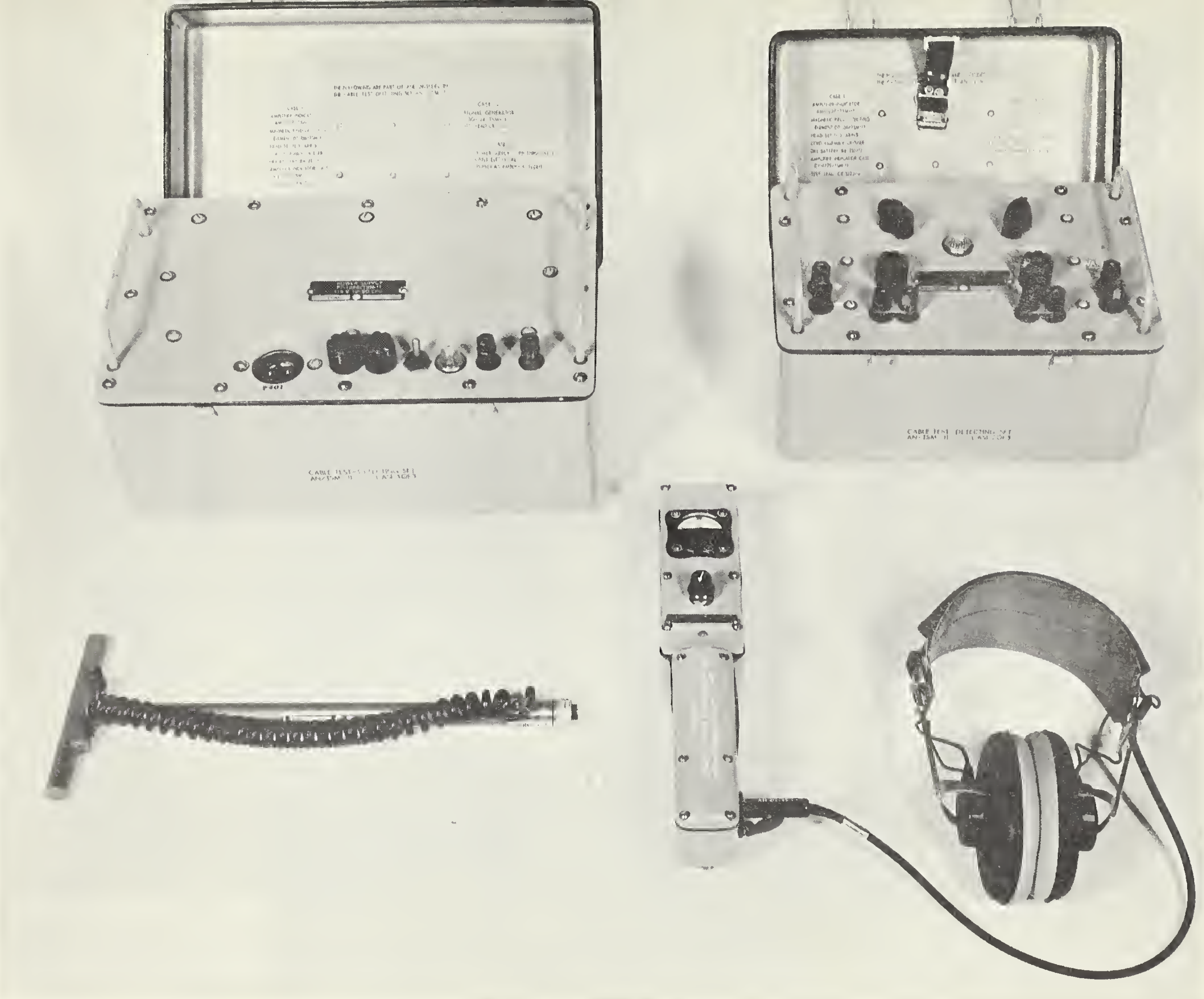
ABSTRACT

The Cable Test - Detecting Set AN/TSM-11 is intended for use primarily in the maintenance of airfield and seadrome lighting cables. The set is used to trace cables and to indicate the location of faults in cables without digging or otherwise exposing the cables for inspection. Field tests using the set have been made over a period of several years to determine the effectiveness and limitations of the set for tracing cables and locating faults, and to determine other potential uses. No tests were made of the effectiveness of the set in tracing cables under water or of locating faults in such cables. The tests made show that the Cable Test - Detecting Set AN/TSM-11 is a suitable device for locating well grounded faults in unshielded airfield lighting cable whether the cable is directly buried or is in nonmetallic conduits. The set was satisfactory for tracing the routing of direct-burial cable under most conditions. The effectiveness of the set in the vicinity of 60-cycle power lines was often reduced because radiated harmonics of the power frequency, especially the 240-cycle harmonic, interfered with the test signal. The set's usefulness in precisely locating the position of ungrounded open faults in underground cables was limited; however, the position of such opens could usually be located to within 200 feet.

1. INTRODUCTION

The Cable Test - Detecting Set AN/TSM-11 is portable equipment designed for use in locating and following buried or submerged cables and for locating faults therein. The Cable Test - Detecting Set consists of the following major components (see figure 1): Signal Generator SG-124/TSM-11, Magnetic Field Detecting Element DT-156/TSM-11, Amplifier-Indicator AM-1207/TSM-11, and Headset H-3/ARR-3. The equipment will hereafter be referred to as the set, generator, detector, indicator, and headset, respectively. The generator produces a 250-cps voltage which, when applied to the buried or submerged cable under test, causes a current to flow in the cable. The current flowing in the cable produces a magnetic field surrounding the cable. When the coil of the detector is placed in the vicinity of the cable, a 250-cps voltage is induced in the coil. The voltage induced in the coil of the detector by the test magnetic field is applied to the input of the indicator which is tuned to 250 cps. The indicator then amplifies this voltage to approximately 100,000 times the voltage induced in the coil. The amplified signal is applied to the headset and, in addition, is



NBS Report 8596 Figure 1. Photograph of the AN/TSM-11 Cable Test - Detecting Set

rectified and then is applied to an indicating meter on the indicator. The headset and meter on the indicator allow the operator to hear a tone and to see a meter indication which is a function of the strength of the test magnetic field at the detector.

An additional unit, which is not always a part of the standard set, is the Power Supply, PP-1296/TSM-11. This power supply unit serves to convert 115-volt, 60-cycle alternating current to 6-volt direct current suitable for powering the generator. This unit is very convenient to use in the airfield lighting vault or in locations where alternating current is more readily available than 6-volt direct current.

The set is intended primarily for use in the maintenance of airfield and seadrome lighting cable, with the following stated capabilities and limitations.

"(a) It may not be able to follow a cable with a metallic sheath, depending on the type of sheath and extent of the shielding.

"(b) If the cable impedance is high (10,000 ohms or greater), it may not be possible to locate or follow the cable unless the magnetic field detecting element of the AN/TSM-11 is within a few inches of the cable. The maximum separation possible between the magnetic field detecting element and the cable is a function of the current flowing in the cable." [1]

The set was tested for its effectiveness in tracing a variety of types of cable and for locating grounds and open-circuit cable faults. These tests were made primarily at the Arcata Airport, Arcata, California, where the soil has poor conductivity. A limited number of tests were made at the Rohnerville Airport, Rohnerville, California, where the soil conductivity is somewhat better. This Guide is based upon the results of these field tests. The limitations of the equipment and special procedures for use in problem situations are discussed. Instructions for using the equipment on shorts between cables and high-series-resistance faults are included. The results of tests using the equipment as a depth gage are given. Other special uses are reported.

2. CABLE TRACING

The set is an excellent device for tracing buried cable which is not shielded by metal. Cable tracing is necessary when the set is used for locating faults as well as for determining the route of a cable. Usually tracing cables with this set is not difficult and requires very little experience.

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[1] NAVAER 08-20-501, Handbook of Operation and Service Instructions, Cable Test-Detecting Set AN/TSM-11, Texas Instruments Incorporated (1955)

2.1 General Procedure for Tracing Buried Cable

The procedure outlined below for using the set to trace cable, which is based on 'NAVAER 08-20-501 Handbook of Operation and Service Instructions, Cable Test-Detecting Set AN/TSM-11', except for steps d and e, was found to be satisfactory. The NOTES and CAUTIONS given in the Handbook apply.

a. Disconnect all known grounds and terminating equipment from the cable. (Series lamps and series isolating transformers may remain connected to the circuit.)

b. Measure the insulation resistance between the conductor and ground to determine if cable ground faults are present, and, if so, whether the insulation resistance is low (below 1000 ohms) or high (above 1000 ohms).

c. If the cable has no faults or if the insulation resistance is high, connect the cable to a driven or other type ground, not connected directly to the station ground, neutral, counterpoise, or static shield. Make the connection at the far end of the cable or at approximately the midpoint of a closed loop. If the cable has low insulation resistance, the fault provides the ground and an intentional ground is not required.

NOTE

Do not use a gas pipe under any circumstances since gas pipes are usually insulated at the joints between sections. Do not use a water pipe for grounding unless no suitable ground is available. Confusion will result between the pipe and the feeder, particularly where the resistance of the earth is high and grounding currents may flow for great distances along the pipe.

d. Connect one side of the output of the generator to the cable to be traced and the other side to station ground or to a grounding rod. (See figure 2 for connections.)

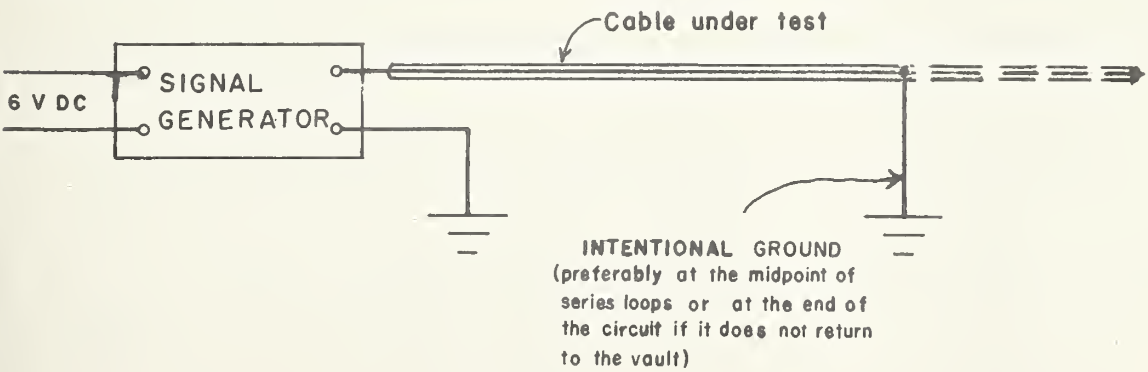

Figure 2. Connections for tracing cable

NOTE

For tracing small multiconductor control cables, connect all conductors in parallel to increase signal strength.

e. Energize the generator from a suitable 6-volt direct-current source (automobile battery or power supply) and, with a voltmeter across the output terminals, place the Output Impedance switch in the position - LOW, MED, or HI - that provides the greatest voltage.

CAUTION

Use only the LOW or MED positions of the signal generator OUTPUT IMPEDANCE switch when testing multiconductor cable with low (below 300-volt) insulation voltage rating. The voltage in HI position may be sufficient to break down the insulation of this type of cable.

Another satisfactory method of selecting the proper position for the Output Impedance switch is to place the detector at a fixed height above the cable under test and determine the switch position which gives the strongest signal.

f. With the detector connected to the indicator, energize the indicator by turning the GAIN switch from OFF and adjust the control for a convenient reading on the meter and sound in the headphones when the detector is over the buried cable. Follow the cable by proceeding along the line of maximum indication, swinging the detector from side to side until the decrease in indication at each side of the cable is appreciable. Set the GAIN control at the lowest position that will give a suitable indication.

g. Mark the route of the cable and note the location of changes in meter reading as positions of possible faults, changes in depth of cable, changes in magnetic shielding, and occurrence of radiated interference.

h. Trace the cable to the intentional ground at the end of the cable or the midpoint of the loop or to the ground fault.

i. If the circuit is a closed loop, connect the output of the generator to the other end of the cable and trace the circuit, as above, to the intentional ground at midpoint or to the ground fault.

j. Clear all ground faults and, if the complete route of the cable has not been traced, finish tracing the circuit, proceeding as above.

k. Disconnect the generator, remove intentional grounds or ground faults, and reconnect the terminating equipment.

l. Mark the route of the cable for future reference and show the location of the cable route on appropriate installation drawings and circuit diagrams.

NOTE: Step d does not agree with the procedure given in the NAVAER 08-20-501 Handbook of Operation and Service Instructions, Cable Test-Detecting Set AN/TSM-11, paragraph 4-9, because often both feeders of closed loop circuits are installed in the same duct or trench and the signal may then be self-canceling (see section 2.5) if the cable is connected across the generator. For step e, the voltmeter or the indicator signal is often more convenient to use than is an ammeter on the generator.

2.2 Tracing Shielded Cable

It may not be possible to follow a cable with a metallic sheath or a cable installed in metal duct or conduit, but often these cables can be traced using the above procedure with adequate care. The feasibility of tracing shielded cables will depend on the type of sheath, the extent of the shielding, the presence of interfering radiation, and the depth of the cable. Any type of metallic shielding will greatly decrease the detector signal, requiring a high GAIN control adjustment. Often the signal can be detected with the headphones when there is no indication on the meter. Use of the interrupted signal, POWER switch in the ON position, may improve signal recognition for better detection and tracing.

When fault-free buried cable is being traced, a sudden decrease in signal which resembles a ground fault may result when the cable enters a metal pipe or duct. Frequently this occurs where a cable crosses a driveway, road, or paved area. The signal will return to normal where the cable emerges from the pipe.

Locating faults in shielded cables or in cables in metallic ducts by using the set is seldom feasible.

The conductivity of the soil affects the usefulness of the set in tracing shielded cable. The greater the conductivity of the soil the weaker will be the signal from shielded cable.

In some cases shielded power cables are easier to follow by using the normal radiation of the power current than by using the generator test signal, because of the high current in the cable.

2.3 Effects of Changes in Cable Depth

Changes in depth of buried cable can make changes in indication which are confusing. The detector signal strength increases as the detector is brought nearer the cable and decreases as it is taken away from the cable. This is the normal response, but if the changes are unexpected, the user may be misled, especially when he is looking for faults. A sudden increase in cable depth may be mistaken for a ground fault or a decrease in depth may mask an indication of a ground fault. Usually the cable will return to the normal depth and, if the indication returns to the earlier value, no major fault has been passed. Sometimes the cable will gradually become shallower and the meter reading will increase until suddenly the cable is returned to the original depth and the decrease in signal is sharp. Although the reading has only returned to normal, the decrease may be mistakenly interpreted as being caused by a fault. To determine if a change in depth of the cable is responsible for a change in reading, digging down and examining the cable installation may be necessary, but often careful checking of signal and inspecting the area will be satisfactory. Check with the detector and indicator along the cable for a distance on either side of the suspected change in depth to find if the signal strength returns to normal. Inspect the area for roads, paving, fill, construction, excavations, erosion, evidence of crossing cables, or other factors which are likely to result in changes of cable depth and check for normal signal strength outside of these areas. Keep in mind the value of the meter indication throughout the cable route in order to know the reading for the cable at normal depth.

2.4 Problems of Radiated Interference

2.4.1 Causes of Radiated Interference. Radiated interference can cause serious problems in tracing cables and locating faults. The most common source of this interference is from the current in power cables. In some cases the current in the power cable may be only a few amperes. The detector and the indicator are tuned to detect and amplify frequencies in a limited frequency range but some of the harmonics of the 60 cycles-per-second frequency are not sufficiently attenuated to eliminate interference in many cases. Factors which tend to increase the interference are:

a. High values of the lower order harmonic components of the power frequency, especially of the fourth and fifth harmonics.

b. A small separation between the test cable and the power cable.

c. A high current in the power cable or a low test current.

d. A low shielding of the power cable or a good shielding of the test cable.

e. A shallower depth of the power cable than of the test cable.

f. Nearly parallel cables.

Power cables supplying rectifiers and gaseous discharge lights are especially troublesome because of the 240-cycle harmonic they generate.

2.4.2 Signals Indicating Radiated Interference. The presence of interfering radiation is indicated by a meter reading and tone in the headset when the test signal is turned off, or when the detector is well away from the known position of the test cable. Often the indicator meter will oscillate as a result of the beat frequency from the 240-cycle harmonic and the generated signal. This beat oscillation may be difficult to distinguish from the interrupted signal from the generator although the generated signal is in the "TEST" or continuous signal position. A beat oscillation may be impossible to read or use to determine where the maximum signal occurs. In some cases the indicator meter may have an indication from interference, but the tone in the headset may be used to differentiate between the location of the test cable and the interference. Differentiation can usually be accomplished if the interference is from the fifth harmonic or 300-cycle component of the power frequency but may not be possible if the interference is from the fourth harmonic.

2.4.3 Tracing Procedure. If the operator uses adequate care, he can usually trace cable in the presence of radiated interference. By carefully following the cable being traced and avoiding inadvertently following the interference, he may trace the test cable through an area of interference. Knowledge of the routing of the various circuits is helpful. Frequently the interrupted signal can be used to differentiate between the test signal and the interference. Often, if the two cables are not very close together and parallel, turning the detector at a slight angle to the path of the cable reduces the strength of the interference more than it reduces the test signal, and the test cable can be followed. In cases of very serious interference, the cable can be traced only by deenergizing the cables creating the interference. If it is not necessary to know the precise route of the cable in the area of severe interference, a search made beyond the area of serious interference may locate the test cable and tracing can then be resumed. For search under these conditions, use the interrupted test signal. Location of faults in areas of serious radiated interference is likely to be more difficult than the tracing of cables unless the interfering circuits can be deenergized.

2.4.4 Special Studies of Radiated Interference. Special tests were made with a variable frequency signal generator to determine the effect of certain higher harmonics of the 60-cps commercial power frequency on the reading of the indicator and on interference with the test signal from the set generator. The indicator sensitivity was only about two decibels lower for a fourth harmonic (240-cps) signal than for a signal of the designed generator frequency (250 cps). The difference in the tone of the 240-cps signal and the 250-cps signal of the set generator was difficult to recognize. In addition, if frequency of the set generator was below 245 cps, which is normal for some of the generators of some sets[2], the beat frequency caused the indicator meter to fluctuate in a manner similar to the manner of the fluctuations produced by the interrupted test signal. A fifth harmonic signal (300 cps) can give an appreciable indication on the indicator meter because the sensitivity has decreased only five to eight decibels at this frequency and in a power cable the fifth harmonic component is usually much greater than the fourth. Although the indicator meter reading produced by a 300-cps signal can not be distinguished from one produced by a 250-cps signal of the set generator, the difference in the tones of the two frequencies can be distinguished. The sensitivity of the indicator to the third harmonic of the power frequency (180 cps) is so low that this harmonic is not likely to cause interference in tracing cables except in unusual cases of frequency distortion.

2.4.5 Radiated Interference from Engines. Another source of radiated interference which may be encountered is the ignition system of near-idling engines. This type of interference may be present when the set generator is powered from the battery of a vehicle the engine of which is kept running to keep the battery charged and is noticeable only at certain speeds of the engine. Operating the engine at other speeds will eliminate this problem.

2.4.6 Tracing Externally Generated Signals. In some instances the radiation from power cables can be used to advantage in tracing cables. For example, a power cable may be traced by using the detector and indicator only, without the generator signal, by following the magnetic field from the energized cable. This method is especially useful in tracing circuits which can not be conveniently deenergized in order to use the standard method of tracing. Of course, radiated interference from other power cables may make this method of tracing a cable impossible.

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[2] NBS Report 21P-18/55, Electrical Characteristics of the Preproduction Model of a Cable Test-Detecting Set AN/TSM-11.

2.5 Problems of Self-Cancellation of Signal

One problem in cable tracing occurs when the paths of the outgoing and return signals are parallel and in close proximity. This causes self-cancellation of the magnetic field and results in a weak or negligible signal in the detector. The most common installations where self-cancellation is a problem are those where both feeders of a series circuit are in the same or nearby ducts or trenches or where a section of cable loops back on itself. Theoretically, if the circuit is without faults and the cables are the same depth and sufficiently close together, the magnetic fields will cancel completely and there will be no radiated signal. Actually there will be some difference in signal strength due to the separation of the cables. This difference in signal strength may be detectable (depending on the depth of the cable or distance from the detector, the shielding of the cable, and the sensitivity of the detector and indicator) and the cable may be traced if care is used. To avoid self-cancellation in tracing closed loops, follow the procedure of paragraph 2.1, using an intentional ground at the midpoint of the circuit and tracing each feeder separately instead of connecting the generator across the terminals of the circuit. It may be impossible to trace the path of a loop in a cable which has no points available for grounding; however, the rest of the circuit can be traced.

A special form of self-cancellation which may be encountered occurs when a cable has a fault, but the return signal, because of low soil conductivity, is concentrated in a nearby paralleling counterpoise, metal duct, static wire, metallic shield, or another cable. The difference in signal may be sufficient for tracing the cable, but the location of the fault may be difficult to determine. In these situations it is very easy to be misled and to follow the return signal path instead of proceeding along the cable route. At times the rapid change in indication where the feeders separate or come together appears to be due to a fault or a change in depth or shielding which does not exist. Keep this in mind when tracing cable where self-cancellation is possible.

2.6 Special Cable Tracing Techniques

In the field test the AN/TSM-11 Set has been used for some special tracing problems with success. The methods used may be helpful to maintenance personnel. Satisfactory results may not always be obtained, but the convenience of the application makes the attempt worthwhile.

2.6.1 Tracing Unburied Cable. The set can be used to trace unburied and overhead cable as well as buried cable, using the same procedures and keeping in mind the same limitations. Overhead cables, which may be in very long runs, may be traced rapidly by using the detector and indicator from a moving vehicle, if roads are suitable for access to the cable route. If the cable route is not fully accessible, the suspected route may be checked at readily accessible positions and a more thorough check may then be made as required. In these cases, self-cancellation from loops and from return paths may create problems.

2.6.2 Tracing Energized Power Cable. As discussed in the section on radiated interference, the detector and indicator respond to some harmonics of power frequencies. This effect can be used to trace energized circuits when it is inconvenient or impractical to deenergize the circuits and use the test signal. Tracing energized power cables is limited by the presence of other interfering power cables, by low current in the cable, by shielding and depth of the cable, and by the lack of suitable harmonics of the power frequency. The actual tracing procedure is similar to that using the test signal.

2.6.3 Tracing Pipe and Metal Conductors. It is frequently possible to trace buried, uninsulated pipes and conduits with the set. In these attempts, use a driven ground rod or ground system for a return that is well removed from the vicinity of the pipe to be traced. Factors facilitating the tracing of pipe in this manner are poor conductivity of the soil, lack of interfering radiation, separation from a system ground or return signal path, and continuity of the pipe. Usually uninsulated pipe can be traced for only limited distances.

2.6.4 Tracing Routes of Drains. The routes of underground drains have been traced successfully by attaching a wire to a float and floating it through the drain. A light, insulated wire should be used and it should be grounded where it emerges from the system or section of drain. Then normal procedures for tracing this wire may then be followed. Metal drains may shield the wire making this method unusable.

3. LOCATING GROUND FAULTS

3.1 General Procedure for Locating Ground Faults

The procedure for locating ground faults is the same as that for tracing cable (see figure 3 for connections) with the following exceptions:

a. If the circuit is a closed loop, note which end indicates the lower insulation resistance and use this end to start fault location. If the resistance readings differ appreciably, this indicates an open circuit or high-series-resistance fault as well as ground faults.

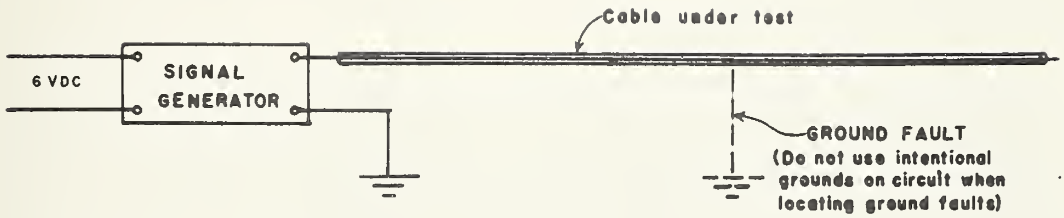

Figure 3. Connections for locating any type of ground fault

b. Since the purpose is to locate the ground fault, the intentional ground is not used even if the insulation resistance is high (above 1000 ohms).

c. In tracing the route of the cable, marking the route is not necessary. However, very carefully note and mark the location of all changes in indication even if doubtful that the change indicates a ground fault. This may aid in finding additional higher resistance faults after the primary fault has been cleared.

d. A marked decrease in signal strength probably indicates the location of a ground fault. Sudden increases in depth of cable or the cable entering a metal duct can give similar indications and such decreases should be investigated to determine the possibility of such causes.

e. After the fault has been cleared, recheck the circuit insulation resistance and, if additional faults are indicated, locate and clear these faults. Rechecking at points where changes in indication were noted may be sufficient to locate the other faults. Often moving the generator to the other end of the cable will give a better indication of the fault. Retrace the complete circuit if necessary.

When checks are made for ground faults at light fixtures, it may be found that the shielding of the base and conduit, self-cancellation of signal, and changes in depth of the cable produce changes in indication which are difficult to interpret. Usually the cable will be at the normal depth at the edge of the base foundation or just a few feet away along the cable run on either side of the fixture, and will be beyond the metal conduit and shielding and any loops that could

result in self-cancellation of signals. The magnitude of changes in indication across the unit which justify inspection of the unit for a possible fault can be determined by checking on a few fixtures for a suitable distance from the fixture to obtain normal indication, and using this as a standard.

3.2 Locating Low-Resistance Ground Faults

The set is very effective in locating low-resistance faults (those which have an insulation resistance of less than 1000 ohms) in direct-burial cable which has broken down to ground at a single point. Little difficulty was found in determining the location of these faults to within less than two feet along the cable run even in soils of low conductivity. Personnel who had received only a brief explanation and demonstration of the set were able to locate faults of this type quickly. Sometimes a low insulation resistance of a circuit is the result of several higher resistance faults instead of one low-resistance fault. These faults may be more difficult to locate. Location of multiple ground faults is described in detail in paragraph 3.4. The presence of strong radiated interference in the area of the fault, or self-cancellation from a concentrated ground signal return may make locating low-resistance ground faults more difficult. (See sections 2.4 and 2.5.)

3.3 Locating High-Resistance Ground Faults

The same procedure is used for locating high-resistance ground faults (those with insulation resistance greater than 1000 ohms) as for locating low-resistance ground faults. High-resistance faults give a smaller change in reading than low-resistance faults. If the insulation resistance is more than a few thousand ohms, it may not be possible to locate the fault even under the best of conditions. However, faults with insulation resistance of several thousand ohms to ground have been located satisfactorily during the tests.

Because of the lower test current and smaller change in indication at the fault, more care in tracing the cable and in noting the changes of indication is required to locate a high-resistance fault than to locate a low-resistance fault. Radiated interference from power cables in the area and self-cancellation from concentrated ground return signals, especially in soils with poor conductivity, are more serious problems for locating high-resistance faults. The operator may be easily misled and find that he is following a wrong cable or a metallic pipe or may continue beyond the fault without recognizing it. When a fault on a series circuit can not be located with the set because its resistance is too high, it may be possible to break down the resistance of the fault. Disconnect one end of the circuit from

the output of the regulator, ground that terminal of the regulator, and energize the regulator. If the regulator is not shut off by the open-circuit protective relay, then the fault has broken down to a low-resistance fault and should be easy to locate. Even if the regulator is shut off by the protective relay, high voltage may have lowered the fault resistance enough that the fault can be located. If there are multiple high-resistance faults, the difficulty in locating the faults is increased greatly. Location of these faults is discussed below.

3.4 Locating Multiple Ground Faults

Multiple ground faults are two or more ground faults on the same circuit. The total insulation resistance may be more or less than 1000 ohms. The resistance measurement may be less than 1000 ohms although the resistance of each individual fault may be much greater than this value if there are several faults. This condition frequently occurs on semiflush light circuits without isolating transformers, especially if the circuit is not regularly inspected and maintained. An insulation resistance measurement will not indicate whether a single ground or multiple grounds are present. The possibility of multiple grounds must always be considered.

The location of multiple grounds is primarily a process of elimination. First, locate, using the procedure of section 3.2, and clear the ground faults which show the most definite indication. Then repeat the procedure, making insulation resistance measurements and generator output voltage adjustments as required, using greater care to detect changes in meter indication as the lower resistance faults are cleared. Changing the generator to the other end of the circuit may aid in locating additional faults. When the insulation resistance of a series circuit is inadequate but the resistance of the individual faults is so high they can not be located with the set, the faults may be broken down by using the regulator as described in section 4.3.1.

Locating multiple faults by elimination is likely to be time consuming. Often the most rapid method of clearing circuits likely to have multiple faults, such as semiflush lights without isolating transformers, is to inspect and clean all units and then to use the set to locate any remaining fault.

3.4.1 An Example of Multiple Fault Testing. Tests were made on the lighting circuit of runway 01-19 at the Arcata Airport. This runway is equipped with type AN-L-9 semiflush, series, runway lights (without isolating transformers) which are fed with a 1-conductor, #8AWG, 3000-volt direct-burial cable with approximately 9,000 feet of circuit and feeders. At the beginning of the tests one feeder cable measured 150 ohms to ground and the other measured 5,500 ohms to ground. Both of these measurements were taken at the runway selector cabinet in the

airfield lighting vault. The light output of the fixtures on this runway appeared satisfactory except for five units with burned out lamps. A check around the complete circuit was made with the set, noting all unusual indications. Then the cover of each light was removed and the inside of the fixture was inspected for faults. One unit had a loose wire inside, which had been arcing. Twelve units had water above the socket level. Of these twelve, five had water above the tops of the lamps. The set had shown definite fault indications at only three of these twelve units. At the other water-filled fixtures, the meter reading on the set showed little or no decrease across the fixture. Otherwise there was a gradual decrease of signal indication throughout the complete circuit. At the completion of the tests and inspection, the resistance to ground of each feeder cable measured 4,000 ohms. Further attempts to locate and clear additional faults were not considered worthwhile in this case.

4. LOCATING OPEN-CIRCUIT FAULTS

4.1 General

Open-circuit faults are of two types, those associated with a ground fault and those which are ungrounded.

4.2 Locating Open Faults With Grounds

When a circuit has an open fault and a ground fault, there will usually be a ground of some sort at the open fault. To locate the open fault, first locate and clear all ground faults, using the procedures of Section 3. The open fault will usually be found with one of the ground faults. After all ground faults from both sides of the circuit have been located and cleared, if the open fault still exists use the procedure of 4.3 below.

4.3 Locating Ungrounded Open Faults

An open fault which is not associated with a ground is very difficult to locate precisely. Two methods may be used to locate an ungrounded open fault with the set. In one method the regulator is used to attempt to break down the fault to ground and in the other the set is used directly on the ungrounded circuit. Neither method is successful in all cases.

4.3.1 Breaking Down Open Faults to Ground. In series circuits, the ungrounded open fault may frequently be broken down to ground safely using the high voltage developed by the regulator. To do this, ground one side of the regulator beyond the open-circuit protective relay, select the proper lighting circuit and brightness step 5, and energize the regulator (see figure 4 for connections).

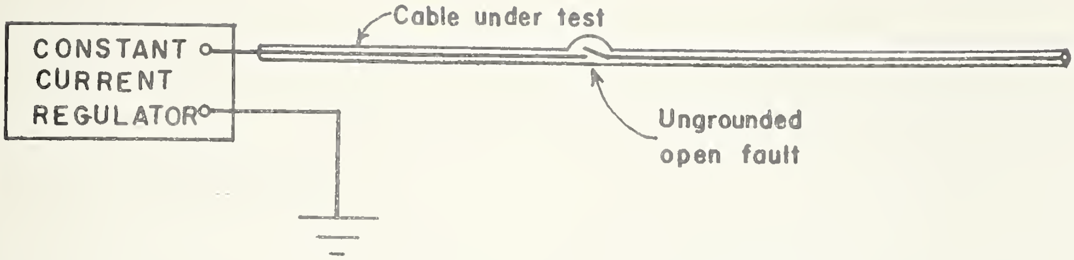

Figure 4. Connections for breaking down ungrounded open fault to ground using constant-current regulator.

CAUTION

Do not bypass the protective relay or prevent its free operation, or the regulator may be damaged.

If the protective relay does not turn off the regulator, the circuit has broken down to ground, probably at the open fault.

If the protective relay turns off the regulator, the circuit did not break down. Move the intentional ground to the other side of the regulator and again energize the regulator.

If the circuit now breaks down to ground, use the set to locate the ground fault. Connect the output of the generator to the feeder without the intentional ground and to ground and use the regular procedure for finding ground faults. Usually the open fault will be at the ground. After repairing the faults, remove the intentional ground, measure the insulation resistance and continuity of the circuit, and, if they are satisfactory, reconnect the regulator to the circuit.

If neither side of the circuit breaks down to ground or if the open fault was not at the point where the circuit broke down, use the procedure of the next paragraph.

4.3.2 Direct Method of Locating Ungrounded Open Faults. Although an ungrounded open fault can seldom be precisely located by using the set, the set may be used to isolate the fault to a limited section of the circuit. When a circuit has an ungrounded open fault, only a very weak signal current flows in the cable. This current is limited to the current required to charge the capacitance of the cable and to the leakage current to ground through the high insulation resistance. Detection of this weak

signal is often difficult unless the conditions of radiated interference, shielding, and depth of cable are favorable, especially in the region of the fault. Frequently the signal can be followed to within 100 to 200 feet of the open fault. After determining that the fault is an ungrounded open and removing all intentional grounds and terminating equipment, use the following procedure:

a. Connect the output terminals of the generator to one end of the cable and to a ground that is well removed from the cable route (see figure 5). Select the HI output impedance position, and energize the generator.

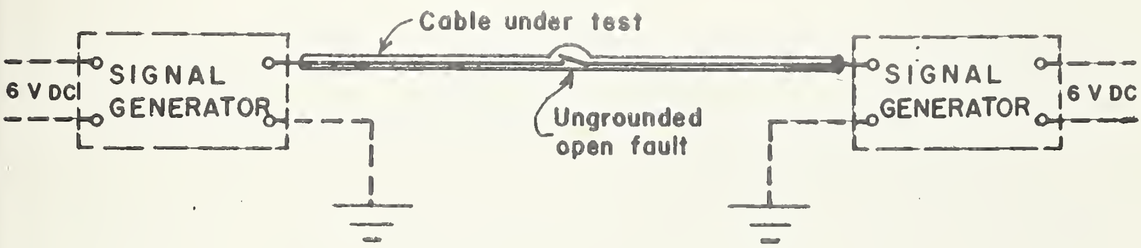

Figure 5. Connections for attempting to locate ungrounded open fault with AN/TSM-11 set. (Alternately test from each end of cable.)

b. With the detector and indicator adjusted as required for this signal and using much care, trace the signal along the circuit as far as possible. Mark this point.

c. Connect the generator to the other end of the cable and trace the signal as far as possible. Mark this point.

The open fault is between the two marked points. Under favorable conditions, the distance between the two may be 400 feet or less. For unfavorable conditions the distance will be greater.

If more accurate location of the fault is needed, the section between the two points may be sectionalized by cut and try methods. After the circuit has been opened for sectionalizing, the set may be used in further localizing of the open fault. This procedure is illustrated in figure 6. Determine the direction of the open fault from the intentional open by intentionally grounding both feeders at the vault and measuring the resistance to ground of each conductor at the intentional open. The open fault is on the section of cable which does not indicate a ground. Connect the generator to the section of cable with the open fault and to a remote ground and trace this section of cable as far as possible. Mark this point. The open fault will be between this point and the point where the signal was lost when it was being traced from the other end of the cable. This sectionalizing may be continued until it is practical to replace the section of cable containing the fault.

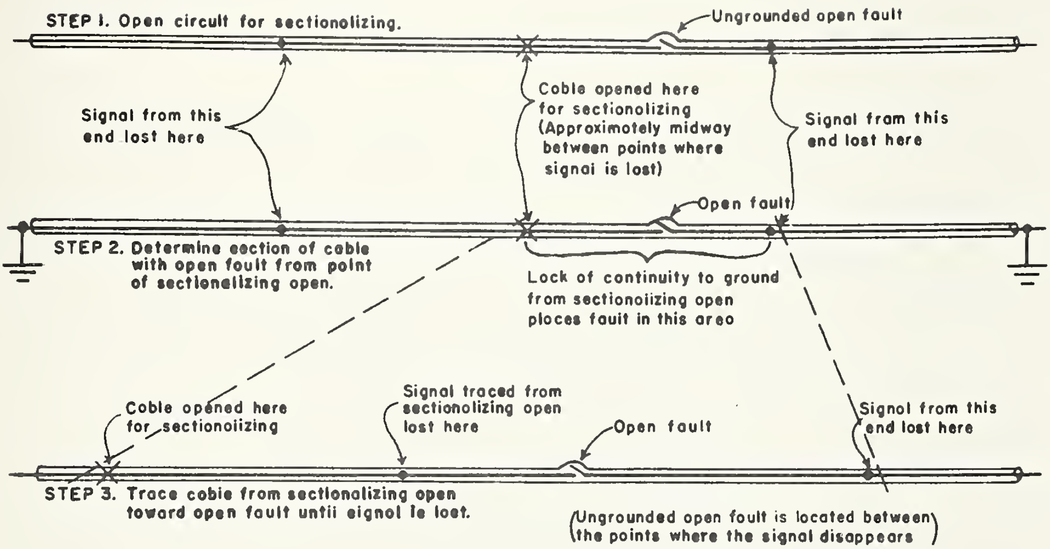

Figure 6. The procedure for more accurately locating ungrounded open faults with the AN/TSM-11 set.

4.3.3 Examples of Ungrounded Open Fault Tests.

(a) Five tests were made on a semiflush runway lighting circuit without isolating transformers and with buried cable to determine if an open fault could be located with the set. In each test the circuit was opened at a light fixture and the circuit was traced from the feeder cable toward the "open fault." In each case the signal indication on the meter and in the headset gradually decreased to zero within approximately 200 feet of the "open fault."

(b) A test was made on a metallic-sheathed cable to determine its routing and termination point. The cable had been abandoned several years earlier with one end taped and buried. The general location of the end of the cable was believed to be known. The resistance to ground measured 120,000 ohms, which was in effect an open circuit. Radiated interference from other cables in close proximity to the cable under test gave confusing indications to the operator attempting to follow the routing of the cable. The cable was traced as far as possible. Exploratory excavation in the area where the cable was believed to terminate located the end of the cable. The end of the cable was approximately 100 feet from the farthest point that the cable could be traced.

5. LOCATING SHORT-CIRCUIT FAULTS BETWEEN CABLES

5.1 General

Short-circuit faults between cables may be classed as grounded or ungrounded shorts. To determine which type of fault exists, disconnect all terminations of both circuits and measure the insulation resistance of one of the cables. If a ground fault, either high or low resistance, is present, use the AN/TSM-11 set (see figure 7 for connections) to locate and clear all ground faults. In most cases the short-between-cables fault will result in a ground fault and the normal procedures and limitations for locating ground faults will apply.

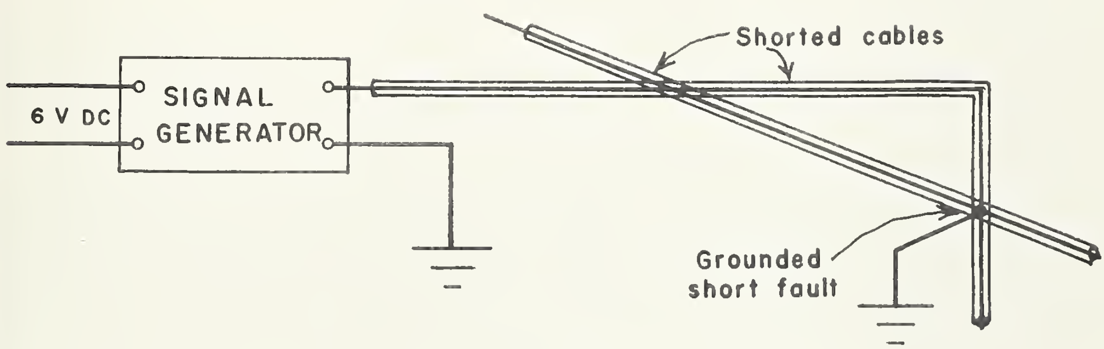

Figure 7. Connections for locating a grounded short-between-cables fault with AN/TSM-11 set.

5.2 Locating Ungrounded Short-Circuit Faults

If the short-between-cables fault is ungrounded, the set may be used to locate the fault by connecting intentional grounds to one or both cables. If the routing of one of the cables is well known, the fault may be located by disconnecting all terminations from both circuits, connecting the output of the generator between the conductor of the cable with the known route and ground, placing an intentional ground on the other circuit at a point well removed from the generator, and tracing the cable (see figure 8 for connections). The fault will be located at the point where the signal departs from the known route of the circuit to which the generator is connected. Of course, by grounding one end of the circuit and tracing from the other end, the route of each circuit can be determined accurately.

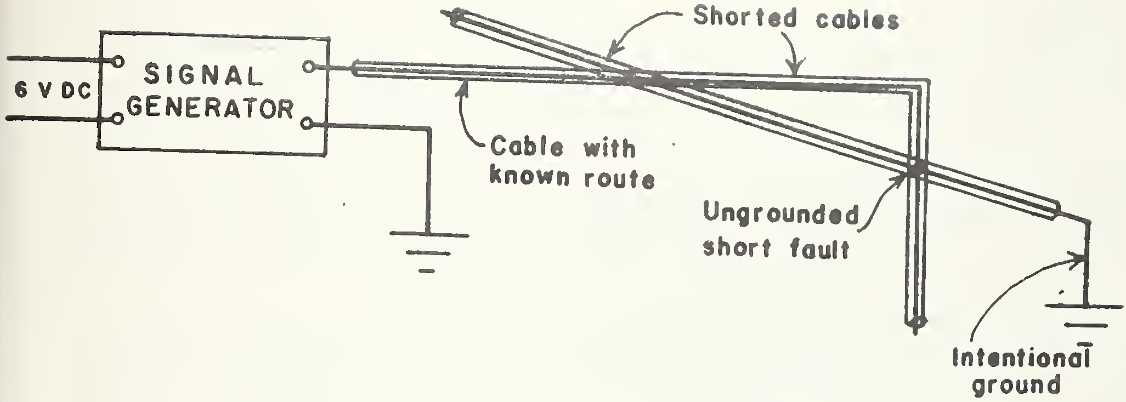

Figure 8. Connections for locating an ungrounded short when the route of one of the cables is known.

The fault may be located in some cases by careful use of the set when the route of neither cable is known. The procedure requires removing all circuit terminations from both cables, connecting the output of the generator between one of the circuits and ground, and connecting an intentional ground at the other terminal of this circuit and an intentional ground at some point on the other circuit (see figure 9 for connections). The three ground points should be well separated.

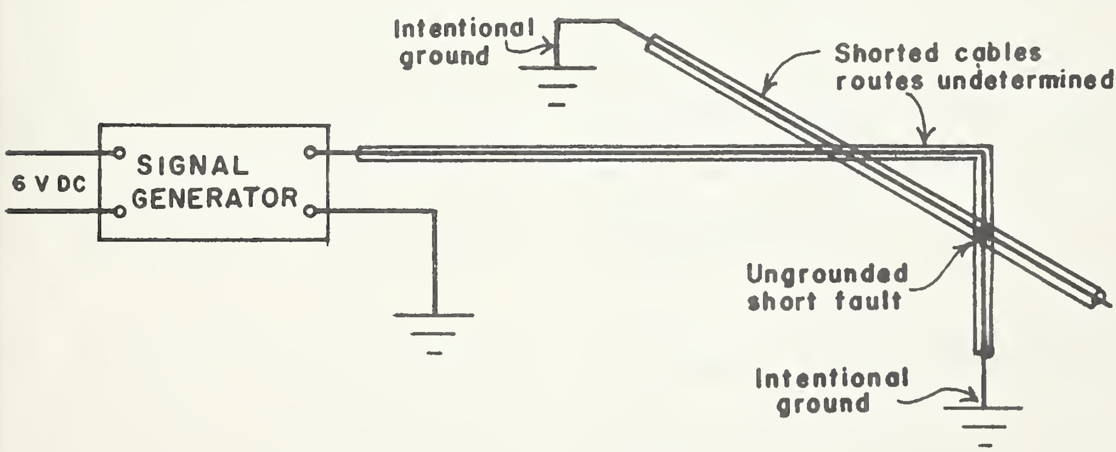

Figure 9. Connections for locating an ungrounded short when the route of neither cable is known.

Energize the generator, and keeping the detector at the same distance from the conductors, check each circuit in turn. Then, from the generator, trace the circuit, noting decreases in signal strength that may indicate the separation of the signal into two circuits. If the signal strengths at the intentional grounds are nearly equal, the decreases in signal strength at the fault should be large, but if the signal strengths at the grounds are very different, the decrease at the short may be small. A careful check at points where the signal indication decreases should reveal the separate signal paths. The ability to obtain good grounds and to determine the effects of the grounds obtained is important in locating ungrounded short-between-cables faults.

An alternate method, especially useful if the signal strengths at the intentional grounds are not nearly equal, is to place the intentional ground on only one of the cables and carefully trace and mark this route. Then move the intentional ground to the other cable and, with the generator still connected as before, again trace and mark the route. The short-circuit fault will be where the routes diverge.

Shorted conductors in a multi-conductor cable or shorts between cables in the same duct or trench are likely to be affected by signal cancellation. This may make such faults more difficult or impossible to locate with the set.

6. HIGH-SERIES-RESISTANCE FAULTS

High-series-resistance cable faults may or may not have associated ground faults. If the fault is also grounded or can be broken down to ground with the regulator, the ground fault and the associated high-series-resistance fault may be located with the set. If the fault can not be broken down to ground, the set is not useful in locating the fault. To break down the circuit to ground, use the procedure as outlined in Section 4.3.1 and figure 4, but first disconnect the circuit from the grounded side of the regulator. If the circuit breaks down, the breakdown will probably occur at the high-series-resistance fault.

7. USING THE SET AS A DEPTH GAGE

Frequently information is needed about the depth at which a cable is buried. A depth determination made without excavation would aid in evaluating an indication of a possible change in depth of the cable. When a cable is to be uncovered, an accurate depth determination would be especially useful to avoid damaging the cable while digging. The set was tested to determine its capability of providing a satisfactory depth indication.

7.1 Determining Depth by a Change of Signal Indication

The strength of the magnetic field along a long straight cable is inversely proportional to the distance from the cable. Hence the depth of the cable in the ground should equal the distance of the detector element above the ground at which the reading is one-half the reading obtained with the detector on the ground above the cable. Numerous tests were made at various distances from the cable and with different values of signal currents in the cable. These tests show that the set used in this manner is not reliable as a depth gage. Under some conditions the results were reasonably accurate, but for other conditions the indicated depth was not of sufficient accuracy to be useful.

The set is not suitable for use as a depth gage in this manner because of the non-linearity of response of the indicator. When the signal strength is too great, the first amplifier stage will saturate regardless of the setting of the GAIN control and the indicated depth is too low. When the signal strength is too weak, the amplifier response is non-linear giving an indication of too great a depth.

7.2 Determining Depth by the Forty-five-Degree-Angle Method

An alternate method of determining depth of cable is feasible but has limited accuracy. This is a simple geometrical solution (see figure 10). In this method carefully determine and mark the surface of the ground directly over the cable, using the maximum indication of the set as a guide. Then, moving to one side of the cable, with the handle of the detector tilted to a 45-degree angle with the horizontal and pointed in the direction of the cable, determine the maximum reading. The handle is then pointed directly at the cable. The depth of the cable below the surface will equal the distance from the point where the line along the handle intersects the ground to the line on the ground directly above the cable.

The accuracy of this indication of depth depends on the accurate determination of the location of the cable and accurate determination of the 45° angle. If this method is used, a simple indicator for determining 45 degrees, attached to the detector handle, will be helpful.

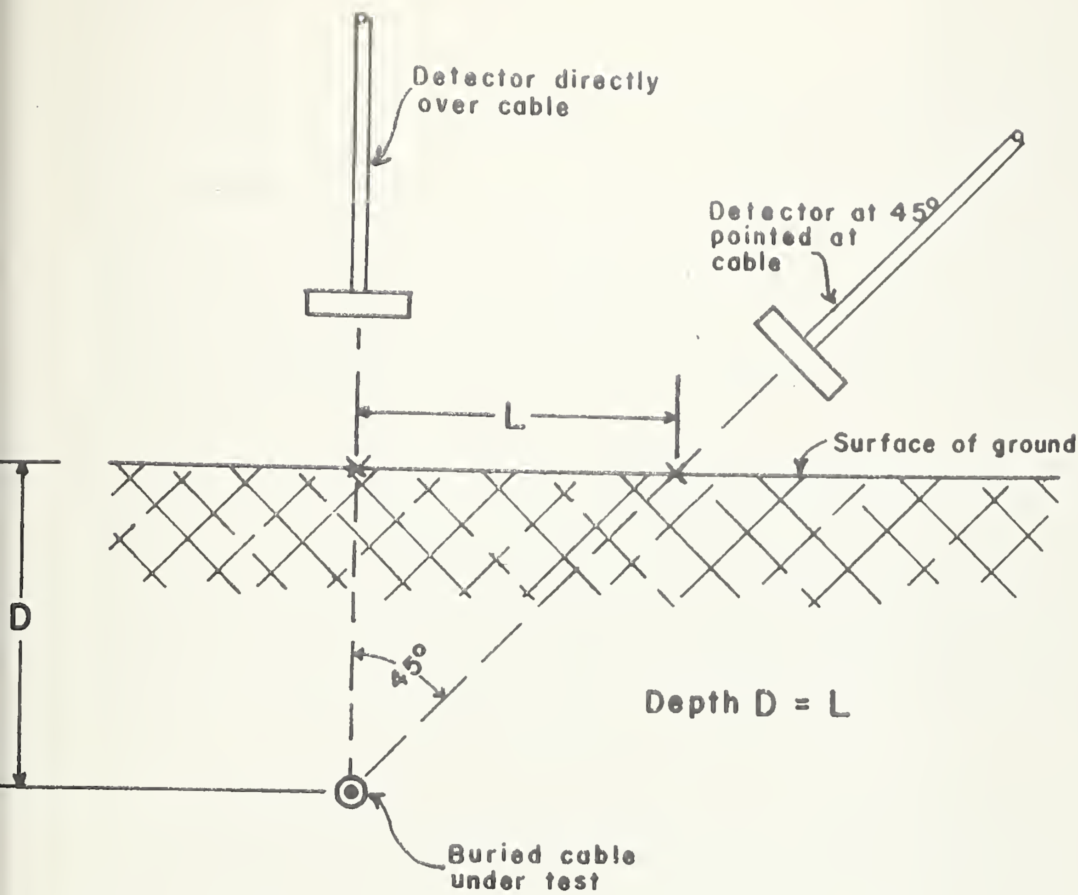

Figure 10. Cross section showing AN/TSM-11 set used to determine depth of a buried cable.

8. LIMITATIONS OF THE SET AND COMPONENT FAILURES

Many of the problems and limitations of the set have been discussed in the appropriate sections on cable tracing and fault location. Other problems that have arisen are concerned with malfunctioning of the equipment and soil conditions and are of a general nature.

8.1 Equipment Malfunctions

Very few malfunctions of the cable test equipment have occurred during ten years of field use. Malfunctions were caused primarily by weak batteries and defective transistors in the indicator unit.

8.1.1 Batteries. The 22.5-volt battery in the indicator has a very limited life. The indicator will operate satisfactorily until the voltage under load is less than 16 volts. If the battery becomes too weak during the process of tracing cables or searching for faults, the resulting decrease in indication can be confusing. One problem in regard to the batteries is that the correct type of battery may not be available locally. A 22.5-volt hearing aid-type of battery may be used as a temporary replacement. However, the life of these batteries is very short when they are used in the indicator. Larger sizes of 22.5-volt batteries may be used by taping the battery to the indicator and extending the connecting leads.

8.1.2 Transistors. Occasionally a transistor in the indicator fails and must be replaced. When replacing transistors, be very careful not to damage the printed circuit boards of the indicator.

8.1.3 Capacitors. Several of the tantalum capacitors in the indicator have failed. If the indicator fails to operate satisfactorily, check the battery and the transistors and, if the trouble still exists, check the capacitors, especially the 20-25-microfarad, 6-volt capacitors.

8.2 Effects of Poor Soil Conductivity

In many instances in the field tests, difficulty in locating faults in underground cables could be attributed to poor soil conductivity. Ground resistance measurements at the Arcata Airport ranged from 5.5 ohms to 750 ohms at various points along the runways, and at the Rohnerville Airport the resistance measurements ranged from 2.5 ohms to 900 ohms. When the conductivity of the soil is poor, abandoned pipes and cables act as a ground return for the signal. Many occasions arose where it was much easier to follow old abandoned pipes and cables than to follow the cable under test. In a test at the Rohnerville Airport where the cable fault was near an underground water line, the signal in the underground water line was approximately one-half the signal strength in the cable under test. (If the cable being traced is buried deeper than the pipe or cable acting as the signal return path, the signal indication on the meter may be less from the cable under test than from the pipe or cable serving as the signal return path.) Paragraphs 4-10 and 4-13 of the Handbook of Operations, reference 1, make particular note of this probable occurrence. In some instances cables in areas of poor soil conductivity may be easier to trace if the counterpoise conductor is disconnected from the vault ground bus because of possible high strength from the return signal in the counterpoise canceling the signal of the cable being traced.

9. CONCLUSIONS AND RECOMMENDATIONS

The tests conducted indicate that the set is an effective device for locating ground faults in airfield lighting circuits where the cables are directly buried in the ground or in non-metallic duct. The equipment has limitations, but even with these limitations the set is a very useful, timesaving device for locating and following buried cable and for locating ground type cable faults.

Ungrounded open faults in cables can not be located precisely, but often can be located to within 200 feet.

Underground piping, grounding (electrical neutral) conductor, or counterpoise systems can give false indications in areas of low conductivity soil because these conductors may be the primary signal return path.

If additional cable test sets are procured, consideration should be given to a set using a test signal more widely separated from harmonics of 60-cycle commercial power, and using a more sharply tuned indicator. This would require a closer tolerance on the frequency of the generator.

The set should be used by the airfield lighting technicians frequently to improve operating skill and to develop ability to overcome some of the limitations of the equipment. If each circuit which is traced is mapped, locating faults which occur in these circuits will be easier and faster.

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