UNDERGROUND CABLE FAULT LOCATION

A HANDBOOK TO TD-153

EPRI EL-363
(Research Project 481-1)

Final Report

January 1977

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NOTICE

FOREWORD

This handbook is designed to serve as a reference document to guide utility operations personnel in the selection and use of fault location equipment on underground power cables. It has been prepared for EPRI (Electric Power Research Institute), Palo Alto, California by The BDM Corporation, Albuquerque, New Mexico. The EPRI Project Managers are J. S. Greenwood and R. S. Tackaberry. The BDM Program Manager is J. J. Schwarz. Major technical contributions were made by R. W. Deltenre and H. J. Wagnon.

The handbook has been prepared under EPRI Project RP 481-1, "Underground Fault Location Techniques." A companion document, "Final Report - Evaluation of Underground Cable Fault Location Techniques," presents the technical results of the study.

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CHAPTER I

INTRODUCTION

A. PURPOSE

This handbook is designed to serve as a reference document to guide utility operations personnel in the selection and use of fault location equipment on underground power cables. The principal emphasis is directed toward distribution cables but transmission cables are also considered in pertinent instances. The contents are organized into three chapters and an appendix:

Chapter I - provides a set of pertinent definitions for terms that are used throughout the text.

Chapter II - is intended for general reference. It identifies and describes seven generic types of fault location equipment.

Chapter III - presents an approach for the selection of a specific fault locator. Two selection procedures are presented. The first procedure treats the initial equipment purchase. The second procedure treats the selection of the equipment best suited to a particular fault.

Appendix A - presents a summary of the available fault location equipment including available specifications.

B. DEFINITIONS

Underground fault location has a history of at least 70 years. During this time the terminology has evolved in response to the available technology and the power system configuration. Unfortunately there is no universally accepted terminology. So, in order to avoid confusion, a few key concepts will be defined here. Granted, some of the definitions may not be familiar but they will at least be consistent within this handbook.

Types of Faults

Open: Conductor physically broken, customer outage but circuit breaker or fuse not blown.

Short: Direct metallic contact between conductors, conductor to neutral, or conductor to ground. Fault resistance less than a few ohms.

Nonlinear: Insulation failure. Fault resistance is a function of applied voltage. An arc forms at a voltage level equal to or less than nominal cable operating voltage.

High Impedance: Actually a nonlinear fault. A large fault resistance is measured below the arc voltage.

Types of Cable

Insulated Wire: Each conductor and the neutral is an independently insulated cable, frequently twisted together in a pair or triplet. Nearly all secondary cable is the insulated wire type.

Concentric Neutral: Conductor and neutral are concentric - neutral may be solid or have helical strands. Polyethylene concentric neutral (PECN) is a typical concentric neutral distribution cable.

Insulated Concentric Neutral: Concentric neutral cable with neutral covered by a nonconducting jacket for support or corrosion protection. Neutral may be solid or stranded.

System Configurations

Transmission System: The cable system between the generator and the substation or between substations - generally operates at voltages greater than 35 kV.

Primary Distribution: The cable system between the substation and the distribution transformer - generally operates at voltages between 4 kV and 35 kV.

Secondary Distribution: The cable between the distribution transformer and the customer meter - generally operates at voltages less than 440 volts.

Branched System: A cable system containing one or more points where the conductor divides - usually the branch point is a T or Y splice. Branched cables are most often encountered in networks.

Types of Fault Location Techniques

Tracing: Technique in which a signal is put on the cable and the effect of the signal is followed or traced to the fault.

Terminal: Technique in which distance to fault is determined from measurements made at cable terminals.

CHAPTER II
FAULT LOCATION TECHNIQUES

A. INTRODUCTION

This chapter describes the currently available fault location techniques. It includes a discussion of the theory of operation, the applicability, and any unique aspects of each technique. In addition, the important specifications are identified for use in the selection methodology discussed in Chapter III.

Fault location techniques can be grossly divided into two general categories: tracing techniques and terminal techniques. Tracing techniques are those which involve putting some signal on the faulted line and following or tracing the effect of the signal to the fault. Terminal techniques are those in which the distance to a fault is determined from measurements made at the cable terminals where the faulted line is isolated.

These two basic categories can be further subdivided in terms of the basic concepts employed as follows:

(1) Tracing Techniques:
- (a) Earth gradient.
- (b) Tone tracer.
- (c) Thumper.
- (d) Tracing current.

(2) Terminal Techniques:
- (a) Bridge.
- (b) Radar.
- (c) Resonance.

In practice, fault location is often most efficient when combinations of these techniques are used. For example, a radar system can be used to determine the approximate location of a fault, then earth gradient techniques can be used to pinpoint the precise location.

B. EARTH GRADIENT TECHNIQUE

1. Theory of Operation

The earth gradient technique locates faults by injecting a fault current into the circuit formed by the faulted conductor and the earth return. The current spreads out in the ground and a potential (voltage) is developed in the ground between the fault and the injection point. If a voltage measurement is made between any two points on the surface of the ground, the direction of the voltage drop generally points toward the fault. This is illustrated schematically in figure II-1.

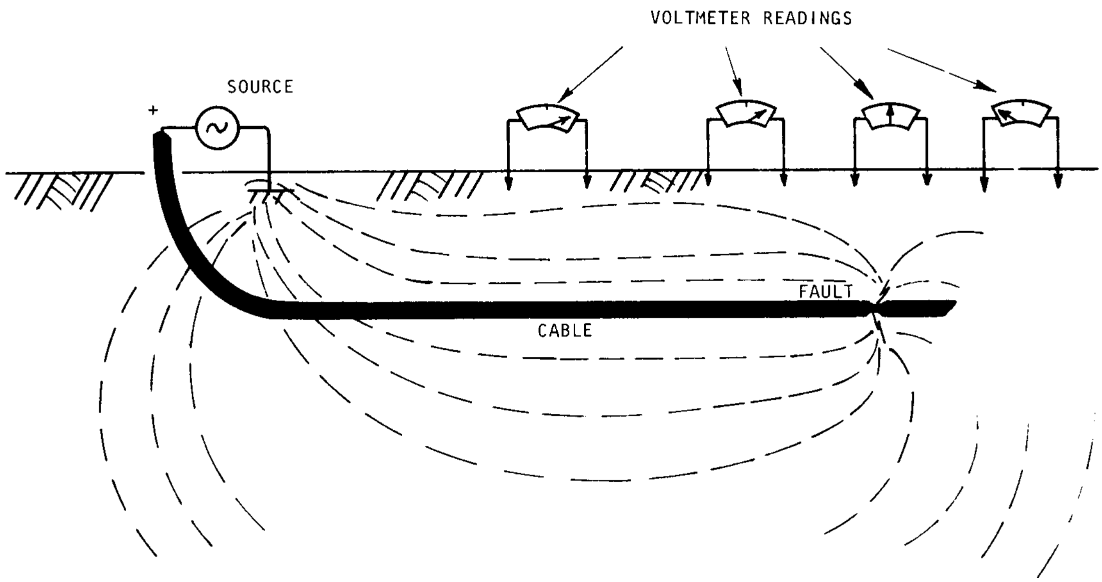


Figure II-1. Earth Gradient Measurements Directly Over Cable

The flow of the return current is indicated by the dashed lines. The voltage measurement is made by inserting a pair of probes into the ground above the cable. As the operator moves along the cable, the voltmeter deflection is in the direction of the fault (assuming proper attention has been given to the polarity of the voltmeter and the current source). When the fault is passed the meter deflection reverses, and when the probes are placed equal-distant from the fault, the meter is in a null position.

If the precise location of the cable is not known, fault location is still possible using the earth gradient technique, but the procedure is somewhat more complicated. Figure II-2 shows a plan view of a faulted cable and a fault current source with the current flow again indicated by dashed lines.

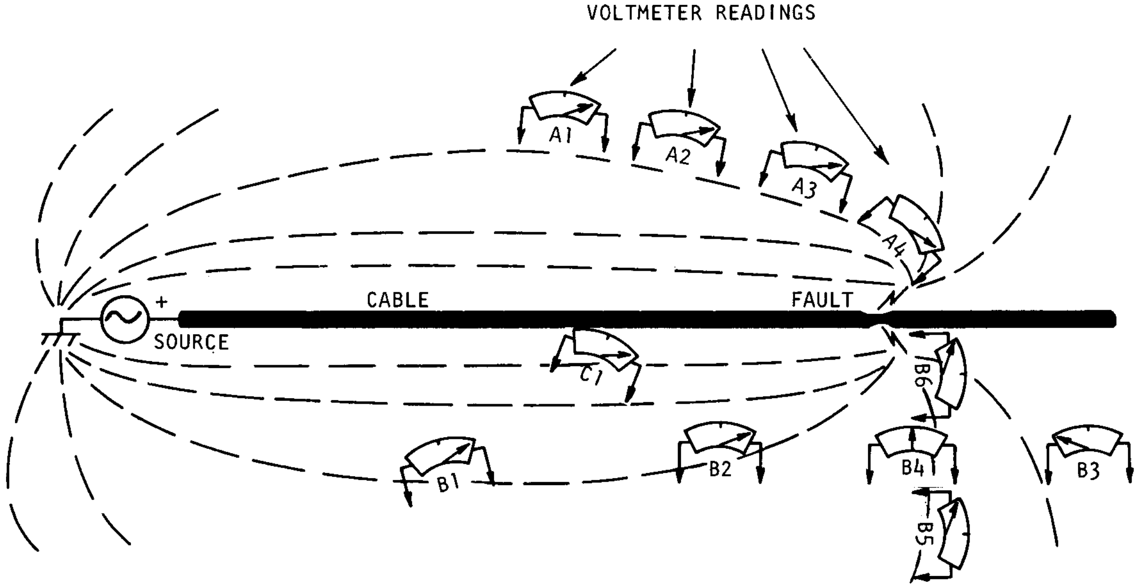


Figure II-2. Earth Gradient Measurements Away From Cable - Plan View

Measurements A1 through A4 demonstrate tracing along a current line. The voltmeter always points toward the fault and a final measurement immediately over the fault would give a voltage null. This illustrates the application of the earth gradient technique to the case where the cable location is not known. However, in practice, the location of the current lines is not known either, so it is not really feasible to follow a given current line directly to the fault. Measurements B1 through B6 show a more probable series of measurements to locate the fault. Measurement B1 is made in the presumed direction of the fault and the succeeding measurements are made in the direction indicated by the deflection of the voltmeter. Measurement B3 shows a polarity reversal indicating that the fault has been passed. Measurement B4 is a null; however, since it is not known whether or not the measurement is made directly above the cable it cannot be presumed that this is actually the location of the fault. Measurements B5 and B6 (made at right angles to B4) indicate the direction to the cable and thus to the fault. If measurement B4 had been truly over the fault, this would have been indicated by opposite polarities on measurements B5 and B6. As it is, the operator must continue in the direction indicated by B5 and B6 until he reaches the cable. A significant difficulty in this type of tracing is indicated by measurement C1. In this case the initial assumption of the fault direction is wrong. As a result, the meter deflection is actually pointing away from the fault. Theoretically, successive measurements would eventually lead to the fault. However, the signal strength would be reduced at large distances from the cable so the process would at best be time consuming and at worst would fail entirely. This problem can be overcome by following a simple procedure in the case where the location of the cable is unknown. The negative probe is inserted first and the positive probe is moved to obtain maximum positive deflection of the voltmeter. The deflection will then always be in the general direction of the fault and tracing can proceed in the sequence shown in B1 through B6.

The major limitation in the use of the earth gradient technique is measurement sensitivity. The ground potential is a function of both cable depth and the distance to the fault. This is illustrated by the graph of figure II-3 which plots ground potential as a function of these two variables.

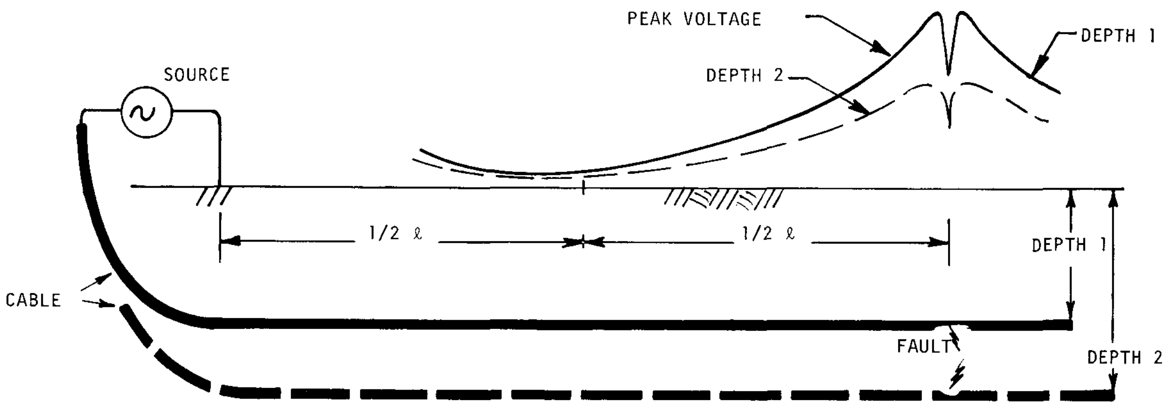


Figure II-3. Voltage Drop Versus Fault Distance for Two Cable Depths

The distance from the fault is seen to be the most important variable. For example, 300 feet from the fault on a cable buried 3 feet deep, the ground potential is only 0.01 percent of the potential measured in the immediate vicinity of the fault. The obvious conclusion is that the usefulness of the earth gradient technique falls off very quickly with increasing fault distance.

The sensitivity of a particular earth gradient model is a function of three key variables:

(1) The output current of the fault current source.

(2) The dynamic range of the voltmeter (that is, the amount of amplification available).

(3) The distance between the voltage probe pair.

Of these variables the importance of the first two should be obvious. Other considerations being equal, higher current output or more amplification should lead to a more sensitive instrument. The voltage probes may be: separate elements connected to a central meter, a pair of probes combined on a single A-frame, or some combination thereof. Increased sensitivity is achieved by increasing the distance between the probes. However, increasing the distance makes the instrument more cumbersome and time consuming to use.

The fault current source can be dc, an ac tone, or a pulse; and each has certain advantages and disadvantages. The dc source is the most common. The major consideration is achieving sufficient supply voltage and current to guarantee current flow through nonlinear faults. The pulsed source is similar to the dc source except that it offers higher fault currents but at a reduced duty cycle. An ac tone offers an advantage in that the same source can be used for tone tracing techniques. Since an ac meter can show only amplitude and not voltage polarity, measurement results would not be as indicated in figure II-1. Rather, relatively large magnitude signals would be detected on either side of the fault, and the measured voltage would fall off as one moved past the fault. Care must be taken to preclude possible 60 Hz interference, and an ac source is generally much lower power than a dc or pulse source of equivalent cost and size.

2. Application

Theoretically the earth gradient technique can be used to locate any conductor-to-ground fault. However, for concentric neutral cables, much of the return current will flow in the neutral rather than the ground and it may be difficult to measure the potential difference at the ground level. For this reason, earth gradient techniques are most applicable to simple insulated wire cables and thus to secondary distribution.

The earth gradient technique can be used to locate either shorts or nonlinear faults. However, the latter requires the availability of a high voltage source with sufficient current capability to maintain current flow through the fault. The earth gradient technique cannot be used to locate opens.

Any significant variations in the conductivity of the ground will distort the path of the ground current flow. This distortion tends to make fault location more difficult and time consuming since the potential drop may point away from the fault in the vicinity of highly conductive objects. This is particularly a problem in land fill areas or in areas where the power cables are in close proximity to other uninsulated cables or metal pipes. However, these variations should not affect the accuracy of the fault location. The earth gradient technique is probably the most accurate fault location technique, and accuracies of ± 1 foot are achievable.

In situations where it is not possible to insert the probes into the ground (for example, on a concrete surface), an alternative is to simply lay large surface area electrodes on the ground. In this case it is usually advisable to improve the contact between the electrode and the ground by means of a conductive solution (for example, salt water).

3. Relevant Specifications

The relevant specifications for earth gradient fault location equipment apply to the fault current source and the voltmeter. The specifications for the fault current source are:

(1) Type of source - dc, ac, or pulse.

(2) Maximum output voltage.

(3) Output current at maximum voltage (i.e., source impedance).

(4) Duty cycle (for pulse type only).

The relevant specifications for the voltmeter are:

(1) Minimum sensitivity (given in volts per unit of probe separation).

(2) Probe configuration (A-frame or separate elements) and maximum separation distance).

(3) Physical characteristics (weight, size, convenience, etc.).

C. TONE TRACING

1. Theory of Operation

Tone tracing locates faults by injecting an audio frequency fault current into the circuit formed by the faulted conductor and the ground as shown in figure II-4a. The flow of current through the conductor causes a net magnetic field shown by the dashed lines.

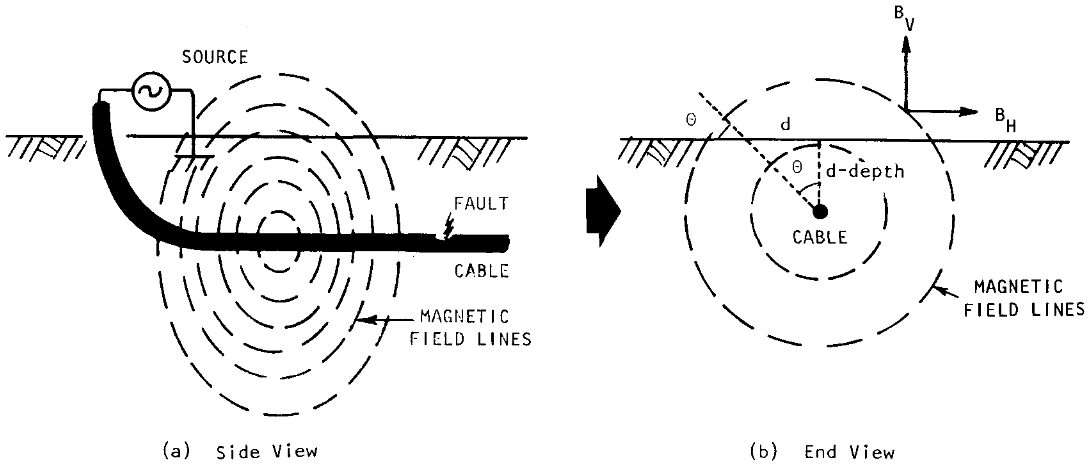


Figure II-4. Tone Tracer Field Geometry

The magnetic field exists both in the ground and in the air. It can be sensed using a simple magnetic loop antenna. The magnetic field lines are curved so that it is difficult to predict the antenna orientation which will intercept the maximum field. Therefore, it is practical to resolve the magnetic field into coordinates relative to the earth: a vertical field component B_V, and a horizontal component B_H. As seen from figure II-4b, the loop antenna which responds to B_H has a maximum excitation directly above the cable. Conversely, the antenna which responds to B_V is a minimum above the cable (theoretically zero). The variation in the antenna response with distance away from the cable is shown in figure II-5.

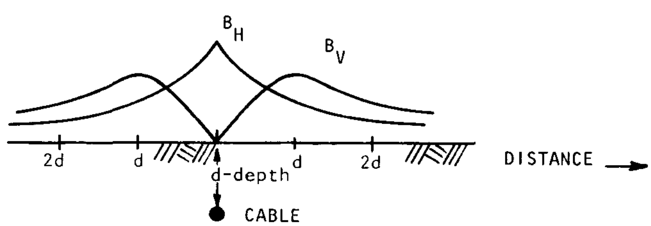


Figure II-5. Magnetic Field Components Versus Distance

These variations in the field pattern provide the basis for use of tone tracing for cable location. The operator moves along the cable swinging the antenna from side to side. If the antenna is responding to B_V (vertical polarization) then the antenna output is a null immediately above the cable. For a horizontally polarized antenna, the output is a maximum immediately above the cable.

The magnetic field also varies in the vicinity of a cable fault. Assuming essentially zero current flows past the fault (the fault shunts the current to ground), the magnetic field characteristics change at the fault. If a horizontally polarized antenna is used, the maximum output falls off rapidly beyond the fault. If a vertically polarized antenna is being used, the change in characteristics is more subtle. The distinct null above the cable disappears beyond the fault and the characteristics of the field become less distinct.

The tone tracing technique is not nearly so precise as the earth gradient technique so the earth gradient is frequently used for pinpointing the fault. The advantage of the tone tracer technique lies in the fact that the magnetic fields are a function of the current and not necesarily a function of the distance to the fault. Thus, the tone tracer provides essentially constant field levels along the cable route.

Tone tracer sensitivity depends on several factors which affect the smallest magnetic field level that can be sensed. These include the amount of current delivered by the fault current source, the antenna characteristics, and the gain of the receiver. Tone tracing implies a CW signal, although in some instruments the CW is repetitively interrupted. Tracing of 60 Hz fault current can easily be confused by signals from unfaulted sources, hence many available tone tracing systems inject a signal that is clearly distinguishable from 60 Hz (or harmonics) by sharp filtering in the detector. The selection of an operating frequency involves practical trade-offs. Higher frequencies improve the efficiency of the antenna. However, the higher frequencies also tend to increase capacitive coupling to other conductors which tends to mask the fault.

The fault current is, of course, a function of the output power capabilities of the source. However, the fault current can be maximized by matching the fault impedance to the source, and many instruments include an adjustment for this purpose.

The receiver sensitivity depends on the gain of the antenna and of the receiver electronics. Many tone tracer detectors use a high permeability ferrite core for the antenna to obtain a maximum output. In addition high-gain amplifiers are often used in the receiver. The actual output display is either presented directly as a tone via earphones or a speaker, or is rectified to drive a meter.

2. Application

Strictly speaking, the theory of operation presented for tone tracers applies only to direct buried, insulated wire cables where the fault is a short to ground. The technique is much less efficient for other fault types and cable configurations. For open circuit faults, the only current flowing is through capacitance to ground through the cable insulation. The current is reduced from the short circuit case so the fields are more difficult to measure. Tone tracing by itself cannot be used to locate nonlinear faults because of the low voltage sources used.

Tone tracing can be used to locate shorts to ground (or the neutral) in concentric neutral cables if the neutral can be isolated from ground so that the fault return current flows through the ground. In this case, the operation is exactly the same as for an insulated wire cable. If a neutral cannot be isolated from ground (that is, if it carries a significant portion of the return current), then the magnetic fields will tend to be cancelled and the overall sensitivity of the system is proportionally reduced.

Tone tracing has one significant advantage over other fault location techniques in that it can be used to locate both the fault and the cable itself. Since it is often necessary to locate the cable before fault location can begin, substantial effort can be saved. In addition, tone tracing can also be used to determine the depth of a cable. Figure II-4b can be used to illustrate this. Note that as the vertically polarized antenna is moved along perpendicular to the magnetic field line, its output is always zero. Simple geometry shows that if the vertically polarized antenna is oriented at 45 degrees relative to the ground and moved away from the cable, the point at which its output is nulled is precisely one cable depth away from the line of the cable. If fault location is to be accomplished by tone tracing alone, the ability to determine depth is essential, otherwise a drop in signal level caused by a change in cable depth might be interpreted as a fault.

Because it is most applicable to insulated wire cables, tone tracing is used most extensively for secondary faults. However, there are some instances where it can be used for fault location on primary distribution.

3. Relevant Specifications

The relevant specifications for tone tracer equipment apply to both the fault current source and the receiver. For the source, the relevant specifications are:

(1) Operating frequency (should avoid harmonics of 60 Hz).
(2) Bandwidth (desirable to have a high Q).
(3) Power output.
(4) Ability to match source impedance to fault impedance.
(5) Power source (internal battery, truck or auto battery, or ac.

For the receiver, the relevant specifications apply to both the antenna and the receiver electronics. They are:

(1) Antenna polarization (horizontal or vertical).
(2) Antenna sensitivity.
(3) Amplifier bandwidth (the receiver should be sharply tuned to the injected signal frequency).
(4) Amplifier gain.
(5) Availability of AGC (automatic gain control).
(6) Type of display (meter, speaker, earphones, etc.).
(7) Physical characteristics (weight, volume, etc.).

D. THUMPER

1. Theory of Operation

The thumper locates faults by using a charged capacitor to create a high energy pulse between the faulted conductor and ground. This pulse is intended to create an arc at the location of the fault. The arc heats the surrounding air and the energy is released as an audible "thump." The arc location can be traced by sensing the acoustical thump, the seismic wave, or the magnetic field generated in the arc. The potential drop can also be traced, using earth gradient equipment. If a loud enough sound is generated, the fault may be located by simply hearing or feeling the thump. A conceptual schematic of fault location using a thumper is shown in figure II-6.

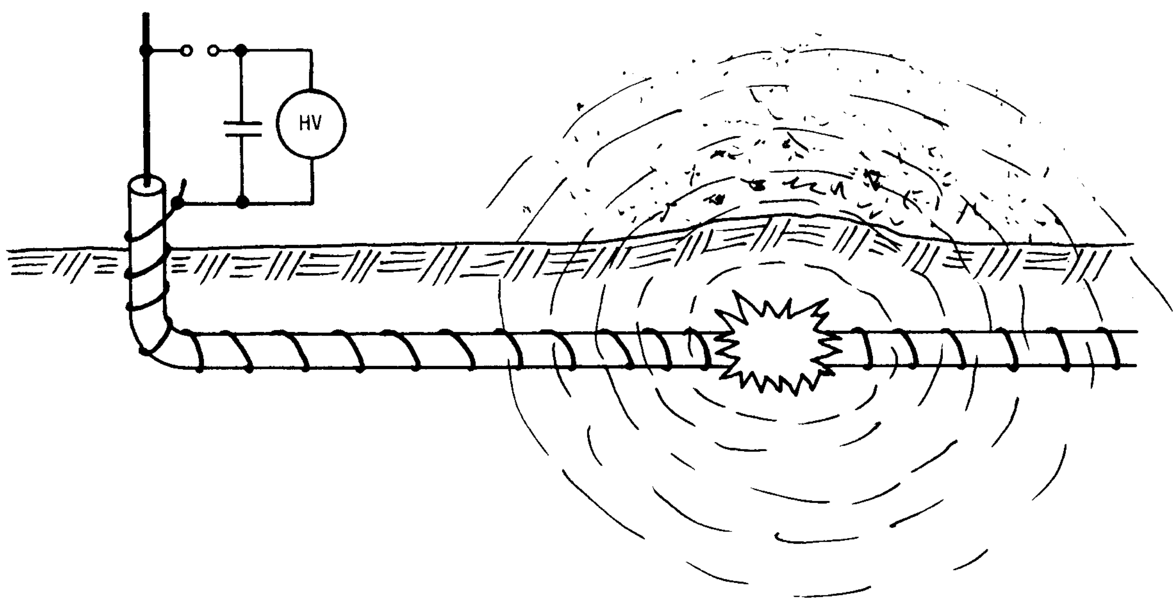


Figure II-6. Thumper Fault Location

The thumper source is simply a capacitive discharge circuit. All that is required in principle is a power supply, a capacitor bank, and a high voltage switch. The most common switch is a simple spark gap. The sensors used to locate the fault can include a magnetic loop antenna, a microphone, or an earth gradient detector. The operation of the loop antenna and the earth gradient probes has already been discussed, so the remainder of this discussion will treat the audible thump as the primary fault location mechanism. The thump may be "heard" (microphones or the ear) or "felt" (seismic sensor or the feet).

The thump is created when the current in the arc heats the air causing a pressure wave to expand outward from the arc channel. The initial current surge causes the air to expand much faster than the energy can propagate away from the arc channel, resulting in an enormous increase in pressure and thus creating a shock wave. The perceived loudness of a thump depends on the amplitude and duration of the current pulse. For a given pulse shape (duration), the intensity of the sound produced is maximized by maximizing the current that flows through the arc. The current amplitude varies directly with the cable voltage at arc initiation and inversely with the source impedance. Further, the arc initiation voltage tends to increase as the pulse risetime is reduced. Thus, the current amplitude is maximized by maximizing the charge voltage and minimizing the risetime and the source resistance and inductance.

The relationship between the loudness of the thump and the electrical pulse duration is more complicated because of a number of filtering actions involved in the interaction. The generation of a shock wave, its propagation, reflections from the earth-air interface, and the characteristics of the human ear (or other sensor) combine to affect both the intensity and the frequency content of the thump. Thus, the relationship between loudness and duration depends on the physical situation. The tendency is for the loudness to increase with the duration; however, the increase is asymptotic to a maximum value which is determined by the current amplitude. Thus, increasing the current duration beyond a certain point has a negligible impact on the loudness but does increase the low frequency content of the thump.

The current duration is proportional to the electrical time constant of the circuit and thus to the resistance-capacitance product. Since it is desirable to minimize the resistance in order to maximize the current amplitude, the capacitance must be used to control the time constant. Hence, the loudness of the thump will increase asymptotically with capacitance as shown in figure II-7.

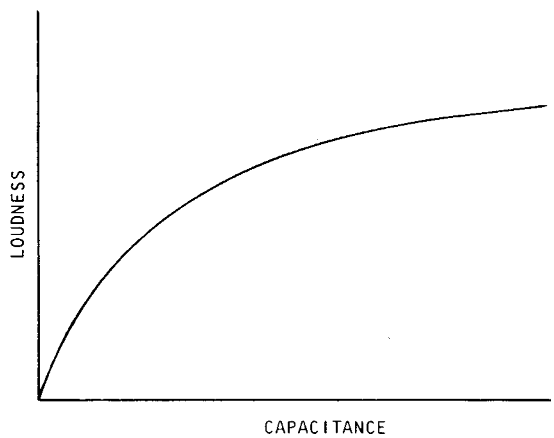


Figure II-7. Increase in Loudness with Capacitance

2. Application

Thumper fault location has been applied to both secondary and primary distribution and to transmission lines. Its major application is to nonlinear faults where an arc is readily formed. While an audible thump is not produced by a dead short, the high current may vaporize some metal and create a nonlinear fault. Generally, the thumper cannot be used to locate opens. However, if the conductor is shorted to ground at the far end, an arc can sometimes be produced across the open and it can be located.

When the thumper's acoustical wave is used for fault location it works equally well on all cable types. However, when the magnetic field or earth gradient detector are used, the same restrictions mentioned for the tone tracer and earth gradient technique apply. Namely:

(1) Best operation on insulated wire cables.

(2) Any nonuniformities in the soil (especially any conducting cables or pipes) will significantly distort the field patterns and make fault location more difficult.

The operation of thumpers is strongly influenced by soil conditions. For example, the presence of highly conductive water provides a low impedance path and may preclude the formation of an arc. On the other hand, extremely dry sandy soil does not propagate the acoustic wave well, so that the ability to locate the fault may be degraded even though an arc is formed. Hard surface layers such as concrete or frozen ground, may reflect the sound wave back into the earth and again reduce the signal available for detection. In any case, the strength of the audible signal falls off with cable depth. However, when conditions are favorable, thumpers are quite accurate and relatively simple to use. Their accuracy can easily be as good as a few feet and is independent of cable length.

3. Relevant Specifications

The relevant specifications for the thumper apply primarily to the fault current source. However, the various sensors should also be considered. The specifications for the source are:

(1) Operating voltage - should exceed maximum system operating phase to ground voltage (that is, system peak voltage not rms voltage).

(2) Capacitance.

(3) Maximum output current.

(4) Risetime - depends on source inductance and resistance and switch characteristics.

(5) Switch characteristics - includes basic type (triggered or untriggered), risetime, lifetime, maximum rated current.

(6) Power supply characteristics - includes efficiency and time to charge capacitor to operating voltage.

(7) Physical characteristics - especially size and weight, portability, and power requirements.

The relevant specifications for the sensors include:

(1) Magnetic sensor - sensitivity, bandwidth, and physical characteristics.

(2) Earth gradient probe - sensitivity, probe spacing, and physical characteristics.

(3) Acoustical sensors - sensitivity, bandwidth, physical characteristics.

(4) Seismic detectors - sensitivity, bandwidth, physical characteristics.

(5) Display - basic type, dynamic range, physical characteristics, convenience features.

E. TRACING CURRENT TECHNIQUE

1. Theory of Operation

The tracing current technique is used to locate faults on branched systems where periodic access to the cable is available via manholes. The fault current is introduced into the circuit formed by the faulted conductor and the ground. A current transformer is used to measure the net cable current at selected manholes. Figure II-8 depicts the usage of the tracing current technique.

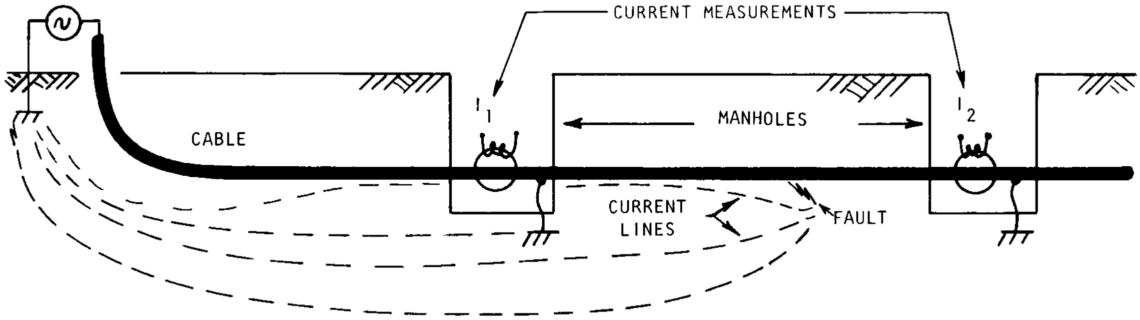


Figure II-8. Tracing Current Technique

For the fault to ground shown, I_1 measures the fault current and I_2 does not. This indicates that the fault is located between these two manholes. This is the maximum accuracy that can be obtained using the tracing current technique by itself. However, if the cable is installed in a duct, then this accuracy is sufficient since the entire cable between the manoles will be replaced. For a direct buried cable, supplemental fault location would be required using the earth gradient, tone tracer, or thumper technique.

The major consideration for use of the tracing current technique is to assure that a substantial percentage of the return current is flowing in the ground rather than in the neutral. If all of the return current flows in the neutral (the shield), then the magnetic field seen by the current transformer is cancelled and the output is essentially zero. Thus, it can appear that the measurement point is beyond the fault when in actuality it is not. This requirement is most important for insulated neutral cables (particularly PILC) where it is necessary to assure neutral to ground contact between the point of the measurement and the fault. Returning to figure II-8, this contact is best assured by placing the current transformer between the source and a local ground point, as shown.

If the neutral is isolated from ground so that most of the fault current flows in the neutral, an alternative approach is to measure the voltage drop along the neutral. As a matter of fact, this approach can be used even if the neutral is not isolated, if the voltmeter is sensitive enough.

2. Application

The tracing current technique applies to shorts or nonlinear faults; however, the latter requires a high voltage source. The source can be dc, ac, or pulse, and the considerations mentioned in the discussion of the tone tracer technique apply here.

As mentioned previously, the tracing current technique is not applicable to insulated neutral cables unless a provision for a ground connection can be made. Otherwise, the technique is applicable to any type of cable where periodic access to the cable is provided.

3. Relevant Specifications

The relevant specifications for the tracing current technique apply to the fault current source and to the current transformer. The specifications for the fault current source are:

(1) Operating voltage - must exceed system operating voltage for nonlinear faults.

(2) Maximum current - must be sufficient for detection with current transformer.

(3) Type of source - dc, ac, or pulse (note, a saturable reactor is often used).

(4) Power supply repetition rate - for pulse sources only.

The specifications for the current transformer system include:

(1) Transformer sensitivity - must be compatible with a maximum source current.

(2) Type of display - oscilloscope, meter, audible tone, etc.

(3) Receiver sensitivity.

(4) Convenience features relevant to operating in a manhole environment.

F. BRIDGE

1. Theory of Operation

The common Wheatstone bridge can be used to locate faults by measuring the resistance of the cable from one end of the fault. If the resistance of the conductor is uniform, the length is proportional to the resistance. The basic theory of the bridge is illustrated in figure 11-9.

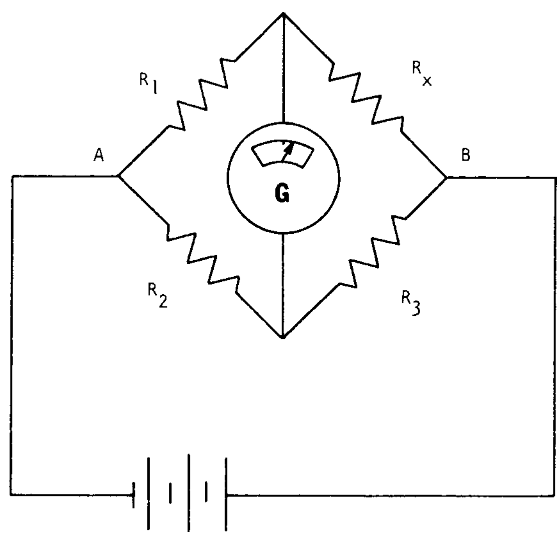


Figure 11-9. Wheatstone Bridge

Three known and one unknown resistances are arranged as shown and a voltage applied between points A and B. If one or more of the known resistors is varied until no current flows through the galvanometer G then,

$$\frac{R_x}{R_3} = \frac{R_1}{R_2}$$

Numerous bridge configurations exist and the Wheatstone bridge is not the most useful as a fault locator. The Murray Loop is the bridge configuration most commonly used to locate faults. It uses a proportional measure so that it is not necessary to know the actual cable resistances. If the conductor is shorted to ground at the fault and an identical unfaulted phase connected to the faulted phase at the far end, then the bridge shown in figure II-9 can be redrawn as shown in figure II-10.

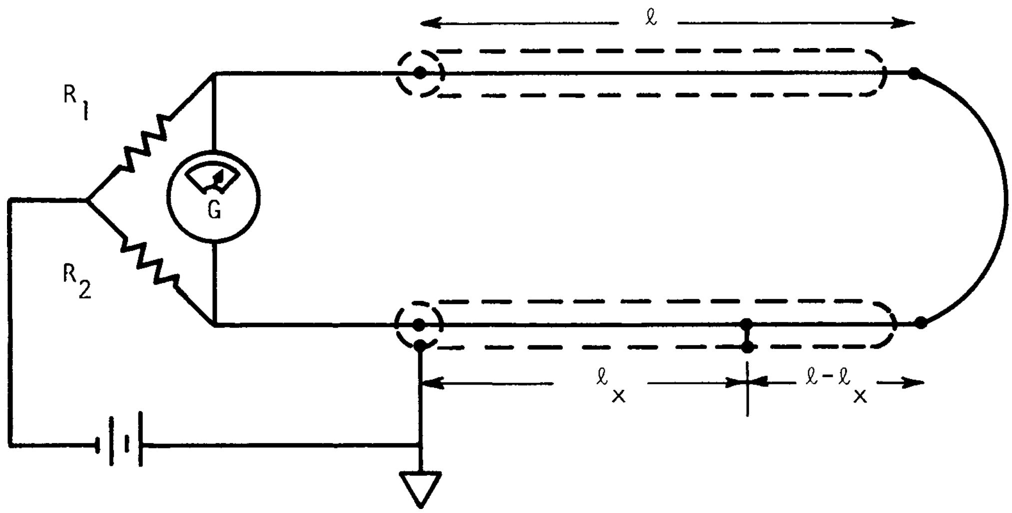


Figure II-10. Fault Location Bridge

Given that ℓ is proportional to R, then

$$\frac{R_2}{R_1} = \frac{\ell_x}{2\ell - \ell_x}$$

This can be simplified if R_1 and R_2 are part of a variable resistor, then

$$\frac{R_2}{R_1 + R_2} = \frac{\ell_x}{2\ell}$$

The Varley Loop is a bridge variation which uses two good phases in order to eliminate lead resistance. Another variation is to locate opens by measuring capacitance rather than resistance. Finally, special high voltage bridges are used to generate sufficient current to drive nonlinear faults.

2. Application

Bridges can be used to locate faults on all cable types. However, most instruments are application limited with respect to fault type. Opens can be located with capacitance bridges. Shorts are located with resistance bridges and nonlinear faults can be located with high voltage resistance bridges.

Most bridge applications require access to both ends of the cable and the use of an unfaulted phase. In addition, all connections must be low resistance and the lead length must be accounted for. While simple in theory, bridges are often difficult to use and require considerable knowledge and experience.

The major limitation of the bridge is the requirement for uniform cables. That is, the entire cable must be of one size. Faults on cables with more than one conductor size can be located since the bridge does in fact measure resistance, but this requires that the conductor sizes vary in the same way on both the faulted phase and the good phase. It also requires good knowledge of the cable lengths and sizes and considerable operator skill, so that the total cable resistance can be calculated.

The use of a bridge on a branched system requires that the faulted branch be identified (in order to place the short between the faulted phase and the good phase) before an accurate reading can be obtained. This requirement, combined with the fact that conductor size often changes where branching occurs, makes use of a bridge undesirable for branched systems.

3. Relevant Specifications

Relevant specifications for a bridge system include:

(1) Operating voltage.

(2) Type of bridge - the Murray Loop is most commonly used for fault location.

(3) Bridge impedance elements - most bridges use resistive elements. These are applicable to shorts and nonlinear faults. If open circuit faults are also of interest, then capacitive elements may be required.

(4) Galvonometer characteristics - both active and passive galvonometer circuits are available with various null displays. If the galvonometer is actually a voltage measuring device as would be the case with most active circuits, then the common mode rejection ratio should be as large as possible.

(5) Accuracy - laboratory bridges can achieve accuracies of 0.01 percent but field instruments can seldom achieve any better than 0.1 percent.

(6) Physical characteristics - weight, size, special ruggedization for field environment, etc.

G. RADAR

1. Theory of Operation

The radar, or pulse-echo, method of fault location is based on the measurement of the transit time of a signal from one end of the cable to the fault and back. Assuming a uniform cable, the transit time, t, and distance to the fault, d, are related by v, the propagation velocity of the signal. Since the signal must travel to the fault and back, or twice the distance, the relationship is simply

$$d = \frac{vt}{2}$$

Alternatively, if it is possible to measure the transit time to the end of the cable or to the end of a similar cable where length, ℓ is known, then a proportional method similar to that used for the Murray Loop can be used and the velocity is not needed, then

$$d = \frac{t_f}{t_\ell} \cdot \ell$$

where t_ℓ and t_f are the transit times to the end of the cable and to the fault, respectively. Note that if the proportional method is used, the calculation of d includes any errors associated with the measurement of t_f, t_ℓ, and ℓ. If ℓ is much greater than d, ($t_\ell >> t_f$) then this method may be less accurate than use of an approximated propagation velocity.

There are two major types of radars differentiated on the basis of the duration of the output pulse. The short pulse is the type most commonly used in instruments developed primarily for power cables. The pulse duration is short compared to the propagation time to the fault. The width of the pulse must be such that it can be observed on an oscilloscope when viewing the entire cable. In practice, this means that the pulse width must be greater than 1 percent of the transit time for the total cable length to be tested. Most commercial systems have a means to change the pulse width depending on the cable length. The pulse duration must be short enough to prevent the trace of the transmitted pulse from obscuring the reflected pulse. Pulse amplitudes are typically on the order of a few volts. The major disadvantage of a short pulse is the difficulty of data interpretation. Reflections from splices may be interpreted incorrectly as faults. A typical waveform is illustrated in figure II-11.

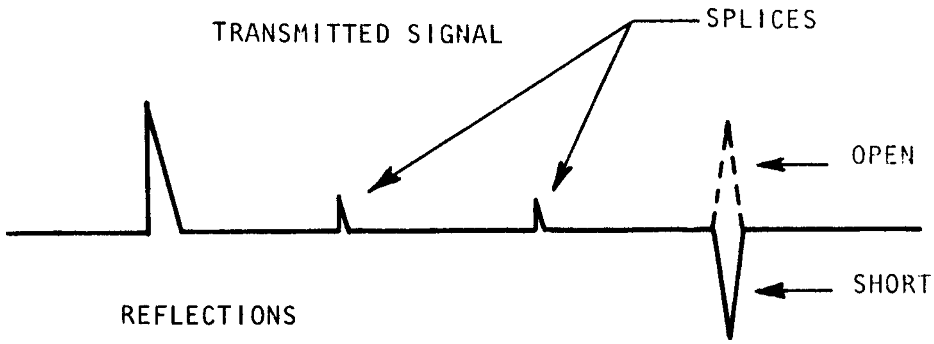


Figure II-11. Short Pulse Radar Waveform

The long pulse system is one in which the pulse is long with respect to the transit time of the cable. In effect, the pulse is a step function and discontinuities are seen as changes in the voltage level of the step. In all other respects, the long pulse is similar to the short pulse. The major advantage of the long pulse is the ease of data interpretation. Splices can be easily differentiated from faults, and changes in cable size can also be observed. A typical waveform is shown in figure II-12.

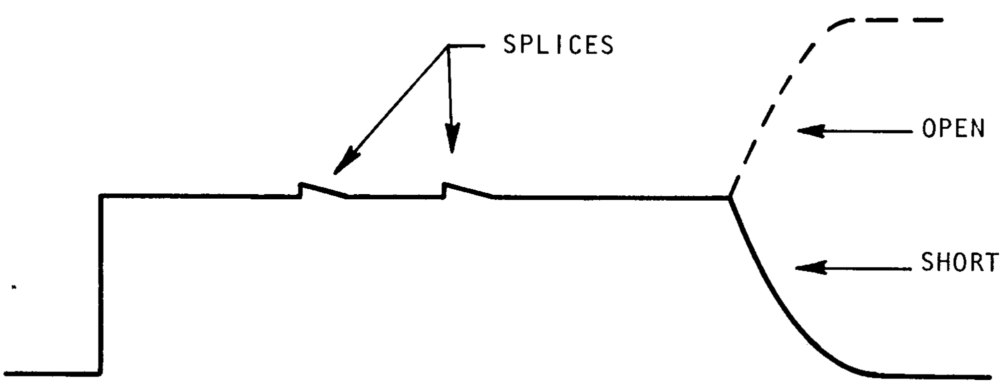


Figure II-12. Long Pulse Radar Waveform

In most cases, the interpretation of data from a radar system is quite simple. The scope trace shows the transmitted signal and the reflected signal. The operator measures the separation, multiplies by the scope calibration factor, and this is the transit time. However, all discontinuities along the cable cause reflections and it is sometimes difficult to pick out the reflection of the fault from the other reflections caused by splices. This problem is dependent on the cable system and particular instruments being used.

2. Application

Radar can be applied to almost any type of power cable. The primary requirement is that propagation velocity be constant along the length of the cable. The propagation velocity depends primarily on the dielectric and to a lesser extent, on the geometry of the cable. Thus, cable size, shape, and dielectric should be uniform for maximum accuracy.

The basic radar works well with opens and shorts but nonlinear faults cannot usually be located. However, some variations are available that can also locate this type of fault. Alternately, the radar can be used in conjunction with a burning set which is used to reduce the fault impedance to a low value.

Radar can be used on branched systems but interpretation of data is difficult and requires considerable skill on the part of the operator.

The accuracy with which the distance along the cable to the fault can be determined is simply the accuracy with which the transit time can be measured. There are two problems associated with the measurement of transit time. The first is simply the accurate measurement of time, and the second is the degradation of the signal as it propagates down the cable and back.

Accurate measurement of time is possible but expensive. The propagation velocity for a typical power cable is on the order of 0.5 feet per nanosecond. Thus, for example, the two-way transit time for a 200-foot long cable is 800 nanoseconds. To measure this to 1 percent accuracy requires the capability of measuring with a resolution of 8 nanoseconds. Most radars used for fault location use an oscilloscope for transit time measurements. Oscilloscope traces can often be read to an accuracy of 1 percent, but the instrument seldom achieves better than 3 to 4 percent sweep time accuracy. An electronic counter can be used to improve accuracy if required.

Signal degradation is a more basic problem since it is a function of the power cable. In order to accurately measure transit time of a signal, the injected signal must have a relatively fast risetime. For precise distance measurements, the pulse reflection should have a similarly fast risetime, but since attenuation and dispersion occur as the signal travels down the cable, the risetime of the reflected signal always exceeds the risetime of the injected signal. This degradation increases with cable length, so the longer the cable (or distance to the fault) the less accurate the measurement.

3. Variations

Three major variations of the radar technique have been developed: the arc-radar technique, the free oscillation technique, and the differential radar.

The arc-radar uses a high voltage pulser in addition to the radar unit so that nonlinear faults can be located. The high voltage pulser causes an arc to form at the fault, much the same as with a thumper, and while the arc is burning, the fault appears as a short and the radar pulse is reflected from the arc-short. The arc current duration is fairly long (typically a millisecond) and during this time, the radar pulse is transmitted and the reflected pulse recorded. Because of the short time available, only one radar pulse is sent per arc pulse. The repetition rate is too low for continuous viewing on an oscilloscope. The pulse must be photographed or recorded on a storage scope.

The second variation, also for nonlinear faults, is the free oscillation technique. This technique also uses a high voltage pulse to break down the fault and form an arc. The breakdown of the arc causes a pulse to be transmitted down the cable. It is this pulse whose transit time is measured to determine the distance to the fault. With the free oscillation technique, the cable end at which measurements are made is terminated in a high impedance, effectively an open, so that the pulse formed at the arc is reflected from the open end to the short at the arc and back to the open end. This reflection back and forth continues until the energy is completely absorbed by the cable. The signal displayed on an oscilloscope is similar to a damped sine wave as shown in figure II-13. The period of the signal is four times the transit time of the pulse as it travels the distance to the fault. Thus, if t is the period, the distance d to the fault is

$$d = \frac{vt}{4}$$

where v is the propagation velocity.

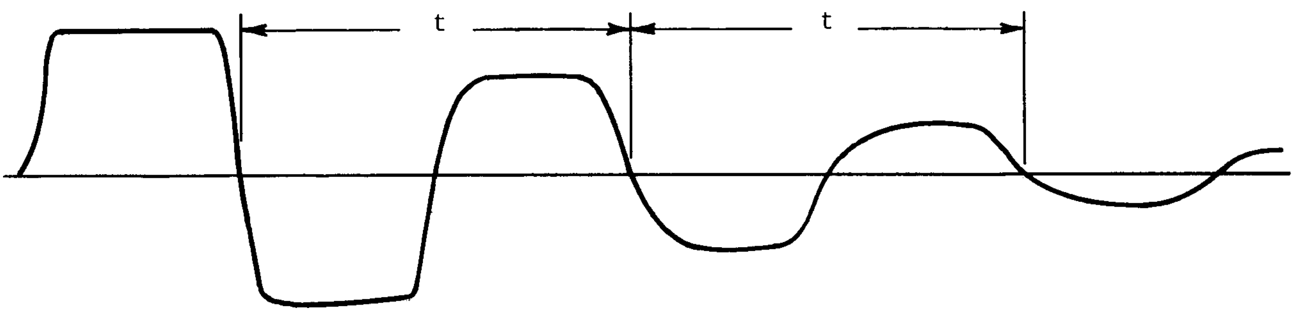


Figure II-13. Free Oscillation Radar Waveform

A third variation on the basic radar principle is applicable for fault location on branched systems. This variation is referred to as the differential radar. The differential radar takes advantage of the fact that a faulted cable phase is almost always paralleled by an identical unfaulted phase. The radar signature of the two phases will be identical except for that part of the signature associated with the fault itself. The differential radar applies the radar pulse to both phases simultaneously and subtracts the returns. The difference signature shows the radar pulse input (a step function for the long pulse radar or a pulse for the short pulse radar) at the point of the fault.

The subtracting of the signals is accomplished by a simple differential amplifier and all that is required is that the common mode rejection ratio (CMRR) of the amplifier be sufficient to preserve the fault signature in the presence of all of the other reflections on the cables.

4. Relevant Specifications

The specifications for the radar system are as follows:

(1) Radar type - long pulse or short pulse.

(2) Display type - oscilloscope, counter, or both.

(3) Operating voltage - should be sufficient to operate in the presence of system noise.

(4) Pulse risetime - depends on desired accuracy - typically less than 10 nanoseconds.

(5) Pulse duration - depends on cable lengths anticipated - usually variable from about 10 nanoseconds to 10 microseconds.

(6) Display time increment range - should range from a few nanoseconds to 100 microseconds.

(7) Display accuracy and linearity - must exceed maximum desired accuracy, typically 1 percent or better.

In addition to these general radar characteristics the special radar versions give rise to their own specifications. Most important, the arc-radar and the free oscillation technique require high voltage pulse sources similar to that of the thumper. The discussion of relevant specifications for thumpers (paragraph D, 3) should be consulted for additional specifications.

H. RESONANCE

1. Theory of Operation

The resonance method fault location is based on the measurement of the frequency at which the length of cable between the terminal and the fault resonates. The resonant frequency is inversely proportional to the wavelength which is related to the fault distance d, as:

$$\lambda = \frac{v}{f} = 4d \quad \text{(for short circuit)}$$
$$= 2d \quad \text{(for open circuit)}$$

where f is the resonant frequency, λ is the wavelength, v the propagation velocity, and d is the distance to the fault. The 4 is included for shorts because the quarter-wave resonance is employed, and the 2 is included for opens because the half-wave resonance is employed. This technique is similar to the radar technique except that the radar operates in the time domain and the resonance operates in the frequency domain.

In operation, a frequency generator or oscillator is attached to the end of the faulted cable. The frequency is varied while observing the peak or rms voltage on the cable. At resonance, the voltage changes rapidly (increases for a short, decreases for an open). The resonant frequency is the point at which the maximum or minimum occurs. The minimum frequency required is determined by the cable length and the maximum frequency is determined by the distance to the nearest point at which a fault may occur. If the minimum fault distance is 10 feet for a 10,000 foot cable, the required frequency range is approximately 12 kHz to 12 MHz.

At first glance, it would appear that the technique would be excellent for extremely long cable, as low frequencies are easy to generate and measure. However, the accuracy to which the resonant peak can be read depends on the cable Q. The Q varies directly with frequency, and therefore, inversely with length. Thus, the accuracy with which the resonant frequency can be measured decreases with lower frequencies and longer cable lengths.

As with the radar technique, the propagation velocity could be considered constant and eliminated from the calculation by measuring the ratio of frequencies and determining the fault distance as a percentage of the cable length. However, the velocity does vary with frequency at the low frequencies, so it may be necessary to account for this. This variation can be a few percent for very long cables as indicated in the following tabulation.

	#2 CABLE		1000 KCM CABLE	
FREQUENCY	DISTANCE	VELOCITY	DISTANCE	VELOCITY
1 KHz	115,500 ft.	.462 ft/ns	117,500 ft.	.470 ft/ns
10 KHz	11,750 ft.	.470 ft/ns	11,750 ft.	.470 ft/ns
100 KHz	1,175 ft.	.470 ft/ns	1,175 ft.	.470 ft/ns

The velocity correction can be derived either theoretically or by measurement. In the latter case, an unfaulted phase can be used to measure the velocity at a harmonic which is close to the fault distance frequency. However, for faults close to the near end of long cable, this implies very high harmonics and cable attenuation may preclude this. A theoretical correction requires knowledge of the cable electrical parameters. The computation is straightforward but not amenable for routine field application.

2. Application

The application of the resonance technique is essentially the same as the radar technique. It can be applied to almost any type of cable. As with the radar, the resonance technique works well with opens and shorts but not with nonlinear faults. It can be used on branched systems but data interpretation is complicated by the many resonances present. The resonance technique is only rarely used for fault location on power cables. No fault locator is manufacturered which uses this technique but oscillators and sweep generators are available which can be used with little or no modification.

3. Relevant Specifications

The relevant specifications for the resonance system are as follows:

(1) Type of oscillator - manually tuned or swept frequency.

(2) Voltage or power output.

(3) Frequency range and bandwidth.

(4) Frequency accuracy, and stability - must be better than the desired fault location accuracy.

(5) Detector type - most resonance systems use a simple square law detector. A phase locked loop detector provides better sensitivity.

(6) Detector dynamic range - must be able to resolve higher resonances in order to empirically determine propagation velocity.

(7) Detector accuracy - must be better than desired fault location accuracy.

CHAPTER III

SELECTION OF A FAULT LOCATOR

A. INTRODUCTION

This chapter describes a systematic approach for the selection of a fault locator to meet a specific requirement. Two cases are treated.

Buying a Fault Locator is directed toward initial equipment purchase. This approach shows how to develop equipment specifications based on the requirements of a specific utility or operating department.

Fault Locator Selection is directed toward selecting from available fault locators to find a given fault.

B. BUYING A FAULT LOCATOR

1. Introduction

Buying an underground fault locator presents some unusual difficulties. The difficulties arise because of the many different types of equipment available and are compounded by the unique requirements of individual power systems. There is no universal fault locator which is optimum for every user. The best fault locator for one application might be of only marginal value in the next. Yet in many cases, a single instrument must serve for all occasions. In this case, it is necessary to make compromises so that the instrument selected may not really be the best for any one application but at least offers a minimum capability across the board.

The intent of this discussion is to provide a systematic approach for the selection of a fault locator. In most cases, the selection is not straightforward and will require subjective judgments. Thus it is not possible to prescribe a cookbook approach to this task. However, it is important that the selection be made on the basis of the hard data that is available rather than on the proficiency of the manufacturer's sales personnel. The approach presented here identifies quantitative factors wherever possible. However, it should be recognized that even these quantitative factors must often be handled in a qualitative way. For example, for an earth gradient device it is known that longer cables require a greater instrument sensitivity. Both cable length and sensitivity can be quantified. However, to precisely relate cable lengths to sensitivity would require a complex analysis. This analysis would include soil properties and thus the results would vary depending on installation site. Obviously, performing this analysis is not justified by the costs involved in the purchase of the instrument.

The approach is illustrated in figure III-1. The rectangles represent hard data that can be gathered for use in the decision making process. The diamonds represent decision points. While the decisions themselves are subjective, it should be obvious that they can be no better than the data on which they are based. The following paragraphs will discuss each of the blocks in figure III-1.

2. System Description (1)

The first step in the selection of the fault locator is to precisely define the power system (or portion thereof) on which the fault locator is to be used. If more than one cable or installation type is involved, the pertinent data on each should be summarized separately. While the specific elements of the system description may vary for some utilities, the most important points are listed below and discussed in the following paragraphs.

(1) Configuration.
(2) Cable type.
(3) Installation.
(4) Voltage.
(5) Cable length.
(6) Cable access.
(7) Total mileage.
(8) Number of faults per mile - year.
(9) Total number of faults per year.
(10) Special considerations.

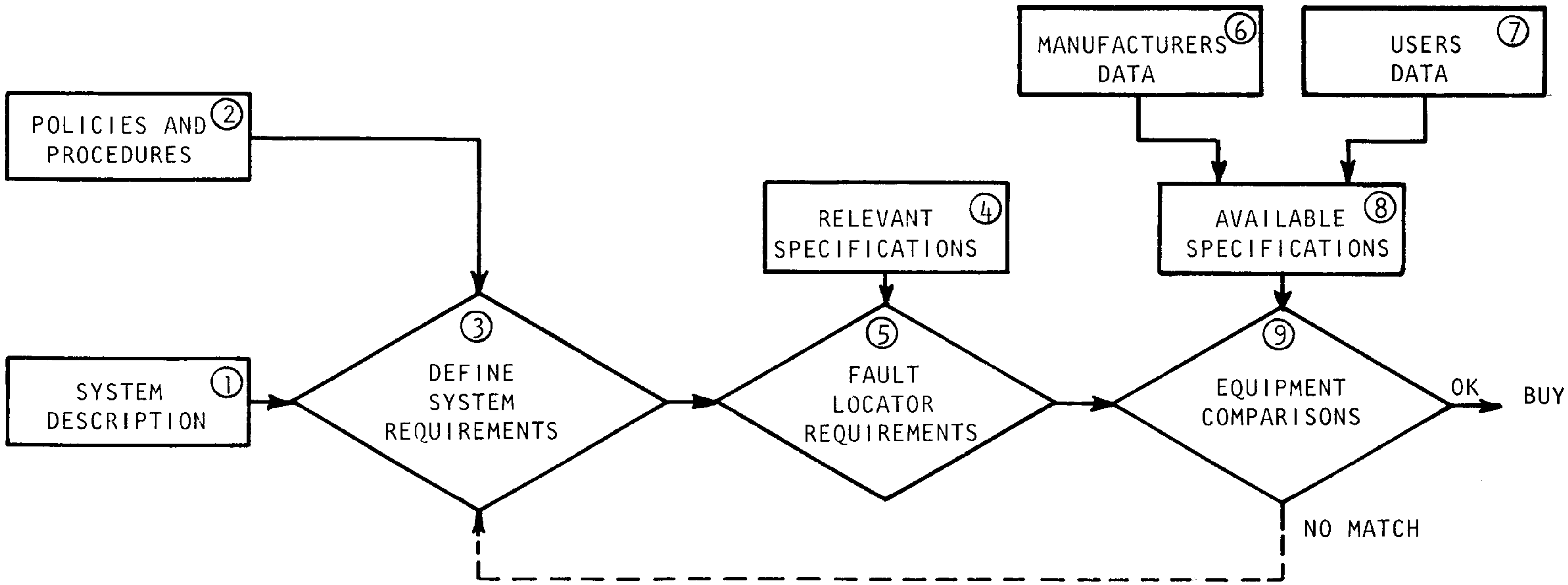


Figure III-1. Fault Locator Selection Approach

System configuration refers to primary, secondary, or transmission and to whether or not a branched system is used. The latter point is most important since cable branches present particular difficulties for fault location.

The next three elements, cable type, installation, and voltage, are fairly straightforward (installation refers to the method of burial: direct burial or duct).

The cable length must consider both the average cable length and the maximum length. The precise values are not important but it is important to have at least a good estimate, since cable length is often a primary determinant in the amount of time required to locate a fault. If many cables are involved, it may be desirable to plot a histogram of number of cables versus length. This will provide a basis for trading ability to locate faults on long cables versus cost.

Cable access refers to the ability to attach to the cable and to inject and measure signals for fault location. Access to the conductor is always required at some point, but fault locators have different requirements for attachment. A radar can be attached to a single pothead while a bridge requires access at both ends of the cable. On the other hand, some tracing measurements do not require conductor access but they do require access to the cable. A good example of this case is the tracing current technique where manhole access is provided periodically along the cable length. Where cable access is important, both maximum and average access distances should be determined.

The next three elements can be used to estimate the anticipated usage of the instrument. If the instrument is to be used on more than one cable type/configuration, then it is desirable to estimate a proportional usage for each type.

3. Policies and Procedures (2)

The standard policies and procedures employed by a utility or a department can dramatically affect the choice of a fault locator. It is important that they be identified so this impact can be evaluated.

It should be recognized that policies and procedures can usually be changed if their impact is shown to be derogatory. However, in most cases, the policies and procedures will remain constant and the fault locator selected should be compatible with them.

The most important policy in this regard is that which determines how fault location is implemented. Usually, different priorities are set for transmission and for primary and secondary distribution. Often the policy will specify the anticipated outage time to be tolerated for the various cable types. Another important policy is that related to the training received by fault location personnel. In some cases fault location is performed by a line crew as part of their regular duties, while in other cases a dedicated team devotes full time to fault location. Generally speaking, the latter situation will result in a better trained fault location team with a capability to use more sophisticated equipment.

Since most utilities already have fault location equipment, the status of that equipment is also important. The type of equipment available, the number of each type, and the usage rate for each instrument should be determined. Also, any special problems with each should be noted.

Finally, the projected growth rate for each cable type should be determined. Since the new fault locator will be in use for quite a few years, it is important that it be tailored to both the current system and the future system.

4. Define System Requirements (3)

Given the output of the first two tasks, a set of system requirements can be defined. This is simply a statement of system characteristics to be used in the selection of the fault locator. One way to approach this task would be to use the worst cases; that is, the maximum length, highest voltage, etc. However, this will normally lead to a high cost and it may be more effective to use the predicted number of faults per year for each cable to modify the worst case. For example, if the maximum length is much greater than the average length, and represented by only one or two cables, it may be more cost-effective to choose the fault locator for the average length and live with the increased time required to locate faults on the longest cable. This, of course, is a matter of judgment and the policies and procedures must also be considered. A given high priority cable, for example, may take precedence over all other considerations in establishing the system requirements. At the other extreme, an existing fault locator may be totally adequate for one or two cables and thus they can be eliminated from further consideration in developing the system requirements. Finally, the operator training level should be explicitly considered to set requirements for features such as equipment automation.

The result of this task will be a detailed set of system requirements that characterize the power system from a fault location standpoint. As a minimum, the system requirements should include:

(1) Configuration.

(2) Cable type.

(3) Installation.

(4) Voltage.

(5) Cable length.

(6) Cable access.

(7) Expected usage rate.

(8) Operator features.

5. Relevant Specifications (4)

The next step is to identify the specifications that can be used to describe the fault locator. Whereas the system requirements refer to the power system, the relevant specifications refer to a specific type of fault location hardware. In order to develop relevant specifications, it is important to understand the principles involved in the equipment operation. This subject is treated in Chapter II of this handbook and a section on relevant specifications is included at that point. Based on reviewing the information in Chapter II, it should be possible to eliminate some of the fault location techniques from further consideration at this point. For example, one would not consider the tracing current technique if the major system requirement was for fault location on direct buried secondary cables.

6. <u>Fault Locator Requirements</u> (5)

Developing the fault locator requirements involves translating the system requirements into a set of specifications. These specifications are based on the relevant specifications developed in the previous step. This is perhaps the most difficult step in the entire selection process. The desired result is a set of requirements which can be directly compared to the manufacturer's equipment specifications. It is generally desirable to have the requirements set as specifically as possible, but it should be realized that if the requirements are too rigid then it may not be possible to meet them, and it will be necessary to repeat the entire procedure.

Some requirements are relatively easy to set. For example, in selecting a thumper, the thumper output voltage should at least equal the system operating voltage (peak voltage, not rms voltage). In other cases, exact specifications are not easy to establish. For example, as pointed out previously, high sensitivity is obviously desirable for an earth gradient instrument. However, unless some data is available based on experience or tests, it is hard to say exactly what sensitivity is required.

The parameters in which the fault locator requirements are expressed are also important. Unfortunatley, the equipment specifications cannot be easily related to system requirements. For example, assume a system requirement for an accuracy of ± 1 foot with a cable length of 1,000 feet, using the radar technique. This type of specification would not be given by a radar manufacturer. As a matter of fact, it would require a substantial analytical or experimental program to establish the accuracy and such a program will generally be beyond the resources of either the buyer or the seller. Thus in setting the fault locator requirements, the measurable equipment characteristics must be considered. For the radar, the ± 1 foot corresponds to a measurement precision of approximatley ± 4 nanoseconds. Other considerations are involved also, but this is one quantity that can be measured. Unless this minimum specification is met, it is obviously impossible to meet an overall specification of ± 1 foot.

The fault locator requirements should also include a budget. Since there is a wide variety of available equipment, in some cases the final decision will be made on the basis of desirable features versus budget limitations.

7. Manufacturer's Data ⑥

The next step is to obtain available fault locator data from manufacturers. Quantitative data is most important to obtain. However, estimates of qualitative performance (such as convenience features) are also valuable. Appendix A presents a current (1975) summary of available manufacturer's data. This information can be used as a first screen in determining who to contact for further information.

8. User Data ⑦

At this point it is desirable to obtain data from other fault locator users. Usually this data will take the form of observations. If so, care must be used to define the conditions under which the observations were made to see if they are applicable to the case at hand. Two conditions of particular importance are soil characteristics and operator training, since both of these can have a very direct impact on the operation of many fault location devices. It is also desirable to get multiple comments on any instrument to assure a fair comparison.

9. Available Specifications ⑧

This step simply involves assemblying the results of the previous two steps into a comprehensive set of data which describes the available fault location equipment.

10. Equipment Comparisons (9)

The final step is to compare the fault locator requirements to the available specifications. In an ideal situation, this step would identify one piece of equipment which meets the requirements and is available within the budgetary constraints. Unfortunately, this is not always the case and it will often be necessary to make compromises in the fault locator requirements. It is important to assure that these compromises are made with the initial system requirements in mind. No compromise can be made at this point which would contradict the system requirements.

11. Iteration

In some cases it is not possible to satisfy the system requirements and the budget constraints with the available equipment. In this case it is necessary to go back to step 3 and redefine the system requirements. If it is assumed that the original system requirements were optimum, then the revised requirements will obviously not meet all of the original objectives. It is important then to carefully consider each requirement to see which can be deferred or eliminated. If the system requirements must be substantially changed, to the point where the fault location capability is seriously compromised, then the budget constraints should be reviewed. It may even be necessary to defer purchase until sufficient funds are available to achieve the necessary capability rather than purchasing an instrument which does not add to the available capability.

C. SELECTION OF THE PROPER FAULT LOCATOR

1. Introduction

This section presents a systematic approach for selecting the fault locator to be used for locating a given fault. The fault locator is simply a tool in the overall fault location process. If a mechanic needs to tighten a 7/16" nut, he immediately realizes that he needs a wrench, not a screw driver. He will quickly discover that a 1/2" wrench will work but that a 7/16" wrench should be used for best results. The problem in selecting a fault locator is similar. However, the decision points are not as obvious and quite a bit of data must be acquired before any decision can be made.

Experience has shown that most of the difficulties associated with fault location arise from the fact that the equipment being used is not applicable to the specific fault condition that exists. In some cases, the proper equipment is available at the service center but not at the fault site, and the operator decides to spend the added time locating the fault rather than traveling back to the service center. The approach described here recognizes that data is collected at two points: at the service center when the fault call comes in, and at the fault site. This data is then combined with the inherent applicability of each technique to select the proper instrument. It is not feasible to lay out a step-by-step procedure that will automatically lead to the selection of the proper equipment. Instead, the key issues will be identified so they can be addressed in an orderly process prior to commencing fault location.

2. Data Collected at the Service Center

If only one piece of fault location equipment is available, then obviously there is no need for decisions about what equipment to take to the fault site. However, for most utilities a variety of equipment is available and the fault location time will be minimized if the proper equipment is selected. Before leaving the service center, the operator should ascertain the power system characteristics for this particular fault. These characteristics apply primarily to the cable and its installation.

The first characteristic of interest is to determine the cable configuration: primary or secondary distribution or transmission, and whether a branched system is involved.

The second step is to determine the cable type, the installation and cable accessibility. These characteristics determine which of the basic fault location techniques can be used. The criteria for deciding which technique can be used are discussed in detail in Chapter II and the operator should be familiar with this information beforehand. The final decision regarding the applicability of a given technique must await determination of the fault type at the fault site.

The third step is to determine the cable voltage and length. These characteristics do not impact the choice of fault location technique but they do govern the selection of a specific instrument. For example, the thumper technique can be used at any cable voltage, but it must be assured that the particular thumper voltage rating is compatible with the cable voltage rating. A 4 kV thumper will probably not be satisfactory for a 34 kV cable. The importance of the cable length is somewhat more subtle. First, it impacts the specific instrument characteristics in that longer cables typically require a higher power or greater sensitivity in the equipment. In addition, the cable length may also dictate the use of combinations of fault location techniques. For example, the thumper can be used on very long cables, but the time required to locate a fault on a 5 mile long cable would probably be excessive. A predetermination of the approximate distance to the fault using a radar would be valuable on a 5 mile long cable but probably superfluous on a 100 foot long cable.

A final consideration is the availability of the equipment itself and skilled operators. Equipment availability speaks for itself, and the importance of operator skill cannot be overemphasized. Despite its apparent desirability based on the preceding factors, there is absolutely no advantage in selecting a fault location technique for which a trained operator is not available.

3. Data Collected at the Fault Site

The final decision as to what fault locator to employ must be based on a knowledge of the fault characteristics. Basic definitions of the three types of faults, open, short, and nonlinear, were given in Section I. This section will discuss the three fault types individually and will indicate how they are recognized.

Opens occur most often on aluminum secondary cables where a break in the insulation allows water to enter and corrode the conductor. Opens can also result from physical stresses on the cable. If the stresses are due to power system currents, then the opens will usually occur at the splices. If the stresses are manmade (dig-ins), then obviously the fault can occur at any point. An open condition is easily identified since customer service is lost without actuation of a circuit breaker or fuse.

A short exists when metallic contact is present between conductors, conductor to neutral, or conductor to ground. Shorts are usually due to stresses placed on the cable. These may be either physical stresses or electrical stresses associated with system transients or lightning. A true short has a very low resistance (a few ohms or less) and can easily be identified by making ohmmeter measurements.

Many cable faults are nonlinear, that is, they resemble shorts at voltages near the operating level and they demonstrate a high impedance at the lower voltages associated with test equipment such as ohmmeters, bridges, radars, etc. Nonlinear faults occur when insulation fails and an arc path forms between conductors, conductor to neutral, or conductor to ground. The arc usually causes some damage which results in dirt and/or carbon filling the gap. The nature of a nonlinear fault is such that a high voltage source is required to identify it. However, it can be assumed that any fault not shown to be an open or a short is a nonlinear fault.

4. Fault Location Technique Applicability

After all of the appropriate data has been gathered, a final fault locator selection can be made. This decision is, of course, based on the applicability of the individual techniques to the fault conditions specified by the data gathered previously. The technique applicability is summarized in the matrix of figure III-2. The matrix presents cable types: insulated wire, concentric neutral, and insulated concentric neutral, versus fault type. Each technique is entered into the matrix blocks where it can be used effectively. The details of the matrix are discussed in the following paragraphs and are categorized by fault type: short, open, nonlinear. Branched systems are discussed separately.

a. Short

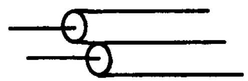
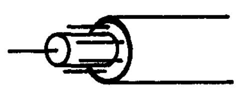
The resistance bridge, radar, and resonance techniques are the most widely applicable for the location of shorts. However, the radar and resonance techniques may be more difficult to use on cables which do not have concentric neutrals. In general, the most applicable methods for shorts are the terminal techniques, which are relatively less accurate than tracer devices.

The earth gradient technique is applicable when the fault is from phase-to-ground. However, its effectiveness is reduced in any concentric neutral application because the neutral tends to shunt the ground return current. If the fault is phase-to-phase on an insulated wire, or phase-to-neutral on an insulated concentric neutral, then the earth gradient cannot be used at all.

The applicability of the tone tracing technique is similar to that of the earth gradient, except that the presence of a concentric neutral has an even greater effect in reducing its sensitivity.

The tracing current technique is applicable to any type of cable although it can only locate faults between access points.

Although a thumper can be used to create a fault current in the case of a short, it has not been listed as effectively applicable

CABLE TYPE	FAULT TYPE		
	OPEN	SHORT	NONLINEAR
INSULATED WIRE PAIR 	TONE TRACER CAPACITANCE BRIDGE RADAR RESONANCE	EARTH GRADIENT TONE TRACER TRACING CURRENT RESISTANCE BRIDGE RADAR RESONANCE	EARTH GRADIENT* TRACING CURRENT* THUMPER* RESISTANCE BRIDGE* RADAR*
CONCENTRIC NEUTRAL 	CAPACITANCE BRIDGE RADAR RESONANCE	TRACING CURRENT RESISTANCE BRIDGE RESONANCE RADAR	THUMPFR* TRACING CURRENT* RESISTANCE BRIDGE* RADAR*
INSULATED CONCENTRIC NEUTRAL 	TONE TRACER CAPACITANCE BRIDGE RADAR RESONANCE	EARTH GRADIENT TONE TRACER TRACING CURRENT RESISTANCE BRIDGE RESONANCE RADAR	EARTH GRADIENT* THUMPER* TRACING CURRENT* RESISTANCE BRIDGE* RADAR*

*HIGH VOLTAGE MODELS ONLY

Figure III-2. Fault Locator Applicability Matrix in this category because it will not create an audible "thump" unless the fault current burns a gap and converts the short into a nonlinear fault.

b. Open

The capacitance bridge, radar, and resonance techniques are the most generally applicable for locating opens. Again, the radar and resonance techniques are easier to use on concentric neutral configurations. Since these are all terminal type devices, their accuracy is a function of cable length.

The tone tracer is the only tracing technique that can easily be applied to locating opens. However, it is less effective for locating opens than it is for shorts and cannot be used with concentric neutral cables unless the return current can be made to flow away from the neutral.

c. Nonlinear Faults

The thumper is the most universal device for locating nonlinear faults. It can be used for all cable types and configurations, even though additional, external circumstances may reduce its effectiveness. Since the thumper is a tracing technique, it is quite accurate although potentially time-consuming on long cable runs.

The tracing current technique can be used for nonlinear fault location subject to the requirements of accessibility to the conductor or neutral.

There are a number of techniques which can be used to locate nonlinear faults if high voltage sources are available. Specifically, these include the earth gradient, the resistance bridge, the resonance, and the radar. Given a high voltage source to create an arc, these techniques operate exactly the same as for application to shorts.

d. Faults in Branched Systems

In general, branched systems may consist of any cable type either direct buried or in ducts. In theory, too, most of the fault finding techniques that are applicable to a given cable type or installation on an unbranched run can also be used on a branched system. In practice however, the difficulty in data interpretation makes many of the techniques highly impractical.

Often, neither the earth gradient nor the tone tracing technique is applicable because most branched systems are concentric neutral cables where these methods are relatively ineffective in the first place. Of the tracing techniques, the tracing current is the most effective. The sound of a thumper can also be detected either above-ground or in manholes.

The terminal techniques suffer from the problem of ambiguity. Their distance readings require a further definition of the system branch to which the distance applies. For the bridge the branch must be identified before an accurate distance can be determined. For the resonance and radar, the numerous branch points and terminations give rise to corresponding reflections which complicate data analysis.

APPENDIX A

SUMMARY OF AVAILABLE FAULT LOCATION EQUIPMENT SOLD IN THE UNITED STATES

This appendix summarizes the available information on fault location equipment sold in the United States. The information was gathered from data sheets provided by the vendors during 1975. Table A-1 relates vendors to the basic categories of fault finding instruments defined in the text. Subsequent entries summarize the equipment handled by each vendor. Two companies (Ion Track Instruments and Varian) not on table A-1 have been included as sources of SF_6 (sulfur hexafluoride) leak detectors which may aid fault location on gas insulated systems.

Some qualifications should be kept in mind when using the information in this appendix:

(1) The specifications listed are meant to be a summary only. In many cases, more complete specifications can be obtained from the vendors. However, much of the promotional literature and even some technical manuals lack complete, technical descriptions.

(2) Some companies consider a tone tracer by itself to be a fault location instrument, while others do not.

(3) Some of the bridges are designed for communication cable fault location and may not be optimized for power system cables.

(4) Many of the HV (high voltage) power supplies used with thumpers provide a fault location burn-down capability. This aspect of fault location has not been specifically noted in this appendix.

(5) Finally, no subjective evaluations are included since it is not possible to simply summarize qualities such as ease of operation or equipment ruggedness.

TABLE A-1. SUMMARY OF FAULT LOCATION MANUFACTURERS

	AQUATRONICS	ASSOCIATED RESEARCH	BECKMAN	BIDDLE	CANADIAN RESEARCH	CHANCE	DELTA ELECTRONICS	FRL INCORPORATED	GOLDAK	HEWLETT-PACKARD	HIPOTRONICS	HIVOLTRONICS	INDUSTRONICS	JAY INDUSTRIES	JOSLYN	LEEDS AND NORTHRUP	MAXWELL	MULTIAMP	PESCHEL INSTRUMENTS	PROGRESSIVE ELECTRONICS	RADAR ENGINEERS	RYCOM	SCULLY-METROTECH	SI CORPORATION	TEKTRONIX	VON
THUMPER		●		●							●	●					●	●	●		●					●
EARTH GRADIENT				●	●						●	●	●	●	●											
TONE TRACER	●	●		●	●				●			●	●				●			●	●	●	●	●		
COMBINATION		●				●		●	●	●											●	●				
TRACING CURRENT				●							●															
BRIDGE			●	●	●					●						●						●				
RADAR				●			●					●									●				●	

1. Aqua-Tronics, Inc.

(See Jay Industries).

2. Associated Research, Inc.
6125 W. Howard St.
Chicago, Illinois 60648
(312) 647-7850

Tone tracer

Model 8700. Battery operated, 7 W transmitter, transmitter wt. 14 lb.

Combination tone tracer and earth gradient fault locator

Model 8500. Transmitter requires ac power and weighs 18 lb. Earth gradient signal: 0-100 mA dc steady or reversing 1000 Vdc open circuit voltage, superimposed ac signal.

Thumpers

Model 8605. 0.5 μF, 12.5 kV. Power supply wt. 72 lb., capacitor discharge unit wt. 32 lb. Requires ac power.
Model 8501. 1 μF, 25 kV. wt. 80 lb. Uses Model 5321 or 5471 insulation tester as power supply.
Model 8610. 3 μF, 25 kV.
Model 8611. 5 μF, 25 kV. Both these models have integrated power supply and capacitor discharge unit mounted on a two wheel cart. Requires ac power.
Model 8613. 15 μF, 25 kV. Power supply on one two-wheel cart and capacitor discharge unit on another. Requires ac power.

Thumper detection system

Model 8609. Acoustic and magnetic field sensing. Detector is battery operated.

Associated Research, Inc. conducts a high voltage cable testing and fault finding school.

3. Beckman Instruments, Inc.
Cedar Grove Operations
89 Commerce Rd.
Essex County
Cedar Grove, New Jersey 07009
(201) 239-6200

Wheatstone Bridge RN-3. Nine ratio arms and three Murray loop settings. Ratio accuracy ±0.05 percent.

4. James G. Biddle Co.
Township Line and Jolly Roads
Plymouth Meeting, Pennsylvania 19462
(215) 646-9200

Tone tracer

Model 656610. Generator/Transmitter produces 50 W at 780 Hz from 12 V auto battery. Wt. 11 lb.
Model 656601. Cable route tracer. Trace or reject 50/60 Hz tone, or trace tone energized cable. Wt. 3 lb.

Earth gradient

Model 651000. Earth gradient set. Transmitter requires ac power. 100 mA continuous or reversing signal, 0 - 1000 Vdc. Wt. 32 lb. Detector: -25 to 25 microampere meter with two 8-foot and one 40-foot probe leads. Wt. 1 lb.

Thumpers

Model 651005. 16 μF, 5 kV, Wt. 146 lb.
Model 651015. 2 μF, 15 kV, Wt. 146 lb.
Model 651025. 1.65 μF, 25 kV, Wt. 285 lb.
Model 651620. 12 μF, 25 kV, Wt. 90 lb., on two wheel cart.
Model 650125. 4 μF, 25 kV, Wt. 150 lbs, on two wheel cart, requires separate HV power supply such as 220040, 221050, 220110, 220160 or may be used in combination with the 651025 impulse unit.
Model 650110. 1 μF, 25 kV, Wt. 43 lb., requires separate HV power supply.
Model 653030. 12 μF, 30 kV, Wt. 550 lb., on two wheel cart.
Model 651401. 2.7 μF, 15 kV, Wt. 41 lb.

All of the above thumpers require ac power (or the HV power supply requires ac power, in the cases where a separate HV source is used).

Thumper detection system

Model 651103. Acoustic detector, microphone sensors with headset and meter indicator, also accepts surface coil magnetic field sensor.
Model 651110. Multipurpose detector for magnetic field sensors and earth gradient measurements, gives direction and magnitude of thumper discharge signals.

Resistance bridge

Model 655763. High resistance bridge, for faults to over 200 megohms, accuracy ±1/2 percent of loop length, requires 12 Vdc auto battery for use.

Radar sets

Model 655110-1. Pulse reflection cable test set 10 V open circuit pulse. Ranges: 250, 500, 1000, 2500, 5000, 10000, 25000 ft. Battery operated. Wt. 18 lb.
Model 655111-1. Pulse amplifier. Gain variable from 1 to 100, battery operated. Wt. 3 lb.
Model 65530. DUFLE (free oscillation variation) measures pulse reflection times associated with thumper voltage, digital display. Range: 20 yards to 99999 yards. Battery operated, used with a thumper. Wt. 26 lb. (including voltage divider).

5. Canadian Research Institute
Division of Criterion Instruments Limited
85 Curlew Drive
Don Mills, Ontario
Canada

Tone tracer

Model CFL-1. Wt. under 10 lb.

Earth gradient

Model DV-50/OHEPC. 0 to 100 mA, 0 to 500 Vdc, Wt. 50 lb.

Receivers

Model PFR-1. -200 to +200 mV and -1000 to 1000 mV at 10000 and 50000 Ω input impedance.
Model PFRT-1. Transistorized. Same ranges as PFR-1 but 2 megohm input impedance.

Bridge

Model RF-70. Resistance bridge.
Model TCB-70. Capacitance bridge. 60 Hz test frequency.

6. A. B. Chance Company
Centralia, Missouri 65240
(314) 682-5521

Tone tracer with earth gradient null

Markcraft Line Detector. Transmitter: battery operated, 90 V square wave 115 Hz signal. Receiver utilizes magnetic field coil and "A" frame type ground probes.

7. Delta Electronics
5534 Port Royal Road
Springfield, Virginia 22151
(703) 321-8945

Radar

Model PRH-1. Requires oscilloscope, ac power. Pulse: to 5 kV maximum, nominal 30 ns width. Wt. 20 lb.

8. FRL Incorporated
Fisher Division
Underground Detection Instruments
517 Marine View Ave.
Belmont, California 94002
(415) 591-8924

Tone tracer with earth gradient null

Model PF-16. Magnetic field tracing with ground probe for nulling over the fault.
Transmitter: 3 W with internal battery or 5 W with car or truck battery. Continuous or pulsed 135 or 990 Hz CW signal. Wt. 10 lb.
Receiver: 15 Hz bandwidth at 135 and 990 Hz and broad-band with or without 60 Hz trap filter. Meter, speaker, and headset indicators. 0.1 microvolt sensitivity at full scale meter deflection. Wt. 3 lb.
Probes: (1) Inductive probe, 0.1 microgauss sensitivity.
(2) Pencil magnetic probe, 1.0 microgauss sensitivity.
(3) A frame ground voltage probe, 1.5 microvolt/meter sensitivity.

9. Goldak Company
727 South Main Street
Burbank, California 91506
(213) 849-6691

Tone tracer with earth gradient null

10. Hewlett-Packard
Delcon Division
690 East Middlefield Rd.
Mountain View, California 94040
(415) 969-0880

Tone tracer with earth gradient null

Model 4904A. Battery powered. 150 or 990 Hz signal. Wt. 22 lb.

Models 4900A and 4901A. Battery powered. 990 Hz signal only. 4901A has built-in ohmmeter on transmitter.

Resistance bridges (designed for communications cables)

Model 4912A. Battery operated. Range: 0 - 100,000 feet in 7 ranges. ±1 percent of full scale reading accuracy. Wt. 12 lb.
Model 4913A. Battery operated. Digital readout. 10 - 199,900 feet. Accuracy typically ±0.5 percent. Wt. 17 lb.
Model 4930A. Battery operated. Digital readout. 0 - 199,900 feet. Resolution 1 ft. on 0 - 999 ft. range, 10 ft. on 1000 - 9,990, and 100 ft. on 10,000 - 199,900. Accuracy ±0.5 percent ± resolution.

Capacitance bridge (designed for communications cables)

Model 4910F. Battery operated. Range: 0 - 100,000 feet in 7 scales. Accuracy: ±1 percent of full scale reading. Wt. 8 lb.

11. Hipotronics Inc.
P. O. Drawer A
Brewster, New York 10509
(914) 279-8091

Earth gradient

Model ECV 2005. Transmitter: 1000 Vdc at 500 mA; 5000 Vdc at 100 mA. Requires ac power. Wt. 45 lb.

Thumper

Model PCFL-1. 2 μF, 15 kV; or 0.5 μF, 30 kV; Wt. 88 lb.
Model PCFL-2. 16 μF, 7.5 kV; or 4 μF, 15 kV; or 1 μF, 30 kV; Wt. 98 lb.

Both of the above require a separate HV power supply.

Model CF60/25-12C. 12 μF, 25 kV, Wt. 475 lb, requires ac power.

Thumper detector

Model FD-2. Magnetic sensor with amplifier for sensing thumper discharge current in a faulted cable.

Integrated tracer current-thumper system

CF 100-4/5-12C. 12 μF, 25 kV thumper. 0 - 100 mA short circuit current, 0 - 100 kVdc open circuit voltage. Thyratron output: 5 Adc for sheath tracing or 5 kVdc open circuit; diode coupled to allow combination with 0 - 60 kVdc fault breakdown voltage. Requires 209/230 Vac power for thyratron operation, 115 Vac for all other features. Wt. 2000 lb.

12. Hivoltronics Corporation
P. O. Box "I"
Atlantic City, New Jersey 08404
(609) 347-1717

Tone tracer

Model T 16/68. 1030 Hz and 12000 Hz, 40 W and 200 W on ac power, 12 W and 40 W on battery. Impedance matching 0.15 to 1500 ohms. Wt. 40 lb.
Model T 16/62. 1030 Hz and 12000 Hz, 20 W, ac or battery operation. Impedance matching 0.15 to 1000 ohms. Wt. 30 lb.
Model T 16/72. 12000 Hz, 3.5 W on ac power, 2 W on battery. Impedance matching 0.5 to 2000 ohms. Wt. 9 lb.
Model T 16/74. Magnetic pick-up wand.

Thumper

Model T 18/3. 96 μF at 3.5 kV, or 24 μF at 7 kV or 6 μF at 14 kV, Wt. 145 lb. External capacitors can be provided for 18 μF at 12 kV or 2 μF at 36 kV and for 12.5 μF at 12 kV or 3.1 μF at 24 kV. Requires ac power.
Model T 18/4. 32 μF at 8 kV, or 8 μF at 12 kV or 2 μF at 24 kV. Wt. 190 lb. Requires ac power.
Model T 25/1. (A HV power supply, for which external capacitor configurations are possible.) 10 μF at 15 kV, 2.5 μF at 30 kV. Wt. 101 lb. plus external capacitors.

Thumper detection

Model T 16/71. Sensor amplifier with meter and headphone signal for use with contact microphones and magnetic pick-up coil.
Model T 16/77. Earth contact microphone 20 - 800 Hz passband with additional selectable filtering of frequencies below 120 Hz.
Model T 16/75. Magnetic pick-up coil.
Model T 32/1. Earth gradient probe.

Radar sets

Model T 01/2. Teleflex. 6 ranges to 9 miles. Requires ac power. Wt. 45 lb.
Model T 04/1. Miniflex. 8 ranges to 12 miles. 40 V pulse into 60 Ω. ac power or battery operation. Wt. 24 lb.

13. Industronics Inc.
211 S. Ewing
Clearwater, Florida 33516
(813) 446-2257

Tone tracer

EMD electromagnetic detector. Magnetic field sensor with audible signal output to earphones. Source generator sold separately. See below.

Earth gradient

EGD earth gradient detector. Uses a high impedance ac voltmeter. Battery operated. Requires fault current source.

Tracing signal source

Mark II Tagger for use with either EMD tracer or EGD detector. Signal variable level 60 Hz, continuous or pulsed. Power up to 300 W at 150 Vac.

14. Ion Track Instruments, Inc.
179 Bear Hill Road
Waltham, Massachusets 02154
(617) 890-4343

Ion Track Instruments makes an instrument for the detection of SF_6 gas leaks. It is also applicable to pressurized air and nitrogen systems through the injection of SF_6 tracer gas.

15. Jay Industries
P. O. Box 25441
Portland, Oregon 97225
(503) 292-9746

Tone tracer

Jay Industries markets Aqua-Tronics Inc., tracing units.
Model AT-9. 60 Hz loaded line locator. Meter and headphone signal indication.
Model A6. Pipe and cable locator. Direct or inductive coupling of tracing signal. Also can be used as a metal detector. Battery operated. 117.85 kHz signal, to 270 V open circuit (17 V into 100 Ω). Wt. 10 lb.

Earth gradient

Pinpointer. Transmitter operates on battery or ac power. 2000 V at 5 mA breakdown signal followed by 28 V at 65 mA.

16. Joslyn Mfg and Supply Co.
7211 South Lockwood Ave.
Bedford Park, Illinois 60638
(312) 284-5800

Earth gradient

Model 163. Pulser: 560 Vdc, 175 ms pulse, battery operated. Detector: meter indicator, -50 to 50 μA sensitivity with amplifier gain of over 3000.

17. Leeds & Northrup Company
Sumneytown Pike
North Wales, Pennsylvania 19454
(215) 643-2000

Leeds & Northrup makes a bridge that is mainly used for communications lines fault location.

Resistance bridge

Model 5430-AM-1. Type U test set. Battery operated. Eight ratio arms plus three Murray loop settings. Ratio accuracy ±0.05 percent. Wt. 9 lb.

18. Maxwell Laboratories, Inc.
4 B Henshaw Street
Woburn, Massachusets 01801
(617) 935-7930

Tone tracer

100 kHz. Transmitter and receiver for pipe tracing. Direct or inductive coupling; also functions as a metal detector.
60 Hz. Loaded cable tracer. Meter and earphone signal.

Primary fault locating system

Combines capability for switching to radar after burning with HV power supply and thumper. Power supply: 27 kV at 100 mA or 1200 mAdc at 2 kV. 14 μF thumper at 20 kV (30 μF at 15 kV optional). Requires ac power.

The above system is also available van or trailer mounted with a 4 kVdc test set.

19. Multi Amp Corporation
4271 Bronze Way
Dallas, Texas 75237
(214) 333-3201

Thumper

Model FF-2E. 2 μF, 15 kV, Wt. 157 lb. Requires ac power.

Thumper detection system

Model FFSA-1. Magnetic field sensing loop, pulse amplifier, audio probe, and audio amplifier and headphones. The pulse amplifier has a zero center meter.

20. Peschel Instruments
1412 Viscaya Parkway
Cape Coral, Florida 33904
(813) 542-3164

Thumper

Model IG25-4. 4 μF, 25 kV, Wt. 125 lb.
Model IG25-8. 8 μF, 25 kV, Wt. 250 lb.

Both of these units require a separate HV power supply, the Model AP30-30; 0 - 25 kVdc at 30 mA, requires ac power, Wt. 60 lb.

Thumper detection system

Model DET-2. Magnetic field and acoustic sensing. Meter and headphone indicators.
Model DET-2G. The above detector modified for earth gradient measurements in addition.

21. Progressive Electronics, Inc.
432 South Extension
Mesa, Arizona 85202
(602) 834-4308

Tone tracer

"The Tracker". Transmitter (Model 77A-2) battery operated. 1000 Hz signal. Detector has meter indicator and headphone output.

22. Radar Engineers
Division of EPIC Corporation
4654 N.E. Columbia Blvd.
Portland, Oregon 97218
(503) 288-8317

Tone tracers

Model 108. 60 Hz signal tracer. Battery powered.
Model 110. Battery powered. 1000 Hz signal generator. Receiver traces 1000 or 60 Hz. Wt. 8 lb.

Combination tone tracer and earth gradient fault locator

Model 410. Transmitter. Battery powered. 1000 Hz tone or 850 Vdc pulse every 5 seconds. Two receivers. Model 4101 for tone tracing. Meter, speaker or earphone indicating. Model 4102 for earth gradient use. Solid state amplified galvanometer. System Wt. 19 lb.

Thumpers

Model 515. 2 μF, 15 kV, requires ac power. Wt. 146 lb.
Model 525. 1.65 μF, 25 kV, requires ac power. On wheels, wt. 285 lb.

Capacitance meter

Model 880. 0 - 0.01 μF, 0 - 0.05 μF, 1 percent. Battery operated, wt. 2 lb.

Radar sets

Model 1455. 75 V pulse into 75 ohms. Ranges: 500, 1,000, 5,000, 10,000, and 20,000 ft. Requires ac power, wt. 18 lb.
Model 755. Primarily for overhead line operations. 350 V pulse in 680 ohms. Ranges: 10, 50, and 100 miles. Requires ac power, wt. 23 lb.
Model 722. For 200 ft. range maximum. 350 V pulse into 680 ohms. Requires ac power wt. 15 lb.

23. Rycom Instruments
Railway Communications, Inc.
9351 East 59th Street
Raytown, Missouri 64133
(816) 353-2100

Tone tracer

Model 2753.

Model 2765. Transmitter: 815 Hz, 3 W, 390 V peak-peak maximum voltage. Battery operated. Detector: 90 dB gain minimum, speaker output. Total wt. 10 lb.

Tone tracer with earth gradient null

Model 2785A. Transmitter: 815 Hz, battery operated, wt. 10 lb. Receiver: 120 dB gain minimum.

Resistance bridge

Model 2790. Range 0 - 100,000 ft. in six steps. Accuracy ±1 percent of fault distance. Battery operated, wt. 7 lb.

24. Scully-Metrotech
475 Ellis Street
Mountain View, California 94043
(415) 968-8389

Tone tracer

Model 440-B. Pipe and cable locator. Direct and inductive signal coupling. Speaker and headphone indication. Battery operated. Wt. 8 lb.

Gas leak detector

Model 200-L. Audio detection of pressurized gas leaks. Meter and headphone indication 112 dB gain. Battery operated. Wt. 9 lb.

25. SI Incorporated
Cockeysville Road
Cockeysville, Maryland 21030
(301) 666-0611

Tone tracer

IT-10. Transmitter: IT-10B. Requires ac power. Wt. 1.5 lb.
Receiver: IT-10A. Battery operated. Wt. 1.5 lb.

Earth gradient

UFL 4000. Transmitter. 1000 Vdc pulses. Requires ac power.

26. Tektronix, Inc.
P. O. Box 500
Beaverton, Oregon 97077
(503) 644-0161

Radar sets

Model 1502. 225 mV step into 50 Ω, 2 ranges 0 - 100 ft, 0 - 1000 ft. 2 percent accuracy. Battery or ac power operation. Wt. 18 lb.
Model 1503. 10 V open circuit, 5 V into 50 Ω, 1/2 sine shape pulse, 10, 100, 100 ns. 2 ranges 0 - 2,500 ft, 0 - 25,000 ft, 2 percent accuracy. Battery or ac power operation. Wt. 18 lb.

27. Varian Associates
NRC Operations
121 Hartwell Avenue
Lexington, Massachusetts 02173
(617) 861-7200

SF_6 detector

Model 2310 Leak Detector. Meter and audio signal. Requires ac power. Wt. 24 lb. Model 2320. Battery operated.

28. The Von Corporation
1038 Lomb Avenue, S.W.
Burmingham, Alabama 35211
(205) 788-2437

Thumper

Model BI-.35. 1 μF, 30 kV, wt 100 lb. Available with optional inverter for operation from auto or truck battery.

Von also sells control gaps and capacitors for use with high voltage test sets: 1 μF, 30 kV, and 4 μF, 15 kV or 0.25 μF, 60 kV.

Thumper detection

Thumphone, mechanical (no electrical parts) seismic detector. Earth gradient detector.