OPERATING INSTRUCTIONS

FOR

MODEL SST15-832

Arc Reflection Sectionalizing System

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I INTRODUCTION

Your new Model SST15-832 Sectionalizing system was designed to aid in URD loop sectionalizing and fault locating on primary underground cable. All components have been built and carefully tested to give you years of trouble free service.

We, at the VON Corporation, are constantly trying to improve our equipment. We would appreciate any comments or suggestions which you may have.

We hope you will share any techniques or applications you find especially useful with us, so that we may share them with all VON users through application notes and instruction manual changes.

Please keep us informed of the names of personnel to receive application notes and instruction manual changes.

For any questions concerning this equipment or its application, write or call:

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It is extremely important that the operator practice using the radar in this system before attempting to use it on an actual cable fault. Suggestions on setups to practice on are contained later in this manual.

II RECEIVING AND CHECKING OUT

The Model SST15-832 is packed to arrive in good condition. Unpack and check to see that there is no physical damage or parts which have come loose during shipment. A reel of cable at least 50 feet (15m) long is required to check out the unit. A roll of RG-58 works very well for this purpose. Two or three reels of URD cable connected together can provide longer lengths. If there are questions about the instructions which follow, see Section VI for more information and sample radar screens. Ground the unit using the green ground cable provided to the system neutral or building ground if inside. Connect the output lead of the system to the test cable. The red lead goes to the center conductor and the green lead goes to the neutral.

1. Turn the unit **ON** to view the cable with the radar. The unit will momentarily show a screen that says “AutoAnalyze cable, wait one moment.” The unit will then show the cable with the right marker at the end. If the end is not marked correctly, push the "RANGE" button until the “brick” on the right side of the screen lines up with the word RANGE, and increase the range with the ARROW keys until the typical up blip for the far end of the test cable is observed. With a jumper, ground the clamps at the end of the HV output lead and watch the display as the “up” blip changes to a “down” blip. The left point where the two waveforms diverge is the end of the HV lead and the beginning of the test cable. If the left marker does not already line up with this point, consult with the factory.

2. Now connect the conductor at the far end of the reel of test cable to its neutral or shield with a jumper. Observe the leftmost point at which the two traces diverge. The up blip at the open end will have an identical down blip from the short. The leftmost point where the two blips change direction is the end of the cable.

3. Make a gap at the far end of the test cable between the center conductor and the cable shield to simulate a fault which can be impulsed (thumped). A distance of .0625" (1.5mm) to .188" (5mm) will do fine for this gap. When additional cable is available, it may be connected to the test cable at this point so the fault will not be exactly at the end. Temporarily short the gap with a jumper and observe the radar screen. Remove the short at the gap.

4. Push the **START** button. A second trace(reference) will appear and the words “WAITING FOR THUMPER” will should appear at the top of the screen. The voltage should rise to the set voltage and then discharge. When the gap fires, the top trace should change. The fault will have a down blip just like when a shorting lead was placed from the center conductor to the shield at the same point. The bottom trace is the cable without the short created by the arc, and will now be active. The left point where the two traces diverge is the fault. By putting the right marker at this point the distance to the fault can be determined. If the gap is too large at the simulated fault, the capacitor will not discharge and the voltage will not fall. In that case, push the **STOP** button, reduce the gap, and try again.

III SAFETY

Personnel safety is a most vital concern when sectionalizing. Only qualified electrical personnel should operate this equipment. Always follow your company's safety procedures. If any recommendation in this manual conflicts with your company's safety procedures, contact the factory for clarification before operating the equipment.

The wearing of insulated safety gloves is strongly recommended while operating the unit and must be worn when making or breaking connections to the faulted cable being worked on. ALWAYS ground the faulted cable with a properly sized grounding set before touching the cable termination and making connections to this equipment .

Always ground the cable to be connected to before connecting or disconnecting this unit. This equipment is designed to be used on unenergized cable only. Connecting the equipment to an energized cable causes severe equipment damage.

While using this equipment, all exposed terminations of the cable being worked on must be roped off or otherwise protected so that the unaware can not come in contact with them.

In sectionalizing, grounding is the most important concern and safety precaution. The heavy green ground lead must be connected to same ground system to which the cable neutral is connected. BEFORE USE: **ALWAYS** check to insure that the high voltage output is tied to the center conductor of the faulted cable and the green high voltage return is connected to the faulted cable neutral.

THE MOST IMPORTANT SAFETY FEATURE: A full recognition on the part of the operator of the inherent danger always present with the use of high voltages will be the most important safety feature that can be applied in the use of this equipment. Your operating procedures should be so designed as to minimize this danger. The operator of this equipment should be responsible for seeing that each member of the assisting crew is thoroughly familiar with the dangers involved.

IV DESCRIPTION AND SPECIFICATIONS

The Model SST15-832 is a self contained portable unit for determining the distance to a fault in a URD loop by the Arc Reflection Method. The weather resistant unit is designed to be operated in most all weather conditions from its internal 12 volt battery, an external 120-240 volt source or an external car battery.

System Specifications

- Capacitor bank provides 832 joules at 15 kV (7.4 mfd)
- Simplified controls: Pushbuttons: "START","STOP", “RADAR/THUMP”, Knob “VOLTAGE ADJUSTMENT”, Radar Controls; Toggle switch "ON/OFF"
- Gap and discharge are electrically operated.
- 0-15 kV digital kilovoltmeter
- Discharge voltage preset to 15 kV. Unit can be discharged at other voltages using the VOLTAGE ADJUSTMENT knob.
- Pulse interval 15 seconds
- Distance: Digitally displayed on the display. The resolution is .5% of the range selected.
- Ranges: 0- 500, 1500, 3000, 6000, 12000, 24000 and 48000 feet (0-150, 500, 1000, 2000, 4000, 8000, 16000 meters) when using a velocity propagation factor of 50.0%. The ranges are selected by pushing the "RANGE" button and then the “UP” or “DOWN” arrow buttons.
- Velocity Factor: Digitally shown on the screen. The initial turn on value of 53.0% can be increased or decreased to the desired value. The velocity factor can be set from 25.0% to 99.0%
- Screen: LCD 3.5"(8.9 cm) x 4.5" (11.4 cm) with 320 x 240 dot matrix providing both trace and text. The display can be easily read in direct sunlight. A backlight is provided so the screen can be viewed in total darkness.
- Memory: Fifteen memories are provided for storage of traces. Traces are stored using the options menu.
- Environmental: Operating temperature -25°F (-31°C) to 110°F (43°C). Sealed so it can be operated in the rain. The radar screen is backlighted so the unit can be operated in total darkness.
- Battery: The internal battery charger has a regulated output so the unit can be left in the charge mode without damaging the battery. The external 12 volt DC input is protected against polarity reversal. The external 12 volt DC source is connected to the unit in parallel with the internal battery and charges the internal battery. The unit automatically switches from internal 12 volt DC to external 120-240 volt AC when connected to 120-240 volts AC.
- Leads: 15 foot (4.5m) long shielded high voltage lead with male MC connector. A hot line clamp, vise grip and elbow adapter with female MC connector are provided to terminate the high voltage lead. Longer lengths are available by request. 15 foot (4.6m) #2 ground cable

V CONTROLS AND INDICATORS

ON- OFF switch operates the main power.

START pushbutton - When the "START" pushbutton is pushed the motorized discharge switch opens, the motorized gap opens, and the high voltage supply begins charging the internal capacitor bank to the set limit. The “START” pusbutton also toggles the TDR between arc reflection and radar modes. In the RADAR position the sentence "WAITING FOR THUMPER" must appear at the top, If “WAITING FOR THUMPER” does not show push the “START” pushbutton a second time. “WAITING FOR THUMPER” indicates the system is armed and can be triggered by a "thump" The trigger pulse from the thump starts the ARC REFLECTION SEQUENCE. After a very short delay which is controlled by the DELAY switch, a radar pulse is injected into the faulted cable. The resulting waveform is automatically transferred into the bottom trace.

STOP pushbutton- Drops out the high voltage ready relay which kills the high voltage supply, closes the motorized discharge device to discharge any internally stored charge, and after a delay closes the impulse control gap to discharge the output cable.

RADAR/THUMP pushbutton- Alternates mode of operation between “Radar” or Arc Reflection for pre-location and “Thump” for pinpointing. When in “Thump” mode, the TDR screen will go blank, to indicate this..

VOLTAGE ADJUSTMENT knob - adjusts the discharge voltage from a low value to the maximum voltage of 15kV.

GAIN button - Provides manual vertical gain adjustment from 0 to 20 dB by using the up and down arrow keys

OPTIONS pushbutton - Pressing the OPTION key presents a menu of available options such as delay and left starts. This button is not normally used during operation.

RANGE pushbutton- allows the operator to use the arrow buttons to change the range. The width of the transmitted pulse is adjusted automatically when the range is changed. When the power is turned on, the unit will automatically attempt to find the end of the cable and select the appropriate range. If the software is unable to identify the end of the cable, the default (normally 1500 foot/500m) range is automatically selected. The current range is displayed in the bottom right hand corner of the screen.

ARROW ▾◂ / ▸▴ pushbuttons- Changes the function where the “brick” or onscreen ▸ is located.

RIGHT MARKER pushbutton - Allows the operator to use the arrow buttons to move the right vertical line. The vertical line on the right of the display that sets the end point for all measurements.

LEFT MARKER pushbutton - Allows the operator to use the arrow buttons to move the left vertical line. The vertical line on the left of the display sets the beginning point for all measurements. When the radar is turned on the left marker is put at the saved end of the test lead position. This setting is changed via the options menu.

VELOCITY pushbutton - Allows the operator to use the arrow pushbuttons to adjust the velocity factor. Adjust velocity factor as needed to match the faulted cable. When the unit is initially turned on, the radar is automatically set to the default VF of 53% (Correct for most primary cable)

TRACE pushbutton- Allows the operator to use the arrow pushbuttons to move the bottom waveform up and down.

CONTRAST knob- This control adjusts the LCD background intensity and allows the operator to optimize the contrast of the display for the particular viewing conditions such as direct sun or shade. The backlight is always on.

LCD DISPLAY - All information is displayed on this screen. The number in the bottom left corner is the distance between the two markers. The number in the bottom center is the velocity factor. The number in the bottom right corner is the current range. When a single trace is shown (active radar mode), it is “active” and shows what the unit is currently connected to. When two traces are shown (arc reflection mode), the bottom trace is an active trace and the top trace is the “captured” trace from the arc.

The **FUSE** is next to the on off switch. This 12V control fuse is rated 10 amps slow blow and disconnects the internal battery from the control circuit and motors. The fuses are intended to limit and damage due to a component failure or short to the case. Remove the fuses and unplug the unit when taking the unit out of it’s case for maintenance.

VI-A BASIC OPERATION

Practice in a test situation with the radar before field use is very important. Be sure that you know how to locate the end of the units test lead with the radar before connecting to a faulted cable. Sample traces in various situations are provided in later sections.

1. Remove all the green ground cable and uncoil it. Route the cable without loops to the system neutral and tightly fasten its clamp to the ground grid where the faulted cable neutral is connected. Connect the output lead of the system to the faulted cable or loop. The output lead can be terminated with a hot line clamp, vise grip, or feed through adapter since MC connectors are provided. Be sure the ground return clamp (normally painted green) fastened to the shield of the coaxial HV output cable is connected to the neutral of the faulted cable as close to the cable end as possible. This connection should be closer to the faulted cable than the green safety ground. Connect the center conductor of the HV output lead (normally marked with red) to the center conductor of the faulted cable.

2. The unit can be operated from its internal battery, an external battery, or 120-240 volts AC. To operate from an external battery plug in the battery leads to the DC power input connector and then connect to an external battery. To operate from 120-240 volts AC connect to a 120-240 volt source.

3. Turn the unit ON.

4. Identify the far end of the cable under test. When the unit is turned on, it will automatically attempt to mark the far end of the cable. Always look at the trace to see if you agree with the software. If the Autorange software fails the unit will go to the default range (normally the 1500 feet/500 meters). Increase the range until the upward blip typical of the open end is seen on the display. The relative size of the blip depends on the length of the cable and how much pulse energy is absorbed by the cable. To <u>increase</u> the range: first push the Range button, then press the up Arrow button. If the you pass the range that puts the cable end closest to the right side of the display, push the "DOWN" arrow button until the desired range is selected. As the ranges get longer the amplification normally needs to be increased with the GAIN button.

   If a downward deflection is seen instead of an upward deflection, either the end of the cable is shorted or there is a grounded fault in the cable.

   To verify that a given upward blip is the cable end, alternately ground and open the far end while observing the display. The end blip will be downward when the end is grounded and upward when it is open.

   Normally the far end has a distinctive up blip and is the highest up indication on the waveform. If the cable has a fault with low resistance (less than 200 ohms at 10 volts) a down blip will appear at the fault. The far end of the cable will not show past such a low resistance fault.

5. The maximum voltage can be adjusted using the VOLTAGE ADJUSTMENT knob. It is recommended that except on 5kV and below cable, the VOLTAGE ADJUSTMENT be kept at or near maximum, as the transformers in the loop dissipate much of the energy. With the entire section on the display, push the **START** button until the sentence "WAITING FOR THUMPER" appears on the top of the display and the thumper will start charging up to the selected voltage. When the gap fires, the ARC REFLECTION SEQUENCE should begin in the radar and a new trace made during the arc will appear at the bottom.

6. On loops with transformers connected the sound inside the unit is the same for a good cable and a faulted cable. If the radar pulse that was sent out by the trigger circuit arrived a the fault while it was arcing over to ground the top memory will contain the trace of the cable showing a low impedance down blip at the fault. If both displays are the same then there is no apparent fault. Two approaches are available if the radar does not still indicate the fault.

7. After pulsing the cable, the bottom trace will be identical to the top trace until the location of the fault. At that point the bottom trace will diverge and change shape from the top reference trace. The first left hand point at which the two traces diverge is the fault. (After the divergence the two cable waveforms do not match up) Units with Autolocate software will attempt to automatically mark this point. If autolocate fails you can manually determine the distance to the fault by setting the left and right hand markers. The left marker is normally preset for the end of the test lead and the

beginning of the faulted cable. This eliminates the need to subtract the apparent lead length from the distance shown. The right marker is normally adjusted to the location of the fault to give the distance to the fault from the hook up location. Distance measurements are displayed in the lower left portion of the display which represent the distance between the left marker and the right marker.

8. Push the **STOP** button to discharge the cable and the internal capacitor.

9. Use the distance indicated to determine which section the fault is in.

VI-F SECTIONALIZING URD LOOP SYSTEMS

The arc reflection system is a method for determining the faulted cable section in a loop without using fuses and subjecting the system to excessive fault currents or opening each transformer cabinet to inspect fault indicators. By connecting the SST15-832 at the open cutout or at a center transformer cabinet the operator can determine the distance to the cable fault using the radar. Then the faulted cable section can be disconnected and all customers can be returned to service. When all customers are returned to service the SST15-832 can then be connected to the faulted cable and the distance to the fault determined using traditional methods.

Some customers have expressed concerns that putting an arc reflection pulse on the source side or transformers feeding customers would send damaging pulses into the customers system. Only a small percent of the energy can go through the transformer. Since the SST15-832 is rated 60 watts and typically the customers connected are attempting to pull many thousands of watts there is no way that damaging pulses can get into the customers system.

Currently the most popular approach to sectionalizing using an arc reflection system is to open a transformer halfway between the pole and the open point. The arc reflection system is then connected to both pieces of the circuit one at a time to determine where the fault is located. If both traces are identical on a run then it does not have a fault and can be refused. The arc reflection system will not locate internal transformer failures so if the fuse blows each transformer in that section should be inspected for failure. The arc reflection system should be connected to the second section and impulsed using the “START” button. The low voltage radar pulses alone can be used to verify that the faulted cable has been disconnected from the system so that power can be restored to the customers.

VI-B HINTS AND TYPICAL TRACES

1. The radar must show the faulted cable ends before any attempt is made push the START button which automatically puts out a high voltage pulse.

2. Remember that the magnitude of down blip at the fault can not be greater than the magnitude of the up blip due to an open circuit at the same point.

3. If different types of cable are spliced together, the trace itself can go up or down after the discontinuity at the splice.

4. The first step in sectionalizing using radar is to find both ends of the cables. This is done by touching each end to ground and finding the left most point where the trace changes direction.

5. Notice that locating the beginning of the cable by shorting it to ground requires the most skill. Everything past the fault changes.

6. Notice that a short at the end of the cable is easy to find and locate.

7. Remember that the first major divergence between the reference trace and the active trace is what you are looking for. The down blip at the fault may not be down on the screen but only below the reference trace. In some faults at the divergent point the captured trace is a straight line while the reference trace goes up. This is most likely to happen on very short cable where the cable trace is very wavy.

8. When the cable trace looks similar to the trace of the end of the test lead alone then the faulted cable is very short (most likely burned in two pieces) Very short runs have a large number of ups and downs in the waveform.

Figure 1 shows a typical cable trace for an isolated run. The cable is approximately 589 feet long. Notice how the right marker is at the point where the upward movement of the trace begins.

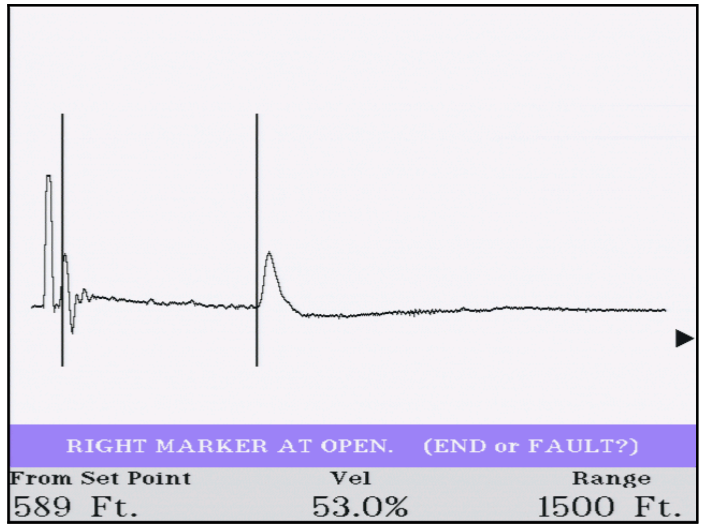

Figure 1

Figure 2 shows a typical faulted trace. Notice that the right marker has moved to the beginning of the downward movement of the lower trace. The distance now shows being approximately 355 feet from the hook up point to the fault.

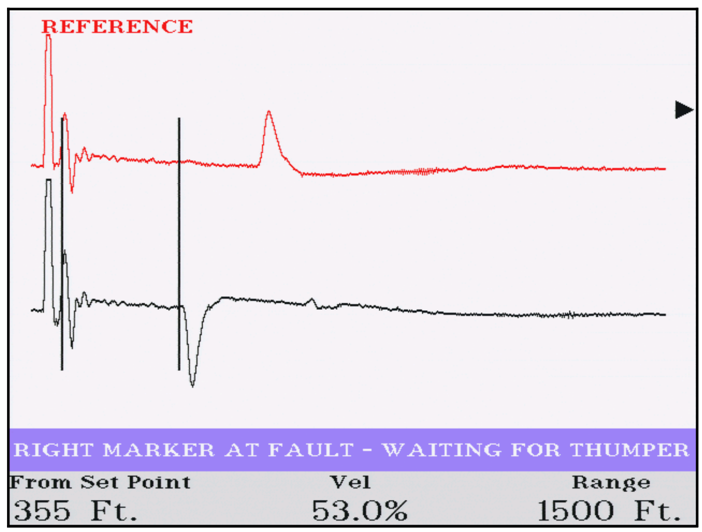

Figure 2

Figure 3 shows another typical faulted trace. This time the fault is at approximately 387ft.

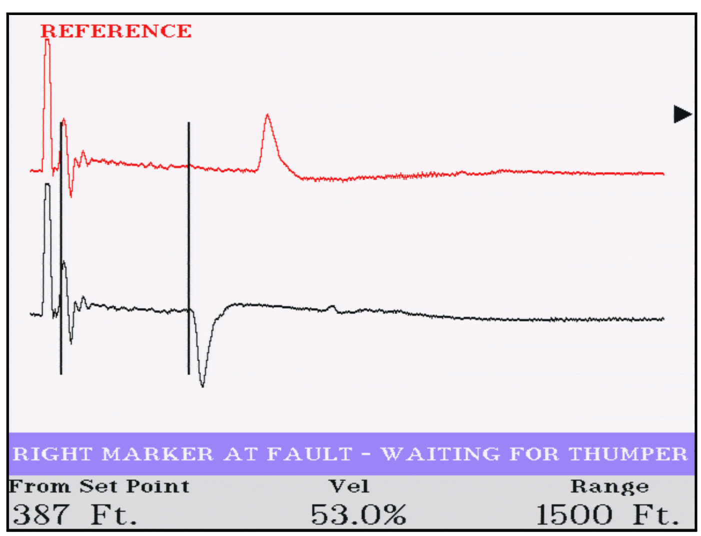

Figure 3

Figure 4 shows a typical sectionalizing trace. The up blips before the end of the cable are made by transformers. Splices along the cable route make the same signature but smaller.

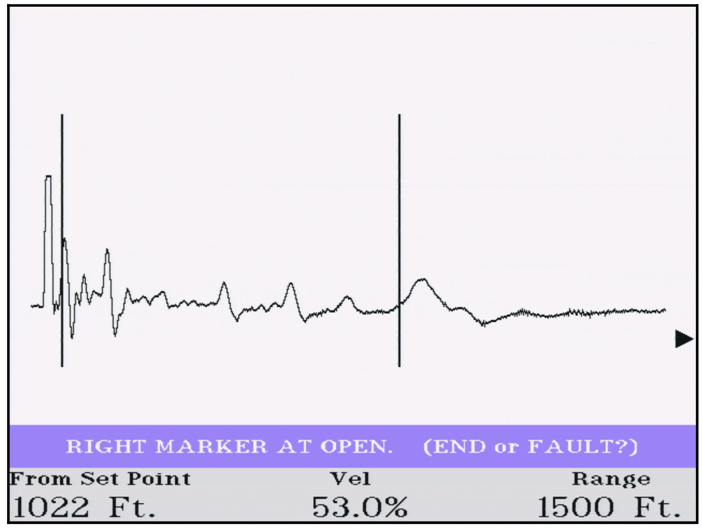

Figure 4

Figure 5 shows a faulted trace. Notice that the fault is close to the far end of the cable. Instead of measuring from the current end to the fault, it may be easier to measure from the far end. The distance from the far end can be determined by subtracting the distance to the fault (948 ft) from the previously determined length of the cable (1022 ft). This gives you an approximate distance of 74 feet from the far end of the cable.

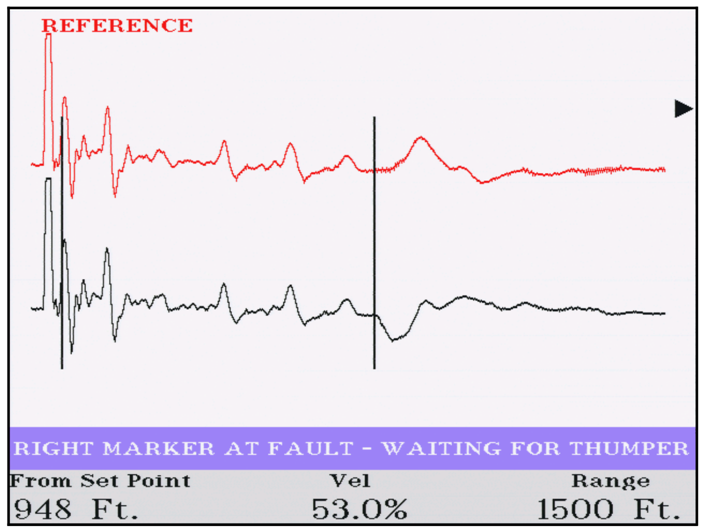

Figure 5

Figure 6 shows another faulted trace for the cable. The fault is at approximately 364 feet.

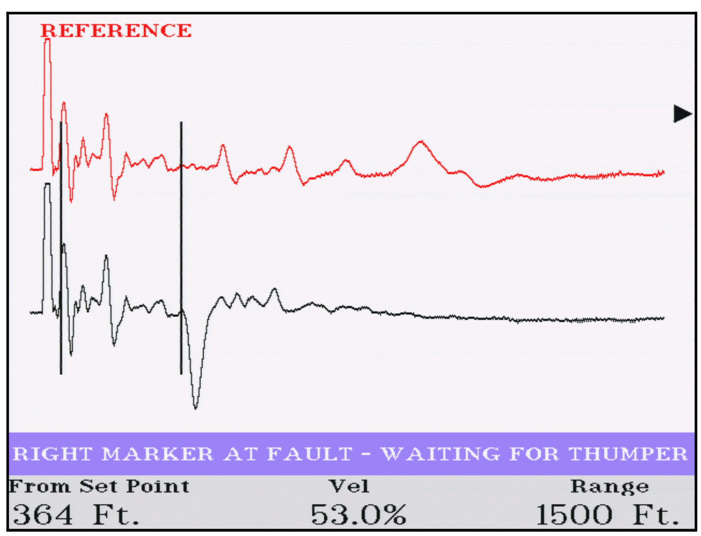

Figure 6

VI-E TESTING AN ISOLATED CABLE

NOTE: This will not work on a loop with transformers connected. The transformer will act as a connection to ground and discharge the capacitor energy.

NOTE: This will not work on EZRS15-1264 without a voltage adjust knob.

The voltage may be adjusted using the VOLTAGE ADJUSTMENT knob. Push the START button. If the cable is good, the voltage will not drop significantly when the gap closes and connects the internal capacitor bank to the external cable. A small voltage drop is expected on good cables proportional to the length of the cable due to charging current of the cable. Push the STOP button to discharge the internal capacitor and the external cable.

VI-G RADAR OPTIONS MENU

The options menu allows you to change the default settings and access advanced features. This menu is not normally used in day to day operation of the equipment. The available options are different depending on the firmware revision. Please follow the onscreen instructions for your specific firmware revision. Please contact the factory before attempting to modify parameters in the options menu.

VII IN CASE OF DIFFICULTY

Opening the unit should only be done by trained, and qualified individuals under consultation with the factory.

To Open Unit remove the hex head screws from around the edge of the unit. There are ten (10) screws total around the edge. This is most easily done with a 5/16" nut driver. Take care to save the screws, lock washers and flat washers. The unit pulls straight up and out of the case. About half way up you must pause, and disconnect the external 12V DC and 120-240V AC connections. Set the unit on a clean, dry surface. If troubleshooting calls for operation of the equipment outside the case, then the surface the unit is sitting on must be insulating to 20kV.

IN CASE OF LOW BATTERY

In case of low or dead battery, connect the unit to 120-240V AC or and external 12V DC source. Cables have been provided for this purpose. If the battery is low, then the unit should begin to work immediately. If the battery has gone completely dead, then it may be required to charge the unit for several minutes before it will come on to operate.
NOTE: The sealed lead acid battery used cannot survive discharging below approximately 10.5V. There is circuitry inside the unit that will try to prevent this situation. If this still happens, the unit will only operate from external power and the battery needs to be replaced as soon as possible.

More To Be Added Later

VIII TEST LEADS, BATTERY MAINTENANCE, AND STORAGE

The high voltage test lead is provided with a male MC connector. This allows the lead to be terminated with a hot line clamp, vise grip, or elbow adapter. Push the male connector into the female to release the locking connection. Be careful to insure the sliding ring of the male probe stays movable. Any substance which causes the ring to not move will prevent the female connector from being removed from the male. The high voltage lead is available with RG-8U polyethylene cable or EPR x-ray cable.

The ground lead must always connected to the neutral bus! Be sure to pull all the cable out of the storage area and lay on the ground such that there are no loops.

The internal sealed lead acid battery should be kept charged to at least 11.5 volts during storage since it can be severely damaged if stored below 10.5 volts. The internal battery charger regulates the voltage at approximately 13.6 to 13.8 volts so the unit should be left connected to 120-240 volts AC to store between uses. To check battery voltage at any time use battery check switch. The battery can also be charged by connecting the DC input to the unit to a van or truck battery or to an external battery charger.

The battery will eventually wear out. Projected life is 2 to 5 years. Indications of a worn out battery are that the unit will only run a short time on battery power. Contact the factory for details on replacing a dead battery

Keep the outer case clean and store in a dry location to prevent corrosion of the internal connections. Tighten any parts or connections that loosen in use.

The unit should be stored plugged into a 120-240 volt supply or external 12V Supply such as a vehicle power source.

IX CIRCUIT DIAGRAM AND PARTS LIST

To Be Added Later

X RADAR THEORY

Cable radar has been available for over thirty five years. Cable radar is also called the Pulse-Reflection Method, the Pulse-Echo Method, and Time-Domain Reflectometry. Because it works well only on shorts (less than 150 ohms at 10 volts) and opens, it has mainly been used in the telephone industry on communication cable. Radar can be successfully used to locate faults on electric power cable faults by permanently lowering the fault resistance by burning or temporarily lowering the fault resistance using the arc reflection method.

Short duration pulses are transmitted along a cable by a radar. When these pulses reach a discontinuity such as a splice or fault in the cable, a reflection occurs peculiar to the type of discontinuity. By observing these reflections on a CRT or scope and knowing the propagation velocity or the speed at which the pulse travels on the cable, the distance to the discontinuity can be determined. The cable radar is essentially a pulse generator and a cathode-ray oscilloscope. Special circuitry is normally provided with the oscilloscope for determining the distance and for changing the pulse length for different distance ranges.

Pulses are generated and put on a cable that must have consistent distributed capacitance. A reflection will result when a discontinuity or significant change of impedance occurs. An upward reflection or blip would indicate a higher-impedance discontinuity such as the cable ends, or a place where the cable neutral is missing. A downward reflection or blip will result from a lower-impedance discontinuity such a cable fault. The reflection is upwards when the impedance of the discontinuity is above the characteristic impedance of the cable. The reflection is downwards when the impedance of the discontinuity is below the characteristic impedance of the cable.

The characteristic impedance of a transmission line is important since it affects what types of discontinuities will show up on the radar. However it cannot be measured directly with an impedance bridge for a finite length of line. It can be calculated from the distributed-circuit co-efficients of the line at any frequency using the following basic equation.

$$Z_0 = \sqrt{\frac{R + j\omega L}{G + j\omega C}}$$

The equation contains the parameters of resistance, conductance, inductance, and capacitance and is also related to frequency. As the frequency is increased above 1 megahertz, the above equation will reduce to a simplified equation based on the distributed inductance and capacitance; and this simplified equation is shown as follows.

$$Z_0 = \sqrt{\frac{L}{C}}$$

In the case of primary underground cable which acts as a coaxial line we have the published

$$Z_0 = \frac{138}{\sqrt{K}} \log \frac{r_2}{r_1} \, ohms$$

equation:
K = dielectric constant based on the insulation material
r_1 = inside radius of insulation
r_2 = outside radius of the insulation

Thus the characteristic impedance of the cable varies with the diameter of the cable, thickness of the insulation and the type of insulation. A few common values of Z_0 are 20 ohms for 35kv 1000MCM polyethylene cable, 42 ohms for 35kv 1/0 polyethylene cable, and 74 ohm for RG59U polyethylene cable.

Any change in Z_0 along the length of the cable to the fault will cause reflections. The size of the blip will be based on the reflection coefficient whose maximum value is 1 or -1. The equation for the reflection coefficient p is:

$$p = \frac{Z - Z_0}{Z + Z_0}$$

At the far end terminals with the following impedances:

Z = 0 (short circuit)	p = - 1
$Z \gg Z_0$	p = 1
$Z = Z_0$	p = 0
$Z = 1/2 \, Z_0$	p = -.33

Thus when the fault impedance exactly equals the cable impedance it will not show up on the screen. Fortunately this almost never occurs in the field.

Distance is figured by a radar using the time delay which is based on how fast the radar pulse travels along the cable. The distance to the fault is related to the time the pulse takes to get to the fault and return. The accuracy of the speed of the pulse in the cable (called the velocity of propagation) determines how accurately the distance to the fault can be calculated.

XI THEORY OF ARC REFLECTION METHOD

The arc reflection method utilizes the low resistance path to ground (less than 50 ohms) created at the cable fault by an arc. The arc is provided by a capacitor discharge fault locator (thumper) to temporarily display the fault on a standard radar. Using the low resistance of an arc overcomes the main limitation in the past of radars which alone could not see the high resistance faults most common in underground primary power cable. The arc reflection method does not overcome the limitations of radar itself. The operator must become proficient in the use of the radar especially in recognizing faults near the ends of the cable. On cable with missing neutral, a cable radar may not even show the far end of the cable. Because of the time it takes for a reflection on the radar to recover to the zero level, the operator must be skilled when locating faults near discontinuities in the cable such as splices or the cable terminals. The radar is connected to the faulted cable through a coupler(filter) and displays the low resistance at the fault as a down blip during the time of the arc. The coupling system performs three functions.

1. Induce the high frequency radar signal onto the faulted cable through high voltage isolation required to protect the radar.
2. Provide a wave trap so the radar does not see the low impedance of the impulse fault locator with each discharge.
3. Lengthen the impulse with a large air coil inductor so that it provides current to the arc at the fault for a longer time so the fault position can show up on the radar. The inductor keeps the current flowing into the low resistance arc until the charge in the capacitor bank is dissipated. Increasing the size of the capacitor bank in the impulse fault locator lengthens the pulse and thus the time of the arc at the fault.

When the radar signal is induced on the cable, all discontinuities in the cable such as splices, change in cable insulation, change in neutral construction, connected transformers, and ends show up on the radar screen.

This system:

1. Reduces the number of thumps required to pinpoint a cable fault.
2. Uses standard radar so operator training is simplified.
3. Shows cable ends and splices so that an approximate location can be determined looking at the screen.
4. Provides the conductor distance to the fault. Only the conductor distance is displayed. Actual ground distances are subject to variations caused by the cable route and the cable depth. The accuracy of any distance determined by the radar is dependent on the correct velocity of propagation and the operator's skill.

XII CABLE DISTANCE MEASUREMENTS

The distance provided by a radar is conductor distance not ground distance. Accuracies of 2% of cable length are possible but not often achieved. Information is provided in this section on how to get the most accuracy using the radar. For maximum accuracy use the two terminal method where the fault distance is determined from both ends of the cable. The fault will be between both marks made using these distances.

All distances provided by a radar are determined using time measurements based on the speed at which the pulses move up and down the cable. The pulse speed is based on characteristics of the cable such as conductor size, shielding type, insulation thickness, eccentricity, and insulation material. The speed changes as the cable insulation ages. If the neutral shield is solid, the dielectric constant of the insulation is the determining factor in the velocity of propagation. For maximum accuracy, the speed (or time) must be determined from a known length of cable with identical characteristics to the cable being worked upon. This speed is entered into each radar in several forms. The speed is normally compared to the velocity of an ideal conductor in free air of 983 feet/microsecond.

To determine the true velocity of propagation or velocity of propagation factor of a cable the following procedure is recommended.

1. Connect the radar to a cable of known length, size, insulation type, shielding type and condition. Unburied cable is best since the actual cable length can be measured accurately. Buried cable lengths are less accurate due to the allowances that must be made for cable depth and coils of wire put at the ends to handle future expansions.
2. Use the turn on velocity factor or set the propagation velocity factor to an assumed value or the value of a similar cable obtained from a chart such as that found in the end of this section.
3. Short to the cable neutral at both the near end HV lead connection point and the far end to identify these points on the radar screen.
4. Determine the total length to the end of the cable being measured.
5. To determine the true propagation velocity or propagation velocity factor, multiply the assumed propagation velocity for propagation velocity factor by the actual cable length and divide by the measured cable length.

$$\frac{\text{Assumed propagation velocity x actual cable length}}{\text{Cable length measured with the radar}} = \text{True Propagation Velocity}$$

6. Reset the radar with the True Propagation velocity determined above. Repeat steps 3 and 4 to verify that the measured cable length equals the actual cable length

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The propagation velocity factor is determined by dividing the actual velocity of propagation in feet/microseconds by 983. Some representative values are shown below.

INSULATION TYPE & CONDUCTOR SIZE	INSULATION THICKNESS AND TYPE	PROPAGATION VELOCITY FACTOR
XLPE- 1/0	175 mil insulation	.562
XLPE- 1/0	260 mil insulation	.555
XLPE- 1/0	345 mil insulation	.623
XLPE- 1/0	345 mil water impervious	.582
EPR- 1/0	345 mil	.588
XLPE- 400kcmil	260 mil water impervious	.643
XLPE- 600kcmil	260 mil	.598
XLPE- 750kcmil	345 mil-CN	.562
XLPE- 1000kcmil	260 mil-CN or Jacketed	.600
XLPE- 1000kcmil	260 mil water impervious	.541
air- most common sizes	.98	
PILC- most common sizes		.38
EPR- range of sizes		.55-.62
HMWP- range of sizes		.52-.58
XLPE- range of sizes		.49-.64

The fault can be located by the following two methods even when the velocity of propagation is not known.

The comparative method of locating a fault using radar utilizes the fact that an overall length of the cable is known or a specific distance is known to a splice or landmark such as a transformer. Determine the distance to the fault with the radar. Then determine the distance to the known point with the radar. Using the following formula, the actual distance to the fault can be determined.

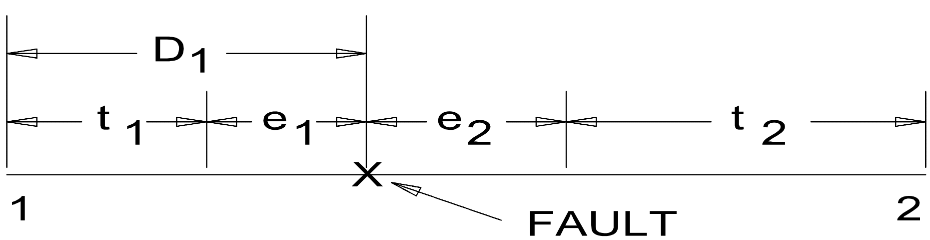
$$D_1 = \frac{t_1}{t_2} \times D_2$$

Where D_1 = Actual distance to the fault
D_2 = Actual distance to known point
t_1 = Distance provided by radar to fault
t_2 = Distance provided by radar to known point

The three stake method or two terminal method of locating faults is used when the velocity of propagation or a specific distance is not known. This method can also be used whenever maximum accuracy is required.

a. Take a reading from one end of the cable to the fault. Measure out the distance with a wheel and drive a stake.
b. Without changing the propagation velocity on the radar take a reading from the opposite end of the cable. Again measure out the distance with a wheel and drive a stake.
c. The fault will lie between the two stakes. By using the following formulas, the fault location can be determined.

Where D_1 = Distance to the fault
t_1 = Radar distance reading from point 1
t_2 = Radar distance reading from point 2
e_1 = Error distance between t_1 and the actual distance to the fault D_1
e_2 = Error distance between t_2 and the actual distance to the fault
$(e_1 + e_2)$ = Distance between stakes



FAULTED CABLE

$$D_1 = t_1 + e_1$$

$$e_1 = \frac{t_1 (e_1 + e_2)}{t_1 + t_2}$$