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The desired amount of snowfall was not obtained, so conclusions were based on laboratory testing and limited field data. The field measurements did indicate, however, that the instrumentation was very robust. The investigators are confident that it would work under snow depths exceeding 30 feet and with much longer cable runs than were used in the tests.

An additional review of alternative technologies was performed after the buried cable tests were completed. The potential of using modern surveying techniques to establish centerline appeared a viable alternative.

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CONVERSION FACTORS

English to Metric System (SI) of Measurement

Quality	English Unit	Multiply By	To Get Metric Equivalent
Length	inches (in) or (")	25.40	millimetres (mm)
		.02540	metres (m)
	feet (ft) or (')	.3048	metres (m)
	miles (mi)	1.609	kilometres (km)
Area	square inches (in^2)	6.432×10^{-4}	square metres (m^2)
	square feet (ft^2)	.09290	square metres (m^2)
	acres	.4047	hectares (ha)
Volume	gallons (gal)	3.785	litre (l)
	cubic feet (ft^3)	.02832	cubic metres (m^3)
	cubic yards (yd^3)	.7646	cubic metres (m^3)
Volume/Time (Flow)	cubic feet per second (ft^3/s)	28.317	litres per second (l/s)
	gallons per minute (gal/min)	.06309	litres per second (l/s)
Mass	pounds (lb)	.4536	kilograms (kg)
Velocity	miles per hour (mph)	.4470	metres per second (m/s)
	feet per second (fps)	.3048	metres per second (m/s)
Acceleration	feet per second squared (ft/s^2)	.3048	metres per second squared (m/s^2)
	acceleration due to force of gravity (G)	9.807	metres per second squared (m/s^2)
Density	(lb/ft^3)	16.02	kilograms per cubic metre (kg/m^3)
Force	pounds (lb)	4.448	newtons (N)
	kips (1000 lb)	4448	newtons (N)
Thermal Energy	British thermal unit (BTU)	1055	joules (J)
Mechanical Energy	foot-pounds (ft-lb)	1.356	joules (J)
	foot-kips (ft-k)	1356	joules (J)
Bending Moment or Torque	inch-pounds (in-lb)	.1130	newton-metres (Nm)
	foot-pounds (ft-lb)	1.356	newton-metres (Nm)
Pressure	pounds per square inch (psi)	6895	pascals (Pa)
	pounds per square foot (psf)	47.88	pascals (Pa)
Plane Angle	degrees (°)	0.0175	radians (rad)
Temperature	degrees fahrenheit (°F)	$\frac{°F - 32}{1.8} = °C$	degrees celsius (°C)
Concentration	parts per million (ppm)	1	milligrams per kilogram (mg/kg)

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John Nail, Foreman
Long Barn Maintenance Station

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Office of Electrical and Electronic Engineering

Terry Quinlan, Associate Electrical Engineer
Office of Electrical and Electronic Engineering

Arnold Ludwig, LS, Senior Land Surveyor
District 10 (Stockton)

INTRODUCTION

During early spring snow removal operations for winter close (Class E) roads, Caltrans maintenance crews often have difficulty in locating the roadway under heavy snow cover. Snow cover as deep as 40 feet has presented snow removal crews with a major task. Present techniques of locating the roadway under heavy snow cover are time consuming and present a safety hazard to personnel and equipment.

The California Department of Transportation presently classifies roads requiring winter snow removal under classes A through E. Class A roads have the highest priority and receive the necessary maintenance to keep them open under harsh winter conditions. Class E roads are at the other end of the scale. They are closed after the first winter storm and reopened in early spring.

Snow has been known to accumulate to depths of greater than 40 feet during the winter closure. Hazards are created that threaten the safety of both the personnel and the equipment that are used to open the roadway. In one incident an equipment operator was severely injured when he misjudged his position. Deep snow cover conceals hazards such as cliffs, embankments, boulders, trees, and avalanche debris. In many instances, equipment is damaged by collisions with buried obstacles. Avalanches and drifting snow often modify the terrain to the extent that even seasoned operators find it difficult to determine the exact location of the roadway.

California has twelve class E road segments, totaling 170 miles, distributed among Districts 02 (Redding), 09 (Bishop), and 10 (Stockton). The spring opening procedures vary slightly between the districts.

In some districts, the snow is probed with poles and a path is staked for bulldozers to follow. The bulldozers remove sufficient snow to enable snow blowers or plows to operate. Blowers and plows are most effective with snow depths limited to three or four feet.

Other districts rely entirely on the heavy equipment operator's familiarity with the snow removal area. There is no placement of stakes or poles to identify the roadway location. The bulldozer operators remove sufficient snow to allow the snow blowers/plows to operate.

The objective of this research is to develop a system that can be used by snow removal personnel to easily locate the roadway under snow covers in excess of 40 feet. The goal is to make the spring road opening process more efficient and to reduce the hazard to both personnel and equipment. It is considered necessary to fix position relative to the roadway to an accuracy of less that one meter to effectively meet these objectives.

TECHNOLOGY OPTIONS

BURIED TARGETS

Buried Cables

The National Park Service in Lassen Volcanic National Park has, since 1968, used a cable detection system for locating the roadway under heavy snow cover. The system consists of a Hewlett-Packard (HP) Cable Fault Locator, Model 4900A, that is used to detect a 12-mile long buried cable. The cable fault locator has an electronic tone transmitter and a receiver system for locating shield-to-earth faults, conductor-to-shield faults, and crosses and shorts in buried cable.

Although the HP Cable Fault locator is now obsolete, there are numerous alternatives currently on the market. A buried cable system appeared to be the most promising technology and was evaluated during this research. The method evaluated employed a wire buried near the center of the roadway. An electronic device, similar to the HP cable fault locator, was used to impress a signal on the wire. A separate probe unit was then used to detect the wire and thus, locate the roadway. This will expedite the staking process, and make snow removal a safer and more efficient operation.

Implementation requires the following installations:

- A buried wire down the centerline of the roadway.
- Excitation hookups at intervals of approximately one mile that are visible and accessible under the heaviest of snow covers and are not in avalanche areas.
- Protected (buried) connections from the hookups and the centerline wire.

The buried cable technique was successfully tested and is included as a recommended method. It is discussed in detail below.

Radio Frequency Transponders

Radio frequency (RF) tags were considered. This system was technically complex and may be difficult to support in the harsh environment.

Dipoles

Another alternative was to bury dipole antennas along the roadway centerline and then use microwave antennas to scan for the buried dipoles. The response would be a "hole" in the backscatter instead of a more usable positive anomaly. It was decided that the concept had little chance of success and that it was technically beyond the scope of this project.

REMOTE SENSING

Infrared

The attenuation of infrared through snow and ice was too great to use as a remote sensing technology.

Ultrasound and Microwave

Both ultrasonic and microwave remote sensing were considered, and potential vendors were interviewed. Both technologies could succeed, but proposed implementation was technically complex and required sophisticated analysis.

SURVEYING

Global Positioning System (GPS)

GPS systems are available that can fix position to centimeter resolution. There were two main problems with GPS in this application. The topography of the mountain passes could block the required line of sight between the instruments and some of the satellites. Centimeter resolution requires stationary setups, base recording stations, and post processing.

Real time, autonomous GPS is available with accuracies in the range of tens of meters. This does not meet the requirement of sub-meter accuracies.

Real time GPS systems that uses a local base station in constant communication with the rover has reported accuracies close to the requirements. This is a technology that is evolving and may be practical in the near future.

GPS would have the following requirements for implementation:

- o Location of the centerline in terms that are compatible with the output of GPS receivers.
- o Local monuments that would remain visible under maximum snow depths.

GPS is not considered practical at this time. Future developments may change this perception.

Photogrammetry

Aerial photograph based mapping could be used to perform the desired functions. An aerial photograph based plot of the centerline could be obtained during dry conditions. Targets would then be placed on the snow along the route in the spring just prior to again flying the route. The location of the centerline with respect to the freshly placed and photographed targets could then be determined photogrammetrically. This concept appeared complex and expensive. It would require excessive coordination to complete the process within a usable time frame.

However, photogrammetry would be very useful to develop a machine readable map of the roadway centerline and is recommended below in that context.

Surveyed Traverse

It may be feasible to establish survey monuments and backsight targets in locations that are consistently clear of snow in the spring. These monuments would assist a survey crew to locate the centerline and determine snow depths in the spring.

Survey equipment exists in each of the districts that has a range of 1500 meters and can electronically read angles and distance to a portable target. The centerline information can be programmed into an integral computer and position relative to the centerline can be determined in a few seconds. This would allow a survey crew to quickly stake centerline and determine snow depths.

This approach requires:

- o Local monuments that are visible above maximum snow accumulations and outside of avalanche areas.
- o A machine readable map of the centerline referenced to the monuments.

The surveying approach is considered viable and is discussed below in more detail.

TECHNOLOGY SELECTIONS

BURIED CABLE

The buried cable technology option was selected for evaluation. The Sonora Pass section of State Route 108 was selected as the test site. Three sections of highway, approximately 3800 feet, had cable buried in a slot down the center of the road. The ends of this cable were routed to the shoulder and on to landmarks. Appendix A discusses this installation.

A Metrotech 850 cable fault locator was selected as the test instrumentation as is discussed in Appendix B. The 850 has two components. An excitation unit is hooked to one end of the cable to be detected. A hand unit is then used to trace the buried cable. The hand unit displays signal power level and emits an audible tone that changes as the unit passes from one side of the buried cable to the other. Tracing a buried cable is quick and intuitive and requires minimal training.

Laboratory tests were performed using a unburied cable. These tests are discussed in appendix C. These tests indicated the system was robust and easy to use.

Field measurements were made in the spring of 1990 but the maximum snow depth encountered was in a drift and reached only 8 feet. Angled measurements, however, showed that the cable could easily be sensed through 15 feet of snow. Appendix D discusses the field measurements.

The field measurements did indicate that the instrumentation was very robust. The investigators are confident that it would work under snow depths exceeding 30 feet and with much longer cable runs than were used in the tests.

SURVEY

A review of technologies was performed after the buried cable tests were completed. The potential of using modern surveying techniques to establish centerline appeared a viable alternative and was investigated. Arnie Ludwig, the District 10 surveys coordinator, was approached with the idea of using computerized theodolites and laser ranging devices. Mr. Ludwig thought that the problem was well within the capability of existing equipment and crews.

Arnie Ludwig, John Nail, and Walt Winter visited the Sonora Pass site and discussed the advantages and trade offs of both the buried cable and survey solutions. It was decided that the two technologies were both viable and, indeed, compatible. The installation required for the buried cable would facilitate the survey solution.

Mr. Ludwig estimated that a survey crew of three could survey in several miles of centerline a day if monuments and alignment data were available.

CONCLUSIONS

The desired amount of snowfall was not obtained, so conclusions must be based on the laboratory testing and limited field data. The researchers are confident that the buried cable system will work well for detecting a roadway under heavy snow cover. Even though the system was evaluated under only eight feet of snow cover, the buried cable system performed exceptionally well.

RECOMMENDATIONS

A pilot installation of the buried cable should be installed at the Sonora Pass site. This area should also be prepared for the use of the survey solution. The implementation should be used for a year or two to determine operational advantages and problems.

IMPLEMENTATION

The suggested implementation is in the same area as the tests were performed. A continuous cable should be buried in the centerline of State Route 108 for about 10 miles in the area of Sonora pass as selected by maintenance personnel. Cables should be spliced to the continuous cable on approximate one mile intervals and run, underground, to monuments in protected areas beside the road.

The monuments should be standing pipes adequate to withstand the rigors of the mountain winters. They should be of adequate length to be above snow level in the spring. They should be located in areas not subject to excessive snow accumulation or avalanching. The monument locations should also be selected with their use as survey monuments in mind.

Underground cables that connect to the highway centerline cable should enter the standing pipes below ground level. The cable should go up the center of the pipe, out the top and down the side. It should be tied to the side of the pipe but insulated from it. The wire should not be terminated.

The location of the monuments should be surveyed so they can be used as survey monuments when needed.

The centerline of the roadway should be digitized from aerial photographs and tied to the monument survey. Existing photographs will probably be adequate and the photogrammetry can be performed by Caltrans personnel on a non-priority basis.

The Metrotech 850 should be stored and maintained by the Laboratory until needed to locate the roadway during spring road opening. Less than an hours training should be adequate to allow maintenance personnel to use the equipment.

The Maintenance crew should then report to the Laboratory any difficulties encountered during the pass opening operation. The Laboratory should make any repairs necessary to the system.

The first year of deep snow should use both the survey and buried wire techniques. The design, installation, costs, efficiencies, and accuracies of each method should be documented in a report prepared by the Laboratory, from information supplied by all personnel.

APPENDIX A: INSTALLATION

The site selected was near Sonora Pass on Route 108 in District 10 (Stockton). Figure 1 is a topographic map of this area. The buried cable system was installed in three locations between post miles 63.3 and 64.5. Figure 2 shows the test sites in more detail. The total distance between the lower end of the first cut and the upper end of the third cut is 1.647 miles. Subtracting the distance between installation locations results in 1.647 - 0.92 = 0.727 mile of buried cable.

Installation started on October 30, 1989. Four Lab personnel and approximately five District personnel were required for the installation.

A 35 horsepower self-propelled concrete saw fitted with a 1/4-inch diamond asphalt blade was used to make the cut in the center of the roadway in which the cable was installed. The cable used was AWG 12 inductive loop cable.

The wire was installed near Sonora Pass in the Sierra Nevadas on Route 108 at an approximate elevation of 9000 feet. Concrete saw operation was simplified by starting at the upper elevation and proceeded downhill. A truck with a utility body that carried a water tank was driven alongside the saw and operator. This method was decidedly the most convenient and easiest for the remote area in which the system was installed. Installation was completed as per the following schedule:

Date	Comments
10/30/89	Deliver equipment to work site
10/31/89	Cut upper section (Section 3)

Date	Comments
11/01/89	Cut Sections 2 and 1. This is the actual order in which the sections were cut. Install cable in Section 3.
11/02/89	Install cable in Sections 2 and 1. Checked Section 1 with HP unit borrowed from Lassen National Park. Mapped installation sites. Took photographs of installed cable areas and landmarks.

The cable installation was performed by first making the cut in the center of the roadway at the upper elevation, working downhill. After the cut was made, the slot was cleaned of debris by blowing compressed air into the slot. After the slot was cleaned, the cable was dispensed from a reel attached to a cart, and still proceeding downhill, the cable was inserted into the slot. A grooved wheel attached to a handle was used to insert the cable into the slot in the center of the roadway. The next step was to seal the slot containing the cable. A sealant, RS-1, was used to accomplish the sealing. The sealant was next covered with sand.

At each end of a section of buried cable, it was necessary to cut a slot at a right angle to the center-of-roadway slot and route the cable toward the shoulder. The cable was routed toward the shoulder then to a landmark where the cable could be easily located. Both trees and snowpoles were used as termination points for the ends of the buried cable sections. A copper ground rod with a 12 to 20 foot length of cable was located at the end of each section. This permitted attaching the transmitter of a cable fault locator to either end of the wire.

The only inconvenience encountered was running out of water for the concrete saw. Since the water carried was a limiting factor in determining the distance the pavement could be cut, once the water supply was exhausted, the cutting process was stopped. District Maintenance personnel with a portable pump provided enough water to complete the pavement cutting.

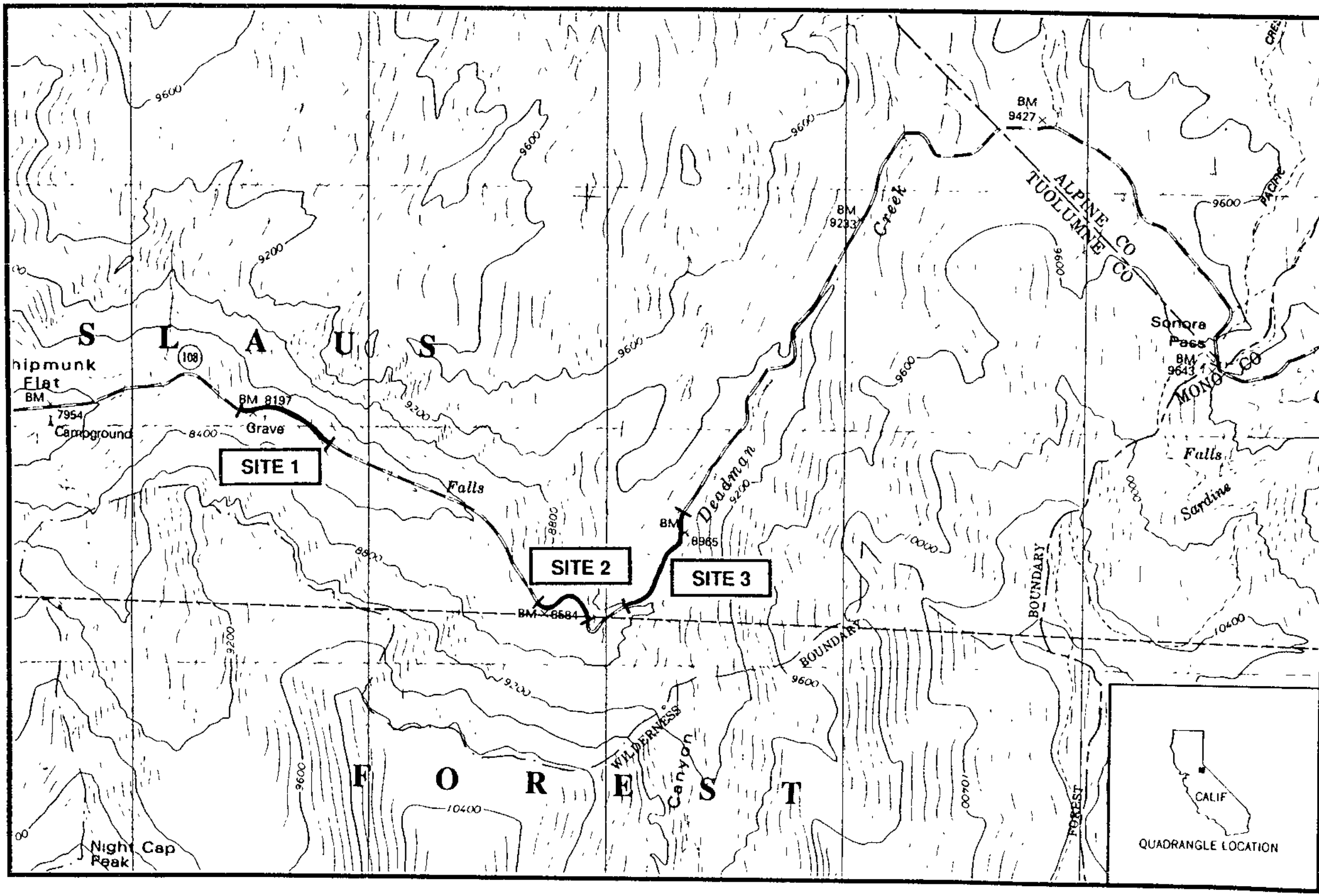
The experience of the maintenance crew was used in selecting sites where locating the roadway was difficult.

Figure 3 shows the central tangent of Site 2. An eight foot drift at this point was the deepest snow found during field tests.

Figures 4, 5 and 6 show details of how the wire was routed from the pavement to a snow pole. A second wire was then routed from the pole to a grounding rod.

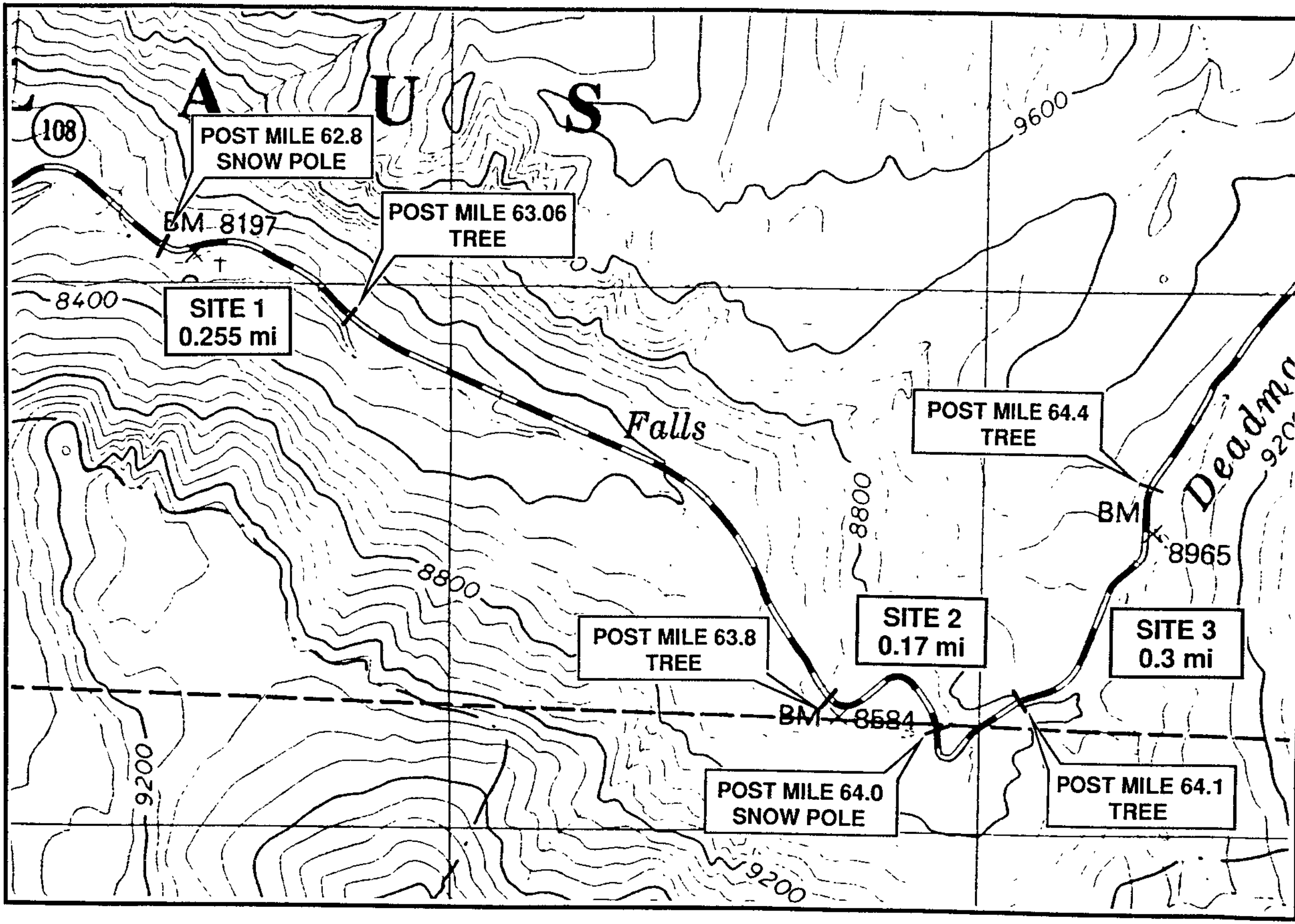
Figure 7 shows a typical grounding rod installation.

Figure 8 shows rodent damage to the wire. Rodents are notorious for eating insulation from wiring.



TOPOGRAPHIC MAP OF SONORA PASS TEST SITES

FIGURE 1



DETAIL MAP OF SONORA PASS TEST SITES

FIGURE 2

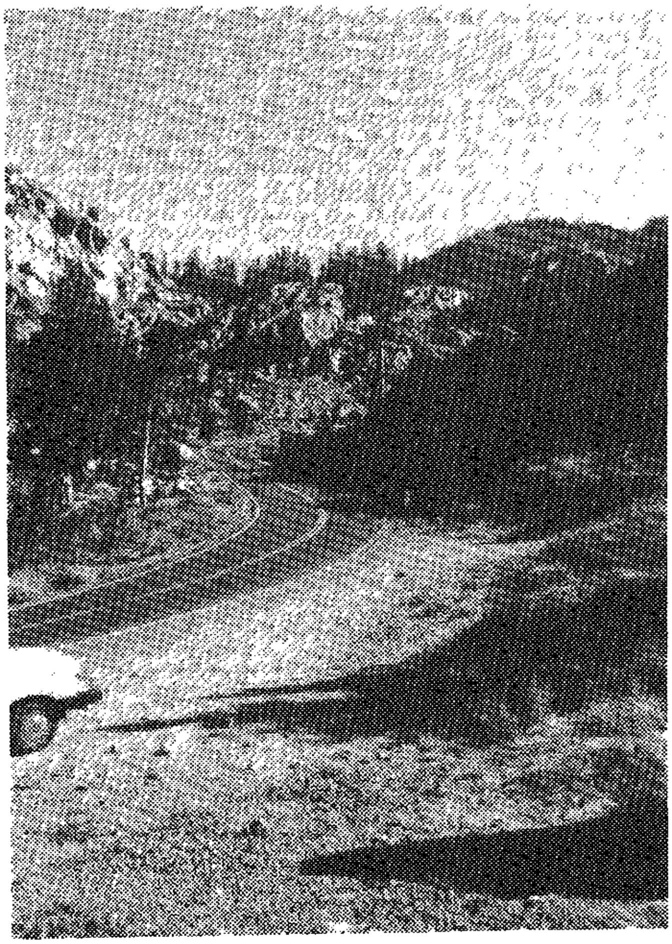


Figure 3

Site 2

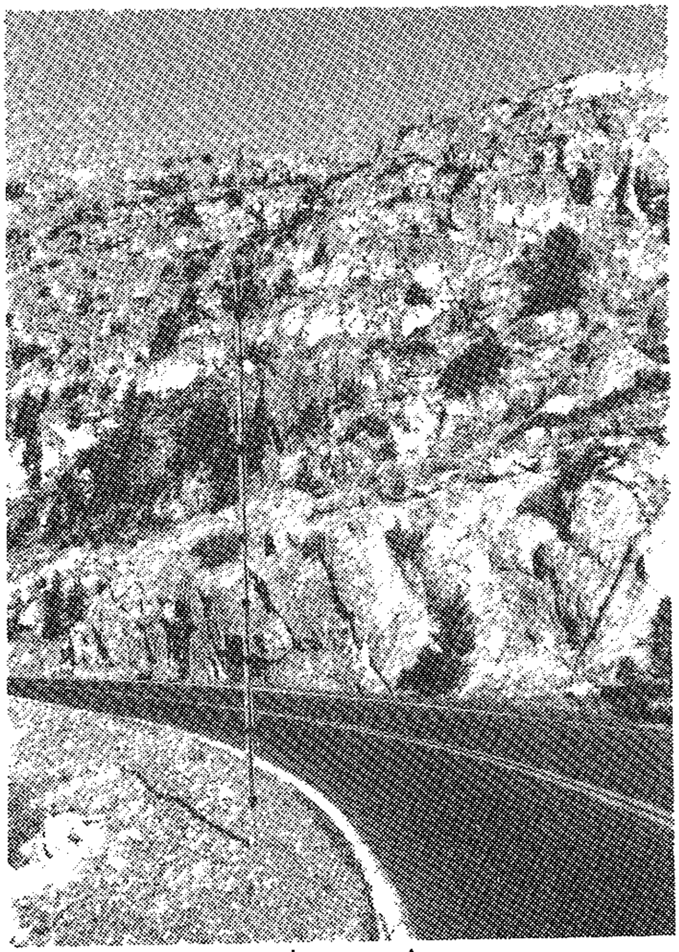


Figure 4

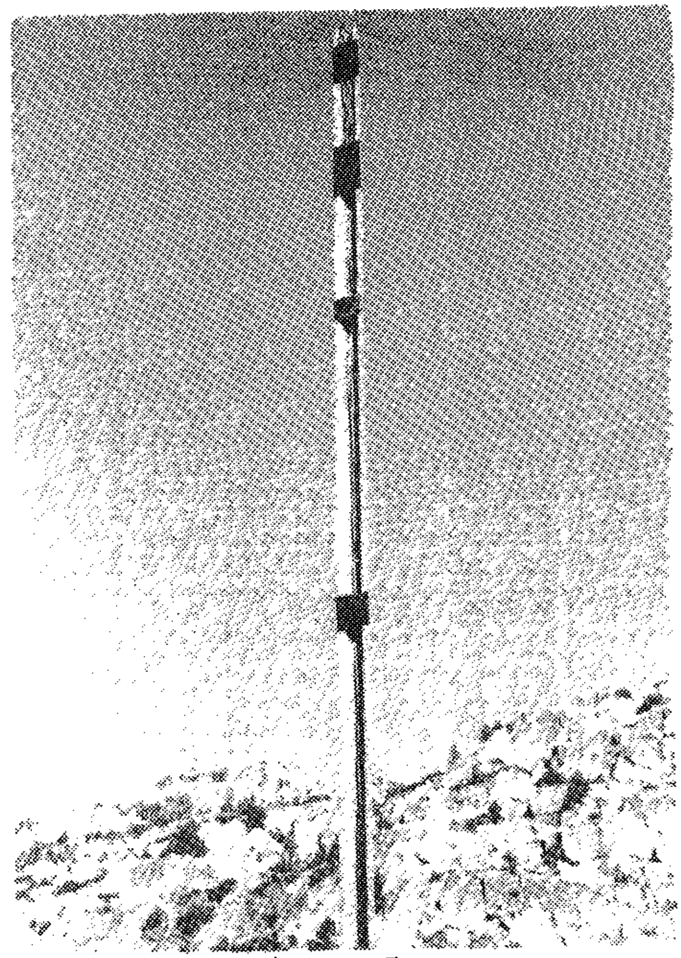


Figure 5

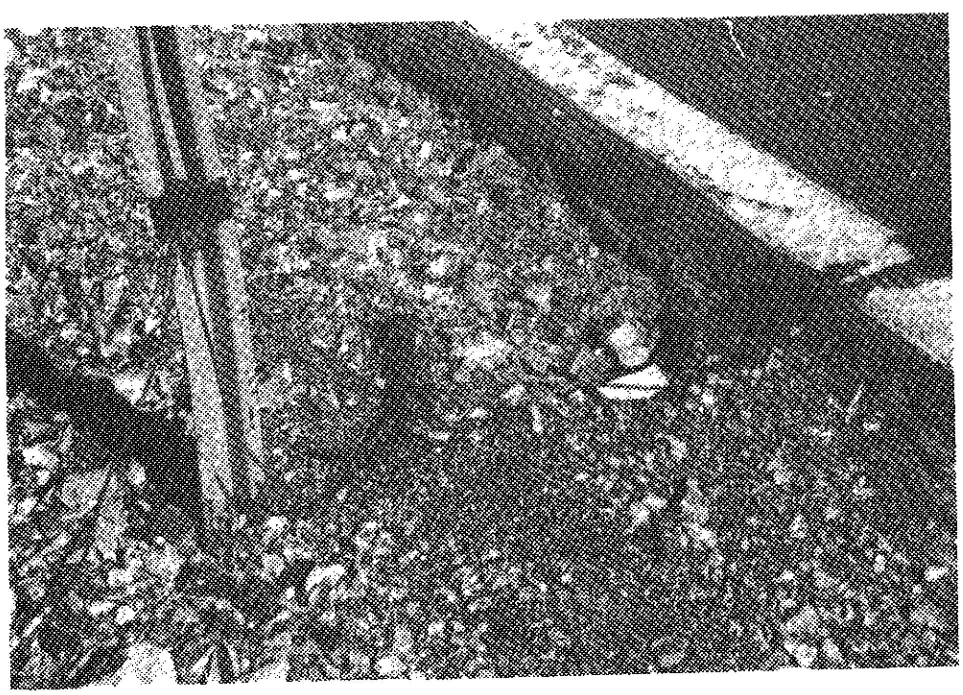


Figure 6

Snow Pole Installation

Figure 7
Grounding Rod

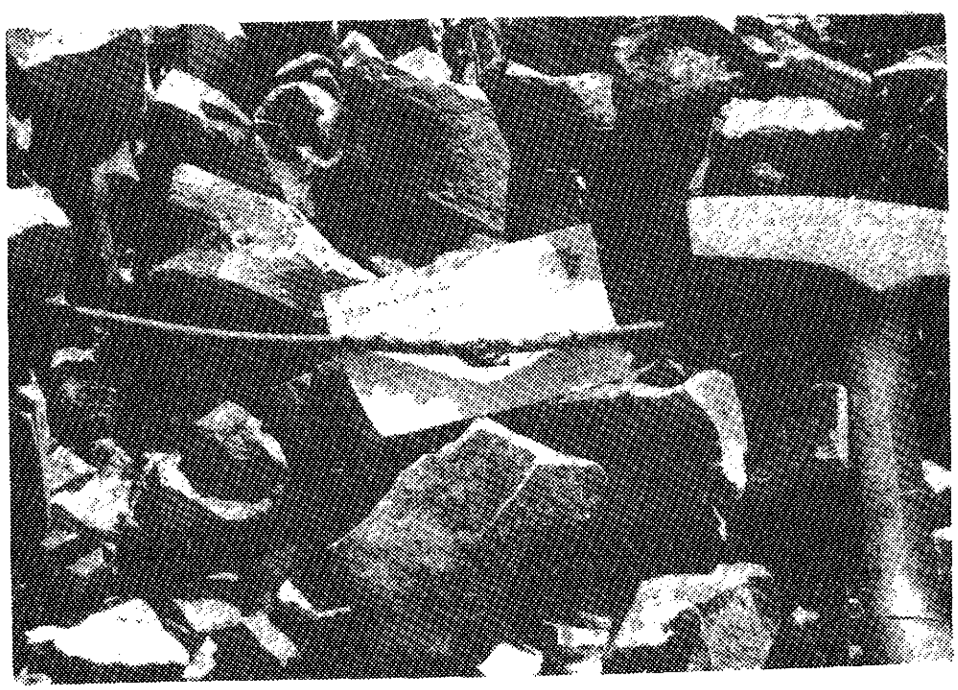


Figure 8
Rodent Damage

APPENDIX B: INSTRUMENT SELECTION

Several brands of cable fault locators were tested. All, except one, of the cable fault locators were borrowed from either the District 03 (Marysville) Electrical Shop or the Sacramento Municipal Utility District (SMUD). The remaining unit was the Hewlett Packard (HP) locator borrowed from Lassen National Park. Since the method used by each locator to indicate the position of a conductor varied, the table below briefly summarizes each unit's operational ability to perform the required task. To explain, some locators use an audible tone only, others use an analog meter to indicate relative signal strength, while others use a digital display and/or an audible tone.

EQUIPMENT	SIGNAL STRENGTH VS CONNECTION METHOD
RadioDetector 400	Good
Metrotech 850	Better
Metrotech 480	Good
Tracker II	Good
HP 4900A	Good

Because the Metrotech cable fault locators were newer units and possessed a feature that showed the operator's position relative to the buried conductor, a Metrotech 850 was purchased for this project. The Model 850 is an upgraded model 480. Also, the HP unit borrowed from Lassen National Park is no longer manufactured. Although it is not apparent from the above table, the Metrotech 850 performed slightly better in the field and provided a better method with more resolution, the digital signal strength meter and the analog meter, of locating the buried conductor.

DESCRIPTION AND SPECIFICATIONS

METROTECH 850 AUDIO FREQUENCY LINE TRACER

The Metrotech 850 is an audio frequency (AF) line tracer, also known as a cable locator or cable fault locator. The line tracer consists of a transmitter and a receiver. The transmitter sends a 9820 hertz signal along a conductor and the receiver locates the buried cable by detecting the transmitted AF signal. The transmitter can be operated in either the low power, 0.6 watt, or high power, 2 watts, mode. When operating in the lower power mode, the transmitter battery life is approximately 24 hours as opposed to 6 to 8 hours for the high power mode. The transmitter uses a 6 volt lead acid battery and the receiver requires four 9 volt batteries.

The line tracer contains a visual and audible left/right guiding system, a digital signal strength indicator, a liquid crystal display (LCD), a push button depth indicator, a multifunction control switch, and an automatic sensitivity control to eliminate manual adjustments. The sensitivity control automatically compensates for changes in signal strength caused by changes in conductor depth and attenuation of signal over distance.

Some of the technical specifications are listed below:

<u>Transmitter</u>	
Nominal output power	0.6 watts 2.0 watts
Output frequency	9820 Hz +/- 0.002%
Weight	5.8 lbs
<u>Receiver</u>	
Trace accuracy	+/- 1 inch from 0 to 3 feet +/- 3% over 3 feet in depth
Weight	4.1 lbs
Temperature Range	0 to 110 degrees Fahrenheit

APPENDIX C: LABORATORY TESTING

Several tests were conducted at the laboratory of the Division of New Technology, Materials and Research (DNTMR) and at the California Highway Patrol (CHP) Academy's Dynamic Vehicle Test Facility. Because of the Dynamic Vehicle Test Facility's remote location, this site was chosen to avoid interference with the Metrotech locator from any conductors, metal, poles, structures, etc.

For tests performed at the DNTMR Laboratory, the referenced 400 foot cable was configured as a right angle with 200 feet of cable on asphalt pavement and the remainder on natural earth. Readings in tests one through five were made one foot above the cable. The tests are explained below:

TEST 1:

Location: DNTMR Laboratory

Objective: Establish reference measurements with the Metrotech 850.

A 400 foot length of AWG 12 loop wire was laid on the ground with signal strength measurements taken every 50 feet at a height of 12 inches. This was first performed with the Metrotech transmitter set to low power, 0.6 watt, and then high power, or 2 watts. No ground connections were made for this test. Refer to Figure 9.

TEST 2:

Location: DNTMR Laboratory

Objective: Compare direct coupling of transmitted signal to an inductively coupled signal.

No ground connections were made for any of the following tests. Refer to Figure 10.

(a) A 60 foot length of wire was placed parallel to and against the 400 foot conductor. One end of the shorter cable was placed 50 feet from one end of the 400 foot conductor. The locator transmitter was connected to the 60 foot conductor at this 50 foot location and signal strength measurements were recorded.

(b) At the 50 foot location of the 400 foot conductor, 20 feet of the shorter parallel conductor was placed at a right angle to the longer cable. This resulted in 40 feet of the 60 foot cable inducing a signal into the longer conductor. The cable fault locator transmitter was connected to the perpendicular end of the shorter cable. Signal strength measurements were recorded every 50 feet along the 400 foot cable.

(c) Same as (b), except 20 feet of inducing cable was parallel and against the longer cable. The locator transmitter was 40 feet from the 400 foot conductor.

(d) Twenty feet of the shorter induction cable was placed parallel to the longer cable with 40 feet forming a right angle to the 400 foot cable at the midpoint of the longer cable. The locator transmitter was connected to the end of the 60 foot cable away from the longer cable.

(e) Same as (d), except 40 feet of the induction cable was placed parallel and alongside the 400 foot cable.

TEST 3:

Location: DNTMR Laboratory

Objective: Compare signal strength from grounded and ungrounded conductors with direct and inductive coupling.

Signal strength measurements were recorded with direct coupling and grounding, direct coupling and no grounding, and inductive coupling with a ground. Refer to Figure 11.

TEST 4:

Location: DNTMR Laboratory

Objective: Evaluate induced signal with various grounding schemes.

Measurements were recorded with just the 400 foot cable grounded, 20 feet of induction cable and all unattached ends grounded, and 60 feet of induction cable with all unattached ends grounded. The cable fault locator transmitter was placed 50 feet from one end of the 400 foot cable and connected to the induction cable. Refer to Figure 12.

TEST 5:

Location: DNTMR Laboratory

Objective: Simulate dry field conditions and vary the grounding scheme.

One end of the 400 foot cable was routed up a pole and the locator transmitter was connected between this conductor and the pole which simulated a ground rod. Signal strength measurements were taken with the opposite end of the long conductor grounded and not grounded. Refer to Figure 13.

TEST 6:

Location: CHP Dynamic Vehicle Test Facility

Objective: Obtain signal strength measurements at various heights above the primary conductor.

Measurements were made on the 400 foot long conductor at heights from 0 to 30 feet in 5 foot increments. Measurements were made at the 100, 200, and 300 foot locations with the conductor grounded and ungrounded. Refer to Figure 14.

TEST 7:

Location: CHP Dynamic Vehicle Test Facility

Objective: Evaluate signal strength measurements with transmitter on high and low power.

Same as for Test 6. Refer to Figure 15.

TEST 8:

Location: CHP Dynamic Vehicle Test Facility

Objective: Evaluate measuring ability of Metrotech when not directly over conductor.

Signal strength readings were obtained 300 feet from the transmitter of the 400 feet cable. The receiver position was varied from 0 to 9 feet in 3 foot increments perpendicular to the conductor, and from ground level to 30 feet in elevation. Refer to Figure 16.

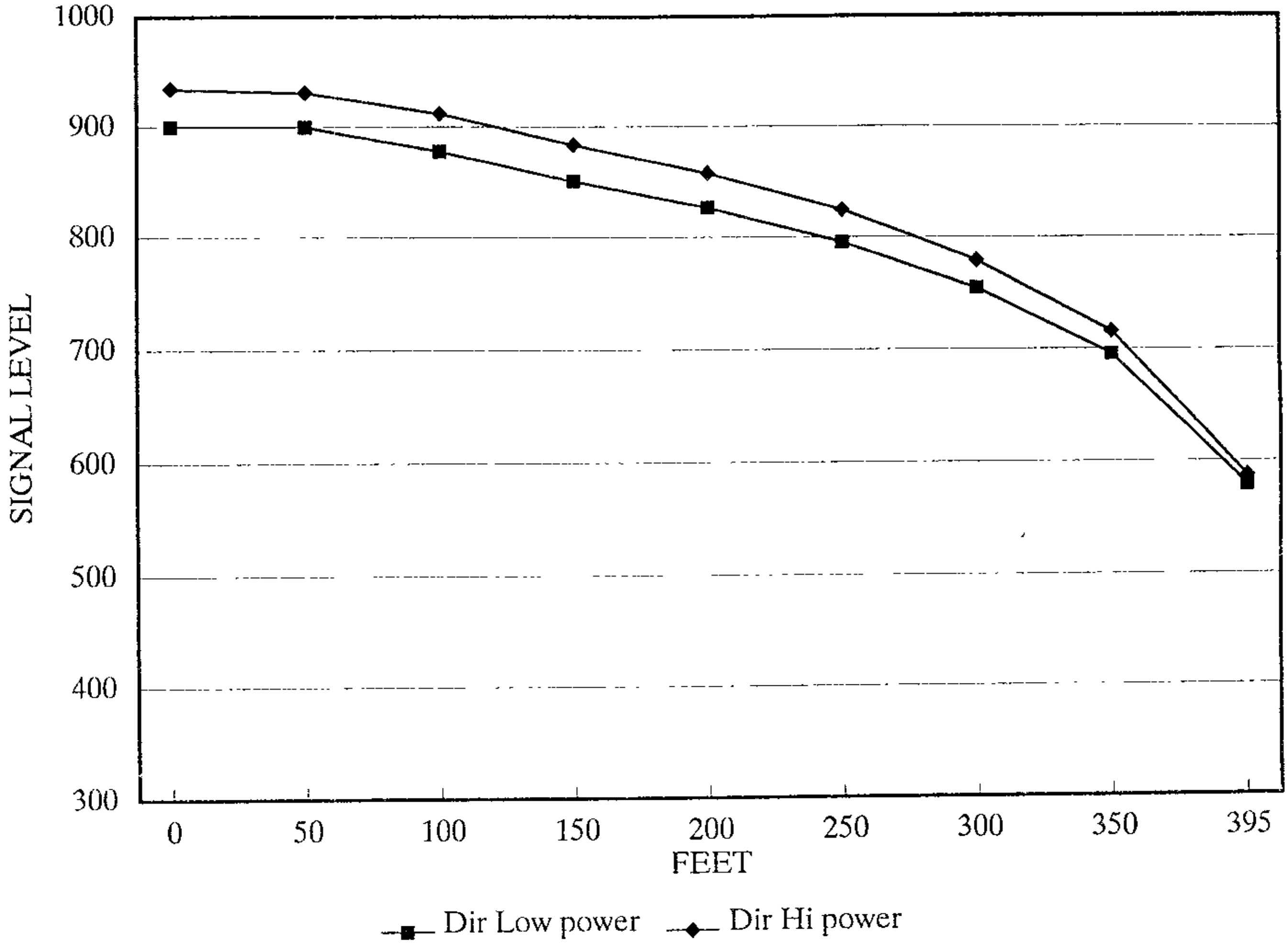


FIGURE 9

UNGROUNDED HIGH AND LOW POWER

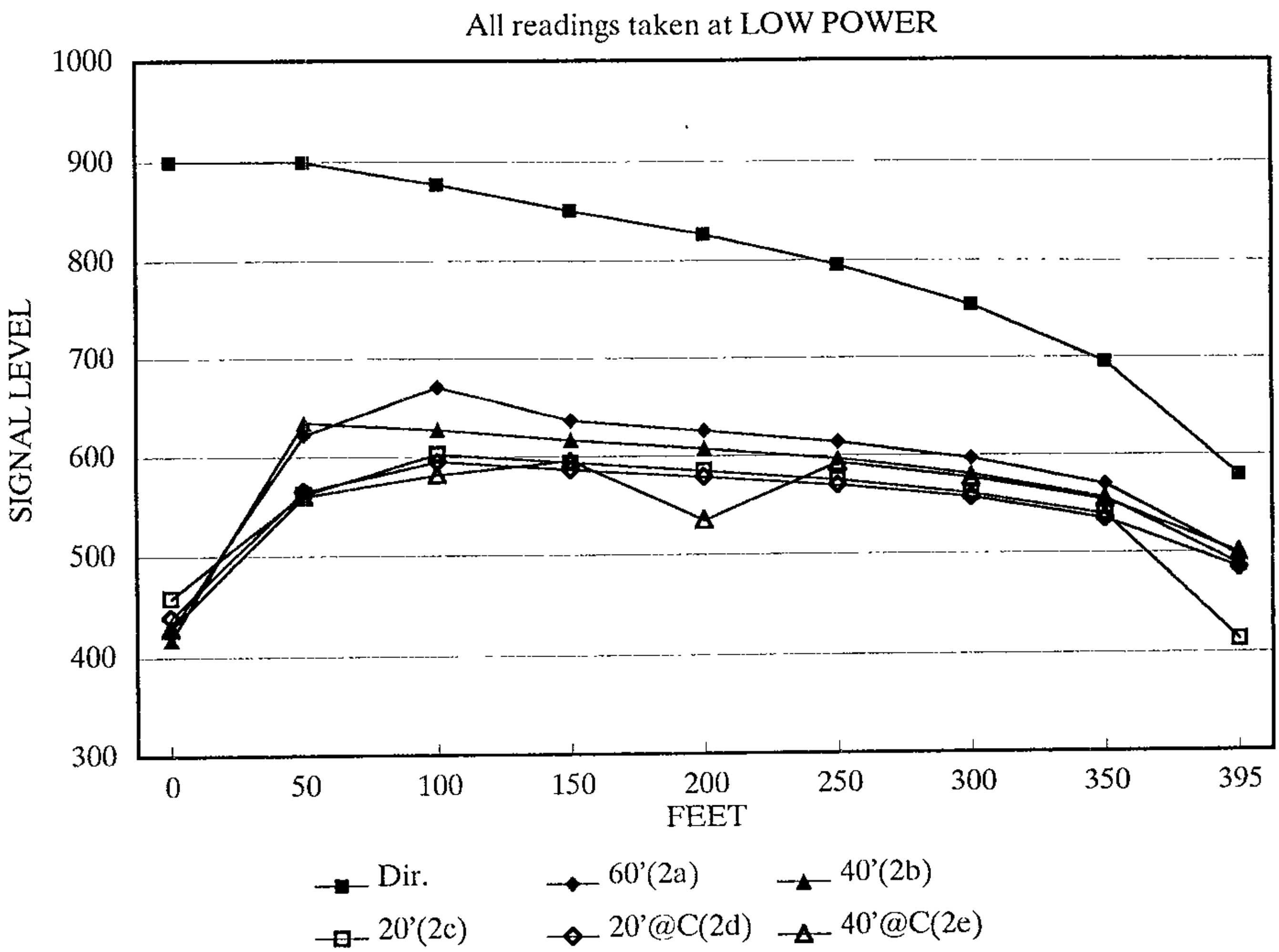


FIGURE 10

DIRECT AND INDUCTIVE COUPLING

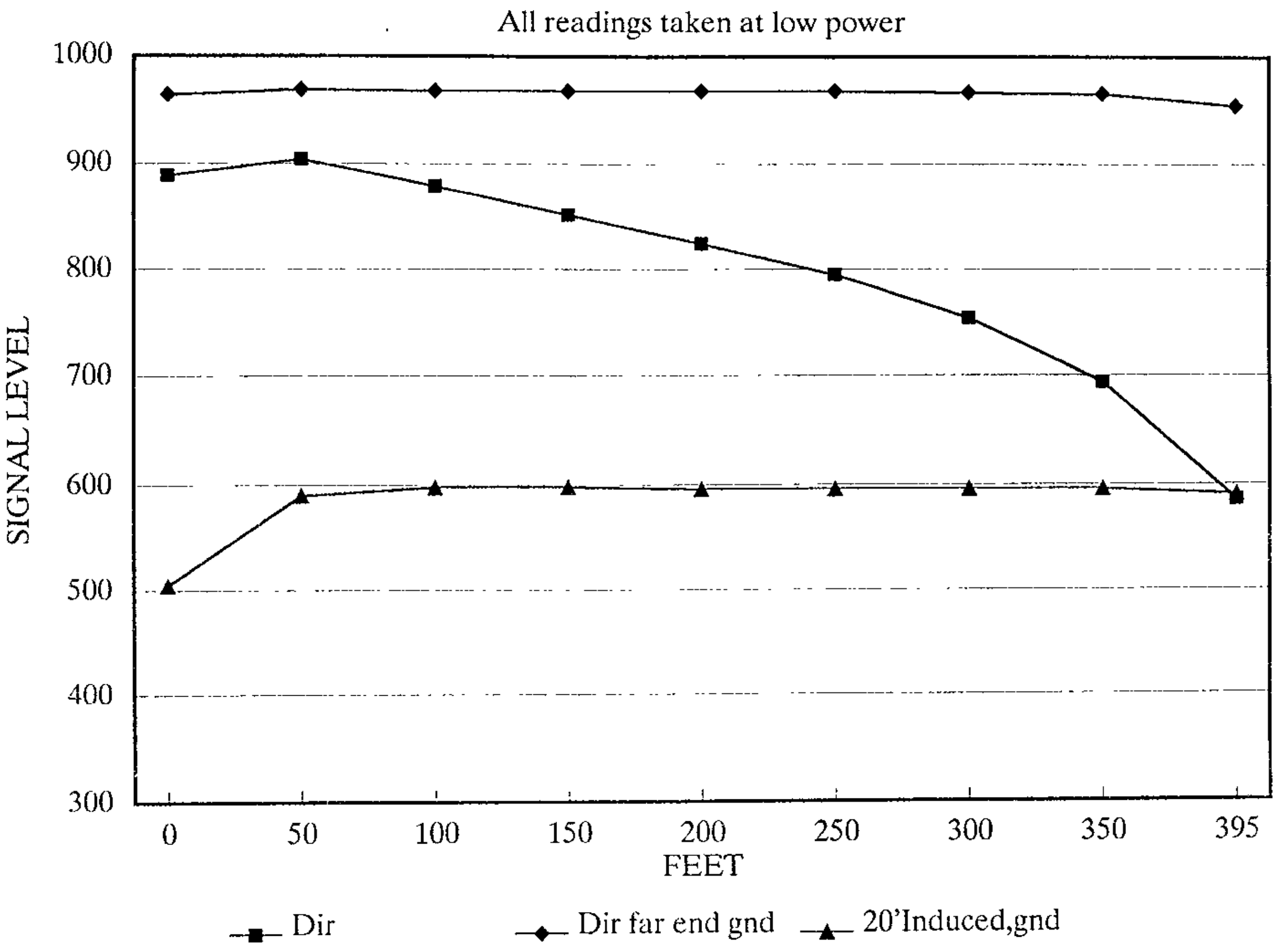


FIGURE 11

DIRECT AND INDUCED, GROUNDED AND NOT GROUNDED

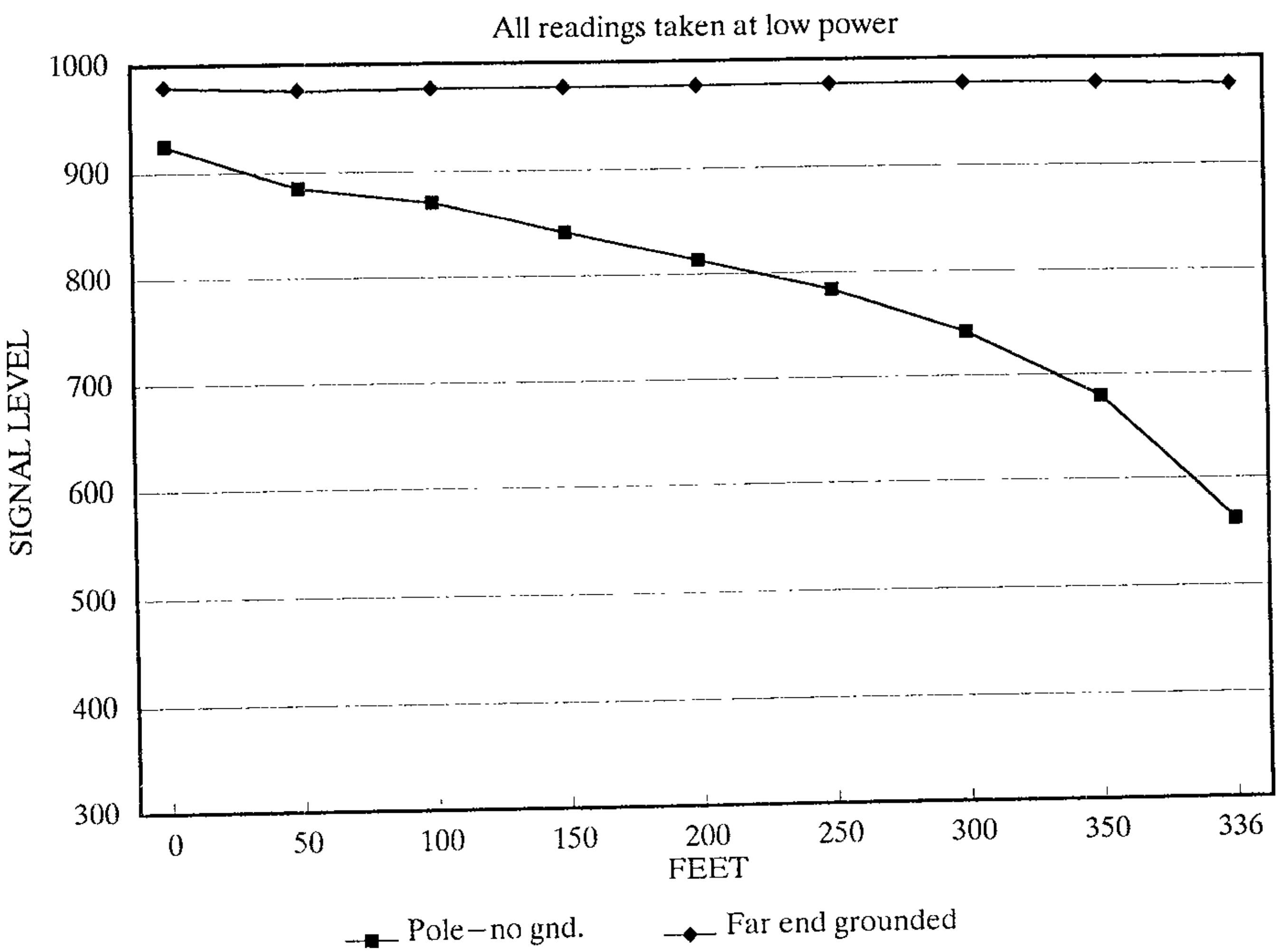


FIGURE 13

STEEL POLE GROUNDS TRANSMITTER

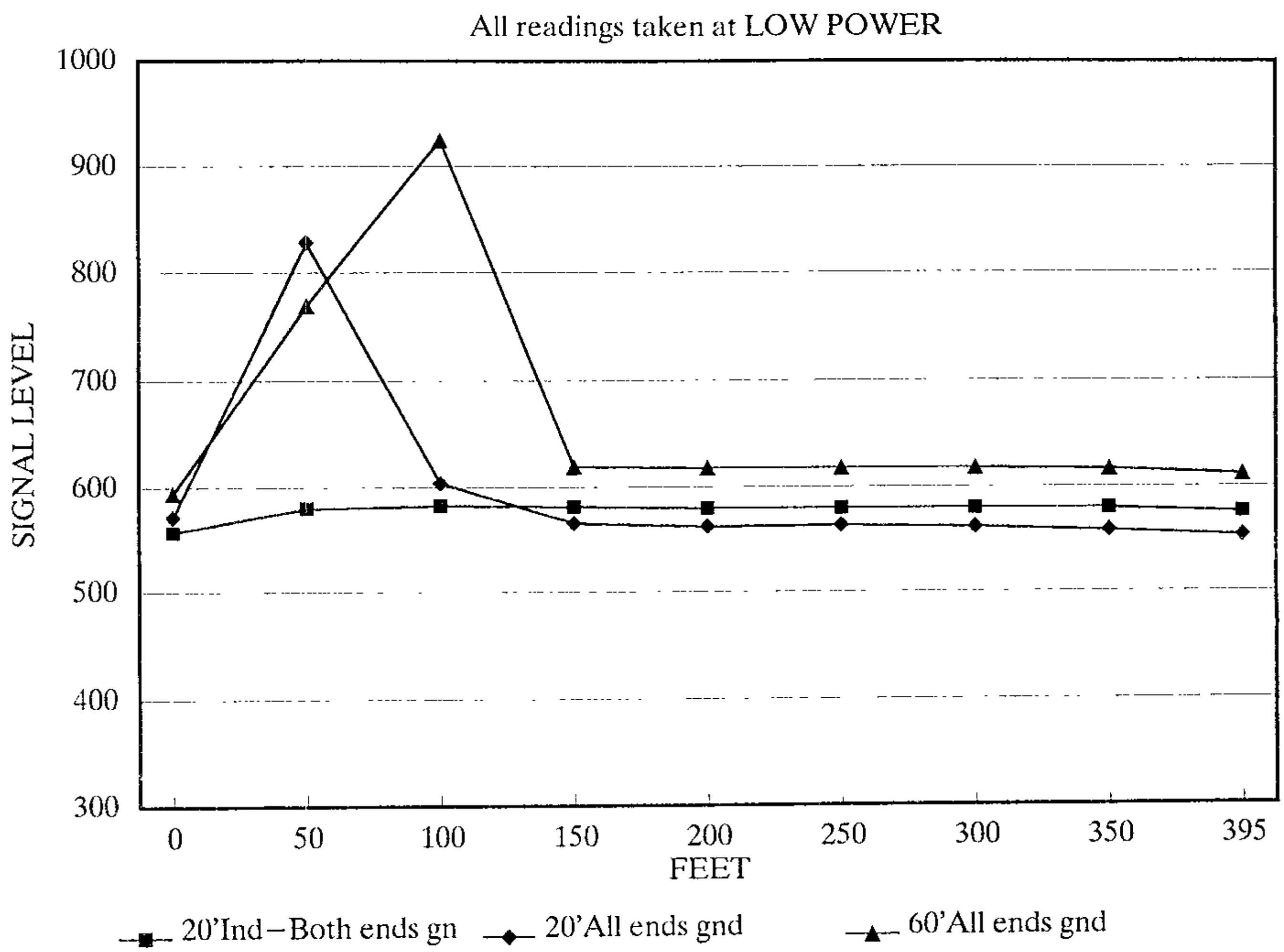


FIGURE 12

INDUCED WITH VARIOUS GROUNDING SCHEMES

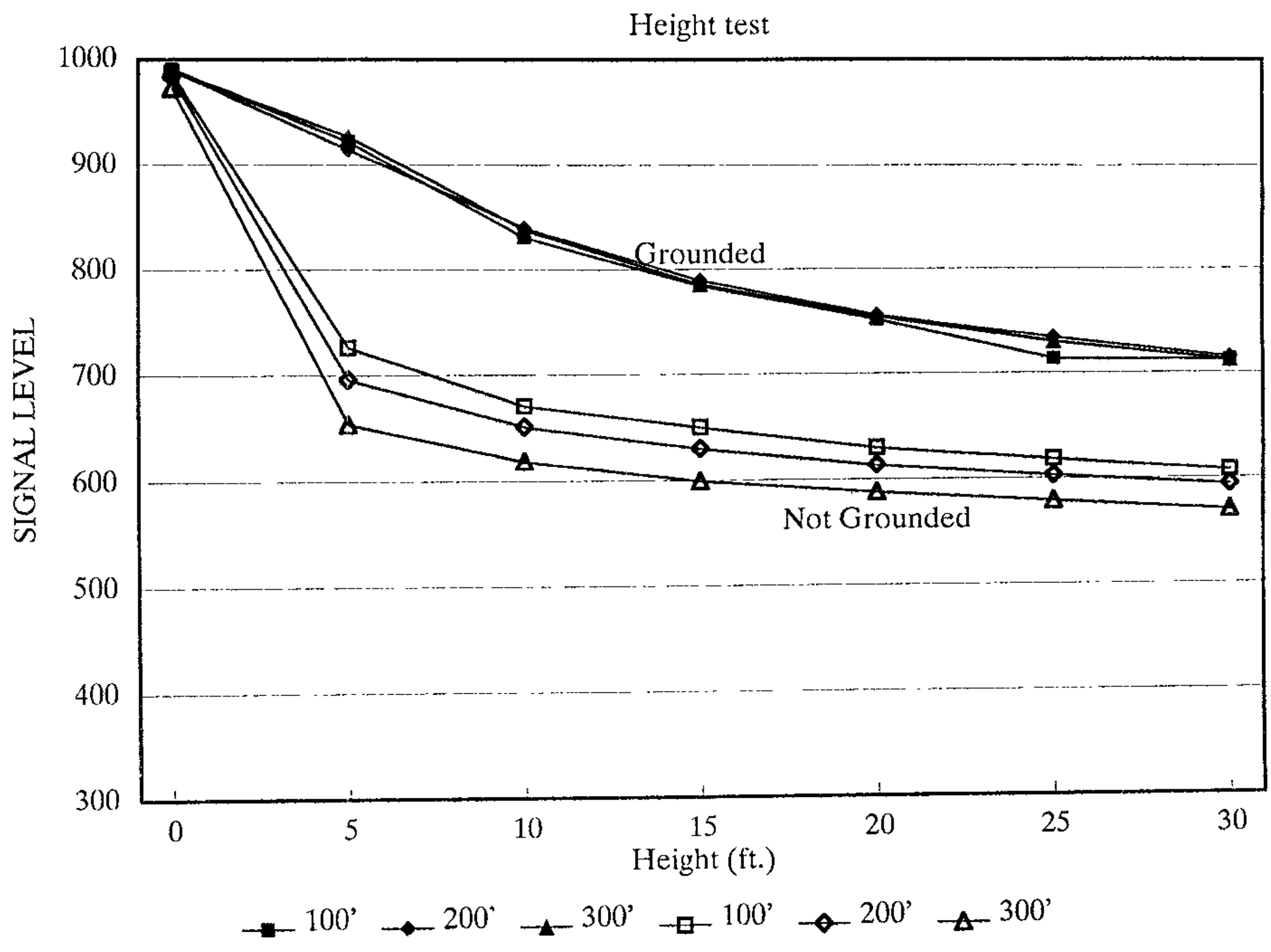


FIGURE 14

SIGNAL STRENGTH VS HEIGHT

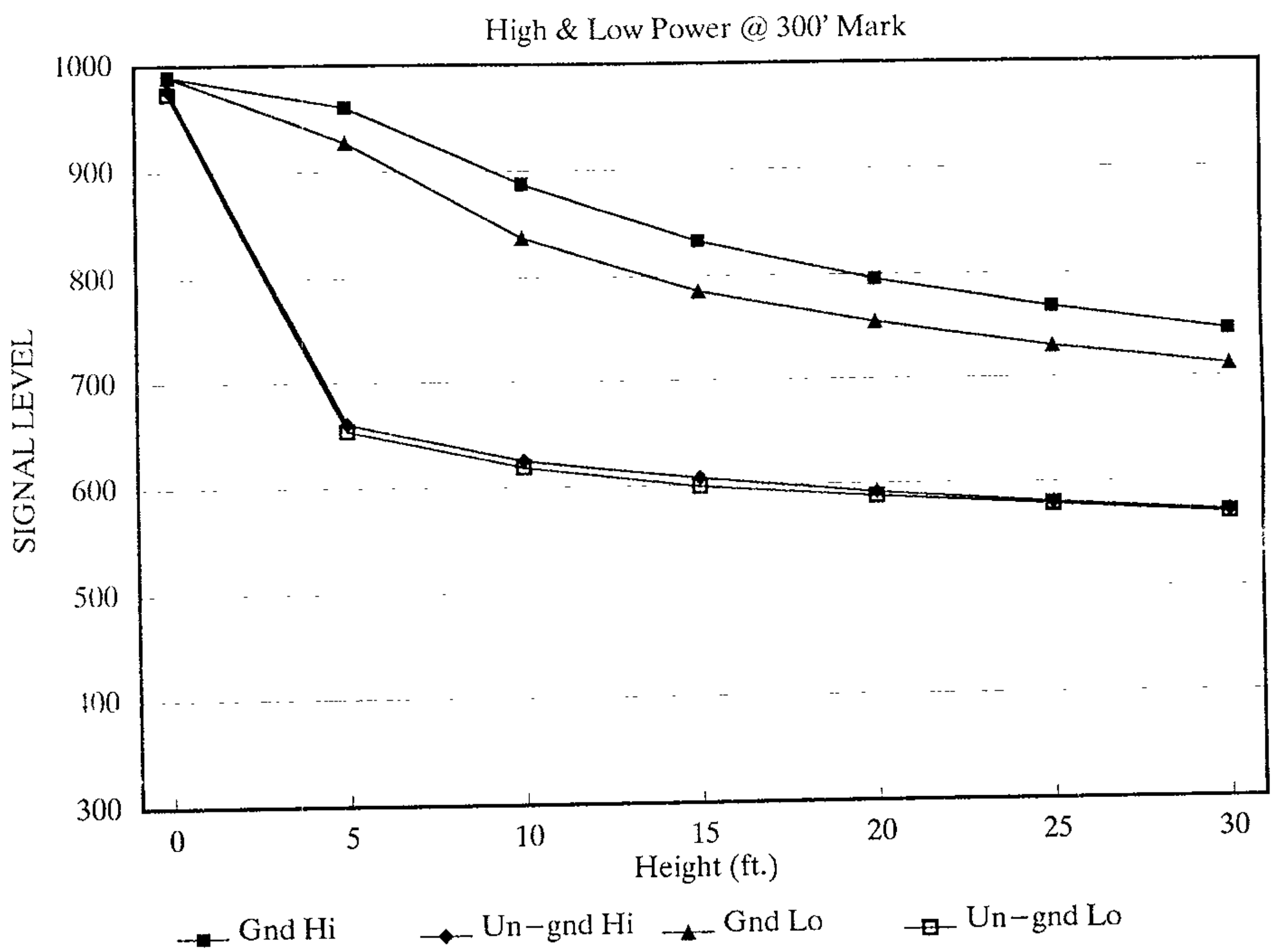


FIGURE 15

VARYING HEIGHT MEASUREMENTS AT HIGH AND LOW POWER

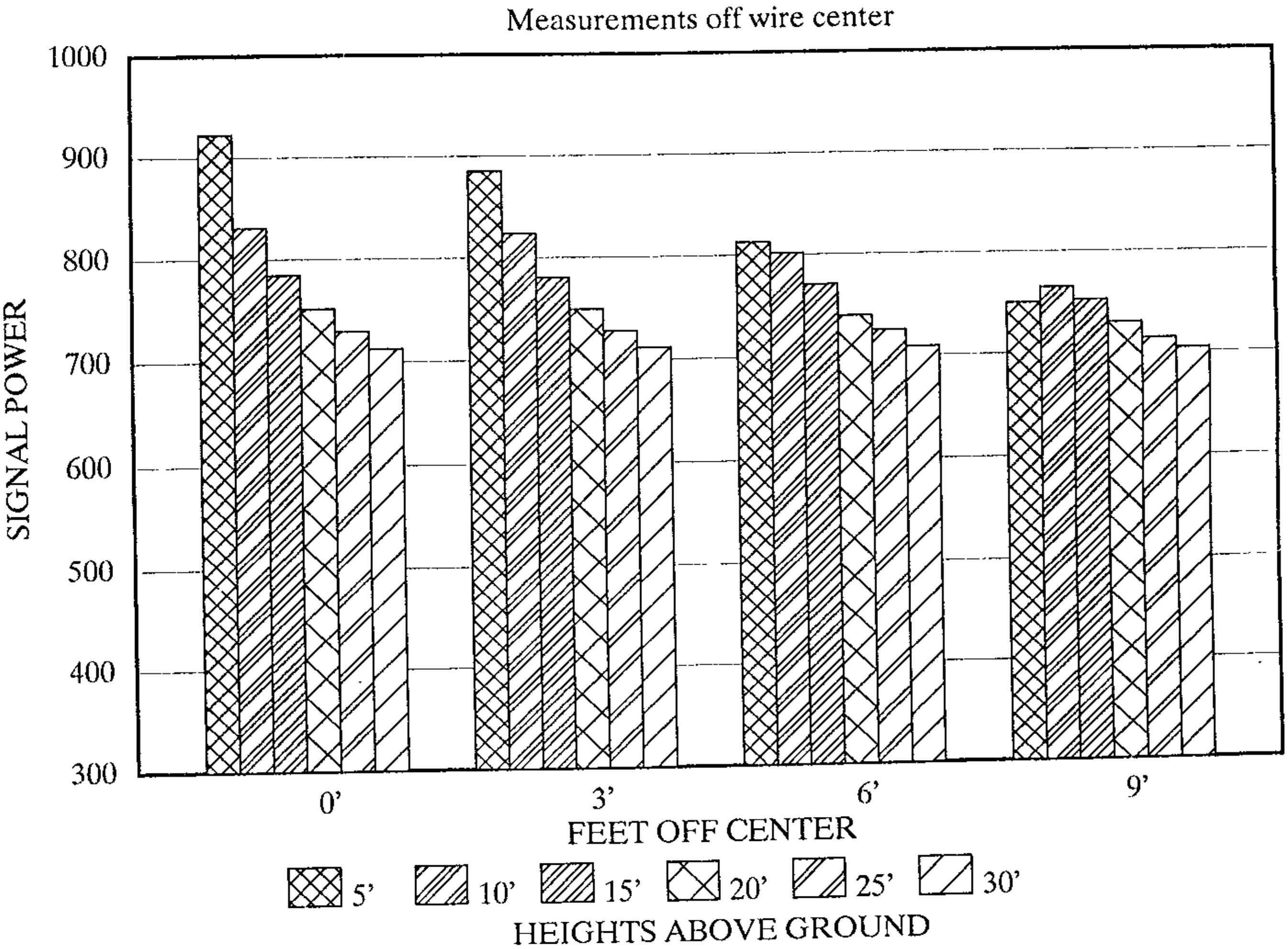


FIGURE 16

SIGNAL STRENGTH AT LATERAL POSITIONS

APPENDIX D: FIELD TESTS

On April 26, 1991, field testing of the installed system at Sonora Pass was conducted. Access to the test site was gained with snowmobiles borrowed from the Summit Ranger Station, Stanislaus National Forest, U.S. Forest Service.

Insufficient time and difficulty in gaining access to the test site permitted testing of only one of the three installation sites. The middle run, which is approximately 900 feet in length, was the subject of the test. Weather conditions consisted of partial cloud cover with periods of bright sunshine. Soft snow at the upper end prevented snowmobile access and discouraged testing at that site.

Testing commenced at the upper end of the second run. The ground and signal conductors for this run are routed up a snowpole at the upper end and up a tree at the lower end.

The first test compared the signal strength readings over the cable about twenty feet from the upper end when the cable fault locator transmitter was connected to different ground points. When the transmitter ground lead was connected to a snowpole, a signal strength of 881 was recorded. When the transmitter ground lead was connected to a copper ground rod, a signal strength of 824 was read. This indicated that the snow pole was an adequate ground for the transmitter.

Next, the buried cable was traced from the upper to the lower end. The locator transmitter ground connection was made at a snowpole. The buried wire was located and its position on the snow was marked with paint from a spray can. This position corresponded to the center line of the road.

At the lower end of the run, a signal strength of 651 to 653 was recorded and the snow depth was measured as four feet. Each measurement was made with the end of the receiver just touching the snow.

A measurement was also taken at the lower end over the buried cable with the signal cable properly shorted to the ground cable. This signal strength was 684 to 685 indicating a only small increase in signal with correct grounding. The reason for this minimal difference is not fully understood, but it is suspected that the signal wire was inductively coupling to both the wet ground and the grounding wire which was routed next to it.

Snow depths and signal strengths were recorded working uphill toward the transmitter from the lower end of the run. These readings are confusing because the greater depths were closer to the transmitter. Nearness to the transmitter was apparently more important than depth of snow. The readings are tabulated below in Table 1.

TABLE 1

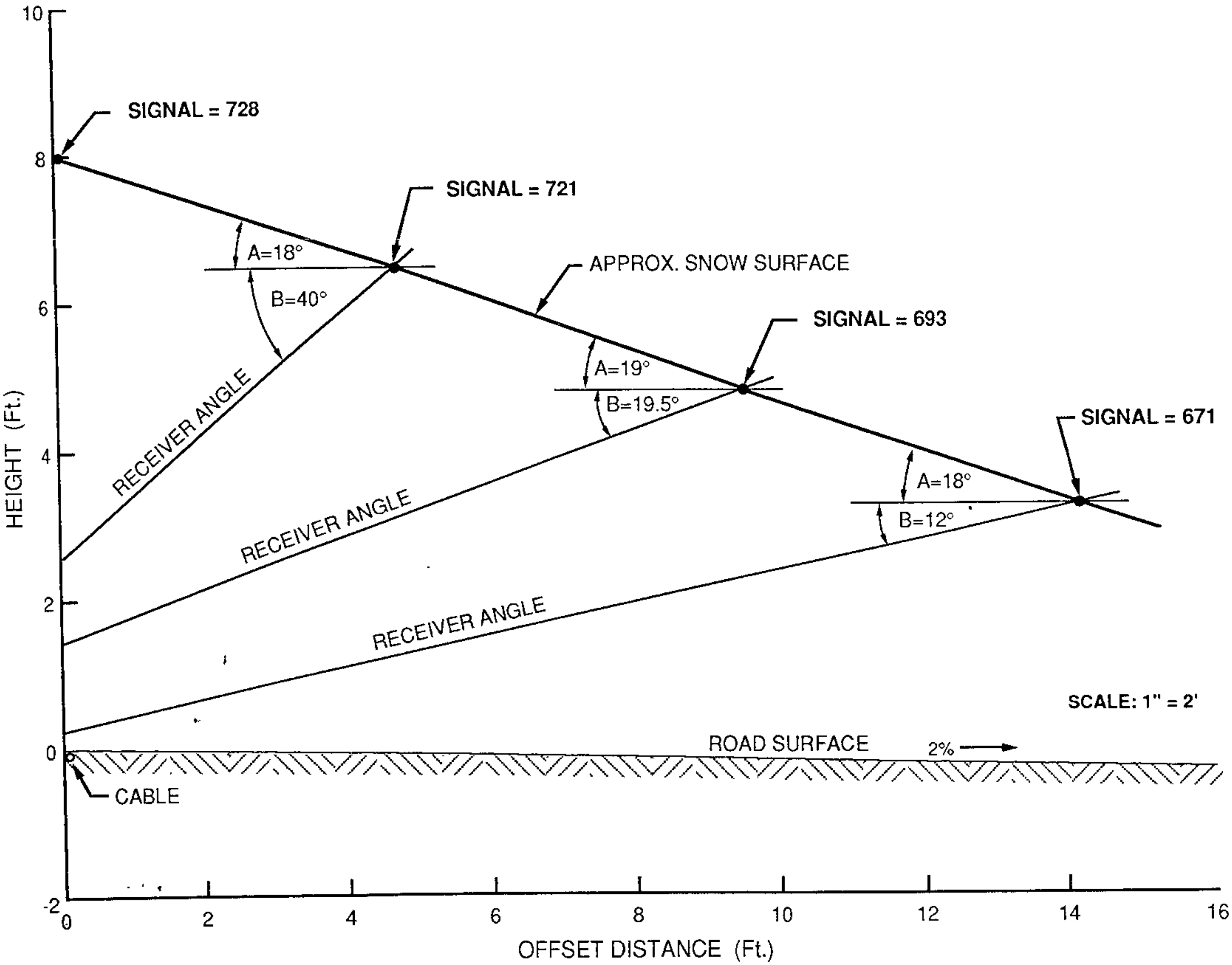
Snow Depth	Signal Strength
4'-8"	704
5'-9"	712
8'-0"	728

A drift was then located at a location approximately 50 to 100 feet uphill from the curve at the lower end of the second run. This appeared to have the greatest depth of snow cover in the site. These measurements are given below in Table 2.

Table 2

Offset	Elevation Angle A	Metrotech Rcvr. Angle B	Signal Strength
15'	18 deg.	12 deg	671
10'	19 deg.	19.5 deg.	693
5'	18 deg.	40 deg.	721
0'		90 deg.	728

The snow was deep at the center of the road but the snow surface then sloped down at about 19 degrees from the horizontal. Several readings were made from points to the side of the cable pointing the probe unit toward the buried wire and measuring the angle of the probe at null. This was attempting to measure the angle from a lateral position to the buried wire. Figure 17 is a plot that illustrates the crossectional plot of these measurements. The instrument failed to accurately triangulate the depth of the wire. Note, however, that the signal strength through 15 feet of snow was not seriously attenuated from the more direct measurements.



SNOW DRIFT CROSS SECTION

FIGURE 17