

A Minerals Research contract report
December 1981

PB83149070



AN APPLICATION OF THE DEDICATED WIRE TECHNIQUE TO IMPROVE COAL MINE TROLLEY CARRIER PHONE COMMUNICATIONS

Bureau of Mines Open File Report 203-82

Contract J0308036
Arthur D. Little, Inc.

REPRODUCED BY: **NTIS**
U.S. Department of Commerce
National Technical Information Service
Springfield, Virginia 22161

REPORT DOCUMENTATION PAGE		1. REPORT NO. BuMines OFR 203-82	2.	3. Recipient's Accession No. PB83 149070
4. Title and Subtitle An Application of the Dedicated Wire Technique to Improve Coal Mine Trolley Carrier Phone Communications			5. Report Date December 1981	
7. Author(s) Robert L. Lagace and Richard H. Spencer			6. Performing Organization Rept. No.	
9. Performing Organization Name and Address Arthur D. Little, Inc. 25 Acorn Park Cambridge, MA 02140			10. Project/Task/Work Unit No.	
12. Sponsoring Organization Name and Address Office of Assistant Director--Minerals Health and Safety Bureau of Mines U.S. Department of the Interior Washington, DC 20241			11. Contract(G) or Grant(G) No. (C) J0308036 (G)	
			13. Type of Report & Period Covered Contract research 11/79--12/81	
14.				
15. Supplementary Notes Approved by the Director, Bureau of Mines, for placement on open file, December 10, 1982.				
16. Abstract (Limit: 200 words) A whole-mine experiment to assess the practical feasibility and utility of the dedicated-wire technique to overcome poor trolley carrier phone system performance at a large underground coal mine was designed, performed, and evaluated. The technique involves the use of a single, low-loss, properly terminated, and branched auxiliary wire placed in the rail haulageway. This auxiliary dedicated wire allows signals to electromagnetically couple to the trolley wire-rail transmission line and thereby significantly decrease the overall signal attenuation rate on the trolley wire-rail line. The in-mine dedicated-wire demonstration program and its results, conclusions, and recommendations are described.				
17. Document Analysis & Descriptors Mining Wired wireless Underground mining Telecommunication Coal mines Mine haulage Mining engineering b. Identifiers/Open-Ended Terms Carrier-wire communication systems Coupled transmission lines Safety Mine communications - trolley wire Tunnel communications Carrier communications Underground communications c. COSATI Field/Group 08I, 09C, 17B				
18. Availability Statement Release unlimited by NTIS.		19. Security Class (This Report)		21. No. of Pages 78
		20. Security Class (This Page)		22. Price

FOREWORD

This report was prepared by Arthur D. Little, Inc., Cambridge, Massachusetts, under USBM Contract No. JO308036. The contract was initiated under the Coal Mine Health and Safety Program. It was administered under the technical direction of the Pittsburgh Research Center with Mr. James R. Means, Jr. acting as the Technical Project Officer. Mr. Nicholas H. George was the contract administrator for the Bureau of Mines. This report is a summary of the work recently completed as part of this contract during the period November 1979 to December 1981. This report was submitted by the authors on December 31, 1981.

No inventions or patents were developed, and no applications for inventions or patents are pending.

The authors wish to thank the mine personnel of Consolidation Coal Company's Robinson Run coal mine, and, in particular, Thomas Poundstone, Robert Mullins, Bruce Roberts and Jack Williams for their cooperation and assistance in planning and performing the work at the mine on this demonstration program; John Burr and David Podobinski of the Lee Engineering Division of Consolidation Coal Company for their cooperation in arranging the opportunity for us to work with the Robinson Run mine; and Thomas Agnew of Control, Inc.* for his timely cooperation. We also wish to thank the mine personnel of North American Coal Corporation's Powhatan No. 1 mine, Eastern Associated Coal Corporation's Harris No. 1 mine, and Beth Elkhorn Corporation's No. 26 mine for their cooperation during visits to their mines as part of this program's mine selection process.

*Reference to specific brands, equipment, or trade names in this report is made to facilitate understanding and does not imply endorsement by the Bureau of Mines.

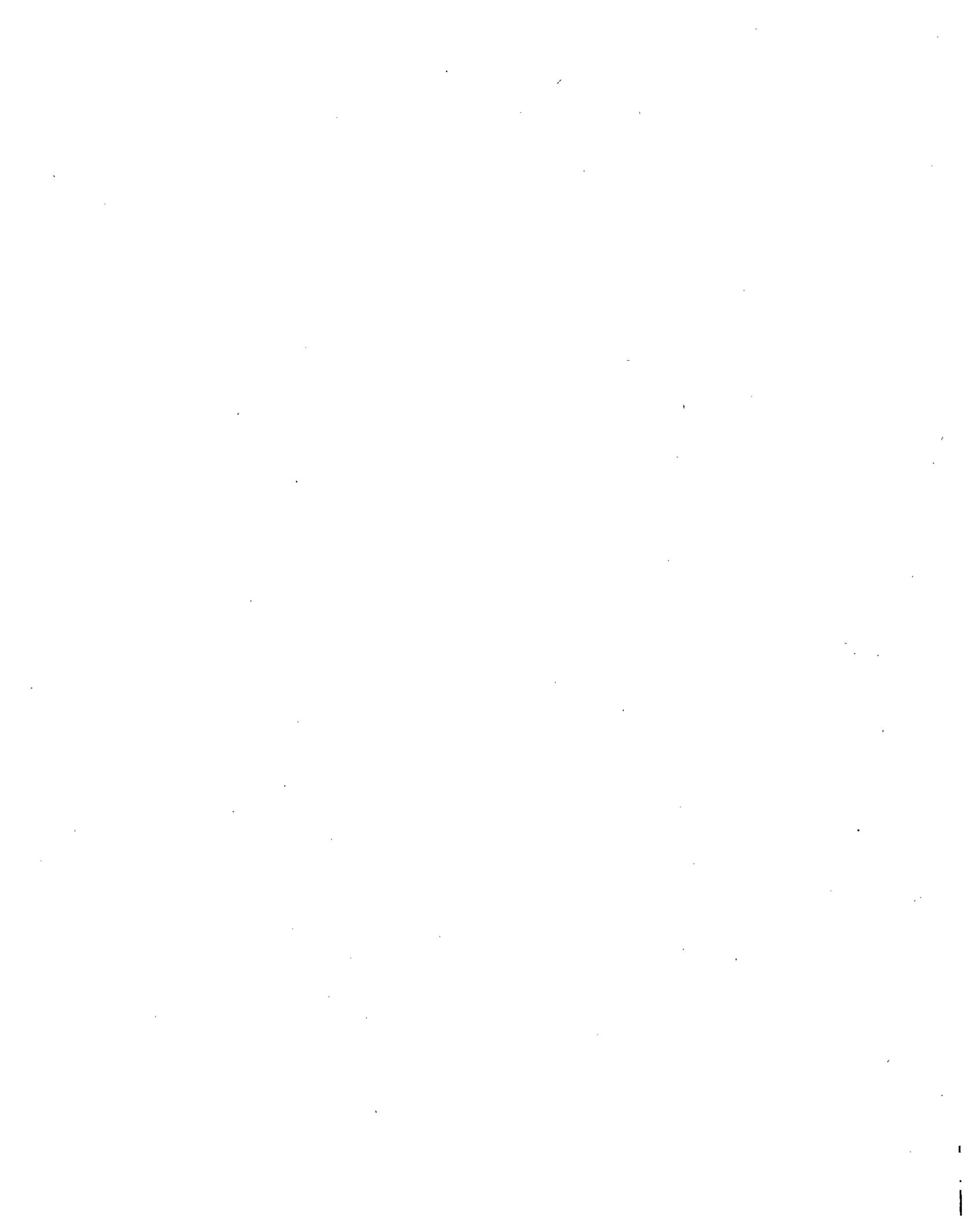


TABLE OF CONTENTS

	Page
Report Documentation Page	1
Foreword	2
List of Figures	5
List of Tables	7
I. EXECUTIVE SUMMARY	8
A. OBJECTIVE	8
B. FINDINGS AND CONCLUSIONS	8
C. RECOMMENDATIONS	9
II. BACKGROUND	11
III. MINE SELECTION	15
A. SELECTION CRITERIA AND SEARCH PROCESS	15
B. THE FIRST THREE PRIME CANDIDATES	16
C. THE FINAL SELECTION – THE ROBINSON RUN NO. 95 MINE	17
IV. PERFORMANCE MEASUREMENTS AND CORRECTIVE DEDICATED WIRE IMPROVEMENTS	20
A. ROBINSON RUN MINE – RAIL HAULAGE NETWORK AND TROLLEY CARRIER PHONE SYSTEM	20
B. THE "BEFORE" PERFORMANCE MEASUREMENTS	27
1. Measurement Procedures	27
2. Initial Observations	28
3. Detailed Data Analysis	30
C. THE IMPROVED DEDICATED WIRE CONFIGURATION	31
1. The Required Changes	31
2. Implementation of the Changes	37
D. THE "AFTER" PERFORMANCE MEASUREMENTS	40

TABLE OF CONTENTS (Continued)

	Page
V. COMPARISONS OF "BEFORE" AND "AFTER" PERFORMANCE	42
A. FORMAT OF SIGNAL COMPARISON PLOTS	42
B. EFFECTIVENESS OF SIGNAL SPLITTING	48
C. ATTENUATION RATE OF DEDICATED-WIRE CURRENT	50
D. PERFORMANCE ALONG EAST MAINS	52
E. PERFORMANCE ALONG WEST MAINS	53
F. PERFORMANCE IN 3-NORTH AREA	54
G. PERFORMANCE ALONG NORTH MAINS	55
H. PERFORMANCE ALONG NORTHEAST MAINS	56
I. PERFORMANCE UNDER OPERATIONAL CONDITIONS	57
J. OVERVIEW	59
VI. REFERENCES	60
APPENDIX A – BRIEF DESCRIPTIONS OF VISITS TO FIRST THREE CANDIDATE MINES	61
APPENDIX B – A DRAFT PLAN FOR THE DEMONSTRATION AT ROBINSON RUN MINE	65
APPENDIX C – INSTALLATION DETAILS FOR CONVERSION OF SIGNAL WIRE TO TRUE DEDICATED WIRE AT ROBINSON RUN MINE	73

LIST OF FIGURES

Figure No.		Page
1	Model Geometry – Cross Section of Tunnel, of Dimensions $d_1 \times d_2$, Showing the Trolley Wire, Dedicated Wire, and Rail, of Respective Radii a, b, c , Separated by Distances S_{ab}, S_{bc}, S_{ac} .	12
2	Dedicated Wire Model – Theoretical Voltage Levels Versus Distance	13
3	Dedicated Wire Model – Theoretical Current Levels Versus Distance	14
4	Simplified Scale Map of Original Dedicated Wire Installation Along Robinson Run Mine Rail Haulage Network	21
5	Detail of Mine Map in Vicinity of Junction of East-West and North Mains	22
6	Detail of Mine Map Showing 3-North Dump Area and Junction with East-West Mains	23
7	Detail of Mine Map Showing 4-North Section and Main West Dump Area	24
8	Detail of Mine Map Showing Main North Dump Area and Active Sections	25
9	Approximate Cross-Section of Main Haulageway Layout	26
10	Plan View of Jeep Haulage Vehicle Showing Approximate Disposition of Equipment and Personnel During Dedicated Wire Measurements	29
11	Simplified Map of Final Dedicated Wire Installation Along Robinson Run Mine Rail Haulage Network	33
12	Schematics of Couplers, Splits, and Terminations	34
13	Installation Diagram for Resistive Terminations	35
14	Installation Diagram for Two-Way Power Split	36
15	Photographs of Termination and Signal Splitting Boxes	38
16	Comparison of "Before" and "After" Carrier Phone Signals for East Mains, 128 Block Transceiver to Outside Rotary Dump	43
17	Comparison of "Before" and "After" Carrier Phone Signals for West Mains, 128 Block Transceiver to 4 North	44
18	Comparison of "Before" and "After" Carrier Phone Signals for 3-North, from E-W Mains Junction into 3 North Loop	45
19	Comparison of "Before" and "After" Carrier Phone Signals for North Mains, E-W Mains Junction to Main North Dump	46

LIST OF FIGURES (Continued)

Figure No.		Page
20	Comparison of "Before" and "After" Carrier Phone Signals for Northeast Mains, North Mains Junction to 11 North Dump	47
21	Illustration of "Before" and "After" Current Splits at Major Dedicated Wire Junctions for Transmissions from 128 Tx	49
B-1	Simplified Scale Map of Original Dedicated Wire Installation Along Robinson Run Mine Rail Haulage Network	67
B-2	Simplified Map of Final Dedicated Wire Installation Along Robinson Run Mine Rail Haulage Network	68
B-3	Schematics of Couplers, Splits, and Terminations	69
C-1	Schematic for Installing a Line Termination at an MSA Carrier Phone Location	76

LIST OF TABLES

Table No.		Page
1	Effectiveness of Signal Splits	48
2	Dedicated-Wire Signal Current Attenuation	51
3	Theoretical Attenuation Rates	51
4	"After" Voltages and Currents at Key Locations During and After Strike	58

I. EXECUTIVE SUMMARY

A. OBJECTIVE

The Pittsburgh Research Center (PRC) of the U.S. Bureau of Mines, has retained Arthur D. Little, Inc., to conduct several research programs⁽¹⁻⁵⁾ which have produced a number of methods and guidelines for significantly improving the operational performance of the two backbone communication systems in U.S. coal mines. These communication systems are the pager telephone system used at fixed stations throughout the mine, and the trolley wire carrier phone system used on rail haulage vehicles. Late in 1979, the PRC awarded another contract to Arthur D. Little, Inc., the objective of which was to demonstrate communication improvements that could be achieved in practice on a mine-wide scale, at coal mines having severe and persistent difficulties with their pager phone and trolley wire carrier phone systems. This report describes the events and results of this contract.

The original intention was to accomplish this objective by working with a single mine having difficulties with both systems. The less favorable alternative was to work with two separate mines, each having problems with only a single system. After an extended search for acceptable candidate mines, the U.S. Bureau of Mines and Arthur D. Little, Inc., jointly agreed that the effort should be concentrated on a single system in a single mine. It was decided that attainable performance improvements should be demonstrated only for the more troublesome of the backbone systems; namely, the trolley wire carrier phone system. This objective was accomplished by completing the following contractual tasks:

- Finding a physically suitable and cooperative mine,
- Conducting mine-wide "before" performance measurements,
- Implementing the recommended corrective actions,
- Conducting mine-wide "after" performance measurements,
- Comparing the "before" and "after" results to demonstrate the improvements.

B. FINDINGS AND CONCLUSIONS

The carrier phone communications improvement program conducted at the Consolidation Coal Company's Robinson Run coal mine showed that the dedicated-wire technique can be used to improve carrier phone communications throughout the rail haulage network of an extensive mine. A dedicated wire consists of a single conductor installed in the haulageway to form a parallel low-loss transmission line comprised of this conductor and the rails. The natural electromagnetic coupling of this dedicated-wire/rail line to the trolley wire/rail line provides the desired signal coupling. The program also confirmed that the average characteristic impedance of a dedicated-wire/rail transmission line is about 200 ohms. This fact can be used as a basis for designing simple matched signal splits and line terminations to prevent standing waves and to facilitate the delivery of strong carrier phone signals to all parts of a mine's dedicated-wire network.

The ability to maintain strong carrier phone signals on the dedicated-wire/rail transmission line will assure that the trolley wire/rail carrier phone voltage will also be maintained in all haulageways containing a parallel dedicated wire. This coverage can even extend to distances of about one-half mile beyond the ends of the dedicated wire. The trolley wire/rail voltage will still exhibit significant variations along the haulageways, because of the large impedance variations found along the trolley wire/rail line. However, these voltages will be maintained at more than adequate levels for reliable rail haulage communications because of the signal regeneration coupling provided by the parallel, well-controlled, dedicated-wire/rail transmission line.

The simple and stable configuration and behavior of the dedicated-wire/rail transmission line in a mine are the keys to its predictable and reliable high performance. The simple configuration also means that problems can be quickly diagnosed and the dedicated-wire network integrity and performance easily maintained.

Furthermore, the dedicated wire technique achieves improved carrier phone system performance *without* using any signal coupler interconnections between the DC-energized trolley wire and any other signal wire. Thus, the potential hazard of the trolley wire DC voltage being inadvertently transferred to other signal lines via such couplers is completely avoided.

The above conclusions are based on our two comprehensive in-mine demonstrations, the first at Consolidation Coal's Montour No. 4 mine and the second at Consolidation Coal's Robinson Run mine. The Montour No. 4 installation provided improved and reliable performance over an approximately 4-mile installation both during the three-day experimental period and for years afterward until the mine became flooded. The Robinson Run 11-mile installation, described in this report, has provided improved and reliable performance since it was installed and measured in May of this year. This period (about seven months) has spanned about half of Robinson Run's annually recurring period of difficult trolley carrier phone communications which typically lasts from spring to mid-summer. Therefore, although we continue to express confidence in the success of the dedicated-wire technique, the final proof of its success at the Robinson Run mine will be its ability to provide improved and reliable communications through the normally troublesome spring and summer seasons in 1982.

C. RECOMMENDATIONS

During this program, we also noticed a phenomenon not observed in previous dedicated-wire experiments and analyses; namely, that sizable increases in trolley wire/rail carrier phone voltages occur in the vicinity of dedicated-wire terminations and other discontinuities, such as signal splits, along the dedicated wire. At the present time, we do not understand the reasons for these significant increases in voltage, although we suspect they may be related to boundary condition changes presented to the propagating guided waves. Since practical coverage benefits can be obtained from the judicious use of such increases in signal strength, further effort

should be devoted to gaining an understanding of this phenomenon and its application to solving practical trolley wire communication problems in coal mines.

The successful demonstration of the dedicated-wire technique in two operating coal mines establishes the technique as a valid and practical one. Therefore, we recommend that the Bureau of Mines take steps to transfer this technology to the mining industry, and to encourage its use by mine operators confronted with the problem of providing reliable trolley carrier phone communications along their rail haulageways.

II. BACKGROUND

Trolley wire carrier phones are used to dispatch haulage vehicles in electric rail haulage coal mines. These carrier phones use the trolley wire/rail as the transmission path for the carrier signal. Experience has shown that this path is often a poor one for carrier signal transmission for a number of reasons, the principal one being the many bridging loads normally found across the trolley wire/rail DC power feeder line. These loads include: mine motors (vehicles), pumps, lights, heaters, rectifiers, insulators, and the carrier phones themselves. In addition, branches occur along the lines and matched terminations are not used. In view of these facts, it is remarkable that the carrier phones work as well as they do.

Under U.S. Bureau of Mines Contract H0346045,⁽²⁾ Arthur D. Little, Inc., developed a theoretical model which showed how a "dedicated wire" would improve the transmission of carrier signals over such lines. The "dedicated wire" consisted of a single conductor installed in the haulageway to form a parallel low-loss transmission line comprised of this conductor and the rails. The natural electromagnetic coupling of this dedicated wire/rail line to the trolley wire/rail line provided the desired signal coupling. The theory showed that an extremely lossy trolley wire/rail could be markedly improved by using such a dedicated wire. This was particularly true for dispatcher-to-vehicle and vehicle-to-dispatcher communications, because the dispatcher could connect his carrier phone directly to the low-loss dedicated wire. The theory showed that trolley wire/rail lines for which the attenuation rates were as high as 20 dB/km could be converted to lines which would exhibit only 1 or 2 dB/km by the use of a single parallel dedicated wire in the haulageway.

The theory was based on representing the trolley wire/rail line as a lossy transmission line. An actual trolley wire/rail is a poor transmission line because of the many discrete bridging loads, as noted above. The theory treats the trolley wire/rail as a line characterized by uniform, continuously distributed shunt and series losses, while the dedicated wire/rail is treated as a low-loss line having only continuously distributed series losses. For most examples treated by the theory, a loss of 1 dB/km was used for this dedicated wire/rail line in the absence of the trolley wire/rail line.⁽¹⁾

Two examples of our previous findings are shown for the conditions illustrated in Figure 1 where we assume the following dimensions in meters:

$$\begin{array}{llll} d_1 = 5 & a = 0.015 & x_a = 0.5 & x_c = 1.25 \\ d_2 = 2.5 & b = 0.0015 & y_a = 2.2 & y_c = 0 \\ h = 0.3 & c = 0.1 & & \end{array}$$

The "dedicated" wire is placed at $x = 2.2$, $y = 2.2$ for calculations of signal strength versus distance from a transmitter. One example is shown in Figure 2, where it is assumed that the transmitter is connected to the dedicated wire. The dedicated wire voltage and the trolley wire voltage are plotted. All voltages are measured with respect to the rail, which serves as a common ground. For comparison, the trolley wire voltage for transmission on the trolley wire in the absence of the dedicated wire is also shown. The companion plot, Figure 3, illustrates the theoretical currents under the same conditions.

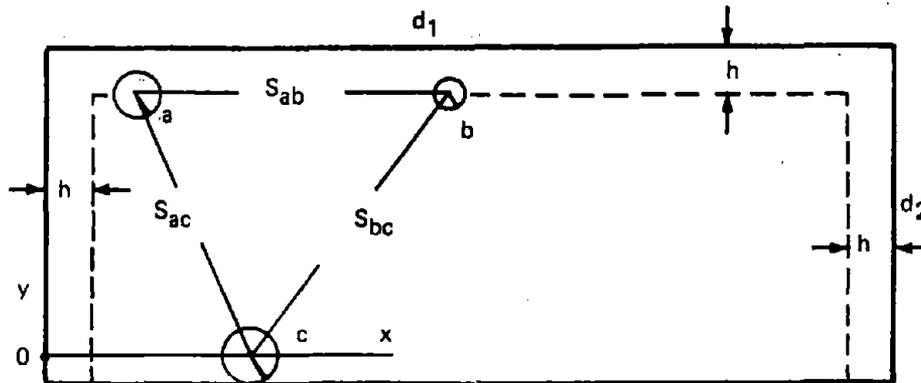
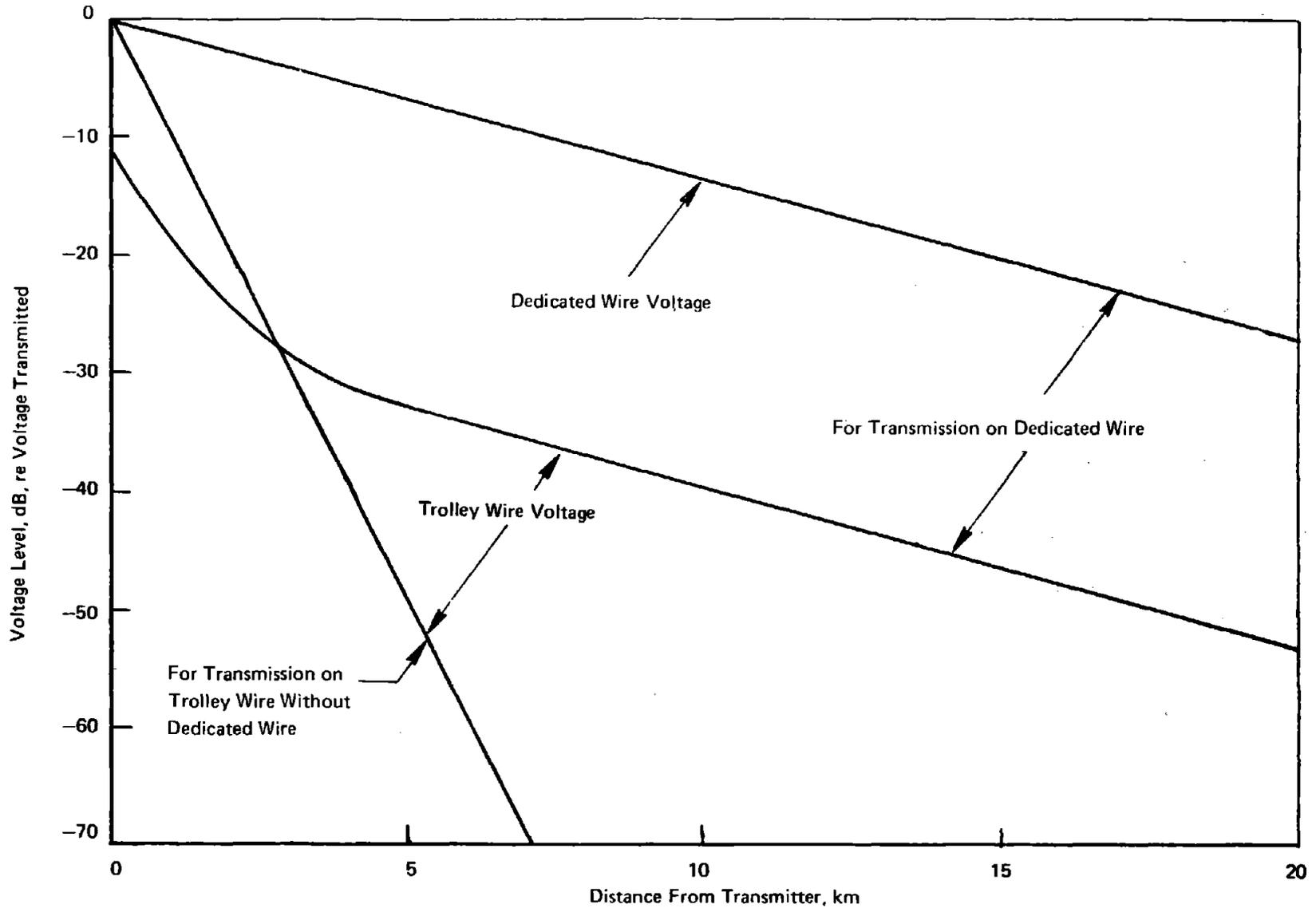


FIGURE 1 MODEL GEOMETRY – CROSS SECTION OF TUNNEL, OF DIMENSIONS $d_1 \times d_2$, SHOWING THE TROLLEY WIRE, DEDICATED WIRE, AND RAIL, OF RESPECTIVE RADII a, b, c , SEPARATED BY DISTANCES S_{ab}, S_{bc}, S_{ac} .

The theory showed that a low loss line comprised of a dedicated wire and a rail could significantly extend the communication range on the trolley wire/rail system.

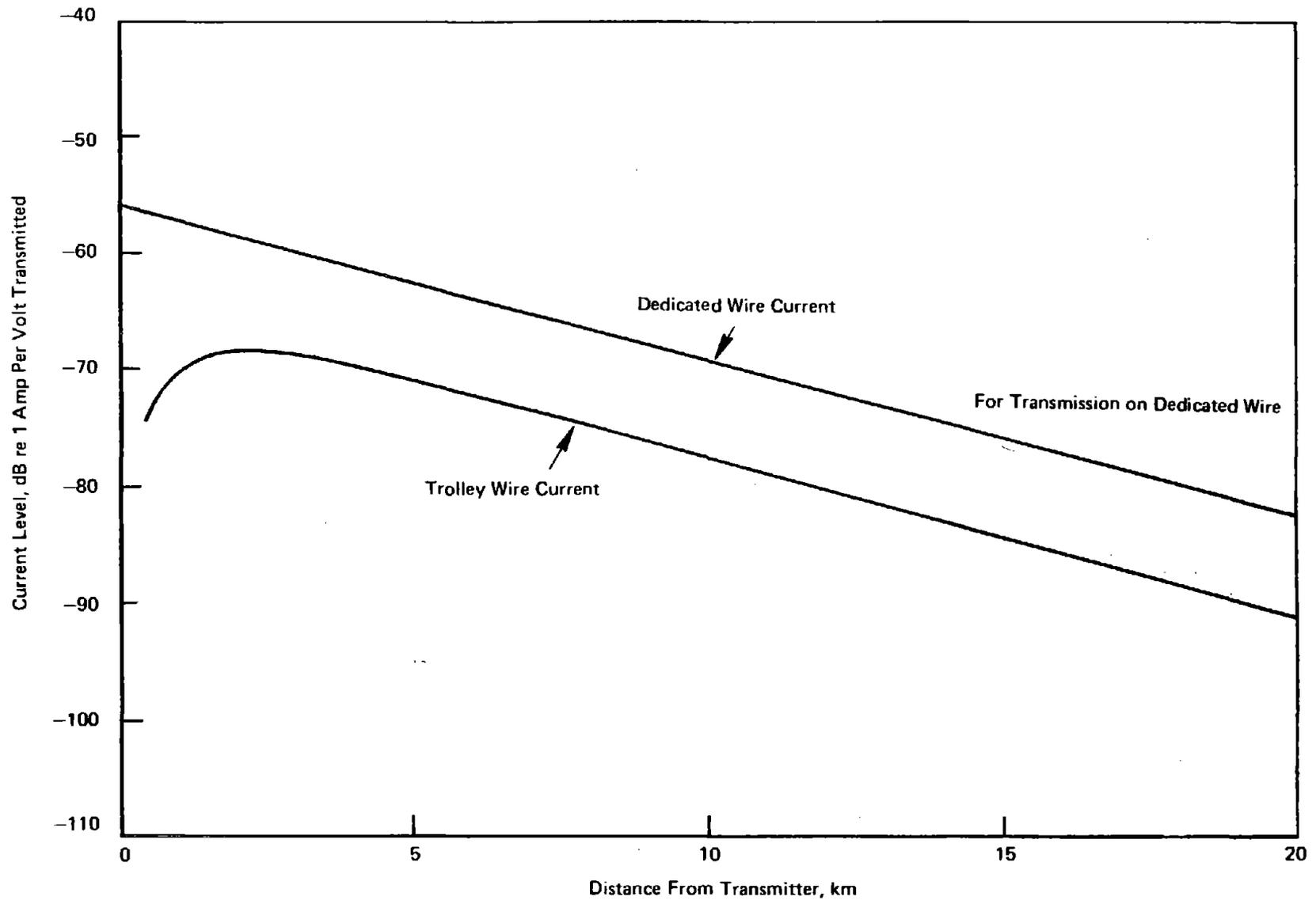
Under U.S. Bureau of Mines Contract No. J0377098,⁽³⁾ we applied the dedicated wire theoretical findings to a section of a large operating coal mine, Consolidation Coal Company's Montour No. 4 mine south of Pittsburgh, PA. Approximately 4 miles of dedicated wire were installed, together with one signal split at a branching point into an area having extremely poor communications. As a result, trolley carrier phone communication between the dispatcher and vehicles was improved, and even extended into an area of the mine which previously could not be reached. Signal attenuation on the dedicated wire was found to be less than 1 dB/km. The signal splits performed as expected, and only small standing waves were found on the dedicated wire. Coupling to the trolley wire/rail was more than adequate to assure good communication throughout all parts of the mine that included the dedicated wire.

These very positive results over a moderate run of haulageway led the Bureau of Mines to sponsor this present program to demonstrate the performance attainable with a comprehensive dedicated wire installation in a large coal mine.



Note: For Attenuation Rates of $\alpha_T = 10$ dB/km For The Trolley Wire/Rail Line in the Absence of the Dedicated Wire/Rail Line, and $\alpha_D = 1$ dB/km For The Dedicated Wire/Rail Line in The Absence of The Trolley Wire/Rail Line.

FIGURE 2 DEDICATED WIRE MODEL – THEORETICAL VOLTAGE LEVELS VERSUS DISTANCE



Note: For Attenuation Rates of $\alpha_T = 10$ dB/km For The Trolley Wire/Rail Line in the Absence of the Dedicated Wire/Rail Line, and $\alpha_D = 1$ dB/km For The Dedicated Wire/Rail Line in The Absence of The Trolley Wire/Rail Line

FIGURE 3 DEDICATED WIRE MODEL—THEORETICAL CURRENT LEVELS VERSUS DISTANCE

III. MINE SELECTION

The selection of a suitable mine for the demonstration program was accomplished in the following manner:

- A set of criteria were defined to identify and screen a list of candidate mines that was obtained from personal contacts in the mining industry.
- The high potential candidate mines were visited for on-site discussions and preliminary measurements of communication systems performance.
- A suitable mine was selected and arrangements made for conducting the performance improvement demonstrations.

A. SELECTION CRITERIA AND SEARCH PROCESS

The following selection criteria were formulated to identify and screen a number of potential candidate mines:

- Severe problems with both trolley carrier phone and pager phone communications systems,
- 300-V or 600-VDC trolley wire-powered electric rail haulage,
- Main line track haulage extending 5 to 10 miles with branching into several widely separated submains,
- Carrier phones of solid-state vintage as opposed to older tube types,
- Production between about 0.5 to 1.0 million ton/yr.,
- More than 10 sections (not closely grouped),
- High coal,
- Economically viable, long term, i.e., producing coal under contract, etc.,
- Relatively low hazard mine — re roof, gas, etc.,
- Preferred locations, vicinity of:
 - Pittsburgh, Morgantown, Wheeling;
 - Charleston, Beckley;
 - Birmingham;
 - St. Louis.

A number of telephone calls and follow-up discussions were then made to personal contacts in the following mining organizations: Eastern Associated Coal Corp., North American Coal Co., Consolidation Coal Co., AEP's Southern Ohio Coal Corp., Jim Walters Resources, Bethlehem Steel's Beth Elkhorn Corp., National Mine Service Co., the U.S. Bureau of Mines' Pittsburgh Research Center, and the Mining Safety and Health Administration (MSHA) District Office serving Pennsylvania and West Virginia.

The objectives and activities of the program were described to the mining company contacts. They were also informed that the mines would:

- Keep the improved communication system installations,
- Not have to pay for special equipment or services,
- Not have to provide demonstrations or tours to outside parties,
- Have their own electrical personnel do the actual installations or changes recommended,
- Not have to change or reduce their normal production activities,
- Be kept fully informed and consulted on all related plans and activities.

All organizations cooperated by identifying one or more possible candidates and helping us pursue the matter within their organizations. However, we found that the availability of mines with owners interested in our study was being adversely affected by the general softening of the coal market in the winter of 1979-1980. This was a result of the slowdown in steel production, the impact of environmental regulations, and the relatively mild winter. In spite of this, we obtained more than 12 candidate mines. Information received about these mines was assembled and organized in a preliminary tabular format for comparing the characteristics of each mine and selecting the "high potential" candidate mines.

B. THE FIRST THREE PRIME CANDIDATES

Three potentially favorable mine candidates were selected, and letters describing the demonstration program were dispatched to mine management prior to visiting each of the mines. The selected mines were:

- North American Coal Corporation's Powhatan No. 1 mine at Powhatan Point, Ohio, south of Wheeling, West Virginia. This is a large mine with 10 miles of high-traffic 300-VDC main line track haulage with three widely separated one-mile branches on which coal, men, and supplies are moved.

- Eastern Associated Coal Corporation's Harris No. 1 mine in Bald Knob, West Virginia, south of Charleston. This is a moderate-sized drift entry mine with about 4 miles of 300-VDC main line track haulage, two major submains, and several shorter branches over which coal, men, and supplies are moved.
- Bethlehem Steel's Beth Elkhorn Corporation No. 26 mine in Jenkins, Kentucky, near the Virginia border. This is an expanding drift entry mine with about 4 miles of 300-VDC main line track haulage, four major submains, and about a mile of main line surface track. Coal, men and supplies are moved over the main line, while the submains use belt haulage for the coal and track haulage for men and supplies.

Experienced Arthur D. Little, Inc., technical staff members visited each of these mines to personally assess the nature and seriousness of the mine communication problems, and to discuss with mine management the details of the program and the suitability of the mine for participation in it.

The assessments of communication system performance were made using simple quantitative measurements and by inspecting each mine's underground communication network. They included:

- Periodic measurements of trolley wire carrier phone voltage along the rail haulage line taken from a jeep equipped with a tuned radio frequency (RF) voltmeter;
- Spotchecks of pager phone performance; and
- Visual inspections and checks of randomly chosen and/or suspected pager and carrier phone units.

None of these three mines participated in the final communication demonstration program. The visits to Powhatan No. 1 and Harris No. 1 proved these mines to be inappropriate candidates for the program. The visit to Beth Elkhorn No. 26, on the other hand, verified that this mine was an excellent candidate. However, snags developed in the process of negotiating a written working agreement with the parent corporation's (Bethlehem Steel) legal staff. This resulted in unacceptable delays in the program schedule. As a result, we were directed by the Bureau of Mines to find a new candidate mine. Information concerning the visits to these mines and the reasons for their non-participation are summarized in Appendix A.

C. THE FINAL SELECTION — THE ROBINSON RUN NO. 95 MINE

A favorable replacement candidate for the Beth Elkhorn No. 26 mine was obtained with the aid of J. Burr, Chief Electrical Engineer, Lee Engineering Division, Consolidation Coal Company. He arranged for the Arthur D. Little team to visit the Consolidation Coal Robinson Run No. 95 mine which had expressed

interest in this program, because of the mine's severe and persistent trolley wire carrier phone problems experienced annually during the spring and early summer.

The Robinson Run No. 95 mine in Shinnston, West Virginia, south of Fairmont, West Virginia, was visited by R. Lagace, R. Spencer, and M. Cohen of Arthur D. Little, Inc., in January 1981. They met with T. Poundstone, Mine Maintenance Superintendent; R. Mullins, mine communications man, and D. Podobinski of Lee Engineering. The Robinson Run mine is a large, high-production, longwall-type, drift entry, coal mine with about 11 miles of 300-VDC main line track haulage for moving coal, men, and supplies. Most of the rail traffic runs along two sets of mains, one running East-West and the other North-South. Both sets have several branches and double runs of track in adjacent entries to handle the heavy flow of ingoing and outgoing traffic. The mine management considers reliable communication systems vital to its coal mining operations.

Our fruitful discussions with T. Poundstone, together with our limited inspection of the mine's communication facilities revealed that:

- The mine's carrier phone system was experiencing signal strength variations that caused communication problems in different parts of the mine. During most of the year, these problems could usually be solved within a reasonable time by the mine communications personnel. However, weak signal and high noise problems become extremely severe and persistent in the spring and early summer of each year, causing significant disruptions and hardships to the mine's coal haulage operations.
- The mine management had already installed an auxiliary dedicated wire along most of the mine's rail haulage network, but its performance improvement capabilities had not been achieved. Its capabilities had not been achieved because the signal transmission characteristics of the dedicated wire transmission line were unpredictable and unstable. This condition was caused by the absence of matched line terminations and matched power splitters, and the presence of numerous trolley wire-to-dedicated wire signal couplers. Therefore, substantial improvement in performance could be expected by optimizing the existing dedicated wire installation.
- The mine's pager phone system consisted of a sectionalized system of recent vintage, which used 12-pair telephone cable. The system was operating very favorably and being maintained satisfactorily.
- The mine's maintenance superintendent was highly interested in solving the carrier phone communication problems by means of this demonstration program. Furthermore, he had the support of his management to proceed and no written agreement was required.

As a result of the extensive mine selection efforts to date, the suitability of this mine's carrier phone problems, the absence of pager phone problems, and the mine's willingness to cooperate, we decided, with Bureau of Mines' concurrence, to delete the pager phone part of the program, and to proceed with the carrier phone performance improvement demonstration at the Consolidation Coal Company's Robinson Run No. 95 mine. The following sections of this report describe the activities and results of this demonstration program.

IV. PERFORMANCE MEASUREMENTS AND CORRECTIVE DEDICATED WIRE IMPROVEMENTS

A. ROBINSON RUN MINE — RAIL HAULAGE NETWORK AND TROLLEY CARRIER PHONE SYSTEM

A simplified scale map of the dedicated signal wire layout along the extensive 300-VDC electric rail haulage network at the Consolidation Coal Co., No. 95 Robinson Run Mine, is shown in Figure 4. This is a drift entry coal mine located in Shinnston, West Virginia, south of Fairmont. The mine was equipped with a suboptimum dedicated signal wire that covered 11 miles of main line rail haulage. This signal wire extended from the outside dispatcher's station and rotary dump area to all underground dump loading points and to the Oakdale shaft portal.

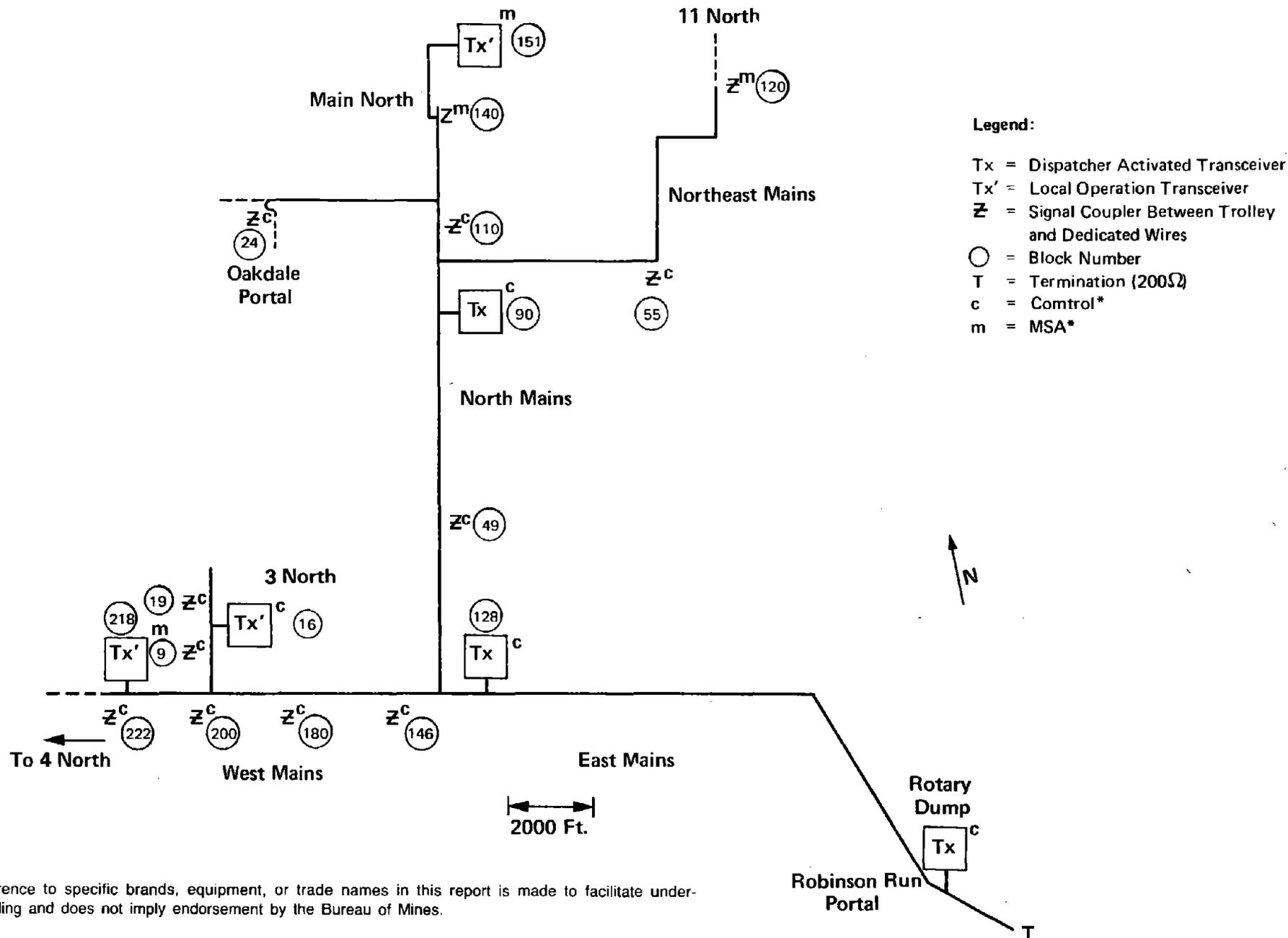
Figure 4 also shows that the mine's trolley carrier phone system has three dispatcher-activated Control* 88-kHz transceivers (designated Tx in Figure 4). Each one is directly connected to the dedicated wire through a Control* signal transformer.† They are located: (1) at the rotary dump, just outside the mine portal; (2) at the 128 block, near the junction of the East-West Mains with the North Mains, and at the 90 block north, near the junction of North Mains with Northeast Mains. These transceivers are activated by the dispatcher through audio and control lines that run to these units from the dispatcher's tower in the yard outside the Robinson Run portal. Four other fixed station transceivers (designated Tx' in Figure 4) are located at the four loading dumps in the mine. These units are either Control* or Mine Safety Appliance (MSA)* carrier phones used to coordinate coal-loading operations, and cannot be activated by the dispatcher.

In addition, the map shows that the dedicated wire signal is split at four places, and there are six ends to the dedicated wire, each requiring a termination. Finally, 12 independent signal couplers† (Z-boxes) (designated Z in Figure 4) were also being used to make transformer connections between the dedicated wire and the trolley wire for the purpose of improving the signal levels on the trolley wire/rail line.

Not shown in Figure 4 are details of the main line track routing, the loading loops at each of the four in-mine dumps, and the runs of supply track into the working sections. Figures 5 through 8 illustrate the detailed track configurations in four important areas. Figure 5 shows the area in the vicinity of the junction of the North and East-West Mains including the location of the principal dispatcher-activated transceiver at 128-block. Figure 6 shows the Main North dump loop and the supply tracks running into several Main North longwall sections. Figure 7

*Reference to specific brands, equipment, or trade names in this report is made to facilitate understanding and does not imply endorsement by the Bureau of Mines.

†In this report, we call the Control* signal coupler a *transformer* when it is used to connect a transceiver to the dedicated wire, and call it a *signal coupler* when it is used to interconnect the trolley wire and dedicated wire.



*Reference to specific brands, equipment, or trade names in this report is made to facilitate understanding and does not imply endorsement by the Bureau of Mines.

FIGURE 4 SIMPLIFIED SCALE MAP OF ORIGINAL DEDICATED WIRE INSTALLATION ALONG ROBINSON RUN MINE RAIL HAULAGE NETWORK

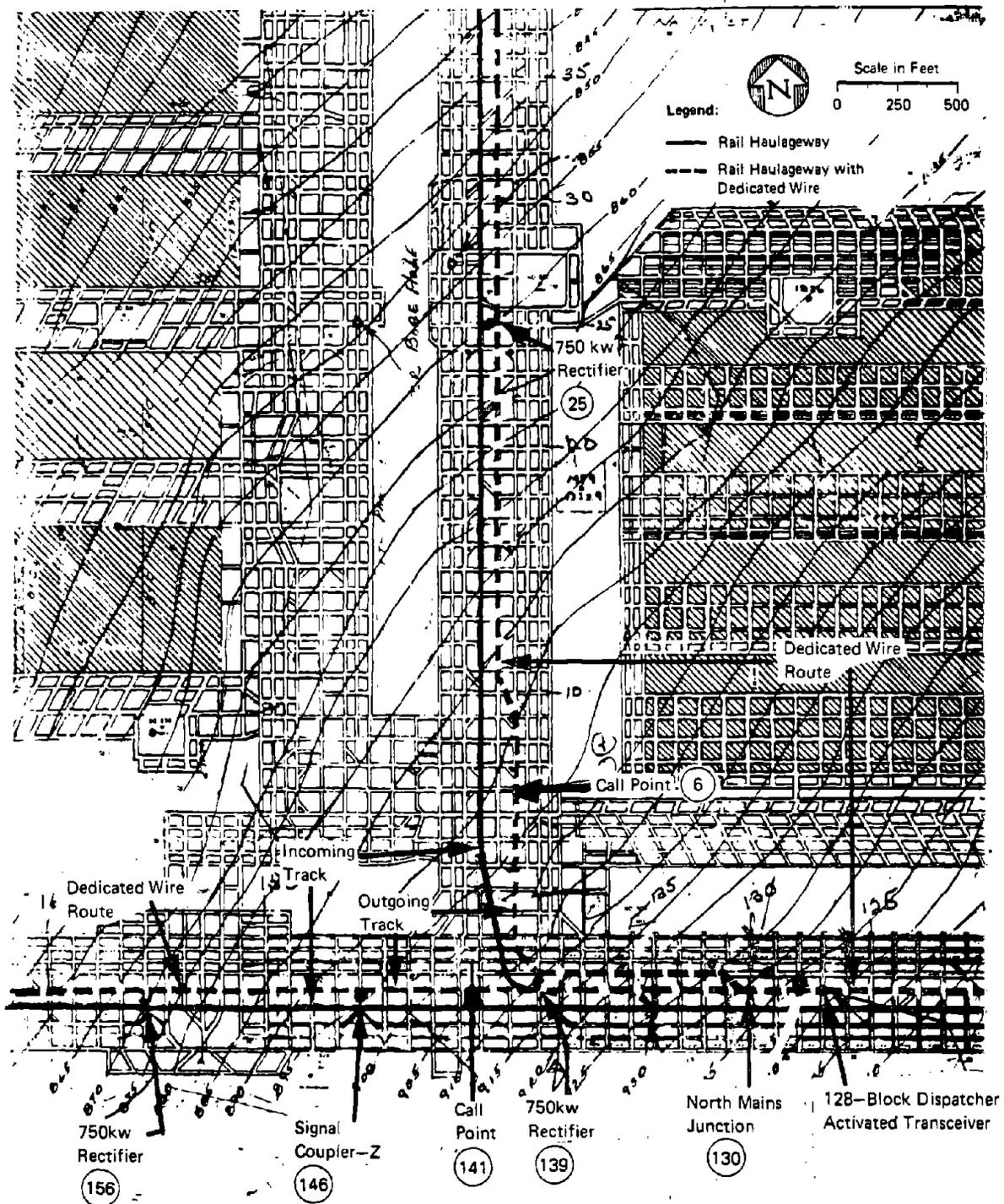


FIGURE 5 DETAIL OF MINE MAP IN VICINITY OF JUNCTION OF EAST-WEST AND NORTH MAINS

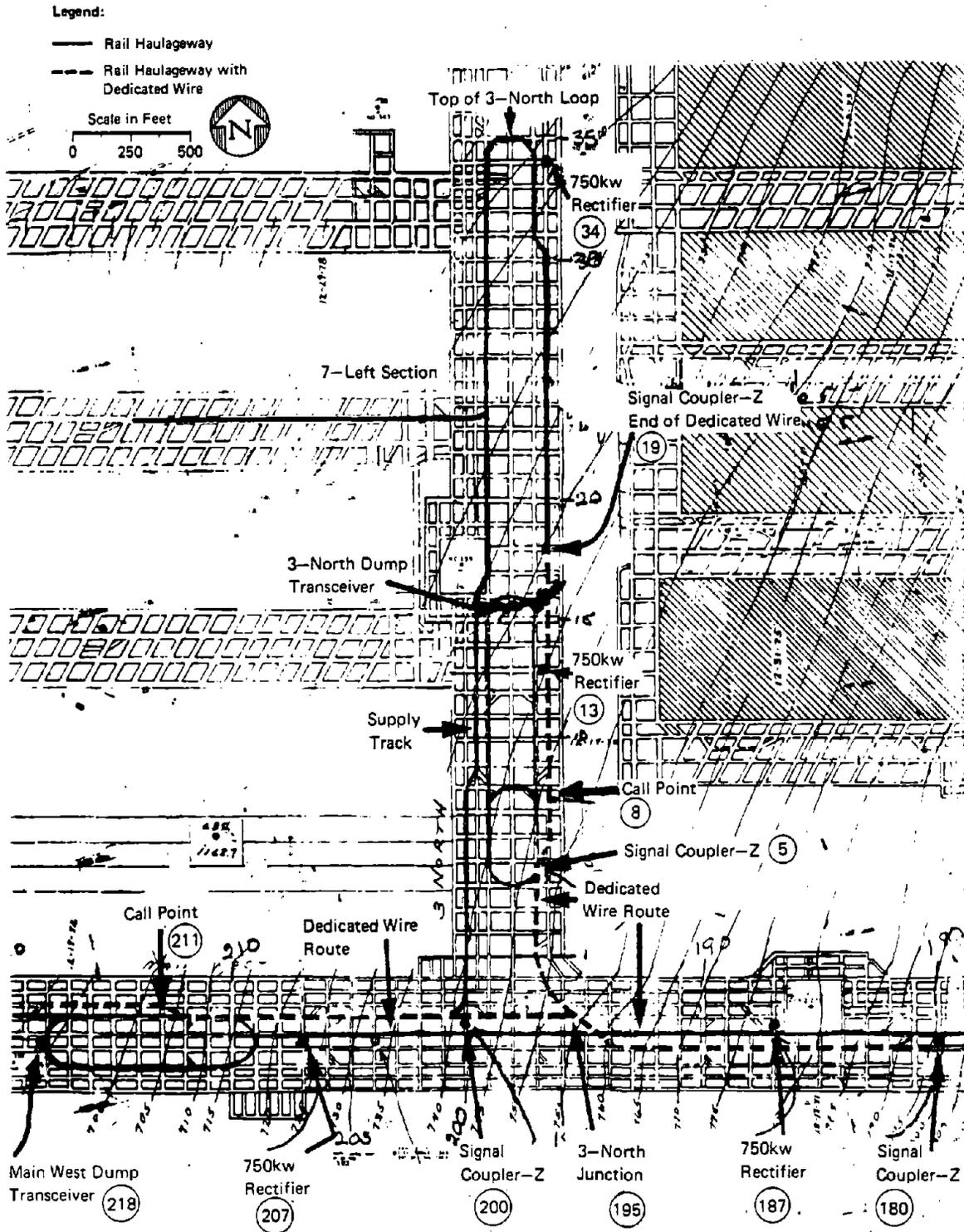


FIGURE 6 DETAIL OF MINE MAP SHOWING 3-NORTH DUMP AREA AND JUNCTION WITH EAST-WEST MAINS

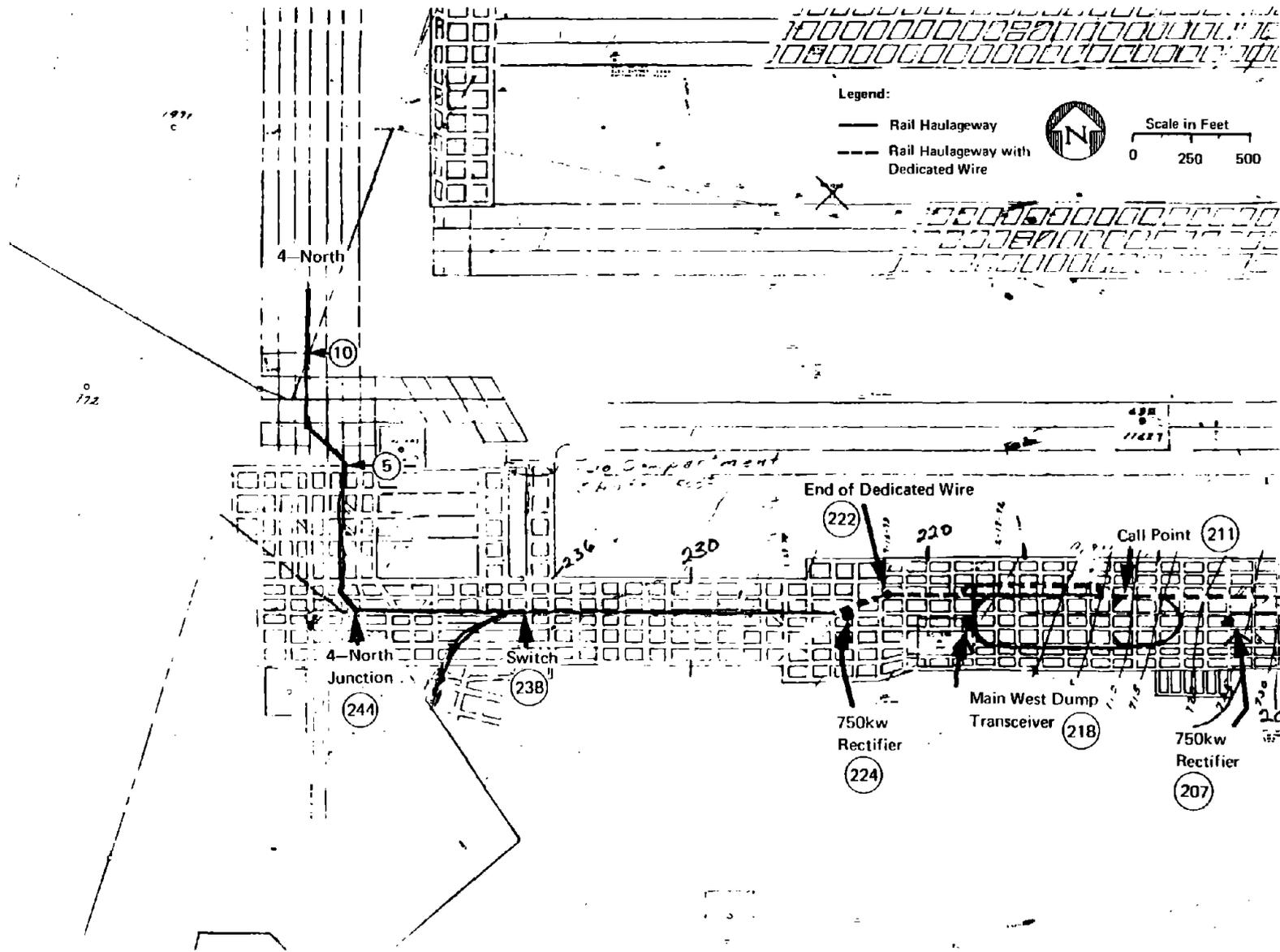


FIGURE 7 DETAIL OF MINE MAP SHOWING 4-NORTH SECTION AND MAIN WEST DUMP AREA

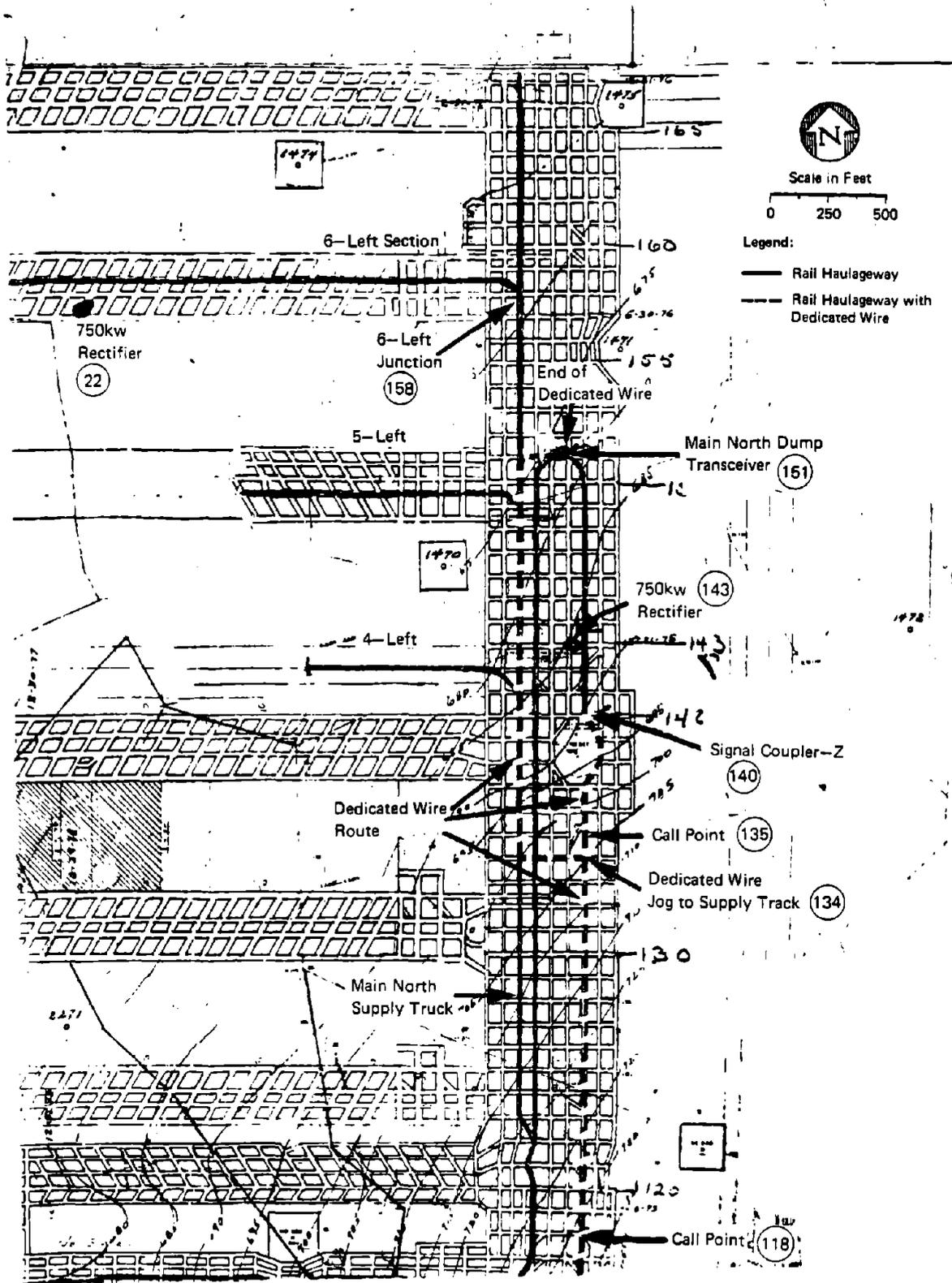
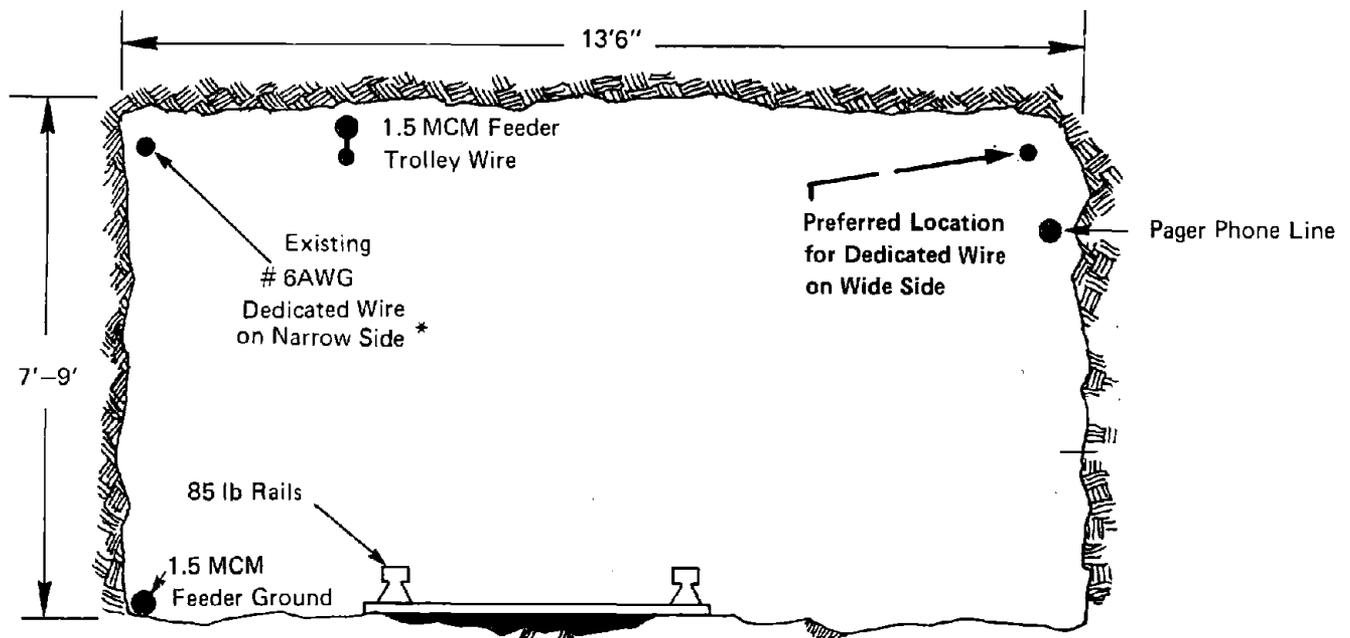


FIGURE 8 DETAIL OF MINE MAP SHOWING MAIN NORTH DUMP AREA AND ACTIVE SECTIONS

depicts the 3-North dump area and sections north of the East-West Mains. Figure 8 depicts the Main West dump area and the 4-North development area at the west end of the East-West Mains. Figures 5 and 7 show the main line double-track configuration. The two tracks, one track in each adjacent parallel coal tunnel (entry), are needed to handle the heavy ingoing and outgoing coal haulage traffic.

Figure 9 shows a cross-section of a typical outgoing haulage tunnel in which the dedicated wire is installed. The main line track consists mostly of 85-lb rails, and the supply track, mainly of 60-lb rails. The trolley wire and its associated 1.5-MCM feeder cable are supported from the roof by insulated hangers, and the rails are intermittently bonded to a 1.5-MCM feeder ground cable. Both trolley wire and ground cable are located on the same (narrow) side of the tunnel. These 1.5-MCM trolley wire feeder and ground cables are also intermittently cross-bonded through crosscut tunnels to their counterparts in the parallel tunnel for incoming traffic.



*Preferred location is near wall on opposite (wide) side of tunnel, for better performance, electrical safety and economy.

FIGURE 9 APPROXIMATE CROSS-SECTION OF MAIN HAULAGEWAY LAYOUT (ALL DIMENSIONS NOMINAL, SIGNIFICANT VARIATIONS IN DIMENSIONS AND DISPOSITION OF CONDUCTORS, INCLUDING POWER CABLES AND WATER PIPES NOT SHOWN, OCCUR WITH DISTANCE)

We found the dedicated wire installed on the rib located on the trolley wire (narrow) side of the tunnel in most of this mine. This accounts for the mine's use of the large No. 6 AWG wire size along most of the haulage network to prevent wire breakage when trolley poles become disengaged from the trolley wire and flap against the coal. Wide side installations of No. 12 wire were found primarily along sections of the Northeast Mains in this mine.

Notwithstanding the dedicated wire installations found at this mine, we do not recommend narrow side installations. Wide side installation of the dedicated wire is greatly preferred because it results in better performance and greater electrical safety, and it allows the use of more economical smaller gauge wire such as No. 12 AWG. Therefore, we recommend that all dedicated wires be installed, like the pager phone lines, on the wide side of track haulageway tunnels, as described in the U.S. Code of Federal Regulations, Title 30, Chapter 1, Part 75, paragraph 75.516-2.

The trolley-wire-to-dedicated-wire lateral separation in this mine varied from about 5 feet to 1 foot, with 2 to 3 feet being typical. Although the spacing is not critical, separations of less than about 1 foot should not be allowed for appreciable lengths to avoid tightly coupling the trolley wire's loads and high-line attenuation to the low-loss dedicated wire line.

The most important and severe shunt loads in this mine are the 25 power rectifiers, typically 750-kW units, connected across the trolley wire/rail line at intervals of about 2000 to 3000 feet. This mine has taken precautions to reduce the carrier frequency loading effects of these rectifiers somewhat by tuning the rectifier leads with capacitors.⁽²⁾ Less serious but important loads are those represented by the heavy locomotives, and by carrier phones with low standby input impedances in the receive mode on a number of haulage vehicles.

B. THE "BEFORE" PERFORMANCE MEASUREMENTS

1. Measurement Procedures

In preparation for the mine-wide diagnostic tests, we defined the measurements to be made and secured the necessary equipment. The key measurements were the trolley wire/rail voltage and dedicated wire current at about 90 selected locations throughout the mine. Test staffing, procedures, and visit dates were arranged with the mine, and preliminary performance information and measurement data were obtained from mine personnel. In addition, we prepared an annotated reduced scale (1000 ft/in.) mine map, and a booklet of 8-1/2 x 11-in. sections of the larger scale (500 ft/in.) mine map in the manner of a "AAA tourguide map" to expedite the measurements and to minimize confusion and disorientation. Samples of these 8-1/2 x 11-in. pages are shown as Figures 5 through 8.

The mine-wide "before" diagnostic measurements were performed during an 11-hour period on Saturday, February 14, 1981, during two maintenance shifts. Weekend shifts were chosen to ensure a significantly more controlled and efficient

data acquisition process than would have been possible during normal production shifts at the mine. This mine has extremely heavy coal haulage traffic during all three of its daily production shifts during the week.

After an early morning consultation with Mine Maintenance Superintendent T. Poundstone, the measurements were taken from a maintenance jeep by R. Spencer and R. Lagace of Arthur D. Little, Inc., and R. Mullins, the mine's communication man. Figure 10 is a plan view of the jeep haulage vehicle, showing the locations of personnel and equipment during the mine-wide "before" signal measurements. A similar configuration was used during the "after" measurements, but with B. Roberts substituted for R. Mullins.

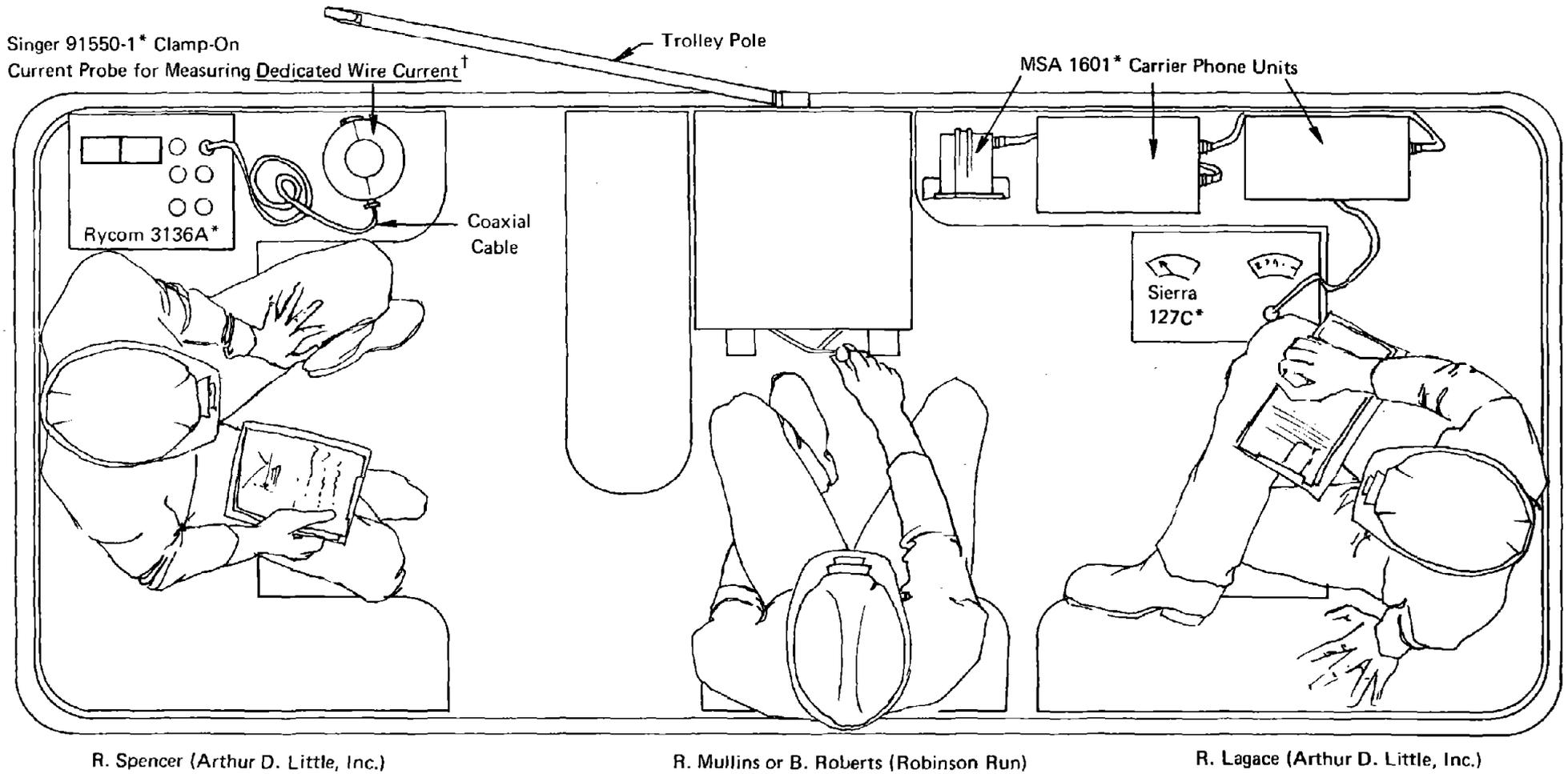
As depicted, the trolley wire/rail voltage was measured with a Sierra 127C* frequency selective RF voltmeter. One lead was connected directly to case ground and the second lead was connected, via a 0.1- μ f, 600 volt capacitor to the trolley pole voltage terminal inside the MSA 1601* carrier phone on the jeep. The dedicated wire current was measured using a clamp-on current probe, Singer Model 91550-1* which was particularly well-suited for this frequency range. This probe was connected, via coaxial cable, to a Rycom 3136A* frequency selective voltmeter for measuring the voltage pickup from the current probe. At each measurement location, the jeep was stopped, and R. Mullins or B. Roberts placed the current probe around the dedicated wire. The dispatcher was then signalled to activate the 128 block transceiver for about 10 seconds, while R. Spencer recorded the current probe voltage and R. Lagace recorded the trolley wire voltage. All major branches and some minor ones were traversed and measured to characterize the mine's signal profiles of trolley wire/rail voltage and dedicated wire current, for diagnosing problems and comparing "before" and "after" performance.

2. Initial Observations

Our measurements throughout the mine's extensive rail haulage network, together with our preliminary on-site examination of the data during the Saturday maintenance shifts revealed the following items of note:

- Trolley carrier phone communications were judged to be of satisfactory audio quality over most of the mine. The main problem areas were in the West Mains area of the mine; namely, at the far reaches of the 3-North dump supply track loop, and beyond the Main West dump along the West Mains, near the end of the dedicated wire. In other areas scattered along the network, some voltage levels fell into a "marginal" range that could lead to unsatisfactory communications performance under operational work shift conditions having higher levels of electrical noise or perhaps weaker signals caused by increased haulageway vehicle traffic loading.
- The principal causes of the poor performance in the West Mains area were most likely related to the severed connection to the original

*Reference to specific brands, equipment, or trade names in this report is made to facilitate understanding and does not imply endorsement by the Bureau of Mines.



[†]CAUTION: Do NOT Use to Measure Trolley Wire Current – Hazardous Voltages Present on Trolley Wire

*Reference to specific brands, equipment, or trade names in this report is made to facilitate understanding and does not imply endorsement by the Bureau of Mines.

FIGURE 10 PLAN VIEW OF JEEP HAULAGE VEHICLE SHOWING APPROXIMATE DISPOSITION OF EQUIPMENT AND PERSONNEL DURING DEDICATED WIRE MEASUREMENTS

coupler terminating the end of the dedicated wire, and the apparently large current drains from the dedicated wire caused by two other signal couplers interconnecting the trolley wire and dedicated wire along the West Mains.

- Communication coverage was good into the 4-left, 5-left, and 6-left Main North sections, beyond the dedicated wire in the Main North dump supply track.
- Significant standing waves in the dedicated wire current were found along the East and North Mains.
- Two defective connections to the dedicated wire were found in the Main North area. The first one was a defective splice where the dedicated wire jogs west from the North Mains run to cover the Main North supply track. Although this defective splice caused a significant decrease in dedicated wire current along this supply track run, the trolley wire voltage remained at serviceable levels. The second one was a severed ground connection to the coupler at the end of the short North Mains spur run of dedicated wire beyond the above mentioned splice. This caused intermittent and noisy communications at the end of this spur.
- To simplify dedicated wire continuity checking, the North Mains dedicated wire has been DC-decoupled from the East-West Mains' dedicated wire by means of a series capacitor at the 130 block junction.

3. Detailed Data Analysis

The detailed signal data that we obtained during the "before" measurements in February were tabulated on a large master chart and plotted on oversized graph paper. This allowed convenient coordination of trolley wire/rail voltage and dedicated wire current readings with distances from the 128 block transceiver and with mine map locations of power rectifiers, signal couplers, track junctions, vehicle call points, transceivers and terminations. These plots and analyses revealed the following additional information.

First, the current in the dedicated wire over most of its length showed substantial standing waves. This, in itself, was not surprising since the dedicated wire was not properly terminated at most end points, nor were matched signal splits installed at junctions in the dedicated wire network. Some of these standing waves indicated that important offenders were the dispatcher-activated Comtrol* transceivers connected to the dedicated wire at the outside rotary dump and at the North Mains 90 block location. These transceivers were presenting an unexpected low-impedance shunt load at each of these locations.

*Reference to specific brands, equipment, or trade names in this report is made to facilitate understanding and does not imply endorsement by the Bureau of Mines.

This problem was eventually solved through the cooperation of R. Mullins of Robinson Run mine, T. Agnew of Comtrol,* and R. Spencer of Arthur D. Little, Inc. Simple measurements were made by R. Mullins and R. Spencer at the outside rotary dump transceiver — and on a similar unit in the mine's repair shop — which confirmed that the transceiver input impedance in the receive (standby) mode was about 25 ohms instead of 200 ohms. Additional factory tests by T. Agnew verified this finding. To assist the successful and timely completion of this demonstration program, Comtrol* delivered to the mine four modified transceiver boards having input impedances around 400 ohms in the receive mode. These boards were retrofitted into the four Comtrol* fixed-station transceivers (designated Tx in Figure 4) prior to the "after" performance measurements.

The plots of dedicated wire current also confirmed the presence of a huge drop in dedicated wire current beyond the signal coupler installed at 141 block along the West Mains. This coupler was behaving as a short circuit shunt load between the dedicated wire and trolley wire, thereby preventing any substantial current from flowing in the dedicated wire beyond this coupler. This information was quickly relayed to R. Mullins at the mine, who significantly improved the West Mains communications performance by disconnecting this coupler from the system.

Finally, the data strongly suggested that, after all the corrections and additions were implemented to provide a true dedicated wire installation, additional dedicated wire would probably not have to be installed to extend communications coverage to most areas of interest beyond the present dedicated wire network.

Further discussion of the dedicated wire current and trolley wire voltage behavior has been deferred to Section V of this report, where the "before" and "after" performance comparisons are treated.

C. THE IMPROVED DEDICATED WIRE CONFIGURATION

1. The Required Changes

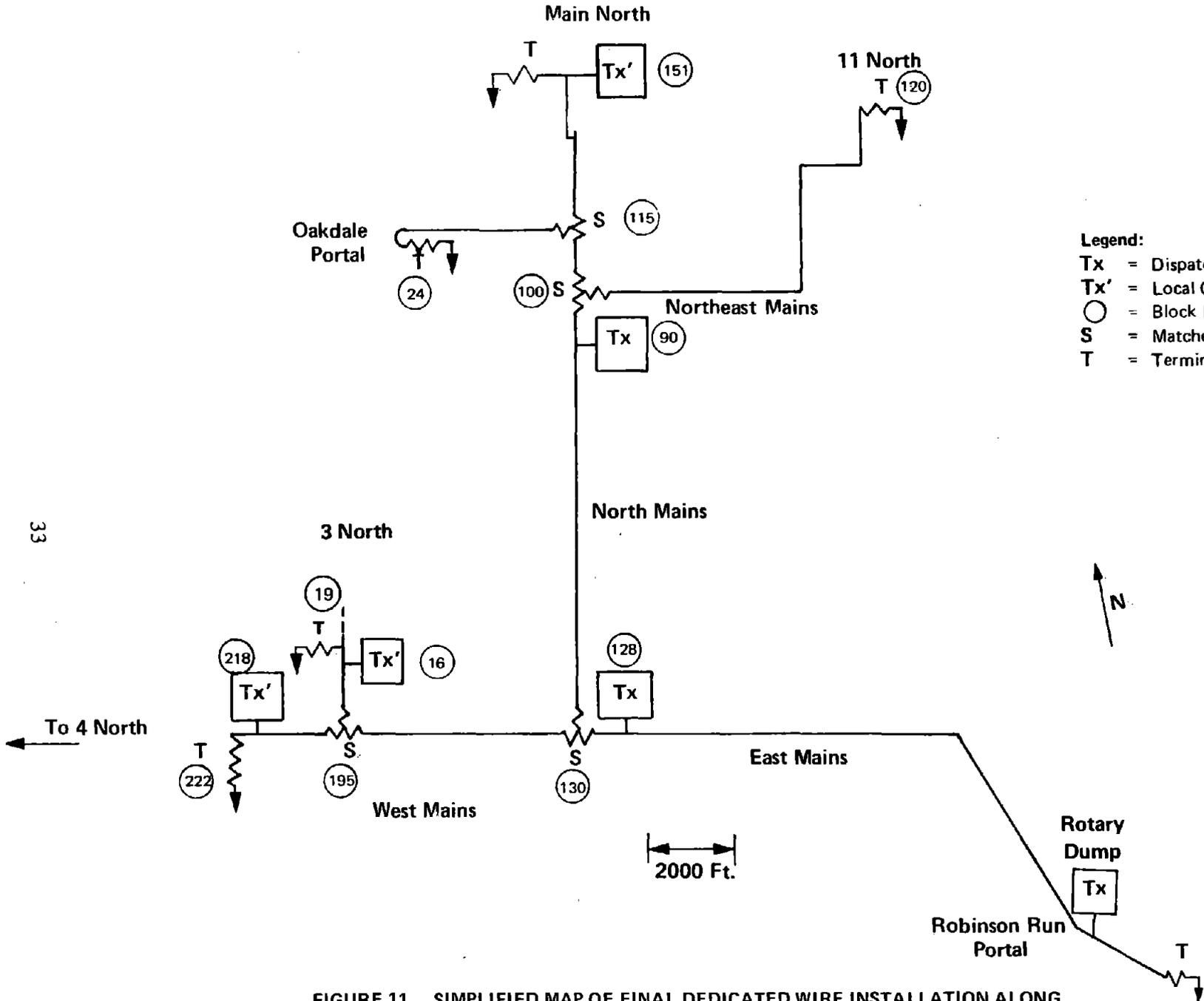
The dedicated wire approach to improving trolley carrier phone systems is based on the principle that a parallel dedicated wire/rail line could be installed which would behave as a true radio frequency (RF) transmission line. This line could then be used to distribute strong signals originating at the dispatcher's transceiver to all parts of the mine with a high degree of integrity. The concept makes use of the natural electromagnetic coupling between the dedicated wire/rail line and the trolley wire/rail line to deliver the required signals to vehicles traveling anywhere on the trolley wire/rail haulage network, and vice versa.

To convert the originally installed signal wire at the Robinson Run mine to a true dedicated wire installation, the following actions were required:

*Reference to specific brands, equipment, or trade names in this report is made to facilitate understanding and does not imply endorsement by the Bureau of Mines.

- All ends of the dedicated wire had to be terminated to the rail through a resistive matched load, resulting in a termination of the dedicated wire/rail transmission line that minimizes standing waves on the dedicated wire line.
- All points or junctions of the dedicated wire had to be equipped with matched resistive signal splitters. These splitters enable the carrier signal to be properly divided at these junction points while minimizing the occurrence of standing waves on the dedicated wire.
- All signal couplers used to physically interconnect the dedicated wire and the trolley wire rail lines had to be disconnected. All such couplers expose the dedicated wire signals to mismatches and associated standing waves, together with opportunities for direct shunting of currents from the dedicated wire onto the high-loss trolley wire, which lead to weaker trolley wire voltage signals at distances well beyond the couplers.
- Transceivers connected to the dedicated wire/rail transmission line had to be coupled to the line in a manner which would deliver the maximum power available from the transceiver to the dedicated wire. On the basis of many measurements and experiments in mines, we have found that the characteristic impedance of dedicated wire/rail lines can be represented by a value of about 200 ohms. Therefore, when a transceiver is connected to a matched dedicated wire running past it, the transceiver output has to be matched to a net parallel load impedance of about 100 ohms.
- Any transceiver connected to the dedicated wire/rail transmission line also has to present a high shunt impedance to the line in the transceiver standby or receive mode to prevent standing waves and current shunting. Carrier phone transceivers with a standby input impedance of 25 ohms will not present a high enough impedance to the line, even with the aid of standard transformers used for this purpose. Transceiver input impedances of about 200 ohms or more are needed.

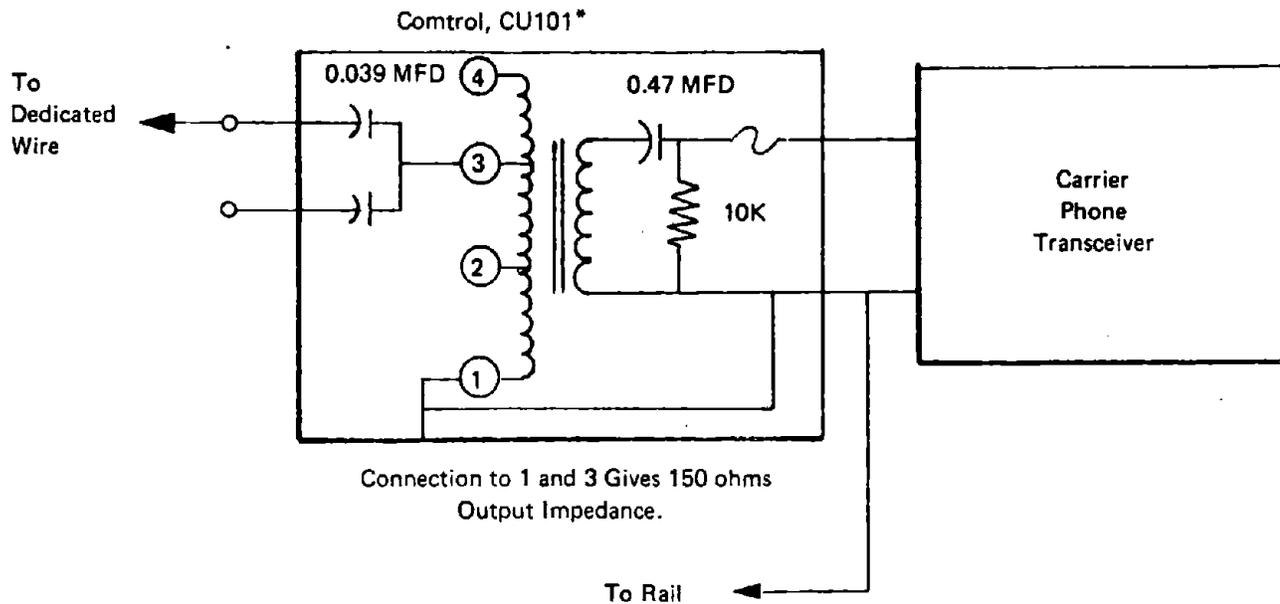
Figure 11 illustrates a true dedicated wire installation for the Robinson Run mine, which can be compared with the original signal wire installation shown in Figure 4. As can be seen, the final installation of Figure 11 has six resistive terminations. Five new terminations had to be installed inside the mine; the outside termination beyond the rotary dump was already in place. Figure 12c is a schematic of the resistive termination, and Figure 13 illustrates how it was installed. A series capacitor has been included to provide DC isolation for the installation. Figure 11 shows the four junctions in the dedicated wire where the signal splits in twodirections. At each of these places, the two-way signal splitters shown schematically in Figure 13b, were installed as shown in Figure 14.



- Legend:**
- Tx = Dispatcher Activated Transceiver
 - Tx' = Local Operation Transceiver
 - = Block Number
 - S = Matched Signal Split
 - T = Termination (200Ω)

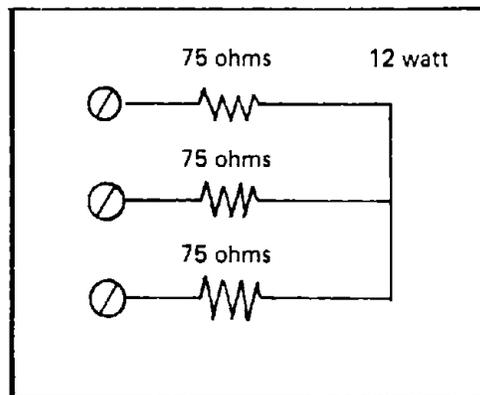
FIGURE 11 SIMPLIFIED MAP OF FINAL DEDICATED WIRE INSTALLATION ALONG ROBINSON RUN MINE RAIL HAULAGE NETWORK

33

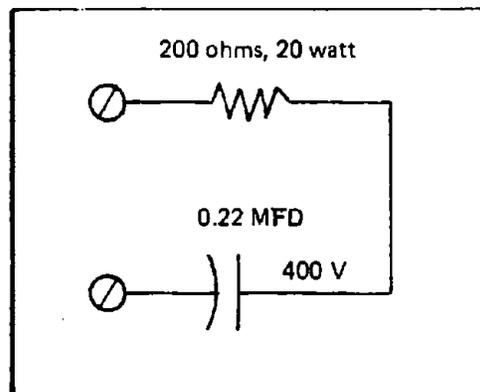


a) Signal Transformer for Connecting Transceiver to Dedicated Wire/Rail Line

*Reference to specific brands, equipment, or trade names in this report is made to facilitate understanding and does not imply endorsement by the Bureau of Mines.



b) Two-way Signal Split



c) Line Termination

FIGURE 12 SCHEMATICS OF TRANSFORMER, SPLIT, AND TERMINATION

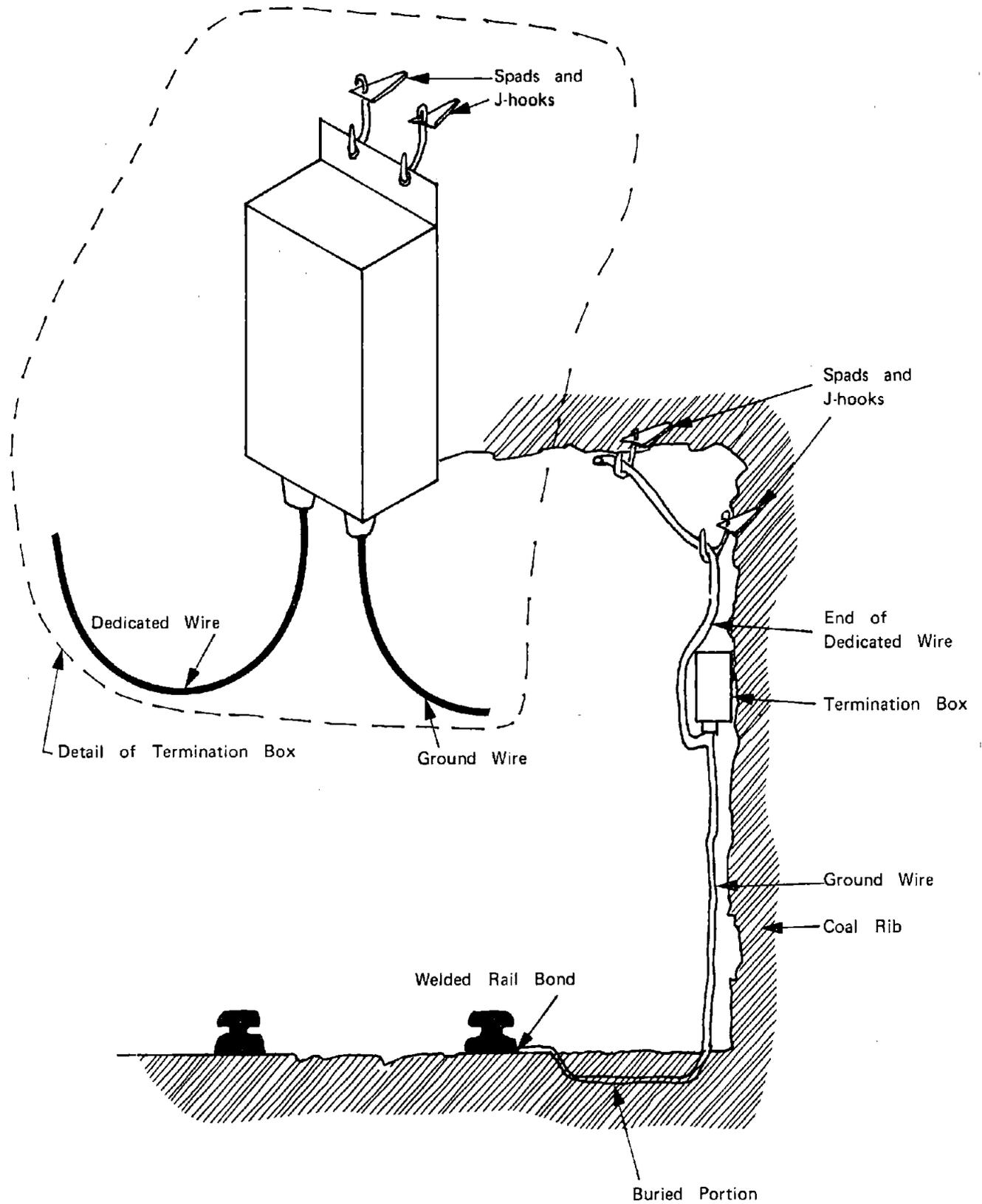


FIGURE 13 INSTALLATION DIAGRAM FOR RESISTIVE TERMINATIONS

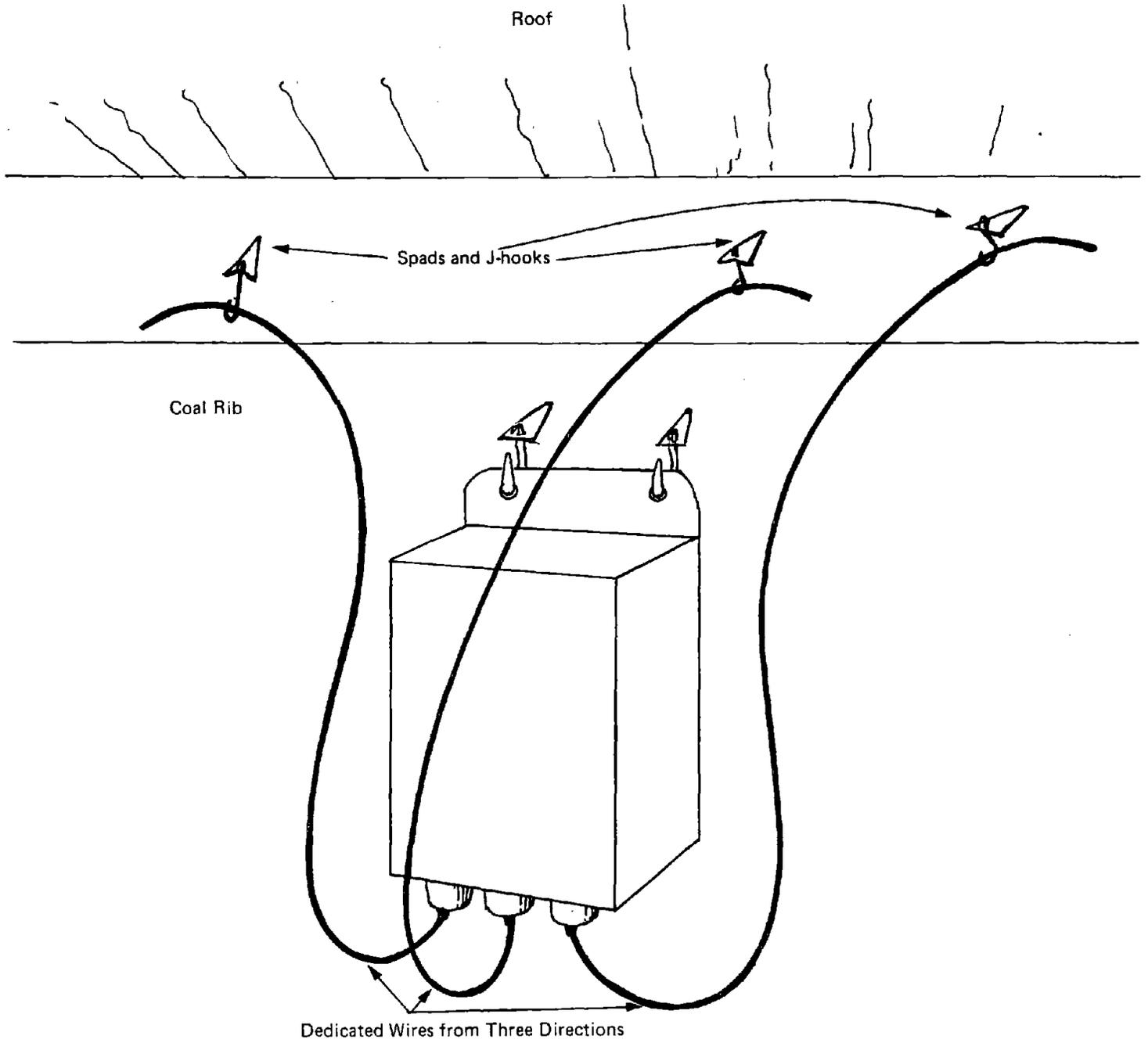


FIGURE 14 INSTALLATION DIAGRAM FOR TWO-WAY POWER SPLIT

Our desire was to keep the in-mine equipment as simple as possible; therefore, we chose only one kind of signal splitter, one which would split the dedicated wire current to each branch in half. The alternative of using a family of "optimum" signal splits that exactly equalized the current to all the branch points farthest from the main transceiver was discarded in favor of the simplicity and ease of maintenance for the common two-way splitter shown in Figure 12b.

Twelve-watt resistors were used in all terminations and signal splits. In view of the 25-watt maximum power output from the carrier phones, this 12-watt rating represents a high margin of safety. The terminations and signal splits were housed in standard Hoffman boxes with rubber gland seals for each entry point, as shown in Figure 15. In addition, the 12 signal couplers shown in Figure 4 had to be disconnected from the dedicated wire. This included the one at block 140 at the end of the short dedicated wire spur in Main North, which we left unterminated because of its short length.

All six fixed station transceivers connected to the dedicated wire were then reconnected to the wire through Comtrol CU101* transformer, as shown in Figure 12a. These couplers were used to raise the nominal transceiver output impedance in the transmit mode from 25 to 150 ohms, the value closest to the 100-ohm load impedance. In addition, the modified boards supplied by Comtrol* were installed in the four Comtrol* units to provide the higher required input impedance to the transceivers when in the receive (standby) mode.

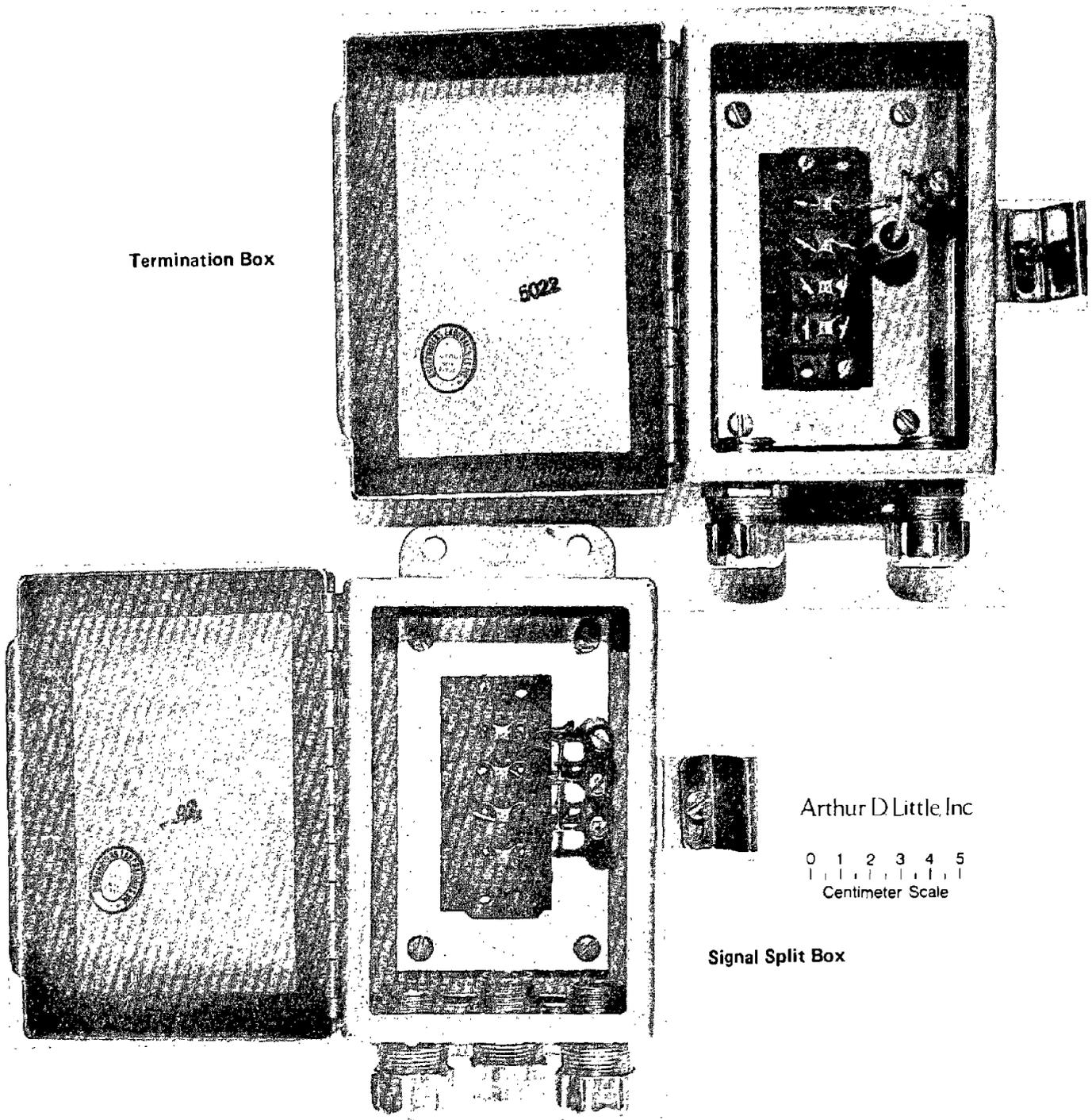
2. Implementation of the Changes

We prepared a draft implementation plan which defined the changes to be made, the steps and sequences required, the manning and equipment requirements, and associated explanatory diagrams and sketches. (This draft plan has been included as Appendix B.) R. Lagace and R. Spencer then visited the Robinson Run mine again to review the implementation plan in detail with T. Poundstone, the Mine Maintenance Superintendent, and to test the performance of a modified transceiver board supplied to the mine by Comtrol.*

The meeting at the mine was successful, resulting in several improvements to the installation plan that allowed the installation to be completed in one day. Plans were made to perform the installations and "after" measurements during the 1981 strike when normal mine activities would be negligible. A three-day period was decided upon to allow for unexpected delays. A tentative start date of May 12 and an alternate date of May 19 were chosen. The final choice was contingent on the mine's receipt of the remaining three modified transceiver boards from Comtrol.* T. Poundstone also agreed to have heavy-duty ground leads welded to the rails and extended to the rib at each termination location prior to the starting date. Our brief test of the modified board installed at the rotary dump showed a satisfactory improvement in transceiver performance.

Specific step-by-step activity sheets and diagrams where appropriate, were then prepared for each installation operation — terminations, power splitters,

*Reference to specific brands, equipment, or trade names in this report is made to facilitate understanding and does not imply endorsement by the Bureau of Mines.



Termination Box

Arthur D Little Inc

0 1 2 3 4 5
Centimeter Scale

Signal Split Box

FIGURE 15 PHOTOGRAPHS OF TERMINATION AND SIGNAL SPLITTING BOXES

Comtrol* radios and couplers, MSA* radios and Comtrol* transformers. These have been included as Appendix C. Hardware was assembled and procedures were also rehearsed with the hardware prior to arrival at the mine.

The in-mine installations were performed by four teams dispatched to different parts of the extensive mine workings: two single-man, mine staff teams each with two end-of-line termination boxes; one two-man team of R. Spencer of Arthur D. Little and B. Roberts of Robinson Run for the four power splitters and the transceivers at 128 block and 90 block; and one two-man team of R. Lagace of Arthur D. Little and J. Williams of Robinson Run for three dump transceivers and one end-of-line termination box.

The work was completed during a single shift under non-operational strike conditions. This included the disconnect of 12 Comtrol* signal couplers between the dedicated wire and trolley wire. However, we did leave these signal couplers in place at the locations where we found them, but with the output to the dedicated wire disconnected. This was done to ensure a rapid changeback capability to the original installation configuration in case the new one presented unanticipated performance problems. Such problems were not encountered either during the strike or when the mine became fully operational again after the strike. All Robinson Run mine personnel were extremely helpful and cooperative on this program.

The required changes to the Robinson Run mine installation took place on May 19, 1981. May 20 and 21 were also reserved for further modifications and for the "after" performance measurements. As mentioned above, T. Poundstone of Robinson Run provided four crews to work simultaneously in the mine to expedite the installation/modification efforts. The four work crews and their assignments are described below.

R. Lagace (ADL) and Jack Williams (RR) — This crew was assigned to modify the three fixed-station transceiver installations located at the Main West, 3 North, and Main North dump loading points in the mine. This effort required verifying that the output impedance setting on the MSA* transceivers was placed at the 25-ohm position. It also required installing a Comtrol CU101* transformer between each transceiver output and the dedicated wire. At the 3 North location, the crew set the transformer to give a 25- to 150-ohm impedance transformation, and retrofitted a modified transceiver board into a Comtrol* transceiver. At the Main North location, the crew had to install an end-of-line resistive termination in parallel with the transceiver/transformer pair. At each transceiver location the crew also verified the voltage level placed on the dedicated wire by the modified transceiver installation.

R. Spencer (ADL) and Bruce Roberts (RR) — This crew was assigned the task of retrofitting the modified transceiver boards on the dispatcher-activated transceivers located at 128 block on East Mains and 90 block on North Mains. This included checking the associated transformer to ensure it was set to the 25- to 150-ohm setting and checking the voltage placed onto the dedicated wire by these transceivers. In addition, this crew was responsible for installing the four signal splits required in the mine, as depicted in Figure 11. This included checking the

*Reference to specific brands, equipment, or trade names in this report is made to facilitate understanding and does not imply endorsement by the Bureau of Mines.

effectiveness of the current split at each location by measuring the voltage produced across each of the three splitting resistors by a transmission from the 128-transceiver.

The remaining two Robinson Run crews were responsible for installing end-of-wire resistive terminations at four locations in the mine, Main West, 3 North, Oakdale portal, and 11 North. Each of the four crews was also responsible for checking each haulageway run for the presence of signal couplers connected between the dedicated wire and the trolley wire, and for disconnecting these where found. A total of 12 coupler sites were so checked by various crews.

The crews undertook their work at the start of the day shift, and finished all tasks well before the end of the day shift. No unusual difficulties were experienced in this process, with the exception of having to trace down and repair a ground connection to the Main North dump transceiver.

The various devices, such as signal splits, terminations, and transformers, were conveniently attached to the ribs of the mine tunnels using spads and J-hooks, as shown in Figures 13 and 14. The wiring and support configuration for the signal splits posed a slightly different problem in this mine; that is, the tautness of the originally installed heavy gauge No. 6-AWG signal wire made it necessary to add short sections of connecting wire and insulator tension supports in a configuration prescribed by T. Poundstone of the mine.

D. THE "AFTER" PERFORMANCE MEASUREMENTS

The "after" signal strength measurements along the trolley-wire/rail haulage network were performed on May 20 and 21 over a period of about 1-1/2 shifts. Two days were required because of the large number of trolley-wire voltage and dedicated wire current measurements performed at 77 locations dispersed over the entire rail haulage network of interest by a single measurement team consisting of R. Spencer and R. Lagace of Arthur D. Little and B. Roberts of Robinson Run. Measurements were made at key locations measured during the "before" tests in February, and at some additional locations beyond the ends of the dedicated wire which we were unable to visit during the February "before" measurements. We used the same equipment and procedures as in the "before" measurements described in Section III-B.

On-site review of the data revealed that the use of power splitters and terminations on the dedicated wire/rail line achieved the desired control and distribution of dedicated wire signal current throughout the mine's dedicated wire/rail network. Good trolley carrier phone communications were established with the dispatcher at all haulageway locations containing the dedicated wire, and also at locations significantly beyond the dedicated wire terminations where communications were not possible before. This favorable communications performance was achieved with trolley wire voltage levels that varied from greater than, to less than, those measured in the "before" tests, but with generally less severe and rapid changes than those experienced with the original installation which employed signal couplers.

Furthermore, the trolley wire voltage was always greater than about 10 dB above the carrier phone receiver sensitivity, with the exception of a few locations well beyond the ends of the dedicated wire.

We made one major unexpected discovery during the "after" measurements. While traversing the North Mains haulage track, we detected a significant standing wave in the dedicated wire current. The cause of this behavior was identified from investigations and measurements made at the 90 block North transceiver. We found about 2000 feet of unterminated signal wire still unintentionally connected to the main dedicated wire near the 90 block transceiver and running up Main North in the parallel haulageway tunnel. This length was long enough for the open circuit at its far end to be translated into a fairly low impedance connection to the dedicated wire in the vicinity of the 90 North transceiver, thereby creating an impedance mismatch and its associated standing wave. We therefore disconnected this section of wire and removed 20 or 30 feet of it to prevent its reconnection. When leaving the North Mains area, we remeasured the North Mains signals and verified that the standing waves caused by the extra wire were no longer present.

Measurements in the West Mains area were deferred until May 21 to avoid working well into the second shift. On May 21, B. Roberts and the Arthur D. Little personnel completed the "after" measurements in the West Mains and 3 North areas, with no unexpected findings.

A final set of "after" measurements were performed under mine operational conditions on July 30, 1981, by R. Lagace and R. Spencer of Arthur D. Little and R. Mullins of Robinson Run, as a final confirmatory check. These measurements were completed in a single working shift using the same equipment and procedures previously described. On this occasion, the measurements were confined to about 17 vital locations and a stretch of track beyond a termination. These locations included the principal vehicle call points, the four signal split locations, the 128 block and 90 block dispatcher activated transceivers, the Oakdale portal track, and the West Mains track beyond the termination into the 4-North section. This run into 4-North was conducted to further examine the trolley wire voltage fall-off behavior beyond a dedicated wire termination.

This set of measurements verified the solid satisfactory performance of the dedicated wire system under operational conditions. It also showed the additional value of a true dedicated wire installation for spotting problems and simplifying the subsequent troubleshooting and repair activities. For example, we noticed a wide discrepancy in the current division at the 3-North splitter and quickly tracked the source to a mechanically caused short circuit in the termination box at the end of the 3-North dedicated wire.

Detail comparisons of the "before" and "after" measurement data are presented and discussed in the following Section.

V. COMPARISONS OF "BEFORE" AND "AFTER" PERFORMANCE

A. FORMAT OF SIGNAL COMPARISON PLOTS

Figures 16 through 20 present comparisons of dedicated wire current and trolley wire voltage for the "before" and "after" conditions of the dedicated wire along five major sections of haulageway in the Robinson Run mine. Behavior of the dedicated-wire current is plotted in the upper part of the figures, and the trolley wire voltage in the lower part. Both are plotted as a function of distance (horizontal axis) from the 128-block transceiver. The vertical-axis current scale in dB relative to 1 ampere is located on the upper-right side of the figures, and the vertical-axis voltage scale in dB relative to 1 volt is located on the lower left side of the figures. The "before" and "after" signal levels along measured sections of the mine haulageway are all plotted for signal transmissions from the principal transceiver used by the mine's dispatcher. This transceiver is the 128-transceiver located at 128-block on the East Mains, as depicted in Figures 4 and 11.

The locations of major loads, junctions, terminations, couplers, transceivers, and rail dispatching call points have been designated on both the upper and lower horizontal axes to aid in the interpretation and understanding of the behavior of the measured signals. Their meanings are described below:

- R's indicate the power rectifiers connected across the trolley wire/rail line that supply the DC traction power for the haulage vehicles. These rectifiers, without adequate carrier frequency impedance compensation, can present unfavorable low-impedance shunt loads to the 88-kHz carrier phone signals.
- T's indicate the 200-ohm terminations placed across the ends of the dedicated-wire/rail lines.
- Tx's represent carrier phone transceivers located at fixed points along the rail haulage network.
- CP's represent call points along the rail network, where vehicle operators are required to contact the dispatcher and receive his clearance instructions before proceeding beyond these locations.
- Z's represent independent signal couplers sometimes used to provide DC-isolated carrier frequency interconnections between the dedicated wire and trolley wire at specific locations.
- S's represent major junctions in the rail haulage and dedicated-wire networks where matched signal splitters were installed prior to the "after" measurements.
- Circled numbers represent the coal block numbers used to identify specific locations along the rail haulageways of the mine.
- End D.W. represents the end of a segment of dedicated wire.

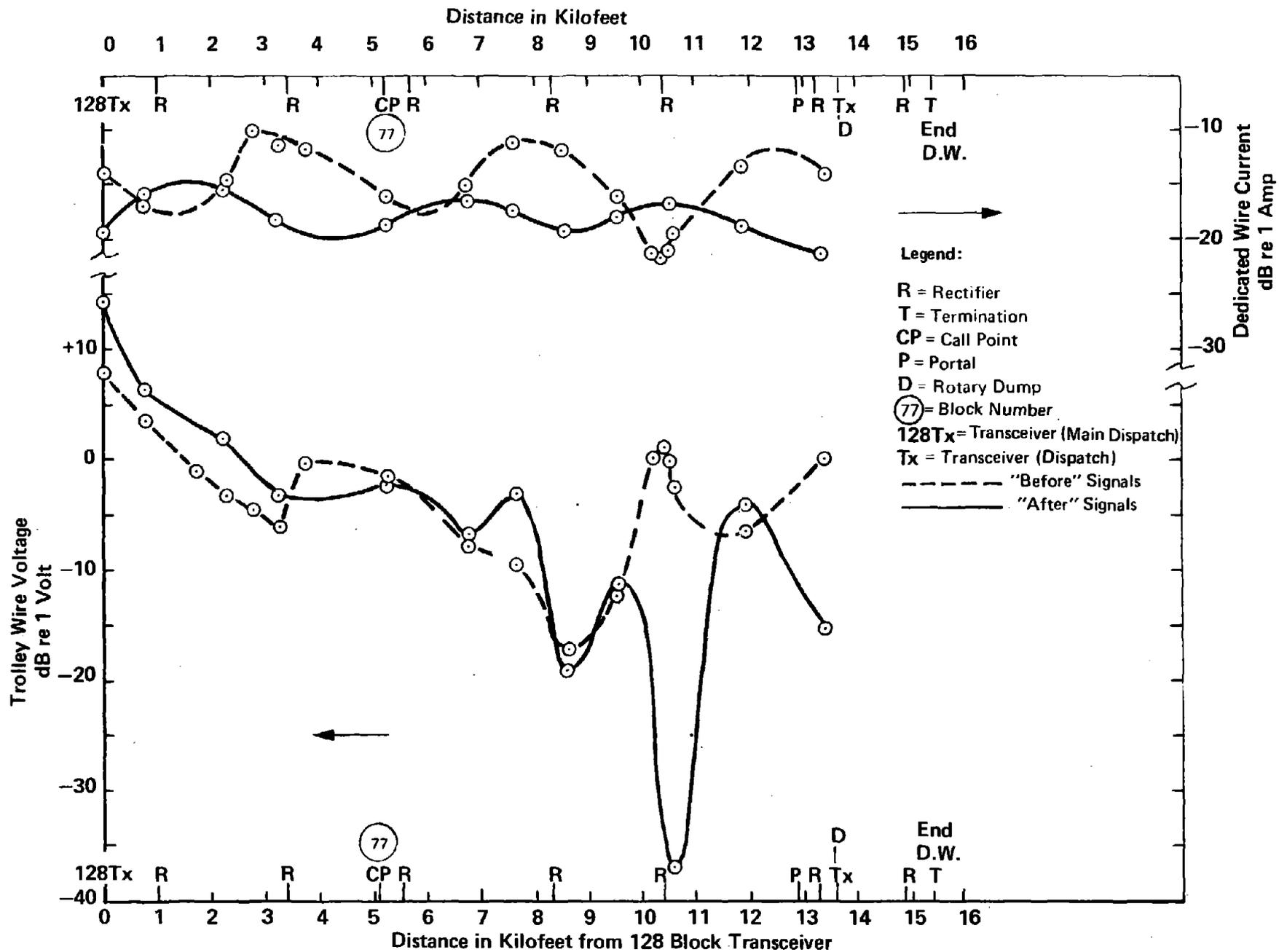


FIGURE 16 COMPARISON OF "BEFORE" AND "AFTER" CARRIER PHONE SIGNALS FOR EAST MAINS, 128 BLOCK TRANSCEIVER TO OUTSIDE ROTARY DUMP

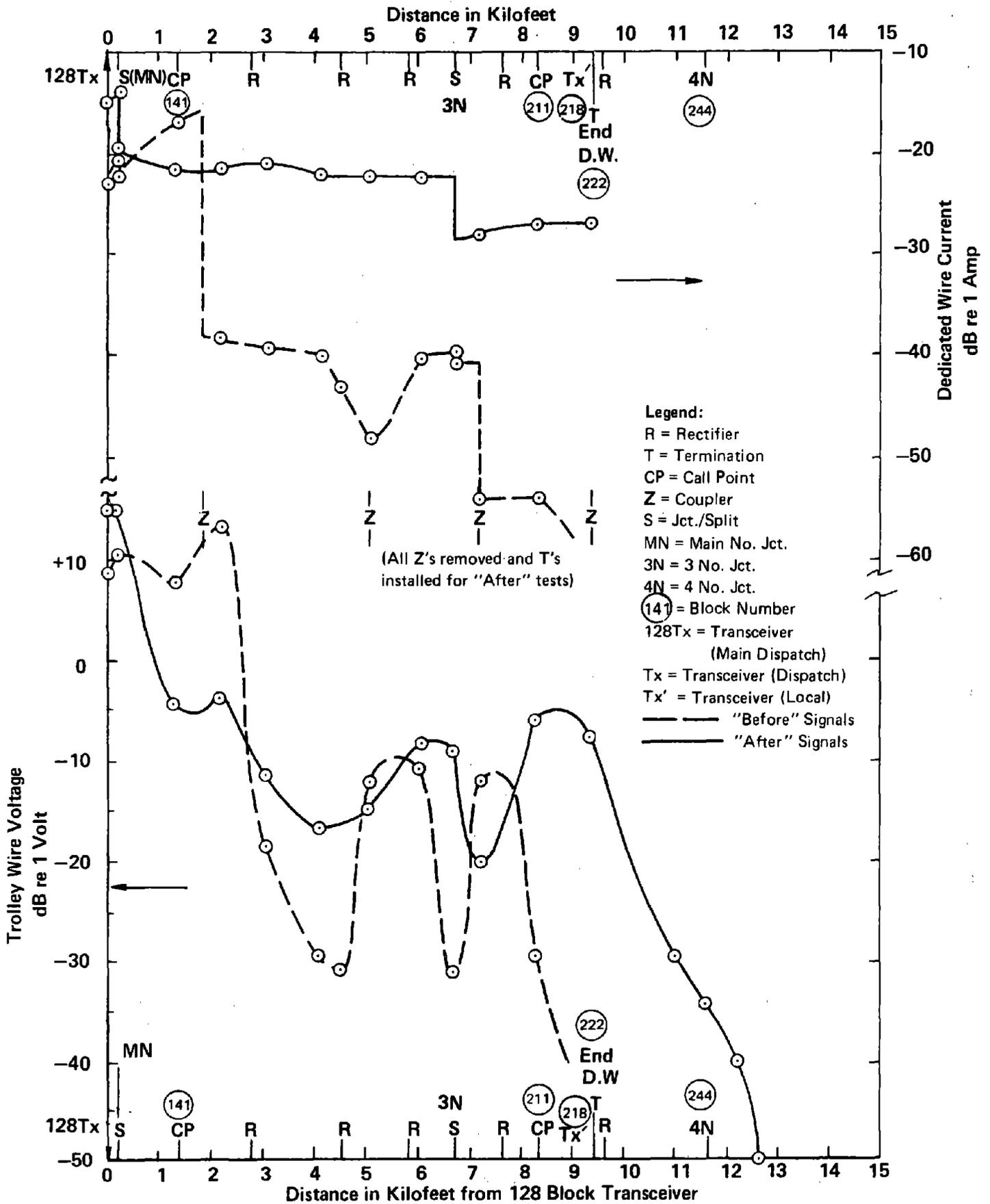


FIGURE 17 COMPARISON OF "BEFORE" AND "AFTER" CARRIER PHONE SIGNALS FOR WEST MAINS, 128 BLOCK TRANSCEIVER TO 4 NORTH

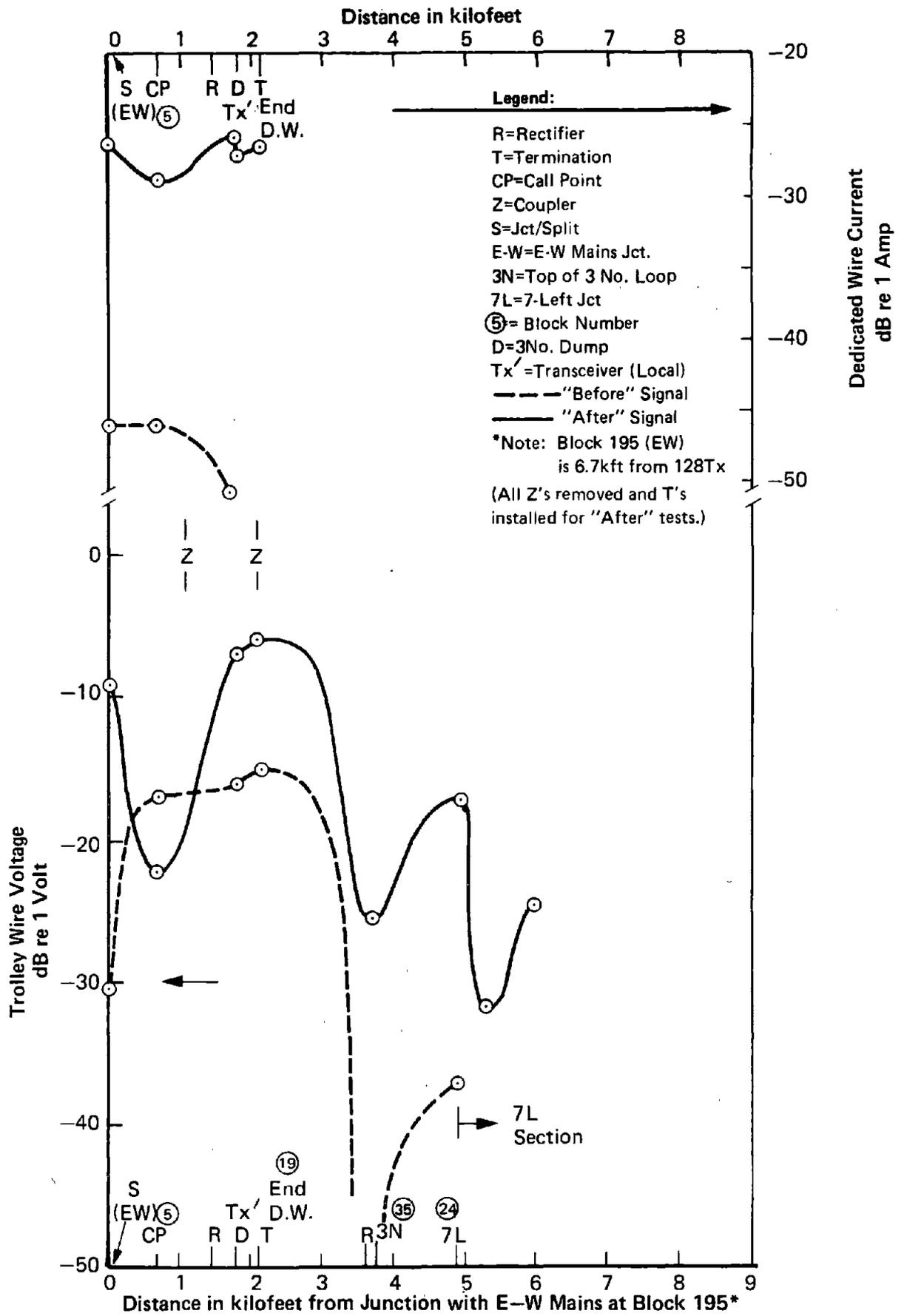


FIGURE 18 COMPARISON OF "BEFORE" AND "AFTER" CARRIER PHONE SIGNALS FOR 3-NORTH, FROM E-W MAINS JUNCTION INTO 3 NORTH LOOP

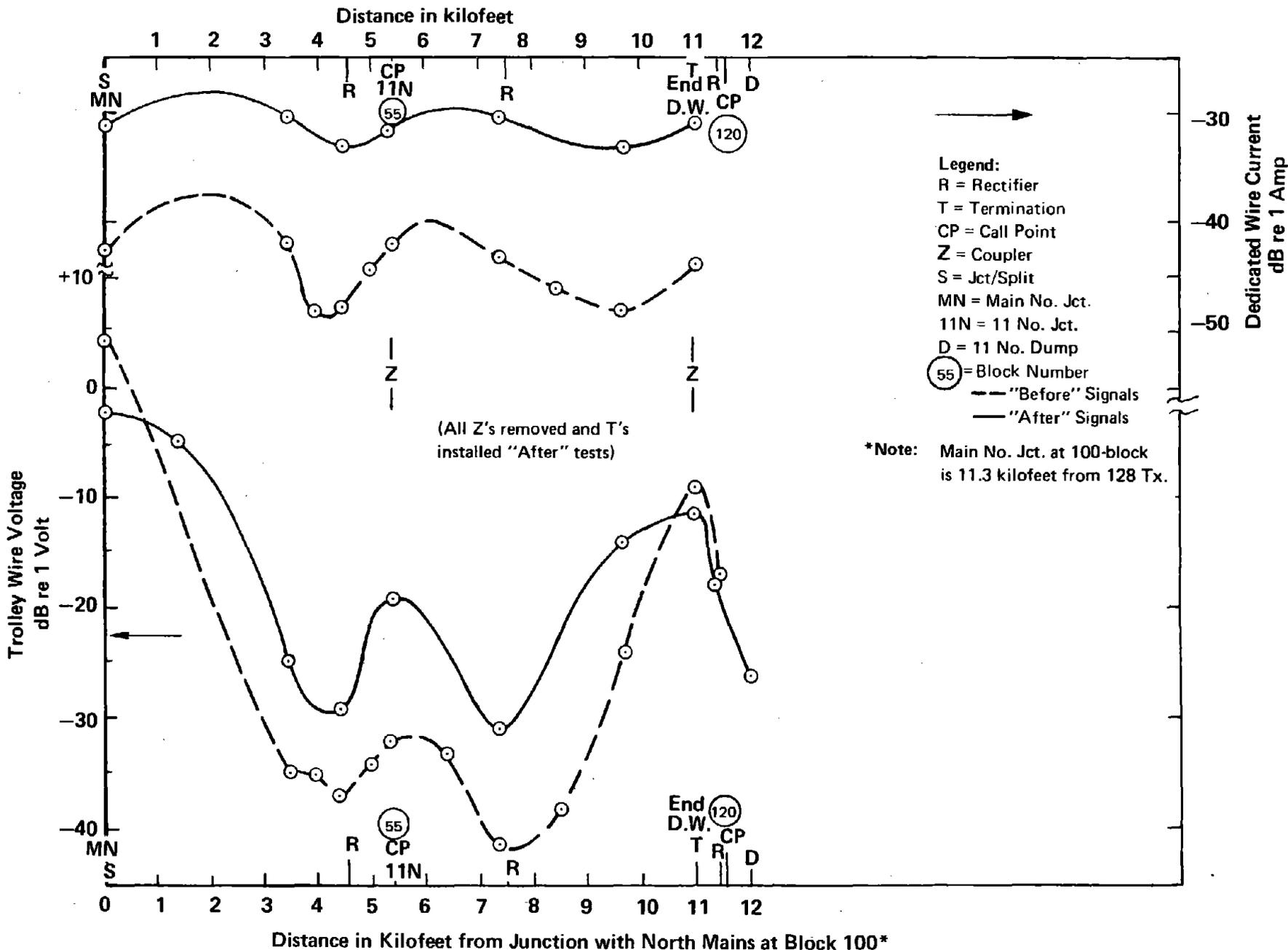


FIGURE 20 COMPARISON OF "BEFORE" AND "AFTER" CARRIER PHONE SIGNALS FOR NORTHEAST MAINS, NORTH MAINS JUNCTION TO 11 NORTH DUMP

The implications of the signal plots in Figures 16 through 20 are discussed in the following sections.

B. EFFECTIVENESS OF SIGNAL SPLITTING

Table 1 offers a comparison of the current-dividing performance with the installed signal splitters and the performance for the "before" condition without the splitters. These results have also been presented in a more graphic manner in Figure 21, which portrays the "before" and "after" input and output currents at their respective splitting points, or nodes, on a simplified map of the mine's dedicated wire network. As indicated, the values apply for transmissions from the 128-block carrier phone transceiver, the principal unit used by the dispatcher to control the mine's rail traffic. Figure 21 also illustrates that, for the "after" condition, the 128 transceiver delivers significantly more current into the mine where it is needed most, instead of toward the outside rotary dump (the situation that prevailed during the "before" condition).

TABLE 1
EFFECTIVENESS OF SIGNAL SPLITS

Split Location	*Without Signal Splits and Terminations			With Signal Splits and Terminations		
	Current In (mA)	Currents Out (mA)		Current In (mA)	Currents Out (mA)	
130 East-West/North	94	75 W	56 N	203	107 W	101 N
100 North/Northeast	26	7 E	18 N	51	26 E	26 N
115 North/Oakdale (W)	21	3 W	20 N	32	15 W	21 N
195 East-West/3 North	10	9 W	5 N	83	32 W	47 N

*As found during "before" measurements.

Table 1 and Figure 21 clearly demonstrate both the higher current levels and the nearly equal splitting of the incoming currents that occur with the matched signal splitters working into lines with matched terminations. The results also indicate that, in each case, the arithmetic sum of the output currents does not exactly equal the input current, but that, in fact, the sum in most cases is larger than the input current. This can occur when the two output currents do not have the same phase. This unequal phase condition is usually more pronounced for unoptimized dedicated-wire configurations without matched splits and terminations to control the line impedances, such as the "before" installation at Robinson Run. For "optimized" configurations, the output discrepancies are still present, but smaller, because the terminations are "matched" only in an "average" sense for practical dedicated-wire installations. When the sum of the measured values of the two output currents is less than that of the input current, the cause is probably related to instrumentation or reading errors.

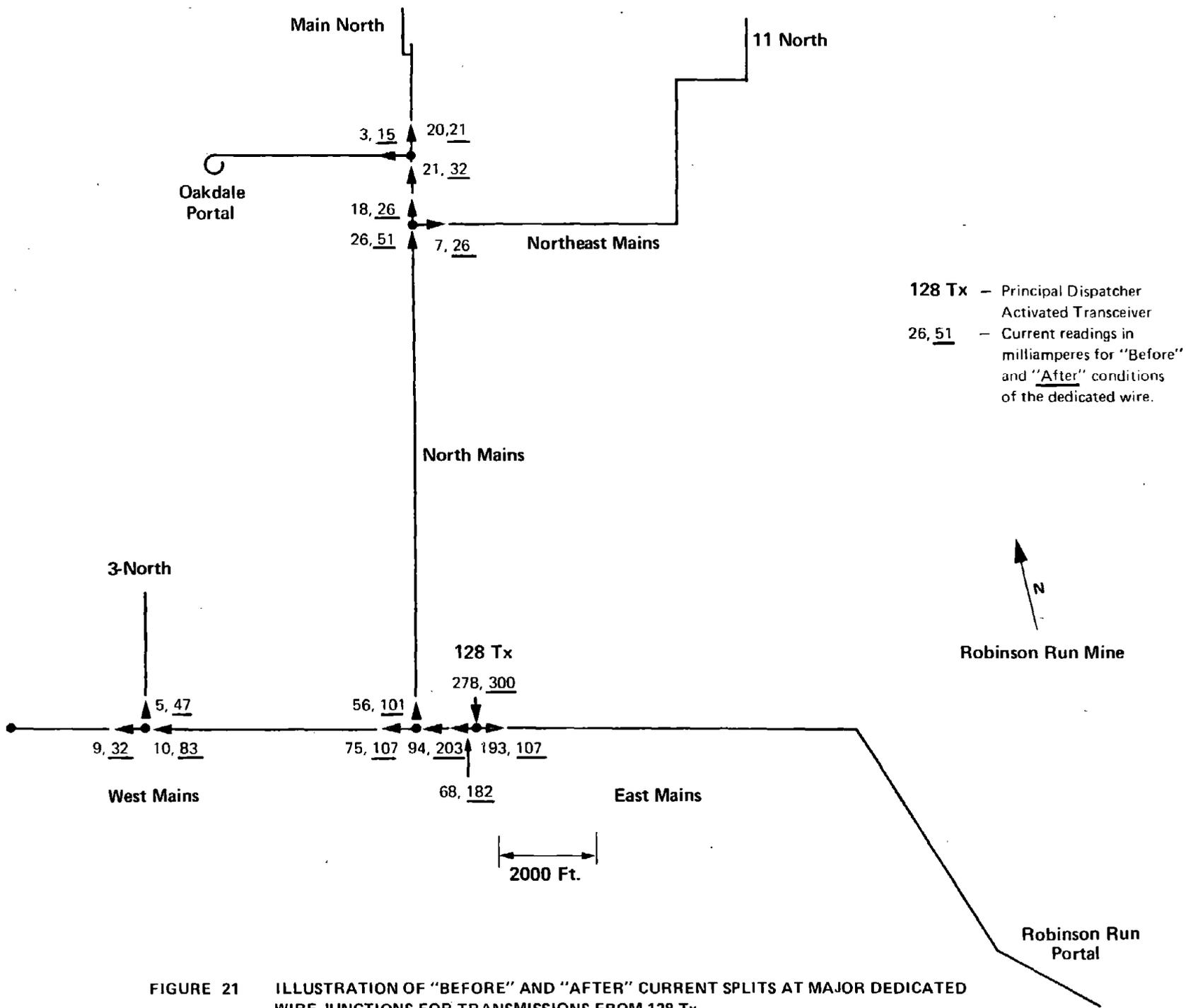


FIGURE 21 ILLUSTRATION OF "BEFORE" AND "AFTER" CURRENT SPLITS AT MAJOR DEDICATED WIRE JUNCTIONS FOR TRANSMISSIONS FROM 128 Tx

C. ATTENUATION RATE OF DEDICATED-WIRE CURRENT

The strength of the signal distributed to distant parts of the mine depends on the amount of attenuation suffered by the signal current on the dedicated-wire/rail matched transmission line. Early Arthur D. Little, Inc., experiments in the Renton coal mine,⁽¹⁾ theoretical work by Wait and Hill,⁽⁶⁾ as well as Arthur D. Little, Inc., experimental results from a dedicated-wire installation at the Montour No. 4 coal mine⁽³⁾ have consistently supported the conclusion that the dedicated-wire/rail transmission line has a low enough signal attenuation rate, at carrier phone frequencies, to provide the desired wide coverage in a mine.

Various segments of the Robinson Run dedicated-wire network were examined to provide attenuation rate estimates. The variation of "before" and "after" dedicated wire current signal strength with distance along these segments is shown in Figures 16 through 20. For the purpose of the present discussion, attention has been focused only on the dedicated-wire current plots. Examination of the "before" and "after" current plots reveals that, after the signal splits and terminations were installed:

- The standing waves were significantly reduced on all segments;
- The currents became well behaved and predictable along the segments; and
- The average current levels were significantly increased along several previously troublesome sections of dedicated wire.

To estimate attenuation rates for the "after" dedicated-wire currents, an "average" straight line was drawn through the small standing wave pattern along each dedicated-wire segment. These residual standing waves occur as a result of imperfectly matched terminations, and local variations in line characteristic impedance and attenuation rate along the segments. These local variations, in turn, are caused by local variations in the dedicated wire's position in the haulageway relative to the rail, the trolley wire, other miscellaneous conductors, and the coal and rock boundaries of the tunnel. The straight-line "averages" over these variations which most likely account for the different attenuation rates found along the major segments of dedicated wire.

Table 2 presents the experimental attenuation rates along four major segments of the dedicated-wire installation at the Robinson Run mine. Examination of the table reveals about a 2 to 1 spread in the experimental rates, ranging from a low of 0.2 dB/1000 ft along the East Mains to a high of 0.45 dB/1000 ft along the North Mains. The average rate obtained by dividing the total loss by the total length is about 0.33 dB/1000 ft, or 1.07 dB/km.

For comparison, Table 3 shows the attenuation rates obtained from theoretical plots by Wait and Hill⁽⁶⁾ for a dedicated-wire/rail transmission line alone in a coal tunnel, with no trolley wire/rail line present. At the Montour No. 4 mine, Arthur D.

Little, Inc., measurements revealed an overall 0.71 dB/km over a nearly four-mile run of dedicated wire in the presence of a trolley wire/rail line, which is consistent with the Table 3 values. The 1.07 dB/km average attenuation rate obtained from the Robinson Run data is somewhat higher than that observed at Montour No. 4 and the Table 3 values. This higher attenuation rate may be caused by tighter coupling to the lossy trolley wire/rail line at Robinson Run. At Robinson Run, the dedicated wire is located on the narrow side (instead of the wide side) of the haulageway, only about 2 feet from the trolley wire on the average.

TABLE 2

**DEDICATED-WIRE
SIGNAL CURRENT ATTENUATION**

Dedicated Wire Segment	Length (kilofeet)	Starting* Current (mA)	Ending* Current (mA)	Attenuation (dB)	Attenuation Rate	
					dB/1000 feet	dB/km
Block 128 East to Rotary Dump	13.4	146	108	2.62	.20	0.66
Block 130 West to Block 196W	6.5	108	80	2.61	.40	1.31
North East Run to 11 North Dump	11.0	37	25	3.41	.31	1.02
Block 130 North to Block 100N	11.3	99	55	5.11	.45	1.48

*Based on straight line fit to data.
Average equals .33 dB/1000 feet equals 1.07 dB/km.

Source: Arthur D. Little, Inc.

TABLE 3

**THEORETICAL ATTENUATION RATES
(for a Dedicated-Wire/Rail Line in a Coal Tunnel)**

Conductivity of Surrounding Coal/Rock (mho/m)	Attenuation Rate	
	(dB/km)	(dB/1000 ft)
10 ⁻¹	.90	.27
10 ⁻²	.65	.20
10 ⁻³	.54	.15

Source: Wait and Hill, Ref. 6, and Arthur D. Little, Inc.

The operational impact of the average attenuation rate can be roughly assessed by computing the distance required to reduce the current level to one-half of its initial value; that is, to incur a 6-dB loss. For the Robinson Run mine, this distance is approximately 6 km, or 19,680 feet, nearly four miles, as compared to the 11 miles of dedicated wire installed at that mine. Thus, the overall attenuation is still low enough to provide satisfactory current signals throughout the mine's dedicated-wire network from a single dispatcher's transceiver. To these losses must be added the 6-dB loss introduced by each signal splitter installed along a given segment. The addition of such splitters may require that the principal dispatcher-activated transceiver be installed at a centralized location in the mine, like the one at Robinson Run, to reduce the overall attenuation suffered by dedicated-wire signals delivered to parts of the mine farthest from the portal.

D. PERFORMANCE ALONG EAST MAINS

The East Mains segment of dedicated wire (shown in Figures 4 and 11) required the least modification, and as a result demonstrated the least change in performance. "Before" and "after" plots of dedicated-wire current and the associated trolley wire voltage are shown in Figure 16. These plots reveal highly satisfactory performance. At all locations, the trolley wire voltage levels were well above -40 to -50 dB relative to 1 volt (10 to 3 millivolts), the marginal performance range where intelligibility deteriorates significantly into the background noise at this mine. Most importantly, a very strong voltage level of about 800 millivolts (-2 dBV) was recorded at the principal East Mains call point at block 77.

As previously indicated, the dedicated wire, as found, had already been terminated with a matched 200-ohm resistive termination about 2000 feet beyond the outside rotary dump. The standing wave depicted in the "before" dedicated-wire current plot was caused by the unexpectedly low input impedance of the rotary dump carrier phone transceiver when operating in the standby (receive) mode. Substitution of a modified transceiver board supplied by Comtrol* cured this problem. The residual "after" standing wave was caused by the mechanisms discussed in the previous section of this chapter, and by the change in line characteristic impedance produced by the absence of tunnel boundaries beyond the mine portal.

The already strong trolley wire voltages were only slightly increased by the transceiver board substitution. These voltages are greater than 300 millivolts over most of the underground section of track along East Mains. The principal exception to this increase was the region around the rectifier located about 10,500 feet from the 128-transceiver, a location of no importance to normal traffic dispatching operations in this mine. Although it is not clear why such a large signal drop occurred at this particular rectifier, the more important point is the restoration of the signal strength beyond the low-impedance rectifier (as shown in Figure 16).

*Reference to specific brands, equipment, or trade names in this report is made to facilitate understanding and does not imply endorsement by the Bureau of Mines.

The plots also reveal a drop of about 15 dB in voltage level at the rotary dump in the rail yard outside the Robinson Run portal. We believe this drop resulted from the removal of the transceiver's impedance mismatch to the dedicated wire at the rotary dump. We have observed in this plot, and the others, that impedance mismatches and discontinuities such as terminations and splits along the dedicated wire, are usually accompanied by increases in the trolley wire voltage in the vicinity of these locations. We do not fully understand the reasons for this apparent increase in coupling to the trolley wire/rail line at such locations. However, the effect should be useful in practice as a means of selectively improving or extending performance near the end-points of the dedicated wire. For example, voltage levels at the rotary dump, and other locations in the outside rail yard, could be increased closer to the "before" levels by moving the outside termination closer to the rotary dump location. We believe this could be accomplished without losing the ability to communicate satisfactorily along the car storage track beyond the dump. Consequently, we recommend that the termination be so moved by the mine, and the expected performance verified.

E. PERFORMANCE ALONG WEST MAINS

The West Mains segment of dedicated wire (depicted in Figures 4, 5, 6, 7 and 11) required the most modifications, and demonstrated the most significant improvements in performance. "Before" and "after" plots of dedicated-wire current and trolley wire voltage are shown in Figure 17. These plots reveal highly satisfactory "after" performance; that is, a well controlled dedicated-wire current distribution, strong trolley wire voltage levels greater than 100 millivolts (-20 dBV) over the whole dedicated-wire segment, very strong voltage levels close to 500 millivolts at both major call points, and voltage levels well above the -40 to -50 dBV marginal performance range for more than a half mile beyond the dedicated-wire termination.

The "after" voltage plot also exhibits, like the Figure 16 plot for East Mains, the expected initial steep attenuation rate close to the transmitter, a gradual flattening out with distance, occasional moderate dips in signal level near some rectifiers, and signal restoration beyond them.

Examination of the "before" current plot reveals significant reductions in the dedicated-wire current caused by the signal couplers shown in the figure as Z's; that is, the hardwired couplers along this section of haulageway were transferring large fractions of the dedicated-wire current to the trolley wire. These couplers were used by the mine to compensate for the severe signal attenuating characteristics of the power rectifiers connected across the trolley wire/rail. Since rectifiers quickly attenuate transferred carrier phone signals too, this method provides only local improvements in trolley wire voltage. Therefore, many such couplers may be required along heavily loaded sections of track to obtain perhaps only marginally acceptable performance. These couplers do not represent the most desirable or practical solution for a number of reasons:

- They introduce additional mismatches to the dedicated wire and trolley wire lines;

- The process for selecting favorable installation points is not reliable nor well understood; and
- They introduce complexity and confusion into troubleshooting and maintenance operations.

The trolley wire "before" voltage beyond the third coupler was quickly attenuated to unusable levels because the connection of the terminating coupler to the end of the dedicated wire had been severed. However, even if the connection had not been broken, the extremely small current left flowing in the dedicated wire beyond the third coupler would probably not have been sufficient to provide any significant improvement in trolley wire voltage beyond this coupler.

The West Mains segment of haulageway provides a good example of the extended coverage and trolley wire voltage attenuation rate beyond the end of a terminated dedicated wire. It also provides two illustrations of the trolley wire voltage buildup found in the vicinity of dedicated-wire discontinuities. On this segment, the discontinuities are the signal split at the 3-North junction and the termination at the end of the dedicated wire. The split results in about an 8-dB increase, and the termination in about a 15-dB increase. Beyond the termination, the straight run of track down West Mains and into 4-North, shown in detail in Figure 7, exhibits an attenuation rate of about 11-12 dB/kft, or 36 to 39 dB/km over a distance of about 3000 feet.

Similar measurements, made under mine operational conditions during a subsequent mine visit on July 30, 1981, to make spot checks, revealed a somewhat lower average attenuation rate of about 8 dB/kft or 26 dB/km. In addition, a 20-dB improvement in voltage level was recorded for the furthest plotted distance of 12.7 kft. The reason for this improved attenuation rate is not fully understood; however, it may be related to changes and extensions made to the trolley wire feeder installation beyond the termination prior to the July 30 visit. The reliability of carrier phone communications to 4-North as the section continues to expand, would be improved by extending the dedicated wire down West Mains and terminating it at the junction to 4-North.

F. PERFORMANCE IN 3-NORTH AREA

The 3-North area is depicted relative to the rest of the mine's rail and dedicated wire networks in Figures 4 and 11, and in detail in Figure 6. The area contains several active longwall sections with their supply tracks, train loading loops, and dump load point. Figure 18 compares the "before" and "after" signals to this part of the mine. The figure reveals a large increase in the strength of the dedicated-wire current, and significant increases in trolley wire voltage in several locations; viz., along the rail network beyond the dedicated-wire termination, at the junction of 3-North with West Mains, and at the top of the 3-North loop. In addition, a strong signal of close to 80 millivolts has been maintained at the 6-block call point.

Although the dedicated wire extends only about 2,000 feet into 3-North, strong trolley wire voltages were recorded at the end of the 7-Left section supply track over a mile into 3-North. The trolley wire voltage also exhibits the characteristic increase found in the vicinity of dedicated-wire terminations. The oscillatory behavior in voltage beyond the termination is most likely due to the rectifier near the top of the loop and the race track nature of the loop.

G. PERFORMANCE ALONG NORTH MAINS

The North Mains segment of dedicated wire is about 1-1/2 times longer than either the East or West Mains segments. As shown in Figures 4, 11, and 8, North Mains has two closely spaced signal splits approximately two miles from the 128-block transceiver and an extended run of dedicated wire to the top of the North Mains loading/supply track loop. Figure 19 presents the "before" and "after" plots of dedicated-wire current and trolley wire voltage along North Mains. Overall, the "after" performance is quite good, although the trolley wire voltage exhibits somewhat larger variations than are found on the East and West Mains.

Figure 19 reveals a well behaved, properly split "after" current distribution, with the exception of the slightly irregular behavior near the Oakdale junction signal split, and the unexpected variation in current beyond the North Mains junction in the dedicated wire. At this junction point, it separates into a short unterminated length of about 600 feet that continues north, and a much longer section which jogs left 4 blocks to a parallel tunnel in the North Mains loading/supply track loop, and then runs north to the dump area where it jogs right 2-1/2 blocks to the termination at the dump transceiver. The unexpected variability in the dedicated-wire current along this section can be explained by the fact that the ground return was inadvertently not taken along with the dedicated-wire down the crosscuts to the other parallel tunnel at the jog points. These jogs introduce two short sections of dedicated-wire transmission line having an unknown but higher characteristic impedance than that of the dedicated-wire rail line. Consequently, these sections cause mismatches in the line that are capable of producing anomalous current behavior patterns.

By including these missing ground conductors in the crosscut jogs, a higher and more uniform dedicated-wire current will occur, together with an associated improvement in the trolley wire voltage along the North Mains dump/supply track. The "before" currents in this North Mains area were also affected by these missing ground conductors in the crosscuts. In addition, the "before" currents in this area were severely attenuated by a defective splice at the junction where the dedicated wire jogs left, and a severed signal coupler ground connection at the end of the short northbound length of wire.

The large standing wave in the "before" current between the West Mains junction and the 90-block transceiver and the large current discontinuity at the 90-block Control transceiver were cured by inserting the modified transceiver board and by disconnecting an extra 2,000 feet of unterminated dedicated wire which had

been inadvertently attached to the North Mains segment near the 90-block transceiver. Examination of the "before" current plot also reveals that the independent signal couplers (Z's) along North Mains did not cause large current drains from the dedicated wire like the couplers installed along West Mains.

Figure 19 also shows that although the North Mains trolley wire voltage was somewhat more variable than that along the East and West Mains, strong voltages in excess of 100 to 200 millivolts (-14 to -20 dBV) were maintained along most of the North Mains segment, with the exception of a region near a rectifier about 6500 feet from the 128-transceiver. Furthermore, the voltages at all but one of the seven major call points exceeded 100 millivolts (-20 dBV), and most exceeded 200 millivolts.

At the exception, the 53-block call point in the vicinity of the above-mentioned rectifier, the "after" voltage dropped to a level of about 35 millivolts (about -29 dBV). This level is still quite satisfactory, since it is more than 10 dB above the beginning of the marginal performance range of -40 to -50 dBV for this mine. The larger than usual 30-dB drop in voltage from the "before" to the "after" condition at this location was caused by the removal of the nearby signal coupler that was producing a localized increase in voltage. Alternative methods for increasing the signal strength at a call point near a troublesome rectifier include: raising the rectifier impedance by tuning its setback leads, and moving the call point a few blocks farther away from the rectifier if possible, preferably on the side nearest the dispatcher's transceiver.

As observed along the East and West Mains segments, the "after" trolley wire voltage exhibits the characteristic steep attenuation rate in the vicinity of the transceiver and a rise in voltage in the vicinity of discontinuities such as splits and terminations. The specific reason for the prolonged run at a higher than expected attenuation rate for the first 6000 feet of North Mains is not known. The rise in trolley wire voltage near the left jog of the dedicated wire at the 134-block call point is probably due to the discontinuity in line characteristic impedance caused by the missing ground wire in the crosscut, as previously discussed. However, in spite of the missing ground wire, the suboptimum dedicated-wire current was sufficient to significantly improve the trolley wire voltage level at the rectifier in 6-Left section, shown in Figure 8. This rectifier is more than a half-mile away from the end of the dedicated wire.

H. PERFORMANCE ALONG NORTHEAST MAINS

The Northeast Mains dedicated wire segment runs 11 kft from the 100-block junction signal split on North Mains to the 11 North dump, as shown in Figures 4 and 11. Since the 100-block junction is 11.3 kft from the 128-block transceiver, the 11 North dump is the farthest location from the dispatcher's main transceiver at 128-block on East Mains. Figure 20 presents the "before" and "after" signal plots for this segment of the dedicated wire.

The figure reveals a greater than 10-dB increase in dedicated-wire current for the "after" condition, and a nearly similar improvement in trolley wire voltage levels over most parts of the segment having the lowest "before" voltage levels.

In addition, the trolley wire voltage exhibits the characteristic rise when approaching a dedicated-wire termination, and decline when receding from a termination or signal split. With the exception of two regions near rectifiers, the trolley wire voltage levels exceed 50 to 100 millivolts (-26 to -20 dBV), and both major call points exhibit a strong level of 100 millivolts (-20 dBV). Even at the two rectifiers near the middle of this segment, the -30 dBV (30 millivolt) voltage level is 10 dB above the top of the marginal performance band.

Finally, Figure 20 shows that a standing wave is still present in the "after" dedicated-wire current. This is not surprising, considering the relatively unmaintained condition of the dedicated-wire installation for long stretches along the old and wet Northeast Mains. Along these stretches, the position of the wire in the tunnel, the wire's support, and its amount of tension are variable in the extreme. Conducting measurements along such a segment of dedicated wire proved fortunate, because the favorable performance results provide strong testimony to the robust character and practicality of the dedicated-wire technique under the difficult operating conditions found in many U.S. coal mines.

I. PERFORMANCE UNDER OPERATIONAL CONDITIONS

A limited set of spot check signal measurements were performed at the mine during the day shift on July 30, 1981. The purpose was to check whether the "after" performance measured under normal mine operating conditions was significantly different from that found under the non-operational strike conditions in May 1981. Table 4 tabulates the trolley wire voltage and dedicated-wire current values measured at the major call points and junctions along all dedicated-wire segments except the Northeast Mains segment. Also tabulated are the corresponding "after" values measured in May 1981, and the July and May sets of "after" values measured at corresponding locations beyond the dedicated-wire termination along West Mains. Our review of the tabulated data leads to the conclusion that the improvements in overall performance are roughly equivalent under both operational and strike conditions.

The dedicated-wire data at two specific locations also flagged the presence of two problems along the dedicated-wire network on July 30. The first was a mechanically caused short-circuit in the resistive termination box at the end of the 3-North dedicated-wire segment. This short circuit was quickly tracked down and repaired on the spot after the current measurements at the 3-North, 195 block signal split showed a large discrepancy from the expected equal-split condition. The readings were: input, 64 mA; output, 47 mA (West); 17 mA (North). After the repair, the readings returned to the more reasonable values: input, 64 mA; output, 40 mA (West); 28 mA (North).

The second problem was an inadvertent grounding of the dedicated wire to a vertical metal support near 46-block along East Mains, caused by worn insulation on the dedicated wire. This condition was noticed by R. Mullins of Robinson Run shortly after the July 30 visit, during a routine inspection of the dedicated wire. Critical examination of the dedicated-wire current data taken at the 128-transceiver also revealed the presence of a potential problem along East Mains. The July

TABLE 4

"AFTER" VOLTAGES AND CURRENTS AT KEY LOCATIONS DURING AND AFTER STRIKE

Haulageway Mains	Block Number (Function)	Trolley Wire Voltage (mV)		Dedicated Wire Current (mA)	
		May (Strike)	July (Operational)	May (Strike)	July (Operational)
East	20 (R)	14	110*	83	143
East	75 (CP)	780	640	205	150
East	128 (Tx)	5,600	5,400	Tx 300	364
				E 107	182
				W 182	165
West (MN)	130 (Jct/S)	5,400	10,000	203	161
				W 107	86
				N 90	101
West	141 (CP)	600	320	75	79
West (3N)	195 (Jct/S)	340	290	83	64
				W 32	40
				N 47	28
West	211 (CP)	490	340	45	46
3-North	5 (CP)	78	330	36	28
North	6 (CP)	590	330	88	83
North	53 (CP)	34	130	68	54
North	80 (CP)	290	230	64	49
North	90 (Tx)	1,800	540	56	47
North (NE)	100 (Jct/S)	740	590	51	43
				E 26	24
				N 26	19
North (Oak)	110 (Jct/S)	270	260	32	25
				W 15	10
				N 21	15
North	118 (CP)	100	260	26	18
North	134 (CP)	400	490	26	15
Oakdale	12	25	50	14	12
Oakdale	24 (T)	—	160	—	13
West	222 (T)	400	590	45	—
(Beyond T)					
↓	238	33	78	N/A	N/A
↓	244 (4N)	20	78	↓	↓
4-North	5	10	37		
4-North	8½	3	—		
	10	—	24		

Notes: Blocks are approximately 100 ft center to center in this mine.

- CP = Call Point
- R = Rectifier
- Tx = Transceiver
- Jct/S = Junction/Split
- T = Termination
- MN = North Mains
- 3N = 3 North
- NE = Northeast Mains
- Oak = Oakdale
- 4N = 4-North Jct
- N/A = Not Applicable
- E = East
- W = West
- N = North

*Level increase to -19 dBV from low of -37 dBV at 10.6 k ft in Figure 16.

30 transmitted current values were: 364 mA (transceiver); 165 mA (West); 182 mA (East); this constituted a fairly even split, but the May 21 values were: 300 mA (transceiver); 182 mA (West); and 107 mA (East), which favored the in-mine direction — the preferred condition in this particular mine having an extensive haulageway network. The key indication in this case was the significant change in the current division ratio.

J. OVERVIEW

This in-mine demonstration program has shown that the dedicated-wire technique is an effective way to improve and stabilize trolley-wire carrier phone communications throughout the rail haulage network of an extensive coal mine. The simple and stable configuration and behavior of the dedicated-wire/rail transmission line are the keys to its predictable and reliable performance. The simple configuration also means that problems can be quickly diagnosed, and the dedicated-wire network integrity and performance can be easily maintained.

The dedicated wire technique for improving and stabilizing trolley-wire carrier phone communications achieves its results without using any signal coupler interconnections between the trolley wire and other signal wires. In this way the potential hazard of the DC trolley-wire voltage being inadvertently applied to other wires is markedly reduced.

VI. REFERENCES

1. Spencer, R.H., Emslie, A.G., Lagace, R.L., et al., "Improvements for Mine Carrier Phone Systems," Arthur D. Little, Inc. Final Report, Task I, Task Order No. 2, Bureau of Mines Contract HO346045, April 1977, NTIS No. PB273292AS.
2. Spencer, R.H., O'Brien, P., and Jeffreys, D., "Guidelines for Trolley Carrier Phone Systems," Arthur D. Little, Inc., Final Report, Bureau of Mines Contract JO166010, March 1977.
3. Lagace, R.L., Jeffreys, D.C., Spencer, R.H., and Williams, J.M., "Trolley Carrier Phone Mine Communications," Arthur D. Little, Inc., Final Report, Bureau of Mines Contract JO377098, February 1979.
4. Long, R.G., Chufo, R.L., and Watson, R.A., "Technical Guidelines for Installing, Maintaining and Inspecting Underground Telephone Systems," A Bureau of Mines Handbook, U.S. Department of Interior, Bureau of Mines, 1978, TN344.U5, 622.06173.
5. Long, R.G., "Acceptability Guidelines for Performance Characteristics of Underground Pager Telephones," Arthur D. Little, Inc., Final Report, Bureau of Mines Contract JO166085, April 1977.
6. Wait, J.R., and Hill, D.A., "Radio Frequency Transmission via a Trolley Wire in a Tunnel with a Rail Return," IEEE Trans. on Antennas and Propagation, Vol. AP-25, No. 2, pp. 248-253, March 1977.

APPENDIX A
BRIEF DESCRIPTIONS OF VISITS TO
FIRST THREE CANDIDATE MINES

I. The Powhatan No. 1 Mine

The Powhatan No. 1 mine at Powhatan Point, Ohio, south of Wheeling, W. VA., was visited by R. Lagace and R. Spencer of Arthur D. Little, Inc., in March 1980. They met with the North American Coal Co., Ohio Division President, W. Goddard, the Mine Superintendent E. Schank, and mine electrical personnel H. Knight and A. Novina. The mine is a large mine in which the rail haulage main line passes through some 7 to 8 miles of mined out area before branching out into several miles of active mine workings.

Although mine personnel believed the mine pager phone system was approaching an overload limit, the phones were performing reasonably well, with the exception of some weak signals at extreme locations. Several high-quality cable splices with wire nuts were observed. They were similar to those recommended in Bureau of Mines installation and maintenance guidelines for mine pager phone systems. We were told that Mining Safety and Health Administration (MSHA) inspectors in the area had been recommending the use of these guidelines.

The carrier phone system, though far from perfect, had recently been improved to reasonable performance levels by disconnecting one of the two trolley wire-to-pager phone line signal couplers (Z-boxes) in the mine. This disconnection had improved performance in the most active parts of the mine and sacrificed some performance near the dispatcher's location at the portal. Our spot measurements of trolley wire voltage with a Comtrol* tuned RF voltmeter revealed that poor performance experienced in some active areas of the mine was caused not by a weak signal, but by high noise levels. These high noise levels might possibly be caused by nearby high horsepower AC belt drives with solid-state SCR speed controls. On the other hand, the strong carrier phone signal levels transmitted over long distances into the active sections may be the result of an unintentional "dedicated wire" effect produced by the pager phone line along the 7-8 mile stretch of unbranched track in the mined out part of the main haulageway.

The somewhat unique noise problems and the several weak signal areas of the mine's carrier phone system, together with the incipient pager phone overloading problem, made this mine a possible compromise candidate for the demonstration program. The Powhatan No. 1 mine was eventually excluded from further consideration, because the most practical solutions to its problems involved reconfigurations of the communication networks. Such reconfigurations did not meet the objectives of this program.

II. The Harris No. 1 Mine

The Harris No. 1 mine at Bald Knob, W. VA., northwest of Beckley was visited by R. Lagace, R. Long, and R. Spencer of Arthur D. Little, Inc., in March 1980. They met with Mine Manager R. Burton, M. Schumate, safety; R. Rhinehart, mine

*Reference to specific brands, equipment, or trade names in this report is made to facilitate understanding and does not imply endorsement by the Bureau of Mines.

electrician; and Randy, the radio man. The mine is a moderate-sized drift mine with about four miles of main line track haulage, two major submains, and several shorter branches into longwall panels.

This mine had been suffering for some time from severe problems with both pager phone and carrier phone systems. Our measurements and inspection of the systems and our discussions with the underground electrical and communication personnel revealed that both systems were functioning at highly satisfactory levels. We were told that this was due primarily to three recent major corrective actions taken by the electrical personnel. These actions included the complete replacement of three to four miles of badly spliced pager phone line, the installation of new rail bonds along a similar stretch of the haulage network, and the hiring of an experienced underground radio man dedicated primarily to upgrading and maintaining the mine communications systems.

The mine also made extensive use of a variety of standard techniques for improving carrier phone system performance. Use of a dedicated wire in this mine could greatly simplify their overall system, by dispensing with all the spot remedies located throughout the mine. However, the mine preferred the maintenance problems associated with these spot remedies, rather than those anticipated with dedicated wires which might be severed by the frequent roof falls experienced in this mine. Since the pager phone line had been replaced, the pager phone system was in good working condition; suffering mainly from the typical problems of defective printed circuit cards, broken or wet handsets, defective page switches and dead batteries, all of which they seemed to have under control. As a result of the highly satisfactory communications performance found at this mine, the mine was eliminated from further consideration as a candidate for this program.

III. The Beth Elkhorn No. 26 Mine

The Beth Elkhorn No. 26 mine in Jenkins, Kentucky, was visited on two occasions. The first time was in April 1980, when R. Spencer and R. Long of Arthur D. Little, Inc., visited the mine to assess its suitability for the program. The second visit was made in August 1980 by R. Lagace of Arthur D. Little, at the request of the mine's management. The purpose was to provide a more detailed briefing on the objectives and activities of the demonstration program, after the mine had been selected as a satisfactory candidate. On the first visit, R. Spencer and R. Long met with M. Collier, Mine Superintendent; L. Hall, Chief Electrical Engineer, and N. Yount, mine communications man. On the second visit, R. Lagace met with S. Kegan, General Superintendent; S. Litton, Chief Engineer and Maintenance Superintendent; L. Hall, Chief Electrical Engineer; R. Delph, electrical engineer, and N. Yount, mine communications man. The mine is a large and expanding longwall-type mine, having four miles of underground main line track haulage and three long submains equipped with belt haulage for coal and track haulage for men and supplies. Before visiting this inconveniently located mine, greater care was taken by inspecting annotated mine maps and by detailed telephone discussions to confirm the presence of significant problems that had not already been solved.

Upon visiting the mine, our inspection and measurements verified that the carrier phone problems were significant, likely to worsen as the mine expanded, and well-suited to the available guideline remedies. The primary carrier phone problems were: moving dead spots in communication along the main line haulageway, high electrical noise levels during periods of extended rainfall, and signal attenuation and fadeout at the ends of the submains. The mine's many submains and panel branches also provided an opportunity for a good test of a dedicated wire installation with many matched power splitters. The pager phone problems were not severe, but of the annoying maintenance and repair variety routinely experienced in mines. Furthermore, the problems were expected to worsen with the planned expansion of both communication systems.

Actions were initiated in August 1980 to obtain a satisfactory written agreement from Beth Elkhorn Corporation that would allow Arthur D. Little, Inc., personnel to undertake the demonstration program at mine No. 26 in a timely manner. However, extended delays by Bethlehem Steel's corporate legal staff in the preparation of a satisfactory working agreement, required Arthur D. Little, Inc., to finally abandon this mine as the prime candidate in January of 1981, and to select another mine for the demonstration program.

APPENDIX B
A DRAFT PLAN FOR THE DEMONSTRATION
AT ROBINSON RUN MINE

Prepared by

Richard H. Spencer
Robert L. Lagace

for

Demonstration Plan Review Meeting with Robinson Run Mine Personnel

C-84086

April 1981

I. INTRODUCTION

Robinson Run mine has agreed to be a demonstration mine for the application of the dedicated wire concept for improving mine carrier phone communications. At present, the mine has an installed signal wire that covers about 11 miles of haulageway. This signal wire is presently operated in a non-optimal manner for a dedicated wire application. The demonstration program will convert this signal wire to a true dedicated wire. This wire will be converted to an RF transmission line that distributes the dispatcher's signals to all regions of the mine where the wire is installed. The conversion will be made by applying signal splits at all branches of the wire and by terminating each end of the wire. The impedance levels of bridging loads that are presently across the dedicated wire/rail transmission line will also be adjusted to higher values where appropriate.

II. OVERVIEW

The steps that will be taken to convert the present signal wire installation at Robinson Run (Figure B1) into a true dedicated wire (Figure B2) are noted below:

- 1) Install and check out the modified transmitter boards in all the fixed-station Control* transceivers.
- 2) Set these transceivers to match to a 150-ohm load by use of the Control* transformers with proper internal connections (see Figure B-3a).
- 3) Install four signal splits, one at each of the branching points in the signal distribution system (see Figure B-3b).
- 4) Install terminating resistors at six places in the mine (see Figure B-3c).
- 5) Set all remaining fixed station transceivers that are on the dedicated signal wire to a 150-ohm output impedance through the use of Control* transformers.
- 6) Remove all presently installed signal couplers between the dedicated wire and the trolley wire (see Figure B1).
- 7) Measure the current in the dedicated wire and the voltage on the trolley wire for transmissions from the 128 block transceiver.
- 8) As a later step, install the modified transmitter boards in all remaining Control* transceivers located on vehicles.

*Reference to specific brands, equipment, or trade names in this report is made to facilitate understanding and does not imply endorsement by the Bureau of Mines.

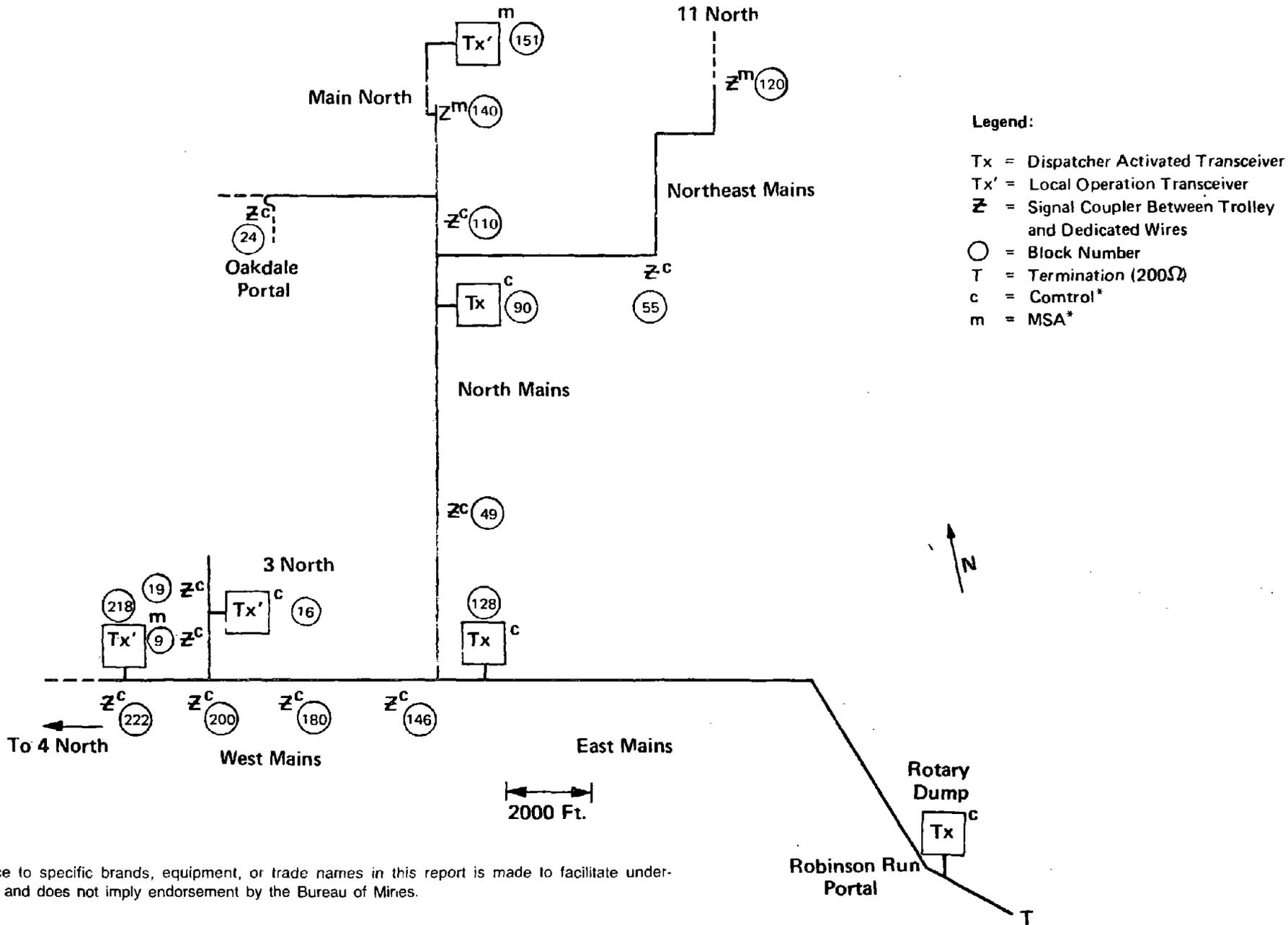


FIGURE B-1 SIMPLIFIED SCALE MAP OF ORIGINAL DEDICATED WIRE INSTALLATION ALONG ROBINSON RUN MINE RAIL HAULAGE NETWORK

*Reference to specific brands, equipment, or trade names in this report is made to facilitate understanding and does not imply endorsement by the Bureau of Mines.

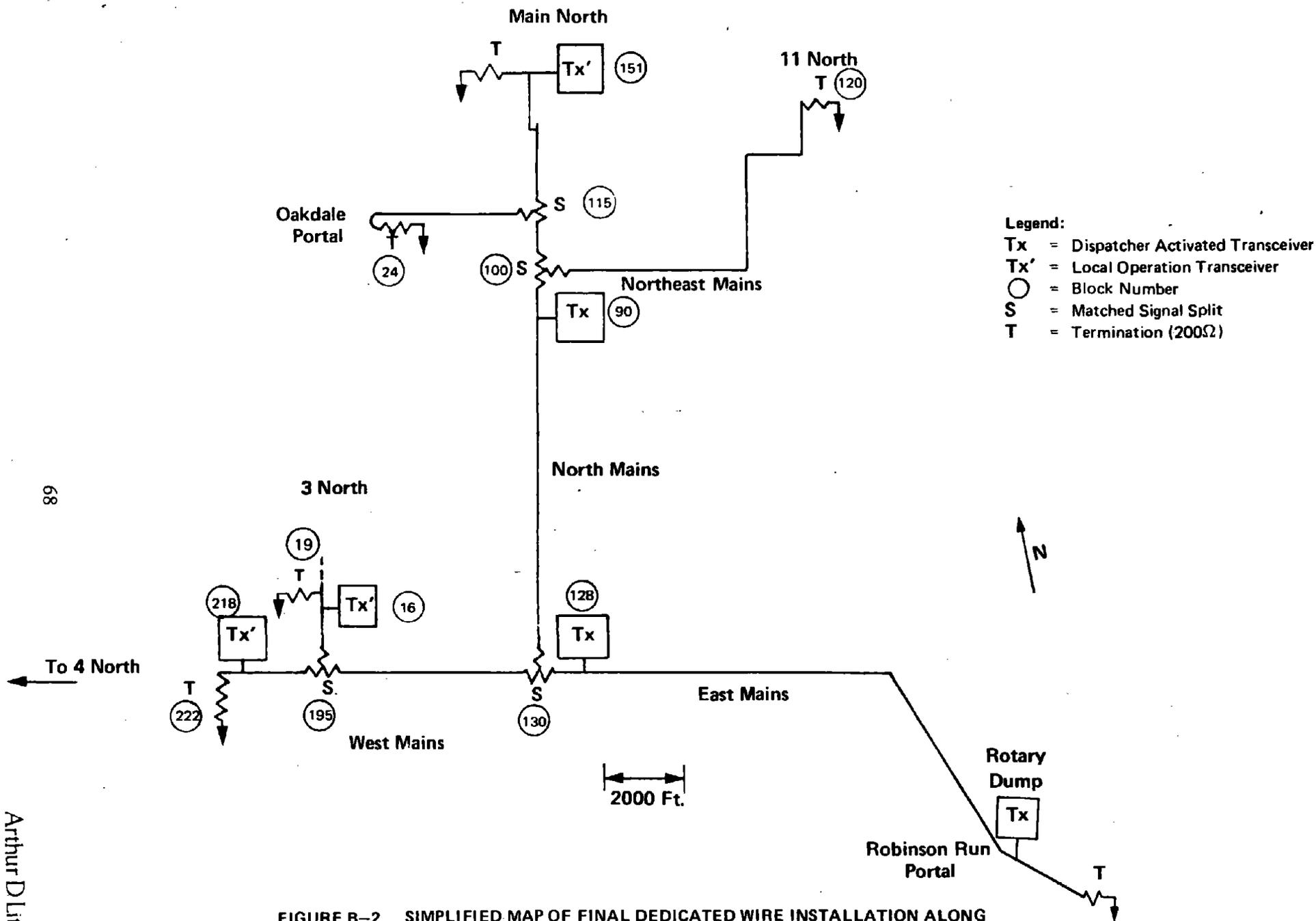
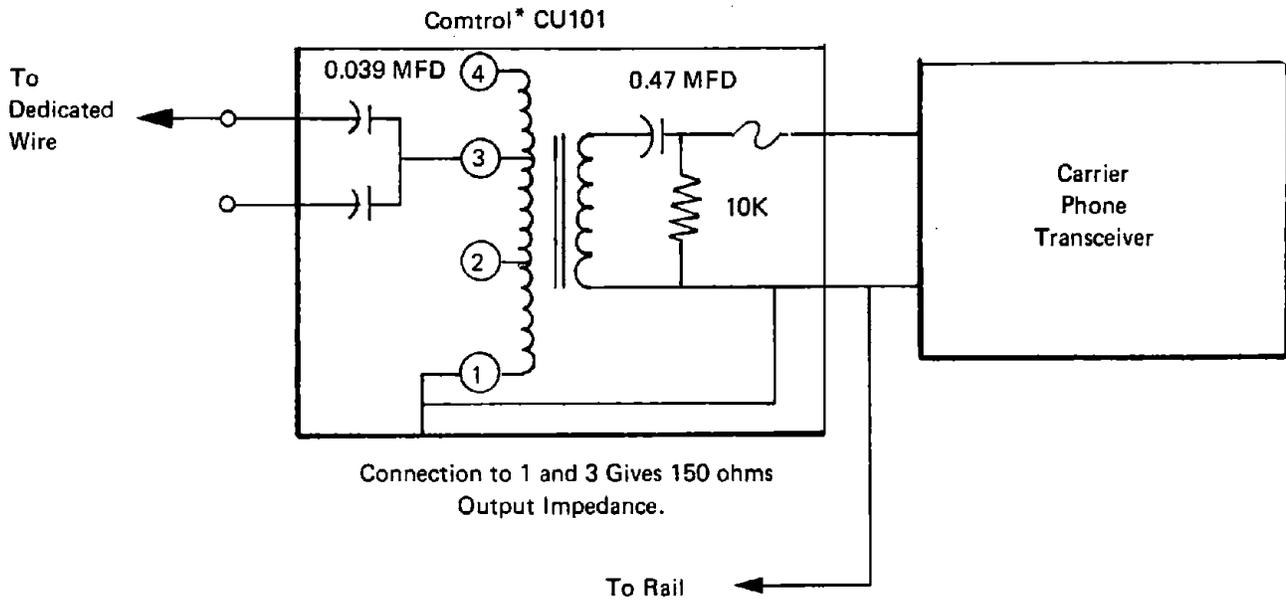
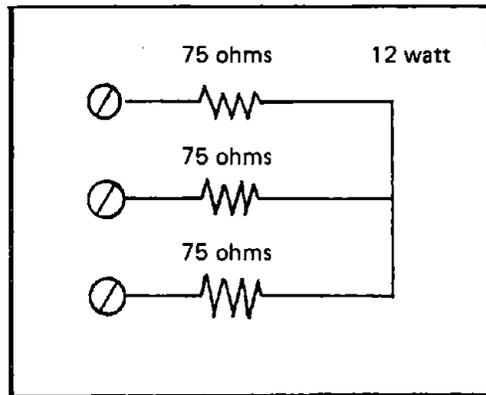


FIGURE B-2 SIMPLIFIED MAP OF FINAL DEDICATED WIRE INSTALLATION ALONG ROBINSON RUN MINE RAIL HAULAGE NETWORK

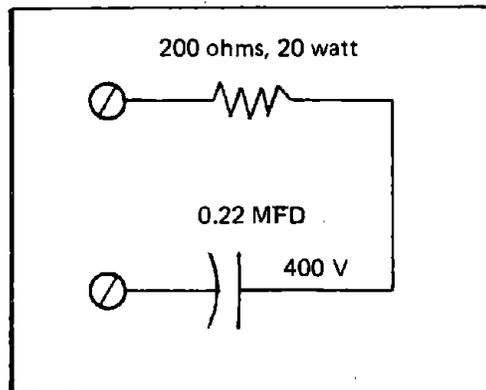


a) Signal Transformer for Connecting Transceiver to Dedicated Wire/Rail Line

*Reference to specific brands, equipment, or trade names in this report is made to facilitate understanding and does not imply endorsement by the Bureau of Mines.



b) Two-way Signal Split



c) Line Termination

FIGURE B-3 SCHEMATICS OF TRANSFORMER, SPLIT, AND TERMINATION

III. SEQUENCE OF PLANNED STEPS

The sequence of installation and modification operations is planned so that any step in the process may be reversed within a short period of time in the event that this step causes a deterioration of the total communication system. To provide this capability, some steps that could be combined are done separately and may appear to be done in a less than optimal way.

The sequence of events is also organized so that the least risky ones are done first. In fact, the first step is one that should, by itself, upgrade the entire system performance.

Step 1

Install a modified transmitter board in the Comtrol* transceiver at the outside rotary dump site. Set the associated coupler to a 150-ohm output impedance level. Verify the operation by checking the voltage delivered between the dedicated wire and rail. It should be between 40 and 70 volts depending on the exact line impedance seen at the point of installation.

Repeat this step at the 128 block Comtrol* transceiver, and at the 90 block north mains Comtrol* transceiver.

Step 2

Install signal splits at four places: Block 130, 100 north, 115 north, and 195 west.

Step 3

Install 200-ohm line termination resistors at five places; that is, at each underground end of the signal wire. For any fixed transceiver station near these terminating points, set the associated signal coupler for 150 ohms of output impedance. The five places for installation of line terminations are: near the Oakdale portal, 151 north, near 11 north dump, at 3 north 25, and at west 225. These installations could be readily made by entering the mine from the Oakdale portal if necessary.

Step 4

Disconnect all signal couplers between the trolley wire and the signal wire. There are 12 places where there are or have been such couplers: near the Oakdale portal, near north 140, near north 110, on the way to 11 north dump, at the 11 north dump, at 49 north, at 146 west, at 180 west, at 3 north 5, at 3 north 25, at 200 west and at 224 west. These installations could also be readily made by entering the mine from the Oakdale portal.

*Reference to specific brands, equipment, or trade names in this report is made to facilitate understanding and does not imply endorsement by the Bureau of Mines.

Step 5

Make a signal map of dedicated wire current and trolley wire voltage throughout the mine. It is estimated that 30 or more points of measurement will be required for the signal map for comparison with the "before" set of measurements made at about 90 points.

Step 6

Install modified transmitter boards in all remaining Comtrol* transceivers, mainly mobile transceiver units on vehicles. This step will probably be done when the replacement boards are received by the mine after Arthur D. Little, Inc., personnel are through with the in-mine measurements.

NOTE: Where required, heavy-duty ground wires bonded to the rails at all termination locations will be installed prior to the system conversion date.

IV. MANNING AND EQUIPMENT REQUIREMENTS

It is expected that several shifts of work will be required to accomplish the above tasks. It is planned that the mine provide a jeep and jeep driver. Arthur D. Little, Inc., will provide 1 or 2 persons to accompany the jeep driver and to carry out most of the tasks. The jeep driver should have general knowledge of the mine and should be responsible for disconnecting all signal couplers between the trolley wire and the dedicated wire when that task is undertaken. Arthur D. Little, Inc., will supply the signal splits and terminations. The supply of cable clamps, any extra wire required, spads, hooks, and fasteners will be worked out between Arthur D. Little, Inc., and the mine.

Measurement equipment will be provided by Arthur D. Little, Inc. (some of which will be on loan from the Bureau of Mines Pittsburgh Research Center).

V. THE MODIFIED TRANSMITTER BOARDS

Measurements made at Robinson Run in February revealed that the Comtrol* fixed transceiver stations attached to the dedicated wire showed a much lower than expected input impedance in the standby mode; namely, 200 ohms were expected and 20-30 ohms were found.

This finding was verified by in-situ and bench tests at the mine and was later confirmed by Comtrol* personnel. Comtrol* has found a way of raising this value to approximately 200 ohms without adversely affecting the performance of the transceiver, and Comtrol* has provided Robinson Run with a modified transmitter board for testing. If this new board proves to have the expected input impedance, then three such boards will be required for the dedicated wire installation demonstration tests, one for each of the dispatcher activated transceivers.

*Reference to specific brands, equipment, or trade names in this report is made to facilitate understanding and does not imply endorsement by the Bureau of Mines.

A brief verification test of the performance of the new circuit board will be made during the demonstration plan review visit to the mine. This will be accomplished by retrofitting the outside rotary dump transceiver with the new board, and making current and voltage measurements under transmit and receive conditions.

APPENDIX C
INSTALLATION DETAILS FOR
CONVERSION OF SIGNAL WIRE
TO TRUE DEDICATED WIRE
AT ROBINSON RUN MINE

I. FOR SIGNAL SPLITS

1. Select location for signal split box
2. Cut and strip three signal wire ends
3. Connect to box terminations (replace sealing gland inserts if required) using appropriate strain relief
4. Attach box to roof or other location using spads and wire and/or tie wraps
5. Visual inspection — leave

II. FOR THE FOUR CONTROL* CARRIER PHONES

1. Locate Control* phone
2. Replace transmitter board
3. Check Control* transformer for 150-ohm connection
4. Test output on signal wire (at transformer output) using multimeter (40 to 60 volts expected)
5. Visually inspect — leave

III. FOR TERMINATIONS WITHOUT A CARRIER PHONE

1. Locate place for termination box
2. Strip signal wire end, strip and connect ground wire
3. Attach signal and ground wire to box terminals
4. Drive spads for box attachment, and attach box to rib using wires and spads
5. Dress signal and ground wires — using spads and J-hooks and tie wraps
6. Measure and record dispatcher's signal with multimeter (across the termination)
7. Final inspection — leave

IV. FOR TERMINATIONS LOCATED AT AN MSA* CARRIER PHONE

1. Decide where to place termination — It should be near the phone

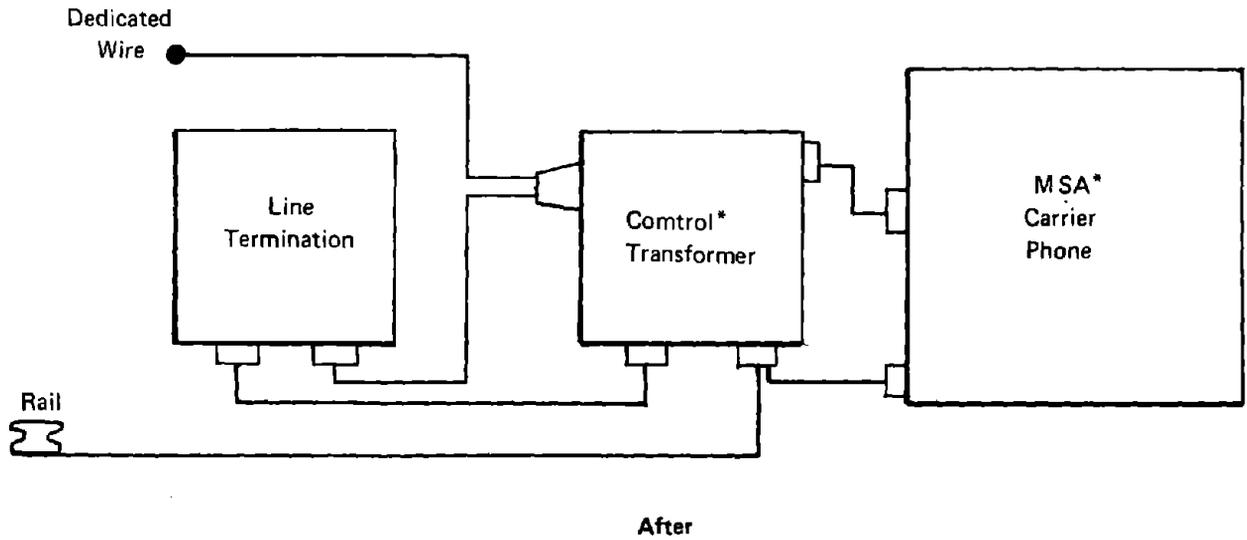
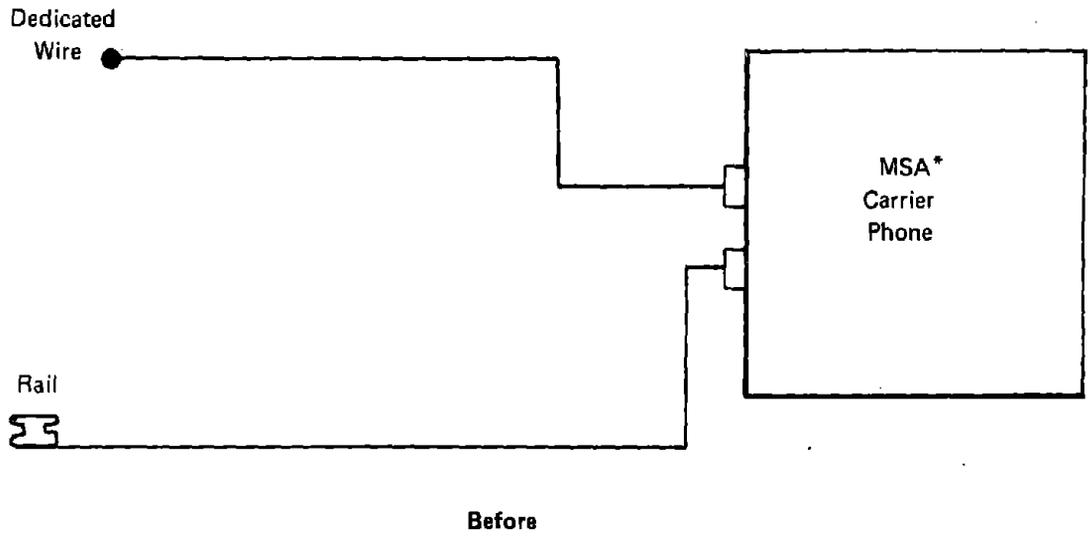
*Reference to specific brands, equipment, or trade names in this report is made to facilitate understanding and does not imply endorsement by the Bureau of Mines.

2. Decide where to place the Control* transformer
3. Open the MSA* phone — Place link to S2 position (mid-position), and secure phone
4. Set coupler for 150-ohm output
5. Rewire the phone output leads†
 - a. Wire that went to rail goes to transformer case
 - b. Wire that went to signal wire goes to transformer through gland
6. Attach new ground wire from rail to transformer case
7. Connect signal wire to transformer at one of insulated outputs on coupler
8. Connect a wire from transformer case to termination box
9. Connect a wire from transformer output (insulated terminal) to termination box
10. Attach coupler and termination to rib or other suitable location — using spads and wire
11. Dress wires using spads, J-hooks, and tie wraps
12. Measure and record dispatcher's signal with multimeter (across the termination)
13. Measure and record local carrier phone signal at same place, expect 40 to 60 volts
14. Make final visual inspection and leave

NOTE: Rubber sealing gland inserts on termination boxes may have to be changed to accommodate wire size.

*Reference to specific brands, equipment, or trade names in this report is made to facilitate understanding and does not imply endorsement by the Bureau of Mines.

†Note: Refer to Figure C-1 for steps 5 to 9.



*Reference to specific brands, equipment, or trade names in this report is made to facilitate understanding and does not imply endorsement by the Bureau of Mines.

FIGURE C-1 SCHEMATIC FOR INSTALLING A LINE TERMINATION AT AN MSA CARRIER PHONE LOCATION