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Anticollision Systems for Large Mine-Haulage Trucks

By Russell E. Griffin

BUREAU OF MINES

UNITED STATES DEPARTMENT OF THE INTERIOR

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CONTENTS

ILLUSTRATIONS

TABLE

UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

dB	decibel	μV	microvolt
ft	foot	mW	milliwatt
h	hour	st	short ton
in	inch	V	volt
kHz	kilohertz	V dc	volt, direct current
MHz	megahertz	yr	year
min	minute		

ANTICOLLISION SYSTEMS FOR LARGE MINE-HAULAGE TRUCKS

By Russell E. Griffin[1]

ABSTRACT

With the development of larger mine-haulage trucks in recent years, the visual field of the driver has diminished correspondingly. Specifically, the operator's lack of direct vision in the right front area and directly to the rear constitutes a serious hazard to personnel in nearby small utility vehicles. Recently developed electronic technology has made it possible to supplement the use of mirrors and fresnel lenses to warn the operator of specific collision dangers in the truck's blind areas.

This Bureau of Mines report describes the results of a coordinated contract and in-house research program to develop and test in-mine prototype electronic systems to detect the presence of smaller vehicles within the blind areas of large mine-haulage trucks. Each system utilized transmitters installed on the smaller vehicles and receivers installed on the haulage trucks. Transmitting techniques tested included both low- and high-frequency radio waves. On-vehicle testing established the engineering feasibility of each approach.

Further private sector product development to improve reliability and reduce system costs is recommended. Mining companies should consider the advantages of each type of system.

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INTRODUCTION

Since the early 1960's, the maximum capacity of off-highway haulage trucks used in surface mines has increased from 65 to over 250 st for current models. Since the size of trucks has increased, the position of the driver in relation to the truck's large engine and appurtenances, coupled with the elevated cab height, has resulted in a dramatic decrease in the direct visual field of the driver. This is particularly true for the areas immediately to the right front and behind the truck. The lack of direct vision in these areas constitutes a serious hazard to personnel in nearby small mobile equipment, especially in the many congested areas of an open pit mine or quarry.

The Bureau of Mines extended its previous investigations and development of passive devices for blind area protection to include rugged active electronics based technology that could detect hazards in blind areas not covered by passive devices and alert the operator to them. This Bureau report summarizes the results of a coordinated contract and in-house research program.

ACKNOWLEDGMENTS

Significant contributions were made by the Anaconda Minerals Co., Telemotive Division of Dynascan Corp., and Motorola, Inc. Also, the extensive help of William C. Yates, process control engineer, Anaconda Research Laboratories, Tucson, AZ, who provided technical input, assisted with the field tests, and provided liaison with the mine sites, is acknowledged.

BACKGROUND AND SYSTEM DESIGN CRITERIA

BACKGROUND

The problem of poor visibility on large mine-haulage trucks has been addressed through previous Bureau research on fresnel lens blind-area viewers, improved rectangular convex mirrors, and closed-circuit television.[2] These devices made it easier for the operators of large equipment to see potential hazards. However, analysis of in-pit usage of these devices indicated that alarms were still needed to alert the operators to specific dangers. In addition to equipping mine-haulage trucks with a variety of shapes and sizes of mirrors and other vision aids as well as providing periodic hazard awareness training to mine personnel, most mines have instituted organizational and operating practices aimed at reducing collision accidents.

Many mines paint all of their vehicles a bright color to improve their visibility. Unfortunately, when a single color is used for all vehicles, there is not color contrast between the hood of the haulage truck (over which the driver is looking) and the rooftops of nearby smaller vehicles, essentially camouflaging potential collision accident victims.

Some mines use poles or wands extending to a height of 15 ft attached to smaller vehicles such as pickup trucks, carryalls, and passenger autos to improve their visibility. In addition, some usage is made of pennant flags attached to the top of the wands and white electric lights for night use to improve the attention-getting visual target.

In order to reduce the uncertainty of where the smaller vehicles are located, some mines have designated stopping areas, usually marked by plastic traffic cones to indicate where smaller vehicles must park. Strict enforcement of the usage of these areas is reported by some mines to have greatly reduced the incidence of hits and near misses by the haulage trucks. However, there is a safety tradeoff effect; driver's reduced expectation that smaller vehicles will be parked outside of the designated areas, may put a disabled smaller vehicle not in a designated parking areas in greater jeopardy. Traffic management plans are also developed to help ensure smooth flow of traffic in and around pit areas. Included are operating practices such as designating right-of-way to loaded vehicles, and traffic control devices such as signs and stop-and-go lights. Nighttime illumination is also provided in congested areas.

SYSTEM DESIGN AND OPERATION CRITERIA

In order to assure maximum anticollision system effectiveness, considerable effort was undertaken to characterize typical collision accidents. Usually two types of collision accidents occur regularly. One type is the truck striking a nonmoving object that the driver cannot see (object in blind area). The other type is the collision of the truck with a moving vehicle, which enters into one of the blind areas without being seen by the driver. There is a third type wherein the operator collides with a visible object directly ahead in the roadway, usually another truck, due to lack of driver alertness. This last type of collision is not covered by the equipment described in this report.

[2]Eirls, J. L., S. F. Hulbert, and A. L. Foote. Improved Visibility Systems for Large Haulage Vehicles. Volume II (contract H0262022). BuMines OFR 127-82, 1982, 122 pp.; NTIS PB 82-251927.

Johnson, G. A. Improved Visibility Systems. Paper in Surface Mine Truck Safety. Proceedings: Bureau of Mines Technology Transfer Seminars, Minneapolis, Minn., June 25, 1980, Birmingham, Ala., July 9, 1980, and Tucson, Ariz., July 24, 1980, comp. by Staff. BuMines IC 8828, 1980, pp. 22-39.

Since it was intended that the anticollision systems developed through this research should augment and integrate with existing organizational and operating practices, system design criteria were developed through direct consultation with mine personnel. Management, safety personnel, and drivers expressed several concerns relative to anticollision system design. There was agreement on the need for an effective and reliable system to reduce the incidence and severity of large haulage truck collisions. There was also concern for costs, both initial purchase and life cycle. However, the greatest concern was for ruggedness and dependability of any system that might be developed. The latter concern was particularly critical to manmanagement because of truck downtime while safety equipment is under repair.

The response pattern of an electronic detector would need to be semicircular, centering near the right front corner and the rear middle of the haulage truck. Overlap at the right rear corner of the truck would provide coverage in addition to the rearview mirror. Detection distance would depend on the size of the truck, but a minimum of 30 ft seemed to be a consensus. Figure 1 illustrates the idealized detector encounter patterns.

Electronic interference must also be minimized. Care must be taken to ensure that the system does not interfere with any existing mine communications system. Also, the system on one truck must not interfere with the system on another truck, and there must not be any interference with nonmine radio frequency (RF) traffic.

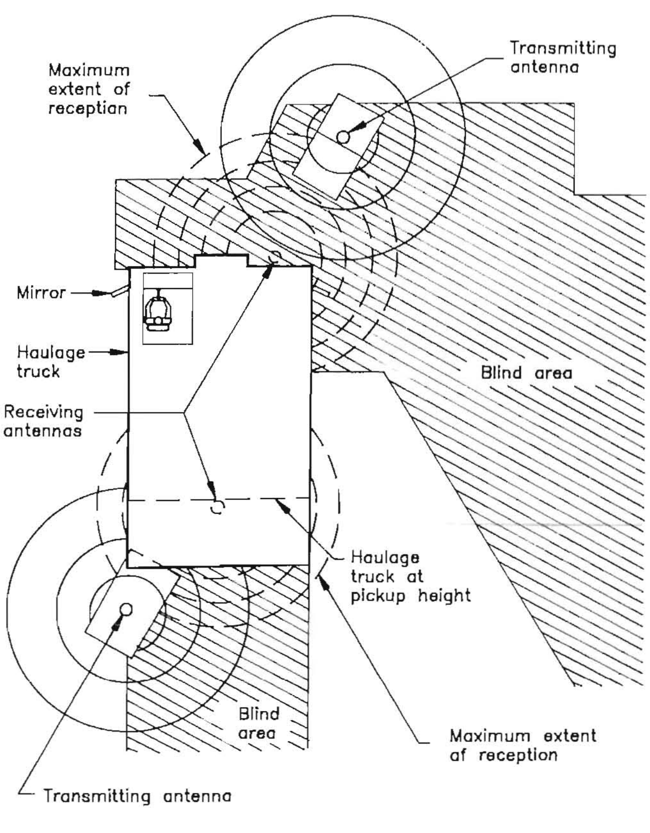

Figure 1.—Idealized detector encounter patterns.

Finally, the harsh vehicle environment must be considered. System ruggedness must be built in to withstand the shock and vibration encountered during the truck's operation. Mounting locations for the various components must be carefully considered for such things as availability of cab space and location of annunciator lights and horns, as well as their intensity. Antennas or other sensing components must be mounted in a secure location where they will not be readily knocked off or compromised by mud, snow, rain, or dust. Connecting wires and cables must be robust and mounted so they are not easily worn through by rubbing or cut by movement of truck components, and do not interfere with normal maintenance and overhaul of various truck parts.

The two prototype systems described in this report detect the nearby presence of other vehicles by the use of transmitting techniques based on very-low-frequency (VLF) radio waves and very-high-frequency (VHF) radio waves. They are similar in concept but differ in the frequencies used. Each system utilizes a transmitter mounted on the smaller vehicle. The signals continuously transmitted by the smaller vehicle are sensed by receiving units mounted on the right front and rear of the large haulage truck. The receiver, which detects a signal, operates warning lights and a buzzer in the cab, thus alerting the operator of the large truck to a possible collision hazard and the general area around the truck in which it exists. Each system is described in detail in this report.

CHARACTERISTICS OF RADIO FREQUENCY TRANSMISSION

VLF systems used for distance detection utilize the unique properties of inductive signal coupling between the radio transmitter and receiver units. This can be compared to the operation of an air-core transformer. The VLF antenna of the transmitter acts as a primary winding. The VLF receiving antenna acts as a secondary winding. The magnetic induction from the transmitting antenna induces the currents in the receiving antenna.

The near field or induction field of a transmitting antenna is usually defined to be the place where the magnetic induction field strength is 10 times or more greater than the radiation field strength from the same antenna. The near-field region can usually be considered to be a region within one-tenth of a wavelength from the transmitting antenna.

In the near field the received signal field strength (in volts per meter or ampere turns per meter) decreases inversely proportional to the cube of the distance between the transmitter and the receiver. This means that, at the receiver, the signal field strength drops to one-eight of its original value when the distance is doubled, and to one twenty-seventh of its original value when the distance is tripled.

The far field or radiation field of a transmitting antenna is usually defined to be the place where the radiation field strength is 10 times or more greater than the magnetic induction field strength from the same antenna. The far-field region can usually be considered to be the region beyond a few wavelengths from the transmitting antenna.

In the far field the received signal field strength (in volts per meter or ampere turns per meter) decreases inversely proportional to distance. This means that, at the receiver, the signal field strength drops to one-half of its original value when the distance is doubled, and to one-third its original value when the distance is tripled. The region between the near field and the far field is usually called the transition field.

The relatively fast decrease of received signal field strength with distance in the near field allows the design of a system that is able to have a well-defined maximum operating range. Thus, to operate in the near field it is necessary to choose a frequency low enough that the near field occurs within practical operating distances. Such a frequency range is the band from 200 to 400 kHz where a wavelength is from 4,900 to 2,500 ft and the near field range limits are 490 to 250 ft.

The antennas used with a VLF system are unique when compared to the usual short whip antenna of a VHF system. The VLF antennas consist of coils of wire, which are wound on a rod of ferrite material. The inductance of the coil, along with the stray capacitance and the circuit capacitance associated with the antenna, are adjusted to resonate at the transmitted frequency.

Most of the power fed to the transmitting ferrite rod antenna is used to set up a time-varying magnetic field. The receiving antenna generates an induced voltage from the intercepted magnetic lines of flux as the secondary coil of an air-core transformer.

Both the receiving and transmitting ferrite rod antennas have a torus-shaped field pattern for describing their directional sensitivity. Figure 2 shows how the axis of the antenna can be oriented for maximum or minimum signal coupling. The low-frequency energy radiated penetrates low-density solids almost as easily as air, and such objects do not obstruct the RF path. However, medium- and high-density solids such as steel have a shielding effect, which obstructs the flux path. The antenna must be kept at least 3 in from mounting surfaces made of steel, aluminum, or other metallic materials.

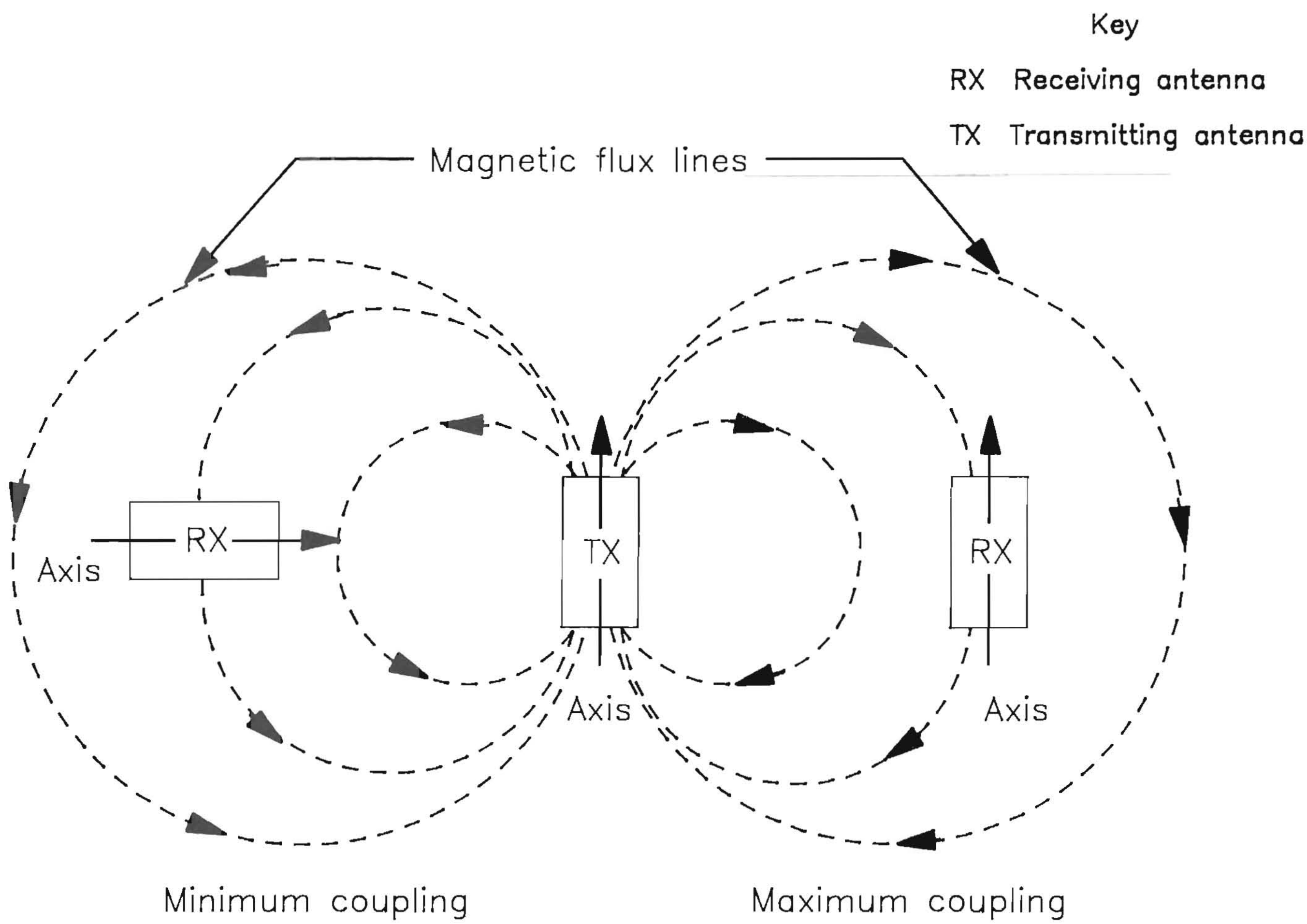

Figure 2.—Antenna orientation for maximum or minimum coupling.

Operation in the VHF part of the RF spectrum for distance detection utilizes the far field or radiation field of the transmitting antenna. At these frequencies (30 to 300 MHz) wavelengths are a few feet, and as mentioned previously, the signal strength of the field decreases inversely proportional to distance. Thus, by using very low transmitting power and sensitive receivers, the detection distance can be kept in the proper range with very little chance of interfering with other signals in the same band. In addition, by means of pulse coding, the receivers can be made to respond only to the desired signal.

TESTING OF PROTOTYPE SYSTEM

VERY-LOW-FREQUENCY SYSTEM

In 1981 cooperative research was initiated by the Bureau with Anaconda Research Laboratories, Tucson, AZ and the Telemotive Division of Dynascan Corp., Chicago, IL who had been marketing a system used on overhead traveling cranes and for some materials handling applications. At the behest of the Bureau and Anaconda, a prototype battery-operated, VLF-type distance detector system was subsequently tested on several haulage trucks ranging in size from 100 to 170 st capacity. Pilot monitor and sensitivity control adjustments were made to detect a small vehicle in the blind areas. Reception patterns and the system noise immunity were good, and further development of the system seemed appropriate.

Based on the success of this test unit, a second-generation prototype system was specified jointly by Bureau, Anaconda, and Telemotive personnel. Features such as high- and low-frequency electromagnetic noise rejection by the system, adjustable system sensitivity, ease of distance calibration, small package size for ease of mounting, low power requirements, and an internal system to continuously self-test all electronic circuits (fault detection) were included.

Specifications also included a two-channel receiver to allow independent monitoring of the front and rear antennas. Each receiver channel would have a separate distance adjustment and two light-emitting diode (LED) lamps. The first lamp would be continuously illuminated when no fault exists in that channel; i.e., all aspects of the receiver system including antenna, cable, and receiver electronics are functional. The second lamp would provide a visual indication to the operator as an approaching vehicle enters a blind area. The two-channel displays together would give an indication of the relative position of the hidden vehicle. The visual display would be accompanied by a pulsating tone, which is resettable.

Additional characteristics of the receiver would include an auxiliary channel for each main channel. This channel, with slightly less sensitivity, would back up the main channel. If the main receiver should fail to sound an alarm because of an electronic failure, the auxiliary receiver will still sound an alarm upon the approach of a vehicle. If the auxiliary receiver is used, the OK light, normally on, would be extinguished, indicating a system failure, but an alarm would still be provided.

The utility vehicle's continuous transmitter would also have fault detection circuitry. A 6-dB (2:1) or greater drop in transmitter output, a shorted, open, or detuned antenna, as well as a complete transmitter failure, would all be detected as faults. An LED lamp on the transmitter front panel would indicate normal operation. A fault condition is indicated by an extinguished lamp.

One second-generation prototype system consisting of a dual-channel receiver and two transmitters, as described above, was fabricated for in-pit testing at the Twin Buttes Mine near Tucson, AZ. The mine provided a 120-st-capacity haulage truck for the tests, along with a half-ton pickup truck. Figure 3 illustrates the mounting location for the front receiving antenna, and figure 4 shows the rear receiving antenna.

With the haulage truck stationary in a truck parking area, the right front and rear detection range thresholds were set to approximately 20 ft beyond the right front and rear wheels. After these initial distances were set and some preliminary tests completed, the truck was driven around the mine area. Sporadic false alarms occurred and continued after the truck returned to the parking area. Examination of the system showed there was a faulty antenna cable to the front antenna and interference from the haulage truck's two-way radio system.

Based on these results, several modifications to the equipment were to be implemented, including increased powerline filtering for the dual receiver, mounting the receiver components in a metallic enclosure, and locating the audio alarm and indicator lights in a separate small enclosure, which would be easier to mount in the driver's line of sight.

After several of these changes were made, testing was resumed at the Berkeley Pit Mine in Butte, MT. An additional system with the same specifications was added to expand the test program. Receiver units were mounted on two different 170-st-capacity haulage trucks. One of the receiver units had been modified to incorporate a remote display. This receiver unit was mounted behind the driver's seat in the cab of the haulage truck, and the separate display was attached to the molding around the instrument panel in front of the driver. The other receiver, not modified, was located on top of the communication receiver located at the right front of the cab. The antennas were located as previously described for the initial test, except now they were mounted in brackets securely fastened to the truck by bolts.

The transmitter antennas were left with magnetic mounting bases for ease of changing vehicles (fig. 5).

Figure 3.—Mounting location of front receiving antenna for Telemotive system.

Figure 4.—Mounting location of rear receiving antenna for Telemotive system.

Figure 5.—Transmitter antenna mounted for Telemotive system.

Transmitter units were installed in two company pickup trucks and one larger service truck.

Initial testing again demonstrated that the units were susceptible to interference caused by the haulage truck communications equipment. The receivers were removed and a metallic foil layer was applied to the exterior of their plastic boxes. Following this, testing showed a major reduction in communications-induced interference to the warning system. Additional tests were performed in a truck parking area and during mine operation. These tests led to the following conclusions:

1. The receiver unit must be in a metallic box to reduce the effects of an electrically noisy environment.
2. The status-warning indicators should be remotely located to allow flexibility in locating the relatively bulky receiver.
3. Bright sunlight in the truck cab requires that the status-warning indicators be brighter or shaded from direct sunlight exposure.
4. The antenna leads should employ a twinaxial cable with a grounded shield.
5. The transmitter needs an audible fault indicator if it is out of sight of the operator.

These two systems remained in place for several months for long-term evaluation. During that time, one of the receiver units failed and was returned to the manufacturer for evaluation. Two of the rear receiver antennas were also replaced. One of the haulage trucks appeared to have a significantly noisier electrical environment, particularly in its rear area. This caused false alarming on the rear channel. To counter this problem, the rear receiver gain was reduced to a threshold range of 30 ft. After these repairs and adjustments, the two units functioned as designed.

The transmitter units produced an interference to the communications units installed in the pickup trucks. This interference was traced to clipping in the output stage, which was producing broadband spurious radiation. Adjustment of the output drive current level and some additional filtering cured this problem.

Another observation made by the operators was that the remote display box lights were annoyingly bright during the night. This led to the introduction of an automatic light level adjustment.

Based on this testing, a third-generation system was developed. Among the changes were (1) mounting the receiver components in a conductive enclosure with mounting tabs, (2) changing the antenna cables from coaxial to a two-wire shielded cable (twinaxial), and (3) relocating the system's in-cab warning unit to a separate small box for ease in mounting. In-pit testing of the third-generation system on two haulage trucks and three smaller vehicles was performed at the Twin Buttes Mine.

Receiver antennas were mounted to special brackets welded to the haulage trucks at a height of about 6 ft and located on the right front of the radiator housing and center rear of the truck. The receivers were mounted under the buddy seat of the respective haulage truck, secured with four 1/4-in bolts welded to the floor. Cab layouts controlled the placement of the display boxes. In one case, the right side of the dash area provided space for the box, and in the other case, dash space was limited so the display box was mounted above the right door, where the driver could observe it as the right rearview mirror was used.

Rear antenna cable was routed from the cab, following existing cables and hoses, down along the truck frame, over the rear axle housing to the location of the antenna. The cable to the front antenna was routed along the existing cables by the instrument control housing, then forward and down to the antenna located on the radiator shroud. Tie-wraps held the cables in place.

Power for the receiver was supplied from the truck's electrical system. The power supply cable was shielded, and the shield was connected to the ground at the receiver chassis.

The transmitters were mounted in their respective small trucks by fastening them to a speaker bracket on the dash, allowing the driver to view the ON-system light for assurance that the transmitter is functioning. The magnetic-mount-based antenna was placed on the roof approximately over the center of the passenger compartment. Its cable was routed over the roof, down the back of the cab, through an existing hole near the bottom of the cab, under the floormat, to the location of the transmitter.

After installation, initial testing showed an electrical noise problem with one of the units, generally affecting the rear channel. The interference appeared to be mixing with the collision protection system's internal frequencies and causing random false alarms. After some searching, the source of the problem was found to be the truck's UHF communications system power source–a direct current-to-direct current switching inverter, which emitted large amounts of broadband RF interference. The other truck's UHF communications transceiver was supplied by a different vendor, and it did not emit a high level of interference. Several remedies were tried to eliminate the noise problem. The most successful solution was to enclose the antenna wiring in conduit.

Because of operational schedules, the communications system on the noisier truck was not tested during ore hauls. The system on the other truck did receive a test period of about 2 months. Use of the dynamic braking system on this truck produced an occasional false alarm, but did not seriously affect the field testing.

The right front alarm distance was adjusted to activate prior to the disappearance of the small vehicle into the blind area of the haulage truck. The rear alarm distance was established at about 39 ft to provide adequate distance to the rear of the truck when backing. Even though this distance seemed excessive to the side of the truck, the haul roads at the mine were sufficiently wide to allow passing clearance with few alarms.

The system proved its worthiness when an operator unfamiliar with the test program was assigned to drive one of the trucks equipped with the prototype anticollision system. As the operator was backing, the alarm sounded. Not knowing the purpose of the signals, the operator stopped the truck and called a mechanic. Upon arriving on the scene, the mechanic found that the haulage truck had nearly backed into a transmitter-equipped unoccupied pickup truck, stopping just in time to avoid a collision.

A final test of the system was performed at the Minorca Mine near Virginia, MN. Additional design changes included improvement of the receiver noise immunity, reduction of the size of the receiver units to about one-half their original size, a change of the system ON lights from red to green LED's, and addition of a dimmer circuit to the annunciator-signal light attachment for nighttime dimming of the system ON lights and the warning lights.

Two prototype anticollision systems were installed on 130-st-capacity-haulage trucks. Transmitters were installed in two foremen's trucks and one maintenance truck. Installation procedures learned from previous field installations were followed (see appendix). One difference was the installation of the front channel receiver antenna at the right corner of the cab deck. After a 12-month endurance test, the systems were functioning properly. No interference problems were observed, either from truck internal sources or external sources such as lightning, mine powerlines, or other nearby vehicles that had no VLF transmitter. Also, no other near-collision incidents were reported.

VERY-HIGH-FREQUENCY SYSTEM

In 1981, cooperative research was initiated by the Bureau with Anaconda Research Laboratories and the Motorola Co. toward development of a VHF radio system for mine haulage truck anticollision applications. The system was based on Motorola VHF portable communications technology. Initial testing was completed on a haulage truck at the Twin Buttes Mine. A transmitter tuned to a frequency of 152.625 MHz, with a quarter-wave antenna, was installed on a pickup truck. A receiver tuned to the same frequency having 50 μV sensitivity was mounted in the cab of a 130-st-capacity haulage truck and connected by 40 ft of antenna line to a quarter-wave antenna mounted at the rear central area of the truck, about 6 ft off the ground.

The haulage truck remained stationary on the ready line while the pickup truck was driven around it, approaching from various angles and speeds. This procedure and system gave a consistent alarm within a 22-ft semicircular radius at the rear of the truck. Also it was reasonably consistent in disengaging at about 35 ft. However, the system responded sporadically within the 22 to 25 ft radius. Also, there were responses from the sides and front of the truck with no consistent pattern.

Even though the responses were not entirely consistent, they did demonstrate the feasibility of the concept of using higher RF's. Therefore, a second-generation system (fig. 6) was developed, which incorporated several improvements over the original design. These included more permanent and rugged packaging, and separation of the reception of front and rear signals. The latter was accomplished by using two independently operated receivers with separately positioned antennas to provide input from the front and rear blind areas, respectively. Though independent, the receivers were tuned to the same carrier frequency and mounted in a single enclosure with two RF connectors for coaxial cable connections to the front and rear antennas. Internal barrier-type terminal strips provided wired connections to 24-V dc power from the truck, and two separate, isolated relay contact closures were provided for connection to external indicators or annunciators. The relay contacts are closed when a signal is being received and open when no signal is present, and they have no latching or interlocking.

Each small vehicle to be protected has a low-power (less than 100 mW) VHF transmitter installed, which continuously radiates a tone-modulated carrier signal. This transmitter is also mounted in a sturdy metal case, fastened under the vehicle's hood and connected to the 12-V battery. Its signal is carried via coaxial cable to a magnetically mounted rooftop whip antenna, which gives a circular signal radiation pattern.

Internal access controls in the receiver box include squelch sensitivity adjustments and a resistive pad for adjusting the input signal attenuation. The transmitter also has a similar resistive pad for adjusting the antenna output. By means of these adjustments, an optimum balance

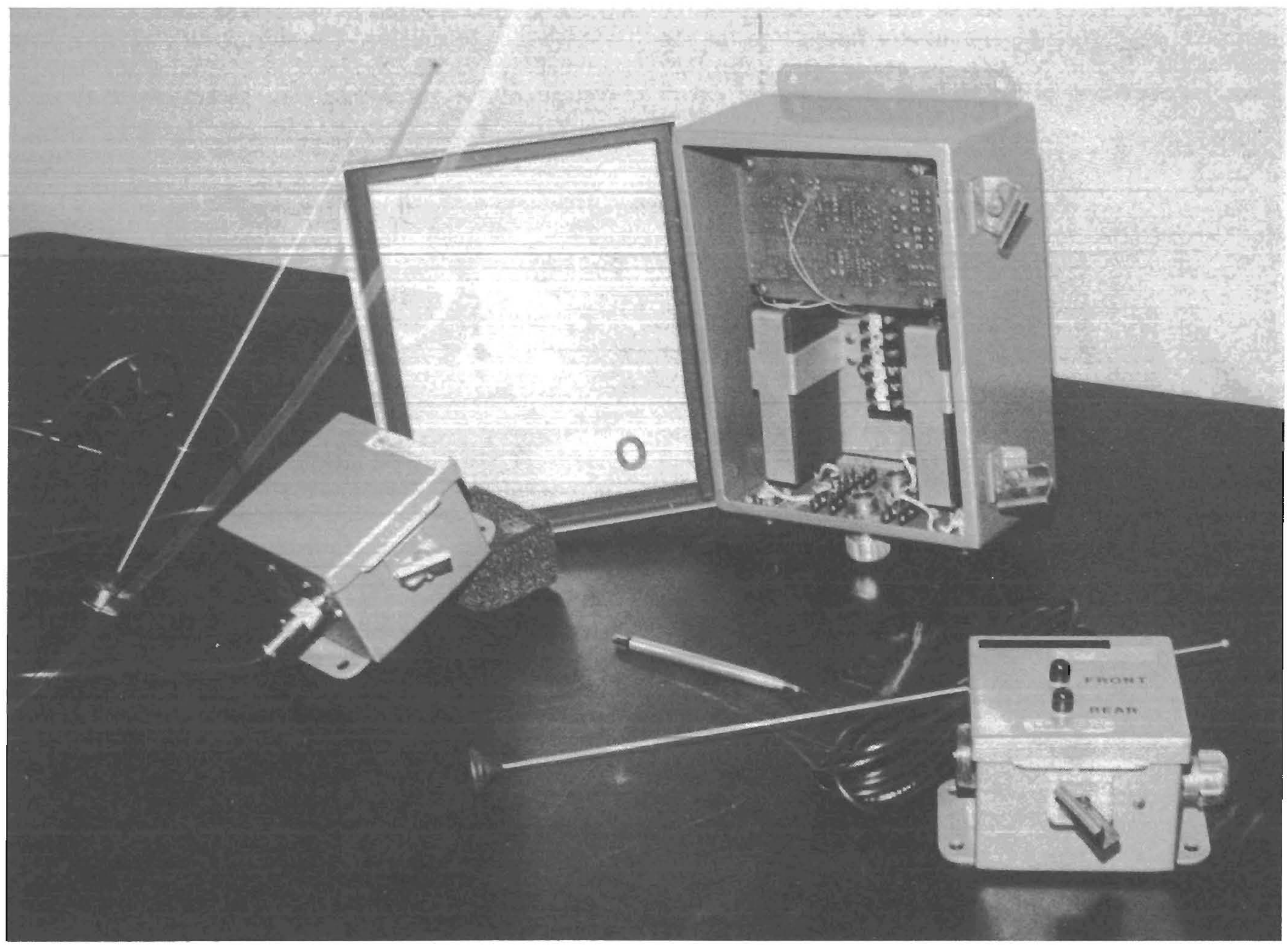

Figure 6.—Second-generation Motorola system.

between signal strength and receiver sensitivity can be obtained at the time of installation to take into account variations in truck size and lead lengths.

The cab display unit is housed in a 4- by 4- by 3-in steel mini-enclosure with mounting flanges. An indicating light is mounted for each channel and marked for front and rear indication. An automatic light dimmer circuit is included to compensate for changes in external light conditions, and an audible alarm sounds continuously (cannot be turned off) when a transmitter is in range. The cab display units are wired to the receiver output terminal strips by environmentally suitable cabling and also receive their operating power from these terminal strips.

Six second-generation units were fabricated for testing after receiving a frequency assignment of 172 MHz from the Federal Communications Commission (FCC). These were functionally tested on a 120-st-capacity haulage truck test fixture.

In-pit testing was undertaken at Carter Mining Co.'s Caballo Mine near Gillette, WY. The system was installed on a 170-st-capacity truck. The dual receiver was physically located on the outside of the front surface of the jump seat base, with the annunciator fastened to the top rear of the divider between the seats, behind the shift lever. Power was obtained from the common circuit breaker bus under the dash cowl such that the system was energized when the truck's master switch was on. Flexible, watertight conduit was run from the right front corner area of the truck deck and the rear center area between the wheels at the backup alarm mount to a point under the cab where it could be inserted into an opening under the dash. Four-inch-square plates were welded at the right corner and rear center onto which the receiver antennas were mounted, pointing downward. From the antenna base, coaxial cable was extended through the conduit to the space under the dash and onto the receiver antenna connection (fig. 7).

A mine utility pickup truck was also provided, and the system transmitter was installed on the engine compartment firewall, with electrical connection to an accessory terminal on the fuse block under the dash. The antenna was mounted on a magnetic base and placed on the roof of the truck with the lead coming down along the left corner past, under the hood, onto the transmitter connection (fig. 8).

After the two installations were completed, the haulage truck was driven out to an open space where it was parked with the engine running. The pickup truck was then driven around it at varying distances to determine the detection pattern of the receivers. The pickup truck could be

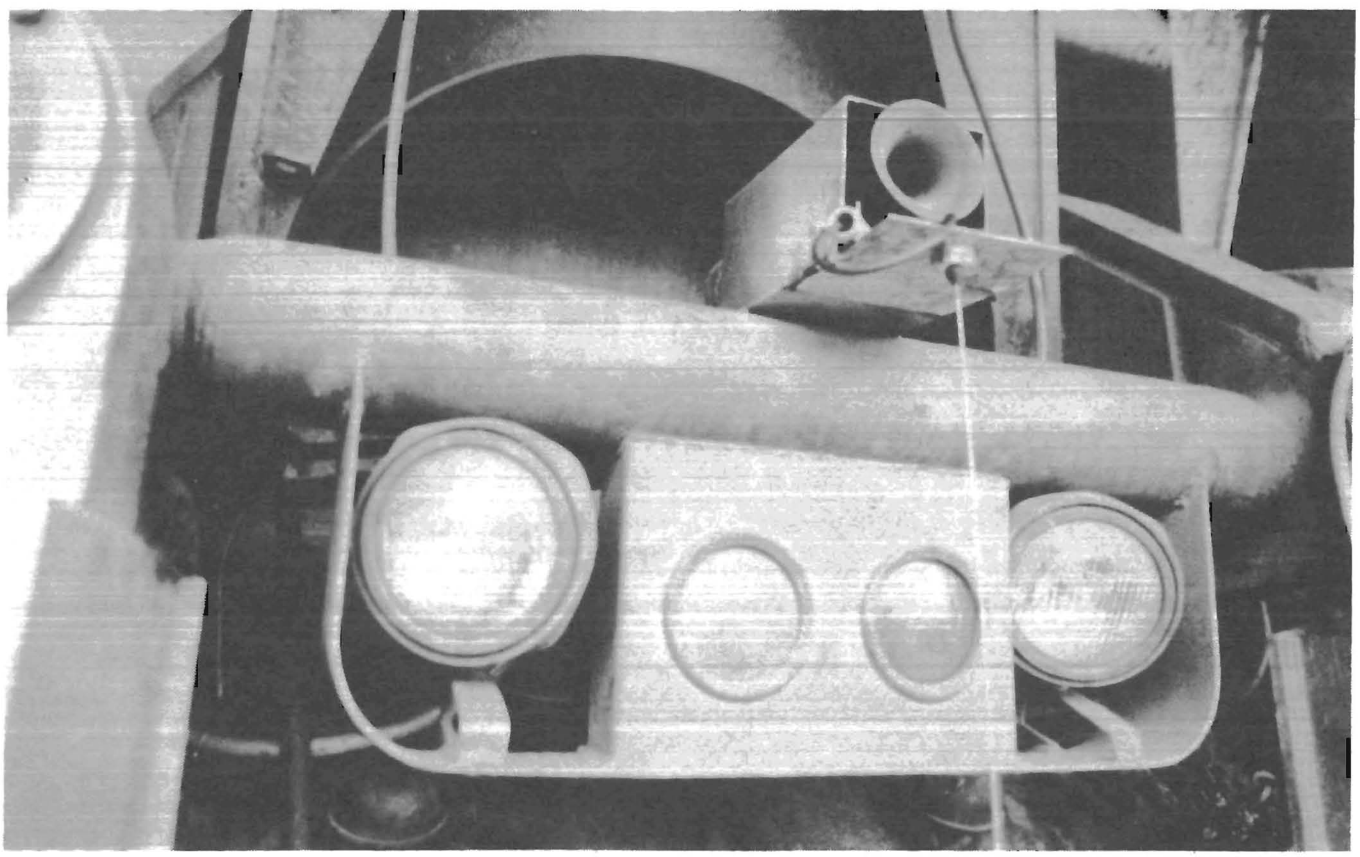

Figure 7.—Rear receiver antenna mounted for Motorola system.

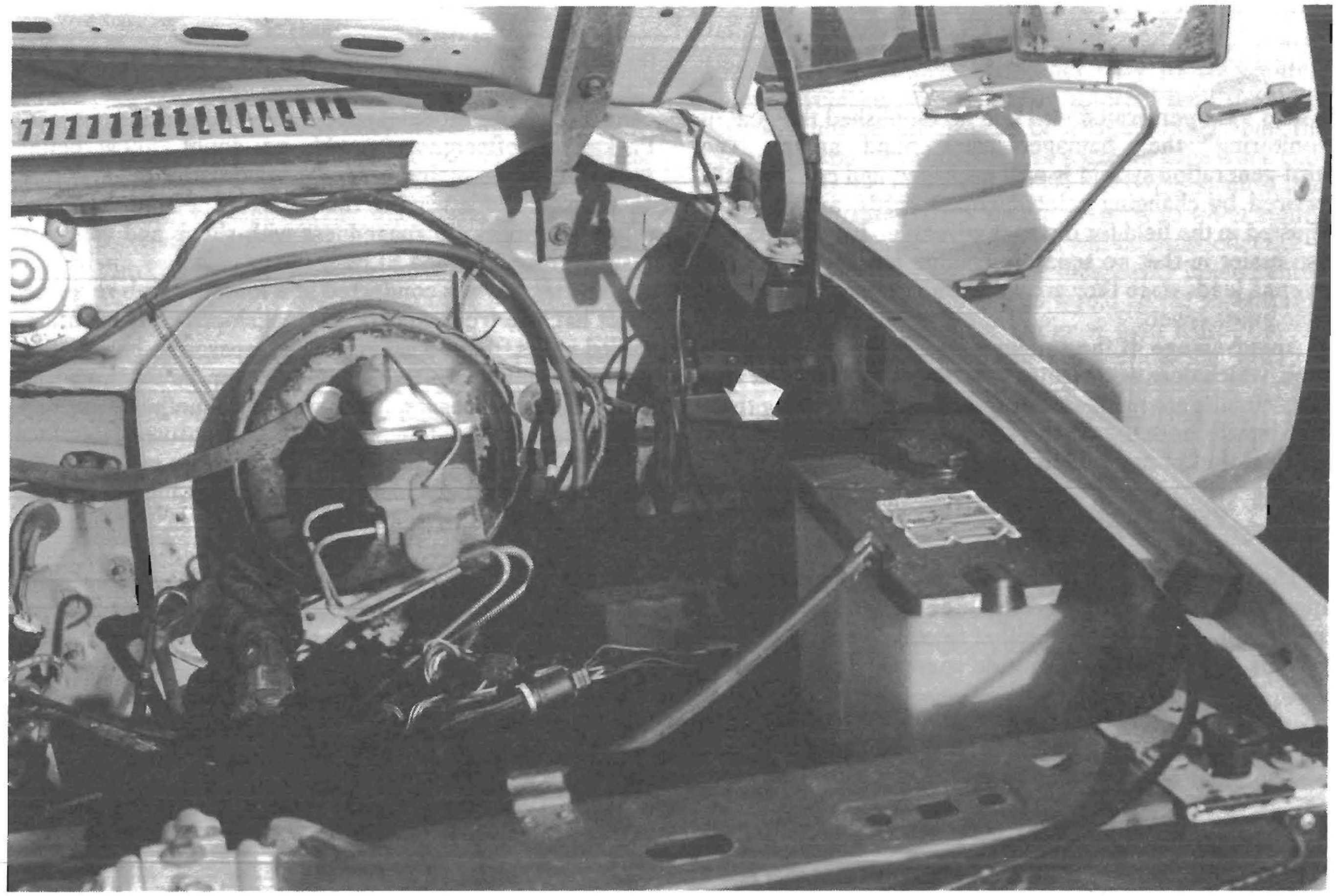

Figure 8.—Transmitter location for Motorola system.

detected by the receivers over an approximate 270° arc around the right front, right rear, and rear blind area of the haulage truck at a distance of 40 to 50 ft. However, the right front receiver seemed less sensitive than the rear receiver and had some dead spots where there was no detection. There was some dual detection about midway on the right side of the truck. It appears that some signal from the transmitter can leak under the truck at certain locations and trigger the wrong channel. This happened only on close approach to the haulage truck and over small areas.

A different receiver was substituted for the original one installed on the haulage truck, with the same front and rear input attenuation settings. Also, the transmitter output attenuation was made one step smaller. This combination worked much better in that there were few real dead spots and the front receiver coverage distance was now about the same as the rear receiver distance, approximately 55 ft. The receiver antenna attenuation was set at 29 dB for the front and 26 dB for the rear; the transmitter antenna attenuation setting was left at 26 dB.

The system was left installed, as described, for mine personnel to monitor for a period of 1 yr. The testing procedure consisted of monitoring, on a shift basis, the effectiveness of the system and documenting any maintenance problems or any accidents the system may have prevented.

Testing was ended when the haulage truck was taken out of in-pit service and the transmitter removed from the utility vehicle. The mine reported that no failure occurred on either the transmitter or the receiver during this time. The only maintenance performed was removing the transmitter from the original pickup truck on which it was installed to another pickup truck because of the reassignment of mine vehicles. This change was completed in approximately 30 min. The transmitter withstood 60,417 miles of pit driving conditions and the receiver 6,780 h of service. The receivers continued to detect the approach of the transmitter-equipped truck within 55 ft of the truck during the test period, but no incidents of possible accidents being prevented were reported.

DISCUSSION OF TEST RESULTS

VERY-LOW-FREQUENCY SYSTEM

The VLF performed well and accomplished the goal of monitoring the haulage truck blind areas. The third-generation system is well packaged and can be easily serviced by changing printed circuit cards, and is easily adjusted in the field for distance coverage. Installation was also easier in that no separate conduit is required for the antenna leads since they are well armored by shielding and their outer cover.

An advantage of the system is the low-frequency operation, which does not require FCC licensing. Also, as long as its circuits are properly adjusted in manufacturing there is no interference to two-way radio communications, which are operated at much higher frequencies.

VERY-HIGH-FREQUENCY SYSTEM

The VHF system had the longest continuous test and appears to have performed the most reliably and consistently with no interference, either to other communications systems or to itself, from outside sources. This system, as tested, was not in an optimum package or configuration. Basically, it is comprised of several different off-the-shelf communications modules adapted for this specific purpose. Packaging refinements would, no doubt, allow better accessibility for maintenance and adjustments of output and reception for varying the detection distance. At the same time, package ruggedness with shock and vibration resistance would need to be retained.

The testing was conducted at a minesite with relatively short haulage truck runs of gradual slopes and well-maintained roads. However, there is no reason to believe that it would not perform as well in a deeper, larger mine with more rugged exposure. The system is another form of a communications system, and these are now used in surface mines in a routine manner without excessive maintenance.

One disadvantage when compared with the other types of systems tested is the requirement for an FCC license. However, this should not be difficult to obtain, especially with the help of a manufacturer whose product lines are dependent on such procedures.

Table 1 summarizes the testing of the two systems.

TABLE 1. - In-mine tests of haulage truck anticollision systems

Test location	Test date	Vehicle capacity, st	Comments
	MOTOROLA		
Twin Buttes, Tucson, AZ	4/81	120	Feasibility test.
Bureau of Mines Twin Cities (MN) Research Center	11/83	120	Preliminary checkout, in-house.
Caballo Mine, Gillette, WY	8/84-7/85	170	No failures, detecting within 50 ft.
	TELEMOTIVE		
Twin Buttes Mine, Tucson, AZ	3/81	170	Feasibility test.
Do	10/81	120	Preliminary field test of prototype system.
Berkeley Pit Mine, Butte, MT	2/82-8/82	170	Interference problems,, 1 failure.
Twin Buttes, Tucson, AZ	11/82-1/83	150	Modified system. 2 installed, 1 on-line. 1 collision avoidance.
Minorca Mine, Virginia, MN	4/86-present	130	2d-generation test. 2 installations; some initial problems, but now working.

CONCLUSIONS

The systems described in this report address only the problem of the relatively restricted blind areas around large mine-haulage trucks. They were similar to each other in that each one depends on the interaction between a transmitter and a tuned receiver with somewhat primitive direction indicating capabilities. They differ in the portion of the electromagnetic spectrum in which they operate. This, in turn, gives rise to different response characteristics, packaging needs, costs, maintenance problems, and environmental interaction.

No attempt was made to link the system response to automatic braking or semiautomatic braking. Because the warnings given pertain to specially marked objects within the truck's blind areas, and the haulage truck will almost always be moving from a standstill position, getting the driver's attention is the most significant factor in the process of preventing blind area collisions. Also, because they were developmental systems, it was desirable to keep them fairly simple in concept and operation. Once a given system is proven to be effective, both in terms of cost and protection, the addition of automatic braking could easily be done at the option of the user, depending on the safety philosophy of the mine management.

Once the systems are developed to the point of being ready for production, there should not be a false alarm problem. The receivers respond only to transmitter-equipped vehicles, and unless an internal fault develops, there will not be any source of a signal other than the objects marked for protection. In some haulage truck cabs there are six or more lights, horns, buzzers, etc., that drivers need to keep track of and respond to when appropriate. Collision warning systems will be most effective if they elicit immediate response. One easily implemented improvement in an alarm system would be the substitution of voice warning output for audio or light alarm output. Digital voice synthesis has made great strides and will continue to come down in cost.

In final production form either system (receiver transmitter combination) should cost less than $2,000 in small quantities.

Each of the techniques described in this report offers a viable approach to collision protection for the right and rear blind areas of large mine-haulage trucks. Additional system improvements with respect to costs, maintenance, and ruggedness would be desirable, and further private sector product development efforts are strongly recommended.

APPENDIX.–INSTALLATION CHECKLIST

During the course of the installations and field trials, several techniques and procedures were found to be of help in maintaining the operating integrity of the systems. The following are some suggestions to aid in any field installations of these systems.

1. Protect long runs of wire and cable from abrasion by installing them in flexible conduit. If possible, it is best to follow existing runs of hoses, wires, or cables. The liquid tight type of conduit is easy to use. Once the conduit is in place it can be fastened with wire ties and the system cables pulled through it with the aid of a "snake." Be sure to use a bushing on each end of the conduit. Also, run wire, cable, or conduit to allow for maintenance and removal of engine components with as little disturbance as possible.

2. Be sure to use some type of environmentally protected housing for the electronics if housing is not supplied by the manufacturer. If possible, locate the control box inside the cab.

3. Physically isolate components from shock and vibration if the manufacturer has not done so.

4. Locate and mount sensors and antennas to allow for easy removal, if needed, for engine or other maintenance access. Also, make sure they cannot be knocked off or broken during machine operation.

5. If a fuse is not included by the manufacturer, use an appropriately sized fuse in the power connection to the system.

6. Consult an individual familiar with the electrical wiring layout of the vehicle to help determine the best place to connect for primary power.

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