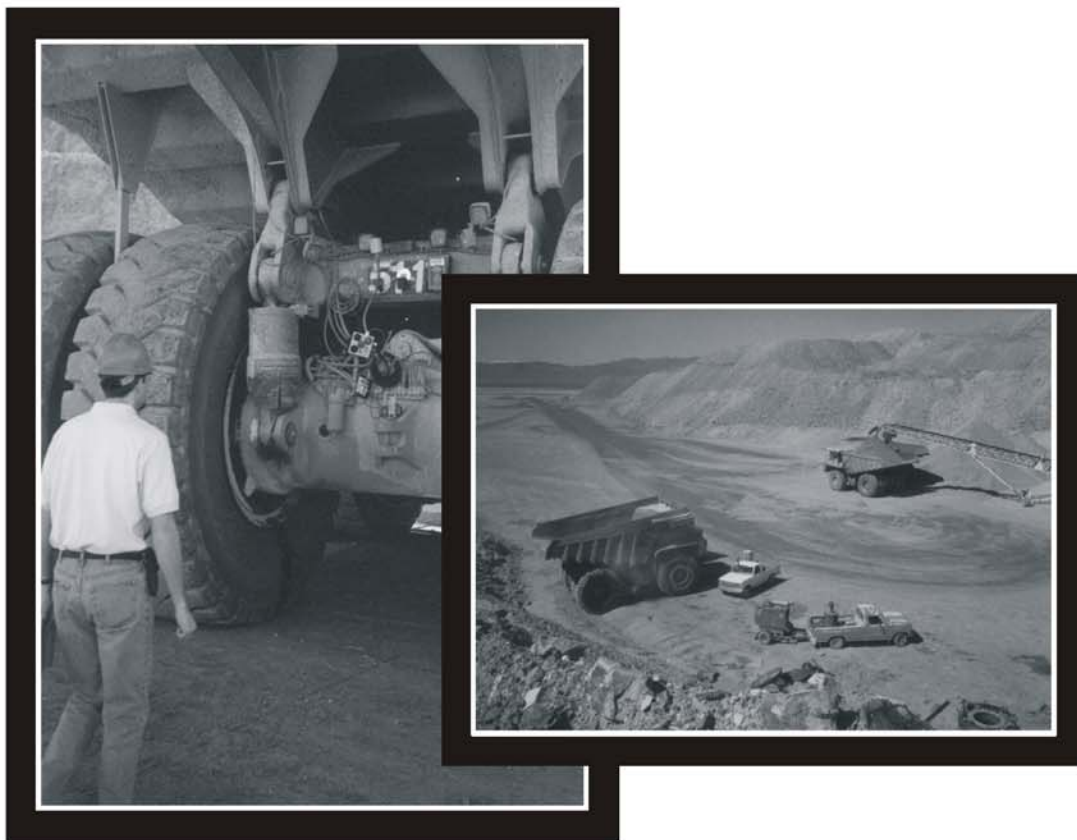




RI 9654

REPORT OF INVESTIGATIONS/2000

Test Results of Collision Warning Systems on Off-Highway Dump Trucks: Phase 2



U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Public Health Service
Centers for Disease Control and Prevention
National Institute for Occupational Safety and Health

NIOSH

Report of Investigations 9654

Test Results of Collision Warning Systems on Off-Highway Dump Trucks: Phase 2

Todd M. Ruff

U.S. DEPARTMENT OF HEALTH AND HUMAN SERVICES
Public Health Service
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November 2000

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UNIT OF MEASURE ABBREVIATIONS USED IN THIS REPORT

cm	centimeter	mm	millimeter
GHz	gigahertz	ms	millisecond
km	kilometer	ft	foot
km/h	kilometer per hour	in	inch
m	meter	mph	mile per hour

TEST RESULTS OF COLLISION WARNING SYSTEMS ON OFF-HIGHWAY DUMP TRUCKS: PHASE 2

By Todd M. Ruff¹

ABSTRACT

This report summarizes ongoing research at the National Institute for Occupational Safety and Health, Spokane Research Laboratory, in which collision warning systems for surface mining dump trucks are being evaluated. Common accidents involve these large trucks running over smaller vehicles or pedestrian workers. Collision warning systems currently use one of several methods, including radar, radio-frequency-signal detection, or ultrasonic signals, to detect and warn of the presence of an object or person in the blind spots of the mining equipment. Most available systems have not been tested on large off-highway dump trucks. This report evaluates several systems on two sizes of trucks, a 50-ton-capacity truck commonly used in quarries and construction and a 240-ton-capacity truck commonly used in open-pit mines. Tests were conducted to determine false alarm rates, alarm effectiveness, and reliable detection zones for a person and a pickup truck. The results indicate that radar and radio-frequency identification systems show promise for this application and that several of the improved systems are ready for extensive field tests. However, challenges still exist in applying these technologies to large trucks.

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INTRODUCTION

This report summarizes the results of continuing tests on collision warning systems for surface mining equipment at the National Institute for Occupational Safety and Health (NIOSH), Spokane Research Laboratory (SRL). Collision warning systems currently use one of several methods, including radar, radio-frequency-signal detection, or ultrasonic signals, to detect and warn of the presence of an object or person in the blind spots of the mining equipment. Phase 1 tests are described in a NIOSH Report of Investigations (RI) entitled “Test Results of Collision Warning Systems for Surface Mining Dump Trucks” [Ruff 2000]. Detailed descriptions of the technologies and other background information are presented in that report.

One goal of the phase 1 tests was to narrow the number of collision warning systems to be tested in an operating surface mine because time constraints would not allow all systems to be tested. The final selection was based on whether or not the system (1) was available off the shelf, (2) had positive test results and adequate detection areas, and (3) was packaged for

the mining environment. Two radar systems and one radio-frequency identification (RFID) system were selected for further tests at a surface mine (phase 2). The radar systems were tested by NIOSH personnel, and only these results are discussed in this RI.²

The second phase involved (1) retesting three of the collision warning systems on a 240-ton-capacity truck at a surface mine, (2) testing three phase 1 systems that had undergone improvements on a 50-ton-capacity truck, and (3) testing two new systems on the 50-ton-capacity truck. Tests on the 50-ton-capacity dump truck are discussed under the section “Test Results, Komatsu 210M.” The results of tests on the larger truck are discussed under the section “Test Results, Caterpillar 793B.”

²The Buddy System by Nautilus International was tested on a Komatsu 930E at the Phelps Dodge Morenci mine by Jason Hart, president of Nautilus International. Test results are not recorded here but are available through Nautilus.

TEST DESCRIPTION³

Tests of the collision warning systems were designed based on experience gained from previous tests, some aspects of SAE J1741 *Discriminating Backup Alarm Standard* [Society for Automotive Engineers (SAE) 1999], and input from the Mine Safety and Health Administration (MSHA). The systems were tested on a rigid-frame, off-highway dump truck that represented those used in industry as closely as possible.

Because of the number of systems and the amount of time required, only two radar systems and one RFID system were tested on a large dump truck at the Phelps Dodge Morenci Mine in Arizona. Specifications for this truck are shown in table 1. For the other systems, a smaller dump truck was rented, and the tests were conducted at a remote auxiliary site of SRL.

The largest dump truck available for rental in the Spokane area was a 50-ton-capacity Komatsu 210M Haulpak⁴ (figures 1 and 2). Although this truck has similar features and is commonly used in sand and gravel operations, it is smaller than most trucks used in surface mining. While not an ideal representation of the larger trucks, the 50-ton truck did provide an adequate platform for initial tests. Specifications for this truck are also shown in table 1.

Each collision warning system was mounted on the truck according to the manufacturer’s suggestions and with the

requirement that the sensor be accessible and not interfere with the truck’s operation. To monitor the rear blind spot of the truck, the sensor was mounted near the light bar above the rear axle. To monitor the front blind spot, the sensor was mounted near the front bumper or on the grill.

The test area at SRL was approximately 60 m (200 ft) long by 30 m (100 ft) wide, while the test area at the Morenci Mine was approximately 30 m (100 ft) long by 30 m (100 ft) wide.



Figure 1.—Side view of Komatsu 210M.

³This section has been updated from RI 9652 [Ruff 2000]. For a full description of the test procedure, see the earlier RI.

⁴Mention of specific products or manufacturers does not imply endorsement by the National Institute for Occupational Safety and Health.

Table 1.—Dump truck specifications

Truck make and model	Komatsu 210M, 50-ton capacity		Caterpillar 793B, 240-ton capacity	
	Meters	Feet	Meters	Feet
Overall length	9.2	30 ft 3 in	12.9	42 ft 3 in
Overall width	4.4	14 ft 7 in	7.4	24 ft 4 in
Tire diameter	2	6 ft 6 in	3.6	11 ft 10 in
Distance, axle to tire edge	0.61	2 ft	1.1	3 ft 6 in
Distance between inner dual tires	1.4	4 ft 7 in	2.5	8 ft 2 in
Height to light bar	1.7	5 ft 8 in	3	10 ft
Distance, truck bed extended past axle	2.7	9 ft	4.6	15 ft
Height of front bumper	0.76	2 ft 6 in	1.2	4 ft
Maximum speed forward	64.4 km/h	40 mph	54.7 km/h	34 mph
Maximum speed reverse	NA	NA	11.2 km/h	7 mph

Both sites were cleared of debris and graded flat. The surfaces of the test areas were dirt and gravel with no large rocks or ruts. This gave researchers a clear field for testing the collision warning systems under ideal conditions. Obstacles and other debris were then added as each test progressed.

The obstacles to be detected by the collision warning system consisted of either a person or a three-quarter-ton, four-wheel-drive pickup truck with an extended cab (figures 3 and 4). The person for these tests was a man between 178 and 191 cm (70 and 75 in) tall, wearing a hard hat, cotton shirt, and jeans.

The reliable detection zone for an obstacle was recorded by standing or parking the truck on the points of a grid with 0.76-m (2.5-ft) spacings marked in the sensor's potential detection area. For the rear blind spot, the dump truck was moved slowly (< 8 km/h [5 mph]) in reverse, and the state of the alarm was monitored. If the alarm turned on immediately (< 200 ms) and consistently after the truck moved, then that point was recorded as a "reliable" detection point. The recorded points on the grid were then joined to form an outline of the reliable detection zone. A second zone was recorded as needed and labeled "sporadic" if an obstacle was detected some of the time, but not always (less than 100% detection, but more than 10%). Note that in certain areas near the dump truck, it would not be safe to move the truck toward a stationary person or pickup. In these cases, the dump truck was kept stationary and the person or pickup moved toward the sensor.

The alarm display for each system was mounted near the sensor or antennas. This allowed researchers to monitor the alarm easily. Normally the alarm display would be mounted in the cab with the operator. Each alarm display was temporarily taken inside the cab and tested to see if the lights were visible and the audible alarm could be heard above engine noise.

According to SAE J1741, it is desirable that a collision warning system ignore an object the size of a cinder block in the blind spot of the dump truck (figure 5). While this may or may not be important to a mine implementing a collision warning system, researchers at SRL tested each radar system to see how it reacted to a cinder block placed at various distances along the truck's centerline.

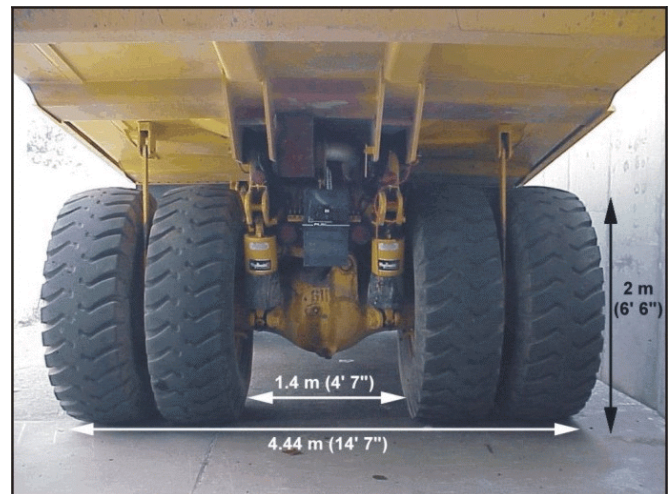
**Figure 2.—Rear view of Komatsu 210M.****Figure 3.—Determining detection zone for a person.**



Figure 4.—Determining detection zone for a pickup truck.



Figure 5.—Detecting a cinder block.

TEST RESULTS, KOMATSU 210M

SYSTEM: SENSOR VISION

Manufacturer: Vision Techniques and Ogden Safety Systems, U.K. www.visiontechniques.co.uk

Description:

This system combines radar technology with cameras to provide a vision system with alarm functions. A Mitsubishi camera was placed near the light bar on the rear of the truck to monitor the rear blind spot. Figure 6 shows three cameras mounted on the truck for testing purposes. Either a cathode ray tube (CRT) or liquid crystal display (LCD) monitor is mounted in the cab to provide the driver with a view of the blind spot. Figure 7 shows both types of monitors temporarily mounted in the cab.

The radar unit is mounted near the camera and detects moving objects in the radar's beam (figure 6). An alarm that consists of a light-emitting diode (LED) and an audible warning is activated in the cab of the truck when an object is detected by the radar unit. This prompts the driver to check the video monitor. Multiple radar systems and cameras can be installed to monitor the front or sides of the truck. While the camera system is available for purchase, the radar system has not yet been approved by the Federal Communications Commission (FCC) for use in the United States.

The radar system uses frequency-modulated continuous wave (FMCW) technology and operates between 13 and 14 GHz. It transmits a low-power signal and measures any return signals reflected from objects within its transmit beam. The characteristics of the reflected signal contain information on distance and movement. Using this principle, it is possible to determine the speed at which the object is approaching the radar unit and the distance to the object.

The radar beam can be configured to meet the requirements of different mining equipment. The width and depth of four zones within the beam can be adjusted to accommodate unique shapes for the detection zone. For example, on larger trucks, it is important to detect objects near the radar unit and inside the rear dual tires. At the same time, it is also important to detect objects immediately behind the rear dual tires, requiring a widening of the beam after it clears the tires.

Test Results:

For the rear blind spot of the truck, the radar unit was mounted level at 1.35 m (53 in) high, near the light bar. The cameras were mounted just above the radar unit at 1.65 m (65 in) high (figure 6). The video monitors and radar alarm

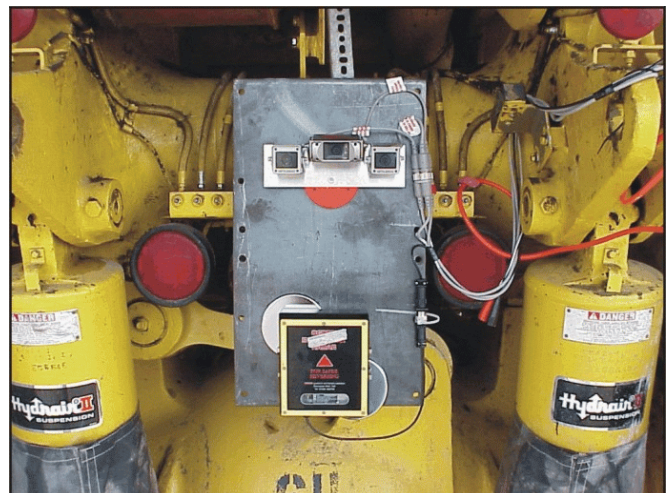


Figure 6.—Sensor Vision system mounted on rear of dump truck. Cameras are on top and radar unit is on the bottom.

were mounted inside the truck's cab. In these tests, the radar's beam configuration was optimized for this particular truck. As mentioned, the beam widths can be adjusted to accommodate larger trucks. However, the overall length of the detection zone is limited to approximately 12.2 m (40 ft).

The first test evaluated the radar's false alarm rate in a totally clear zone behind the truck. No false alarms were activated when the dump truck was moved in reverse. The truck was also backed into an area with low foliage (under 30 cm [1 ft] high), which was not detected.

The next test was to determine if a cinder block was detected behind the vehicle. When the radar unit was mounted level and at a height of 1.35 m (53 in), a cinder block was not detected at any position behind the truck. Lower mounting positions may allow the block to be detected; this will be discussed later.

The detection zone for a pedestrian worker was then recorded as shown in figure 8. The test was conducted primarily by having a person walk toward the stationary dump truck. Several positions behind the truck were also tested with the person remaining stationary while the dump truck moved. This was necessary to verify that the detection zone was consistent when the truck was moving. The detection zone extended out to 12.2 m (40 ft) and adequately covered the width of the truck. Some small adjustments to the detection zone may be needed to ensure that coverage extends as close to the tires as possible.

The detection zone for a pickup truck was recorded as shown in figure 9. The zone adequately covered the width of the dump truck and extended for 12.2 m (40 ft). The pickup truck was reliably detected as long as its entire front bumper was within the zone indicated. The detection zone was verified by moving the dump truck toward the stationary pickup at several test points.

The field of view of the cameras was also tested by walking through each camera's field and recording where a person could



Figure 7.—Two types of monitors mounted in cab of dump truck.

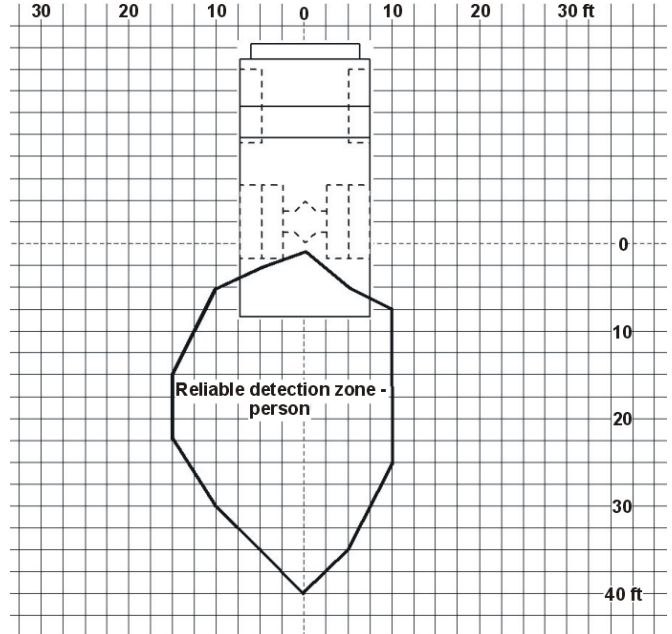


Figure 8.—Detection zone of Ogden radar system and a person at rear.

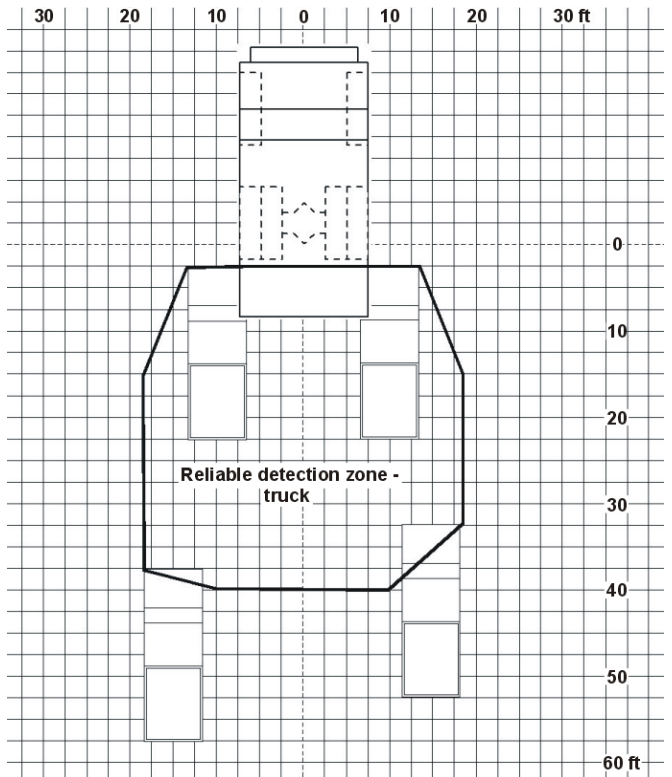


Figure 9.—Detection zone of Ogden radar sysem and a pickup at rear.

no longer be seen in the monitor. Figure 10 shows the field of view for two different lenses. Generally, a wide field of view is preferred so that an object can be seen out by the rear dual tires.

A separate radar unit was mounted on the front bumper of the dump truck at 89 cm (35 in) high and with no cameras (figure 11). This radar unit's beam was configured differently to accommodate the detection zone needed at the front of the truck.

The front detection zone differs from the rear in that it is important to have a wide beam beginning immediately in front of the radar unit to cover the width of the front bumper. Also, a shorter length for the front detection zone is sufficient for this truck because of improved visibility. This is not true for larger

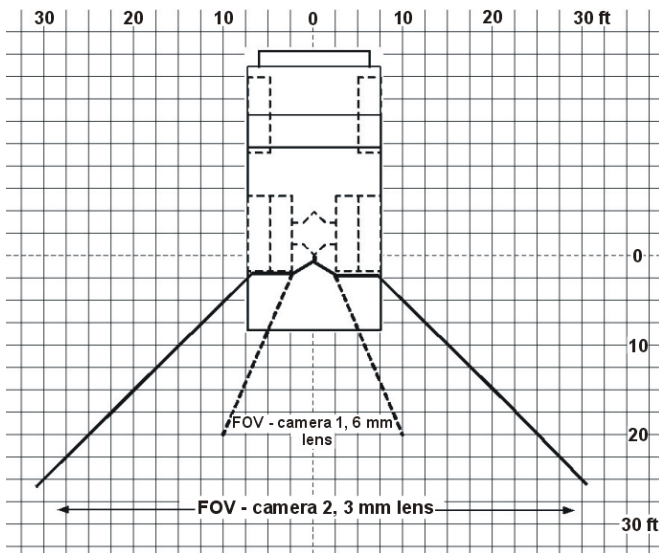


Figure 10.—Field of view of two different cameras monitoring rear of truck.



Figure 11.—Ogden radar system mounted on front bumper.

trucks, however, where front blind spots can extend beyond 12 m (40 ft).

The system was tested for false alarms in a clear zone in front of the truck. No false alarms were activated when the truck was moved forward at slow-to-moderate speeds (< 32 km/h [20 mph]).

The cinder block was then placed in front of the truck. At some locations, the block was detected because of the lower mounting position.

The reliable detection zone was then recorded for a person (figure 12). Detection extended from immediately next to the bumper out to 7.6 m (25 ft) and adequately covered the entire width of the truck. A shorter detection zone was determined to be better for the front of this truck because of the lesser extent of the blind spot. This zone could be adjusted for larger trucks. Again, the detection zone was verified by moving the dump truck toward a stationary person, and similar results were seen.

The front detection zone for a pickup truck is shown in figure 13. The zone extended from the bumper out to 9.1 m (30 ft) and adequately covered the width of the dump truck.

Discussion:

The radar system works well on trucks that have mounting positions below 1.8 m (6 ft). The detection zones are ideal for the Komatsu 50-ton truck. However, larger trucks with high mounting positions may present a problem for this radar system. Initial tests with the Ogden radar system at the Phelps Dodge Morenci Mine on larger trucks showed that the detection zones decreased in size as a result of the high mounting position and the antennas had to be tilted. Figure 14 shows an example of the rear detection zone of a person and a Caterpillar 793

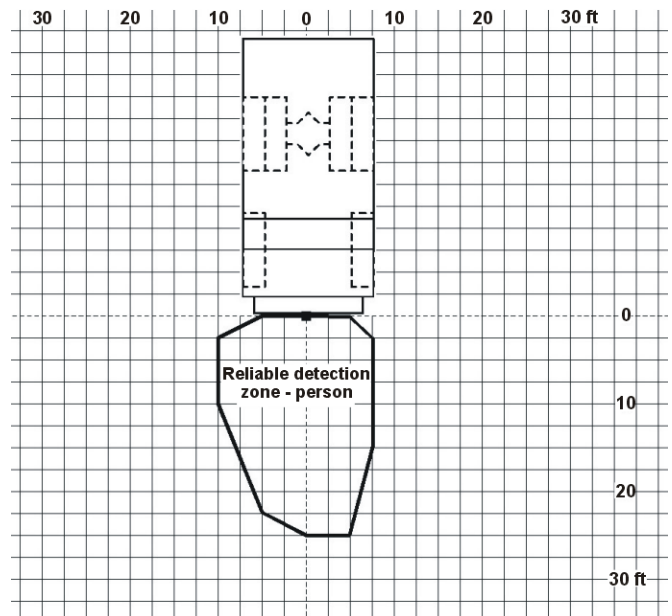


Figure 12.—Detection zone of Ogden radar system and a person in front.

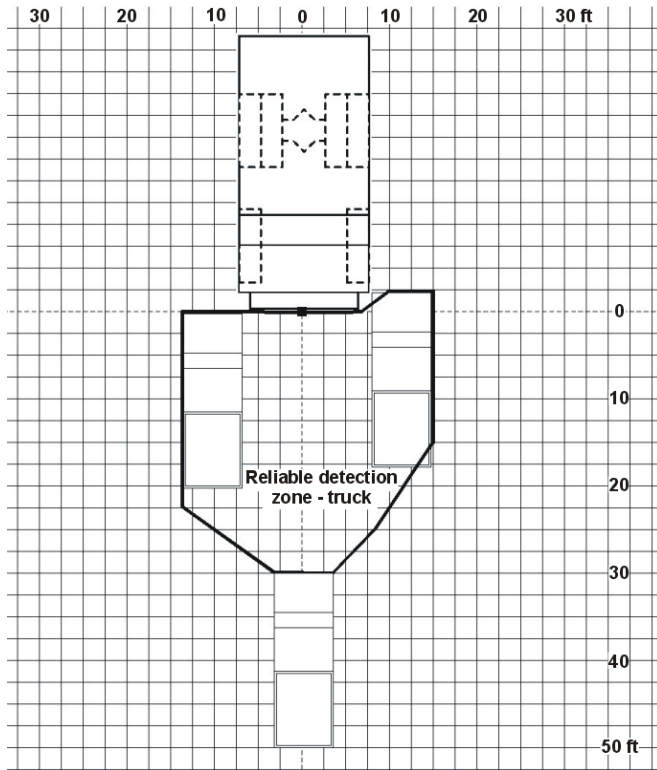


Figure 13.—Detection zone of Ogden radar system and a pickup in front.

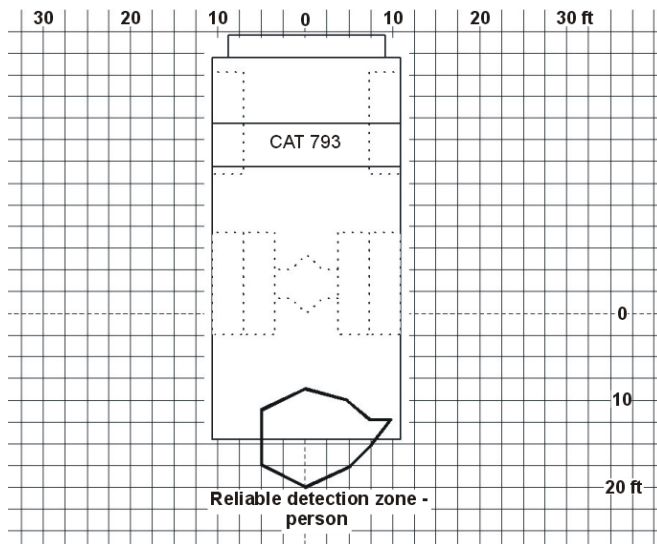


Figure 14.—Detection zone of Ogden radar system on Caterpillar 793 truck and a person.

240-ton truck. These tests are discussed in more detail later. Installing this system on large trucks where the mounting positions will be over 2.5 m (8 ft) above the ground may require a different antenna design. Figure 15 shows the test results of mounting the system high on the front deck of the Komatsu truck.

It was suggested by an Ogden Safety Systems engineer that a trihedral corner reflector should be used to determine the outermost edges of the radar beams. This is useful for determining the area detected by a corner reflector, but one should use caution when trying to equate this area with the actual detection zone for a person or pickup.

Two sizes of reflectors were tested at NIOSH. A small reflector meant to represent a person and a large reflector meant to represent a pickup were constructed from cardboard and covered with metal tape (figure 16). The large reflector is 380 mm (15 in) long on each side, and the small reflector is 140 mm (5.5 in) long. The large reflector was tested first, and its detection zone was compared to the actual detection zone of a pickup truck. Figure 17A shows the results. The detection zone for the reflector was significantly wider and slightly longer than that for the actual truck. There was some question on how

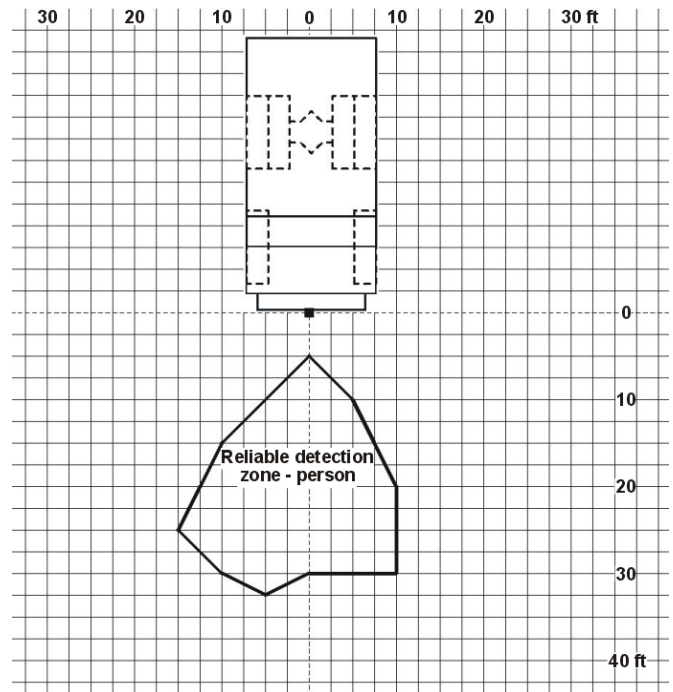


Figure 15.—Detection zone of Ogden radar system mounted high on Komatsu truck and a person.

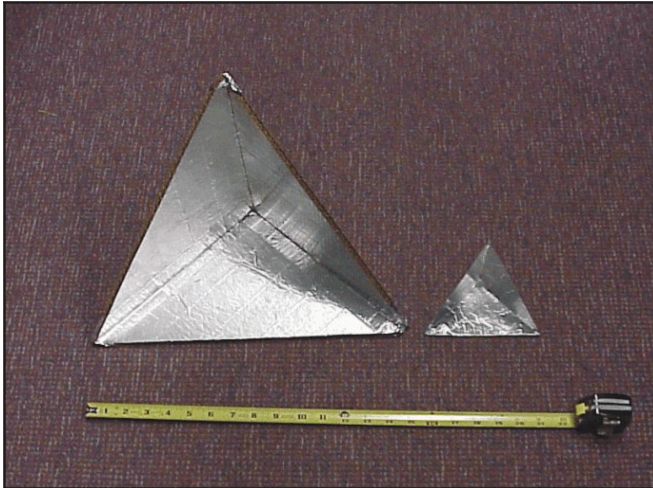


Figure 16.—Trihedral corner reflectors for determining beam dimensions.

to hold the reflector and what effect the person holding the reflector had on the results.

The small reflector was then tested, and its detection zone compared to the detection zone for a person. For this test, the radar unit was taken off the truck and mounted to a test stand 1.14 m (45 in) high. The small reflector must be mounted to a 3-m (10-ft) plastic pole so that the person holding the reflector remains outside the detection zone while the reflector is inside of it. Figure 17B shows the results. The detection zone for the reflector is significantly smaller in this case. It was difficult to determine whether the radar unit was detecting only the reflector and not the person holding it. Also, detection of the reflector depended on height and orientation. This made it difficult to obtain consistent results.

It is known that mud flung from the tires of a dump truck can cause false alarms from the rear-mounted radar unit. This is probably true for all radar systems. This problem could be solved by deactivating the rear unit or decreasing sensitivity when traveling forward. There were no other false alarm sources seen during the limited tests conducted. However, testing the system on a large truck under actual working conditions will be required before further conclusions can be drawn.

The cameras and monitors appeared to be built sturdily enough to withstand a mining environment. Again, further tests will need to be conducted at a surface mine before conclusions can be made. The manufacturer has had camera systems in mines and quarries in England for several years, and the systems have held up well under mining conditions.

The camera view with the wider angle had the best coverage for showing objects near the truck; however, the lens did distort the image, making it difficult to judge distance. The narrow-angle lens did not show objects near the tires of the truck. Both color and black-and-white cameras were tested. The black-and-white cameras operated better under low-light conditions and

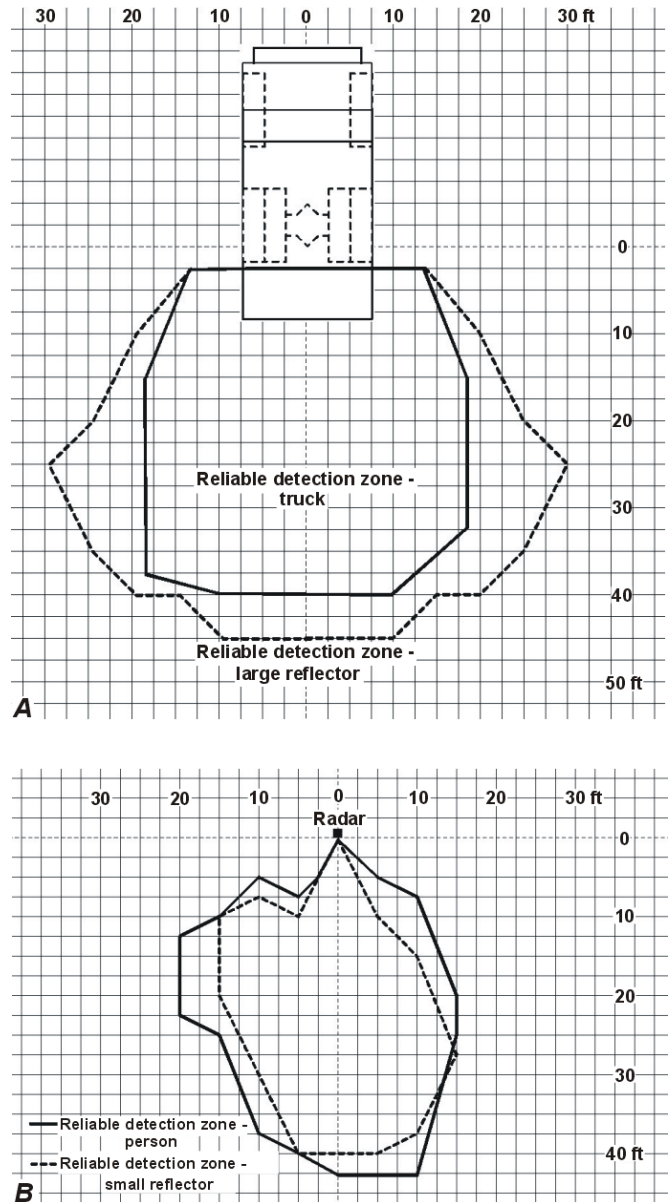


Figure 17.—Comparison of detection zones for (A) a large reflector and a pickup truck and (B) a small reflector and a person.

are best suited for locations that operate in both daylight and at night.

SYSTEM: PREVIEW

Manufacturer: Preco, Inc. Boise, ID www.preco.com

Description:

The Preview system is a pulsed time-domain radar operating at 5.8 GHz. The radar signal is pulsed 40 times per second and detects both stationary and moving targets. The system consists of a radar antenna and processing electronics (figure 18), an

alarm display (figure 19), and wiring. An optional external backup alarm is also available. The system can be activated using the reverse gear input so that the alarm is activated only when moving in reverse and an obstacle is detected.

The radar system can determine distance to an object within its detection zone. This information is displayed on the alarm using eight LED's that indicate distances under 1 m (3 ft) out to 7 m (24 ft). An LED is lit if an object is detected at the corresponding distance. A four-tone audible alarm also indicates distance by changing frequency according to where the object is detected. The radar antenna determines the Preview system's area of coverage and thus is not adjustable by the user.

Test Results:

For the rear blind spot of the truck, the Preview system was mounted level near the light bar at a height of 1.3 m (51 in)

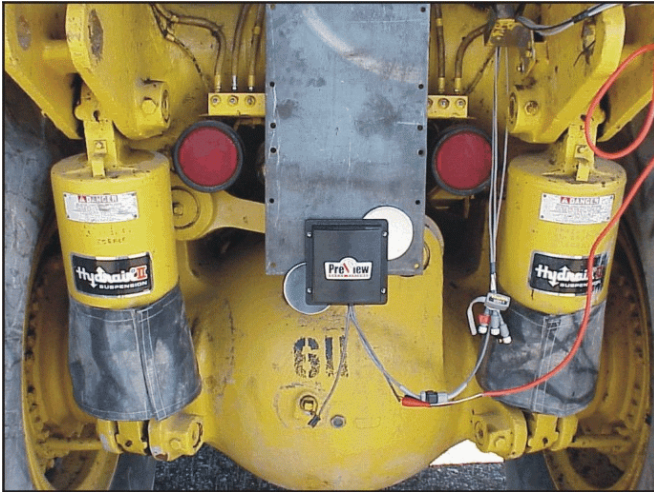


Figure 18.—Preview radar system antenna and electronics enclosure.



Figure 19.—Preview radar system display.

(figure 18). The mounting height was critical for this radar system. If the system were mounted higher than 1.3 m (51 in) from the ground, the radar would constantly detect the bed of the dump truck, causing false alarms. After determining the best mounting position, the system was tested for false alarms in a clear field by moving the truck in reverse. No false alarms occurred. The system did detect low foliage (< 30 cm [1 ft] high) at the edge of the test area.

The cinder block was detected by this radar unit at distances of 7.6 to 9.1 m (25 to 30 ft). The block was not detected if it was closer than 7.6 m (25 ft) to the truck. The reliable detection zone for a person standing behind the truck extended from the radar unit out to 9.1 m (30 ft) (figure 20). The radar unit did detect a person standing near the inner dual tires, but not near the outer dual tires. Small areas were detected sporadically on the fringes of the detection zone. The detection zone was verified at several positions when a person remained stationary while the dump truck moved. Range information shown on the display was correct when a person was detected.

The rear detection zone for a pickup truck was recorded as shown in figure 21. The zone adequately covered the width of the dump truck and extended out to 8.4 m (27.5 ft). The pickup truck was reliably detected as long as its entire front bumper was within the zone indicated. The detection zone was verified by moving the dump truck toward the stationary pickup. The alarm display did not always show the correct range information for the pickup truck. At some test points, all the LED's came on as if the pickup truck were very close to the radar unit, even when the pickup was at the far edges of the detection zone.

The system was then mounted on the front of the dump truck at a height of 94 cm (37 in) (figure 22). Mounting height was not as critical on the front of the truck because no part of the truck extended beyond the bumper. There were no false alarms when the truck was moved forward in a clear field.

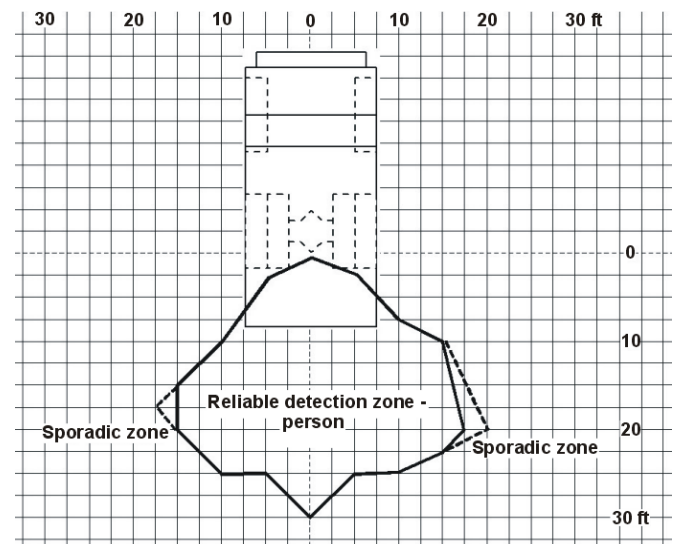


Figure 20.—Detection zone of Preview radar system and a person at rear.

Cinder block detection occurred from 4.6 to 9.1 m (15 to 30 ft) away from the sensor. The lower mounting height caused the system to be more sensitive to low-lying objects. The detection zone for a person extended from the radar unit out to 8.4 m (27.5 ft) (figure 23). However, areas on either side of the radar unit and near the bumper were not covered by the beam.

The detection zone for a pickup truck is shown in figure 24. The zone adequately covered the width of the dump truck and extended out to 9.1 m (30 ft). The pickup truck was reliably detected as long as its entire front bumper was within the zone

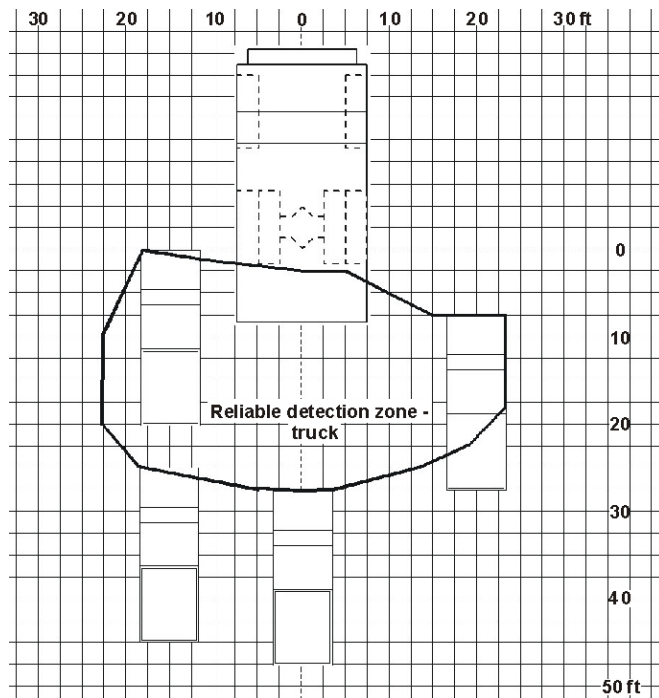


Figure 21.—Detection zone of Preview radar system and a pickup at rear.



Figure 22.—Preview radar system mounted on front bumper.

indicated. The detection zone was verified by moving the dump truck toward the stationary pickup.

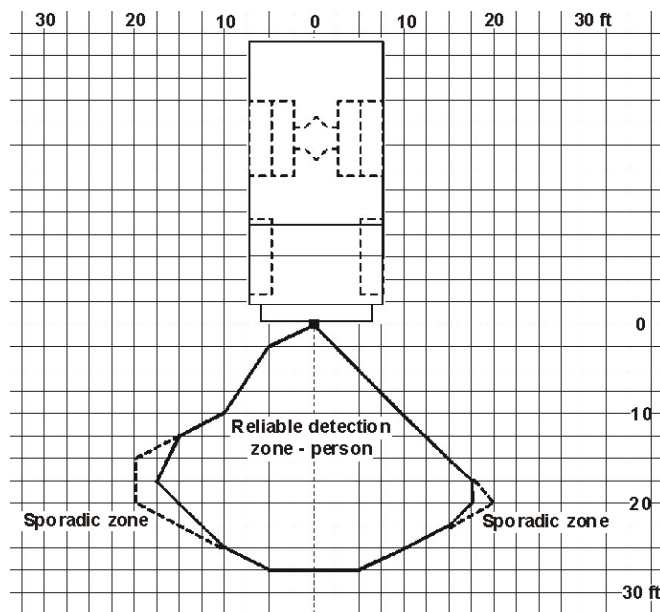


Figure 23.—Detection zone of Preview radar system and a person in front.

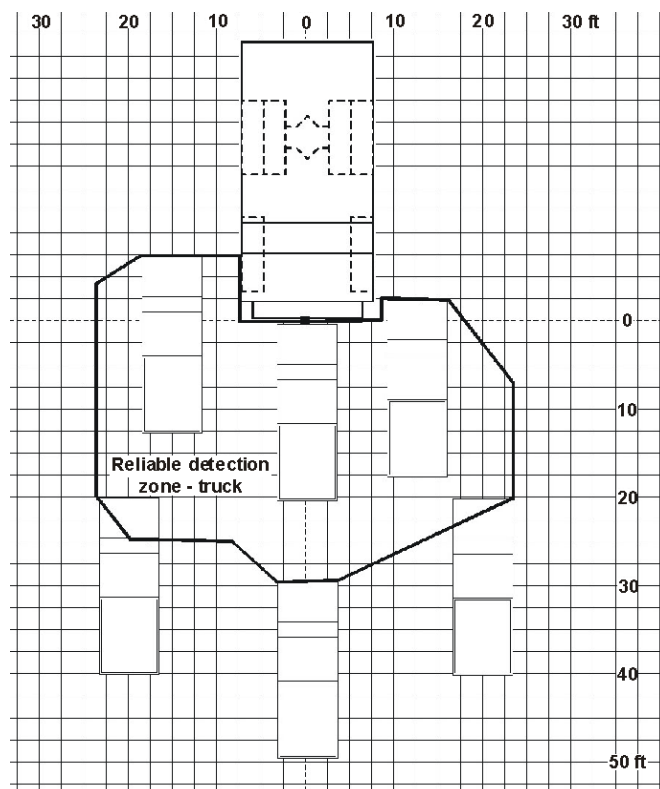


Figure 24.—Detection zone of Preview radar system and a pickup in front.

Discussion:

This system seemed adequate for this size of dump truck, although a wider beam near the bumper would provide better coverage for the front blind spot. The system needs to be tested on a larger truck to verify that it can be used for such trucks. To simulate a higher mounting position on a larger truck, the radar unit was mounted at a height of 2.6 m (103 in) on the front of the Komatsu dump truck. The radar unit had to be tilted downward 30° to ensure detection of a person near the truck when this configuration was used (Figure 25). The detection zone was then decreased in length to 7.6 m (25 ft), and a person could walk very near the truck and not be detected. Additional tests on larger trucks need to be conducted to determine the effect of the overhanging steel from the bed and false alarm rates from tilting the radar unit downward.

The manufacturer has designed this radar system to meet SAE standard J1741 [SAE 1999]. However, at certain mounting heights, the system did detect a cinder block in the center of the detection zone, which should not have occurred according to the standard. However, it is up to each individual mine to determine if this is important or not.

The alarm display has eight LED's and four different audible alarms to indicate the distance to a detected object. When detecting a person, this range information is reliable, and the audible alarms are effective. The audible alarms may need to be louder on certain vehicles, and a volume control may need to be added. When detecting a pickup truck, however, the range information is not always correct. The sensitivity may need to be adjusted to correct this situation, but the adjustment must be done at the factory.

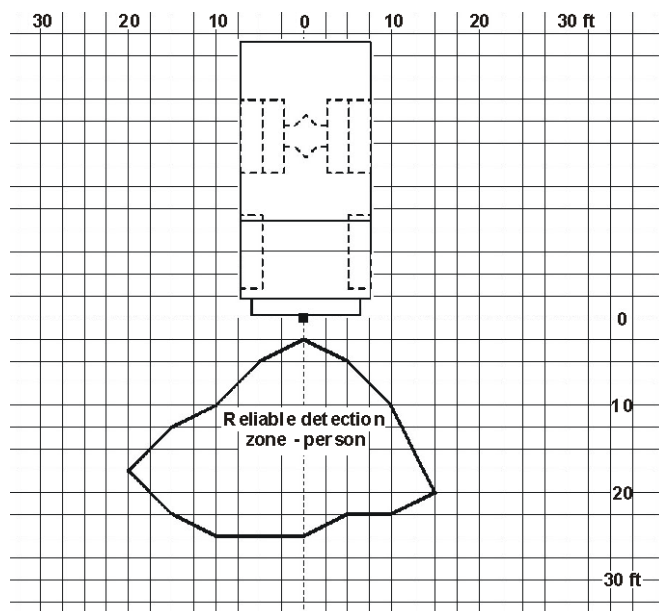


Figure 25.—Detection zone of Preview radar system mounted high on Komatsu truck and a person.

SYSTEM: ULTRAWIDE-BAND RADAR PROTOTYPE

Manufacturer: Multispectral Solutions, Inc. (MSSI),
Gaithersburg, MD www.multispectral.com

Description:

MSSI's radar system is based on ultrawide-band technology that uses nanosecond radar signal pulses to produce a wide, instantaneous bandwidth waveform. It transmits at a center frequency of 5.65 GHz. The radio frequency circuitry for a ultrawide-band system is minimal, consisting of a low-noise amplifier and a broadband tunnel detector. In addition, digital signal processing is employed, further lending to a low-cost modular design and a potentially small-sized package.

A transmitter module emits ultrawide-band radar pulses at a fixed repetition rate from the transmitting antenna. A receiver antenna picks up both transmitted pulses and pulses reflected from the environment and/or targets of interest. A radio-frequency module amplifies and filters the pulses and sends them to a processing board. The transmitted pulses are picked up by one detector of a dual, short-pulse detector (initialization pulse), while the second detector picks up target and clutter information. A high-speed time-detector circuit measures the relative positions of the two pulses and passes this information to a digital signal processor. The digital signal processor then performs calculations to control detector sensitivity and to convert the time difference to a precise measurement of distance for display as a target.

The first version of this radar system had difficulty detecting objects close to the antennas and was only reliable from 9.1 to 13.7 m (30 to 45 ft). Modifications were made over the past year to remedy this problem.

- The receiver-processor board was replaced with an improved design. The new processor board is capable of much finer adjustments in the minimum detection distance. Receiver circuitry was also updated and improved on the new board.
- The radio-frequency transmitter and receiver sections were moved to separate boards and shielded from each other. Previously, energy from the transmitter circuit was coupling into the receiver circuit. This caused the initial pulse coming into the receiver to stretch, limiting detections at close range. When the transmitter and receiver were separated and shielded, the initial pulse length was reduced to less than one-third of its original length.
- A digitally controlled variable attenuator was added to the radio-frequency receiver circuitry. The variable attenuator allows increased sensitivity adjustments and gives optimum attenuation settings over the detection range of interest.
- A new, three-LED range display with audio alarm was built. Modifications were made to the processor board code and field programmable gate array design to set detection ranges and for LED drivers. The system cable was also rebuilt to accommodate the new display.

- The power supply board was redesigned to meet the new system power requirements. LED driver circuitry was installed on this board for the LED range display.

Test Results:

For the rear blind spot of the truck, the ultrawide-band radar system was mounted level near the light bar at a height of 1.37 m (54 in) (figure 26). At the initial sensitivity setting, an occasional false alarm occurred when the dump truck was moved in reverse in a clear field. After the sensitivity was decreased, no false alarms occurred. The cinder block was not detected except sporadically when the block was 6.1 m (20 ft) away from the radar unit.

The reliable detection zone for a person standing behind the truck is shown in figure 27. This zone extended 15.2 m (50 ft) from the radar unit. The radar detected a person standing near the outer dual tires with small areas detected sporadically on the fringes of the detection zone. The detection zone was verified at several positions with the person remaining stationary while the dump truck was moved. Range information shown on the display was accurate and corresponded to the correct distance to the person.

The rear detection zone for a pickup truck was recorded as shown in figure 28. The zone adequately covered the width of the dump truck and extended out to 15.2 m (50 ft). The pickup truck was reliably detected as long as its entire front bumper was within the zone indicated. The detection zone was verified by moving the dump truck toward the stationary pickup. The range information on the display was also correct for the pickup.

The system was then mounted level on the front of the dump truck at a height of 1.32 m (52 in) (figure 29). Lower mounting heights may cause an increase in false alarms due to detection of the ground. There were no false alarms when the truck was moved forward in a clear field. Cinder block detection again occurred sporadically at a distance of 6.1 m (20 ft).

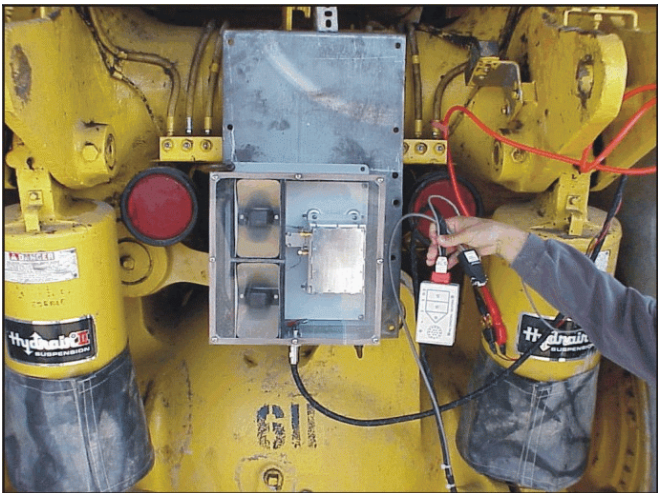


Figure 26.—Multispectral ultrawide-band radar system and alarm display (right).

The detection zone for a person extended from the radar unit out to 13.7 m (45 ft) (figure 30). An area about 4.6 m (15 ft) farther was detected sporadically. The width of the detection zone was adequate beyond the bumper, but a person standing right next to the bumper was detected only sporadically.

The detection zone for a pickup truck is shown in figure 31. The zone adequately covered the width of the dump truck and extended out to 16.8 m (55 ft). The pickup truck was reliably detected as long as its entire front bumper was within the zone indicated. The detection zone was also verified by moving the dump truck toward the stationary pickup.

Discussion:

The improvements made to this system greatly increased its reliability, and the system shows good potential. Additional improvements are being made. While the size of the detection zones for people and pickup trucks may have been too large for a 50-ton-capacity dump truck, they would be adequate for larger trucks. The antenna is being redesigned to cover areas close to the truck when high mounting positions are required. Figure 32 shows the detection zone for a person when the radar unit was mounted 3 m (10 ft) high on the front of the Komatsu truck. Currently, a person close to the radar unit would not be detected and the detection zone is decreased to 7.6 m (25 ft) in length due to the downward tilt of the radar unit. It is anticipated that further improvements to the antennas will

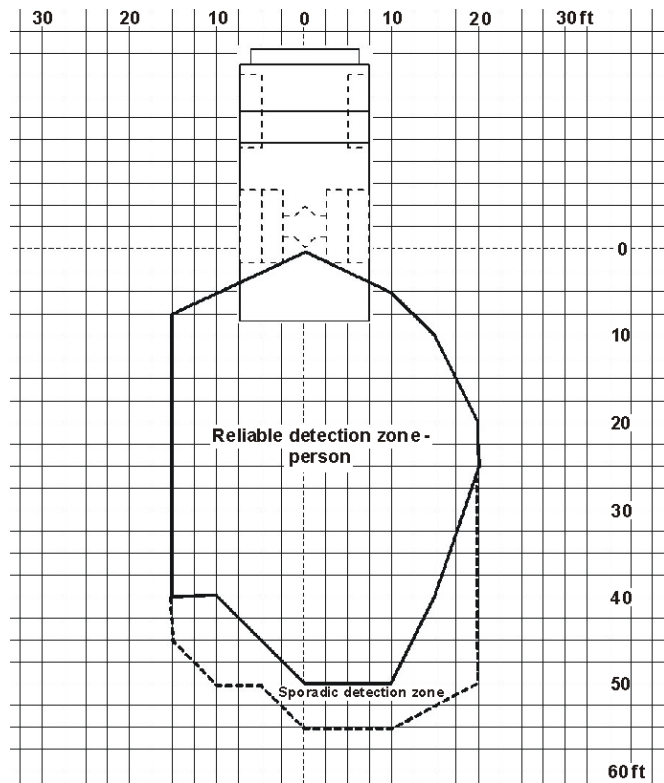


Figure 27.—Detection zone of ultrawide-band radar system and a person at rear.

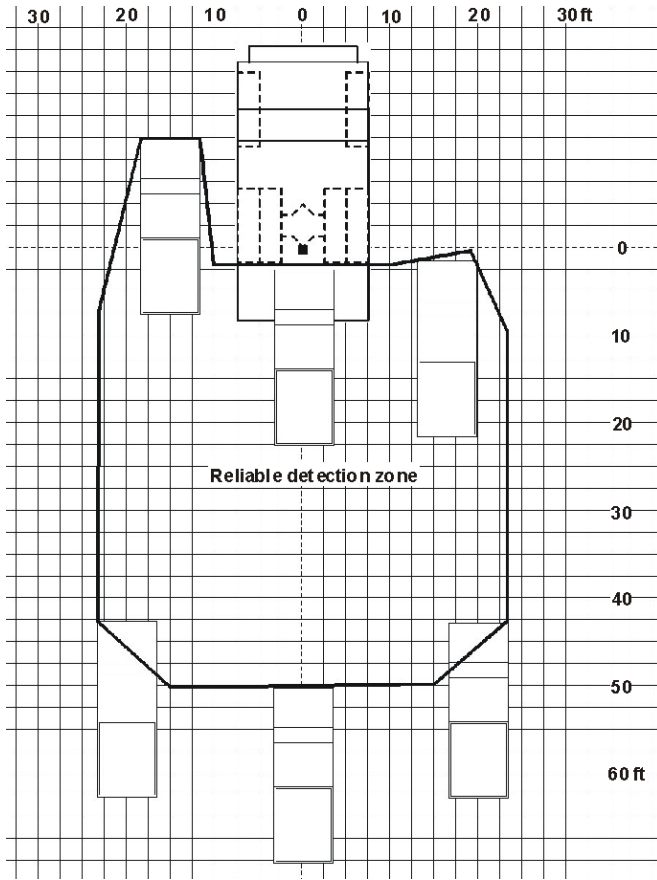


Figure 28.—Detection zone of ultrawide-band radar system and a pickup at rear.



Figure 29.—Ultrawide-band radar system mounted on front grill.

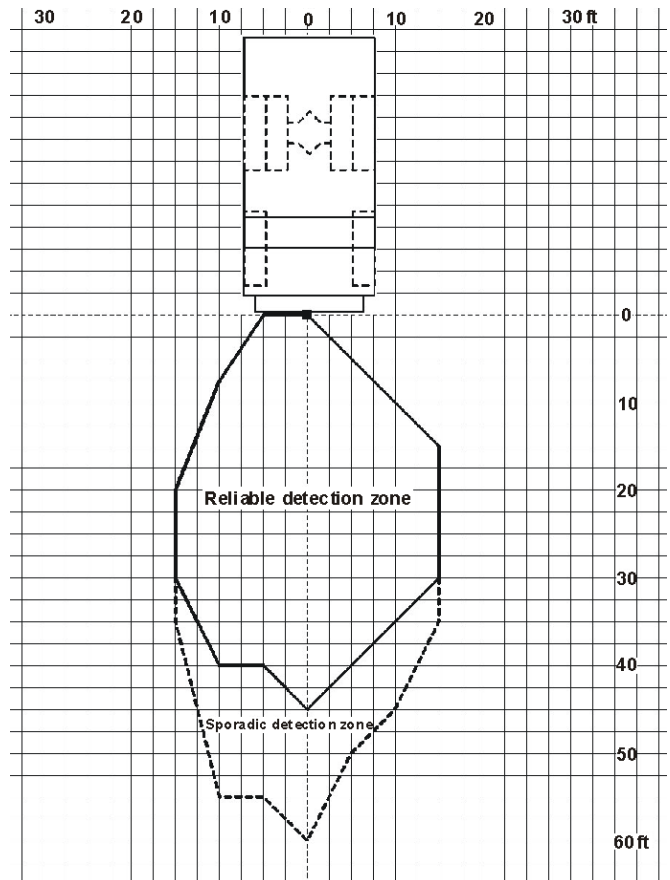


Figure 30.—Detection zone of ultrawide-band radar system and a person in front.

alleviate the problems seen with higher mounting positions. Also, the temporary enclosure for the radar antennas is now being redesigned, and packaging will be improved for mine environments.

The alarm display has three range gates with LED's to indicate the distance to an object. Although these gates were reliable, the audible alarm might be difficult to hear inside the equipment cab. A volume adjustment will be added to the display.

SYSTEM: BUDDY SYSTEM

Manufacturer: Nautilus International, Burnaby, B.C., Canada
www.nautilusinternational.com

Description:

This system is classified as an RFID-based system. It consists of a tag reader mounted on the mining equipment and

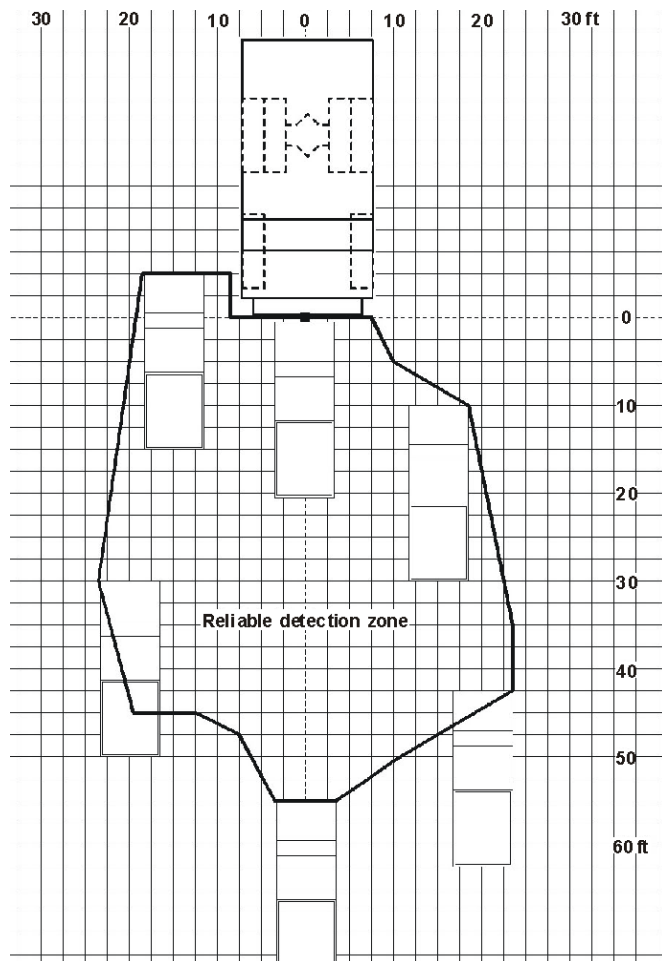


Figure 31.—Detection zone of ultrawide-band radar system and a pickup in front.

tags attached to pedestrian workers or smaller vehicles to be protected. The tag reader consists of processing electronics and a loop antenna (figure 33). It is mounted on the front deck of the dump truck, where it continuously transmits a low-frequency signal that encompasses the entire truck. The processing electronics also contain a separate high-frequency transceiver to communicate with the tags.

Each tag contains a transceiver to communicate with the reader's processing electronics. The tag measures the field strength of the low-frequency signal generated by the loop antenna. The field strength increases as the distance between the tag and the loop antenna decreases. If the field strength exceeds a user-defined limit, this information is sent to the tag reader and an alarm is generated at both the tag and at the alarm display in the dump truck's cab.

Modifications to this system over the last year included a simpler antenna design and enclosure, stand-alone tags, and an LCD monitor for displaying alarm information. The current tag was a prototype for test purposes (figure 34), and smaller versions are being designed. The tags provide an audible

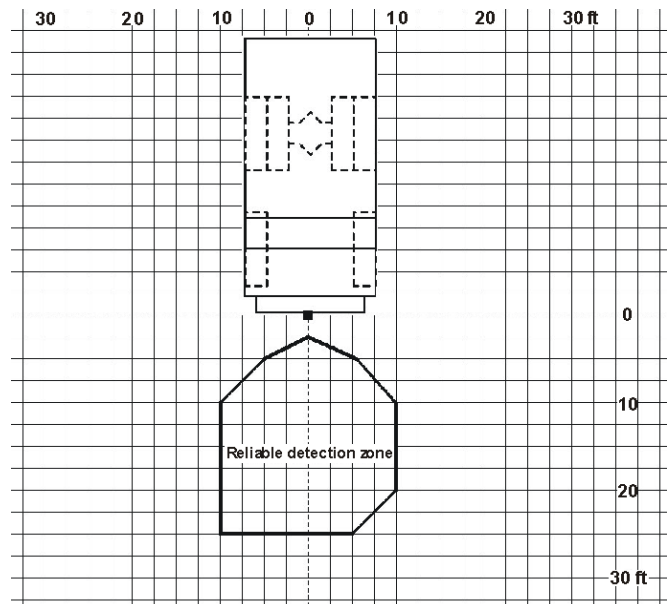


Figure 32.—Detection zone of ultrawide-band radar system mounted high on the Komatsu truck and a person.

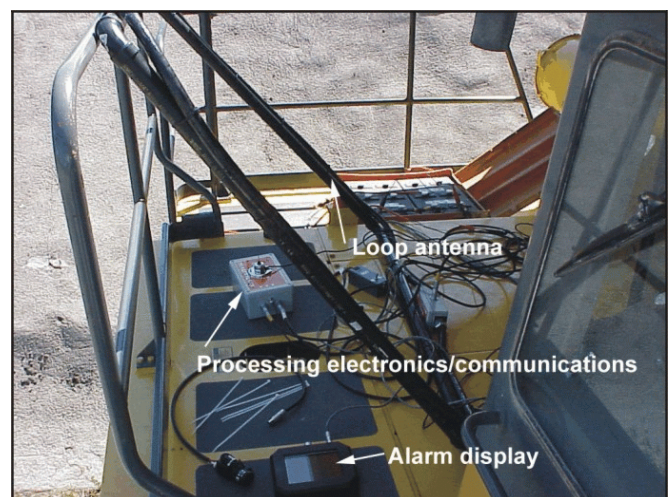


Figure 33.—Installation of Buddy system components on front deck of dump truck.

alarm if they come within the detection zone of a truck; a distance display is optional. The tags can be worn on a belt and must have the battery recharged at the end of each day. The tags also have an override switch that allows a worker to approach a truck without activating the alarm on either the tag or in the truck's cab.

The alarm display shown in figure 35 is an LCD screen that shows an identification and the distance to the tag. The tag ID is programmable and must be configured on a personal computer. The display also acts as a video monitor when the optional camera system is installed.



Figure 34.—Buddy system prototype tag on worker's belt.



Figure 36.—Determining detection zone of Buddy system and a person.

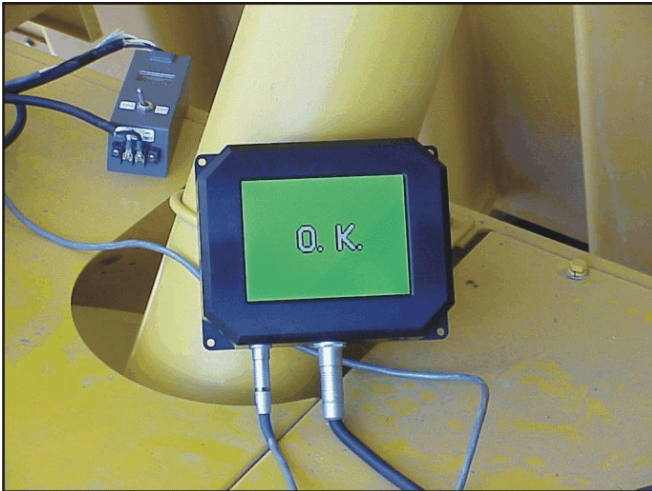


Figure 35.—Buddy system alarm display with no tag detected.

Test Results:

This system was tested by attaching the tag to the belt of a person who then walked around the truck and noted when an alarm was sounded in the cab and on the tag (figure 36). The loop antenna was placed on the front deck of the dump truck and attached to the railing in a near-vertical position (figure 33). The communications antenna was also placed on the front deck of the truck. The alarm display was monitored by the truck driver.

Figure 37 shows the reliable detection zone for a person and a 15-m (50-ft) detection radius. All blind areas are monitored simultaneously with this system. As shown in figure 37, the detection zone extends farther in front of the truck than to the rear because of the position of the loop antenna. The tag was detected at all locations and orientations within the zone shown,

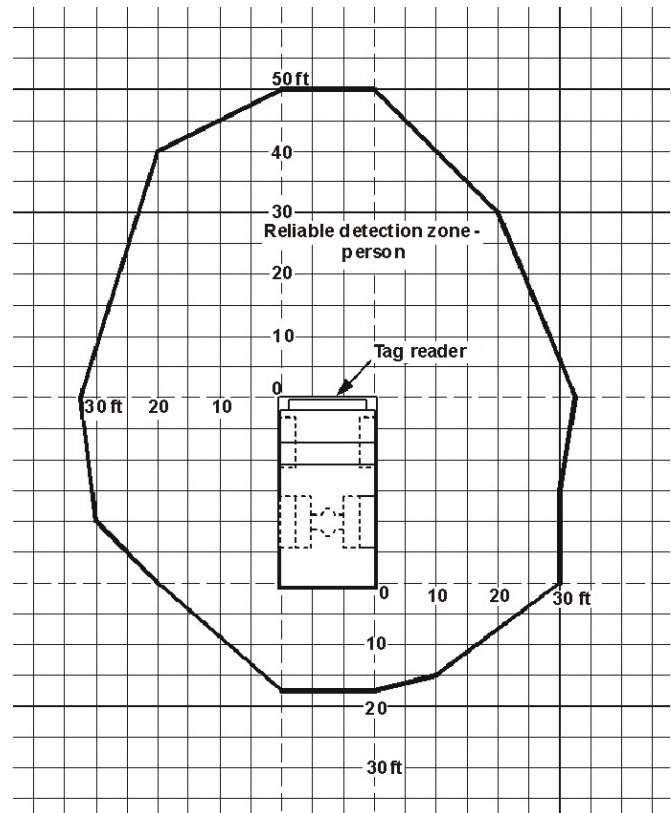


Figure 37.—Detection zone of Buddy system and a person

even in the engine compartment and wheel wells. Additional tests need to be conducted with the tag mounted on a pickup truck to determine the best mounting position. Tests with a cinder block were not conducted because the block would not be detected unless a tag was attached to it.

Discussion:

Mounting the loop antenna at the rear of the truck would solve the problem of the longer detection distance in front. However, two antennas, one at the front and one at the rear, may be required to establish detection zones with more equally sized areas and to allow each zone to be adjusted independently. This arrangement would also provide information on whether the tag was at the rear or the front of the truck.

A desirable feature of this system is that the tag generates an audible alarm so that the pedestrian worker is also alerted when in the detection zone of a dump truck. An optional display on the tag also provides a distance readout.

An override switch allows the tag to be ignored by the system when the worker holds down a button. This cuts down on annoyance alarms when the worker and the driver are mutually aware of each other's presence and activities close to the truck are required.

The alarm display was effective in the cab and displayed both the distance and the unique identification of the tag. Additional tests need to be conducted to determine the effects of multiple tags in the detection zone of a truck.

A disadvantage of this system is that each small vehicle and pedestrian worker must be outfitted with a tag in order to be detected. This makes the system more expensive than radar systems, but its added functionality, size of detection zone, and lack of false alarms may be worth the added cost.

System: Rear Guard

Manufacturer: Castleton, Inc., Westminster, CA
www.rearguard.com

Description:

This system operates by transmitting an ultrasonic signal and detecting echoes from nearby objects. An ultrasonic pulse is transmitted every twentieth of a second from each sensor to provide continuous coverage out to about 2.4 m (8 ft). The sensor beam is wide both horizontally and vertically and is teardrop shaped.

The system consists of sensors mounted on the bumper of the vehicle, an alarm display that provides an audible alarm, and a visual alarm that uses LED's. Two or more sensors can be mounted on the vehicle to cover front and rear blind spots. Wide vehicles may require three or four sensors to cover a blind spot adequately.

Test Results:

The system was mounted on the rear of the truck at a height of 1.37 m (54 in). Sensors were separated by a distance of 36 cm (14 in) (figure 38). It was difficult to find a mounting position at the rear because of the limited space near the light bar, which could result in false alarms set off by the tires and truck bed. The sensitivity of the system had to be reduced to 25% to eliminate such false alarms, presumably as a result of detecting the tires.

The detection area (figure 39) for a person was very limited because of the close mounting of the sensors and the low sensitivity setting. No other mounting position could be found that increased the detection area without also increasing the number of false alarms. The pickup and cinder block were not tested because of the limited size of the detection zone.

Mounting the system was much easier on the front of the dump truck. The sensors were mounted on the front bumper at a height of 1.07 m (42 in). Two separation distances were tried to adjust the detection zone, and sensitivity was increased to 60%.

Figure 40 shows the detection zone for a person with the sensors at the extremes of the bumper and pointing slightly inward (the sensor housing is manufactured this way). The reliable detection zone extended in front of each sensor to about 2.4 m (8 ft). However, a large null space existed in the center of the truck as a result of the configuration of the beams. A third sensor may be required to cover the entire front of the truck, but this was not provided with the system.



Figure 38.—Rear Guard sensors mounted on rear of dump truck.

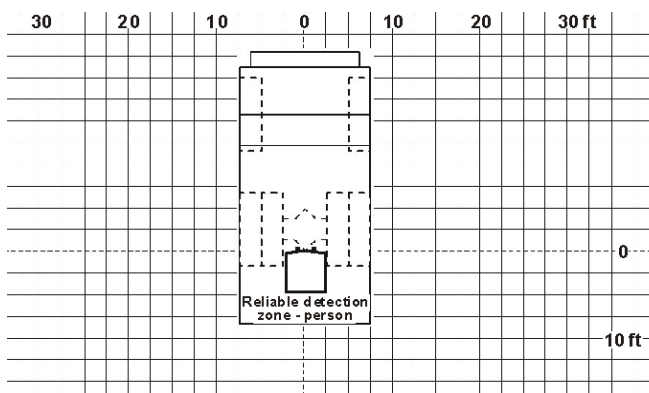


Figure 39.—Detection zone of Rear Guard system and a person at rear.

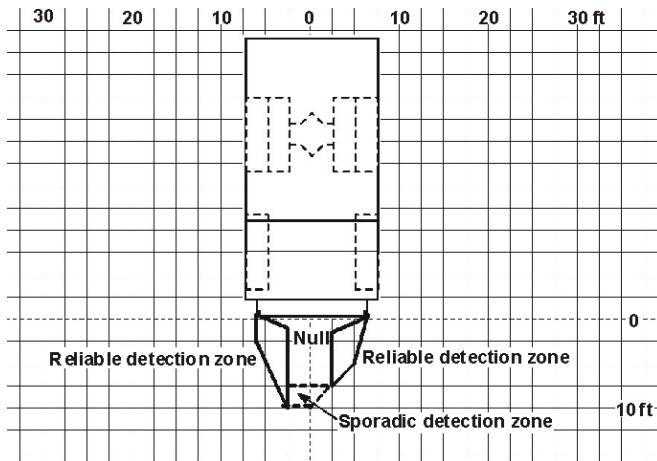


Figure 40.—Detection zones of Rear Guard system with sensors at ends of front bumper. A person is being detected.

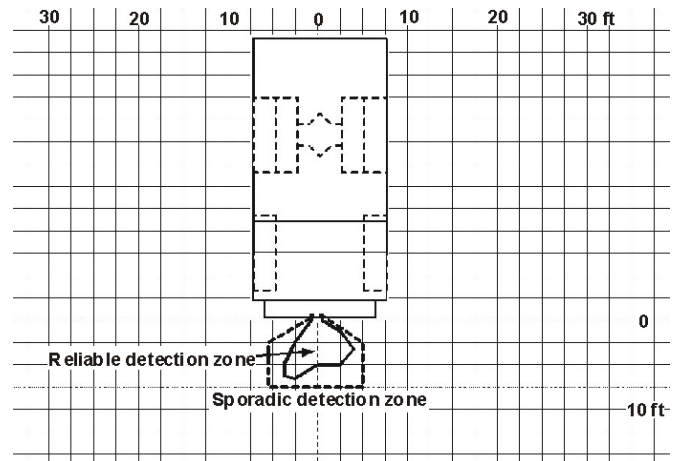


Figure 41.—Detection zones of Rear Guard system with sensors at center of front bumper. A person is being detected.

Figure 41 shows the detection zone for a person when the sensors were mounted next to each other at the center of the bumper and pointed outward (figure 42). The reliable detection zone extended to about 1.8 m (6 ft) in front of the truck, but only covered the center area. Areas near the bumper at the corners of the truck were not covered.

Because of the limited sized of the detection zones, the cinder block and the pickup truck were not tested.

Discussion:

While this system may be adequate for smaller vehicles, it will not work on the large trucks used in mining. The coverage area of the sensors is too limited to detect objects at the distances needed. Also, because of the beam shape, null spaces in the coverage area near the truck will exist.

There was also some concern about the reliability of this system in harsh weather. False alarms may be caused when the system is exposed to heavy rain or snow. False alarms were also generated when the sensitivity settings were above approximately 60%.



Figure 42.—Rear Guard system's ultrasonic sensors mounted close together on front bumper.

TEST RESULTS – CATERPILLAR 793B

System: Ogden Radar

Manufacturer: Ogden Safety Systems
www.visiontechniques.co.uk

Description:

This radar system is the same used in the Sensor Vision system described above. While an older version of the radar system was used in these tests, the general description found in that section still applies. This radar system is not yet available in the United States.

Test Results:

The radar unit was mounted on a Caterpillar 793B 240-ton-capacity dump truck near the light bar on the steel beam that runs above the axle (figure 43). The mounting height was 2.7 m (9 ft) to the bottom of the radar unit. No suitable mounting position was found lower than this. Because of the mounting height, the radar unit was tilted downward 15°. The alarm display was mounted near the axle for easy monitoring during the tests.

First, the radar system was tested for false alarms in a clear field while the truck was slowly moved in reverse. The system

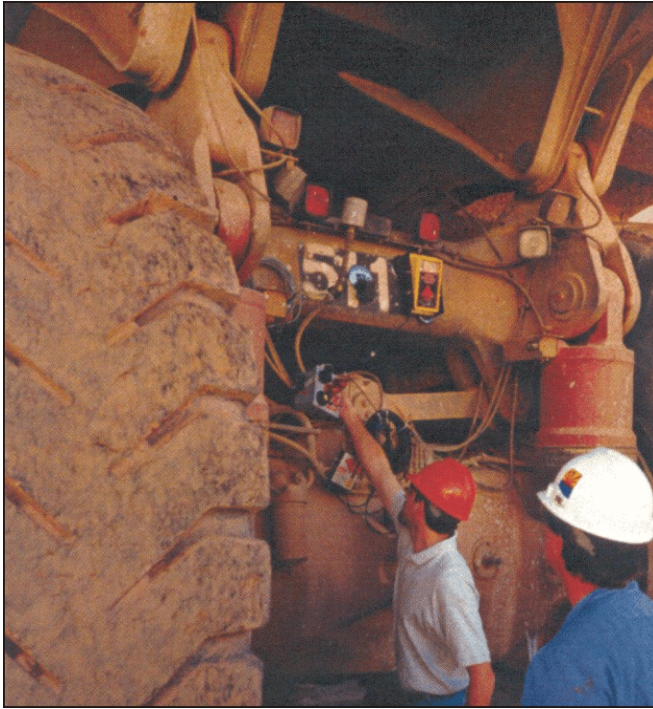


Figure 43.—Radar unit mounting position on Caterpillar 793B.

did not detect the movement of the tires and did not generate false alarms. Also, no false alarms from the ground were generated as the truck moved in reverse.

Figure 14 shows the detection zone for a person. The person walked toward the stationary truck because it was unsafe to move the truck toward a stationary person at grid points close to the truck. At maximum settings, the range of the radar unit was 6.1 m (20 ft) directly behind the truck. There was no detection from 0 to 2.4 m (8 ft) because of the required mounting height, which means that someone near the wheels of the truck would not be detected. Because it is critical to detect a person near the tires of the truck, the radar unit was tilted to 20° using spacers. The person was still not detected from 0 to 1.8 m (6 ft), and the overall range of the system decreased to 5.2 m (17 ft).

Figure 44 shows the detection zone for a pickup truck. The tilt was reset to 15°. The truck was oriented to face the back of the dump truck and slowly driven toward the stationary dump truck (figure 45). The pickup truck was detected from near the rear tires out to 7.6 m (25 ft).

Discussion:

As seen in figure 14, the detection zone was significantly narrower and shorter because of the higher mounting position and tilt. Also, the critical areas near the tires of the truck were not within the detection zone because a person could walk underneath the radar beam. This is consistent with the high mounting positions on the front of the Komatsu truck (figure 15), although the radar settings were adjusted to improve the width of the detection zone.

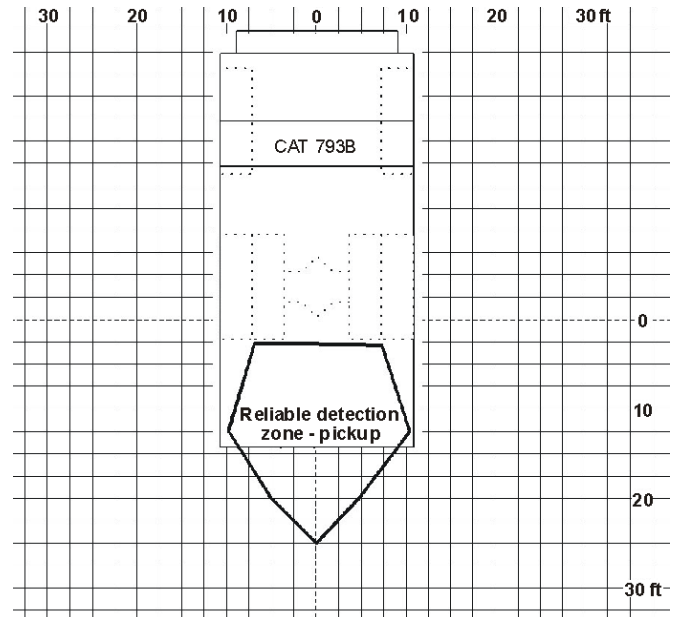


Figure 44.—Detection zone of Ogden radar system on Caterpillar 793B with a pickup at rear.



Figure 45.—Determining detection zone for a pickup Caterpillar 793B.

The detection zone for a pickup truck was also smaller because of the mounting height. However, a pickup was detected when it was near the tires (probably because the back of the pickup remained in the beam even though the front did not). It was concluded that, for high mounting positions, redesign of the antenna would be required in order to detect objects both near the tires and 6.1 to 9.1 m (20 to 30 ft) beyond the end of the dump truck's bed.

The front detection zones for this truck were not determined because lower mounting positions were available and their use would have given data that corresponded to data collected on the Komatsu truck at SRL. Also, tests on cinder blocks were

not conducted because of time constraints.

The radar and alarm display enclosures appeared well built and suitable for mining applications. Wiring could be improved to ensure that it could withstand high temperatures and impacts from flying rock, etc. The alarm display was intuitive and could be heard above engine noise in the cab; however, more thorough tests would need to be conducted to determine its effectiveness under actual operating conditions.

System: Guardian Alert

Manufacturer: Sense Technologies, Inc. Vancouver, B.C. Canada <http://guardianalert.com/warning.htm>

Description [Ruff 2000]:

This motion-sensing radar unit operates at 10.525 GHz. The radar unit does not require on-site licensing and is protected under U.S. patents 4803488 and 5028920.

The radar unit uses frequency modulation of microwave signals to determine the distance to an obstruction. The sensor is also pulse modulated so that it will not activate radar detectors or interfere with other similar devices. In fact, multiple sensors may be used on the same vehicle. The sensor will alert the operator to the nearest obstruction and, rather than requiring a fixed time between the moment it first detects an obstruction, it requires a fixed distance (12 cm [5 in]) in order to react. This makes the sensor insensitive to the velocity of the vehicle and simplifies the analysis.

The system consists of a radar antenna and an electronics enclosure, an alarm display, and wiring. The alarm display is mounted in the cab and provides range gates that indicate distance to the obstacle. Red, yellow, and green LED's flash to indicate an obstacle in a particular range gate, and a beeper increases in frequency as the obstacle gets closer to the equipment. This particular model was configured for three range gates: 0 to 3, 3 to 6, and 6 to 12 m (0 to 10, 10 to 20, and 20 to 40 ft). The total range, beam width, and range gates can be configured at the factory.

Test Results:

The Guardian Alert system was mounted in the same position as the Ogden system at 2.7 m (9 ft) high with a 10° downward tilt (figure 43). The zone behind the dump truck was cleared, and the dump truck was moved in reverse to test for false alarms. The radar unit generated an alarm with a single or double chirp whenever the truck lurched, e.g., when putting the truck into gear or braking suddenly. However, after the truck began moving smoothly in reverse, the Guardian Alert system did not detect tire rotation and did not generate a false alarm.

A person walked toward the stationary dump truck to define the detection zone (figure 46). The range of this system extended from near the tires to 6.1 m (20 ft). The width of the zone extended only 3 m (10 ft), slightly wider than the distance between the tires.

A pickup was then used to define the detection zone (figure 47). The pickup was slowly driven toward the rear of the stationary dump truck. The range of the Guardian Alert system

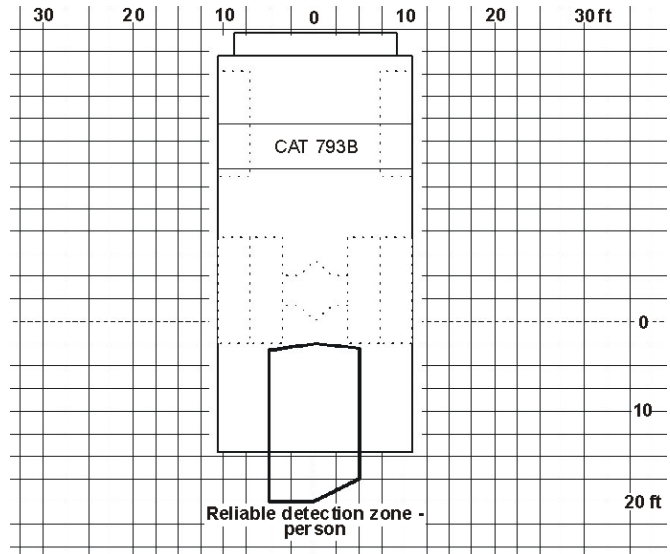


Figure 46.—Detection zone of Guardian Alert radar system on Caterpillar 793B with a person at rear.

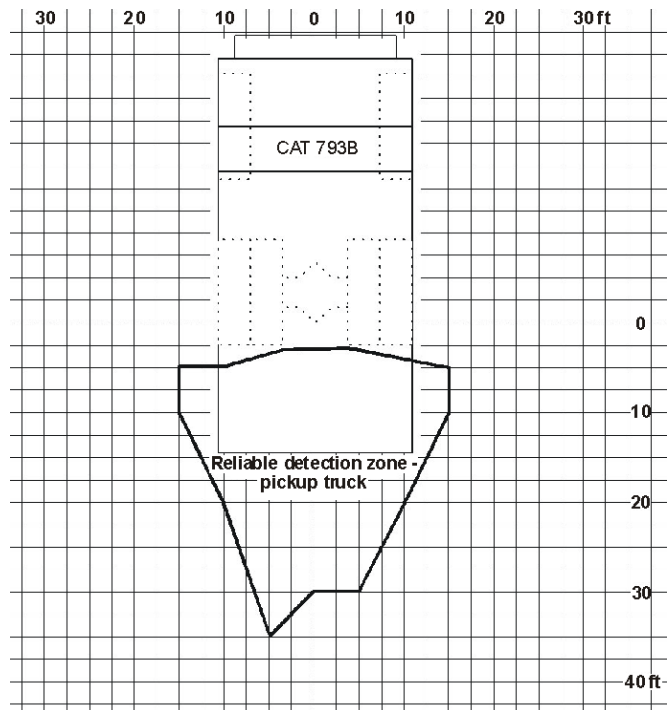


Figure 47.—Detection zone of Guardian Alert radar system on Caterpillar 793B with a pickup at rear.

extended from near the tires out to 10.7 m (35 ft) from the truck. The width of the detection zone improved to around 9.1 m (30 ft).

Discussion:

The detection zone for a person was significantly narrower

on the Caterpillar 793B than on the Komatsu 210M [Ruff 2000]. It appears that the recessed mounting position behind the tires and the mounting height reduced detection zone dimensions. An alternative mounting position or antenna design would be needed if the system were to be used on the rear of this truck. It is anticipated that the system would be effective on the front of the truck.

The detection zone for a pickup truck was better than that for a person; however, a longer distance for the detection zone would be preferred. The pickup was detected near the tires and the entire width of the dump truck was covered as long as the pickup was within 6.1 m (20 ft).

Occasional false alarms occurred when the truck lurched while shifting gears or braking. This could probably be

remedied in the radar's processing algorithms and will be suggested to the manufacturer.

The enclosure for the radar antenna appeared to be adequate for a mining application. The wiring would need to be improved to withstand high temperatures and impacts from flying debris, and the enclosure for the alarm display would need to be made more robust. The audible alarm might not be heard above other noises in the cab, and a volume control should be added. Also, a more intuitive scheme for lighting the LED's would be preferred. Simply lighting one of a series of LED's all labeled with the correct distance information would be easier to interpret.

CONCLUSIONS

Results from these tests have supported the conclusions and recommendations made in a previous report [Ruff 2000], which are summarized and updated in the current report.

Collision warning systems must be tested on the actual equipment on which they are to be used to ensure that the detection zones are adequate for that particular piece of equipment. The distances to components on the truck, such as the truck bed or tires, do affect the characteristics of radio frequency transmissions and radar reflections. Beam widths and distances that are effective for smaller trucks may not be sufficient for larger trucks or other types of equipment, such as front-end loaders. Mounting height also has an effect on the size of the detection zone.

Detection zones must be verified using actual objects, such as a person or a pickup truck, that must be detected in actual practice. Initial determination of detection zones can be accomplished using corner reflectors when radar systems are used; however, detection zones need to be verified using a person and a pickup truck to ensure accuracy. It is understood that repeatability is difficult because of different body types and pickup truck models, but sufficient accuracy can be obtained using a person falling in the range of average height and weight and any common full-sized pickup truck.

The ideal detection zone depends on the type of mining equipment and where the collision warning system is mounted on that equipment. It is important that the detection zone cover the entire width of the equipment and be as close as possible to either the bumper at the front or the tires at the rear. The length of the zone should extend approximately 12 to 15 m (40 to 50 ft) to prevent accidents involving large, slow-moving dump trucks. Higher speeds would require longer detection distances to give the truck driver enough time to react to an alarm; however, accident reports show that most accidents occur shortly after the truck starts moving from a parked position.

It is important to verify the reliability of a collision warning system by actually moving the dump truck toward the obstacle at several points in the detection area where it is safe to do so.

Earlier tests showed that equipment vibration and other moving parts, such as tires, can affect the operation of a system when the equipment is in motion. These effects have ranged from total system failure to occasional false alarms.

A problem seen with radar systems is their susceptibility to false alarms or nuisance alarms from objects that pose no danger, such as rocks or ruts in the roadway. There are also alarms from objects of which the equipment operator is already aware, such as shovels or pit walls. Too many alarms are a major concern because an equipment operator may become frustrated and start ignoring them. It is very difficult to climb out of the truck to verify the source of every alarm. Because of this problem, it is recommended that radar systems be used in conjunction with another secondary system, such as video cameras. This will allow an operator to verify the source of an alarm without leaving the cab. It also improves the reliability of a collision warning system by providing a method of verifying the location of an obstacle and the number of obstacles in a blind area. As the functionality and reliability of radar-based collision warning systems improve, a secondary system may become optional.

RFID systems are not prone to false alarms, but a secondary system, such as a camera, may be helpful in locating the source of an alarm or avoiding collisions with untagged objects. The disadvantage of RFID systems is the requirement that all objects or people that need to be protected must have a tag attached. This could require a large amount of tags at a mine site. Tag reliability must be high, and maintenance kept to a minimum.

Cameras by themselves do not generate an alarm that alerts an operator to an impending collision. It is recommended that a secondary system be used with cameras to provide such an alarm. Such a secondary system would be an effective means of prompting an operator to check his/her video monitor when necessary. Several mine safety managers have expressed a concern over this problem and have had first-hand experience with camera systems that did not help prevent a collision.

Table 2.—Summary of test results for collision warning systems on a Komatsu 210M

System	Buddy System	Body Guard	Knapp	Guardian Alert	Preview	Ogden	Rear Guard	MSSI *
Technology	RFID	RFID	Doppler radar	Doppler radar	Pulsed radar	FMCW radar	Ultrasonic	UWB radar
User-adjustable zones	Yes	Yes	Yes	No	No	Yes	Yes	Yes
Motion required for detection	No	No	Yes	Yes	No	Yes	No	No
Maximum length of rear detection zone as tested (person/pickup in feet)	50/50	50/50	22.5/65	25/45	30/27.5	40/40	8/NA	50/50
Total coverage near outer dual tires	Yes	Yes	Yes	Yes	No	No	No	Yes
Maximum length of front detection zone as tested (person/pickup in feet)	50/50	50/50	22.5/65	30/37.5	27.5/30	25/30	8/NA	45/55
Total coverage near bumper	Yes	Yes	Yes	Yes	No	Yes	No	No
Sporadic detection at zone edges	No	Yes	No	No	Yes	No	Yes	Yes
For use in all weather	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes
False-alarm rate in clear field	None	None	Infreq.	Frequent	None	None	Infreq.	None
Cinder block detection	No	No	Yes	Yes	Yes	Yes	NA	Yes
Level of effort in mounting	High	High	Med.	Low	Med.	Low	Med.	Low
Multiple units needed for entire coverage (front/back)	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Cost (H = above \$8000, M = \$2000-\$8000, L = below \$2000)	High	High	Low	Low	Low	Low	Low	Med.

NOTE: Some system information taken from Ruff 2000.

* Still under development.

RFID = Radio-frequency identification. FMCW = Frequency-modulated continuous wave. UWB = Ultrawide band.

Table 2 summarizes the results from the phase 1 and 2 tests of available collision warning systems on a Komatsu 210M dump truck. These tests were useful in showing the potential for the use of this technology on large trucks, but an actual test

program over an extended time is needed to verify that these systems will be effective in an operating mine and on other types of equipment. This will be the focus of the next phase of testing.

REFERENCES

Ruff, Todd M., Test Results of Collision Warning Systems for Surface Mining Dump Trucks. NIOSH Report of Investigations 9652, 2000, 44 pp.

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