

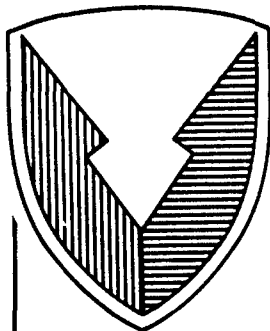
ADA 201172

AD A201172

RD & E

C E N T E R

Technical Report



No. 13387

ROBOTIC VEHICLE COMMUNICATIONS INTEROPERABILITY

AUGUST 1988

Daniele Mariani
U.S. Army Tank-Automotive Command
ATTN: AMSTA-RRT
By Warren, MI 48397-5000

APPROVED FOR PUBLIC RELEASE:
DISTRIBUTION IS UNLIMITED

U.S. ARMY TANK-AUTOMOTIVE COMMAND
RESEARCH, DEVELOPMENT & ENGINEERING CENTER
Warren, Michigan 48397-5000

20020813366

AN-39882

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1a. REPORT SECURITY CLASSIFICATION Unclassified		1b. RESTRICTIVE MARKINGS	
2a. SECURITY CLASSIFICATION AUTHORITY		3. DISTRIBUTION/AVAILABILITY OF REPORT Approved for Public Release: Distribution is Unlimited	
2b. DECLASSIFICATION/DOWNGRADING SCHEDULE		5. MONITORING ORGANIZATION REPORT NUMBER(S) TACOM T.R. 13387	
4. PERFORMING ORGANIZATION REPORT NUMBER(S)		7a. NAME OF MONITORING ORGANIZATION U.S. Army Tank-Automotive Command	
6a. NAME OF PERFORMING ORGANIZATION U.S. Army Tank-Automotive Command	6b. OFFICE SYMBOL (If applicable) AMSTA-RRT	7b. ADDRESS (City, State, and ZIP Code) Warren, MI 48397-5000	
6c. ADDRESS (City, State, and ZIP Code) Warren, MI 48397-5000		9. PROCUREMENT INSTRUMENT IDENTIFICATION NUMBER	
8a. NAME OF FUNDING/SPONSORING ORGANIZATION	8b. OFFICE SYMBOL (If applicable)	10. SOURCE OF FUNDING NUMBERS	
8c. ADDRESS (City, State, and ZIP Code)		PROGRAM ELEMENT NO.	PROJECT NO.
		TASK NO.	WORK UNIT ACCESSION NO.
11. TITLE (Include Security Classification) Robotic Vehicle Communications Interoperability (u)			
12. PERSONAL AUTHOR(S) Mariani, Daniele			
13a. TYPE OF REPORT Final	13b. TIME COVERED FROM Dec 87 to Aug 88	14. DATE OF REPORT (Year, Month, Day) August 1988	15. PAGE COUNT 108
16. SUPPLEMENTARY NOTATION			
17. COSATI CODES		18. SUBJECT TERMS (Continue on reverse if necessary and identify by block number)	
FIELD	GROUP	Robotic communications Communication protocols	
		Communications interoperability	
19. ABSTRACT (Continue on reverse if necessary and identify by block number)			
Communications interoperability (CI) amongst different robotic vehicle systems would provide many benefits to the robotics development and user communities. This report takes a first step towards CI by proposing protocols for a communications interface standard for robotic vehicle communication systems.			
20. DISTRIBUTION/AVAILABILITY OF ABSTRACT ☒ UNCLASSIFIED/UNLIMITED ☐ SAME AS RPT. ☐ DTIC USERS		21. ABSTRACT SECURITY CLASSIFICATION Unclassified	
22a. NAME OF RESPONSIBLE INDIVIDUAL Daniele Mariani		22b. TELEPHONE (Include Area Code) (313) 574-5798	22c. OFFICE SYMBOL AMSTA-RRT

NOTICES

This report is not to be construed as an official Department of the Army position.

Mention of any trade names or manufacturers in this report shall not be construed as an official endorsement or approval of such products or companies by the U.S. Government.

Destroy this report when it is no longer needed. Do not return it to the originator.

TABLE OF CONTENTS

Section	Page
1.0. INTRODUCTION	9
2.0. OBJECTIVE	9
3.0. CONCLUSION	9
4.0. RECOMMENDATIONS	10
5.0. DISCUSSION	11
5.1. <u>Interoperability</u>	11
5.2. <u>Robotic Vehicle System Functions</u>	33
5.3. <u>Representation of the Compiled Information</u>	39
5.4. <u>Protocol Testing</u>	50
SELECTED BLIOGRAPHY	51
APPENDIX A. CONTROL/STATUS OF MANNED MILITARY VEHICLES	A-1
APPENDIX B. CONTROL/STATUS REQUIRED FOR ROBOTIC VEHICLE SYSTEMS	B-1
APPENDIX C. CONTROL COMMAND CODING	C-1
APPENDIX D. STATUS INFORMATION CODING	D-1
DISTRIBUTION LIST	Dist-1

LIST OF ILLUSTRATIONS

Figure	Title	Page
5-1.	Environmental Obscurations	16
5-2.	The OSI Reference Model	20
5-3.	Frame Formats	26
5-4.	Simplified SDLC	28
5-5.	Candidate Message Formats	41
5-8.	Proposed Message Format	46
5-9.	Complete Data Packet	51

LIST OF TABLES

Table	Title	Page
5-1.	Designation of Electromagnetic Waves	15
5-2.	Data Link Layer Protocols	27
5-3.	Data Unit Codes	32
5-4.	Robotic Vehicles Studied	36
5-5.	Message Format Comparison	44

1.0. INTRODUCTION

This technical report, prepared by the Robotics Division of the U.S. Army Tank-Automotive Command (TACOM), describes communications interoperability (CI) between different robotic vehicle systems, and also different robotic modules. It does this by proposing protocols for a communications interface standard for robotic vehicle communication systems.

"Interoperability is critical to the Army's robotics program."¹ Achieving CI will provide three major benefits. The first is the more effective deployment of robotic systems. The second is the significant enhancement of testing and demonstrations. And the third is a reduction in the cost of developing and building these systems.

2.0. OBJECTIVE

The primary goal was to propose a communications interface standard, consisting of a set of protocols and a unique message format, that will lead to CI.

3.0. CONCLUSIONS

This study offers the following conclusions:

- The development and adoption of a communication interface standard is a better approach to CI than the use of translators.
- Now is a good time to develop and test protocols for robotic vehicle communications because many robotic systems are still in the testbed stage.
- The use of a robotic vehicle communication subsystem suggests that:
 - The separation of the video imagery from the command and control data allows the command and control data to be transmitted on a separate, lower frequency carrier in the VHF band. There are advantages to transmitting in this band.

¹Captain Rick Lynch, Program review at TACOM, Warren, Michigan, 23 October 1987

- A digital communication system is superior to an analog one for the command and control of robotic vehicles.
- A simplified version of Synchronous Data Link Control (SDLC) is the most efficient data link layer protocol.
- A protocol for the network layer is not currently needed, but may be added at a later time.
- A transport layer protocol which adds a two-byte header to the message will provide the needed transport services.
- A block message format, developed and compiled in this report, is superior to a fixed or variable length message format because:
 - The use of high-level commands allows for the ability to add additional commands and the capability to use the message for any application. It is extremely flexible and will not become obsolete.
 - It reduces the bandwidth requirements of a communication subsystem on a complex robotic vehicle.
 - It allows for the use of commands which can be ordered by priority.
- Automating functions is a way of reducing the bandwidth requirements of the communication system.

4.0. RECOMMENDATIONS

Based on the results of this investigation, the following recommendations are submitted:

- A communication interface standard should be used in order to achieve CI.
- The protocols and message format proposed in this report should be evaluated and tested for application to robotic vehicle systems. Revisions should then be made to ensure that optimum protocols are available for systems that will be fielded.

- For a robotic vehicle communication sub-system:
 - Video imagery and command and control data should be separated, at least until practical image compression becomes available. The command and control data should be transmitted in the VHF band.
 - Digital communications should be used.
- A simplified version of SDLC should be used as the data link layer protocol.
- A block message format should be used to digitally represent the control commands and the status information that passes between a control station and an RV.
- As many functions on-board the robotic vehicle as possible should be automated.

5.0. DISCUSSION

5.1. Interoperability

5.1.1. Standard vs. Translator. Achieving interoperability requires one of two approaches:

- Have each entity talk in its own language, and have a "translator" interpret the language it receives.
- Develop and adopt a communications interface standard.

Each of these two approaches has advantages. Using the translator is the best way to achieve CI for a robotic vehicle (RV) system that has already been built. It would be costly to redesign an existing system so that it would meet a standard's specifications.

Adopting a standard, however, is a better approach for systems which have not yet been built because it is more efficient, and it will result in cost savings.

Without a standard, most developers will design their system with no concern for communications interoperability. Then at a later time they will need to implement a translator. Designing to an existing standard will save time and money down the road.

A different translator would be needed for every system that is talked to. Also, it would need to be modified with the changes in functionality of every vehicle.

Using a standard cuts out one step in the communication process. With the translator, there is a "middle man" between the two entities that are communicating. Using a standard allows the two to "speak" directly to each other.

Building a communication system to standard specifications will result in several types of cost savings. The first is in the design of communication/control subsystems. Since the communication interface to be used will be described in the standard, it will not need to be designed.

The second savings will be in hardware and software costs. All communication systems adhering to the standard will have common hardware and software. Once the software is written and the hardware developed for one system, they can be used at minimal cost for other common systems.

Also, the best way to keep costs down is through competitive procurement. To achieve the cost savings of competitive procurement, and to get the highest performance possible, a high degree of compatibility between contractor's subsystems will be necessary. Adoption of a communication standard will provide this compatibility.

5.1.2. Background. TACOM contacted two offices to determine if a standard for robotic vehicle communications had already been developed: 1) The Interoperability Network Directorate of the U.S. Army Communications-Electronics Command (CECOM) at Fort Monmouth, New Jersey, which has the responsibility of making Army communication equipment compatible. 2) The Joint Tactical C3 Agency (JTC3A) of the Defense Communications Agency (DCA) in Washington, D.C., which has the responsibility of ensuring compatibility of communication equipment in the joint community (all the military services). This investigation yielded no standard.

There are three other Army programs which address inter-vehicle communications.

- Inter Vehicle Intercommunication System (IVIS) deals with digitally transferring information that is now transferred by voice. It is an Armor School concept for communicating at the battalion level and below. It is being proposed for M1A1 Block II.
- Combat Vehicle Command and Control (CVC2) is the next generation IVIS. It provides for

the networking of vehicles at the individual vehicle, platoon, company and battalion commander echelons. CVC2 applies to M1A1, Bradley, and future combat vehicles.

- Battlefield Management System (BMS) is the networking of all assets at battalion level and below.

These three programs are in the very early stages. At this point it is difficult to speculate how robotic vehicle communication systems will be affected by these programs, which are targeted for manned vehicles.

Most likely there will be commonality between the robotic vehicle communication standard and these other battlefield communication techniques. But robotic vehicle communication needs are unique in some ways and thus should be addressed.

5.1.3. Communications Interface Standard. The standard must completely describe:

- The information - its structure, format, and meaning.
- The communication system - the hardware, protocols, and signals used to transfer the information.

This report will describe and use the Open Systems Interconnection Reference Model (OSI-RM) as a means of discussing the issues involved in the development of a standard interface document. Before further discussing the OSI-RM, however, it is important to clarify what needs to be communicated by these subsystems, what portion of those communications will be addressed in this report, and what format (digital or analog) the communication system should use.

5.1.4. Communication Needs. A robotic vehicle system communication subsystem provides for continuous, bidirectional communications between a control station and one or more RVs. From a control station to an RV, the subsystem provides for the transmission of signals generated at the control station which control the functions of the RV (movement, weaponry, etc.).

From an RV to a control station, the subsystem provides for the transmission of signals which allow the remote operator located in the control station to effectively operate the RV. These signals depict the status of the RV and its subsystems. Also, video and other sensory information captured by cameras and other sensors aboard the RV are

needed.

5.1.5. Communication Portion Addressed. Robotic vehicle systems need to maintain continuous communications to avoid a control station losing control of its RVs. The ability to do so is hindered due to spectrum jamming, natural electromagnetic interference (EMI), signal attenuation, and foliage and terrain blocking the line of sight (LOS) path between the two communicating vehicles.

The communicating medium can be either hardwired (fiber optic cable, coaxial cable) or softwired (radio communications). For radio communications, there are specific advantages to transmitting at lower frequencies (VHF or UHF) as opposed to higher frequencies. See Table 5-1 for a designation of the frequencies.

These advantages include:

- The ability to penetrate foliage and other obstructions increases as frequency decreases. (See Figure 5-1)
- As frequency decreases, signal attenuation decreases.
- Simple antennas can be used instead of complex arrays.

An obstacle to using the lower frequency bands is the lack of available frequency bandwidth. Using current technology, about 6 MHz of bandwidth are required for a single FM-modulated video channel. For an RV with four video channels, bandwidth needed would be a minimum of 36 MHz.

Currently, there are no VHF or UHF bands allocated for an application requiring so much bandwidth. The existing bands are extremely congested with both military and commercial users, and it is unlikely that any bands will become available. Therefore the video imagery will need to be transmitted in the higher frequency ranges, at least until practical image compression techniques become available. Once practical compression techniques become available, it will be possible to transmit video in a VHF or UHF band.

The command and control information requires far less bandwidth than uncompressed video. The exact bandwidth required is yet to be determined, but it is in the range of 5-100 kHz. This is narrow enough to be placed in a VHF or UHF band. Therefore, it is advantageous to separate the video information from the command and control information, transmitting the video channels in the microwave band or

Table 5-1. Designation of Electromagnetic Waves

Frequency Band	Designation
3 - 30 kHz	Very low frequency (VLF)
30 - 300 kHz	Low frequency (LF)
300 - 3000 kHz	Medium frequency (MF)
3 - 30 MHz	High frequency (HF)
30 - 300 MHz	Very high frequency (VHF)
300 - 3000 MHz	Ultrahigh frequency (UHF)
3 - 30 GHz	Superhigh frequency (SHF)
30 - 300 GHz	Extremely high frequency (EHF)
NOTE: 500 MHz - 40 GHz is also designated as the microwave band.	

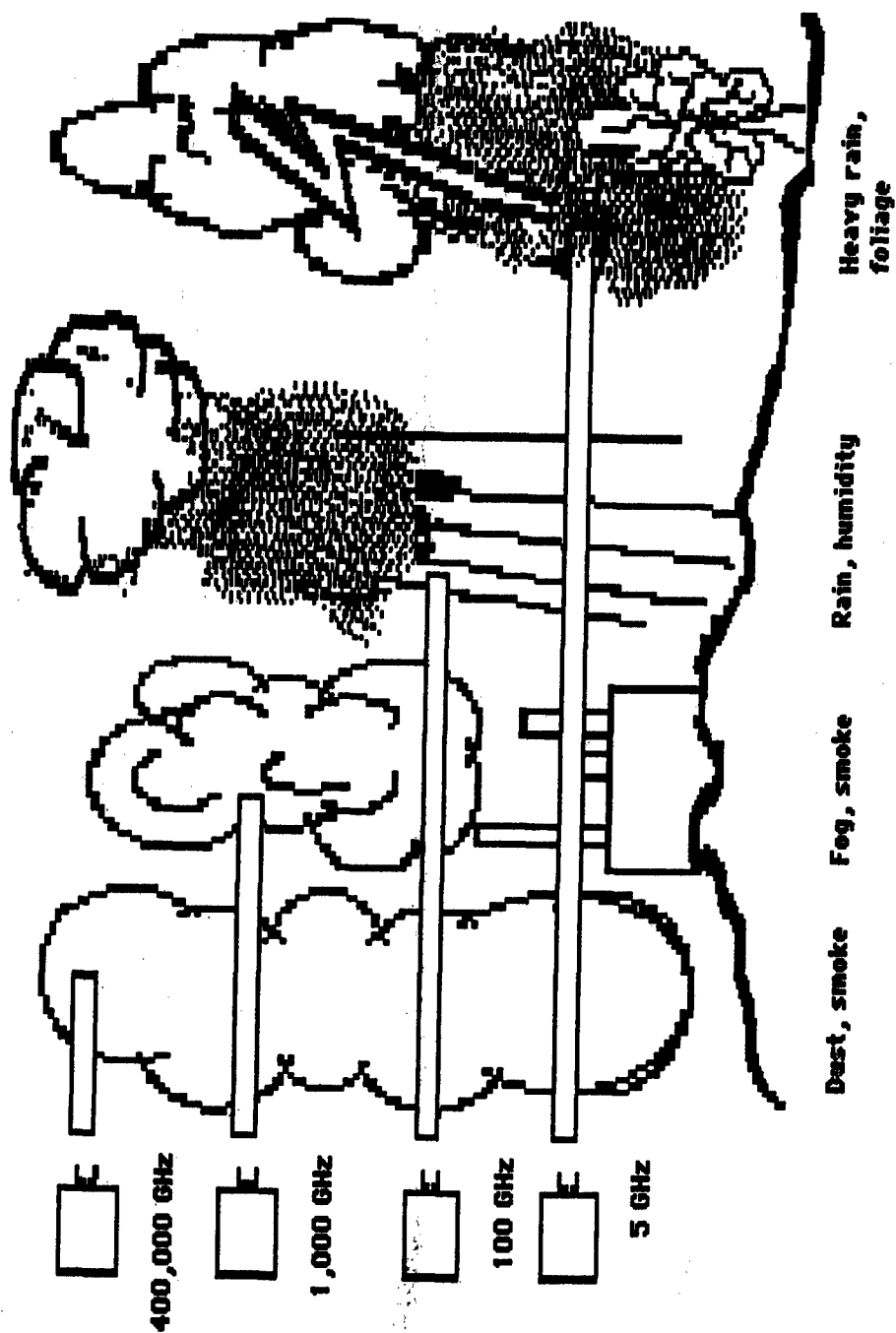


Figure 5-1. Environmental Obscurations

higher, and the command and control channels in the VHF or UHF band. Command of the RV can be maintained even as the video picture fades out.

The rest of this report will deal only with compatibility for the transmission of command and control information. It will not deal with compatibility for the transmission of video and other sensory imagery.

5.1.6. Digital Versus Analog. Command and control signals can have one of two representations, either digital or analog. Both systems have advantages.

5.1.6.1. Digital advantages.

- Good performance is possible with a signal-to-noise ratio of only 20 to 30 decibels (dB). A frequency-modulated analog system would require 30-40 dB for similar quality, and an amplitude-modulated analog signal an even higher signal-to-noise ratio.
- Works well with systems requiring the data to be relayed over multiple hops, because the digital information is regenerated at each relay. This is in contrast to an analog system, where the noise and distortions are not simply those of the weakest link, but those of the accumulation of all the relays.
- Error control techniques can be used to detect and/or correct most bit errors.
- Most encryption techniques are discrete in nature, allowing for data security.
- Transparent to the type of data. The signal could be voice, video, or computer data and any user with a compatible digital interface could receive the information. For analog systems, channels must be modeled according to the nature of the signal.
- A higher capacity per carrier frequency can be accommodated, using a time division multiple access (TDMA) technique. TDMA is a more efficient multiplexing technique than frequency division multiplexing (FDM), which is used with analog systems.

5.1.6.2. Analog advantage. Most sensors have an analog output. To use a digital system, an analog-to-digital (A/D) conversion must take place. This process increases

system complexity and cost. It also can introduce a quantization error.

5.1.6.3. Preferred Signal Representation. A digital system is superior to an analog system for the robotic vehicle communications application because of:

- Superior performance with the same signal-to-noise ratio
- Superior performance over multiple hops
- Available error control techniques
- Compatibility with encryption techniques
- Transparency to the type of data
- Higher capacity per carrier

The rest of this chapter will deal only with digital data communications.

5.1.7. The OSI Reference Model.

5.1.7.1. Introduction. The International Organization for Standardization (ISO) is a voluntary organization formed to make standards. TC97, one of ISO's technical committees, is concerned with information systems. TC97 developed, and in 1978 ISO introduced, the Open Systems Interconnection Reference Model (OSI-RM).

The OSI-RM is a model of a computer communications architecture. It was developed to promote compatible communications among a wide variety of digital systems. It is a framework for developing standards, and it provides the terms of reference for discussing communication system design. It has succeeded in winning general acceptance in the telecommunication industry, and therefore will be applied to the problem of robotic vehicle system's communication compatibility.

5.1.7.2. Description. The OSI-RM is not a protocol standard. Instead, it specifies seven distinct layers that define the functions involved in communicating. To implement the OSI-RM, protocols have been and are being developed and standardized at each layer.

One advantage of the OSI-RM is that all the layers are modular. This allows different groups to develop protocols at different layers with some assurance that the various layers can work together in a system. Modularity also permits the existence of sublayers, meaning multiple proto-

cols at each layer.

Each layer must communicate with the layer above and below it. They must follow rules for these interlayer interfaces.

For communicating between entities, it is imperative that all the entities have identical layers and use the same protocols.

The OSI-RM is shown in Figure 5-2. It ranges from the medium, to the Physical (lowest) Layer, and up through the Application (highest) Layer.

The bottom three layers are communication layers, concerned with the transmission of bits and bytes. These layers are hardware dominated. The top three layers are the information processing layers, adding intelligence to the bits and bytes which will be or have been transmitted. These layers are software dominated. The fourth, or middle layer, bridges the gap between these two sets of layers.

The following sections describe the medium and each layer in some detail.

- The Medium. The medium refers to the type of channel over which the signal is transmitted. Some possibilities include:
 - Air
 - Twisted pair wire
 - Coaxial cable
 - Fiber optic cable
 - Water
 - Laser
- The Physical Layer. The physical layer is the bottom, and first, layer of the OSI-RM.

Its responsibility is to send and receive bits over the medium. It covers the physical interface between devices and the rules by which bits are sent and received. This layer is concerned with the following functions:

- Matching the physical medium.
- Channel encoding the data.

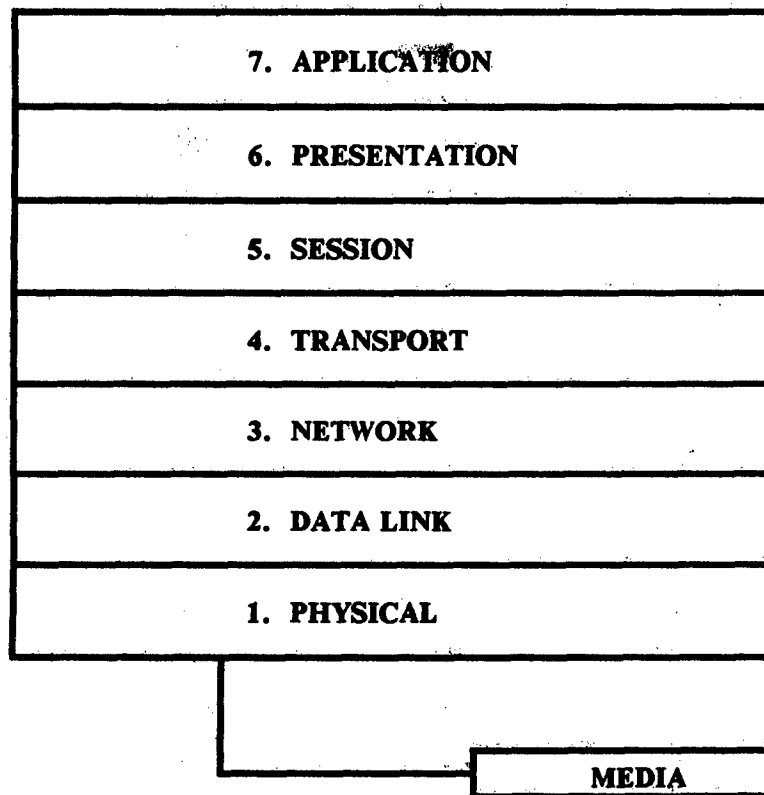


Figure 5-2. The Open Systems Interconnection Reference Model

- Sequencing of events for transmitting data.
- Physically connecting the devices.
- Modulating and demodulating the signals.
- The Data Link Layer. The data link layer is the second layer of the OSI-RM. It attempts to make the physical layer reliable. It performs the following functions:
 - Link management - activation, maintenance, and deactivation of the link.
 - Error control - bit error detection and/or correction.
 - Flow control - does not allow a fast sender to clobber a slow receiver.
 - Synchronization - synchronizes the sender and the receiver that are exchanging data.
 - Addressing - identifies the sender and/or receiver of the data.

To perform these functions, the bits are arranged into frames. The frames add overhead bits, which are used to perform the functions of this layer. These frames are passed down to the physical layer for transmission. The layer above the data link layer can assume error free data because the transmission errors have been corrected by this layer.

- The Network Layer. The third layer is the network layer. The network layer routes data through a network of computers/terminals. It relieves the upper layers of the need to know anything about the methodology used to establish the connection between the end entities. It also allows the lower two layers to deal only with point to point communications.

It does this by organizing the data into packets. Packets are the frames from the data link layer with additional overhead added.

- The Transport Layer. The transport layer is

the fourth, and middle, layer. It is the bridge between the three lower communications layers and the three higher information processing layers. The transport layer is responsible for end-to-end (originating source to ultimate destination) services. These services include flow control, error control, sequencing, survival of the connection, and expedited delivery.

The transport layer does for an end-to-end link (including relays and repeaters) what the data link layer does for point-to-point links. It performs these functions by assembling the data into transport protocol data units (TPDU). The TPDU's add overhead bits, which are used to perform the functions of this layer.

- The Session Layer. The fifth layer is the session layer. The session layer provides the mechanism for controlling the dialogue between applications. It can do the following:
 - Establish and terminate connections.
 - Provide one of three types of dialogue: full-duplex, half-duplex, or simplex.
 - Allow either abrupt or graceful disconnections, meaning a message can or can not be disrupted in the midst of a transmission, and also what to do if the message is interrupted.
- The Presentation Layer. The presentation layer is the sixth layer. The presentation layer ensures that information is delivered in a form that the receiving system can understand. Its purpose is to resolve differences in format and data representation by defining the syntax used.

Security through encryption, message compression, and syntax conversion can also be done at this layer.

- The Application Layer. The application layer is the seventh, and top, layer. It serves as a window between the application process and the OSI communications environment. This layer manipulates information and manages

resources to support distributed applications. To the user, this layer appears to be doing the real work.

5.1.7.3. Application of the OSI-RM.

- The Physical Layer. There are a variety of standard protocols for the physical layer which define all the functions for this layer. The most popular are:

- RS-232-C
- RS-449/422-A/423-A
- CCITT X.21

All three provide the necessary mechanical, electrical, functional, and procedural specifications.

RS-232-C is the oldest and most widely used of the interface standards.

The RS-449/422-A/423-A set of protocols was designed specifically to replace the RS-232-C. It provides performance advantages over the RS-232-C in the areas of achievable transmission distances, speed characteristics, and modem control. While the RS-232-C remains the most popular interface protocol, the RS-449/422-A/423-A set is experiencing increasing growth in usage.

X.21 is the newest and thus far the least used of the three protocols. It provides fewer circuits (pin connections) than the other two protocols, but adds more logic. With the falling cost of logic circuitry, this can be an advantageous approach.

X.21 provides the same speed characteristics and transmission distances as the RS-449/422-A/423-A set of protocols. It is also more flexible and potentially less costly.

Choosing the optimum physical layer protocol will involve weighing the following advantages against each other:

- The extremely wide-spread use of the RS-232-C.

- The improved performance and growing use of the RS-449/422-A/423-A.
- The strong performance, flexibility, and potential cost savings of the X.21.

The analysis of these three protocols and the choice of an optimum one for robotic vehicle systems is outside the scope of this report.

- The Data Link Layer. To perform the functions of the data link layer, overhead bits are added to the data bits and arranged into frames. An optimum frame format is one which can effectively perform the needed functions, and do so with the minimum number of overhead bits. A minimum number of overhead bits is desired because as the overhead goes up, the amount of data that can be transmitted drops, assuming constant bandwidth.

The functions needed at the data link layer for robotic vehicle systems are:

- Synchronization
- Vehicle addressing
- Error control

Synchronization refers to the ability of the receiving entity to determine when a signal being transmitted to it starts and ends. This is usually done using some type of flag.

Vehicle addressing refers to the ability of a control station to transmit information to the RV it intends to. When there is a one-to-one control-station-to-RV ratio, as with current robotic vehicle systems, this is not necessary. Also, if each vehicle is controlled over a different channel, as with near term systems, it is unnecessary. But for far term systems, when one control station will be supervising multiple RVs, an addressing scheme will be necessary.

Error control is the ability of the receiving entity to detect and either correct or disregard data frames that have been damaged (contain erroneous bits) during transmission.

There are a variety of standard protocols

which perform these necessary functions. Some of the more widely used ones are:

- High-level data link control (HDLC)
- Synchronous data link control (SDLC)
- Digital data control message protocol (DD CMP)
- IEEE 802.3

HDLC and SDLC are virtually identical, and thus will be treated as one protocol.

In addition, there are many nonstandard data link layer protocols used by communication systems.

Using a standard protocol offers the advantage of using already developed and available communications controller hardware. Therefore the protocol proposed will be an existing standard.

Choosing the standard will be done by determining which protocol performs the needed functions in a satisfactory manner with the minimum overhead. This can be done by examining the frame format of each protocol mentioned above. The different frame formats are shown in Figure 5-3. Table 5-2 shows a comparison of the different protocols.

As shown, HDLC/SDLC has the least overhead bits per frame and also allows for a large number of data bytes to be transmitted in each frame. Therefore, it is the most efficient.

For robotic vehicle systems, a simplified version of the SDLC protocol is proposed. (See Figure 5-4.) This protocol provides all the needed functions.

- Network Layer. The network layer routes data through a network of communicating entities. For current robotic vehicle system applications, all communications are simple point to point (control station directly to RV). Therefore, no protocol is needed for this layer.

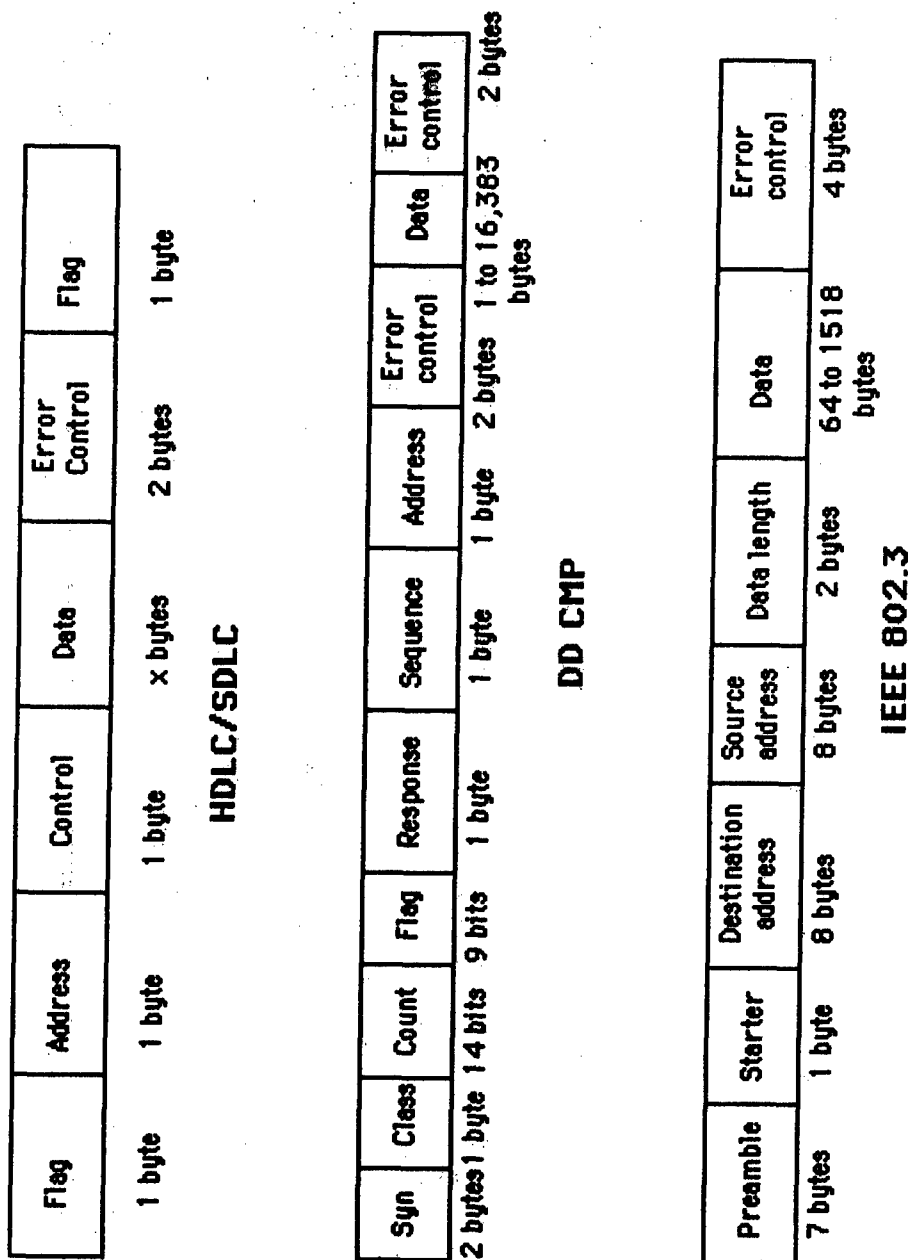


Figure 5-3. Frame Formats

Table 5-2. Data Link Layer Protocols

Protocol	Synchron- ization	Vehicle Address	Error Control	Overhead Bits/frame	Data Bytes/ Frame
HDLC/ SDLC	Yes	Yes	Yes	48	Any number of bytes
DD CMP	Yes	Yes	Yes	98	1-16,383
IEEE 802.3	Yes	Yes	Yes	208	64-1518

Flag	Address		Data	CRC	Flag
	RCC	RV			
01111110	3 bits	5 bits	n bits	16 bits	01111110

Figure 5-4. Simplified SDLC Frame Format

As robotic vehicle systems become more intelligent, however, they will need to cooperate and thus should be networked together. Also, using an RV that is in the line-of-sight of the control station as a signal repeater is one way to maintain a data link with other RVs that are not in the line-of-sight of the control station.

Due to the modular nature of standards developed using the OSI-RM, a network layer protocol may be added at a later time without affecting the protocols at the other layers.

- Transport Layer. The transport layer makes end-to-end transmissions reliable. It does for a multihop network what the data link layer does for point-to-point communications.

Since currently we are only dealing with a direct data link between the control station and the RV, some of the transport layer services are not needed. The following services are needed:

- Sequencing
- Expedited delivery
- Survival of the connection

Transport Protocol Data Units. These services are provided by assembling the data into TPDUs. For robotic vehicle systems, a TPDU consisting of a two-byte header added to the message received from the upper layers is proposed.

The first header byte is the data unit code. The second header byte is the sequence number.

TPDU Types. There are three types of TPDUs:

- Information packet
- Acknowledgement packet
- Blank packet

Information Packets. An information packet carries the message from the higher layer. There are six different types of information

packets:

- Normal data (ND). Has the lowest priority. Will be sent last when expedited or express-type packets are waiting to be sent.
- Expedited data (ED). Has middle priority. Will be sent before normal but after express data.
- Express data (XD). Has the highest priority. Will be sent before any other packet type.
- Normal data with acknowledgement (NA). Lowest priority but requires an acknowledgement.
- Expedited data with acknowledgement (EA). Middle priority with acknowledgement required.
- Express data with acknowledgement (XA). Highest priority with acknowledgement required.

Acknowledgements Packets. An acknowledgement packet is used when the receipt of an information packet requires an acknowledgement. Only positive acknowledgements are provided. If a positive acknowledgement is not received before the transport timer expires, the software treats it as the negative acknowledgement of an information packet. A 125-ms timer is proposed.

There are three types of acknowledgements:

- Positive acknowledgement for normal data (ACK)
- Positive acknowledgement for expedited data (ECK)
- Positive acknowledgement for express data (XCK)

Blank Packets. Blank packets are used to let the other side know that the communication link is still up even though there is no information to be sent. A blank packet is sent when the transport has nothing to send

for 200 ms. When nothing has been received for three cycles (600 ms), an alarm message is sent to the appropriate application software saying that there is something wrong with the communication link.

Data Unit Codes. Table 5-3 has a list of the data unit codes.

Sequence Number. Each packet is numbered sequentially. Since it is a one byte number, 256 (2⁸) TPDUs can be numbered before starting over.

TPDU Lengths. Each information packet has the two byte header followed by a data field of unlimited length. An acknowledgement packet has a total length of three bytes, the two byte header and the sequence number of the received information packet to be acknowledged. A blank packet consists of only the two byte header.

- Session Layer. The session layer can be rather lean due to the simple point to point communications. One issue that can be settled at this layer is the dialogue type.

There are three dialogue types:

- Simplex: can transmit only in one direction.
- Half-duplex: can transmit in both directions, but only one at a time.
- Full-duplex: can transmit in both directions simultaneously.

For maintaining effective, real-time control of an RV, many of the control signals from the control station and status signals from the RV must be relayed as soon as they are available for transmission. This requirement warrants the use of full-duplex communications.

Another issue that should be discussed at this layer is the type of disconnection, either graceful or abrupt, that should be employed. With a graceful disconnection, a message that is cut off before it is completely transferred will be retransmitted as soon as the resources to do so are available.

Table 5-3. Data Unit Codes

TYPE	DATA UNIT	CODE
Information Packet	ND	0000 0000
	ED	0000 0001
	XD	0000 0010
	NA	0000 0100
	EA	0000 0101
	XA	0000 0110
Acknowledgment packet	ACK	0000 1000
	ECK	0000 1001
	XCK	0000 1010
Blank Packet	BLNK	0001 0000

With an abrupt disconnection, the message that is not completely transferred is ignored.

The need for graceful disconnections arises from systems exchanging large amounts of data, such as file transfers, with no time restriction. In contrast, controlling a robotic vehicle requires many short command and status messages. Because of this, retransmission of cut off messages is not required. Therefore abrupt disconnections are proposed.

- The Presentation Layer. For robotic vehicle communication system applications, the presentation layer must provide for security and must describe the bit and byte representations of the control commands and the status information. Current and very near term robotic vehicle systems are primarily technology demonstrators, and thus do not require data security. Future fielded systems, as well as mid and far term demonstrators, will require security, and this can be provided by an encryption sub-layer of the presentation layer. Addition at a later date of this sub-layer is possible due to the modular nature of the OSI-RM.

Description of the bit and byte representations of the control commands and the status information can be achieved by the development and implementation of a robotic vehicle message format. The development of a message format for this purpose is detailed in sections 5.2 and 5.3.

Application Layer. The application layer takes care of functions such as file transfers, graphics, data base management, etc. Proposing protocols for this layer is out of the scope of this report.

5.2. Robotic Vehicle System Functions

5.2.1. Introduction. A message format describes the bit and byte representations of the control commands and status information used by a robotic vehicle system. A message format is part of the Presentation Layer of the OSI-RM, as described in the previous section.

The development of a message format can be broken down into

two main tasks:

Compilation of the control functions and status information required to remotely operate a vehicle.

A method of representing the compiled information.

This section will address the first task, that of compiling the information needed to remotely control a vehicle. The objective is to make the compilation as comprehensive as possible so that the message format can be used by any and all military robotic vehicle systems, both now and in the future, performing a wide variety of missions.

5.2.2. Manned Military Vehicles. Operating a vehicle remotely requires performing, at a remote location, the operations normally performed by a crew within the vehicle. To begin compiling a list of all the control commands and status information necessary to remotely control a vehicle, the operation of current manned vehicles can be studied.

5.2.2.1. Vehicles studied. For this study, four vehicles were chosen:

M1A1 Abrams Main Battle Tank

M2/M3 Bradley Fighting Vehicle

High Mobility Multipurpose Wheeled Vehicle (HMMWV)

ACEC Cobra

These four particular vehicles were chosen for two reasons:

- All are state-of-the-art vehicles, recognized as performance leaders in their individual fields.
- They represent a good cross section of military vehicles.

- They represent the three general weight classes of vehicles:

Heavy - M1A1

Medium - M2/M3, Cobra

Light - HMMWV

- Three are tracked, one is wheeled (the HMMWV).

- Three are diesel powered, one is turbine powered (the M1A1).
- Three have mechanical transmissions, one has electric drive (the Cobra).

By studying four vehicles which are significantly different in design, a more complete list of control commands and status information which will be required on future robotic vehicle systems performing a wide variety of missions can be obtained. Appendix A gives the results of the survey of the four vehicles.

5.2.3. Unmanned Vehicle Systems. Compiling a list of functions and status information needed for robotic vehicle systems can be aided by studying current robotic vehicle systems and learning from what has already been done. This was done with systems developed or under development by the six organizations listed in Table 5-4.

These systems were studied, but the documents describing the systems will not be included in this report because of the competitive situation these companies are in.

5.2.4. Additional Functions. Surveying current manned and unmanned military vehicles was very helpful in compiling a control/status listing. But future vehicles will continue to change and progress, and will have additional requirements for command and control.

To predict requirements of future systems, a series of meetings was held with personnel from TACOM's Robotics Division. At these meetings, additional controls and status were discussed and compiled.

5.2.5. Higher Level Control Commands. Surveying the four manned vehicles has led to an accumulation of low-level commands required to control a vehicle. Likewise, the Grumman, Kaman, and Sandia systems were completely teleoperated, thus accumulating more low-level vehicle control commands.

5.2.5.1. RV intelligence. The commands required to control an RV vary greatly with the intelligence of the vehicle. Robotic vehicle system developers are working to continually increase the intelligence of their RVs.

When RVs lack intelligence, they require many explicit low level directions on what to do and on how to do it. As RVs gain intelligence, a smaller quantity of high level

Table 5-4. Robotic Vehicles Studied

- **FMC Corporation**
- **General Dynamics Land Systems**
- **General Motors Delco**
- **Grumman Corporation**
- **Kaman Sciences Corporation**
- **Sandia National Laboratories**

commands can be substituted for the many low level commands.

5.2.5.2. Autonomy. An increase in onboard RV intelligence means the vehicle has become more autonomous. An RV with increased autonomy is desired for two reasons:

1. The RV to control stations data link has a decreased bandwidth requirement.
2. Workload of RV operator is decreased.
 - Decreased Bandwidth Requirement. Inter-vehicle communications on the battlefield are hindered by enemy electromagnetic warfare, as well as by natural obstacles (hills, trees, foliage) and natural electromagnetic interference. The greater the amount of information needed to be transmitted, the greater the bandwidth requirement of the communication system, and the more difficult it is to successfully transfer the data.

Conversely, the less information that must be transmitted, the smaller the bandwidth requirement of the communication system, and the capability to successfully transfer the data is improved. Decreasing the number of commands needed by an RV lessens the amount of information that must be transmitted.

- Decreased Operator Workload. As an RV's autonomy increases, the number of moment-to-moment commands generated by the operator to command the vehicle is decreased, thus decreasing the operator workload. If the workload is sufficiently decreased, the operator can perform other duties while at the same time maintaining control of the RV. Other duties may include controlling additional RVs. This increases the productivity of the operator, and thus increases force effectiveness.

5.2.5.3. Examples. To further describe high-level commands, two examples, using vehicle speed and weapon usage, will be given.

- Vehicle Speed. At the lowest level, the speed of a vehicle is controlled by adjusting the engine throttle. This requires the operator to constantly change the throttle depending upon the vehicle, road and weather

conditions.

A higher level command would set the vehicle speed. It would then be the job of the RV, independent of the human operator, to generate the moment-to-moment throttle commands needed to maintain the desired speed. A cruise control device, common on commercial automobiles, could be mounted on an RV and could carry out this higher level command.

Another high-level command might be to tell the RV to go from point A to point B in the shortest time possible. Now the RV would attempt to maintain the highest speed possible while taking into account the terrain and weather conditions and the engine and vehicle limitations.

- **Weapon Usage.** At the lowest level, the operator would detect a target. He would then send commands to position the weapon and to fire it.

At a higher level, the operator might still need to detect the target. He could then send a command, "Lock on target." When the weapon had autonomously locked on the target, the operator could send a command to fire.

At the highest level, the operator could give the single command, "Engage enemy." The RV would then autonomously detect a target, position the weapon, and fire at the target.

5.2.5.4. Need for high-level commands. The principal argument used against the adoption of standards is that they tend to freeze technology, and become obsolete. It is imperative that the developer of a standard take into account future requirements so that the standard would not become obsolete.

With RVs, the trend is for increased onboard intelligence. Therefore, the standard message format developed in this document must include high-level control commands, as well as have the flexibility to add additional high-level commands as they are needed.

5.2.6. Automated Functions. Increasing the autonomy of RVs (using high-level commands) is one method by which to reduce the bandwidth requirements of robotic vehicle communication systems. Another method is to automate as many functions as possible.

An automated function is one which normally must be performed by a human operator but can be done autonomously. It differs from a high-level command in that it needs no operator supervision at all.

There are many functions that have the potential to be automated. An example of one is the operation of a vehicle's bilge pumps.

Bilge pumps are turned on by a vehicle's crewmember when water has entered the hull. The function of turning on the bilge pump could be automated by putting water sensors in appropriate locations. Upon sensing a predetermined amount of water, the bilge pumps would automatically turn on. Also, the pumps would automatically turn off when the water has been flushed out. Automating the operation of the bilge pumps would give the RV operator one fewer function to control and would delete the need to send a control command.

Some of the other functions that are candidates for automation include:

- Interior temperature

- Suspension height

- Fuel tank selector

- Fire extinguishing system

- Camera lens focus

5.2.7. Complete Control/Status Listing. Appendix B contains the results of this section.

5.3. Representation of the Compiled Information

The control commands and the status information compiled in the previous section can be digitally represented by a message format. Three different types of message formats are considered:

- Fixed-length message format

- Variable-length message format

- Block message format

5.3.1. Description of the message formats. The three types of message formats are described below.

5.3.1.1. Fixed-length message format. A fixed-length

message format is a stream of parameters in a predetermined sequence. (See Figure 5-5.(a)) The location of the parameters within the stream dictates the function being controlled and the status information being transferred.

The RV knows what to do with each parameter because of its location in the sequence. No function identification is necessary in this type of message format.

5.3.1.2. Variable-length message format. A variable-length message format, like a fixed-length message format, is also a stream of parameters in a predetermined sequence. With a variable-length format, however, a parameter is only sent when it is needed.

Whether or not a parameter is needed is depicted by a "parameter needed (PN)" bit. (See Figure 5-5(b)) When the PN bit is set (has a value of one), a parameter is needed and will immediately follow. When the PN bit is not set (has a value of zero), a parameter is not needed and thus will not follow. The following bit will instead be another PN bit.

5.3.1.3. Block message format. With a block message format, each parameter is individually identified. (See Figure 5-5(c)) Parameters are not part of a data packet with a predetermined parameter sequence, as with the fixed-and-variable length message formats.

Not being part of a sequence, different parameters can be sent at different frequencies. For example, an RV being remotely driven out to a sentry post may require hundreds of steering commands, but no weapon control commands.

Because the parameters are not transmitted in a predetermined sequence, they must each be identified. This is done with a series of labels.

The message length is variable. When little or no activity is required, the message length will approach zero bytes. An RV performing a variety of functions in a complex environment will have a long message length.

The parameter labels also vary in length. Some messages require more bits than others to be accurately identified.

5.3.2. Analysis of the message formats.

5.3.2.1. Fixed-length message format. The fixed-length message format offers two advantages. The first is that no bits are needed to identify to what application the transmitted parameters apply. All the bits of data are parameters. This makes for an efficient use of the data

Steer	Brake	Throttle	Camera	Gear
--------------	--------------	-----------------	---------------	-------------

(a) Fixed Length Format

PN	Steer	PN	Brake	PN	Throttle	PN	Gear
-----------	--------------	-----------	--------------	-----------	-----------------	-----------	-------------

(b) Variable Length Format

Function Identifier	Control Parameter
----------------------------	--------------------------

(c) Block Format

Figure 5-5. Candidate Message Formats

link.

The second advantage is the simplicity with which an RV and a control station can handle the received message. Routing the parameters to the proper location is easily done since the parameter applications are predetermined.

There are three disadvantages to using a fixed-length message format. The first is that the frequency with which a parameter is sent cannot be varied. A parameter is sent once in every message. Even though a parameter may not be needed, it is still transmitted. This leads to the transmission of unneeded parameters.

The second disadvantage is that there is no way to order the parameters by priority. Since the parameters must be sent in their predetermined sequence, there is no means to send a more important parameter before a less important one.

The third disadvantage is the lack of flexibility that this type of message format offers. Different types of robotic vehicles require different control commands and status information depending upon their configuration and the mission they are performing. A message format must be able to accommodate different requirements if it is to become a standard. The fixed-length message format does not offer this flexibility since it would need to be altered for each different application.

5.3.2.2. Variable-length message format. The advantages and disadvantages of the fixed-length message format also apply to the variable-length message format, with two differences. The first is that the variable-length message format is more data rate efficient than the fixed-length format. This is because parameters are not transmitted if they are not needed.

The second difference is that there is an increase in the processing required of the receiving entity when using the variable-length format. The receiving entity must determine if it should or should not route the parameters to certain applications, depending on the value of the "parameter needed" bit.

5.3.3.3. Block message format. There are three advantages to using a block format. The first advantage is the flexibility of this format. Functions can be identified for each vehicle and mission module, but only those applicable to a particular system need to be used.

As requirements for robotic vehicle systems develop and evolve, new messages can be added and obsolete ones

deleted. This will keep the message format from becoming obsolete.

The second advantage is that the parameters can be ordered by priority. This is possible since they are not arranged in a predetermined sequence.

The third advantage is that messages are only sent when needed, decreasing data rate requirements.

There are two disadvantages to using a block message format. The first is that each parameter needs to be identified. This can be done with a label two bytes in length.

The second disadvantage is the burden put on the receiving entity. Upon the receipt of data, it must be processed to determine what application the parameter is for.

5.3.4. Comparison. Table 5-5 summarizes the advantages and disadvantages of the three message formats presented in this chapter.

As shown, the bandwidth required for each message format varies with the complexity of the message. For a robotic vehicle system requiring few commands, the variable-and fixed-length message formats can operate over links using slower data rates. The block format requires faster rates.

For a more complex robotic vehicle system requiring many different commands, the block format can use the link with the slowest data rate because it only sends messages when they are needed.

The block format is flexible and allows commands to be ordered by priority. Flexibility is extremely important for a message format that is to be part of an interface standard. Without flexibility, the standard will not likely be adopted.

Neither the fixed-nor-variable length message formats offer flexibility or the ability to order commands by priority.

A communication system using a functional block format requires the most processing by the receiving entity. The fixed-length message format requires the least processing, and the variable-length format requires an intermediate amount.

The increased amount of processing time and resources required when using a functional block format is a penalty to adopting this format. But this penalty is negligible

Table 5-5. Message Format Comparison

Message Format	Flexible	Bandwidth required	Processing required	Prioritized commands
Fixed Length	No	Varies with message complexity	Least	No
Variable Length	No	Varies with message complexity	Medium	No
Functional Block	Yes	Varies with message complexity	Most	Yes

because of the increasing speed and decreasing cost of computer equipment.

These facts, plus the flexibility and the ability to order the messages by priority, make the block format the best message format for a robotic vehicle communications interface standard.

5.3.5. Proposed Message Format. There are many different possible structures that a block message format can take. The format proposed for robotic vehicles is shown in Figure 5-6. Appendices C and D define the digital coding for the messages.

5.3.5.1. Field descriptions. The message length field is one byte in length and describes the length (number of bytes) of the message, including the length byte itself. The source address field is also one byte in length and it tells where the message originated.

The message field can be broken down into multiple commands. Each command consists of:

- A length field one byte in length which describes the length (number of bytes) of the command, including the length byte itself.
- A block field one byte in length. This field is the first part of the command/status identifier. Its one byte length makes it possible to identify 256 (2^8) different blocks. The blocks are the result of the control commands and the status information being classified according to their function.
- One or more function fields. Each function field consists of a one byte function identifier, which is the second part of the command/status identifier. The one byte length makes it possible to identify 256 functions per block. Where necessary, a parameter one or more bytes in length follows. A parameter is the actual control or status value.

5.3.5.2. Parameter types. There are three types of parameters which can be used:

Numeric (N)

Select (S)

Proportional intensity (PI)

The type of parameter associated with each block is shown in Appendices D and E.

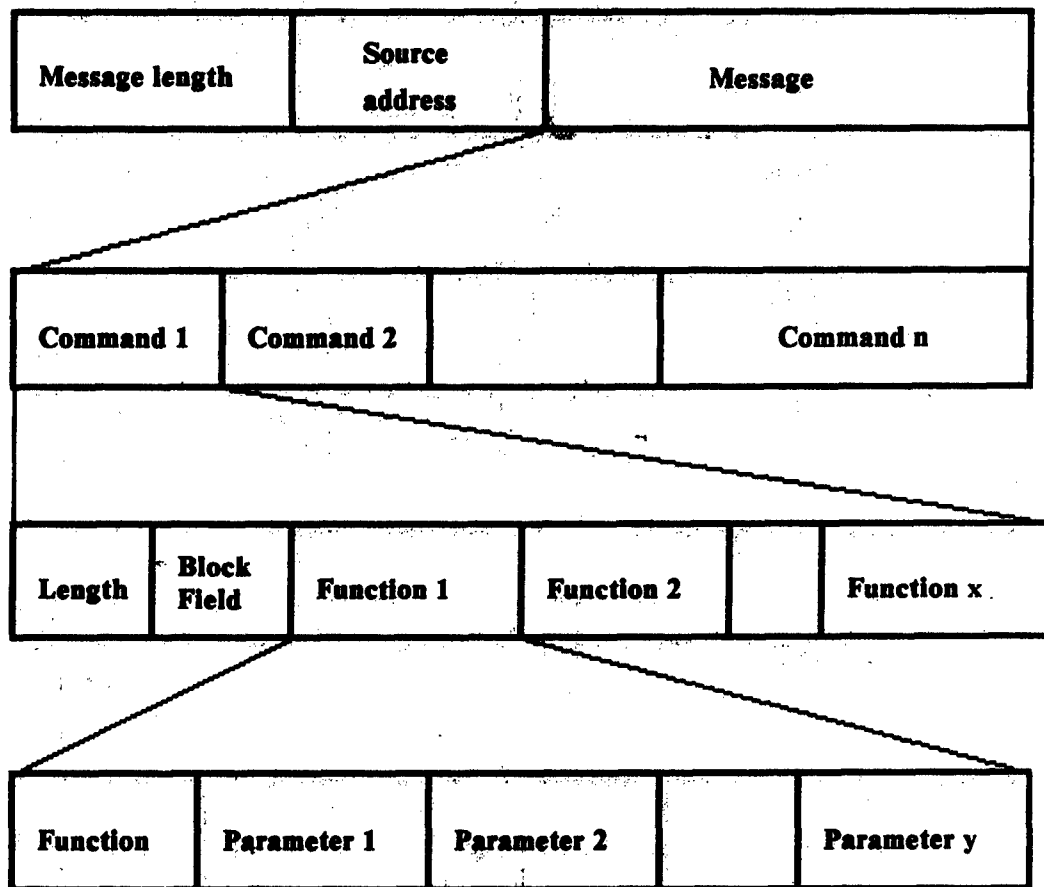


Figure 5-6. Command/Status Message Format

5.3.5.3. Parameter representations. Numeric parameters are represented with binary encoding. For example, decimal 71 is represented by 0100 0111. This is hexadecimal 47.

Select parameters are used when we need to choose one or more options from a group of choices.

Proportional intensity parameters are used to represent three types of commands/status:

Off, incrementally increasing to full on.

Down, incrementally rising to full up.

Straight ahead, incrementally changing to full left or full right.

- Off to on is represented by a one-byte parameter. Hexadecimal 00 (binary 0000 0000) represents off. Hexadecimal FF (binary 1111 1111) represents full on. All values inbetween represent proportional positions.
- Down to up is represented by a one-byte parameter. Hexadecimal 00 represents full down. Hexadecimal FF represents full up. All values inbetween represent proportional positions.
- Left to right is represented by a one-byte signed parameter. Hexadecimal 7F is full left. Hexadecimal 00 is straight ahead. Hexadecimal FF is full right. All values inbetween represent proportional positions.

5.3.5.4. Message generation. Messages are generated using the following steps:

Determine the block field codes from Appendices D and E.

Get the function field code from Appendices D and E.

Append the required parameters.

Determine the message length and the command lengths.

Enter numeric values into the message format.

5.3.5.5. Examples. Three examples are given which

illustrate using Appendices D and E and the message format to generate coded messages which represent control commands and status information.

Example 1. An operator initiates the following commands:

- Turn vehicle full right
- Engine at half throttle
- Turn on headlights
- Turn on the power to the FLIR

The following chart is used to put the commands into the required message format:

Command Number	Message	Block Function			
		Field	Field	Parameter	Length
1	Vehicle full right	03	01	FF	04
2	Engine half throttle	01	03	40	04
3	Turn on headlights	0E	01		03
4	Power to the FLIR	18	01		03

The resulting message, in hexadecimal values, is:

10 03 04 03 01 FF 04 01 03 40 03 0E 01 03 18 01

NOTE: Source address has arbitrarily been chosen to be 03. Also, the above codes would be put in the SDLC format for transmission over the data link.

Example 2. An operator initiates the following commands:

- Engine at zero throttle
- Turn heater on
- Turn air conditioner off
- Turn on bilge pump
- Stop transmitting video from the left and right peripheral cameras
- Begin transmitting images from the reconnaissance camera and the FLIR

The following chart is used to put the commands into the required message format:

Command Number	Message	Block Function			
		Field	Field	Parameter	Length
1	Zero throttle	01	03	00	04
2	Heater on	0D	03		04 05
	AC off		06		
	Bilge pump on		09		
3	Stop transmission of right peripheral camera imagery	10	08		04 06
	Stop transmission of left peripheral camera imagery		06		
	Transmit FLIR images		0F		
	Transmit reconnais-- sance images		0B		

The resulting message, in hexadecimal values, is:

11 03 04 01 03 00 05 0D 03 06 09 06 10 08 06 0F 0B

Example 3. An RV's central control unit initiates the following status messages:

- Engine hot
- Fuel low
- Interior temperature 72°

The following chart is used to put the commands into the required message format:

Command Number	Message	Block Function			
		Field	Field	Parameter	Length
1	Engine hot	81	06		03
2	Fuel low	8B	02		03
3	Interior temperature	8D	01	48	04

Message: 0C 03 03 81 06 03 8B 02 04 8D 01 48

5.3.5.6. Request for status. A request for status is made by sending the appropriate status identifier from a command center to an RV. For example, a request command for the RV's heading would have the block field B0 and the function identifier 01.

5.3.5.7. Room for growth. The proposed message format will only be effective if it does not hinder the

development of new systems and subsystems. Therefore it must be flexible and have room to grow. By using one byte to identify the message block, there are 256 possible blocks. The current compilation of messages resulting from the investigation described earlier produced 62 blocks, leaving ample room for expansion. Also, by using one byte to identify the functions in each block, there are 256 possible functions. So far, the most identified for any one block is 27.

5.3.6. Complete Message. The message format described in the previous sections will become part of the whole data packet that is transferred between entities. The whole packet also includes the transport layer protocol overhead as well as the data link layer protocol overhead.

Figure 5-7. illustrates the entire data packet including data link, transport, and presentation layer protocols overhead.

5.4. Protocol Testing

The proposed protocols and message format will be implemented in TACOM's Robotic Combat Vehicle program in fiscal years 1989 and 1990. This will allow the protocols to be tested.

Also, TACOM will make the documentation available to other robotic systems being developed so that they may evaluate the proposed protocols as well. This will lead to identification of any revisions or improvements required to make the protocols fully functional.

By evaluating and testing communication protocols now, while robotic vehicle systems are still in the testbed stage, an optimum set of protocols can be available when robotic vehicles are ready for full-scale development.

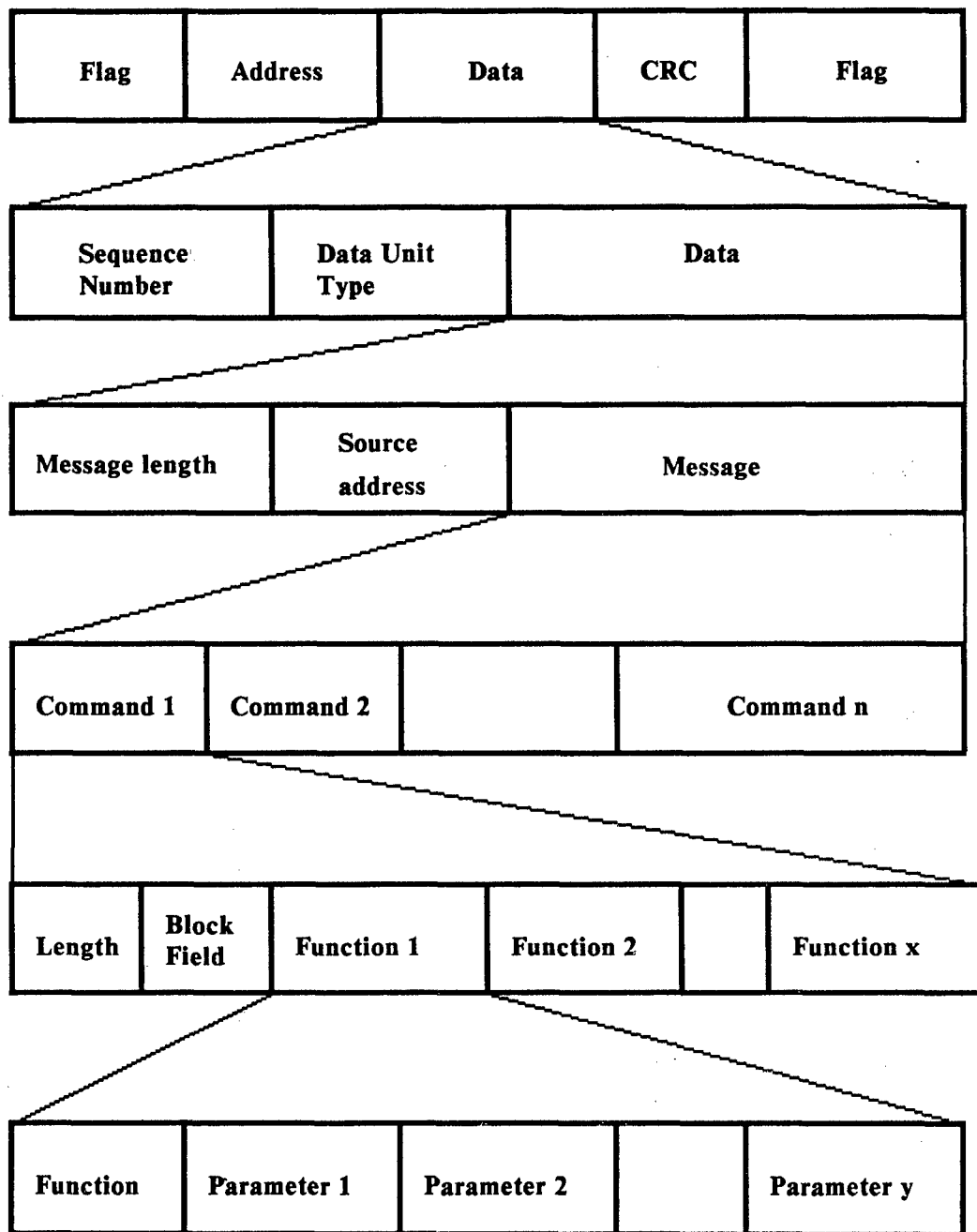


Figure 5-7. Complete Data Packet

SELECTED BIBLIOGRAPHY

- Caskey, B.C., and Hoover, E.R. "Robotic Combat Vehicle System Study." Sandia National Laboratories, (July 1987)
- Chandra, Sarat. FMC Corporation. Presentation, (24 November 1987)
- Collin, Robert E. "Antennas and Radiowave Propagation", New York: McGraw-Hill Book Company, (1985)
- Comdel Incorporated, "Radio Communication Systems for Robotic Vehicles," (April 1987)
- Fitzgerald, M.L., and Barbera, A.J. "A Low-Level Control Interface for Robot Manipulators," National Bureau of Standards, (1985)
- Garg, Ewa. "RCC-RV Data Link Protocol Proposal," FMC Corporation. (26 April 1988)
- Klarer, Paul R. "Communication Systems for Robotics at Sandia," Sandia National Laboratories, Letter, (18 November 1987)
- Osterhoff, Michael D. "Wireless Communication Link for Passenger Compartment Electronics," Fisher Body Central Engineering, (15 April 1984)
- Schehr, Steve. "RCC/ROBAT Interface Specification Requirements." U.S. Army Tank-Automotive Command, (20 July 1987)
- Stallings, William. "Data and Computer Communications", New York: Macmillan Publishing Company, (1985)
- Voelcker, John. "Helping Computers Communicate," IEEE Spectrum, (March 1986)

APPENDIX A

CONTROL/STATUS OF MANNED MILITARY VEHICLES

MANNED VEHICLE CONTROLS

Description of function	M1 Abrams (heavy)	M2/M3 Bradley (med)	HMMWV (light)	Cobra (elec)
Accelerator			X	X
Bilge pumps on/off	X	X		X
Brake	X	X	X	X
Defroster control			X	
Driver's night vision viewer	X			
Driver's periscope wiper	X			
Engine accesory		X		
Engine shutoff	X		X	
Engine starter	X		X	X
Engine starter (cold start)		X		X
Fire suppression		X		
Fording control			X	
Fuel control		X		
Fuel tank selector	X			
Garage toggle				X
Gear selector	X	X	X	X
Hazard warning light			X	X
High/low ratio selector				X
Horn		X	X	
Infrared lenses	X			

MANNED VEHICLE CONTROLS

Description of function	M1 Abrams (heavy)	M2/M3 Bradley (med)	HMMWV (light)	Cobra (elec)
Intercom	X	X		
Light selector	X	X	X	X
Master power	X	X		
NBC system on/off		X		X
Panel lights control	X	X	X	X
Parking brake release	X		X	
Parking brake set	X	X	X	
Periscope adjustment	X			
Periscope washer pump	X			
Pivot	X	X		X
Road/water toggle				X
Service brake	X	X		
Smoke screen generator	X	X		
Splash guard up/down				X
Steering	X	X	X	X
Steering wheel lock cable			X	
Tactical idle	X			
Throttle control	X	X	X	
Transfer case			X	
Transmission on/off				X

MANNED VEHICLE CONTROLS

Description of function	M1 Abrams (heavy)	M2/M3 Bradley (med)	HMMWV (light)	Cobra (elec)
Turn indicator		X	X	X
Water barrier release		X		
Windshield washer/wiper			X	

MANNED VEHICLE STATUS

Description of function	M1 Abrams (heavy)	M2/M3 Bradley (med)	HMMWV (light)	Cobra (elec)
Air cleaner clogged warning		X	X	
Alternator temperature high				X
Back door open				X
Battery charge low	X			
Bilge pump (fwd,rear)	X	X		X
Brake master cyl fluid level low			X	
Brake worn	X			
Cable disconnected	X			
Circuit breaker open	X			
Cold start indicator		X	X	
Coolant high temp warning		X		X
Coolant low level warning		X		X
Engine started	X			
Engine abort	X			
Engine accessory indicator		X		
Engine coolant temp gauge	X	X	X	
Engine hour meter	X			X
Engine oil filter clogged	X			
Engine oil low				X
Engine oil pressure gauge	X	X	X	

MANNED VEHICLE STATUS

Description of function	M1 Abrams (heavy)	M2/M3 Bradley (med)	HMMWV (light)	Cobra (elec)
Engine oil pressure warning	X	X	X	X
Engine oil temperature high	X			X
Exhaust temperature				X
Fire detector sensor	X			
Fire ext bottle pres gauge	X			
Fire supp discharge indicator	X	X		
Fire supp manual indicator		X		
Fuel (F, 1/2, 1/4, E)				X
Fuel control faulty	X			
Fuel filter clogged warning	X	X		
Fuel gauge	X	X	X	
Fuel level low	X			
Full pivot				X
Gas over temperature	X			
Headlights high beam	X	X	X	X
Headlights low beam	X			X
Heater control			X	
Heater fan			X	
Hydraulic system malfunction	X			
Master caution	X			

MANNED VEHICLE STATUS

Description of function	M1 Abrams (heavy)	M2/M3 Bradley (med)	HMMWV (light)	Cobra (elec)
Master power indicator	X	X		
Master warning	X			
NBC filter clogged	X			
NBC on				X
NBC overheated	X			
NBC overpressure	X			
NBC system indicator		X		X
Night periscope	X			
Odometer	X	X	X	X
Parking brake sys hyd pres gauge	X		X	
Parking lights on				X
Parking/service brake on	X			
Ramp unlock indicator		X		
Rear left fuel pump bad	X			
Rear right fuel pump bad	X			
Road mode				X
STE/ICE diagnostic connector			X	
Slope indicator		X		
Smoke screen generator on	X	X		
Speedometer	X	X	X	X

MANNED VEHICLE STATUS

Description of function	M1 Abrams (heavy)	M2/M3 Bradley (med)	HMMWV (light)	Cobra (elec)
Tachometer	X			X
Transmission damage-inspect	X			
Transmission gear selected	X	X	X	X
Transmission off				X
Transmission oil filter clogged	X			
Transmission oil low	X			
Transmission oil pressure warning	X	X		
Transmission oil temp warning	X	X		
Trip odometer				X
Turn indicator lights	X	X	X	X
Turret power indicator		X		
Turret seal pressure gauge	X			
Voltage gauge	X	X	X	
Water mode				X

APPENDIX B

CONTROL/STATUS REQUIRED FOR ROBOTIC VEHICLE SYSTEMS

**Controls Required for
Robotic Vehicle Systems**

- | | |
|-----------------|--------------------------------|
| 1. Power plant | 9. Turret |
| 2. Brakes | 10. Interior |
| 3. Steering | 11. Lights |
| 4. Transmission | 12. Electro-optic Sensors |
| 5. Suspension | 13. Condition Sensors |
| 6. Fording | 14. Communications |
| 7. Mobility | 15. Inertial Navigation System |
| 8. Fuel | 16. Mission module |

REQUIRED CONTROLS

1. Power plant

Start

Cold start

Kill

Throttle

Idle set

Tactical idle

Fuel delivery

Cruise control (CC)

CC Set

CC Resume

CC Accelerate

CC Decelerate

CC Coast

Electric current *

2. Brakes

Brake

Parking brake set/unset

Service brake set/unset

3. Steering

Steer

Radius of turn

Heading

Directional movement

* For battery power plant

REQUIRED CONTROLS

4. Transmission

Automatic gear select

Park
Reverse
Neutral
Drive
Drive, L
Pivot
Tow

Manual Gear select

Transfer case

High
Low
Neutral

Wheel drive

5. Suspension

Air shock height

Hydroneumatic suspension level control

6. Fording

Road/water propulsion

Splash guard up/down

Water barrier release level

Exhaust pipe rise

7. Mobility

Emergency stop

Velocity

Move to grid coordinates

Pivot

CARD mode

Autonomous road following mode

REQUIRED CONTROLS

8. Fuel

Fuel tank selector

Fuel filler lock/unlock

Fuel filler open/close

9. Turret

Power

Enable (turret travel lock)

Slew

Elevation

10. Interior

Defroster

Heater

Air Conditioner

Temperature setting

NBC system On/Off

Bilge pumps, front

Bilge pumps, rear

Fire suppression

Horn

Vent open/close

Vent fan

Wipers

Heated glass

Doors lock/unlock

Windows up/down

REQUIRED CONTROLS

11. Lights

Head lights

High beam
Low Beam

Parking lights

Turn indicator

Left
Right

Hazard lights

Blackout lights

Interior lights

Exterior flood lights

Exterior spot light

Fog lights

Back-up lights

12. Electro-optic Sensors

Sensor switch

Video
Radar
IR Thermal imaging system
Image intensifier
Laser ranger

Video camera selector

Forward
Stereo
Rear

Sensor control

Azimuth
Elevation
Tilt
Scan rate
Sector size

REQUIRED CONTROLS

12. Electro-optic Sensors (cont)

Sensor control

- B & W/Color
- Contrast
- Iris F/B switch
- Shutter speed
- Zoom
- Focus
- Home
- Wipers
- De-icer
- Convergence
- Hot/white
- Logic select
- Field of view

13. Condition sensors

- Radar detector
- Magnetic field detector
- Motion detector
- Frequency detector
- Light detector
- Sonic detector
- NBC detector
- Noise detector
- Rain detector
- Snow detector

14. Communications

System choice

- RF
- Fiber optic
- Microwave
- Laser

REQUIRED CONTROLS

14. Communications (cont)

Radio options

- Frequency select
- AJ techniques
- Transmitting power

Fiber optic options

Antenna control

- Elevation
- Azimuth
- Polarization
- Auto-track

15. Inertial navigation system

- Initialize

- Reset

16. Mission module

- Reconnaissance module

- Mine field breacher

- Weapons package

- CARD module

- Jamming device

- Smoke generator

- Others to be determined

**Status Required for
Robotic Vehicle Systems**

- | | |
|-----------------|------------------------------|
| 1. Power plant | 10. Interior |
| 2. Brakes | 11. Lights |
| 3. Steering | 12. Electro-optic Sensors |
| 4. Transmission | 13. Condition Sensors |
| 5. Suspension | 14. Communications |
| 6. Fording | 15. Inertial Navigation Data |
| 7. Mobility | 16. Mission modules |
| 8. Fuel | 17. Circuit breaker faults |
| 9. Turret | 18. Exterior |

REQUIRED STATUS

1. Power plant

Running/started

Tachometer

Coolant

Temperature gauge

Low level

High temperature

Oil

Pressure gauge

Pressure low

Level low

Temperature high

Alternator

Temperature high

Not functioning

Cold start indicator

Exhaust temp high

Battery charge low

Voltage gauge

Air cleaner clogged

Oil filter clogged

Fuel filter clogged

Fuel pump bad

Fuel control faulty

Hour meter

Throttle feedback

Microphone in engine compartment On/Off

REQUIRED STATUS

2. Brakes

- Brake feedback
- Brakes worn
- Master cylinder fluid level low
- Brake line pressure gauge
- Low brake air
- Brakes nonfunctional
- Parking brake
 - On/Off
 - Hydraulic pressure gauge

3. Steering

- Steering feedback

4. Transmission

- Automatic transmission gear selected

- Park
 - Reverse
 - Neutral
 - Drive
 - Drive, L
 - Drive, H
 - Pivot
 - Tow

- Manual transmission gear selected

- Transfer case
 - High
 - Low
 - Neutral

- Wheel drive

- Transmission fluid

- Filter clogged

- Pressure warning

REQUIRED STATUS

4. Transmission (cont)

- Temperature warning
- Level low
- Damaged
- Shift gear indicator

5. Suspension

- Air shock height
- Hydroneumatic suspension level

6. Fording

- River depth
- River current speed
- Road/water propulsion

7. Mobility

8. Fuel

- Fuel gauge
- Fuel low
- Fuel temperature high
- Fuel filler cover on/off, lock/unlock
- Fuel leak alarm
- Instantaneous MPG
- Battery powerpack charge level

9. Turret

- Power
- Seal pressure gauge

REQUIRED STATUS

10. Interior

Vehicle interior temperature

NBC system

On/Off

Filter clogged

System overheated

System overpressure

Bilge pump, front

Bilge pump, rear

Fire suppression

Detector

Discharge indicator

Extinguisher bottle pressure gauge

Wipers on/off

Door lock/unlock

Windows up/down

Vent open/close

Vent fan on/off

Cabin pressure

Moisture detector alarm/level meter

Door/hatch ajar

Heater on/off

Air conditioner on/off

Absorbed power

11. Lights

Head lights

High beam

Low beam

Parking lights

REQUIRED STATUS

11. Lights (cont)

- Turn indicators
- Hazard lights
- Blackout lights
- Interior lights
- Exterior flood lights
- Exterior spot lights
- Fog lights
- Back-up lights
- Engine compartment lights
- Bulb burned out

12. Electro-optic sensors

Sensor switch

- Video
- Radar
- IR Thermal imaging system
- Image intensifier
- Laser ranger

Video camera selector

- Forward
- Stereo
- Rear

Sensor control

- Scan rate
- Sector size
- B & W/Color
- Iris F/B switch
- Shutter speed
- Wipers
- Convergence
- Hot/white
- Logic select
- Field of view

REQUIRED STATUS

13. Condition sensors

- Radar detected
- Magnetic field detected
- Motion detected
- Frequency detected
- Light detected
- Sound detected
- NBC detected
- Noise detected
- Rain detected
- Snow detected

14. Communciations

System choice

- RF
- Fiber optics
- Microwave

Radio options

- Frequency selected
- AJ technique
- Transmitting power

F.O. status

- Cable used
- Cable left
- Cable cut

Antenna

- Polarization
- Auto-track on

REQUIRED STATUS

15. Inertial navigation system data

Heading

Altitude

Roll

Pitch

Yaw

Roll limit warning

Pitch limit warning

Slope indicator

Speedometer

Odometer

Trip odometer

Doppler speed

Wheel count speed

UTM coordinates

Latitude

Longitude

16. Mission modules

Reconnaissance module

Mine field breacher

Weapons package

CARD module

Jamming device

Smoke generator

Others to be determined

REQUIRED STATUS

17. Circuit Breaker Faults

Master

Light

Ignition

Brake boost

18. Exterior

Vehicle hit

Track off

Exterior temperature

Audio sensors (microphone)

Tire flat

Intrusion detection system

APPENDIX C

CONTROL COMMAND CODING

RCC TO RV CONTROL COMMAND CODING

<u>Function/status Description</u>	<u>Block Field</u>	<u>Function Field</u>	<u>Parameter Field</u>
Power plant	01		
Start		01	
Kill		02	
Throttle		03	
Cold start		04	PI
Tactical idle on		05	
Tactical idle off		06	
Idle set		07	PI
Fuel turn on		09	
Fuel shut off		0A	
Cruise control set		0B	
Cruise control resume		0C	
Cruise control accelerate		0D	
Cruise control decelerate		0E	
Cruise control coast		0F	
Electric current flow		10	PI
Brakes	02		
Brake		01	PI
Parking brake set		02	
Parking brake unset		03	
Service brake set		04	
Service brake unset		05	
Steering	03		
Steer		01	PI
Radius of turn		02	N
Heading		03	N
Directional movement		04	N
Automatic transmission	04		S
Park			01
Reverse			02
Neutral			03
Drive			04
Drive, L			05
Drive, H			06
Pivot			07
Tow			08
Manual transmission	05		S
Reverse			00
First			01
Second			02
Third			03

CONTROL COMMAND CODING

<u>Function/status Description</u>	<u>Block Field</u>	<u>Function Field</u>	<u>Parameter Field</u>
Fourth			04
Fifth			05
Transfer case	06		S
Wheel drive	07		S
Suspension	08		
Air shock height		01	PI
Suspension height		02	PI
Fording	09		
Road propulsion		01	
Water propulsion		02	
Splash guard up		03	
Splash guard down		04	
Water barrier set		05	
Water barrier release		06	
Exhaust pipe rise		07	
Exhaust pipe lower		08	
Mobility	0A		
Emergency stop		01	
Velocity		02	N
Grid coordinates		03	N
Pivot left		04	PI
Pivot right		05	PI
CARD mode, enter		11	
CARD mode, exit		12	
CARD command identifier		13	
Autonomous road following, on		15	
Autonomous road following, off		16	
Fuel	0B		
Fuel tank A		01	
Fuel tank B		02	
Fuel filler lock		03	
Fuel filler unlock		04	
Fuel filler open		05	
Fuel filler close		06	
Turret	0C		
Power on		01	
Power off		02	
Enable		03	
Disable		04	
Slew		05	PI

CONTROL COMMAND CODING

<u>Function/status Description</u>	<u>Block Field</u>	<u>Function Field</u>	<u>Parameter Field</u>
Elevation		06	PI
Interior	0D		
Defroster on		01	
Defroster off		02	
Heater on		03	
Heater off		04	
Air conditioner on		05	
Air conditioner off		06	
NBC system on		07	
NBC system off		08	
Bilge pumps, front, on		09	
Bilge pumps, front, off		0A	
Bilge pumps, rear, on		0B	
Bilge pumps, rear, off		0C	
Fire suppression on		0D	
Fire suppression off		0E	
Vent open		11	
Vent close		12	
Vent fan on		13	
Vent fan off		14	
Wipers on		15	
Wipers off		16	
Heated glass on		17	
Heated glass off		18	
Doors lock		19	
Doors unlock		1A	
Temperature setting		20	N
Horn		21	
Windows up/down		22	PI
Lights	0E		
Head lights on		01	
Head lights off		02	
High beam on		03	
High beam off		04	
Parking lights on		05	
Parking lights off		06	
Right turn indicator		07	
Left turn indicator		08	
Hazard lights on		09	
Hazard lights off		0A	
Blackout lights on		0B	
Blackout lights off		0C	
Interior lights		0D	
Fog lights on		0E	
Fog lights off		0F	

CONTROL COMMAND CODING

<u>Function/status Description</u>	<u>Block Field</u>	<u>Function Field</u>	<u>Parameter Field</u>
Back-up lights on		10	
Back-up lights off		11	
Exterior flood lights		12	
Spot light on		13	
Spot light off		14	
Spot light elevation		15	PI
Spot light azimuth		16	PI
Spot light tilt		17	PI
Electro-optic Sensor			
Image Transmit Select	10		S
Video, forward, transmit			01
Video, forward, do not transmit			02
Video, Stereo, transmit			03
Video, Stereo, do not transmit			04
Video, left peripheral, transmit			05
Video, left peripheral, do not transmit			06
Video, right peripheral, transmit			07
Video, right peripheral, do not transmit			08
Video, rear, transmit			09
Video, rear, do not transmit			0A
Video, reconnaissance, transmit			0B
Video, reconnaissance, do not transmit			0C
Driver's thermal viewer (DTV), transmit			0D
Driver's thermal viewer (DTV), do not transmit			0E
Forward looking infrared (FLIR), transmit			0F
Forward looking infrared (FLIR), do not transmit			10
Radar, transmit			11
Radar, do not transmit			12
Laser, transmit			13
Laser, do not transmit			14
Video, forward	11		
Power on		01	
Power off		02	
Slew		03	PI
Elevation		04	PI
Tilt		05	PI
Scan rate		06	N
Sector size		07	N
De-icer on		08	
De-icer off		09	
Wipers on		0A	
Wipers off		0B	
Contrast		0C	PI
Iris adjust		0D	PI
Shutter speed		0E	N

CONTROL COMMAND CODING

<u>Function/status Description</u>	<u>Block Field</u>	<u>Function Field</u>	<u>Parameter Field</u>
Zoom		0F	PI
Focus		10	PI
Home		11	
Convergence		12	PI
Video, Stereo	12		
Power on		01	
Power off		02	
Slew		03	PI
Elevation		04	PI
Tilt		05	PI
Scan rate		06	N
Sector size		07	N
De-icer on		08	
De-icer off		09	
Wipers on		0A	
Wipers off		0B	
Contrast		0C	PI
Iris adjust		0D	PI
Shutter speed		0E	N
Zoom		0F	PI
Focus		10	PI
Home		11	
Convergence		12	PI
Video, left peripheral	13		
Power on		01	
Power off		02	
Slew		03	PI
Elevation		04	PI
Tilt		05	PI
Scan rate		06	N
Sector size		07	N
De-icer on		08	
De-icer off		09	
Wipers on		0A	
Wipers off		0B	
Contrast		0C	PI
Iris adjust		0D	PI
Shutter speed		0E	N
Zoom		0F	PI
Focus		10	PI
Home		11	
Convergence		12	PI
Video, right peripheral	14		
Power on		01	

CONTROL COMMAND CODING

<u>Function/status Description</u>	<u>Block Field</u>	<u>Function Field</u>	<u>Parameter Field</u>
Power off		02	
Slew		03	PI
Elevation		04	PI
Tilt		05	PI
Scan rate		06	N
Sector size		07	N
De-icer on		08	
De-icer off		09	
Wipers on		0A	
Wipers off		0B	
Contrast		0C	PI
Iris adjust		0D	PI
Shutter speed		0E	N
Zoom		0F	PI
Focus		10	PI
Home		11	
Convergence		12	PI
Video, rear	15		
Power on		01	
Power off		02	
Slew		03	PI
Elevation		04	PI
Tilt		05	PI
Scan rate		06	N
Sector size		07	N
De-icer on		08	
De-icer off		09	
Wipers on		0A	
Wipers off		0B	
Contrast		0C	PI
Iris adjust		0D	PI
Shutter speed		0E	N
Zoom		0F	PI
Focus		10	PI
Home		11	
Convergence		12	PI
Video, reconnaissance	16		
Power on		01	
Power off		02	
Slew		03	PI
Elevation		04	PI
Tilt		05	PI
Scan rate		06	N
Sector size		07	N
De-icer on		08	

CONTROL COMMAND CODING

<u>Function/status Description</u>	<u>Block Field</u>	<u>Function Field</u>	<u>Parameter Field</u>
De-icer off		09	
Wipers on		0A	
Wipers off		0B	
Contrast		0C	PI
Iris adjust		0D	PI
Shutter speed		0E	N
Zoom		0F	PI
Focus		10	PI
Home		11	
Convergence		12	PI
Driver's thermal viewer (DTV) 17			
Power on		01	
Power off		02	
Slew		03	PI
Elevation		04	PI
Tilt		05	PI
Scan rate		06	N
Sector size		07	N
De-icer on		08	
De-icer off		09	
Wipers on		0A	
Wipers off		0B	
Contrast		0C	PI
Iris adjust		0D	PI
Shutter speed		0E	N
Zoom		0F	PI
Focus		10	PI
Home		11	
Convergence		12	PI
Stand by		13	
Thermal hot		14	
Thermal cold		15	
Forward looking infrared (FLIR) 18			
Power on		01	
Power off		02	
Slew		03	PI
Elevation		04	PI
Tilt		05	PI
Scan rate		06	N
Sector size		07	N
De-icer on		08	
De-icer off		09	
Contrast		0C	PI
Zoom		0F	PI
Focus		10	PI

CONTROL COMMAND CODING

<u>Function/status Description</u>	<u>Block Field</u>	<u>Function Field</u>	<u>Parameter Field</u>
Home		11	
Flir thermal level		13	PI
Flir thermal gain		14	PI
Flir focus		15	PI
Flir contrast		16	PI
Conditions Sensors	20		
Radar detector on		01	
Radar detector off		02	
Magnetic field detector on		03	
Magnetic field detector off		04	
Motion detector on		05	
Motion detector off		06	
Frequency detector on		07	
Frequency detector off		08	
Light detector on		09	
Light detector off		0A	
Sonic detector on		0B	
Sonic detector off		0C	
NBC detector on		0D	
NBC detector off		0E	
Noise detector on		0F	
Noise detector off		10	
Rain detector on		11	
Rain detector off		12	
Snow detector on		13	
Snow detector off		14	
VHF radio	21		
Power on		01	
Power off		02	
Frequency select		03	N
Radio transmitting power		04	PI
Antenna azimuth		05	PI
Antenna elevation		06	PI
Antenna polarization		07	S
Antenna auto-track on		08	
Antenna auto-track off		09	
Microwave radio	22		
Power on		01	
Power off		02	
Frequency select		03	N
Radio transmitting power		04	PI
Antenna azimuth		05	PI
Antenna elevation		06	PI
Antenna polarization		07	S

CONTROL COMMAND CODING

<u>Function/status Description</u>	<u>Block Field</u>	<u>Function Field</u>	<u>Parameter Field</u>
Antenna auto-track on		08	
Antenna auto-track off		09	
Fiber optic link	23		
Laser link	24		
Inertial navigation system	30		
Initialize		01	TBD
Reset		02	
Mission module platform	40		

APPENDIX D

STATUS INFORMATION CODING

RV TO RCC STATUS INFORMATION CODING

<u>Function/status Description</u>	<u>Block Field</u>	<u>Function Field</u>	<u>Parameter Field</u>
Power plant	81		
Engine running		01	
Engine not running		02	
Tachometer		03	N
Coolant temperature gauge		04	N
Coolant level low		05	
Coolant temperature high		06	
Oil pressure gauge		07	N
Oil pressure low		08	
Oil level low		09	
Oil temperature high		0A	
Oil filter clogged		0B	
Alternator temperature high		0C	
Alternator not functioning		0D	
Cold start indicator		0E	
Exhaust temperature high		0F	
Battery charge low		10	
Voltage gauge		11	N
Air cleaner clogged		12	
Fuel filter clogged		13	
Fuel pump bad		14	
Hour meter		15	N
Throttle feedback		16	PI
Engine microphone on		17	
Engine microphone off		18	
Brakes	82		
Brake		01	PI
Brakes worn		02	
Master cylinder fluid level low		03	
Brake line pressure gauge		04	N
Low brake air		05	
Brakes nonfunctional		06	
Parking brake set		07	
Parking brake hydraulic pressure gauge		08	N
Steering	83		
Steering feedback		01	PI
Automatic transmission gear	84		S
Park			01
Reverse			02
Neutral			03

RV TO RCC STATUS INFORMATION CODING

<u>Function/status Description</u>	<u>Block Field</u>	<u>Function Field</u>	<u>Parameter Field</u>
Drive, L			05
Drive, H			06
Pivot			07
Tow			08
Fluid filter clogged			10
Fluid pressure low			11
Fluid temperature high			12
Fluid level low			13
Transmission damaged			14
Manual transmission gear	85		S
Reverse			00
First			01
Second			02
Third			03
Fourth			04
Fifth			05
Fluid filter clogged			10
Fluid pressure low			11
Fluid temperature high			12
Fluid level low			13
Transmission damaged			14
Shift gear indicator			1A
Transfer case	86		S
Wheel drive	87		S
Suspension	88		
Air shock height		01	N
Hydronuematic suspension level		02	N
Fording	89		
River depth		01	N
River current speed		02	N
Road propulsion		03	
Water propulsion		04	
Mobility	8A		
In CARD mode		11	
In autonomous mode		15	
Fuel	8B		
Fuel gauge		01	N
Fuel low		02	

RV TO RCC STATUS INFORMATION CODING

<u>Function/status Description</u>	<u>Block Field</u>	<u>Function Field</u>	<u>Parameter Field</u>
Fuel temperature high		03	
Fuel filler cover off		04	
Fuel filler cover unlocked		05	
Fuel leak		06	
Instantaneous MPG		07	N
Battery power pack charge level		08	N
Turret	8C		
Power		01	
Seal pressure gauge		02	N
Interior	8D		
Temperature		01	N
NBC system on		02	
NBC filter clogged		03	
NBC system overheated		04	
NBC system over pressure		05	
Front bilge pump on		06	
Rear bilge pump on		07	
Fire detected		08	
Fire suppression discharged		09	
Fire extinguisher bottle pressure gauge		0A	N
Wipers on		0B	
Doors unlocked		0C	
Windows down		0D	
Vent open		0E	
Vent fan on		0F	
Cabin pressure		10	N
Moisture level high		11	
Door/hatch ajar		12	
Heater on		13	
Air conditioner on		14	
Absorbed power		15	N
Lights	8E		
Head lights low beam		01	
Head lights high beam		02	
Parking lights		03	
Left turn indicator		04	
Right turn indicator		05	
Hazard lights		06	
Blackout lights		07	
Interior light, front		08	
Interior light, middle		09	
Interior light, back		0A	

RV TO RCC STATUS INFORMATION CODING

<u>Function/status Description</u>	<u>Block Field</u>	<u>Function Field</u>	<u>Parameter Field</u>
Exterior flood light		0B	
Exterior spot light		0C	
Fog lights		0D	
Back-up lights		0E	
Engine compartment light		0F	
Bulb(s) burned out		10	S
Electro-optic Sensor			
Image Transmit Select	90		S
Video, forward, transmitting			01
Video, forward, not transmitting			02
Video, Stereo, transmitting			03
Video, Stereo, not transmitting			04
Video, left peripheral, transmitting			05
Video, left peripheral, not transmitting			06
Video, right peripheral, transmitting			07
Video, right peripheral, not transmitting			08
Video, rear, transmitting			09
Video, rear, not transmitting			0A
Video, reconnaissance, transmitting			0B
Video, reconnaissance, not transmitting			0C
Driver's thermal viewer (DTV), transmitting			0D
Driver's thermal viewer (DTV), not transmitting			0E
Forward looking infrared (FLIR), transmitting			0F
Forward looking infrared (FLIR), not transmitting			10
Radar, transmitting			11
Radar, not transmitting			12
Laser, transmitting			13
Laser, not transmitting			14
Video, forward	91		
Power on		01	
Power off		02	
Scan rate		06	N
Sector size		07	N
Shutter speed		0E	N
Video, Stereo	92		
Power on		01	
Power off		02	
Scan rate		06	N
Sector size		07	N
Shutter speed		0E	N
Video, left peripheral	93		
Power on		01	
Power off		02	

RV TO RCC STATUS INFORMATION CODING

<u>Function/status Description</u>	<u>Block Field</u>	<u>Function Field</u>	<u>Parameter Field</u>
Scan rate		06	N
Sector size		07	N
Shutter speed		0E	N
Video, right peripheral	94		
Power on		01	
Power off		02	
Scan rate		06	N
Sector size		07	N
Shutter speed		0E	N
Video, rear	95		
Power on		01	
Power off		02	
Scan rate		06	N
Sector size		07	N
Shutter speed		0E	N
Video, reconnaissance	96		
Power on		01	
Power off		02	
Scan rate		06	N
Sector size		07	N
Shutter speed		0E	N
Driver's thermal viewer (DTV)	97		
Power on		01	
Power off		02	
Scan rate		06	N
Sector size		07	N
Stand by		10	
Thermal hot		14	
Thermal cold		15	
Forward looking infrared (FLIR)	98		
Power on		01	
Power off		02	
Scan rate		06	N
Sector size		07	N
FLIR thermal level		13	PI
FLIR thermal gain		14	PI
FLIR focus		15	PI
FLIR contrast		16	PI
Condition sensors	A0		
Radar detected		01	

RV TO RCC STATUS INFORMATION CODING

<u>Function/status Description</u>	<u>Block Field</u>	<u>Function Field</u>	<u>Parameter Field</u>
Magnetic field detected		02	
Motion detected		03	
Frequency detected		04	
Light detected		05	
Sound detected		06	
NBC detected		07	
Rain detected		08	
Snow detected		09	
VHF radio	A1		
Power on		01	
Power off		02	
Frequency select		03	N
Radio transmitting power		04	PI
Antenna azimuth		05	PI
Antenna elevation		06	PI
Antenna polarization		07	S
Antenna auto-track on		08	
Antenna auto-track off		09	
Microwave radio	A2		
Power on		01	
Power off		02	
Frequency select		03	N
Radio transmitting power		04	PI
Antenna azimuth		05	PI
Antenna elevation		06	PI
Antenna polarization		07	S
Antenna auto-track on		08	
Antenna auto-track off		09	
Fiber optic link	A3		
Fiber optic cable cut		02	
Fiber optic cable left on spool		03	N
Fiber optic cable dispensed		04	N
Laser link	A4		
Navigation	B0		
Heading		01	N
Altitude		02	N
Roll		03	N
Pitch		04	N
Yaw		05	N
Roll limit warning		06	
Pitch limit warning		07	
Slope indicator		08	N

RV TO RCC STATUS INFORMATION CODING

<u>Function/status Description</u>	<u>Block Field</u>	<u>Function Field</u>	<u>Parameter Field</u>
Speedometer		09	N
Odometer		0A	N
Trip odometer		0B	N
Doppler speed		0C	N
Wheel count speed		0D	N
UTM coordinates		0E	N
Latitude		0F	N
Longitude		10	N
Mission Modules platform	C0		
Circuit Breaker Faults	D0		
Master		01	
Light		02	
Ignition		03	
Brake boost		04	
Exterior	E0		
Vehicle hit		01	
Track off		02	
Exterior temperature		03	N
Tire flat		04	
Intrusion detection		05	

DISTRIBUTION LIST

	Copies
Commander Defense Technical Information Center ATTN: DDAC Bldg. 5, Cameron Station Alexandria, VA 22304-9990	12
Manager Defense Logistics Studies Information Exchange ATTN: AMXMC-D Fort Lee, VA 23801-6044	2
Commander U.S. Army Tank-Automotive Command ATTN: AMSTA-DDL (Technical Library) Warren, MI 48397-5000	2
Commander U.S. Army Tank-Automotive Command ATTN: AMSTA-CF (Mr. G. Orlicki) Warren, MI 48397-5000	1
Commander U.S. Army Tank-Automotive Command ATTN: AMSTA-RVE (Adams) Warren, MI 48397-5000	1
Royal Armament R&D Establishment VT4 ATTN: Alan Barradale Chobham Lane, Chertsey Surrey, KT16 OEE United Kingdom	1
Jet Propulsion Laboratory ATTN: Mr. Roger Bedard 4800 Oak Grove Drive Pasadena, California 91103	1
U.S. Marine Corps ATTN: GATORS V0310 (Colonel Ray Bowles) Quantico, VA 22134	1
AFV Task Force ATTN: DAMO-AFV-C (Major Robert Buckstad) Fort Eustis, VA 23604-5597	1

DISTRIBUTION LIST (Continued)

	Copies
Naval Explosives Ordnance Disposal ATTN: Mr. Frank Clark Code 501 Indian Head, MD 20640-5070	1
Microwave Radio Corporation ATTN: Mr. Edward Dahn 847 Rogers Street Lowell, MA 01852	1
Michigan Automated Vehicle Research Consortium ATTN: Mr. Herbert Dobbs 2727 Second Street Detroit, Michigan 48201	1
Harry Diamond Labs ATTN: SLCHD-RT-RD (Emmerman) 2800 Powder Mill Road Adelphi, MD 20783	1
FMC Corporation Central Engineering Labs ATTN: Ewa Garg 1205 Coleman Avenue Box 580 Santa Clara, California 95052	1
John Deere Dubuque Works ATTN: Mr. Dan Griswold P.O. Box 538 Dubuque, Iowa 52004-0538	1
Commander U.S. Army Human Engineering Lab ATTN: Mr. Gary Haaz Aberdeen Proving Grounds, MD 21005-5001	1
Kraft TeleRobotics ATTN: Mr. Steve Harbur 11667 West 90th Street Overland Park, KS 66214	1
Naval Ocean Systems Center ATTN: Mr. Tom Hughes Code 531 Kailua, HA 96734-0997	2
Commandant U.S. Army Infantry School ATTN: ATSH-CD-MLS-E (Johnson) Fort Benning, GA 31905-5400	1

DISTRIBUTION LIST (Continued)

	Copies
Sandia National Laboratories 52-67 ATTN: Mr. James Kelsey Albuquerque, NM 87185	1
Grumman Electronics Systems Guided Weapons Systems Products ATTN: Mr. Jerry Kirsch Mail Stop B01-45 Bethpage, New York 11714-3585	1
Sandia National Laboratories Advanced Technology Division 5267 ATTN: Mr. Paul Klarer Albuquerque, NM 87185	1
Oak Ridge National Laboratory ATTN: Mr. Bill Knee Building 6025, Mail Stop 360 P.O. Box X Oak Ridge, TN 37391-6360	1
Commander U.S. Army Communications-Electronics Command ATTN: AMSEL-RD-ASCO-SC (Kobylarz) Fort Monmouth, NJ 07703	2
Honeywell ATTN: Mr. Bill Kraetz Mail Station MN 50-4300 5901 S. County Road 18 Edina, MN 55436	1
Oakland University School of Engineering & Computer Sciences ATTN: Dr. Nan K. Loh Rochester, Michigan 48063	1
Oak Ridge National Laboratory Instrumentation & Controls Division ATTN: Mr. Wayne Manges P.O. Box X Oak Ridge, TN 37831	1
General Dynamics Land Systems Division ATTN: Mr. Phil McCown P.O. Box 2074 MZ 436-32-23 Warren, Michigan 48090	1

DISTRIBUTION LIST (Continued)

	Copies
Odetics, Inc. ATTN: Mr. Bob Merket 557 Arundel Drive Severna Park, MD 21146	1
Delco Systems Operations ATTN: Chris Michaels Mail Code E603 6767 Hollister Avenue Goleta, California 93117	1
U.S. Army Transportation School ATTN: ATSP-CDC (Captain Milling) Fort Eustis, VA 23604-5393	1
Honeywell Defense Systems Group Advanced Systems Center ATTN: Pat Narendra 5901 South County Road 18 Edine, MN 55436	1
Commander U.S. Army Tank-Automotive Command ATTN: AMSTA-R (Major Leonard Ogborn) Warren, MI 48397-5000	1
Delco Electronics Corporation Delco Systems Operations ATTN: Ferenc Pavlics 6767 Hollister Avenue Goleta, California 93117	1
Commander U.S. Army Missile Command ATTN: AMSMI-RD-ST-GD (Dr. John Prater) Redstone Arsenal, AL 35898	2
Commander U.S. Army Communications-Electronics Command ATTN: AMSEL-RD-C3-IS (Saganowich) Fort Monmouth, NJ 07703	1
Commander U.S. Army Tank-Automotive Command ATTN: AMSTA-TD (Schmitz) Warren, MI 48397-5000	1
Advanced Decision Systems ATTN: Marcel Schoppers 1500 Plymouth Street Mountain View, California 94943	1

DISTRIBUTION LIST (Continued)

	Copies
National Bureau of Standards ATTN: Mr. Harry Scott Building 220, Room B124 270 Quince Orchard Road Gaithersburg, MD 20899	1
Commander U.S. Army Human Engineering Labs ATTN: SLCHS-CS (Chuck Shoemaker) Aberdeen Proving Grounds, MD 21005-5001	1
U.S. Army TCE & FLW ATTN: ATZT-CD (Dr. Bob Sickler) Fort Leonardwood, MD 65473-5000	1
Kaman Sciences ATTN: Mr. Kieth Stokes P.O. Box 7463 Colorado Springs, Colorado 80933-7463	1
U.S. Army Armor Center ATTN: ATSB-CD-SD (Captain Dennis Szydlowski) Fort Knox, KY 40121	1
Royal Armament R&D Establishment (Vehicle Dept) ATTN: John Tindle Chobham Lane, Chertsey Surrey, KT16 OEE England	1
Vectran Corporation ATTN: Mr. Tom Wilson 261 Kappa Drive Pittsburgh, Pennsylvania 15238	1
FMC Corporation Central Engineering Labs ATTN: Yue Min Wong 1205 Coleman Avenue Box 580 Santa Clara, California 95052	1
International Microwave Systems Corporation ATTN: Mr. Mike Young 2416 Our Country Road Escondido, California 92025	1
Headquarters, Department of the Army ATTN: SARD-TR (Bruce Zimmerman) Washington, D.C. 20310	1

DISTRIBUTION LIST (Continued)

Director

AMSAA

ATTN: AMXSY-MP (Mr. Cohen)

Aberdeen Proving Ground, MD 21005-5071

Copies

1

Dist-6