Designation: Exxx--xx

Standard for
Dedicated, Short Range, Two-Way Vehicle to Roadside Communications Equipment

1 Scope
1.1 This standard defines the protocol and radio system for dedicated short-range, half-duplex, active, two-way vehicle-to-roadside communications (VRC) equipment.

1.2 This standard is intended to meet the requirements for many of the VRC applications defined by the Intelligent Transportation Society of America for Commercial Vehicle Operations (CVO), Advanced Traveler Information Systems (ATIS), Advanced Vehicle Control Systems (AVCS), Electronic Toll and Traffic Management Systems (ETTM), Advanced Public Transportation Systems (APTS), and Advanced Transportation Management Systems (ATMS).

1.3 This standard defines a means to guarantee accurate and valid message delivery, between moving vehicles randomly entering a communications zone and a fixed roadway infrastructure, for both wide-area (multi-lane, open road) and lane-based applications.

1.3.1 The wide-area protocol permits transactions with several vehicles traveling on a multiple lane roadway without restricting the vehicle to any fixed lane, trajectory or speed. The applications may be characterized by the capability to perform general two-way digital communications with multiple vehicles simultaneously in an open-road operating environment, with minimal implementation restrictions. The protocol provides interoperability with existing dedicated short-range vehicle communications standards during assigned TDMA timeslots.

1.3.2 The lane-based protocol permits a transaction with a single vehicle traveling on a restricted trajectory. The applications may be characterized by the capability to exchange a short duration, fixed length message with a single vehicle when it passes through a specific location on the roadway. The lane-based protocol is defined to be a subset of the wide-area protocol, and permits interoperability with other existing dedicated short-range vehicle communications standards described herein.

1.4 The VRC equipment is composed of two principal components: a Beacon and a Transponder.

1.4.1 The Transponder is intended for, but not restricted to, installation in or on a motor vehicle.

1.4.2 The Beacon (also referred to as the Reader) controls the protocol, schedules the activation of the Transponder, reads from or writes to the Transponder, and assures message delivery and validity. It is intended for, but not restricted to, installation at a fixed location on the roadway. Application-specific interoperability with other existing dedicated short-range communication standards shall be a function of the beacon equipment.

1.5 The beacon and antenna equipment must be capable of receiving and decoding data messages from closely-spaced transponders in the same lane and/or adjacent lanes. This standard defines a system which shall communicate and perform reliable message transactions between the beacon and any transponder at speeds up to 200 kph (~125 mph), and at spacing between transponders as low as 0.5 meter. Degradation of performance below the specified levels shall not take place within the above speed and spacing requirements.

1.6 This standard defines a non-proprietary, open architecture using the simplified OSI 7-layer reference model (per ISO 7498) shown in Figure 1-1. This standard provides complete flexibility to develop VRC communications systems for single-lane or multi-lane configurations.

1.6.1 The physical layer (Layer 1) is defined as a half-duplex radio frequency medium, not restricted to any operating frequency.

1.6.2 The data link control layer (Layer 2) defines a Time Division Multiple Access (TDMA) messaging protocol in which both the downlink and uplink are completely controlled by the roadside beacon equipment.
to the link is based upon an adaptive Slotted ALOHA scheme to recover from collisions during activation. The protocol permits basic authentication of each transponder and provides a mechanism to assure reliable completion of each transaction in the communications zone.

1.6.3 The application layer (Layer 7) defines specific functions and message formats to support Intelligent Vehicle Highway System (IVHS) and other services. Implicit or pre-set message formats may be used. Data encryption, data certification, and mutual transponder/beacon authentication may be performed.

1.6.4 The network layer (Layer 3), transport layer (Layer 4), session layer (Layer 5), and presentation layer (Layer 6) are eliminated due to the short-range, short-duration nature of the VRC system.

1.7 This standard also may be used for any non-roadway environment which can utilize this type of dedicated short-range radio communications.

1.8 This standard is not restricted to operation in the United States only.

1.9 A summary of operational characteristics is given in Table 1.

Table 1 - Summary of Characteristics

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Characteristic</th>
</tr>
</thead>
<tbody>
<tr>
<td>Carrier Frequency</td>
<td>Country/Application Specific (subject to assignment)</td>
</tr>
<tr>
<td>Carrier Modulation</td>
<td>Unipolar ASK (Manchester Encoded)</td>
</tr>
<tr>
<td>Data Bit Rate</td>
<td>500 kbps</td>
</tr>
<tr>
<td>Message Data</td>
<td>512 data bits per TDMA packet, single or multi-packet transactions</td>
</tr>
<tr>
<td>Technology Type</td>
<td>Two-way Active RF</td>
</tr>
<tr>
<td>Antenna Location</td>
<td>Application Specific</td>
</tr>
<tr>
<td>Protocol</td>
<td>TDMA/Adaptive Slotted Aloha Access</td>
</tr>
</tbody>
</table>

2 Referenced Documents

2.1 Reports from CEN/TC278/WG9 on DSRC

2.2 ITS America Strategic Plan

2.3 ANSI Specification C95.1 - current revision

2.4 Heavy Vehicle Electronic License Plate (HELP) Specification for Automatic Vehicle Identification Equipment (October 1991)

2.5 ANSI MH5.1.9-1990, American National Standard for Freight Containers - Automatic Identification

2.6 Compatibility Specification for Automatic Vehicle Identification Equipment, California Code of Regulations, Title 21, Chapter 16

2.7 ISO 7498 - OSI seven layer-reference-model

3 Terminology

3.1 Definition of Technical Terms:

3.1.1 AM - Amplitude Modulation

3.1.2 ASK - Amplitude Shift Keying

3.1.3 AVI - Automatic Vehicle Identification

3.1.4 CRC - Cyclic Redundancy Check

3.1.5 Downlink - Communications from a Roadside Beacon to a Vehicle

3.1.6 ERP - Effective Radiated Power = peak antenna gain x transmit power

3.1.7 EM - Electromagnetic

3.1.8 FCC - Federal Communications Commission

3.1.9 FCM - Frame Control Message

3.1.10 HELP - Heavy Vehicle Electronic License Plate

3.1.11 ID - Device Identification

3.1.12 kbps - kilobits per second
3.1.13 kHz - kilohertz (103 hertz)
3.1.14 kph - kilometers per hour
3.1.15 MHz - megahertz
3.1.16 RAM - Random Access Memory
3.1.17 RF - Radio Frequency
3.1.18 Uplink - Communications from a Vehicle to a Roadside Beacon
3.1.19 VRC - Vehicle-to-Roadside Communications

3.2 Definition of Physical Layer Terms:
3.2.1 Carrier Frequency - A location in the Electromagnetic Spectrum allocated for VRC system services.

3.3 Definition of Data Link Layer Terms:
3.3.1 Beacon - A fixed position controller, also referred to as a Reader, associated transmit and receive (Tx/Rx) antenna(s), and modulation and demodulation hardware and software. Communication with existing dedicated short-range AVI transponders shall require dual mode operation in the beacon.

3.3.2 Byte Order - Numeric fields shall be transmitted most significant bit first. If a numeric field is represented by multiple bytes, the most significant bit of the most significant byte shall be transmitted first. This document represents the most significant, and first transmitted, to the left on a line and to the top of a multi-line tabulation.

3.3.3 CRC - This field is defined as a Cyclic Redundancy Check. Error detection must be performed each time a data message is sent so that the receiving party can ascertain the validity of the data stream. The specified form of the cyclic redundancy check is the CRC-16, with generator polynomial of $x^{16} + x^{15} + x^2 + 1$. This results in a 16-bit value transmitted with each data message. The data packet protected by the CRC excludes any preceding header in every case.

3.3.4 Data Packet - The message information, excluding the Header, communicated between the transponder and beacon. Multiple packets may be transferred in each frame, and in multiple frames.

3.3.5 Frame - A cyclic structure consisting of the Message Control Phase, the Transaction Phase with one or four message slots, and the Activation Phase using Slotted ALOHA link access techniques.

3.3.6 Header Code - The Header defines the start of each message and consists of an 8-bit self-synchronization pattern (Selsyn) and an 8-bit start-of-message flag for a total of 16 bits. The Selsyn pattern has binary value of 01010101. The start-of-message flag has binary value of 10011011.

3.3.7 Link Validation - A 7-bit linear sequence generator shall be used to perform link validation. The generator shall be a 7-stage shift register with polynomial $x^7 + x + 1$. Only messages transmitted in the message slots (within the Transaction Phase) shall be validated. All data fields except the Header and CRC shall be included in the validation process. The beacon shall pick a random 64-bit Validation Seed each frame and transmit it in the Frame Control Message. This seed shall be used, along with the message data, by the message source (transponder or beacon) to generate a Validation Check byte. This value shall be calculated for each Slot Data Message transmitted in the frame. The Validation Seed shall be used to initialize the sequence generator by clocking it through the generator. The sequence generator shall be re-initialized by the Validation Seed for each Slot Data Message transmitted in the frame. During reception, data is then clocked through the sequence generator. Following the data, eight additional zeroes are clocked. The output of the sequence generator for these eight bits is the Link Validation Check byte. This is compared to the check byte in the received message to determine validity.

3.3.8 Link Validation Check Byte - An 8-bit field generated by the validation algorithm, and appended to the transmission to validate a received Slot Data Message.

3.3.9 Link Validation Seed - A 64-bit random or pseudo-random number which initializes the validation algorithm for all message transactions in a given frame. This feature provides uplink playback protection for the beacon.

3.3.10 Slot Command - A field which defines the type of transmission or reception that the transponder will perform during the transaction phase.

3.3.11 Transponder - An electronic device attached to a vehicle and containing information that can be communicated with the beacon.

3.3.12 Transponder ID Number - The code or serial number that uniquely identifies a transponder, as described in section 5.9.8.

4 Physical Layer Radio Frequency Characteristics
4.1 RF Carrier Frequency - The VRC system shall operate at an RF carrier frequency which permits a
4.2 **AM Modulation Scheme** - The modulation scheme shall be unipolar amplitude shift keying (ASK) of the RF carrier using Manchester encoding as shown in Figure 4-1. A data bit '1' is transmitted by sending an RF pulse during the first half of the bit period and no signal during the second half. A '0' data bit is transmitted as no signal during the first half of the bit period and an RF pulse transmission during the second half.

![Manchester AM ASK Coding](image)

**Figure 4-1: Manchester AM ASK Coding**

4.3 **Bandwidth** - The data bit rate for all messages shall be 500 Kbps (kilobits per second). This data rate implies a minimum transponder receiver bandwidth of approximately 1.5 MHz.

4.4 **RF Carrier On/Off Ratio** - The ratio of power output in the "on-burst" to the power output in the "off-burst" shall be more than 20 dB.

4.5 **Transponder Characteristics:**
4.5.1 **Antenna Location** - The transponder shall establish a communication link with a beacon located at any point in the hemisphere in front of the transponder antenna. Transponders shall meet the performance specified herein when positioned in the front window, or, if suitably packaged, on the front bumper or license plate.
4.5.1.1 Transponder may be mounted separately from its antenna for specific applications.
4.5.1.2 Alternative mounting positions, for use on specific applications, shall maintain a clear line of sight to the beacon antenna.
4.5.2 **Antenna Polarization** - RF transmissions shall be horizontally polarized. Operational characteristics shall be tested when transmitting in an anechoic environment using a horizontally polarized test antenna.
4.5.3 **Antenna Beamwidth** - 3 dB beamwidth shall be 100° minimum in elevation and 70° minimum in azimuth.
4.5.4 **Transponder Activation** - A transponder shall initiate activation in less than 20 milliseconds after entering the beacon communication zone. This zone is defined by the area in which the received field strength exceeds the specified transponder threshold.

4.6 **Beacon Characteristics:**
4.6.1 **Antenna Polarizations** - The beacon transmit and receive antennas shall have predominant electromagnetic (EM) field components. Horizontal linear, vertical linear, circular or elliptical polarizations are allowed. Polarization is application-specific.
4.6.2 **Antenna Location** - For lane-based and wide-area operation the beacon antenna location is site-specific.
4.6.3 **Field Strength** - The beacon shall transmit at RF power levels allowed at the operating frequency for each country, region, and/or application.

5 **Data Link Layer (Layer 2) Description**
5.1 **General Protocol** - The beacon shall control all transactions with transponders, and implement a slotted ALOHA, time division multiple access (s-TDMA) data link control protocol as defined below. The protocol is based on a cyclic structure, known as a frame, as shown in Figure 5-1. Frames are transmitted continuously and contiguously. The frame consists of a Message Control Phase (with the Frame Control Message), a Transaction Phase (with data message slots), and an Activation Phase (with activation slots). The protocol permits multiple transponders to simultaneously request permission to perform a transaction. The beacon then commands up to four
transponders to communicate in one or more specific message slots within the frame. At the conclusion of each transaction, a confirmation mechanism is used. If the transaction fails for any reason, a mechanism to repeat the transaction is initiated.

5.2 Selectable Frame Structure - The VRC protocol implements a dual-frame structure to optimize performance for both wide-area (open-road) and lane-based applications.

5.2.1 Wide Area Frame - There shall be four message slots and sixteen activation slots.

5.2.2 Lane-Based Frame - There shall be one message slot and four activation slots.

5.3 Message Control Phase - The frame structure, synchronization, message slot assignments, transaction type, and data link control shall be commanded by the beacon during this phase via the Frame Control Message (FCM). Assignments are based upon requests received during Activation Phases of preceding frames. The beacon may assign multiple message slots and/or multiple frames to a transaction with a transponder. In this case, the slot command and Transponder ID will appear in multiple slot assignment fields in the FCM.

5.4 Transaction Phase - The slot command in the FCM shall indicate the type of transaction and in which slot(s) the transaction shall be performed. A transaction may be transmit or receive, addressed or broadcast, and internal or external data messages.

5.4.1 Message Acknowledgement - The beacon shall send an acknowledgment message after each scheduled addressed transponder transmission. The transponder shall send an acknowledgment message after each scheduled addressed transponder reception. The acknowledgment shall be set positive if a valid message is received (i.e., no CRC error and no link validation error). Otherwise, the acknowledgment shall be set negative. An incorrectly received acknowledgement shall be considered negative.

5.5 Activation Phase - The Beacon shall transmit a FCM at the beginning of each frame to define the frame structure, enable activation, and establish synchronization with transponders. Transponders successfully decoding the FCM shall randomly choose an Activation Slot and prepare to send a Transponder ID message. The beacon shall listen for Transponder ID Messages in all of the activation slots at the end of the current frame, and shall make appropriate transaction assignments in the next available frame. A sample activation and link entry sequence is shown in Figure 5-2.

5.6 Timing Accuracy - Unless otherwise noted, the frame and data rate timing accuracy shall be ±450 ppm (parts per million) for all transponder transmissions and shall be ±100 ppm for all beacon transmissions.

5.7 Guard Bands and Extended Headers

5.7.1 Guard Bands - Guard Bands, defined as a time period of no RF transmission, shall be as follows:

- Following each FCM: 100 µsec
- Following each Activation Phase: 250 µsec
- Following each Transponder ID Msg: 8 µsec
- Following each Transponder-Originated SDM: 40 µsec

- Following each Beacon-Originated SDM: 100 µsec

5.7.2 Extended Headers - An extended header, consisting of one of the following data patterns – all binary "1's", all "0's", or alternating 1's and 0's – shall be transmitted prior to the messages specified below. The preferred data pattern is "0101...". The number of bits of extended header shall be as follows:

- Prior to the FCM: 375 bits
Prior to each Beacon-Originated Acknowledgement Msg  30 bits

Prior to each Beacon-Originated SDM  30 bits

5.8  Message Formats and Field Sequencing:

5.8.1  Frame Control Message - The Frame Control Message provides link control, frame parameters, and dictates the transaction assignments that are to be performed by transponders in the current frame.

Field Definition

<table>
<thead>
<tr>
<th>No.</th>
<th>Bits</th>
<th>Binary Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Header Code</td>
<td>8</td>
<td>01010101</td>
</tr>
<tr>
<td>Flag</td>
<td>8</td>
<td>10001101</td>
</tr>
<tr>
<td>Frame Control</td>
<td>4</td>
<td>-</td>
</tr>
<tr>
<td>Message Type</td>
<td>4</td>
<td>100</td>
</tr>
<tr>
<td>Slot 1 Command</td>
<td>8</td>
<td>-</td>
</tr>
<tr>
<td>Slot 1 Transponder ID</td>
<td>32</td>
<td>-</td>
</tr>
<tr>
<td>Slot 2 Command</td>
<td>8</td>
<td>-</td>
</tr>
<tr>
<td>Slot 2 Transponder ID</td>
<td>32</td>
<td>-</td>
</tr>
<tr>
<td>Slot 3 Command</td>
<td>8</td>
<td>-</td>
</tr>
<tr>
<td>Slot 3 Transponder ID</td>
<td>32</td>
<td>-</td>
</tr>
<tr>
<td>Slot 4 Command</td>
<td>8</td>
<td>-</td>
</tr>
<tr>
<td>Slot 4 Transponder ID</td>
<td>32</td>
<td>-</td>
</tr>
<tr>
<td>Sleep Timeout</td>
<td>4</td>
<td>-</td>
</tr>
<tr>
<td>Spare</td>
<td>2</td>
<td>00</td>
</tr>
<tr>
<td>Activation Response Parameter</td>
<td>2</td>
<td>-</td>
</tr>
<tr>
<td>Validation Seed</td>
<td>64</td>
<td>-</td>
</tr>
<tr>
<td>CRC</td>
<td>16</td>
<td>-</td>
</tr>
</tbody>
</table>

Total 272

5.8.2  Slot Data Message - The Slot Data Message contains a data packet to or from the transponder. Content of the Message Data is application specific. Unused bits should be set to zero.

Field Definition

<table>
<thead>
<tr>
<th>No.</th>
<th>Bits</th>
<th>Binary Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Header Code</td>
<td>8</td>
<td>01010101</td>
</tr>
<tr>
<td>Flag</td>
<td>8</td>
<td>10001101</td>
</tr>
<tr>
<td>Data Link Header</td>
<td>4</td>
<td>1000</td>
</tr>
<tr>
<td>Message Type</td>
<td>4</td>
<td>01xx</td>
</tr>
<tr>
<td>Message Data</td>
<td>512</td>
<td>-</td>
</tr>
<tr>
<td>Validation Check</td>
<td>8</td>
<td>-</td>
</tr>
<tr>
<td>CRC</td>
<td>16</td>
<td>-</td>
</tr>
</tbody>
</table>

Total 560

5.8.3  Acknowledgement Message - The Acknowledgement Message indicates whether or not the prior Slot Data Message was received properly. The format is the same for both the beacon and transponder. All Slot Data Messages shall be acknowledged with a positive or negative response, except for Broadcast messages.

Field Definition

<table>
<thead>
<tr>
<th>No.</th>
<th>Bits</th>
<th>Binary Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Header Code</td>
<td>8</td>
<td>01010101</td>
</tr>
<tr>
<td>Flag</td>
<td>8</td>
<td>10001101</td>
</tr>
<tr>
<td>Data Link Header</td>
<td>4</td>
<td>1000</td>
</tr>
<tr>
<td>Message Type</td>
<td>4</td>
<td>1001 (Positive Ack) or 1000 (Negative Ack)</td>
</tr>
</tbody>
</table>

5.8.4 **Transponder ID Message** - The Transponder ID Message is used by the transponder to notify the beacon that it is present in the communication zone, and to request establishment of a logical link to perform a transaction with the beacon. Battery condition detection status is a vendor option. When detection is implemented, Message Type field shall be coded as shown. Otherwise, Message Type field shall return a 0001 response.

**Field Definition**

<table>
<thead>
<tr>
<th>No.</th>
<th>Bits</th>
<th>Binary Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Header Code</td>
<td>8</td>
<td>01010101</td>
</tr>
<tr>
<td>Flag</td>
<td>8</td>
<td>10001101</td>
</tr>
<tr>
<td>Transponder Type</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Message Type</td>
<td>4</td>
<td>0000 (Low Battery)</td>
</tr>
<tr>
<td>Transponder ID</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td>CRC16</td>
<td>16</td>
<td></td>
</tr>
</tbody>
</table>

Total 72

5.8.5 **External Transponder ID Message** - After establishment of a logical link between the transponder and the beacon, the External Transponder ID Message may be used by an attached application layer process to notify the beacon that it has data to send. This message is equivalent to a system interrupt.

**Field Definition**

<table>
<thead>
<tr>
<th>No.</th>
<th>Bits</th>
<th>Binary Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Header Code</td>
<td>8</td>
<td>01010101</td>
</tr>
<tr>
<td>Flag</td>
<td>8</td>
<td>10001101</td>
</tr>
<tr>
<td>Transponder Type</td>
<td>4</td>
<td></td>
</tr>
<tr>
<td>Message Type</td>
<td>4</td>
<td>0010</td>
</tr>
<tr>
<td>Transponder ID</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td>CRC16</td>
<td>16</td>
<td></td>
</tr>
</tbody>
</table>

Total 72

5.9 **Field Formats and Bit Definitions:**

5.9.1 **Activation Response Parameter** - This 2-bit field specifies the probability transponders will use to determine if they will transmit a Transponder ID message in the current frame, or defer activation to a future frame. This field permits the beacon to modulate the level of activity in systems where large numbers of transponders are in the communications zone. The field is coded as follows:

<table>
<thead>
<tr>
<th>Code</th>
<th>Activation Probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>00</td>
<td>100%</td>
</tr>
<tr>
<td>01</td>
<td>50%</td>
</tr>
<tr>
<td>10</td>
<td>25%</td>
</tr>
<tr>
<td>11</td>
<td>12.5%</td>
</tr>
</tbody>
</table>

5.9.1.1 Deleted

5.9.1.2 If the transponder chooses to respond in the current frame, the transponder shall interpret the Frame Control field to determine the current frame structure. The transponder shall then randomly select one of the activation slots in which to send the Transponder ID message.

5.9.1.3 If the transponder chooses to defer to a future frame, then no Transponder ID message shall be transmitted in the current frame.

5.9.2 **Data Link Header** - This 4-bit field is reserved for future message control between the transponder and beacon. This field shall be set to a value of binary 1000 to define "no operation".

5.9.3 **Frame Control** - This 4-bit field identifies the type of beacon protocol and activation control.

**Bit Code Definition**

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3.1 Wide-Area Frame
0 Lane-Based Frame

21 Transponder Activation Inhibited
0 Transponder Activation Enabled

11 External Activation Inhibited
0 External Activation Enabled

00 Normal TDMA Framing
1 Extended Variable Framing

5.9.3.1 Frame Type - Bit 3 identifies which frame structure shall be used for the current frame, as shown in Figure 5-1.

5.9.3.2 Transponder Activation Enabled - If Bit 2=0, transponders entering the communications zone shall make an attempt to gain entry by transmitting an appropriate Transponder ID Message during the Activation Phase. The probability of responding during the Activation Phase, however, shall be governed by the Activation Response Parameter.

5.9.3.3 Transponder Activation Inhibited - If Bit 2=1, transponders shall not respond with a Transponder ID Message during the current Activation Phase. The remainder of the FCM shall still be interpreted and processed, however, and the transponder shall perform any commanded operations.

5.9.3.4 External Activation Enabled - If Bit 1=0, transponders shall be allowed to respond with an External Transponder ID Message during the current Activation Phase. The probability of responding during the Activation Phase, however, shall be governed by the Activation Response Parameter.

5.9.3.5 External Activation Inhibited - If Bit 1=1, transponders shall not respond with an External Transponder ID Message during the current Activation Phase. The remainder of the FCM shall still be interpreted and processed, however, and the transponder shall perform any commanded operations.

5.9.3.6 Normal TDMA Framing - If Bit 0=0, then remaining Frame Control field bits define normal protocol operation as shown in Figure 5-1.

5.9.3.7 Extended Variable Framing - If Bit 0=1, then remaining Frame Control bits must be set as follows: Bit 3=0, Bit 2=0, Bit 1=1. This combination provides a means to permit a beacon to generate an extended variable frame messaging structure. This feature is designed for future expansion. The specific protocol is outside the scope of this standard.

5.9.4 Message Type - This 4-bit field identifies the specific type of VRC message. The bits are coded as follows:

<table>
<thead>
<tr>
<th>Code</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>0000</td>
<td>Transponder ID Message with Low Battery Indication</td>
</tr>
<tr>
<td>0001</td>
<td>Transponder ID Message with Battery OK Indication</td>
</tr>
<tr>
<td>0010</td>
<td>External Transponder ID Message</td>
</tr>
<tr>
<td>0011</td>
<td>(unused)</td>
</tr>
<tr>
<td>0100</td>
<td>Normal Slot Data Message</td>
</tr>
<tr>
<td>0101</td>
<td>(unused)</td>
</tr>
<tr>
<td>0110</td>
<td>Reserved for Factory Programming Message</td>
</tr>
<tr>
<td>0111</td>
<td>Reserved for Agency Programming Message</td>
</tr>
<tr>
<td>1000</td>
<td>Negative Acknowledgment Message</td>
</tr>
<tr>
<td>1001</td>
<td>Positive Acknowledgment Message</td>
</tr>
<tr>
<td>1010</td>
<td>(unused)</td>
</tr>
<tr>
<td>1011</td>
<td>(unused)</td>
</tr>
<tr>
<td>1100</td>
<td>Frame Control Message</td>
</tr>
<tr>
<td>1101</td>
<td>(unused)</td>
</tr>
<tr>
<td>1110</td>
<td>(unused)</td>
</tr>
<tr>
<td>1111</td>
<td>(unused)</td>
</tr>
</tbody>
</table>

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Draft 6: February 23, 1996
5.9.4.1 *Reserved Codes* - Message Type codes 0110 and 0111 are not user accessible and shall be reserved only for Factory and Agency programming functions.

5.9.5 *Message Data* - This 512-bit field contains the packet of information that is transferred to or from the transponder. This data could be either a single internal transponder data packet, or external single or multi-packet application data, depending upon Bit 4 of the associated Slot Command in the Frame Control Message.

For a Downlink Internal Message only, the first eight bits of the message are reserved for a driver interface command field. The coding is given below:

<table>
<thead>
<tr>
<th>Field Definition</th>
<th>Bit</th>
<th>Coding</th>
</tr>
</thead>
</table>
| Visual Signal    | 7,6 | 00 = Visual Signals Off  
                 |     | 01 = Activate Green     
                 |     | 10 = Activate Red        
                 |     | 11 = Activate Yellow     |
| Audio Signal     | 5,4 | 00 = Audio Signals Off   
                 |     | 01 = Activate Continuous |
                 |     | 10 = Activate Intermittent|
                 |     | 11 = Not Used            |
| Data Field Indicator | 3,2 | 00 = Data Field Valid   
                       |     | 01 = Driver Interface Command Only - Ignore Data Field |
                       |     | 10, 11 = Not Used        |

Reserved 1, 0

5.9.6 *Sleep Timeout* - This 4-bit field defines the period of time that a transponder shall not attempt activation after a completion of the current transaction with the beacon. The field is coded as binary values from 0000 to 1111. Each value is then multiplied by 2 seconds, i.e., 0-30 seconds.

5.9.7 *Slot Command* - This 8-bit field identifies the transaction assignment for a specific Message Slot. The bits are coded as follows:

| Bit Code Definition | 7,1 | Transmit Message To Beacon  
                    | 0,0 | Receive Message From Beacon |
|--------------------|-----|-----------------------------|
|                    | 6,1 | Acknowledged Message        
                    |     | Unacknowledged Message      |
|                    | 5,1 | Last Frame of Transaction  
                    |     | Transaction Not Complete    |
|                    | 4,1 | Internal Memory/Application 
                    |     | External Memory/Application |
|                    | 3,2 | Normal Slot                
                    | 0,0 | Idle Slot                  
                    | 10 | Continuous Wave Slot       
                    | 11 | (undefined)                |
| Reserved           | 1,0 |                             |

5.9.7.1 Bit 7: Transmit/Receive - The transponder shall transmit (Bit 7=1) or receive (Bit 7=0) in the indicated slot depending on the value of this bit field.

5.9.7.2 Bit 6=1: Acknowledged Message - The transponder shall perform the commanded transmission or reception, with acknowledgment. Global ID is not permitted. Positive or negative acknowledgment status shall be passed to the application layer.

If the transponder receives an error-free message during the associated slot, then the transponder shall transmit a positive acknowledgment at the end of the slot. Otherwise, the transponder shall transmit a negative acknowledgment.

If the transponder transmits a message during the associated slot, then the transponder shall expect an acknowledgment from the beacon at the end of the slot. If no acknowledgment is received, then a negative acknowledgment shall be assumed.

5.9.7.3 Bit 6=0: Unacknowledged Message - The transponder shall perform the commanded transmission or reception without acknowledgment. No acknowledgment message shall be transmitted or expected. This bit shall be ignored when the beacon uses the Global ID to broadcast messages to all transponders.

5.9.7.4 Bit 5=1: Last Frame - The transponder shall attempt to complete the assigned transaction in the current frame, then process the sleep function. If the transaction is completed successfully, the transponder shall initiate the sleep function at the end of the frame, using the sleep timeout value included in the FCM. If the transaction is not completed successfully, the transponder shall not initiate the sleep function at the end of the frame.

For an addressed receive slot assignment, the transaction is considered complete if a valid Slot Data Message is received and acknowledged by the transponder in the associated slot.

For any other type of slot assignment, the transaction shall be considered complete after the operation indicated by the Slot Command is carried out by the transponder.

5.9.7.5 Bit 5=0: Transaction Not Complete - Transponder shall maintain link activation as additional messages are pending to complete the transaction.

5.9.7.6 Bit 4=1: Internal Memory/Application - A single packet message will be sent from or received to the memory within the transponder.

If the single packet is a transponder receive message, then the most significant 8 bits of the 512-bit field are reserved for transponder application layer control purposes. The remaining 504 bits are interpreted as the data field.

If the single packet is a transponder transmit message, then the entire 512 bits shall be constructed using internal transponder memory and ID information.

5.9.7.7 Bit 4=0: External Memory/Application - Single-packet or multi-packet messages shall be transferred to or from an attached application buffer, depending upon whether the Slot Command indicates receive or transmit. That is, none of the 512 bits in each packet are interpreted by the transponder. The data field is considered to be an end-to-end message between the beacon and the transponder-attached application process.

5.9.7.8 Bit 3 & 2: Slot Type - These two bits shall be coded as follows to determine what type of slot is commanded:

<table>
<thead>
<tr>
<th>Code</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>00</td>
<td>A normal communication slot, as commanded by bits 7 through 4.</td>
</tr>
<tr>
<td>01</td>
<td>The addressed transponder shall remain idle for the associated slot. In this case, bits 7, 6, and 4 shall be ignored.</td>
</tr>
<tr>
<td>10</td>
<td>The addressed transponder shall transmit a continuous wave signal for the 560-bit duration of the assigned message slot. In this case, bits 7, 6, and 4 shall be ignored.</td>
</tr>
<tr>
<td>11</td>
<td>Currently undefined. When these bits are set to 11, the transponder shall default to idle.</td>
</tr>
</tbody>
</table>

5.9.8 Transponder ID - A 32-bit binary value which uniquely identifies the link address of each transponder. A mechanism shall be established by an approved authority or organization to allocate unique ID values among manufacturers. Unique ID values shall be in the hexadecimal range between 0000 0001 through FFFF FFFE, inclusive. Remaining addresses are reserved. Four types of transponder IDs are permitted:

5.9.8.1 Global ID - A reserved address with the hexadecimal value of 0000 0000. Every transponder shall decode this value. It shall be used exclusively for broadcast transmission from the beacon to all transponders in the
communications zone.

5.9.8.2 **Public ID** - A permanent, unique 32-bit identifier that is used to determine the link address of each transponder. This identifier shall be programmed once into the unit during factory programming. This identifier shall be used as the Transponder ID only if the Transponder Type field indicates "Public Link Entry". Otherwise, this identifier shall not be used. The Global ID value is not permitted.

5.9.8.3 **Random ID** - A 32-bit identifier that is chosen at random by the transponder, for the purpose of "Anonymous Link Entry". This identifier shall be chosen only once, upon wake-up, and shall not change value until the transponder exits the logical link (sleeps and re-awakens). This identifier shall be used as the Transponder ID only if the Transponder Type field indicates "Anonymous Link Entry". Otherwise, this identifier shall not be used. The Global ID value is not permitted.

5.9.8.4 **Private ID** - A permanent, unique 32-bit identifier which may be used exclusively to validate Agency Programming Messages (Message Type Code 0111). This identifier shall be programmed into the unit during factory programming. The Global ID value is not permitted.

5.9.9 **Transponder Type** - This 4-bit field specifies the type of transponder, what capabilities are available for the transaction, and identifies which transponder ID is used for activation.

<table>
<thead>
<tr>
<th>Bit Code</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td>31</td>
<td>Open-Road Frame capable</td>
</tr>
<tr>
<td>00</td>
<td>Open-Road or Lane-Based capable</td>
</tr>
<tr>
<td>20</td>
<td>Public Link Entry (Use Public ID for Transponder ID)</td>
</tr>
<tr>
<td>11</td>
<td>Anonymous Link Entry (Use Random ID for Transponder ID)</td>
</tr>
<tr>
<td>1,000</td>
<td>Extended Protocol Capable</td>
</tr>
<tr>
<td>01</td>
<td>Internal Read-Only</td>
</tr>
<tr>
<td>10</td>
<td>Internal Read/Write</td>
</tr>
<tr>
<td>11</td>
<td>Internal and External Read/Write</td>
</tr>
</tbody>
</table>

5.9.9.1 **Extended Protocol** - The Transponder Type field must be set to binary 0000 to signal the beacon of a capability to support an extended protocol. This feature is designed for future expansion. Any specific protocol is outside the scope of this standard.

5.9.10 **Validation Check** - This 8-bit field is generated by the link validation algorithm and is used by the beacon or transponder to validate a received Slot Data Message. It is based upon the Validation Seed and the Slot Data Message. All fields except the Header Code are included in the calculation.

5.9.11 **Validation Seed** - This 64-bit field contains the random number seed used to initialize the validation algorithm in a given frame. This seed is used in the validation of every Slot Data Message transmitted in the Transaction Phase. This feature provides uplink playback protection for the beacon.

5.10 **Message Processing (Refer to Figure 5-3):**

5.10.1 **Link Protocol Flow** - The VRC communications protocol permits two-way messaging between the beacon and one or more transponders in an application-specific communications zone. Messages are separated into one or more data packets of 512 bits each.

5.10.1.1 Packet communications may be accomplished by, but is not limited to, any of the following means:

- Single packet per vehicle, one to four vehicles simultaneously each frame
- Multiple packets per vehicle per frame
- Multiple packets per vehicle in multiple frames
- Multiple packets for one or more vehicles in multiple frames

5.10.1.2 The protocol flowchart is shown in the following figures:

- Figure 5-3a: Overall Protocol Flow
- Figure 5-3b: Activation Phase
- Figure 5-3c: Transaction Phase
- Figure 5-3d: Slot Command Processing
5.10.2 Transponder ID Message - Upon first entering the beacon communication zone (after sleep timeout expires) and receiving a valid Frame Control Message (FCM), the transponder shall determine whether or not it is allowed to respond during the Activation Cycle. If the Frame Control field in the FCM indicates "Transponder Activation Enabled", then the transponder is allowed to respond in the Activation Cycle with a Transponder ID Message. In this case, the transponder shall use the Activation Response Parameter provided in the FCM in order to determine the response probability. The response probability shall be used to determine if the transponder will choose to respond in the current frame, or defer to a future frame. If the transponder chooses to defer to a future frame, then no activation message shall be transmitted in the current frame.

However, if the transponder chooses to respond in the current frame, the transponder shall interpret the Frame Control field in order to determine the current frame structure (i.e., how many activation slots). The transponder shall then randomly select one of the activation slots in which to send this message. As long as the Frame Control field indicates "Transponder Activation Enabled", the transponder shall repeat this process each frame until link entry is successful, as evidenced by an internal or external message slot assignment that is specifically addressed to the transponder. A message slot assignment with the Global ID of 0000 0000 shall not be considered sufficient to assume that link entry is successful. However, any such message slot assignment shall be processed properly.

If the Frame Control field indicates "Transponder Activation Inhibit", then the transponder shall refrain from responding during the Activation Cycle of the current frame.

5.10.3 External Transponder ID Message - Upon receiving a transmit request from an attached application layer host, the transponder shall determine whether or not it is allowed to respond during the Activation Cycle. If the Frame Control field in the FCM indicates "External Activation Enabled", and if the transponder is currently in the link (i.e., the transponder has been previously assigned a message slot with its own Transponder ID), then the transponder is allowed to respond in the Activation Cycle with an External Transponder ID Message.

In this case, the transponder shall use the Activation Response Parameter provided in the FCM in order to determine the response probability. The response probability shall be used to determine if the transponder will choose to respond in the current frame, or defer to a future frame. If the transponder chooses to defer to a future frame, then no activation message shall be transmitted in the current frame. If the transponder chooses to respond in the current frame, the transponder shall interpret the Frame Control field in order to determine the current frame structure (i.e., how many activation slots). The transponder shall then randomly select one of the activation slots in which to send this message. As long as the Frame Control field indicates "External Activation Enabled", and the transponder remains in the link, the transponder shall repeat this process each frame until transponder host link access is provided, as evidenced by an external message slot assignment. A message slot assignment with the Global ID of 0000 0000 shall not be considered sufficient to assume that link entry is successful. However, any such message slot assignment shall be properly processed.

If the Frame Control field indicates "External Activation Inhibited", then the transponder shall refrain from responding during the Activation Cycle of the current frame.

5.10.4 Downlink Internal Message Slot - A message from the beacon to the transponder internal 512-bit message buffer. If the message was received without error then a positive acknowledgement shall be sent to the beacon if so commanded. If the data was received in error, the information shall be discarded and a negative acknowledgement sent to the beacon, if so commanded.

If the Data Field Indicator in the driver interface command field indicates that the message data is valid, then the 256 least significant bits of the message shall be stored in the general-use portion of the transponder's internal memory. If the Data Field Indicator in the driver interface command field indicates that the message data is not valid, the message data shall be discarded. However, the driver interface command shall be executed in all cases of a valid message reception.

Upon receipt of a valid Downlink Internal Message, the transponder shall activate the appropriate signals immediately. These signals shall be activated independently of the sleep function. Furthermore, the specified signal command shall override any previous signal command that is still active.

5.10.5 Downlink External Message Slot - A message from the beacon to a 512-bit buffer not located in the transponder. If the message was received without error then a positive acknowledgement shall be sent to the beacon if so commanded. If the data was received in error, the information shall be discarded and a negative acknowledgement sent to the beacon, if so commanded.

5.10.6 Uplink Acknowledgement Message - During an assigned message slot in which the transponder is scheduled to receive an addressed Slot Data Message, the transponder shall transmit an Acknowledgment Message with either a positive or negative indication. Note that, during non-addressed message slots, acknowledgments are not expected, and should be ignored entirely.

5.10.7 Uplink Internal Message Slot - A scheduled transmission in an assigned message slot from the transponder.
to the beacon. The entire 512-bit field shall be constructed using internal transponder memory and ID information. The least significant 256 bits of this field shall be copied directly from the general-use memory. The lower 192 bits of the most significant 256 bits shall be copied directly from the agency memory. The most significant 64 bits shall be used for transponder identification. Of these 64 bits, the most significant 32 bits shall be set equal to the Transponder ID (which could be either the Public ID or the Random ID). The lower 32 bits of this 64-bit field shall be set to zero (the Private ID shall never be transmitted). The bit positions of each field in the uplink message are defined below:

<table>
<thead>
<tr>
<th>Field Definition</th>
<th>Field Size (Bits)</th>
<th>Bit Number</th>
</tr>
</thead>
<tbody>
<tr>
<td>Transponder ID</td>
<td>32</td>
<td>480-511</td>
</tr>
<tr>
<td>All Zeros</td>
<td>32</td>
<td>448-479</td>
</tr>
<tr>
<td>Agency Memory Contents</td>
<td>192</td>
<td>256-447</td>
</tr>
<tr>
<td>General-Use Memory Contents</td>
<td>256</td>
<td>0-255</td>
</tr>
</tbody>
</table>

5.10.8 Uplink External Message Slot - A scheduled transmission in an assigned message slot from the transponder to the beacon. The transponder shall obtain the message packet from an external 512-bit buffer (application layer) and build the Slot Data Message.

5.10.9 Downlink Acknowledgement Message - During an assigned message slot in which the transponder is scheduled to transmit an addressed Slot Data Message, the beacon shall transmit an Acknowledgment Message with either a positive or negative indication. Note that, during non-addressed message slots, acknowledgments are not expected, and should be ignored entirely.

6 Application Layer (Layer 7) Description

6.1 Services - The application layer of the data link model offers five (5) general services to system application processes. (See Figure 6-1.)

6.1.1 File Broadcast Service - Permits the cyclical transmission of files from the beacon to the vehicle without acknowledgement.

6.1.2 Message Collection Service - Permits the transmission of autonomous acknowledged single and/or multi-packet messages from vehicles to beacon.

6.1.3 Message Distribution Service - Permits the transmission of autonomous acknowledged single and/or multi-packet messages from beacon to vehicles.

6.1.4 File Collection Service - Allows file transfer from vehicles to beacon.

6.1.5 Interactive Service - Offers a real-time "transaction-based" dialogue between roadside applications and on-board applications.

6.2 ITS System Applications - The following core VRC applications have been defined by the Intelligent Transportation Society of America:

- Electronic Toll Collection
- Commercial Vehicle Operations
- Hazardous Materials Tracking
- Airport Non-Public Areas
- Emergency Messaging
- Traveler Information
- Intermodal Transit Operations
- Communication Services
- Traffic Management
- Waste Management
- Safety Systems
- Environmental Monitoring

7 Lane Based Interoperability

7.1 HELP Systems - The Lane-Based TDMA data link protocol is defined to be interoperable with the "Heavy Vehicle Electronic License Plate (HELP) Specification for Automatic Vehicle Identification Equipment". It is intended to support 128-bit Type 2 and Type 3 transactions with a single transponder, traveling through a pre-defined zone in each lane on the roadway.

7.1.1 Deleted.

7.1.2 A HELP transaction shall be performed by a dual mode beacon with the capability to perform the trigger/response communications protocol during a TDMA message slot that was not assigned in that frame's FCM, as shown in Figure 7-1.

7.1.3 The dual mode beacon transmits the HELP Trigger and Beacon ID message. If a HELP transponder is in the communication zone, it shall respond with a Data Uplink Message. The beacon may then transmit a Data Downlink Message to the transponder.

7.2 CALTRANS Title 21 Interoperability - The Lane-Based TDMA data link protocol is defined to be interoperable with the "Compatibility Specification for Automatic Vehicle Identification Equipment, California Code of Regulations, Title 21, Chapter 16".

7.2.1 Deleted.

7.2.2 A Title 21 transaction shall be performed by a dual mode beacon with the capability to perform the trigger/response communications protocol during a TDMA message slot that was not assigned in that frame's FCM, as shown in Figure 7-2.

7.2.3 The dual mode beacon transmits the Title 21 Trigger and Polling message. If a Title 21 transponder is in the communication zone, it shall respond with a Data Uplink Message. The beacon may then transmit a Data Downlink Message to the transponder.

7.3 ANSI MH5.1.9-1990 Systems - The lane-based TDMA data link protocol is defined to be interoperable with the "ANSI MH5.1.9-1990, American National Standard for Freight Containers -Automatic Identification". It is intended to support the identification of a vehicle traveling through a pre-defined zone on each lane in a roadway.

7.3.1 Interoperability with the ANSI MH5.1.9-1990 will allow for additional interoperability with the following standards:

7.3.1.1 American Trucking Association Standard for Automatic Equipment Identification.

7.3.1.2 Association of American Railroads Standard for Automatic Equipment Identification.


7.3.1.4 IATA Recommended Practice 1640, Use of Radio Frequency Technology for the Automatic Equipment Identification of Unit Load Devices.

7.3.2 Deleted.

7.3.3 An ANSI transaction shall be performed by a dual mode beacon with the capability to perform the trigger/response communications protocol during unassigned TDMA message slots, as shown in Figure 7-3. The Beacon shall not assign any TDMA message slots and shall select the Transponder Activation Inhibited bits in the FCM before the start of the interoperability mode.

7.3.4 The dual mode beacon transmits the ANSI polling message, composed of a minimum of 4 milliseconds of continuous wave carrier signal. If an ANSI transponder is in the communications zone, it shall respond with a Data Uplink Message (composed of at least the first 20 data bits of the message).

7.3.5 Upon receiving the first 20 bits of the message, the beacon shall continue to accept the uplink message until the entire ANSI data frame has been received, or until the ANSI transponder leaves the communications zone.

7.3.6 If no ANSI transponder responds to the trigger within 4.3 milliseconds, the beacon may truncate the interoperability mode. If in the lane-based mode, a new frame can be initiated immediately. If in the wide-area mode, a new frame can be started at the end of the current frame.

If a data is received in response to a trigger, the transaction may be completed. If in the lane-based mode, a new frame can then be initiated immediately. If in the wide-area mode, a new frame can be started at the end of the current wide-area frame.

7.4 Interoperability Polling Sequence - For those systems which require interoperability with multiple transponder protocols, a suitably equipped multi-mode beacon shall be used.

For lane-based operation, the beacon shall sequentially attempt to establish communications with each transponder protocol during the transaction phase as shown in Figure 7-4a. The order in which to establish communications shall be site and application dependent.

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For open-road operation, TDMA slots in the transaction phase may be assigned for the purpose of interoperability to the extent that system requirements dictate as shown in Figure 7-4b.

Once proper communication is established with the particular transponder in the zone, the beacon may remain in that operating mode until either vehicle communications is lost or the transaction is complete.

8 General Requirements

8.1 Safe Operating Radiation Levels - VRC equipment shall not generate radiation levels greater than the power density limits specified in ANSI specification C95.1 - 1982. The VRC equipment shall not degrade beyond the specified limits throughout its operating life.
APPENDIX A. Detailed Timing and Flow Figures For VRC Protocol

Figure 1-1: Simplified OSI Model for VRC
Figure 5-1: Frame Structure and Timing
Figure 5-1a: H407 Frame Structure and Timing
Figure 5-2: Sample Activation and Link Entry Sequence
Figure 5-3a: Top Level Protocol Flowchart
Figure 5-3b: Activation Phase
Figure 5-3c: Transaction Phase
Figure 5-3d: Message Slot Processing
Figure 6-1: Layer 7 Application Services
Figure 7-1: HELP Interoperability System Timing for Lane Based Frames
Figure 7-2: CALTRANS Title 21 Interoperability System Timing for Lane Based Frames
Figure 7-3: ANSI MH5.1.9-1990 Interoperability System Timing for Lane Based Frames
Figure 7-4: Multiple Protocol Interoperability System Timing for Lane Based Frames
Figure 1-1: Simplified OSI Model for VRC
Frame structure & timing for both Lane-Based and Open-Road frame types. (The detailed slot timing is common to both frame types.)

Figure 5-1: Frame Structure and Timing
Modified timing used by Raytheon and Mark IV for system operations on Highway 407.

Figure 5-1a: H407 Frame Structure and Timing
1. Transponder receives the FCM here, and processes it. The transponder extracts the control information, prepares to perform any commanded operations, and decides whether or not to respond during the activation cycle.

2. If the transponder decides to respond during the activation phase, then a transponder ID Message is transmitter in a randomly selected slot.

3. In this example, the Beacon heard the transponder in the previous frame, and has commanded transmission to perform a transmission in slot 3.

4. The transponder performs the commanded transmission and awaits acknowledgement.

5. The Beacon transmits either a positive or negative acknowledgement.

Sample link-entry sequence with a transmission assignment in slot 3.
Transponder VRC Link Protocol Flow

5-3a: Top Level Protocol Flowchart
Transponder Activation Phase Processing

CHECK STATUS
Check Link-Entry Status

LINK-ENTRY GRANTED

Is Activation Mode enabled?
No

ARP Processing
Decide whether or not to respond in current frame

Defer

Current Frame

ACTIVATION *
Select activation slot. Prepare & xmit Act Msg.

Yes

Is the host requesting link access?

Yes

ARP Processing
Decide whether or not to respond in current frame

Defer

Current Frame

ACTIVATION **
Select activation slot. Prepare & xmit Act Msg.

* Use Transponder ID Message
** Use External Transponder ID Message

Figure 5-3b: Transponder Activation Phase Processing
1 - Addressed Transmit
2 - Continuous Wave Xmit
3 - Broadcast Receive
4 - Idle or Undefined
5 - Addressed Receive
6 - Nack Rcvd or No Ack
7 - Ack Rcvd
8 - Error-Free Msg. Rcvd
9 - No Valid Msg Rcvd

Interpret the slot command

Was the transponder specifically addressed?

Yes

Interpret CMD.
Interpret the slot command

Link Entry
Set Link-Entry Status to indicate 'Link-Entry Granted'

NO

Process MSG
Pass message to higher layer for processing

Was "Last Frame" Commanded?

YES

Is the host requesting link access?

NO

EXIT LINK

NO

Process MSG
Pass message to higher layer for processing

YES

Process MSG
Pass message to higher layer for processing

Transponder Message Slot Processing

Addressed Tx
Prepare & xmit the message. Wait of Ack/Nack

Pass NACK to App Layer

Pass ACK to App Layer

Broadcast Rcv
Wait for valid message or end of message slot.

Process MSG
Pass message to higher layer for processing

Process MSG
Pass message to higher layer for processing

Transmit ACK

Transmit NACK

Addressed Rx
Wait for valid message or end of message slot.

Process MSG
Pass message to higher layer for processing

Process MSG
Pass message to higher layer for processing

IDLE
No activity. Idle until end of slot

Pass ACK to App Layer

Pass NACK to App Layer

Process MSG
Pass message to higher layer for processing

Was the transponder specifically addressed?

NO

CW Transmit
Enable transmission of continuous wave signal

1 - Addressed Transmit
2 - Continuous Wave Xmit
3 - Broadcast Receive
4 - Idle or Undefined
5 - Addressed Receive
6 - Nack Rcvd or No Ack
7 - Ack Rcvd
8 - Error-Free Msg. Rcvd
9 - No Valid Msg Rcvd

Process MSG
Pass message to higher layer for processing

Was "Last Frame" Commanded?

YES

Is the host requesting link access?

NO

EXIT LINK

EXIT

Figure 5-3d: Message Slot Processing
Figure 6-1: Layer 7 Application Services
Interoperability Phase

**LANE-BASED FRAME**
 FRAME = 3.652 ms

Interoperability Phase

**LANE-BASED FRAME**
 FRAME = 3.652 ms

FCM Slot 1

Beacon

$\begin{array}{c}
\text{Trigger} \\
100 \mu S \\
20 \mu S
\end{array}$

$\begin{array}{c}
\text{Beacon ID} \\
20 \mu S \\
80 \mu S
\end{array}$

Transponder

$\begin{array}{c}
\text{Uplink Data} \\
20 \mu S \\
20 \mu S \\
256 \mu S
\end{array}$

$\begin{array}{c}
\text{Downlink Data} \\
256 \mu S \\
228 \mu S \\
80 \mu S
\end{array}$

7-1: HELP Interoperability System Timing
Interoperability Phase

LANE-BASED FRAME FRAME = 3.652 ms

Interoperability Phase

LANE-BASED FRAME FRAME = 3.652 ms

Beacon

Transponder

Wakeup Polling Downlink Data Acknowledge Sequence Uplink Data Backscatter Sequence

10 μs 10 μs 30 μs 100 μs 200 μs 413.3 μs 100 μs 413.3 μs 363.3 μs

Figure 7-2: CALTRANS Title 21 Interoperability System Timing

Figure 7-3a: ANSI MH5.1.9-1990 Interoperability for Lane-Based Frames
Interoperability
Phase LCME Phase
FRAME = 3.652 mS
FRAME = 3.652 mS

FCM Slot 1 FCM Slot 1

Beacon
Unmodulated RF Carrier
100 uS Guard Band
4 mS Wakeup

Transponder
Uplink Modulated Backscatter Data
12.80 mS (128 bits)
OPEN-ROAD FRAME
FRAME DURATION = 9.676 ms

Set transponder activation inhibit
No TDMA slot assignments

Transaction Phase
(4 message slots)

Activation Phase
(16 Activation Slots)
1 mS Guard Band

If ANSI message received
skip next frame.

Message Control Phase

Slot 1 Slot 2 Slot 3 Slot 4

Figure 7-3b: ANSI MH5.1.9-1990 Interoperability for Open-Road Frames
LANE-BASED FRAME
FRAME DURATION = 3.652 mS

<table>
<thead>
<tr>
<th></th>
<th>Message Control Phase</th>
<th>Transaction Phase</th>
<th>Activation Phase</th>
<th>Guard Band</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frame N</td>
<td>FCM</td>
<td>TDMA</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frame N + 1</td>
<td>FCM</td>
<td>HELP</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frame N + 2</td>
<td>FCM</td>
<td>Caltrans</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Frame N + 3</td>
<td>FCM</td>
<td>ANSI</td>
<td></td>
<td></td>
</tr>
<tr>
<td>New Frame</td>
<td>FCM</td>
<td>TDMA</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Figure 7-4a: Multiple Protocol Interoperability System Timing for Lane-Based Frames

OPEN-ROAD FRAME
FRAME DURATION = 9.676 mS

<table>
<thead>
<tr>
<th></th>
<th>Message Control Phase</th>
<th>Transaction Phase</th>
<th>Activation Phase</th>
<th>Guard Band</th>
</tr>
</thead>
<tbody>
<tr>
<td>Frame N</td>
<td>FCM</td>
<td>Slot 1</td>
<td>Slot 2</td>
<td>Slot 3</td>
</tr>
<tr>
<td></td>
<td>TDMA</td>
<td>TDMA</td>
<td>HELP</td>
<td>Caltrans</td>
</tr>
</tbody>
</table>

Frame N + 1

<table>
<thead>
<tr>
<th>FCM</th>
<th>Slot 1</th>
<th>Slot 2</th>
<th>Slot 3</th>
<th>Slot 4</th>
</tr>
</thead>
</table>

Frame N + 2

<table>
<thead>
<tr>
<th>FCM</th>
<th>Slot 1</th>
<th>Slot 2</th>
<th>Slot 3</th>
<th>Slot 4</th>
</tr>
</thead>
</table>

Figure 7-4b: Multiple Protocol Interoperability System Timing for Open-Road

1  FCC Certification:

1.1  U.S. Operation - The VRC system shall operate in compliance with FCC rules CFR90.353, or current applicable rules, for licensed operation of dedicated short range vehicle to roadside communications in this frequency band.

2  RF Operating Frequency:

2.1  Center Frequency - The VRC system shall operate at a nominal frequency of 915 MHz and shall be accurate to within the tolerances required by FCC rules, but no less accurate than ±1000 MHz.

2.2  Deleted.

3  Transponder RF Characteristics:

3.1  Transmit Field Strength - The transmit amplifier and antenna shall operate at a field strength between 170 millivolts/meter to 350 millivolts/meter, when measured at one (1) meter along the antenna boresight.

3.2  RF Damage Protection - No permanent damage shall be caused by placing the transponder in an electromagnetic field with a signal strength of 16.5 volts/meter continuous or 50 volts/meter for 30 seconds (per SAE specification 1455).

3.3  Bit Error Rate - The received bit error rate shall be no greater than 1x10-5 when the transponder is placed in a horizontally polarized beacon electric field with a signal strength from 165 mV/meter to 5400 millivolts/meter.
<table>
<thead>
<tr>
<th>Paragraph Number</th>
<th>Draft 5</th>
<th>Draft 6</th>
<th>Reason for Change</th>
</tr>
</thead>
<tbody>
<tr>
<td>5.7.1</td>
<td>Following each Activation Phase 250 µsec +10%,-0%</td>
<td>Following each FCM 100 µsec</td>
<td>Re-written for clarity.</td>
</tr>
<tr>
<td></td>
<td>Following each Transponder ID Msg 8 µsec</td>
<td>Following each Activation Phase 250 µsec</td>
<td>Eliminated tolerance for Activation Phase guard band.</td>
</tr>
<tr>
<td></td>
<td>Preceding the Extended Header of each Reader-Originated SDM or Acknowledgement 40µsec</td>
<td>Following each Transponder ID Msg 8 µsec</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Preceding each Transponder-Originated SDM or Acknowledgement 100 µsec</td>
<td>Following each Transponder-Originated SDM 40 µsec</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>Following each Beacon-Originated SDM 100 µsec</td>
<td></td>
</tr>
<tr>
<td>5.7.2</td>
<td><strong>Extended Headers</strong> - An extended header, consisting of one of the following data patterns – all binary &quot;1's&quot;, all &quot;0's&quot;, or alternating 1's and 0's – shall be transmitted prior to the messages specified below. The preferred data pattern is &quot;0101....&quot;. The number of bits of extended header shall be as follows:</td>
<td><strong>Extended Headers</strong> - An extended header, consisting of one of the following data patterns – all binary &quot;1's&quot;, all &quot;0's&quot;, or alternating 1’s and 0’s – shall be transmitted prior to the messages specified below. The preferred data pattern is &quot;0101....&quot;. The number of bits of extended header shall be as follows:</td>
<td>For consistency, changed references of &quot;Reader-Originated&quot; to &quot;Beacon-Originated&quot;.</td>
</tr>
<tr>
<td></td>
<td>Prior to the FCM 375 bits</td>
<td>Prior to the FCM 375 bits</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Prior to each Reader-Originated Acknowledgement Msg 30 bits</td>
<td>Prior to each Beacon-Originated Acknowledgement Msg 30 bits</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Prior to each Reader-Originated SDM 30 bits</td>
<td>Prior to each Beacon-Originated SDM 30 bits</td>
<td></td>
</tr>
<tr>
<td>5.9.3.3</td>
<td><strong>Transponder Activation Disabled</strong> - If Bit 2=1, transponders shall not respond with a Transponder ID Message during the current Activation Phase. The remainder of the FCM shall still be interpreted and processed, however, and the transponder shall perform any commanded operations.</td>
<td><strong>Transponder Activation Inhibited</strong> - If Bit 2=1, transponders shall not respond with a Transponder ID Message during the current Activation Phase. The remainder of the FCM shall still be interpreted and processed, however, and the transponder shall perform any commanded operations.</td>
<td>For consistency, changed reference of &quot;Transponder Activation Disabled&quot; to &quot;Transponder Activation Inhibited&quot;.</td>
</tr>
<tr>
<td>5.9.7.1</td>
<td><strong>Bit 7: Transmit/Receive</strong> - The transponder shall transmit or receive in the indicated slot depending on the value of this bit field.</td>
<td><strong>Bit 7: Transmit/Receive</strong> - The transponder shall transmit (Bit 7=1) or receive (Bit 7=0) in the indicated slot depending on the value of this bit field.</td>
<td>For clarity, specified bit value for transmit and receive.</td>
</tr>
<tr>
<td>---</td>
<td>---</td>
<td>---</td>
<td>---</td>
</tr>
<tr>
<td>5.10.2</td>
<td>As long as the Frame Control field indicates &quot;Transponder Activation Mode&quot;, the transponder shall repeat this process each frame until link entry is successful, as evidenced by an internal or external message slot assignment that is specifically addressed to the transponder. A message slot assignment with the Global ID of 0000 0000 shall not be considered sufficient to assume that link entry is successful. However, any such message slot assignment shall be processed properly. If the Frame Control field indicates &quot;Activation Inhibit&quot;, then the transponder shall refrain from responding during the Activation Cycle of the current frame.</td>
<td>As long as the Frame Control field indicates &quot;Transponder Activation Enabled&quot;, the transponder shall repeat this process each frame until link entry is successful, as evidenced by an internal or external message slot assignment that is specifically addressed to the transponder. A message slot assignment with the Global ID of 0000 0000 shall not be considered sufficient to assume that link entry is successful. However, any such message slot assignment shall be processed properly. If the Frame Control field indicates &quot;Transponder Activation Inhibited&quot;, then the transponder shall refrain from responding during the Activation Cycle of the current frame.</td>
<td>For consistency, changed &quot;Transponder Activation Mode&quot; to &quot;Transponder Activation Enabled&quot;, and &quot;Activation Inhibit&quot; to &quot;Transponder Activation Inhibited&quot;.</td>
</tr>
<tr>
<td>5.10.3</td>
<td>As long as the Frame Control field indicates &quot;External Activation Enabled&quot;, and the transponder remains in the link, the transponder shall repeat this process each frame until host link access is provided, as evidenced by an external message slot assignment. A message slot assignment with the Global ID of 0000 0000 shall not be considered sufficient to assume that link entry is successful. However, any such message slot assignment shall be properly processed. If the Frame Control field indicates &quot;External Activation Disabled&quot;, then the transponder shall refrain from responding during the Activation Cycle of the current frame.</td>
<td>As long as the Frame Control field indicates &quot;External Activation Enabled&quot;, and the transponder remains in the link, the transponder shall repeat this process each frame until transponder host link access is provided, as evidenced by an external message slot assignment. A message slot assignment with the Global ID of 0000 0000 shall not be considered sufficient to assume that link entry is successful. However, any such message slot assignment shall be properly processed. If the Frame Control field indicates &quot;External Activation Inhibited&quot;, then the transponder shall refrain from responding during the Activation Cycle of the current frame.</td>
<td>For clarity, changed &quot;host link&quot; to &quot;transponder host link&quot;. For consistency, changed &quot;External Activation Disabled&quot; to &quot;External Activation Inhibited&quot;.</td>
</tr>
<tr>
<td>Section</td>
<td>Description</td>
<td></td>
<td></td>
</tr>
<tr>
<td>---------</td>
<td>-------------</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.10.4</td>
<td>If the data field valid field in the driver interface command field indicates that the message data is valid, then the 256 least significant bits of the message shall be stored in the general-use portion of the transponder's internal memory. If the data field valid field in the driver interface command field indicates that the message data is not valid, the message data shall be discarded. However, the driver interface command shall be executed in all cases of a valid message reception.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.10.7</td>
<td>Public ID 32 480-511 Transponder ID 32 480-511 Changed &quot;Public ID&quot; to &quot;Transponder ID&quot; in Field Definition column of table. This change indicates either a Public or Private ID may be used in this field.</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

For clarity, changed "data field valid field" to "Data Field Indicator".