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TIRIS Technology by Texas Instruments™

Software Specification
for
LUHF Vehicle Transponder (U.S.)

RI-TRP-VUSA

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1. INTRODUCTION

1.1 SCOPE

This document describes the LUHF Vehicle Transponder Software Specification definition to implement the TIRIS Automatic Recognition of Consumers (ARC) system. The scope of this document extends from the Vehicle Transponder Hardware Specification. The interrelationships and interfaces between the Vehicle Transponder Hardware Specification and this software specification are defined in detail. The relationships of this software specification within the ARC system are contained in the higher-level specifications (see 1.2 Applicable Documents, below).

If anything in this document is ambiguous or incorrect, it should be immediately reported to the Project Managers for the Texas Instruments ARC Team, and corrected. This document is a TI internal document only.

1.2 APPLICABLE DOCUMENTS

The hierarchy of documentation pertaining to this specification is depicted below.

Document Number	Document Title
06-01-02-700	ARC System Specification (U.S)
11-09-05-700	Hardware Specification for LUHF Vehicle Transponder
11-09-05-701	Software Specification for LUHF Vehicle Transponder
24-09-05-012	TIRIS Digital Signature Transponder Algorithm and Software Requirement
TQM	TIRIS QUALITY MANUAL

1.3 DEFINITIONS, ACRONYMS, AND ABBREVIATIONS

ARC	Automatic Recognition of Consumers
CRC	Cyclic Redundancy Check
Downlink	RF Data Transmission from Dispenser to Transponder (134 kHz Carrier)
LSB	Least Significant Bit
LUHF	Low / Ultra High Frequency
MSB	Most Significant Bit
PLL	Phase-Locked Loop
RFU	Reserved for Future Use
TIRIS	Texas Instruments Registration and Identification System
Uplink	RF Data Transmission from Transponder to Dispenser (902.8 MHz Carrier)
VCO	Voltage-Controlled Oscillator

2. PROTOCOL

The protocol to be used by the transponder is as follows:

Downlink Message	Downlink Type	Downlink Format	Uplink Message	Uplink Type	Uplink Format
Identification	0	1	Identification	0	1
Authentication (first challenge)	1	2	none	-	1
Authentication (second & subsequent)	1	2	Authentication	1	1
Account Data	2	2	Account Data	2	1
Reserved for Future Use	3-7	-	none	-	-

The Downlink messages are defined in section 2.1 and the Uplink messages are defined in section 2.2

2.1 DOWNLINK

The Downlink Messages or Polls shall conform to the defined message types and its associated message format. The messages shall be transmitted most significant bit first.

2.1.1 Downlink Formats

Format 1

Data Field	Length	Description
Preamble	12 bits	Always $E1A_{16}$
Message type	3 bits	Always 000_2 : Type 0 – Identification
Customer Page	5 bits	Transponder must have corresponding Customer Flag and Customer Mask enabled to answer.
Station	3 bits	Station Number
Dispenser ID	4 bits	Dispenser ID Number
Dispenser Side	1 bit	0 : SIDE A 1 : Side B
CRC	8 bits	CRC-8 polynomial ($x^8 + x^2 + x^1 + 1$) over entire message, excluding preamble. Start value = 0xFF MSB sent first
Total	**36 bits**	

Format 2

Data Field	Length	Description
Preamble	12 bits	Always $E1A_{16}$
MESSAGE TYPE	3 bits	001_2 : Type 1 - Authentication 010_2 : Type 2 - Account Data
Customer Page	5 bits	Transponder must have corresponding Customer Flag and Customer Mask enabled to answer.
Station	3 bits	Station Number
Dispenser ID	4 bits	Dispenser ID Number
DISPENSER SIDE	1 bit	0 : Side A 1 : Side B
Variable data	40 bits	Content depends on message type
CRC	8 bits	CRC-8 polynomial ($x^8 + x^2 + x^1 + 1$) over entire message, excluding preamble. Start value = 0xFF MSB sent first
Total	**76 bits**	

2.1.2 Downlink Messages Ending

Upon completion of the last data bit of the defined downlink message, the transmitter shall transition the output and maintain this state for >1/2 bit periods. This 1/2 bit period guard time shall not be considered as part of the message and all timing is reference to this transition at the end of the last bit.

2.1.3 Downlink Messages

2.1.3.1 Identification (Type 0)

Poll message type 0 requests only the identification number from the transponder. The Customer Page is set to indicate what transponder Customer this dispenser will accept. The Station/dispenser ID uniquely identifies a dispenser at a single installation.

2.1.3.2 Authentication (Type 1)

Poll message type 1 requests the identification number and corresponding authentication data from the transponder. The Customer Page is set to indicate what transponder customer this dispenser will accept. The Station/dispenser ID uniquely identifies a dispenser at a single installation. The variable data is set to a random number that serves as the cryptographic challenge.

2.1.3.3 Account Data (Type 2)

Poll message type 2 requests the identification number and account data from the transponder. The Customer Page is set to indicate what transponder customer this dispenser will accept. The Station/dispenser ID uniquely identifies a dispenser at a single installation.

2.1.3.4 Reserved for Future Use (Types 3-7)

Poll message types 3 through 7 shall be reserved for future use. The transponder shall not respond to these message types.

2.1.4 Customer Page

Each transponder shall have one default Customer Page, Page 0, and 31 unique Customer Pages. Each of the 31 unique Customer Pages and the one default Customer Page shall have both a Customer Flag and a Customer Mask. The transponder shall respond to a downlink message only if the message's Customer Page has both the corresponding Customer Flag and the Customer Mask enabled. The Customer Flag shall reside in the unlocked memory portion of the microcontroller, which will always be readable and programmable. This will allow a Customer Flag to be enabled at either the initial activation or anytime in the future at a programming station. Once the Customer Flag has been enabled it can never be disabled. The Customer Mask shall reside in the locked memory portion of the microcontroller, which can not be read or changed after the memory lock bit has been set at a programming station.

Assignment of customer specific or customer requested pages, masks and/or flags shall be done by TIRIS - Texas Instruments.

Transponders for demonstration and pilot programs will typically use Customer Page 31. Demo Transponders will have Customer Mask 31 enabled and Customer Flag 31 enabled.

2.1.5 Encryption Key

Each transponder shall have at least one Encryption Key and may have up to 2 different Encryption Keys. The Encryption Key(s) shall reside in the locked memory portion of the microcontroller which can not be read or changed after the memory lock bit has been set at a programming station. Each of the 32 different Customer Pages will map to a corresponding Encryption Key. The default Customer Page (Page 0) shall use Encryption Key 0. The remaining Customer Pages (Pages 1 through 31) shall all use Encryption Key 1. For processing type 1 Authentication messages, the corresponding Encryption Key shall be used as one of the inputs into the DST Encryption Algorithm. Customer specific encryption keys and their format shall be determined by TIRIS - Texas Instruments.

Demonstration transponders will typically have only one Encryption Key used for Customer Page 31.

2.2 UPLINK

The Uplink Messages or Responses shall conform to the defined message types and its associated message format. The messages shall be transmitted most significant bit first.

2.2.1 Uplink formats

Format 1

Data Field	Length	Description
Preamble	12 bits	Always AAC_{16}
MESSAGE TYPE	4 bits	000_2 : Type 0 - Identification 001_2 : Type 1 - Authentication 010_2 : Type 2 - Account Data

Station	3 bits	Station Number
Dispenser ID	4 bits	Dispenser ID Number
DISPENSER SIDE	1 bit	0 : Side A 1 : Side B
Transponder ID	32 bits	Identification code programmed into transponder
Variable data	24 bits	Contents depends on message type
CRC	16 bits	CRC-CCITT polynomial ($x^{16} + x^{12} + x^5 + 1$) over entire message, excluding preamble. start value = 0x0FFF, MSB sent first
Total	**96 bits**	

2.2.2 Uplink Message Beginning

The microcontroller shall activate the output FSK no less than 500 uS prior to the start of the first data bit. The microcontroller shall output a data '1' (positive frequency deviation) during initial part of the activation period. The microcontroller shall output a series of 8 Manchester-encoded ones during the 400 uS period immediately before the first data bit. Refer to the Vehicle Transponder Hardware Specification, 11-09-05-700, for uplink FSK Oscillator Startup time. During normal operation, the uplink message shall start 1.2 mS +/- 5% after the end of the downlink message. The first uplink after wake-up is used to initialize the PLL frequency settings. During frequency initialization, the uplink message shall start 1.45 mS +/- 5% after the end of the downlink message. All timing is referenced to the beginning of the first transmitted data bit in the uplink message.

2.2.3 Uplink Messages

2.2.3.1 Identification (Type 0)

Response message type 0 is used to respond to a poll message type 0. If the transponder has both a Customer Flag and Customer Mask enabled for the corresponding Customer Page in the downlink message, this response is generated. The variable data shall contain the Service Table data.

Format of the Service Table:

(MSB) aaa bbb nnn nnn nnn nnn nnn nnn (LSB)[1]

Field 'aaa': Message type 1 capabilities (authentication)

Value	Capability	Poll Format	Variable Data	Response Format	Variable Data
111	No Authentication	None	None	No response	None
110	DST	2	DST Challenge	1	DST Response
101-000	RFU	RFU	RFU	RFU	RFU

Field 'bbb': Message type 2 capabilities (Fleet Identification)

Value	Capability	Poll Format	Variable Data	Response Format	Variable Data
111	No Data	None	None	No response	None
110	Pre-loaded Application Data	2	0	1	Application Data
101-000	RFU	RFU	RFU	RFU	RFU

Field 'nnn': Future capabilities

Value	Capability	Poll Format	Variable Data	Response Format	Variable Data
111	No Additional Capability	None	None	No response	None
110-000	RFU	RFU	RFU	RFU	RFU

Notes:

1) The default bit value in the service table is a '1', indicating no additional capability. Since a '1' is the un-programmed value in the microcontroller, this allows the service table to be updated if a capability is added. For example, a Fleet Account Identifier could be programmed into the transponder after delivery. In this case, the value for field 2 would be changed from '111' to '110' to indicate the newly added capability. In general, new capabilities will not be added to an existing transponder since it will likely require additional software.

2) Additional entries are available in the service table. This allows future extensions for message types and capabilities not yet defined for the existing transponder.

2.2.3.2 Authentication (Type 1)

Response message type 1 is used to respond to a poll message type 1. If the transponder has both a Customer Flag and Customer Mask enabled for the corresponding Customer Page in the downlink message, a response is generated or a pre-calculation is initiated. The variable data is set to the cryptographic response calculated from the challenge and the selected Encryption key.

The transponder shall compare the received challenge and Customer Page to the most recent challenge and Customer Page received. If they are identical, the transponder shall respond with the pre-calculated response data. If they are different, the transponder shall not respond and shall calculate and save the cryptographic response.

2.2.3.3 Account Data (Type 2)

Response message type 2 is used to respond to a poll message type 2. If the transponder has both a Customer Flag and Customer Mask enabled for the corresponding Customer Page in the downlink message, a response is generated. The variable data consists of the 24 bit account data field.

2.2.3.4 Reserved for Future Use (Types 3 - 15)

Response message types 3 through 15 shall be reserved for future use. These message types shall not be transmitted by the transponder.

3. FUNCTIONAL REQUIREMENTS

When the Vehicle Transponder Software is programmed into the Vehicle Transponder's microcontroller, the software provides the functionality required to:

- Wake-up on DL Data pin transition.
- Decode a 1 kbps, FM0, poll message.
- Process the received poll message and generate a response message.
- Transmit a 20 kbps, Manchester encoded response.
- Go into a low power sleep mode when transmission ceases.

3.1 SOFTWARE OVERVIEW

A top-level overview of the Vehicle Transponder Software is depicted in Figure 3-1 below. The major blocks of the software are the Wake-up, Wait, Receive, Message Processing, Response, and DST Encoder. The interrelationships of these subsystems are shown in Figure 3-1.

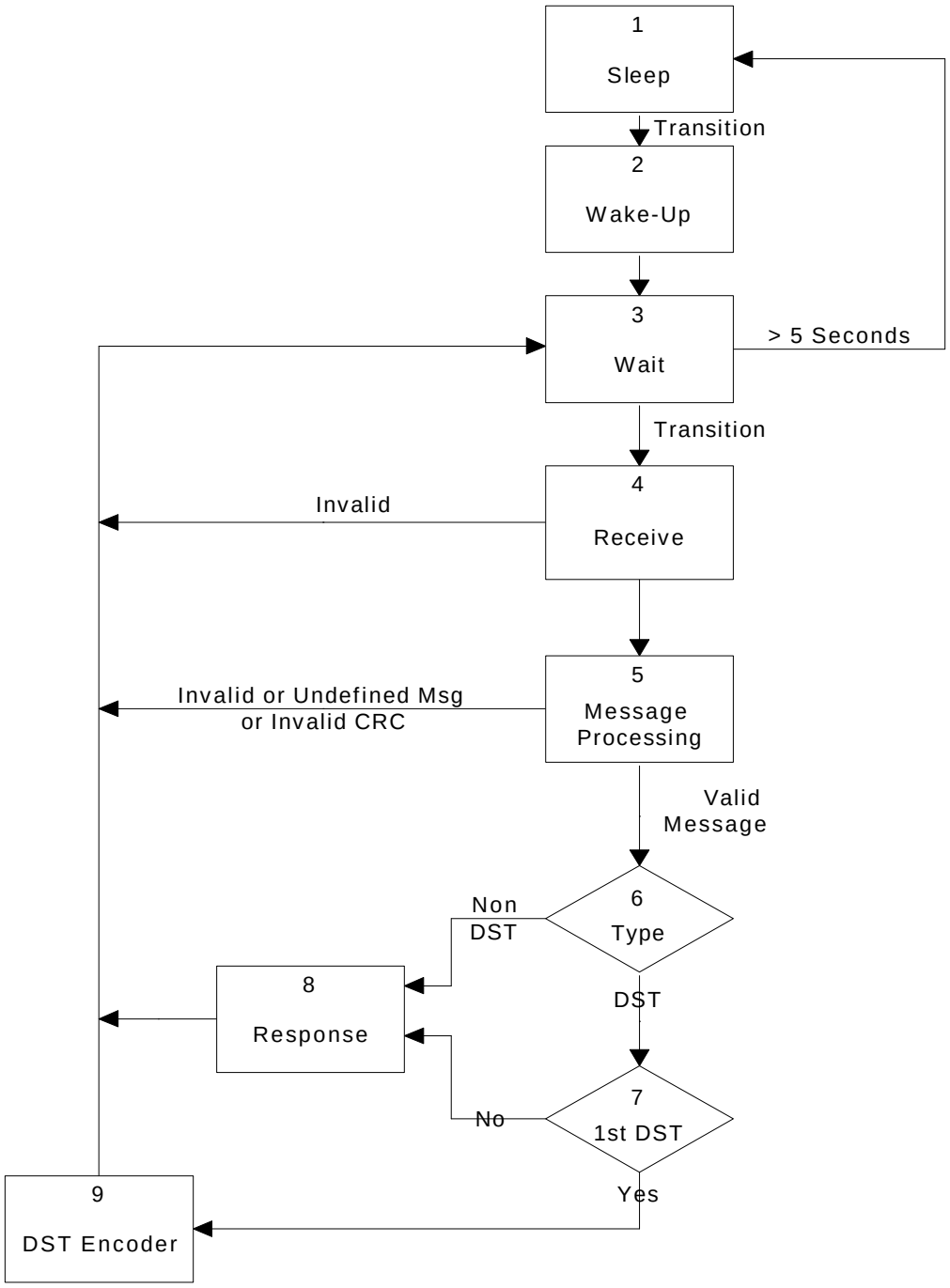

Figure 3-1. Software Flow Diagram.

3.1.1 WAKE-UP

The microcontroller shall transition from a low power sleep mode to an initialized active mode within 150 mS of any transition on the DL Data pin. Upon completion of the initialization, the transponder shall then enter a wait mode.

3.1.2 WAIT

The microcontroller shall enter the wait mode after exiting any of the following modes: Wake-up, Receive mode with invalid poll, DST calculation, or Response mode. The microcontroller shall transition to the Receive mode on a transition on the DL Data pin or exit to Sleep mode if there are no transitions within 5 s +/- 15%.

3.1.3 RECEIVE

The microcontroller shall enter the Receive Mode after an DL Data pin transition from the Wait mode. In this mode, the microcontroller shall be capable of processing the downlink data with the protocol as defined in section 2 with the characteristics defined in Doc. No. 11-09-05-700 with the following additional constraints:

- Less than 100 uS transition time from high to low level input.
- Less than 50 uS transition time from low to high level input.
- FM0 modulation asymmetrical waveform as shown below. This asymmetry is caused by the transponder detector circuitry, and is not allocated to the Downlink Transmitter.

FM0 Modulation Asymmetry

Input Data	Level	Minimum	Maximum
0	Low	0.15 mS	0.65 mS *
0	High	0.35 mS	0.85 mS *
1	Low	0.65 mS *	1.20 mS
1	High	0.85 mS *	1.35 mS

* Note: Interrelated - Data 0 low maximum <=> Data 1 low minimum
Data 0 high maximum <=> Data 1 high minimum

The microcontroller shall exit the Receive mode under one of the following conditions: Invalid Data, complete reception of a valid Poll, or the end of DL Data pin transitions for greater than 1.5 bit periods. At any time the microcontroller receives downlink data characteristics that do not conform to the defined requirements, the microcontroller shall return back to the Wait mode within 100 uS.

As the downlink message begins, the microcontroller must first identify the last four bits of the preamble (synch). Upon identifying the synch, the message length is set to minimum message length, and the 8 bit CRC is preloaded with 0xFF. As the message continues, the received data bits are decoded and stored, and the CRC value is updated with each bit. When the full Message Type has been received, the message length counter will be updated and control when the full message has been received. If DL Data pin transitions stop for greater than 1.5 bit periods prior to receiving the full message, the microcontroller shall exit to Wait mode. When the full message has been received, the microcontroller shall proceed to the Message Processing mode within 100 uS.

3.1.4 MESSAGE PROCESSING

The microcontroller shall complete processing of all received poll information within 400 uS and transition into one of the following Modes: Wait, Response, or DST Encoder. The received downlink message shall be checked for the following: CRC is zero; valid Message Type; and Customer Page has both the Customer Flag and Customer Mask enabled. If any of these are invalid or inactive, the microcontroller shall exit to Wait mode. The Customer Page, Station, Dispenser ID, Side, and Variable Data fields received shall be saved for use in both processing and uplink data message.

If an Authentication Poll is received, the Customer Page, Station, Dispenser ID, Side, and Challenge (from Variable Data) fields are compared with the stored values from the last DST Encoded fields. If the fields are different, the microcontroller shall exit to DST Encoder mode. If the fields match, the microcontroller will then create the appropriate response message array using the Uplink format defined in section 2 and exit to Response Mode.

If either an Identification or Account Data Poll is received, the microcontroller shall create the appropriate response message array using the Station, Dispenser ID, and Side, received in the downlink message. The Uplink format shall be as defined in section 2 and exit to Response Mode.

3.1.5 RESPONSE

The microprocessor shall first activate the VCO in accordance with paragraph 2.2.2 before transmitting the data on the UL Data pin. The transmit data consists of the response message array created during the Message processing mode followed by the calculated CRC. The protocol used shall be as defined in section 2. The transmitted data parameters shall be as specified in the Vehicle Transponder Hardware Specification, 11-09-05-700, with the following additional requirements.

Parameter	Requirement
Data Rate	20 kbps +/- 4%
Duty Cycle	50 +/- 0.5 %

3.1.5.1 VCO Control

The uplink frequency of the transponder is governed by a PLL and VCO combination. A programmed transponder will contain the appropriate constants to initialize the PLL to the desired uplink frequency. In order to operate the transmitter during an uplink, the VCO and PLL must be placed in an active, or powered, state. This is accomplished by setting a program-controlled output of the PLL to a logic high. When the uplink is complete, the PLL and VCO are set to an inactive, or off, state. This is accomplished by setting a program-controlled output of the PLL to a logic low. The microcontroller sets the state of the program-controlled output by sending a serial command message to the PLL.

3.1.6 DST ENCODER

The microcontroller shall use the DST algorithm as specified in TIRIS Digital Signature Transponder Algorithm and Software Requirement, #24-09-05-012, to encode the received message. The microcontroller shall create the encoded response using the challenge data in the variable data field in the received message and the appropriate Encryption Key stored in the microcontroller locked memory area. The encoded DST response along with the original Challenge, Customer Page, Station,

Dispenser ID, and Side from the received message will then be stored in the DST challenge data area. The microcontroller must complete the full DST encoding routine and return to the Wait mode within 200 mS. The DST Algorithm will use the 8 msb's of the Transponder ID as the Manufacturer's Code specified in the DST specification.

3.1.7 SLEEP

The microcontroller shall enter into a low power sleep mode within 100 uS of the start of the sleep mode processing.

4. MICROCONTROLLER HARDWARE INTERFACE

The Microchip PIC12C509 microcontroller interface pin definition from the RF detector and to the PLL and RF FSK transmitter is as follows:

Name	Description	Type	Pin Number
Vbat	Positive Supply	Power	1
Gnd	Ground	Ground	8
OSC1	Oscillator Input	I	2
OSC2	Oscillator Input	I	3
VPP / DL_DATA	Programming Power / Downlink Data	I	4
PLL_LE	PLL Latch Enable	I/O	5
PLL_CLK / UL_DATA	PLL Serial Clock / Uplink Data / Programming Clock	I/O	6
PLL_DATA	PLL Serial Data / Programming Data	I/O	7

Absolute Maximums

Signal	Minimum	Maximum
Vcc	0 V	7.0 V
DL_DATA, UL_DATA, PLL_LE, PLL_DATA, OSC1, OSC2	Gnd –0.6 V	Vcc + 0.6 V
Vpp	Gnd – 0.6 V	13.5 V

Digital Voltage Level

Digital Value	Minimum	Maximum
0	0 V	0.2 * Vcc
1	0.2 * Vcc + 1V	Vcc

Critical System Parameters

Parameter	Minimum	Maximum
Voh, Ioh=3mA	Vcc - 0.7 V	-
Vol, Iol = -3mA	-	0.6 V
Input Leakage	-1 uA	+1 uA
Input Capacitance	-	10 pF

5. QUALITY ASSURANCE PROVISIONS

The Vehicle Transponder Software shall be designed, controlled, and tested in accordance with the TQM.