AN675

KEELOQ HCS410 Transponder Decoder Using a PIC16C56

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INTRODUCTION

This document describes a secure transponder system. The system is suitable for use in security applications such as cars, motor bikes, and scooters (two-wheelers). Microchip's secure HCS410 KEELOQ® code hopping transponder is used. The decoder is implemented on a Microchip PIC16C56 microcontroller. The software can be used to implement a stand-alone decoder or can be integrated into a security system. The maximum operating range of this particular application circuit is 25 millimeters (one inch).

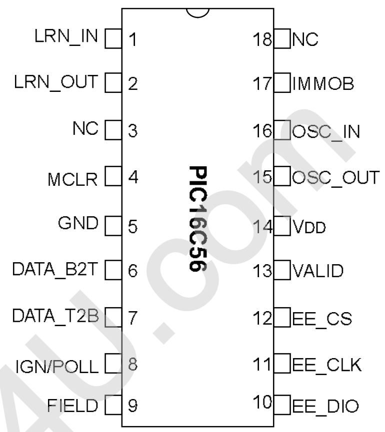
KEY FEATURES

- Stand-alone transponder decoder
- Compatible with KEELOQ HCS410 transponder
- Twelve learnable transponders
- Two function outputs
- XT oscillator

TYPICAL APPLICATIONS

- Automotive/scooter/motorcycle
- Access control
- Gate and garage door openers
- Identity tokens

PIN FUNCTIONS



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Microchip's Secure Data Products are covered by some or all of the following patents:
Code hopping encoder patents issued in Europe, U.S.A., and R.S.A. — U.S.A.: 5,517,187; Europe: 0459781; R.S.A.: ZA93/4726
Secure learning patents issued in the U.S.A. and R.S.A. — U.S.A.: 5,686,904; R.S.A.: 95/5429

HARDWARE

Overview

The hardware for this application note consists of a microcontroller circuit, a transponder, and a base station circuit. Figure 1 shows an overview of the hardware and the interface between each block. The base station is shown in Figure 2. The transponder and microcontroller are shown in Figure 3.

FIGURE 1: TRANSPONDER SYSTEM BLOCK DIAGRAM

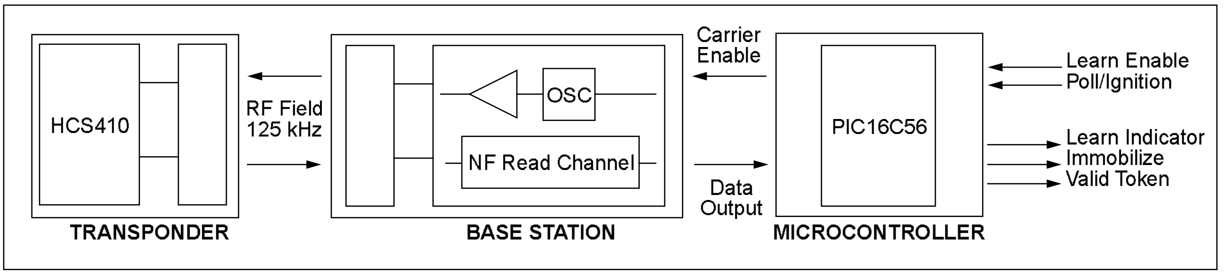


FIGURE 2: READ/WRITE BASE STATION

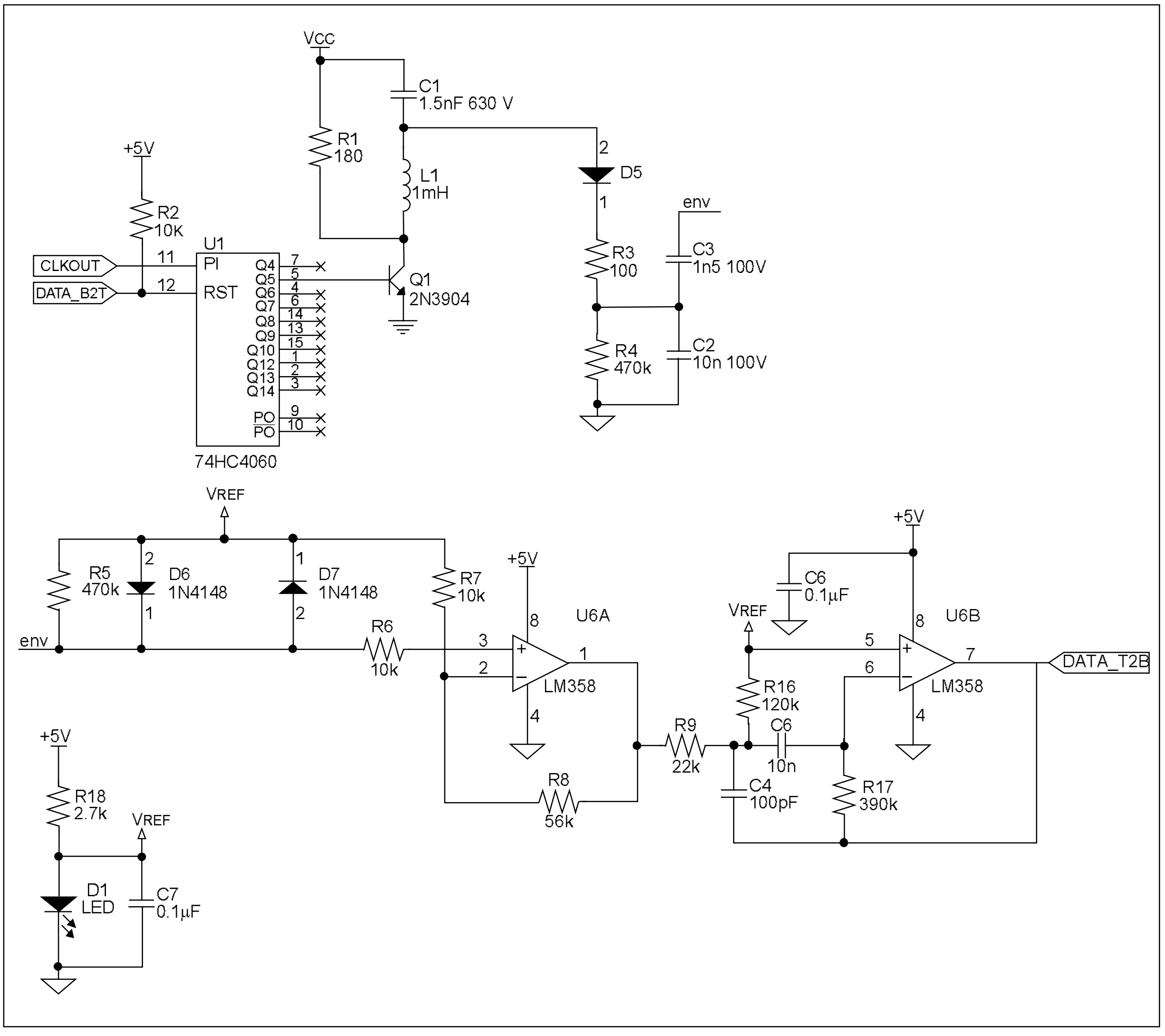
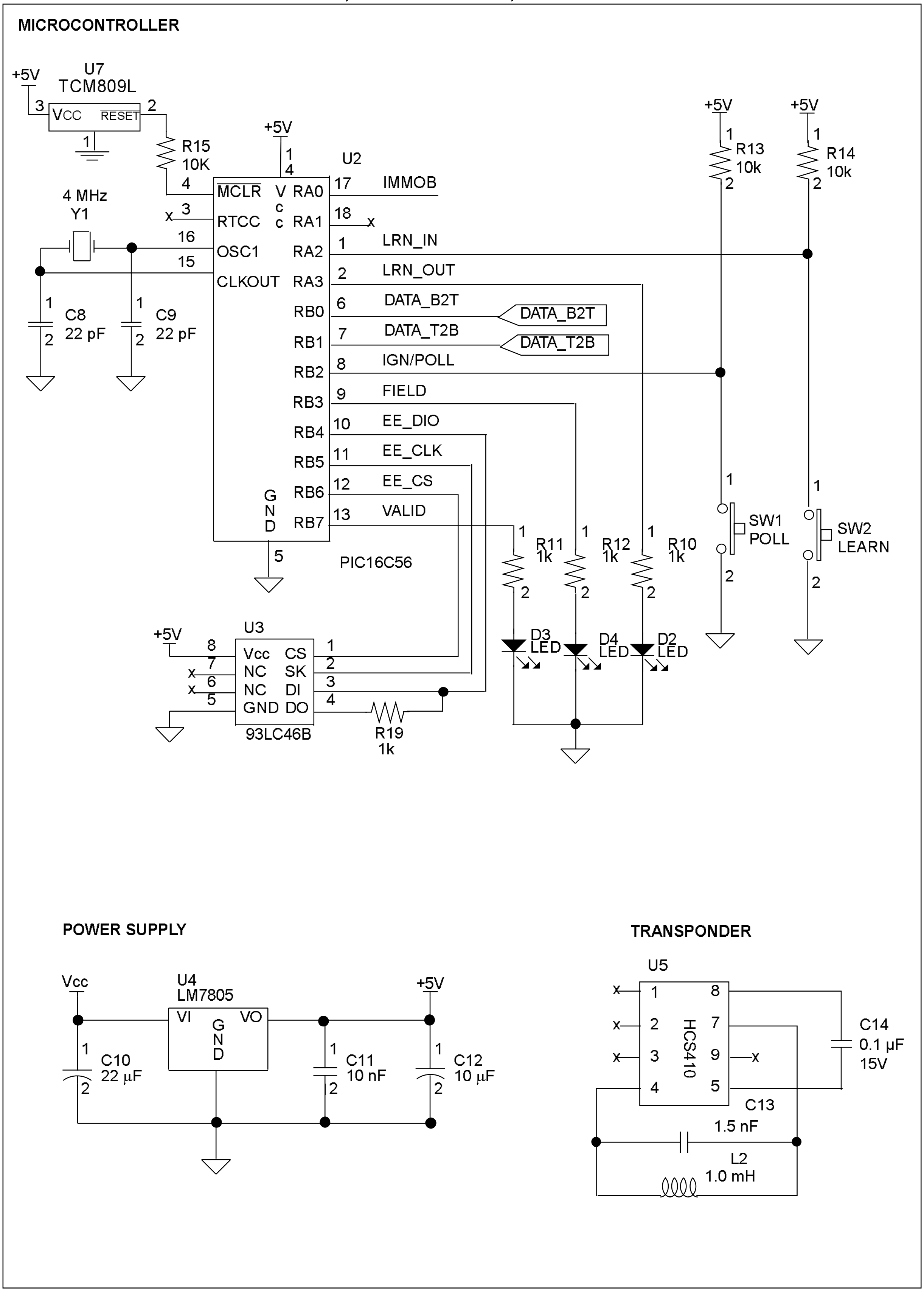


FIGURE 3: MICROCONTROLLER, POWER SUPPLY, AND TRANSPONDER



Microcontroller

The microcontroller consists of the following components:

- Microchip PIC16C56 microcontroller
- A Microchip 93LC46B serial EEPROM used to store all the information of learned transponders
- A 5V supply voltage regulator
- A supply supervisor that inhibits the microcontroller during low voltage events
- Two push buttons used for user inputs
- Three indicator LEDs used for user feedback and indication of function outputs

The microcontroller interfaces to the base station circuit by means of two wires: DATA_T2B used to read data from the transponder to the base station. The carrier enable line of the read/write base station (DATA_B2T) used by the base microcontroller to send data to the transponder.

Table 1 lists the I/O pin assignment for this application.

Read/Write Base Station

The base station is designed to operate from supply VCC between 9V and 12 V.

The 14-bit binary counter U1 divides the 4MHz microcontroller clock CLKOUT to produce a 125kHz clock to transistor Q1. This transistor drives the resonant circuit formed by R1, C1 and L1 to produce a magnetic field. The microcontroller can switch the magnetic field on and off via signal DATA_B2T for communication to the transponder.

The transponder is powered by coupling with the magnetic field produced by L1. The transponder also modulates this field for communication back to the microcontroller. The field modulation is detected at the junction of C1 and L1 by the envelope detector circuit input at diode D5. The envelope detector output signal is amplified by U6A and the data is recovered by bandpass filter U6B. The filter output DATA_T2B is fed directly to the microcontroller.

Table 8 lists the components used in the decoder circuit as shown in the schematics, in Figure 2 and Figure 3.

Table 9 lists the components used for the transponder in Figure 3.

TABLE 1: PIC16C56 I/O PIN ASSIGNMENT

Pin Number	Pin Function	Device Pin	Description
17	IMMOB	RA0	Immobilize function output
1	LRN_ IN	RA2	Input to initiate learning
2	LRN_OUT	RA3	Output to show the status of the learn process (in an integrated system this will be combined with the system status indicator).
6	DATA_B2T	RB0	Data from base station to transponder
7	DATA_T2B	RB1	Data from transponder to base station
8	IGN/POLL	RB2	Input to activate transponder polling
9	FIELD	RB3	Magnetic field is active
10 11 12	EE_DIO EE_CLK EE_CS	RB4 RB5 RB6	Interface lines to external serial EEPROM
13	VALID	RB7	Valid token pulse function output

INTRODUCTION TO THE HCS410 KEELOQ TRANSPONDER

The HCS410 is a KEELOQ code hopping transmitter/transponder designed for secure entry and identification system. The device combines the circuitry required for Remote Keyless Entry (RKE) and inductively coupled Identify Friend or Foe (IFF) This section describes software which uses the inductive coupled IFF functions of the HCS410.

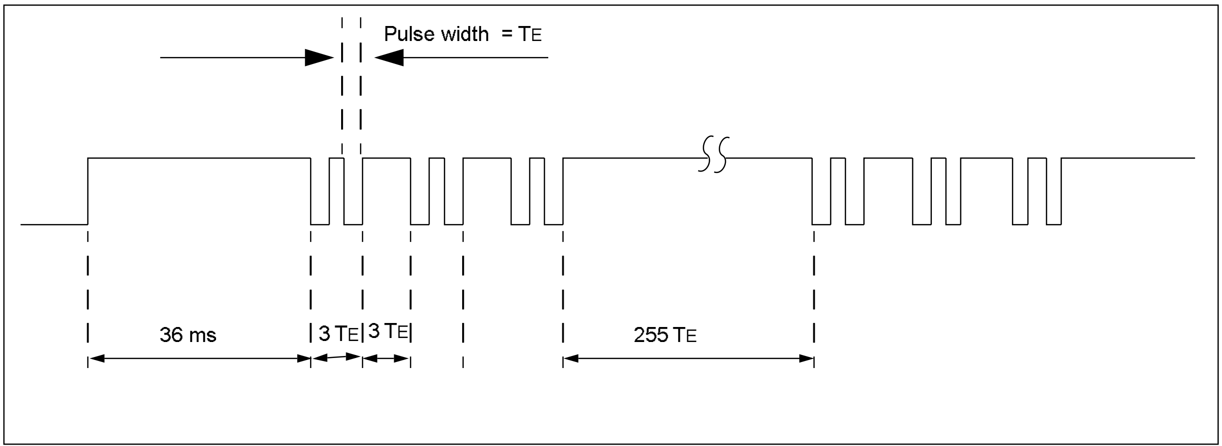
IFF Activation

IFF mode is activated when the HCS410 senses a signal on its LC0 pin. After the HCS410 verifies application of power and elapse of the normal debounce time, the device starts to acknowledge IFF activation by loading the LC pins with continuous acknowledge pulses as shown in Figure 4. This is an indication that the HCS410 is ready to receive a command. All the communication timing is done in multiples of the basic time element TE.

IFF Commands

The HCS410 transponder responds to 5-bit IFF commands or opcodes. The opcodes are sent to the HCS410 with the least significant bit (LSb) first. Depending on the command, additional data may be required for the HCS410 to respond. A list of IFF commands can be found in the HCS410 data sheet (DS40158).

FIGURE 4: IFF ACTIVATION WAVEFORM

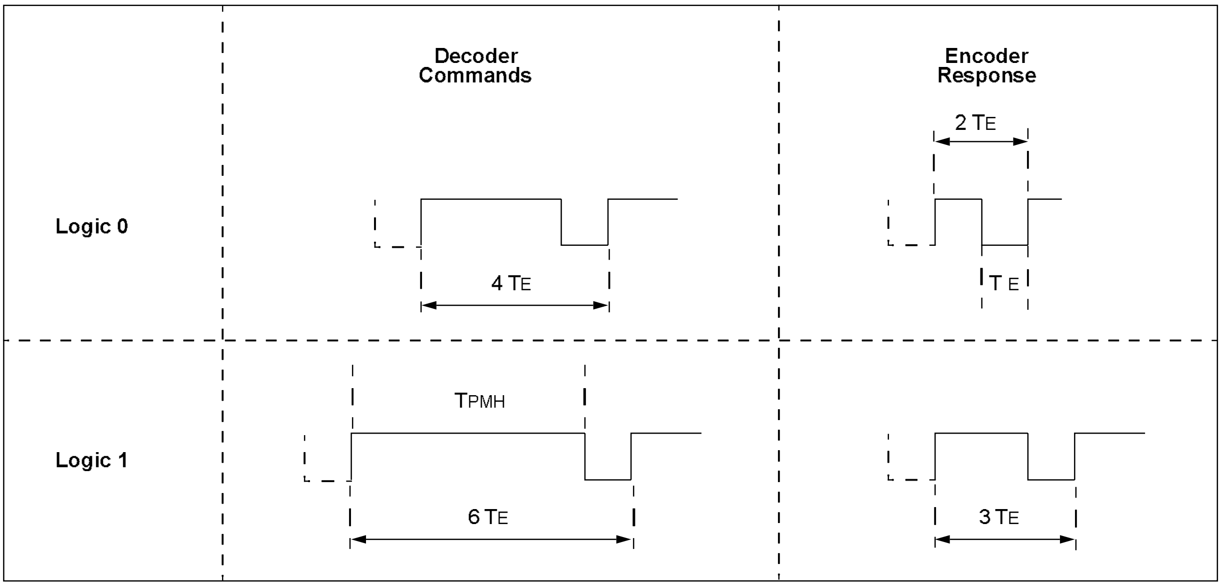


IFF Communication Protocols and Waveforms

All communication to and from the HCS410 during IFF is done in asynchronous Pulse Position Modulation (PPM) format. The format differs when sending commands and data to the HCS410 and when receiving data from the HCS410. After a complete transaction, the HCS410 is ready for the next command and will continue to send out acknowledge pulses. Commands to the HCS410 start with a pulse of 2 T_E. Time is measured from rising edge to rising edge with a logic 1 being 6 T_E and a logic 0, 4 T_E.

Data coming from the HCS410 starts with a start pulse of 1 T_E. Again, time is measured from rising edge to rising edge with a logic 1 being 3T_E and a logic 0, 2 T_E. All data words are preceded by two preamble bits with the logic value 01_2 before the data is sent out.

FIGURE 5: IFF COMMUNICATION WAVEFORM



Identify Friend or Foe (IFF)

Identify Friend or Foe (IFF) is a procedure used to authenticate a transponder. IFF challenges the transponder with a random 32-bit value and then verifies the response.

HCS410 Commands Used

This application uses the following transponder commands: The IFF READ command (Figure 6) is used to read the two portions of the 32-bit serial number (SER1 and SER0).

The IFF CHALLENGE command (IFF1 using key-1 and HOP algorithm) is used to validate the transponder. The microcontroller generates a 32-bit random challenge and then validates the transponder's 32-bit response by decrypting the response using the KEELOQ decryption algorithm.

FIGURE 6: IFF READ COMMAND

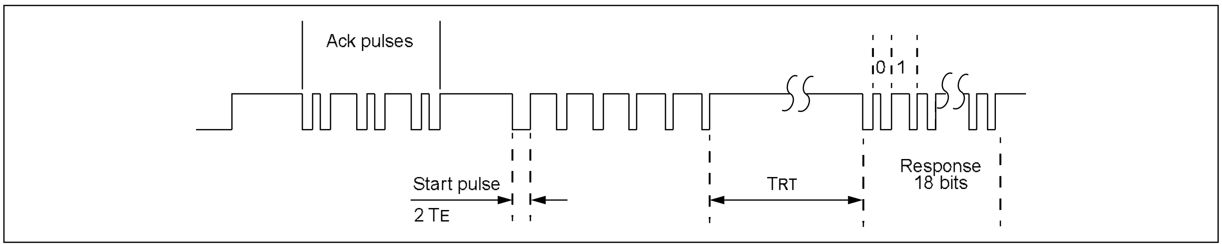
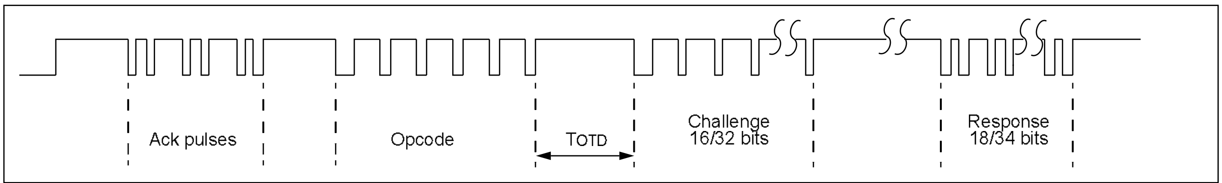


FIGURE 7: IFF CHALLENGE COMMAND



SOFTWARE DESCRIPTION

Overview (Figure 8)

After reset, the decoder enters the main loop. The main loop checks the learn button and if pressed (TST_LEARN) enters the learn mode. The decoder also checks the IGN/POLL input and if low it starts polling for transponder acknowledge pulses for up to 30 seconds. If a transponder is detected, it is validated by means of a 32-bit challenge/response IFF. The decoder pulses the VALID output pin for 500 ms and asserts the IMMOB output for the duration that the IGN/POLL input is held low if the transponder is authentic.

Transponder Validation Flow

The decoder reads the transponder's 32-bit serial number after it detects the acknowledge pulses. It then calculates the 16-bit serial number checksum value. The decoder then searches through all the EEPROM memory blocks for a matching checksum value. Then, it challenges the transponder with a 32-bit random challenge. The decoder validates the transponder by decrypting the 32-bit response with the 64-bit transponder key and comparing it to the 32-bit challenge.

Transponder Learn Flow

The 64-bit Manufacturer's Code is read from the ROM table after the decoder enters learn mode. The decoder then starts polling the field to check if there is any transponder in the field for up to 30 seconds. The decoder reads the transponder's 32-bit serial number after it detects acknowledge pulses. The transponder's decryption key is then calculated using the 64 bit Manufacturer's Code and the 32-bit serial number. The decoder then challenges the transponder with a 32-bit random challenge and validates the 32-bit response by using the newly calculated 64-bit transponder key. The decoder calculates the 16-bit serial number checksum then stores both the 16-bit checksum value and the 64-bit transponder key in EEPROM.

Calibration on Acknowledge Pulses (WAIT_ACK)

The WAIT_ACK function determines if there is a transponder in the field. The routine also calibrates on the acknowledge pulses of the transponder, thereby determining the basic elemental periods TE, which is used for communication to the HCS410 transponder. The routine switches on the inductive field and waits for 30 ms for the transponder to activate. It then waits for up to 100 ms for a falling edge on the data output line of the read/write base station. The decoder calibrates on the time between the two rising edges. This time, which is equal to 2 TE, is the used by the WAIT_TE routine during communication to the HCS410. The decoder waits for three acknowledge pulse pairs before it indicates that there is a transponder in the field by setting the zero flag and returning E_OK.

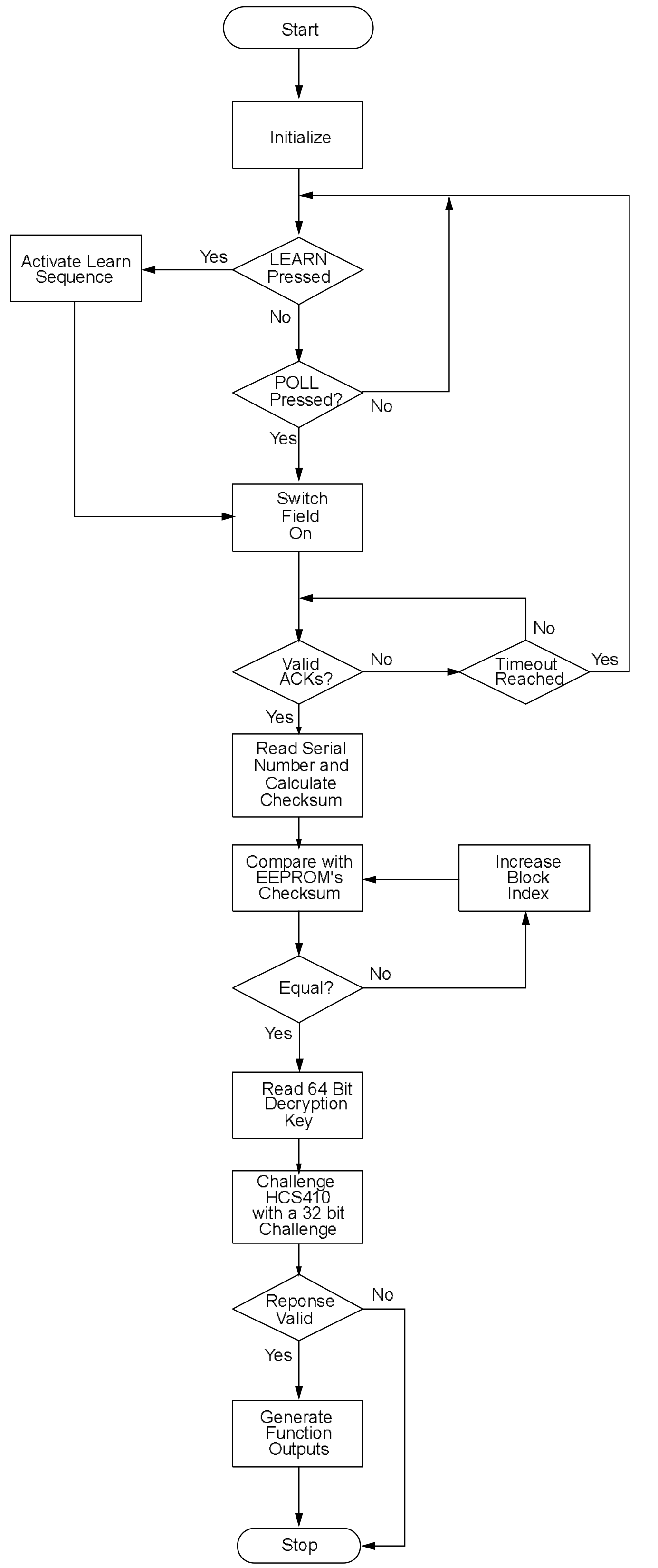
Capturing Data from the HCS410 (REC_PPM)

The REC_PPM function is used to receive PPM data from the transponder. The decoder waits for the start bit, after which it starts measuring the time from rising edge to rising edge. The decoder then checks if this values if less than 2 TE in which case, the result bit value is set to logic 0. Otherwise, the bit value is set to a logic 1. The function receives either 18- or 34-bits, depending on the initial value of the loop counter (CNT2) The incoming data is stored in a 32-bit temporary shift register (TMP3:TMP0). The two preamble bits are rotated though the shift register and their values are ignored.

Source Code

A floppy disk containing the source code for this application note is available under no fee license from your Microchip distributor. The disk order number is DS40149.

FIGURE 8: PROGRAM FLOW DIAGRAM



ADDING/LEARNING TRANSPONDERS

Overview

Adding/learning a transponder involves calculating the transponder's decryption key, then challenging the transponder and verifying the response using the newly derived key. If the learn was successful, the key and a serial number checksum will be stored in EEPROM. The decoder reads the transponder's 32-bit serial number, forces the upper 4 bits to 6h or 2h to calculate the two input seed algorithms. Then, using these two input seeds and the decryption algorithm, the 64-bit transponder key is calculated. The Manufacturer's Code is stored in a ROM table in program memory.

Generating the 64-bit Key

SEED1 = 6h + 28 bit Serial Number

SEED2 = 2h + 28 bit Serial Number

The transponder key is derived using the KEELOQ decryption algorithm and the 64-bit Manufacturer's Code as follows:

$$Key_{\text{Upper 32 bits}} = F_{\text{KEELOQ Decrypt}}(\text{SEED1})\,|_{\text{64-Bit Manufacturers Code}}$$

$$Key_{\text{Lower 32 bits}} = F_{\text{KEELOQ Decrypt}}(\text{SEED2})\,|_{\text{64-Bit Manufacturers Code}}$$

Calculating the 16-bit Checksum From 28-bit Serial Number

The serial number checksum value stored in EEPROM is calculated by as follows:

$$\text{Checksum} = [(\text{SER\_3} \oplus \text{SER\_1}) \ll 8] + (\text{SER\_2} \oplus \text{SER\_0})$$

> **Note:** If the calculated checksum is zero the value is changed to 5AA5h.

APPENDIX A: MEMORY ALLOCATIONS

TABLE 2: MEMORY FOR EACH TRANSPONDER

	Name	Description	Bytes
1	Checksum	16-bit checksum value of the serial number	2
2	Key	64-Bit decryption key	8
		Total	**10**

TABLE 3: COMBINED EEPROM MEMORY ALLOCATION

	Name	Description	Bytes
1	Block 1	Scratch pad	6
2	Block 2	16-bit seed counter used by random generator	2
3	Block 3	Stored data for transponder #1	10
4	Block 4	Stored data for transponder #2	10
5	Block 5	Stored data for transponder #3	10
6	Block 6	Stored data for transponder #4	10
7	Block 7	Stored data for transponder #5	10
8	Block 8	Stored data for transponder #6	10
9	Block 9	Stored data for transponder #7	10
10	Block 10	Stored data for transponder #8	10
11	Block 11	Stored data for transponder #9	10
12	Block 12	Stored data for transponder #10	10
13	Block 13	Stored data for transponder #11	10
14	Block 14	Stored data for transponder #12	10
		Total	**128**

TABLE 4: MEMORY MAP EEPROM (16-BIT WORDS)

Address	Mnemonic	Address	Mnemonic
00	CHAL_LW	20	KEY6_2
01	RESP_LW	21	KEY6_3
02	RESP_HI	22	CHKSUM_7
03	CHAL_SEED	23	KEY7_0
04	CHKSUM_1	24	KEY7_1
05	KEY1_0	25	KEY7_2
06	KEY1_1	26	KEY7_3
07	KEY1_2	27	CHKSUM_8
08	KEY1_3	28	KEY8_0
09	CHKSUM_2	29	KEY8_1
0A	KEY2_0	2A	KEY8_2
0B	KEY2_1	2B	KEY8_3
0C	KEY2_2	2C	CHKSUM_9
0D	KEY2_3	2D	KEY9_0
0E	CHKSUM_3	2E	KEY9_1
0F	KEY3_0	2F	KEY9_2
10	KEY3_1	30	KEY9_3
11	KEY3_2	33	CHKSUM_10
12	KEY3_3	32	KEY10_0
13	CHKSUM_4	33	KEY10_1
14	KEY4_0	34	KEY10_2
15	KEY4_1	35	KEY10_3
16	KEY4_2	36	CHKSUM_11
17	KEY4_3	37	KEY11_0
18	CHKSUM_5	38	KEY11_1
19	KEY5_0	39	KEY11_2
1A	KEY5_1	3A	KEY11_3
1B	KEY5_2	3B	CHKSUM_12
1C	KEY5_3	3C	KEY12_0
1D	CHKSUM_6	3D	KEY12_1
1E	KEY6_0	3E	KEY12_2
1F	KEY6_1	3F	KEY12_3

CHAL_LW	Temporary storage of lower 16 bits of challenge
RESP_HI	Temporary storage of upper 16 bits of HCS410's response
RESP_LW	Temporary storage of lower 16 bits of HCS410's response
CHAL_SEED	16 bit seed counter used by random generator to calculate a 32 bit random seed
CHKSUM	Transponder's serial number 16 bit checksum storage
KEY	These bytes contain the 64 bit decryption key for each transponder

TABLE 5: RAM MEMORY MAP (8-BIT BYTES)

Address	Mnemonic	Description
0D	FLAGS	Decoder flags
0E	ADDRESS	Address register – points to address in EEPROM
0F	TXNUM	Current transponder's block index
10	XP_CNT	Transponder loop counter
08	OUTBYT	General data register, mask register used in decryption
09	TMP0	Temporary registers
0A	TMP1	
0B	TMP2	
0C	TMP3	
11	CNT0	General loop counters
12	CNT1	
13	CNT2	
07	CNT3	
14	CSR0	32-bit Code shift register used in decryption and key generation
15	CSR1	
16	CSR2	
17	CSR3	
18	KEY7	64-bit shift register holds decryption key
19	KEY6	
1A	KEY5	
1B	KEY4	
1C	KEY3	
1D	KEY2	
1E	KEY1	
1F	KEY0	

Many of the memory locations in RAM are used by multiple routines. A list of alternate names and functions are given in the table below.

Address	Mnemonic	Also known as	Description
18	DTA1	TMP0	32-bit hop code register
19	DTA2	TMP1	
1A	DTA3	TMP2	
1B	DTA4	TMP3	
OD	EHOP3	ADDRESS	Extended 32-bit buffer used during key generation as a 32-bit buffer
1C	EHOP2	TXNUM	
1D	EHOP1	TE_CNT	
1E	EHOP0	CNT2	
17	SER_0	CSR0	Shift register for unencrypted 32 bits received from transponder
16	SER_1	CSR1	
15	SER_2	CSR2	
14	SER_3	CSR3	

TABLE 6: MANUFACTURER'S CODE IN PROGRAM MEMORY (RETLW TABLE)

Address	Mnemonic	Description
09B	MKEY_0	64-Bit Manufacturer's Code (Used to generate decryption keys)
09C	MKEY_1	
09D	MKEY_2	
09E	MKEY_3	
09F	MKEY_4	
0A0	MKEY_5	
0A1	MKEY_6	
0A2	MKEY_7	

TABLE 7: TIMING PARAMETERS

Parameter	Typical	Unit
Output activation duration	500	ms
Transponder validation duration	330	ms
Erase all duration	4.2	s
Learn mode time-out	25	s

TABLE 8: BILL OF MATERIALS FOR BASE STATION

Item	Reference	Supplier	Part Number	Description
1	C1	Digi-Key	P3499	1.5nF, 630V Polypropylene Capacitor
2	C2	Digi-Key	P4797	10nF, B Series 100V Polyester Capacitor
3	C3	Digi-Key	P4787	1.5nF, B Series 100V Polyester Capacitor
4	C4	Digi-Key	P4773	100pF, B Series 100V Polyester Capacitor
5	C5	Digi-Key	P4797	10nF, B Series 100V Polyester Capacitor
6	C6, C7, C11, C14	Digi-Key	1210PHCT	0.1μF, 50V Axial Ceramic Capacitor
7	C8, C9	Digi-Key	P4016A	22pF, 50V Ceramic Disc Capacitor
8	C10	Digi-Key	P918	22μF 25V, KG Series Miniature Aluminum Electrolytic Capacitor
9	C12	Digi-Key	P6629	10μF 25V, Z Series Miniature Aluminum Electrolytic Capacitor
10	D1, D2, D3, D4	Digi-Key	P403	3mm Red Diffused High Brightness LED
11	D5, D6, D7	Digi-Key	IN4148DICT	100V, 500 MW Fast Switching Diode
12	L1	Coilcraft	DO5022P-105	1mH, DO5022 Series Surface Mount Power Inductors
13	Q1	Digi-Key	2N3904	Small Signal General Purpose Transistor
14	R1	Digi-Key	180R W-1	180R, 5% Metal Oxide Film Resistor
15	R2, R6, R7, R13, R14, R15	Digi-Key	10K W-1	10k, 5% Metal Oxide Film Resistor
16	R3	Digi-Key	100R W-1	100R, 5% Metal Oxide Film Resistor
17	R4, R5	Digi-Key	470K W-1	470k, 5% Metal Oxide Film Resistor
18	R8	Digi-Key	56K W-1	56k, 5% Metal Oxide Film Resistor
19	R9	Digi-Key	22K W-1	22k, 5% Metal Oxide Film Resistor
20	R10, R11, R12, R19	Digi-Key	1K W-1	1k, 5% Metal Oxide Film Resistor
21	R16	Digi-Key	120K W-1	120k, 5% Metal Oxide Film Resistor
22	R17	Digi-Key	390K W-1	390k, 5% Metal Oxide Film Resistor
23	R18	Digi-Key	2.7K W-1	2.7k, 5% Metal Oxide Film Resistor
24	SW1, SW2	Digi-Key	P8006S	Momentary Push-button Switch
25	U1	Digi-Key	MM74HC4060N	14 Stage Binary counter
26	U2	Digi-Key	PIC16C56-XP/P	8-Bit CMOS Microcontroller
27	U3	Digi-Key	93LC46B-I/P	2K CMOS Serial EEPROM
28	U4	Digi-Key	LM78L05ACH	+5V 100 mA Positive Regulator, TO-39
29	U6	Digi-Key	LM358N	Low Power Dual OP Amp
30	U7	Digi-Key	158-2021-2	IC 4.63V UP Reset Monitor SOT-23
31	Y1	Digi-Key	X911	4 MHz ZTA Series Ceramic Resonator

Note: Different value of the same order may have to be used to compensate for tolerance variations in R1, L1, and C1 to keep the peak-to-peak voltage across L1 at 100V.

TABLE 9: BILL OF MATERIALS FOR TRANSPONDER

Item	Reference	Supplier	Part Number	Description
1	U5	Microchip	HCS410	KEELOQ Transponder IC
2	L2	Digi-Key	DN7437	1000 μH Power Axial Inductor
3	C13	Digi-Key	P4787	0.0015 μF 100V Poly B Series CAP
4	C14	Digi-Key	1210PHCT	0.1μF, 50V Axial Ceramic Capacitor

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Microchip received QS-9000 quality system certification for its worldwide headquarters, design and wafer fabrication facilities in Chandler and Tempe, Arizona in July 1999. The Company's quality system processes and procedures are QS-9000 compliant for its PICmicro® 8-bit MCUs, KEELOQ® code hopping devices, Serial EEPROMs and microperipheral products. In addition, Microchip's quality system for the design and manufacture of development systems is ISO 9001 certified.