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AN1266

KEELOQ™ with XTEA Microcontroller-Based Code Hopping Encoder

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INTRODUCTION

This application note describes the design of a microcontroller-based KEELOQ™ Hopping Encoder using the XTEA encryption algorithm. This encoder is implemented on the Microchip PIC16F636 microcontroller. A description of the encoding process, the encoding hardware and description of the software modules are included within this application note. The software was designed to emulate an HCS365 dual encoder. As it is, this design can be used to implement a secure system transmitter that will have the flexibility to be designed into various types of KEELOQ receiver/ decoders.

BACKGROUND

XTEA stands for Tiny Encryption Algorithm Version 2. This encryption algorithm is an improvement over the original TEA algorithm. It was developed by David Wheeler and Roger Needham of the Cambridge Computer Laboratory. XTEA is practical both for its security and the small size of its algorithm.

XTEA security is achieved by the number of iterations it goes through. The implementation in this KEELOQ Hoppping Decoder uses 32 iterations. If a higher level of security is needed, 64 iterations can be used.

For a more detailed description of the XTEA encryption algorithm please refer to AN953, "*Data Encryption Routines for the PIC18*".

TRANSMITTER OVERVIEW

As this is an emulation of the HCS365, the transmitter has the following key features:

Security:

- Two programmable 32-bit serial numbers
- Two programmable 128-bit encryption keys
- Two programmable 64-bit seed values
- Each transmitter is unique
- 104-bit transmission code length
- 64-bit hopping code

Operation:

- 2.0-5.5V operation
- Four button inputs
- 15 functions available
- Four selectable baud rates
- Selectable minimum code word completion
- Battery low signal transmitted to receiver
- Nonvolatile synchronization data
- PWM, VPWM, PPM, and Manchester modulation
- Button queue information transmitted
- Dual Encoder functionality

DUAL ENCODER OPERATION

This firmware contains two transmitter configurations with separate serial numbers, encoder keys, discrimination values, counters and seed values. This means that the transmitter can be used as two independent systems. The SHIFT(S3) input pin is used to select between encoder configurations. A low on this pin will select Encoder 1, and a high will select Encoder 2.

FUNCTIONAL INPUTS AND OUTPUTS

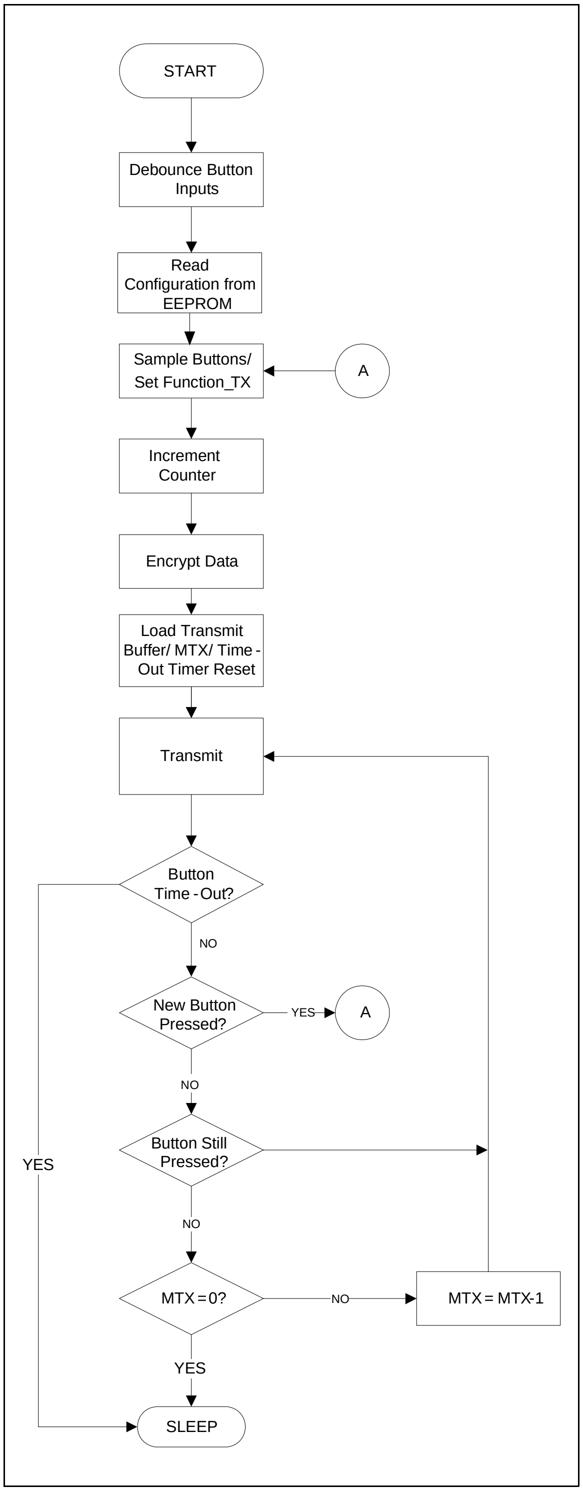
The software implementation makes use of the following pin designations:

TABLE 1: FUNCTIONAL INPUTS AND OUTPUTS

Label	Pin Number	Input/ Output	Function
S0	2 (RA5)	Input	Switch Input S0
S1	3 (RA4)	Input	Switch input S1
S2	4 (RA3)	Input	Switch Input S2
S3	5 (RA2)	Input	Switch Input S3
RF_OUT	6 (RA1)	Output	Encoded transmitter signal output
LED	7 (RA0)	Output	LED On/Off

OPERATION FLOW DIAGRAM

FIGURE 1: OPERATION FLOW DIAGRAM



SAMPLE BUTTONS/WAKE-UP

Upon power-up, the transmitter verifies the state of the buttons inputs and determines if a button is pressed. If no button pressed is detected, the transmitter will go to Sleep mode. The transmitter will wake-up whenever a button is pressed. Wake-up is achieved by configuring the input port to generate an interrupt-on-change. After the wake event, the input buttons are debounced for 20 ms to make a determination on which buttons have been pressed. The button input values are then placed in the transmission buffer, in the appropriate section.

LOAD SYSTEM CONFIGURATION

After waking up and debouncing the input switches, the firmware will read the system Configuration bytes. These Configuration bytes will determine what data and modulation format will be for the transmission.

All the system Configuration bytes are stored in the EEPROM. Below is the EEPROM mapping for the PIC16F636 transmitter showing the configuration and data bits stored.

TABLE 2: EEPROM MAPPING FOR THE PIC16F636 TRANSMITTER

Offset	Bits								
Bytes	**7**	**6**	**5**	**4**	**3**	**2**	**1**	**0**	**MNEMONIC**
0x00	Sync Counter, Byte 0, Transmitter 0, Copy A								EE_CNT0A
0x01	Sync Counter, Byte 1, Transmitter 0, Copy A								
0x02	Sync Counter, Byte 2, Transmitter 0, Copy A								
0x03	Sync Counter, Byte 3, Transmitter 0, Copy A								
0x04	Sync Counter, Byte 0, Transmitter 0, Copy B								EE_CNT0B
0x05	Sync Counter, Byte 1, Transmitter 0, Copy B								
0x06	Sync Counter, Byte 2, Transmitter 0, Copy B								
0x07	Sync Counter, Byte 3, Transmitter 0, Copy B								
0x08	Sync Counter, Byte 0, Transmitter 0, Copy C								EE_CNT0C
0x09	Sync Counter, Byte 1, Transmitter 0, Copy C								
0x0A	Sync Counter, Byte 2, Transmitter 0, Copy C								
0x0B	Sync Counter, Byte 3, Transmitter 0, Copy C								
0x0C	—	—	—	—	—	—	—	—	
0x0D	Sync Counter, Byte 0, Transmitter 1, Copy A								EE_CNT1A
0x0E	Sync Counter, Byte 1, Transmitter 1, Copy A								
0x0F	Sync Counter, Byte 2, Transmitter 1, Copy A								
0x10	Sync Counter, Byte 3, Transmitter 1, Copy A								
0x11	Sync Counter, Byte 0, Transmitter 1, Copy B								EE_CNT1B
0x12	Sync Counter, Byte 1, Transmitter 1, Copy B								
0x13	Sync Counter, Byte 2, Transmitter 1, Copy B								
0x14	Sync Counter, Byte 3, Transmitter 1, Copy B								
0x15	Sync Counter, Byte 0, Transmitter 1, Copy C								EE_CNT1C
0x16	Sync Counter, Byte 1, Transmitter 1, Copy C								
0x17	Sync Counter, Byte 2, Transmitter 1, Copy C								
0x18	Sync Counter, Byte 3, Transmitter 1, Copy C								
0x19	—	—	—	—	—	—	—	—	
0x1A	Serial Number, Byte 0, Transmitter 0								EE_SER
0x1B	Serial Number, Byte 1, Transmitter 0								
0x1C	Serial Number, Byte 2, Transmitter 0								
0x1D	Serial Number, Byte 3, Transmitter 0								
0x1E	Seed Value, Byte 0, Transmitter 0								EE_SEED
0x1F	Seed Value, Byte 1, Transmitter 0								
0x20	Seed Value, Byte 2, Transmitter 0								
0x21	Seed Value, Byte 3, Transmitter 0								
0x22	Seed Value, Byte 4, Transmitter 0								
0x23	Seed Value, Byte 5, Transmitter 0								
0x24	Seed Value, Byte 6, Transmitter 0								
0x25	Seed Value, Byte 7, Transmitter 0								
0x26	STRTSEL_0	QUEN_0	XSER_0	HEADER_0	TMOD_0:1	TMOD_0:0			TX0_CFG0
0x27	User Value, Byte 0, Transmitter 0								EE_DISC
0x28	User Value, Byte 1, Transmitter 0								
0x29	User Value, Byte 2, Transmitter 0								
0x2A	User Value, Byte 3, Transmitter 0								
0x2B	Encryption Key, Byte 0, Transmitter 0								EE_KEY
0x2C	Encryption Key, Byte 1, Transmitter 0								
0x2D	Encryption Key, Byte 2, Transmitter 0								

TABLE 2: EEPROM MAPPING FOR THE PIC16F636 TRANSMITTER (CONTINUED)

0x2E	Encryption Key, Byte 3, Transmitter 0								
0x2F	Encryption Key, Byte 4, Transmitter 0								
0x30	Encryption Key, Byte 5, Transmitter 0								
0x31	Encryption Key, Byte 6, Transmitter 0								
0x32	Encryption Key, Byte 7, Transmitter 0								
0x33	Encryption Key, Byte 8, Transmitter 0								
0x34	Encryption Key, Byte 9, Transmitter 0								
0x35	Encryption Key, Byte 10, Transmitter 0								
0x36	Encryption Key, Byte 11, Transmitter 0								
0x37	Encryption Key, Byte 12, Transmitter 0								
0x38	Encryption Key, Byte 13, Transmitter 0								
0x39	Encryption Key, Byte 14, Transmitter 0								
0x3A	Encryption Key, Byte 15, Transmitter 0								
0x3B	Serial Number, Byte 0, Transmitter 1								B_EE_SER
0x3C	Serial Number, Byte 1, Transmitter 1								
0x3D	Serial Number, Byte 2, Transmitter 1								
0x3E	Serial Number, Byte 3, Transmitter 1								
0x3F	Seed Value, Byte 0, Transmitter 1								B_EE_SEED
0x40	Seed Value, Byte 1, Transmitter 1								
0x41	Seed Value, Byte 2, Transmitter 1								
0x42	Seed Value, Byte 3, Transmitter 1								
0x43	Seed Value, Byte 4, Transmitter 1								
0x44	Seed Value, Byte 5, Transmitter 1								
0x45	Seed Value, Byte 6, Transmitter 1								
0x46	Seed Value, Byte 7, Transmitter 1								
0x47	STRTSEL_1	QUEN_1	XSER_1	HEADER_1	TMOD_1:1	TMOD_1:0			TX1_CFG1
0x48	User Value, Byte 0, Transmitter 1								B_EE_DISC
0x49	User Value, Byte 1, Transmitter 1								
0x4A	User Value, Byte 2, Transmitter 1								
0x4B	User Value, Byte 3, Transmitter 1								
0x4C	Encryption Key, Byte 0, Transmitter 1								B_EE_KEY
0x4D	Encryption Key, Byte 1, Transmitter 1								
0x4E	Encryption Key, Byte 2, Transmitter 1								
0x4F	Encryption Key, Byte 3, Transmitter 1								
0x50	Encryption Key, Byte 4, Transmitter 1								
0x51	Encryption Key, Byte 5, Transmitter 1								
0x52	Encryption Key, Byte 6, Transmitter 1								
0x53	Encryption Key, Byte 7, Transmitter 1								
0x54	Encryption Key, Byte 8, Transmitter 1								
0x55	Encryption Key, Byte 9, Transmitter 1								
0x56	Encryption Key, Byte 10, Transmitter 1								
0x57	Encryption Key, Byte 11, Transmitter 1								
0x58	Encryption Key, Byte 12, Transmitter 1								
0x59	Encryption Key, Byte 13, Transmitter 1								
0x5A	Encryption Key, Byte 14, Transmitter 1								
0x5B	Encryption Key, Byte 15, Transmitter 1								
0x5C	GSEL_0		BSEL_0		SDTM_0		SDMD_0	SDLM_0	TX0_CFG1
0x5D	LEDOS_1	LEDBL_1	TSEL		RFENO	INDESEL	MTX		SYSCFG1
0x5E	GSEL_1		BSEL_1		SDTM_1		SDMD_1	SDLM_1	TX1_CFG1
0x5F	LEDOS_0	LEDBL_0	PLLSEL	VLOWSEL	VLOWL	CNTSEL	WAKE		SYSCFG0

CONFIGURATION WORDS DESCRIPTION

TABLE 3: TX0_CFG0 (FOR TRANSMITTER 0, FOR TRANSMITTER 1 USE TX1_CFG0)

BIT	Field	Description	Values
0	Not used	—	—
1	Not used		
2	TMOD:0	Transmission Modulation Format	00 = PWM 01= Manchester 10 = VPWM 11 = PPM
3	TMOD:1		
4	HEADER	Time Length of Transmission Header	0 = 4*Te 1 = 10*Te
6	QUEN	Queue Counter Enable	0 = Disable 1 = Enable
7	STRTSEL	Start/Stop Pulse Enable	0 = Disable 1 = Enable

TABLE 4: TX0_CFG1 (FOR TRANSMITTER 0, FOR TRANSMITTER 1 USE TX1_CFG1)

BIT	Field	Description	Values
0	SDLM	Limited Seed Enable	0 = Disable 1 = Enable
1	SDMD	Seed Mode	0 = User 1 = Production
2	SDTM <3:2>	Time Before Seed Code Word	00 = 0.0 sec 01= 0.8 sec 10 = 1.6 sec 11 = 3.2 sec
3			
4	BSEL <5:4>	Transmission Baud Rate Select	00 = 100 µs 01 = 200 µs 10 = 400 µs 11 = 800 µs
5			
6	GSEL <7:6>	Guard Time Select	00 = 0.0 ms 01 = 6.4 ms 10 = 51.2 ms 11 = 102.4 ms
7			

TABLE 5: SYSCFG0

BIT	Field	Description	Values
0 1	WAKE <1:0>	Wake-up	00 = No wake-up 01 = 75ms 50% 10 = 50ms 33% 11 = 100ms 16.6%
3	VLOWL	Low-Voltage Latch Enable	0 = Disable 1 = Enable
4	VLOWSEL	Transmission Baud Rate Select	0 = 2.2V 1 = 3.2V
5	PLLSEL	PLL interface Select	0 = ASK 1 = FSK
6	LEDBL_0	Low-Voltage LED Blink	0 = Continuous 1 = Once
7	LEDOS_0	LED On Time Select	0 = 50 ms 1 = 100 ms

TABLE 6: SYSCFG1

BIT	Field	Description	Values
0 1	MTX <1:0>	Maximum Code Words	00 = 1 01 = 2 10 = 4 11 = 8
2	INDESEL	Dual Encoder Enable	0 = Disable 1 = Enable
3	RFEN0	RF Enable Output Select	0 = Disable 1 = Enable
4 5	TSEL	Time-out Select	00 = Disabled 01 = 0.8 sec 10 = 3.2 sec 11 = 25.6 sec
6	LEDBL_1	Low-Voltage LED Blink	0 = Continuous 1 = Once
7	LEDOS_1	LED On Time Select	0 = 50 ms 1 = 100 ms

EE_SER AND B_EE_SER

These locations store the 4 bytes of the 32-bit serial number for transmitter 1 and transmitter 2. There are 32 bits allocated for the serial number and the serial number is meant to be unique for every transmitter.

EE_SEED AND B_EE_SEED

This is the 64-bit seed code that will be transmitted when seed transmission is selected. EE_SEED for transmitter 0 and B_EE_SEED for transmitter 1. This allows for the implementation of the secure learning scheme.

EE_KEY AND B_EE_KEY 128-BIT ENCRYPTION KEY)

The 128-bit encryption key is used by the transmitter to create the encrypted message transmitted to the receiver. This key is created using a key generation algorithm. The inputs to the key generation algorithm are the secret manufacturer’s code, the serial number, and/or the SEED value. The user may elect to use the algorithm supplied by Microchip or to create their own method of key generation.

COUNTER-CODE DESCRIPTION

The following addresses save the counter checksum values. The counter value is stored in the Counter locations (COUNTA, COUNTB, COUNTC described on the EEPROM table. This code is contained in module CounterCode.inc.

BUTTON PRESS DURING TRANSMIT

If the device is in the process of transmitting and detects that a new button is pressed, the current transmission will be aborted, a new code word will be generated based on the new button information and transmitted. If all the buttons are released, a minimum number of code words will be completed. If the time for transmitting the minimum code words is longer than the time-out time, or the button is pressed for that long, the device will time-out.

CODE TRANSMISSION FORMAT

The following is the data stream format transmitted (Table 7):

TABLE 7: KEELOQ/XTEA PACKET FORMAT:

Plaintext (40 bits)				Encrypted (64 bits)		
CRC (2 bits)	VLOW (1 bit)	Function Code (4 bits)	Serial Number (32 bits)	Function Code (8 bits)	User (24 bits)	Counter (32 bits)

Data transmitted LSb first

A KEELOQ/XTEA transmission consists of 64 bits of hopping code data, 36 bits of fixed code data and 3 bits of status information.

HOPPING CODE PORTION

The hopping code portion is calculated by encrypting the counter, discrimination value, and function code with the Encoder Key (KEY). A new hopping code is calculated every time a button press is pressed.

The discrimination value can be programmed with any fixed value to serve as a post decryption check on the receiver end.

FIXED CODE PORTION

The 40 bits of fixed consist of 32 bits of serial number and four bits of the 8-bit function code.

Each code word contains a preamble, header and data, and is separated from another code by guard time. The Guard Time Select (GSEL) configuration option can select a time period of 0ms, 6.4ms, 51.2ms or 102.4ms.

All other timing specifications are based on the timing element (Te). This *Te* can be set to 100 µs, 200 µs, 400 µs or 800 µs with the Baud Rate Select (BSEL) configuration. The calibration header time can be set to 4*Te or 10*Te with the Header Select (HEADER) configuration option.

The firmware has four different transmission modulation formats available. The Modulation select (TMOD) Configuration Option is used to select between:

- Pulse-Width Modulation (PWM) – Figure 2
- Manchester (MAN) – Figure 3
- Variable Pulse-Width Modulation (VPWM) – Figure 4
- Pulse Position Modulation (PPM) – Figure 5

FIGURE 2: PULSE-WIDTH MODULATION (PWM)

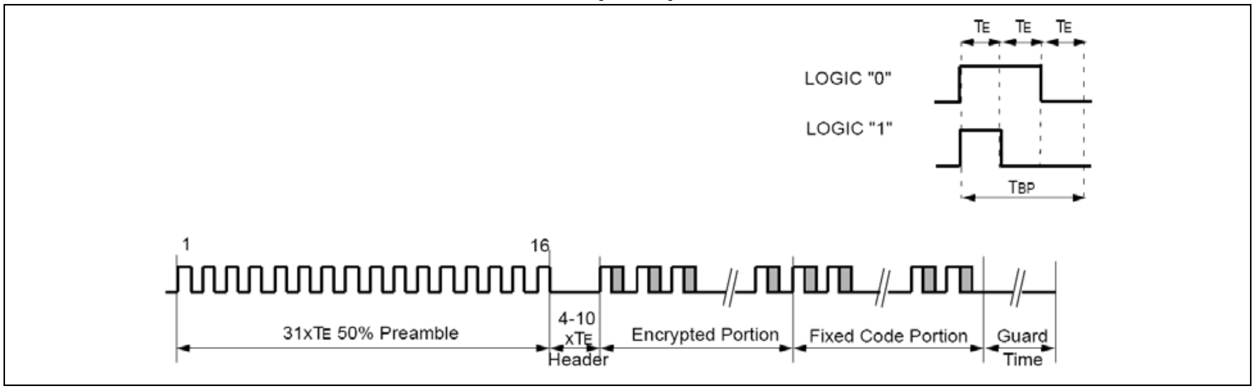


FIGURE 3: MANCHESTER (MAN)

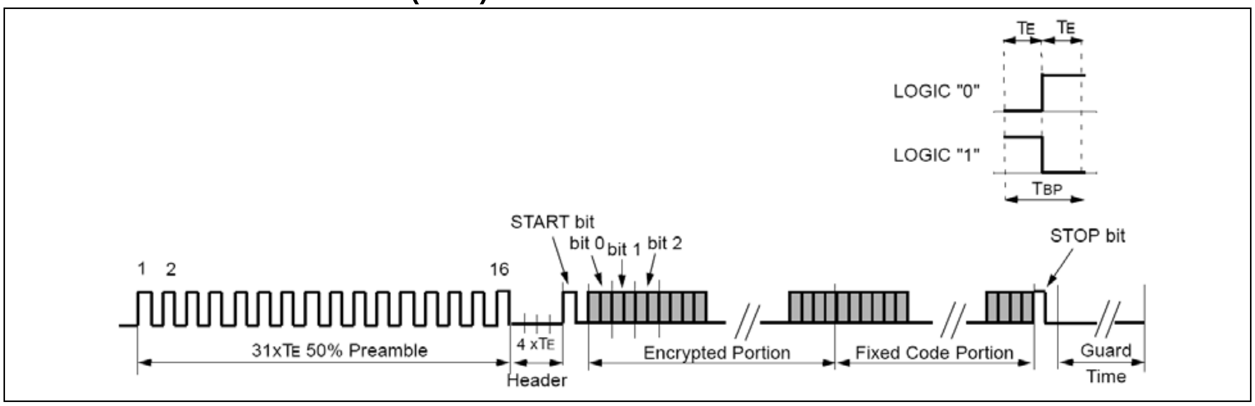


FIGURE 4: VARIABLE PULSE-WIDTH MODULATION (VPWM)

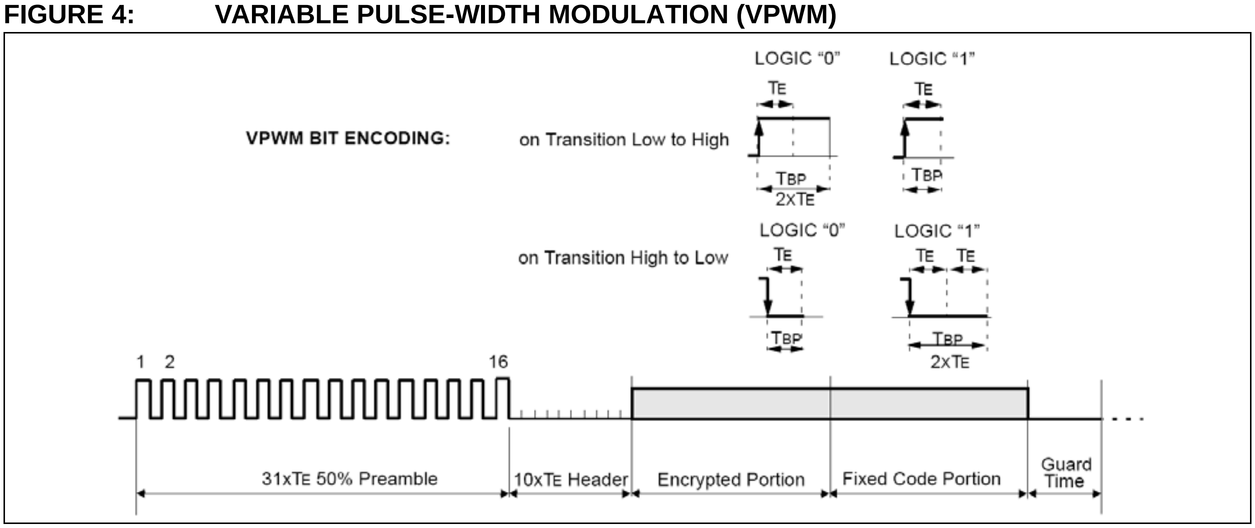
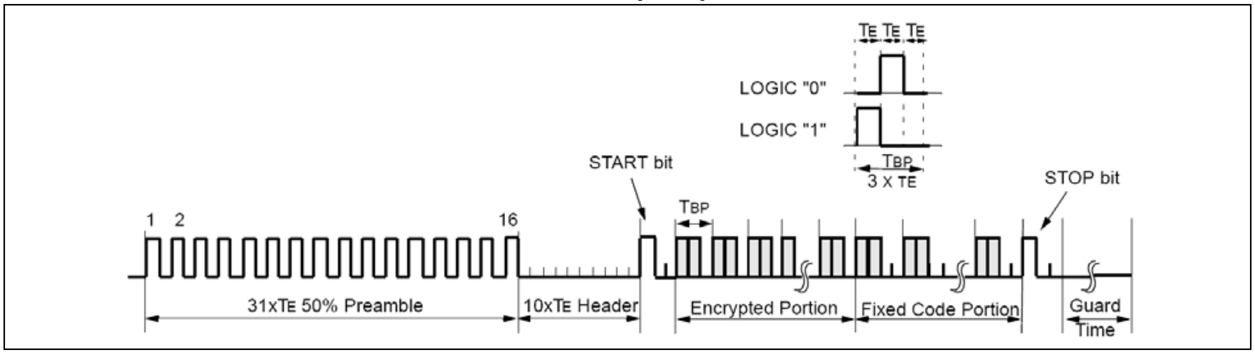


FIGURE 5: PULSE POSITION MODULATION (PPM)



If the Start/Stop Pulse Enable (STEN) configuration option is enabled, the software will place a leading and trailing '1' on each code word. This bit is necessary for modulation formats such as Manchester and PPM to interpret the first and last data bit.

A receiver wake-up sequence can be transmitted before the transmission starts. The wake-up sequence is configured with the Wake-up (WAKE) configuration option and can be disabled or set to 50 ms, 75 ms, or 100 ms of pulses of Te width.

FIRMWARE MODULES

The following files make up the KEELOQ transmitter firmware:

- `XTEA_KLQ 16F636.asm`: this file contains the main loop routine as well as the wake-up, debounce, read configuration, load transmit buffer and transmit routines.
- `XTEA_Encrypt.inc`: this file runs the XTEA encryption algorithm.
- `XTEA_eeprom.inc`: this file contains the EEPROM data as specified on the EEPROM data map.
- `CounterCode.inc`: Calculates the checksums and confirms the validity of the counter.

Because of statutory export license restrictions on encryption software, the source code listings for the XTEA algorithms are not provided here.

These applications may be ordered from Microchip Technology Inc. through its sales offices, or through the corporate web site: www.microchip.com.

CONCLUSION

This KEELOQ/XTEA transmitter firmware has all the features of a standard hardware encoder. What makes this firmware implementation useful is that it gives the designer the power and flexibility of modifying the encoding and/or transmission formats and parameters to suit their security system.

REFERENCES

C. Gübel, AN821, "*Advanced Encryption Standard Using the PIC16XXX*" (DS00821), Microchip Technology Inc. 2002.

D. Flowers, AN953, "*Data Encryption Routines for the PIC18*" (DS00953), Microchip Technology Inc., 2005.

NOTES:

Note the following details of the code protection feature on Microchip devices:

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