Application Report

SLAA644B–October 2014–Revised June 2015

Infrared Remote Control Implementation With MSP430FR4xx

Collins Cheng

MSP430

ABSTRACT

This application report provides an insight into several of the most frequently used infrared protocols and especially their flexible implementation using the TI MSP430FR4xx series of low-power microcontrollers.

The MSP430FR4xx microcontrollers are primarily targeted at remote control application that are equipped with infrared modulation function and an LCD display. The infrared modulation combinatory logic works with rich peripheral resources (for example, timers, RTC, WDT, and SPI) to generate infrared waveforms for transmitting infrared signals with minimal software overhead and intelligent power consumption.

Contents

1 Introduction

Infrared remote controls use infrared (IR) light to convey information. The infrared light is emitted from an IR LED controlled by the modulated signal from the transmitter's MCU. Modulation can help the receiver distinguish the desired signals from other infrared noise sources. Modulation is done by modulating a carrier signal (usually a square wave with higher frequency) with an envelope signal that bears the effective information.

The receiver uses a photodiode to convert the IR light to current. A transimpedance amplifier is frequently used to convert the current into voltage, which goes through a gain amplifier and filter before demodulation. The carrier signal is stripped off during demodulation. The demodulated signal can be directly connected to a receiver's MCU for decoding (see Figure 1).

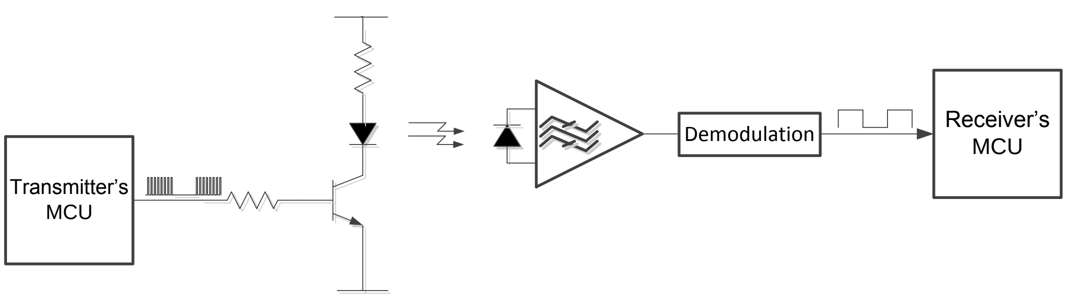

Figure 1. Infrared Modulation and Demodulation

MSP430 is a trademark of Texas Instruments.
All other trademarks are the property of their respective owners.

IR wireless communication is simple to design, inexpensive to manufacture, robust, and power efficient, and therefore it is widely used in consumer products today.

2 Infrared Remote Control Modulation and Encoding Theory

All modern infrared remote control designs use digital modulation. Two basic digital modulation technologies are Amplitude Shift Keying (ASK) and Frequency Shift Keying (FSK). ASK represents logic 1 and 0 by changing the carrier amplitude, and FSK represents these logic levels using two different carrier frequencies.

2.1 ASK Modulation

ASK is one of the oldest and simplest techniques, and it is favored by many consumer electronics companies. It has become the most popular modulation mode because of its good performance (robust and low power), design simplicity, and low cost.

In the transmitter, the effective data is modulated into a group of carrier pulses with a frequency in the range of 30 to 60 kHz. A space is inserted when no signal is transmitted.

The receiver is tuned to the same frequency as the transmitter's carrier, and all other noise is blocked by the receiver's bandpass filter. Many manufactures supply fully integrated receiver modules that provide demodulated signals to interface with a receiver's microcontroller. The typical carrier frequency is 30, 33, 36, 38, 40, or 56 kHz.

Several main encoding methods in ASK modulation system are described in the following sections.

2.1.1 Pulse Position Encoding

Pulse Position Encoding is the basic ASK modulation. Each bit width is constant. The carrier modulated pulse stands for logic 1, and the space represents logic 0 (see Figure 2).

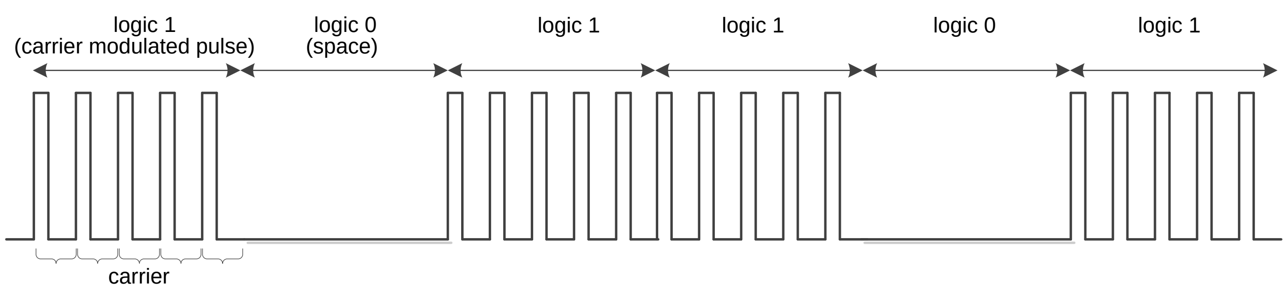

Figure 2. Pulse Position Encoding

2.1.2 Pulse Distance Encoding

In Pulse Distance Encoding, each bit is composed of a carrier modulated pulse and a space. The space width distinguishes logic 1 and logic 0, and the carrier modulated pulse width is constant (see Figure 3).

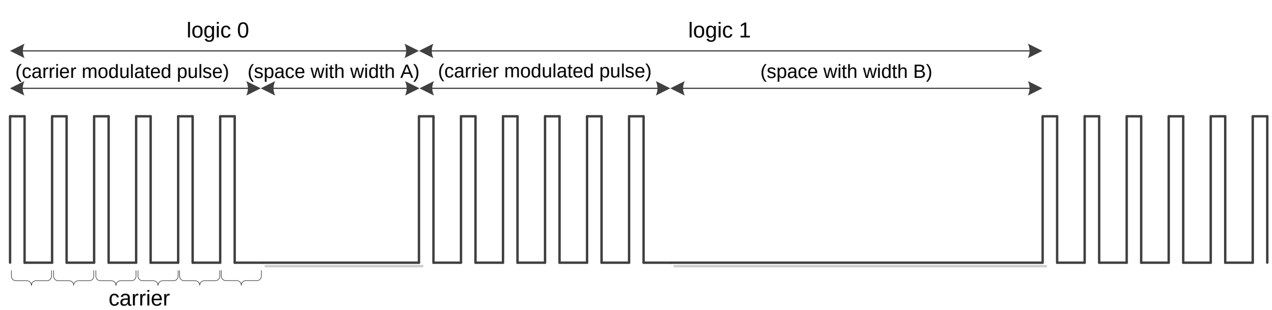

Figure 3. Pulse Distance Encoding

2.1.3 Pulse Width Encoding

In Pulse Width Encoding, each bit is composed of a carrier modulated pulse and a space. The carrier modulated pulse width distinguishes logic 1 and logic 0, and the space is constant (see Figure 4).

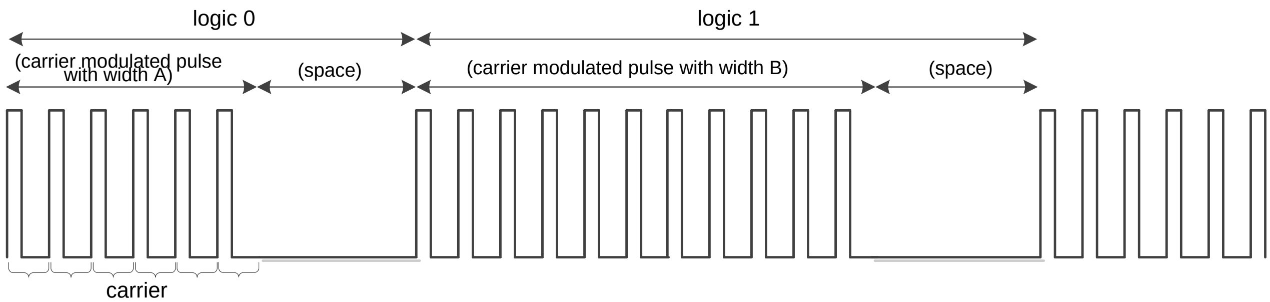

Figure 4. Pulse Width Encoding

2.1.4 Manchester Encoding

Manchester encoding is also known as biphase encoding. Each bit is composed of a carrier modulated pulse and a space. The polarity of the transition between modulated pulse and space defines the logical level. For instance, "modulated pulse to space" denotes logic 1, and "space to modulated pulse" denotes logic 0 (see Figure 5).

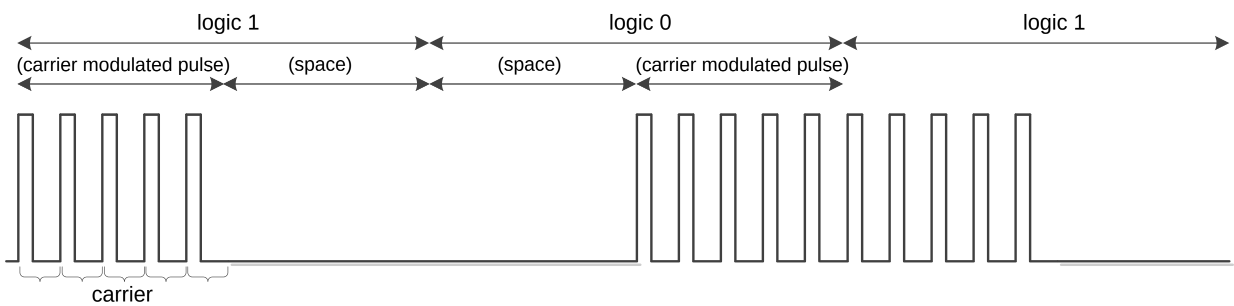

Figure 5. Manchester Encoding

2.2 FSK Modulation

FSK uses two different carrier frequencies for logic 1 and logic 0, and there is no space between pulses (see Figure 6). This is a less attractive solution because adoption of two frequencies increases the demodulation complexity and cost; hence, FSK is not widely used.

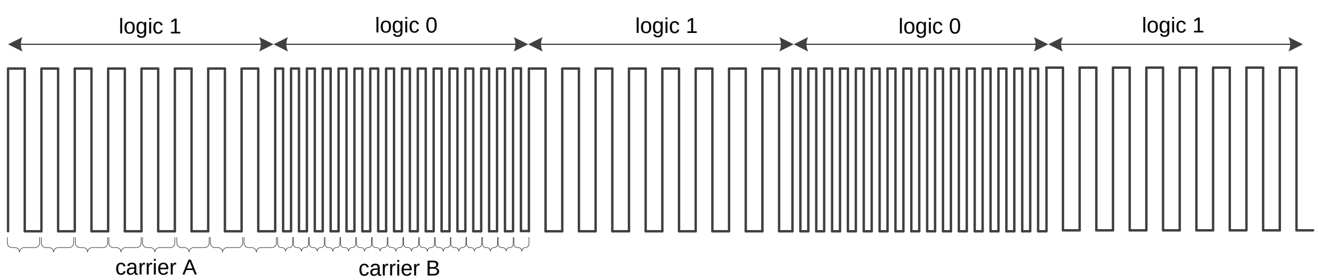

Figure 6. FSK Modulation

3 MSP430FR4xx Overview

The MSP430FR4xx is a member of the ultra-low-power MSP430™ family of 16-bit microcontrollers. It features optimized peripheral resources and IR modulation logic, which make it ideal for remote control applications. A powerful LCD display function and abundant capacitive touch I/Os resources extend its use in other fields like blood pressure meters, water meters, and one-time-password token (OTP) generators. For complete descriptions, see the *MSP430FR4xx and MSP430FR2xx Family User's Guide* (SLAU445) and the MSP430FR4133 data sheet (SLAS865).

4 MSP430FR4xx Infrared Remote Control Implementation

Traditionally, infrared modulation is implemented mainly by software with limited hardware resource (that is, one timer to generate an accurate time slot). The software overhead is large because the time slot is small. The MSP430FR4xx has several internal interconnected hardware resources, such as timers and SPI, that can enable IR modulation with lower software overhead.

The IR modulation logic in MSP430FR4xx is a combination of two cascaded timers and additional combinatory logic (see Figure 7).

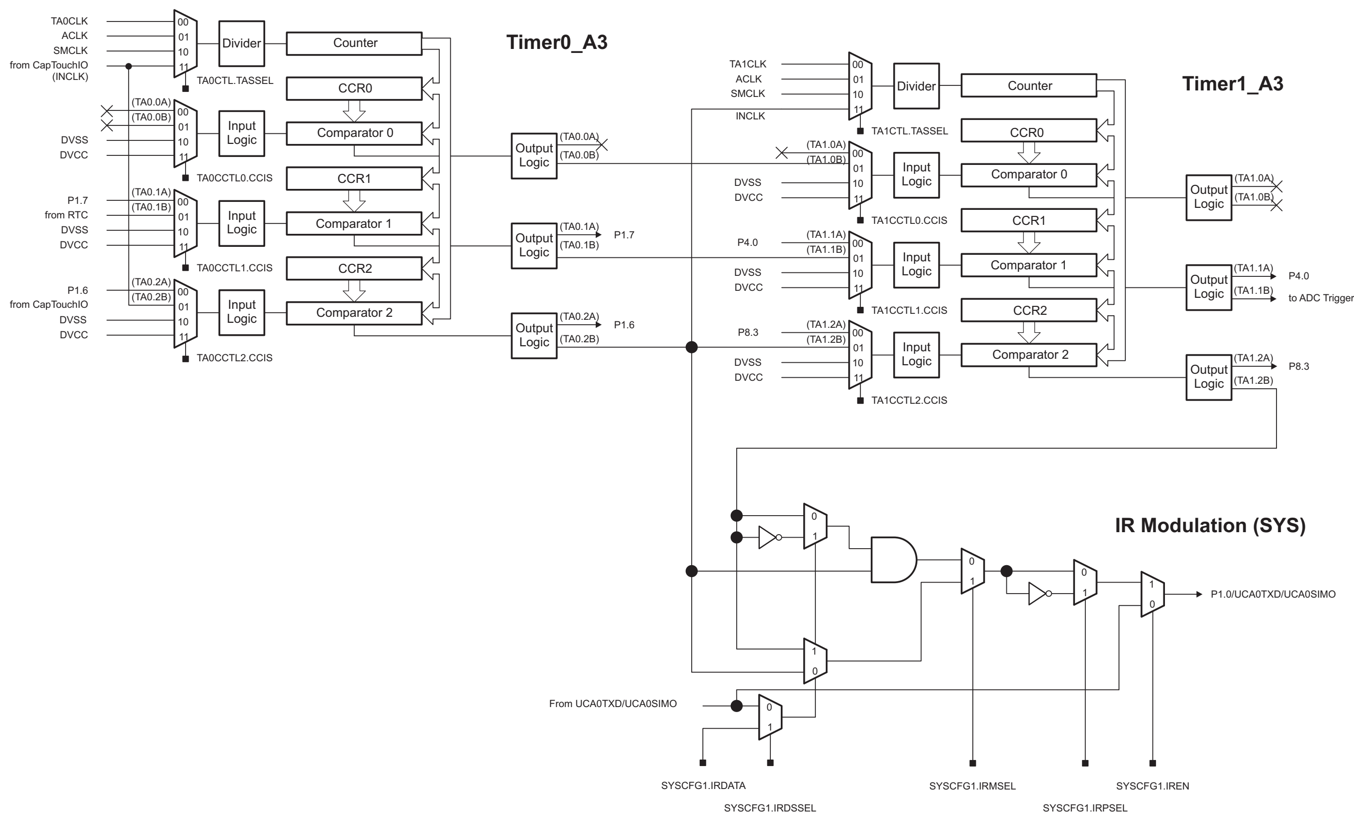

Figure 7. IR Modulation Logic

The IR modulation logic can be enabled by setting the IREN bit in SYSCFG1 register. The logic has two different PWM input signals (from TA0 and TA1) to support either ASK or FSK modulations. In ASK modulation, the first PWM from TA0 is used for carrier generation, and the second PWM from TA1 or output from eUSCI_A can be used to generate the envelope. In FSK modulation, two PWM signals individually represent two different carrier frequencies. IRMSEL bit in SYSCFG1 register specifies the modulation mode. Before being output to the external pin, the modulated signal's polarity can be inverted by setting the IRPSEL bit in SYSCFG1 register for adapting to different external drive circuitry.

The envelope waveform generation can be achieved by hardware or software. In hardware mode, the envelope signal comes from TA1 (only available for ASK) or eUSCI_A. When from the latter, it works in SPI mode and 8-bit data is automatically serially sent. In software mode, IRDATA bit in SYSCFG1 register controls logic 0 or logic 1 to send. The IRDSSEL bit in SYSCFG1 register selects hardware or software mode to use.

4.1 Modulation scheme

4.1.1 ASK Modulation

The IRMSEL bit defaults to ASK modulation. Its data flow is represented in Figure 8. Two inputs of the AND gate are modulated to drive an external LED: one is the carrier from TA0, the other is the envelope timing from TA1, eUSCI_A or IRDATA bit. When from IRDATA bit, another independent counter (TA1, RTC or WDT) is required to periodically update this bit.

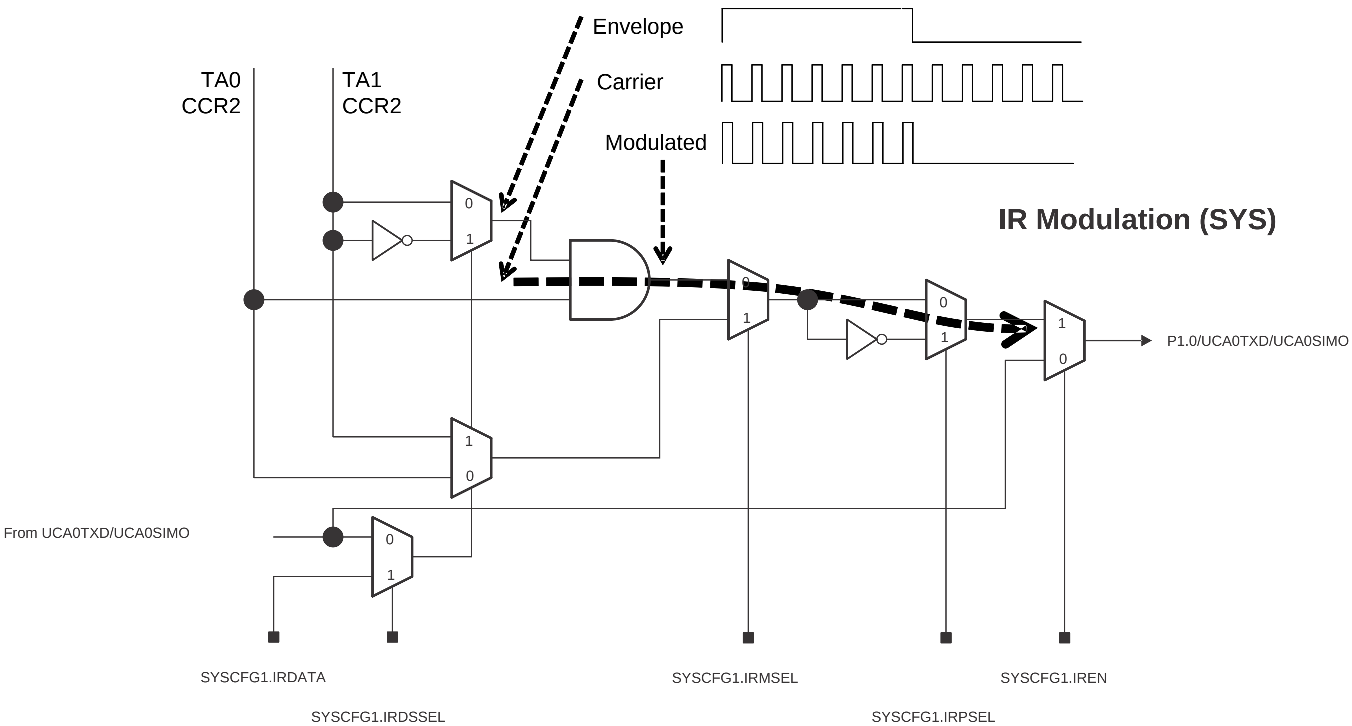

Figure 8. Data Flow in ASK Modulation

4.1.2 FSK Modulation

When IRMSEL bit is set, FSK mode is enabled. Its data flow is shown in Figure 9. TA0 and TA1 generate two separate carrier frequencies respectively. The envelope waveform can be generated from eUSCI_A or IRDATA bit; when from IRDATA bit, another independent counter (RTC or WDT) is required to periodically update this bit.

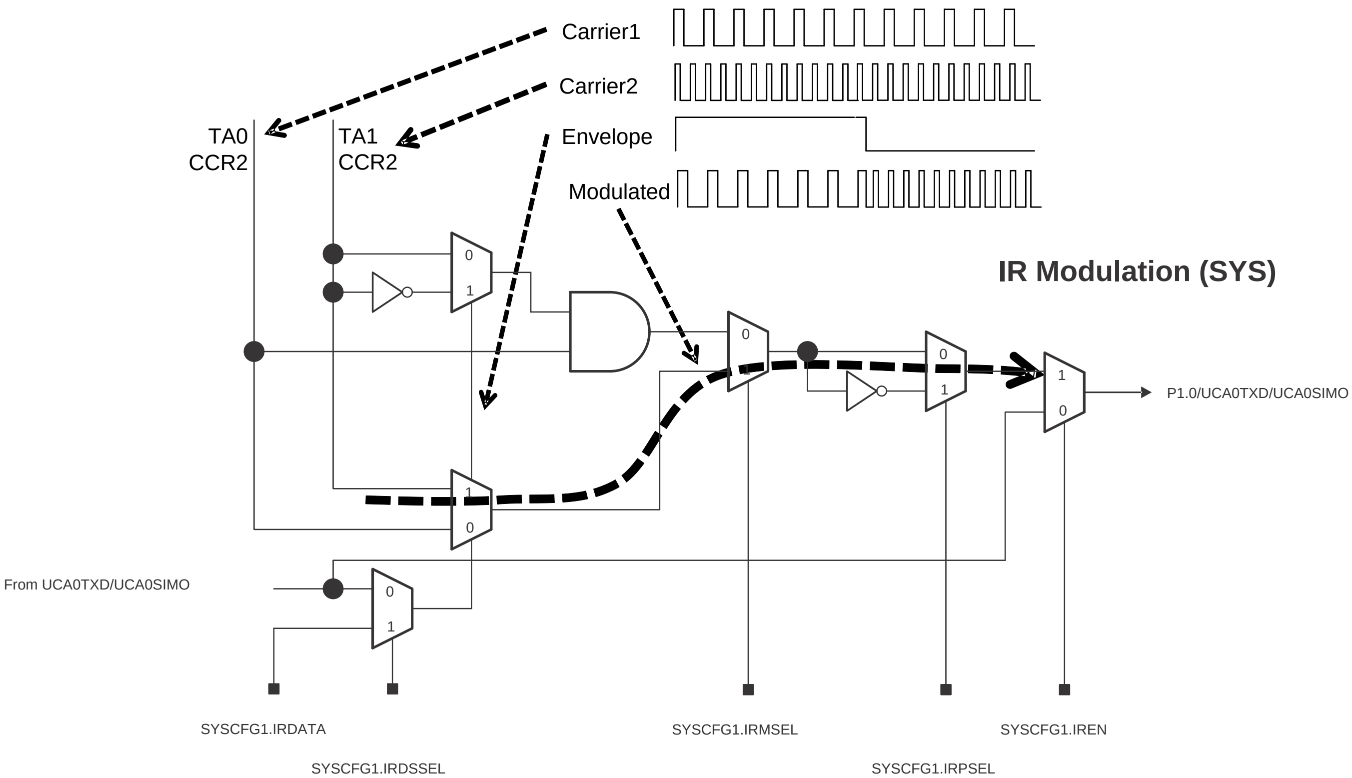

Figure 9. Data Flow in FSK Modulation

4.2 Carrier Generation

The timer is used to generate the carrier. Both TA0 and TA1 can source from high-frequency SMCLK to achieve higher resolution and wider frequency range. The timer counters can work in either up or up/down mode. CCR0 controls the carrier period, while CCR2 determines the carrier duty cycle. Smaller duty cycle helps with lower power from a system perspective. Typical duty cycle is approximately 3/16 to 4/16. Up to seven kinds of output modes allow flexible carrier generation (see Figure 10). After starting the carrier generation, users do not need to update its configuration until a frame transmitting finishes.

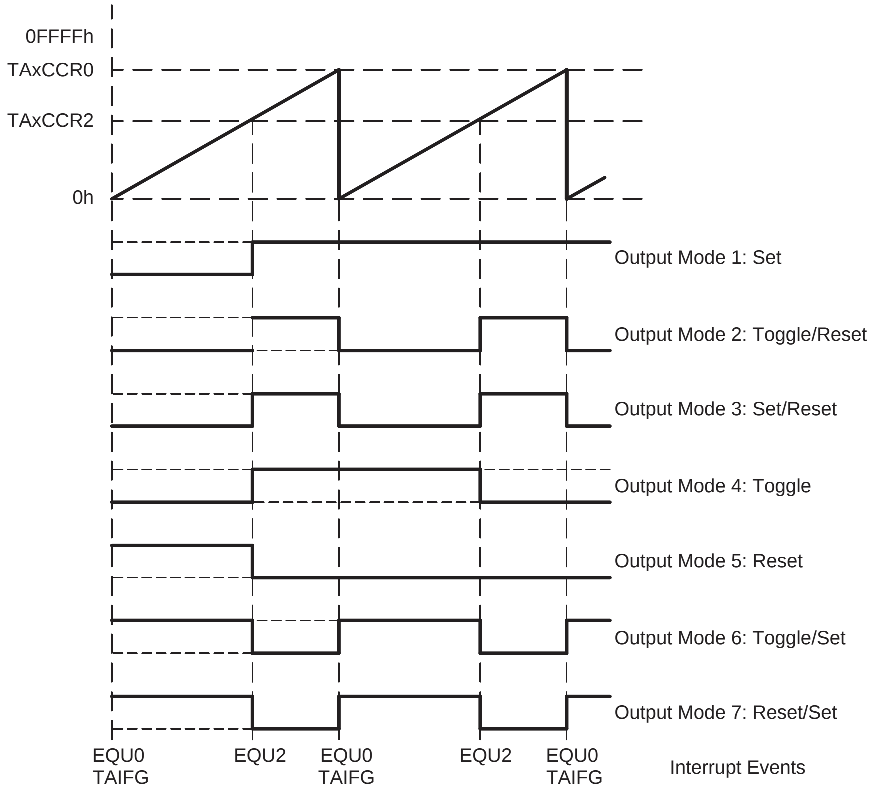

Figure 10. Output Example – Timer in Up Mode

4.3 Waveform Envelope Generation

Envelope waveform is decided by the data sent as well as the encoding mode used. User can use TA1, eUSCI_A or IRDATA to generate envelope waveform according to the modulation mode selected.

When TA1 is used in ASK modulation, CCR0 sets the period of the envelope, and CCR2 sets the duty cycle. Because of this, CCR0 should be configured to one or two times each bit's width for different encoding modes; CCR2 needs to be updated before next bit to be sent. The number of bits to be sent determines the number of times the interrupt will have to fire in a transmission, so it is directly added to the software overhead and current consumption.

When eUSCI_A is used in SPI mode (see Figure 11), its baud rate should be configured to one or two times the effective data's baud rate. For instance, same baud rate is configured in pulse position encoding but doubled in Manchester encoding. Adoption of SPI can greatly reduce interrupt times and, thus, the software overhead.

When IRDATA is used, another independent counter (generally RTC) is required to update IRDATA bit.

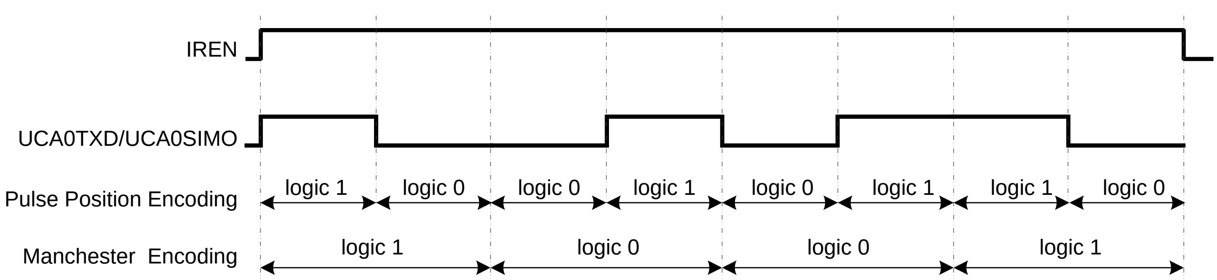

Figure 11. Envelope Example Generated from SPI

4.4 Hardware and Software Overhead Consideration

The MSP430 family is designed for ultra-low-power applications to extend battery life. The top principle for reducing power consumption is to maximize the time in low-power modes (for example, LPM0 or LPM3) whenever possible. It is strongly suggested to use low-power integrated peripheral modules in place of software-driven functions. Because the high-frequency SMCLK is essential in generating the carrier, it is recommended to maximize the time in LPM0 with respect to modulation and encoding mode during IR data transmitting. From this perspective, eUSCI_A is mostly preferred because it can attain the longest time slot (four or eight bits). But in some applications where eUSCI_A is needed for other tasks, other hardware resources like TA1 and RTC can be the substitution.

5 Example Protocols

There are many infrared protocols across the industry, but most are evolved from a few base protocols with variations of frequency or format. As most popular protocols, Pulse Distance Protocol and Manchester Protocol (RC5) are described in the following sections. More details about how to design a complete remote control system can be found in the *BOOST-IR User's Guide* (SLAU598).

5.1 Pulse Distance Protocol

Pulse distance protocol is widely used by many appliances companies. It uses ASK modulation and pulse distance encoding with a carrier frequency of 38 kHz.

5.1.1 Frame Format

There are two kinds of frames in protocol: data frame and repeat frame.

A data frame consists of a leading code and data payload. The leading code is a burst with a length of 9 ms, followed by a pause of 4.5 ms. The data payload consists of 8 bits address to identify the device and 8 bits command for control words. Both are sent twice for reliability. The second transmission of address and command are complementary, therefore the total length of the data frame is constant (67.5 ms). The payload is finalized by a 560-µs carrier modulated tail pulse, to finish the last bit data gap.

Logic 1 is defined as a 560-µs carrier modulated period followed by a 1690-µs space period. Logic 0 is defined as a 560-µs carrier modulated period followed by a 560-µs space period (see Figure 12).

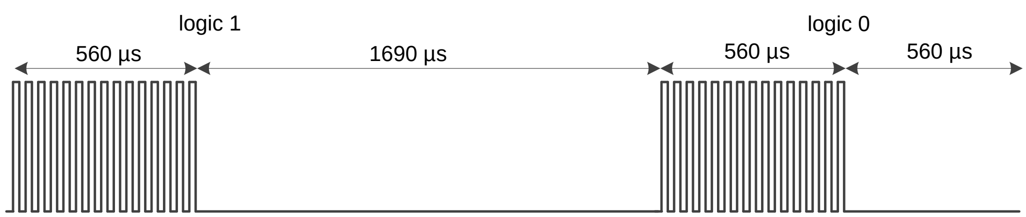

Figure 12. Pulse Distance Protocol, Bit Encoding

A complete data frame format is shown in Figure 13.

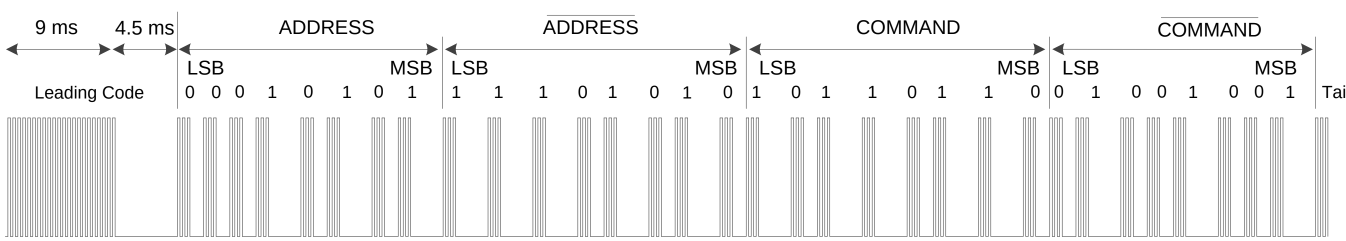

Figure 13. Pulse Distance Protocol, Data Frame Format

Repeat frame is defined to handle auto-repeat function and does not carry any address or command information. It includes train pulses and a tail pulse following (its format is shown in Figure 14). The repeat frame is repeated every 110 ms while the same key is still pressed.

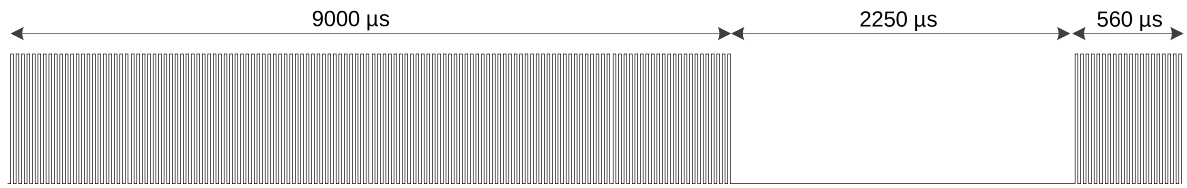

Figure 14. Pulse Distance Protocol, Repeat Frame Format

The full sequence format of pulse distance protocol is shown in Figure 15.

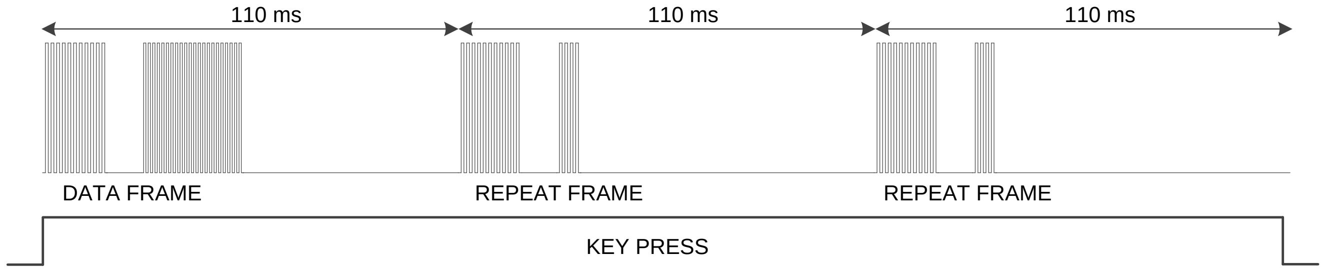

Figure 15. Pulse Distance Protocol, Full Sequence Format

The envelope waveform depends on the frame format. It is easy to quantize all above items with minimum time slot of 0.56 ms (see Table 1).

Table 1. Pulse Distance Protocol, Data Encoding Quantization

Items	Leading Code		Logic 1		Logic 0		Tail Code	
	Carrier modulated pulse	Space	Carrier modulated pulse	Space	Carrier modulated pulse	Space	Carrier modulated pulse	Space
Length	9 ms	4.5 ms	0.56 ms	1.69 ms	0.56 ms	0.56 ms	0.56 ms	0 ms
Quantization	16	8	1	3	1	1	1	0

5.1.2 Envelope Generation

If TA1 is used to generate envelope waveform, each pair of carrier modulated pulse and space needs to update CCR0 and CCR2 one time. CCR0 depends on the carrier modulated pulse period plus the space period, and CCR2 depends on the carrier modulated pulse period. For example, if TA1 sources from SMCLK of 4 MHz and uses the default divider configuration, CCR0 and CCR2 are configured as 54000 and 36000, respectively, to generate the leading code (9-ms carrier modulated pulse paired with 4.5-ms space), and updated to be 9000 and 2240, respectively, for logic 1 (see Figure 16). To send one full data frame, CCR0 and CCR2 need to be updated 34 (1 + 8 × 2 + 8 × 2 + 1) times, which is achieved in the TA1 interrupt routine.

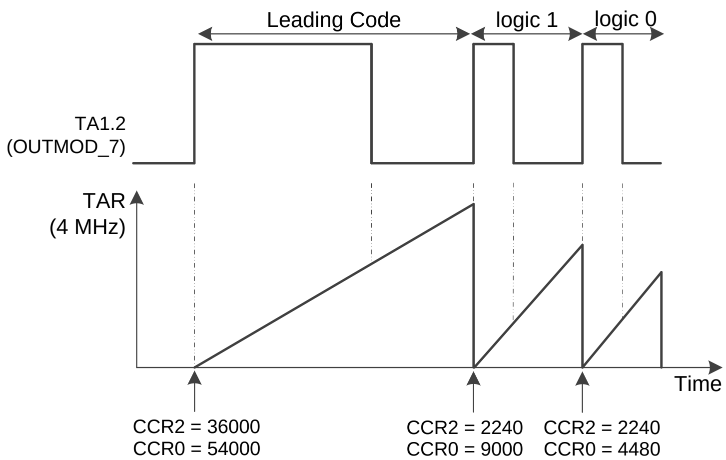

Figure 16. Pulse Distance Protocol, TA1 in Envelope Generation

If SPI is used to generate the envelope waveform, its baud rate should be set equal to the minimum time slot of 0.56 ms. The TXBUF should send three bytes of data (0xFF, 0xFF, 0x00) to transmit the leading code while other bytes that are sent will depend on the payload. Details are shown in Figure 17, where a total of sixteen ones and sixteen zeros are in each data frame. TXBUF of SPI must be updated approximately 15 (121 / 8) times, which is done in the SPI interrupt service routine. The SPI software overhead is half of the TA1 overhead.

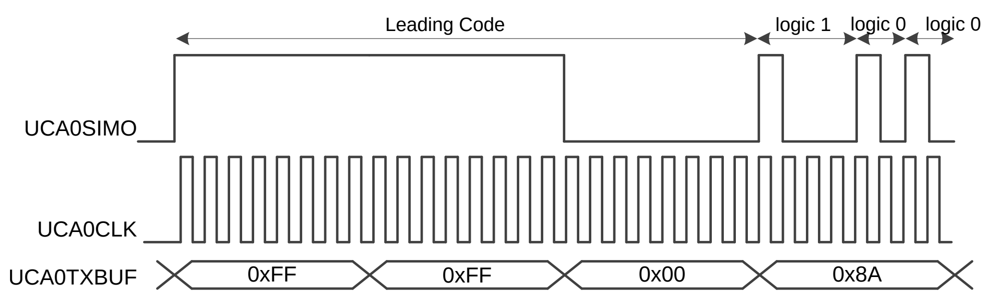

Figure 17. Pulse Distance Protocol, SPI in Envelope Generation

5.1.3 Carrier Generation

To generate a 38-kHz carrier with one-fourth duty cycle, CCR0 and CCR2 of TA0 are configured according to SMCLK. For example, with a 4-MHz SMCLK, CCR0 and CCR2 are configured to be 105 (4000 / 38) and 26 (4000 / 38 / 4), respectively. Figure 18 shows how the duty cycle setting works.

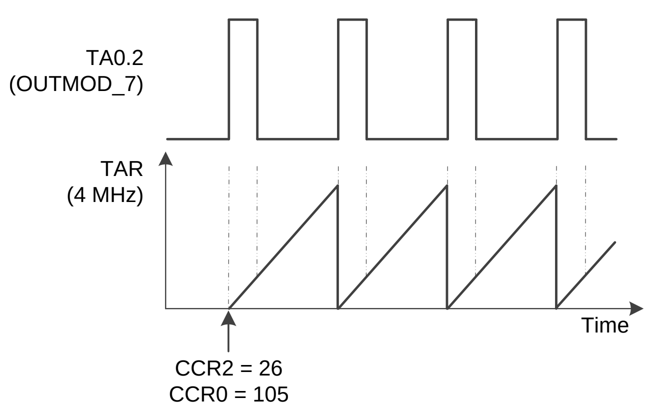

Figure 18. Pulse Distance Protocol, TA0 in Carrier Generation

5.2 Manchester Protocol (RC5)

The RC5 protocol was introduced by Philips. It uses ASK modulation and Manchester encoding with carrier frequency fixed at 36 kHz.

5.2.1 Frame Format

The RC5 data frame begins with two start logic 1 bits (S1 and S2) followed by one toggle bit (T), the payload consists of a 5-bit address and a 6-bit command. The toggle bit changes its value at each new key press. The five address bits identify the device to be controlled, and the six command bits contain the information to be transmitted.

Logic 1 is defined as an 889-µs space period followed by an 889-µs carrier modulated pulse period. Logic 0 is defined as an 889-µs carrier modulated pulse period followed by an 889-µs space period (see Figure 19).

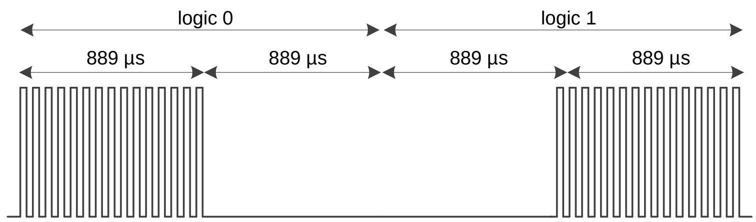

Figure 19. RC5 Protocol, Bit Encoding

Complete data frame has fixed length of 24.9 ms, and its format is shown in Figure 20.

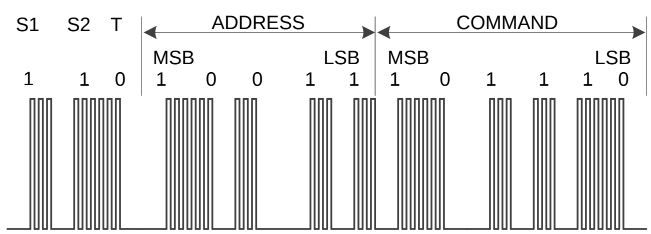

Figure 20. RC5 Protocol, Data Frame Format

Auto-repeat function is handled by repeating data frames with same toggle bit. In the extended version of RC5, the S2 start bit is interpreted as an inverted sixth address bit instead of the fixed logic 1. The full sequence is shown in Figure 21.

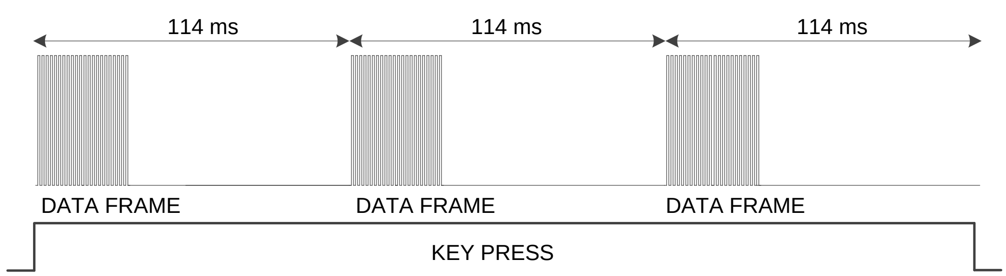

Figure 21. RC5 Protocol, Full Sequence Format

5.2.2 Envelope generation

The minimum time slot is 889 µs. It is required to update TA1's output mode to generate the envelope waveform. For example, TA1 sources from SMCLK of 4 MHz, CCR0 and CCR2 are fixed to be 7112 (2 × 889 / 0.25) and 3556 (889 / 0.25), respectively. Details can be seen in Figure 22. The TA1 output mode needs to be updated at most 14 (3 + 5 + 6) times in each data frame, which is handled in the TA1 interrupt service routine.

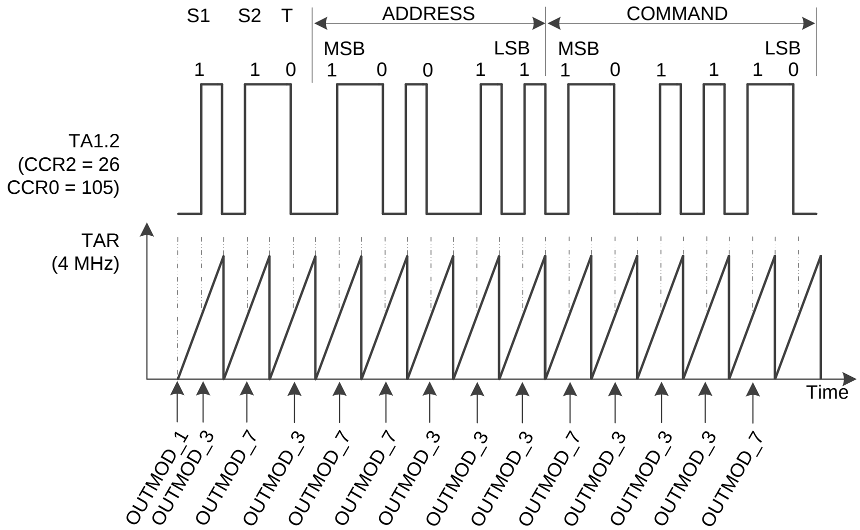

Figure 22. RC5 Protocol, TA1 in Envelope Generation

If SPI is used, the baud rate is set with period of 889 µs. Its TXBUF needs being wrote about 4 (2 × 14 / 8) times to transmit one data frame, which can be handled in the SPI interrupt routine. Its operation is shown in Figure 23.

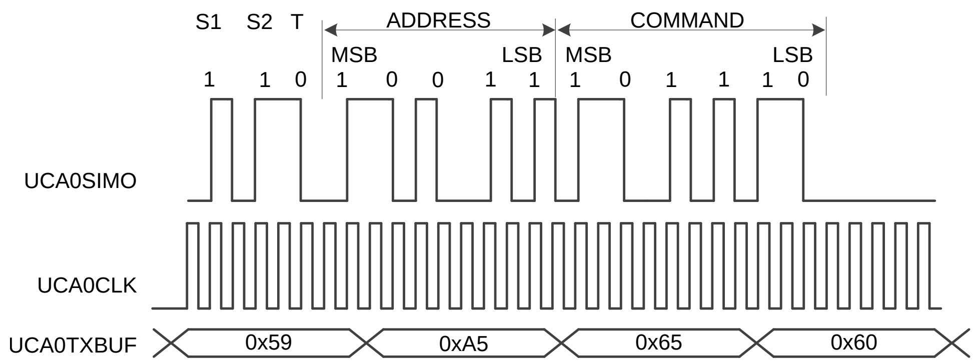

Figure 23. RC5 Protocol, SPI in Envelope Generation

5.2.3 Carrier Generation

To generate 36 kHz carrier with one-third duty, CCR0 and CCR2 of TA0 are configured according to SMCLK's frequency. For example with 4 MHz SMCLK, CCR0 and CCR2 are configured to be 111 (4000 / 36) and 37 (4000 / 36 / 3), respectively. If SMCLK is 8 MHz, above two values should be doubled. Its working is shown in Figure 24.

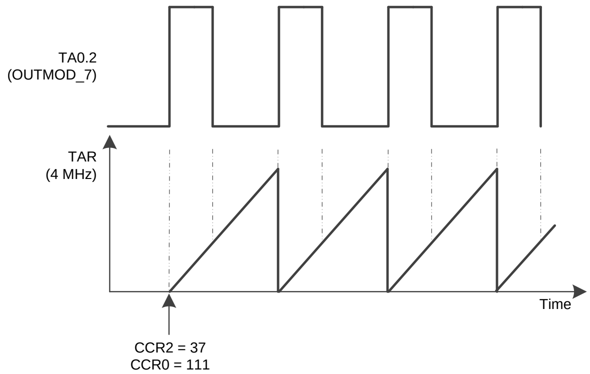

Figure 24. RC5 Protocol, TA0 in Carrier Generation

6 Software Design and Overhead Comparison

Without IR modulation logic, a timer is generally used to finish Infrared transmit through controlling its PWM output. Its counter period and channel duty are consistent with carrier period and duty. Based on this, software updates its PWM output according to the timer's overflow number. For instance in pulse distance protocol's leading code generation, software counts 342 (9 ms / (1 / 38 kHz)) overflow to output carrier pulse of 9 ms and 171 (4.5 ms / (1 / 38 kHz)) to output space of 4.5 ms. During the overflow interval, device stays in LPM0 to save power. Frame length decides the wakeup times.

With IR modulation logic, device only needs to wake up very limited times for envelope generation during which carrier is automatically generated without any intervention. Software flow for transmitting one frame with different implementation methods is shown in Figure 25.

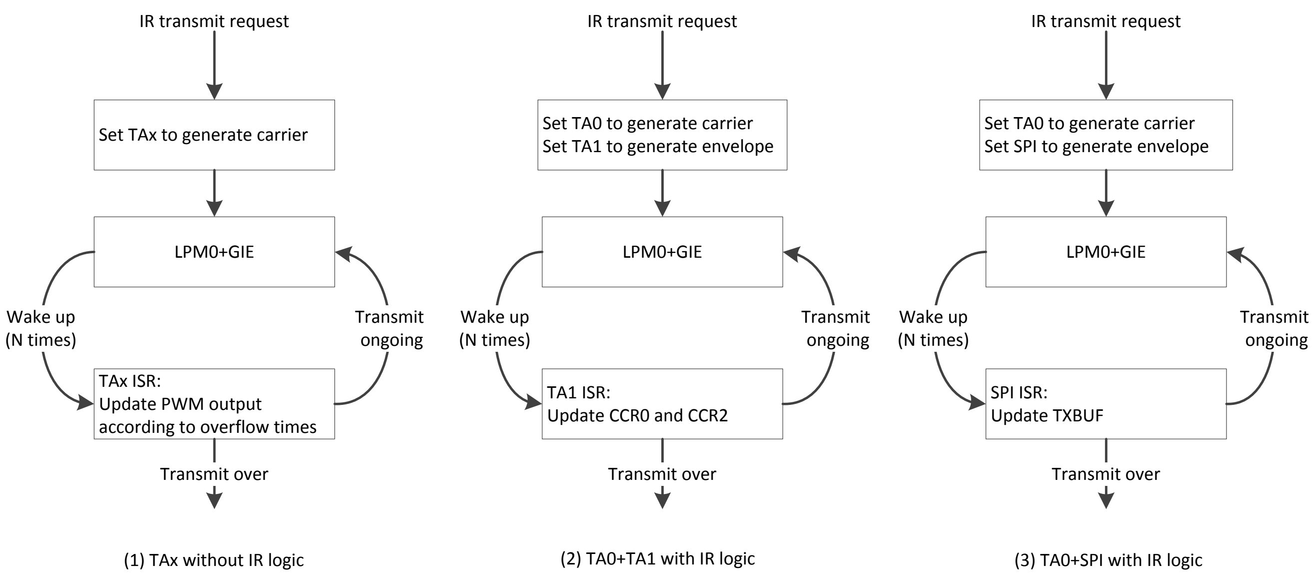

Figure 25. Software Flow for Transmitting One Data Frame With Different Methods

To better understand the superiority of IR logic in software overhead during transmitting one full frame, interrupt times using different methods are compared for both Pulse Distance Protocol and Manchester Protocol. Details can be seen in Table 2.

Table 2. Software Overhead Comparison in Transmitting One Data Frame

Protocol	Pulse Distance			Manchester (RC5)		
Implementation Method	TAx without IR logic	TA0+TA1 with IR logic	TA0+SPI with IR logic	TAx without IR logic	TA0+TA1 with IR logic	TA0+SPI with IR logic
Interrupt Times	2583	34	15	896	14	4

7 Conclusion

The MSP430FR4xx devices contains abundant peripherals and specific IR modulation logic that aid development of infrared remote control implementation with either ASK or FSK modulation. Carriers can be easily generated by TA0 and TA1 with minimal software intervention. Multiple methods can be selected to generate envelope: TA1, eUSCI_A in hardware mode, or IRDATA bit in software mode. Two typical examples are shown that envelope generation from eUSCI_A gets the greatest reduction of software overhead.

8 References

1. *MSP430FR4xx and MSP430FR2xx Family User's Guide* (SLAU445)
2. *MSP430FR413x Mixed-Signal Microcontrollers* (SLAS865)

Revision History

Changes from May 18, 2015 to June 29, 2015 **Page**

- Corrected the spelling of the IRDSSEL bit in Figure 7, *IR Modulation Logic* 4
- Corrected the spelling of the IRDSSEL bit in the paragraph that starts "The envelope waveform generation can..." 5
- Corrected the spelling of the IRDSSEL bit in Figure 8, *Data Flow in ASK Modulation* 5
- Corrected the spelling of the IRDSSEL bit in Figure 9, *Data Flow in FSK Modulation* 6

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Products		**Applications**	
Audio	www.ti.com/audio	Automotive and Transportation	www.ti.com/automotive
Amplifiers	amplifier.ti.com	Communications and Telecom	www.ti.com/communications
Data Converters	dataconverter.ti.com	Computers and Peripherals	www.ti.com/computers
DLP® Products	www.dlp.com	Consumer Electronics	www.ti.com/consumer-apps
DSP	dsp.ti.com	Energy and Lighting	www.ti.com/energy
Clocks and Timers	www.ti.com/clocks	Industrial	www.ti.com/industrial
Interface	interface.ti.com	Medical	www.ti.com/medical
Logic	logic.ti.com	Security	www.ti.com/security
Power Mgmt	power.ti.com	Space, Avionics and Defense	www.ti.com/space-avionics-defense
Microcontrollers	microcontroller.ti.com	Video and Imaging	www.ti.com/video
RFID	www.ti-rfid.com		
OMAP Applications Processors	www.ti.com/omap	**TI E2E Community**	e2e.ti.com
Wireless Connectivity	www.ti.com/wirelessconnectivity		

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265