An Introduction to Computer Engineering using the Renesas Sakura Microcontroller Board

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Preface

This book is the result of a long relationship the author has enjoyed with Renesas Electronics America, Inc. (and one of its predecessors, Mitsubishi Electronics). I originally worked with this company because of their commitment to providing a low-cost evaluation board and free development software that students could purchase and use in classes and senior design projects. Over the years the boards have remained as affordable (and popular) as ever, and the software development tools available have added more functionality while still available for free to our students.

I have been teaching embedded systems courses for over fourteen years (and working in the field even longer). I had not been able to find a book suitable for using in an Introduction to Computer Engineering course that would lend itself to the theoretical and applied nature of the discipline and embedded systems design. When Renesas released the GR-SAKURA board, I knew I have the perfect platform to use in the course. This book was developed to augment the hands-on exercises we use. This book also has a radical feature not seen in many books currently on the market (if any). It is freely available for download. It is also available for purchase in hardcopy form for a modest price.

This book would not have been possible had it not been for the assistance of numerous people. Several students and educators contributed to and extensively tested some of the chapters, including: Yevgeny Fridlyand (2, 3, 4), Adam Harris (1, 2, 3), Anthony Harris (3), Onkar Raut (2, 4) Suganya Jebasingh (2, 4), and Steven Erdmanczyk (4) . Thanks go to the publisher, Linda Foegen, and especially June Harris, Rob Dautel and Todd DeBoer of Renesas for their help in getting this book produced and published (and for their patience!). Many, many thanks go to the reviewers who offered valuable suggestions to make this book better, especially David Brown and students from my UNC Charlotte Introduction to Engineering and Embedded Systems courses.

I would like to personally thank my parents, the Conrads, and my in-laws, the Warrens, for their continued assistance and guidance through the years while I worked on books. Also, I would especially like to thank my children, Jay, Mary Beth, and Caroline, and my wife Stephanie for their understanding when I needed to spend more time on the book than I spent with them.

James M. Conrad, March 2014

Contents

Chapter 1

Introduction to Embedded Systems

1.1 LEARNING OBJECTIVES

In this chapter the reader will learn:

- What an embedded system is
- Why to embed a computer
- What functions and attributes embedded systems need to provide
- What constraints embedded systems have

1.2 CONCEPTS

An embedded system is an application-specific computer system which is built into a larger system or device. Using a computer system rather than other control methods (such as non-programmable logic circuits, electro-mechanical controls, and hydraulic controls) offers many benefits such as sophisticated control, precise timing, low unit cost, low development cost, high flexibility, small size, and low weight. These basic characteristics can be used to improve the overall system or device in various ways:

- Improved performance
- More functions and features
- Reduced cost
- Increased dependability

Because of these benefits, billions of microcontrollers are sold each year to create embedded systems for a wide range of products.

1.2.1 Economics and Microcontrollers

Microcontrollers are remarkably inexpensive yet offer tremendous performance. The microprocessor for a personal computer may cost $100 or more, while microcontrollers typically cost far less, starting at under $0.25. Why is this so?

2.3 MICROCONTROLLER BASICS

2.3.1 Bits and Bytes

The basic concept of an embedded system is electricity. If we ignore the underlying voltage value and just consider the maximum voltage of the system, it is easy to recognize two conditions:

- presence of the maximum voltage of the system—we'll call this state "1"
- absence of a voltage of the system (most often 0 (zero) volts)—we'll call this state "0"

This basic unit of information is the *binary digit,* or *bit.* Values with more than two states require multiple bits. Therefore a collection of two bits has four possible states: 00, 01, 10, and 11. A collection of eight bits is called a *byte.* Often we group bits together to represent them in a larger number representation, called hexadecimal. A grouping of four bits is represented by one hexadecimal digit, usually preceded by an 'x,' as represented in Table 2.1. As an example, the binary number 1010 is xA in hexadecimal and 10 in decimal. Binary number 01011100 is hexadecimal x5C.

TABLE 2.1 Hexadecimal Representation

BINARY	HEXADECIMAL	DECIMAL	BINARY	HEXADECIMAL	DECIMAL
0000	x0	0	1000	x8	8
0001	x1	1	1001	x9	9
0010	x2	2	1010	xA	10
0011	x3	3	1011	xB	11
0100	x4	4	1100	xC	12
0101	x5	5	1101	xD	13
0110	x6	6	1110	xE	14
0111	x7	7	1111	xF	15

These values are moved around inside the microcontroller and stored in memory locations called registers. Each register has a unique location which will be addressed. These memory locations are in addition to larger stores of useable memory.

union of variables within that structure. An example of how the PDR is defined inside a port *structure* as follows:

```
 1. struct st_port4 {
 2.    union {
 3.       unsigned char BYTE;
 4.       struct {
 5.          unsigned char B0:1;
 6.          unsigned char B1:1;
 7.          unsigned char B2:1;
 8.          unsigned char B3:1;
 9.          unsigned char B4:1;
10.          unsigned char B5:1;
11.          unsigned char B6:1;
12.          unsigned char B7:1;
13.       } BIT;
14.    } PDR;
15. }
```

Line 1 shows that port4 has been defined as a *structure.* Lines 2 to 14 suggest that the Port Direction Register (PDR) has been defined as a *union* with the variable BYTE and a structure called BIT. This organization helps in easy access of the bits of the PDR. Unsigned char B*n*:1(*n*: 0 to 7) indicates that the character variable is assigned one bit.

To select a particular pin as the input pin, the corresponding bit of the PDR has to be set to '0'; and to select a pin as output, the corresponding bit of the PDR has to be set to '1.' The general syntax to set a bit of the PDR is PORTx.PDR.BIT.Bn ($x = 0$ to 5, A to G, J; and $n = 0$ to 7) since ports are defined as *structures,* hence accessing structure *members* is done in this way. To configure multiple pins at the same time, the *char* variable BYTE can be used. All pins are configured as inputs at reset, by default.

Set Switch 1 (Port A bit 7) as Input

```
PORTA.PDR.BIT.B7 = 0;
```

When a pin is selected as an input from a peripheral, the Input Buffer Control Register (ICR) has to be enabled. The ICR will be explained a little later. Selecting a pin as an output involves setting the Data Register (DR) and the Port Direction Register (PDR).

Port Output Data Register (PODR)

The Port Output Data Register (PODR) is also defined as a *union* of variables inside the port *structure,* in the 'iodefine_gcc63n.h' file. It is presented just like the PDR. Unsigned char: 1 is used to represent reserved pins.

	B7	B6	B5	B4	B3	B2	B1	B0
Value after reset:	0	0	0	0	0	0	0	0

Figure 2.6 Port Output Data Register [1], page 662.

The syntax to access the bits of the Data Registers (DR) is PORTx.PIDR.BIT.Bn (x = 0 to 9, A to G, J; and n = 0 to 7) for those port pins configured as inputs and PORTx.PODR.BIT.Bn for those port pins configured as outputs. To select a pin as an output pin, first set the Port Output Data Register (PODR) to a known value, preferably 0, so that changes in the output can be easily observed. The *char* variable BYTE can be used to set multiple pins as output at the same time.

Set LED0 (Port A bit 0) as Output

```
1. PORTA.PDR.BIT.B0 = 1;
2. PORTA.PODR.BIT.B0 = 0;
```

Line 1 sets LED0 as an output and line 2 switches on the LED.

Sets LEDs 1, 2, 3, and 4 (Port A bit 0, 1, 2, and 3) as Outputs

```
1. PORTA.PDR.BYTE = 0x47;
2. PORTA.PODR.BYTE = 0xB8;
```

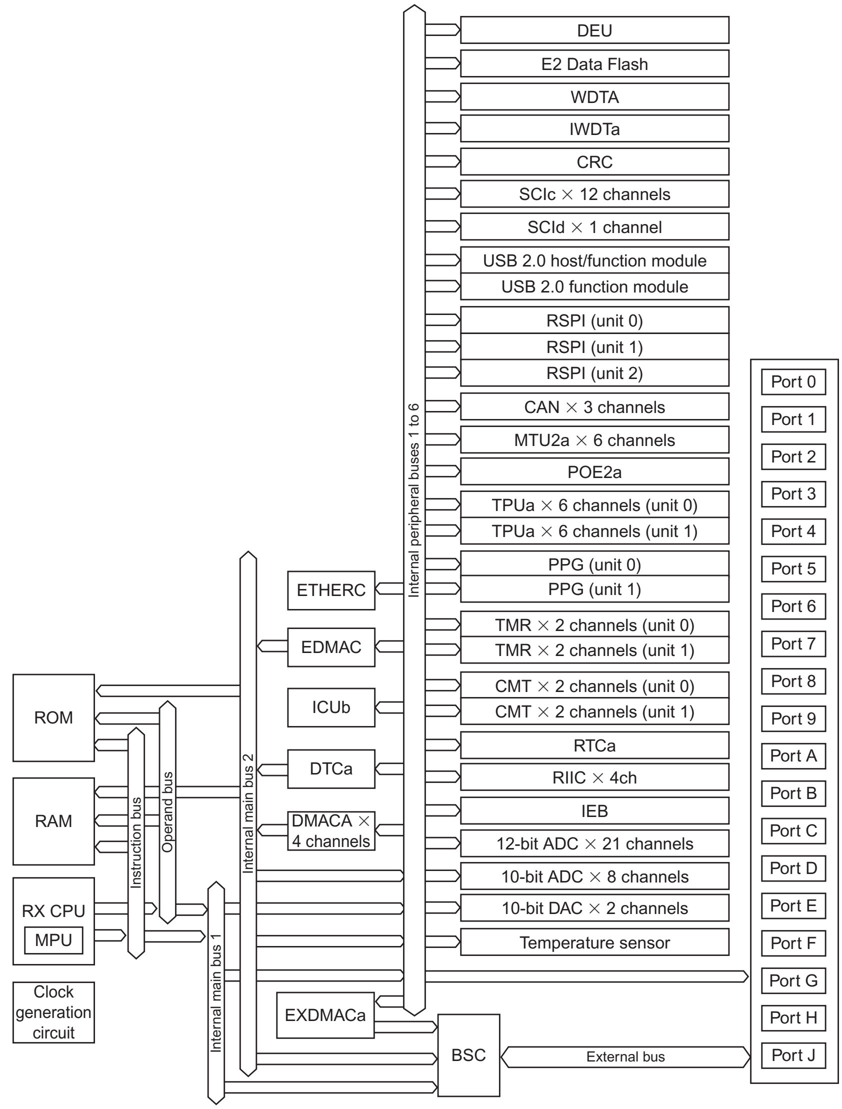
Line 1 sets LED1, 2, 3, and 4 as outputs and line 2 switches on the LEDs.

Port Input Data Register (PIDR)

The Port Input Data Register is also defined as a union of variables inside the port structure in the 'iodefine_gcc63n.h' file. PORTx.PIDR.BIT.Bn (x = 0 to 9, A to G, J; and n = 0 to 7) is used to read the state of a pin and the state is stored in the Port Input Data Register regardless of the value in the Port Mode Register (PMR). This register also has some reserved bits. These bits are read as 1 and cannot be modified.

	b7	b6	b5	b4	b3	b2	b1	b0
Value after reset:	0	0	0	0	0	0	0	0

Figure 2.7 Port Input Data Register [1], Page 663.



ETHERC :Ethernet controller
EDMAC :DMA controller for Ethernet controller
ICUb :Interrupt controller
DTCa :Data transfer controller
DMACA :DMA controller
EXDMACa :EXDMA controller
BSC :Bus controller
WDTA :Watchdog timer
IWDTa :Independent watchdog timer
CRC :CRC (cyclic redundancy check) calculator
SCIc, SCId :Serial communincations interface
MPU :Memory protection unit
RSP1 :Serial peripheral interface
CAN :CAN module
MTU2a :Multi-function timer pulse unit 2
POE2a :Port output enable 2
TPUa :16-bit timer pulse unit
PPG :Programmable pulse generator
TMR :8-bit timer
CMT :Compare match timer
RTCa :Realtime clock
RIIC :I^{2}C bus interface
IEB :IEBus controller
DEU :Data encryption unit

Figure 3.4 Block diagram [1], page 66.

3.4 SAKURA EXAMPLE PROJECT

Let's go through the sample project to get better acclimated with the development tools for the GR-SAKURA board. From the SAKURA board website, click on the "Try Guest Login" link.

When you first login, a window will pop-up asking you to create a project. You will need to select a "template" and a project name as seen below. Let's use the name "GR_SAKURA_Lab1" for this project.

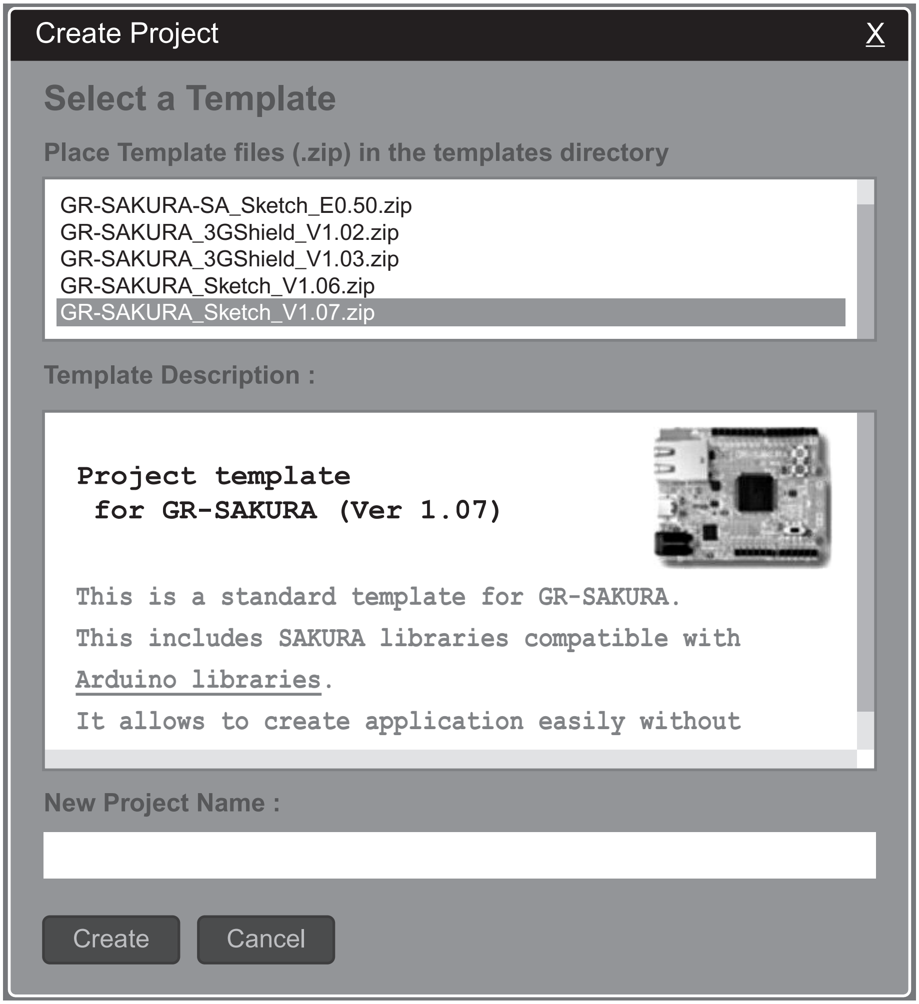


Figure 3.9 Create a project from a template.

Calculate how many rotations of the wheels we will need to travel one meter. To do this we will need to compute the circumference of the wheel then divide the forward distance by the circumference.

$$2\pi r = d\pi = 2.5 \text{ in} \times \pi \approx 7.854 \text{ in}$$
$$\frac{39.37 \text{ in}}{7.854 \text{ in/rotation}} \approx 5.012 \text{ rotations}$$

Now that we know how many rotations of the wheel we will need, we can compute the total rotations of the motor by multiplying the wheel rotations by the gear ratio.

$$5.012 \text{ wheel rotations} \times \frac{53 \text{ motor rotations}}{1 \text{ wheel rotation}} \approx 265.636 \text{ motor rotations}$$

Lastly, let's identify the total time that we will need to enable the motors in forward motion by taking the total motor rotations and dividing it by the rated RPM and converting to milliseconds.

$$\frac{265.636 \text{ motor rotations}}{6700 \text{ rotations/min}} \approx 0.039647 \text{ min}$$
$$0.039647 \text{ min} \times \frac{60 \text{ sec}}{1 \text{ min}} \times \frac{1000 \text{ ms}}{1 \text{ sec}} \approx 2378.82 \text{ ms}$$

We need to calculate the total distance that the wheels will need to rotate in opposite directions to make a 90 degree turn. First, calculate the distance from one wheel to the other. This can be achieved by simply measuring the platform from the center of one wheel to the other. To achieve a 90 degree turn, each wheel will need to travel ¼ of the total circumference in opposite directions.

Figure 3.39 shows a diagram of how we would expect the vehicle to move about its axis when the wheels are turning in opposite directions.

$$\frac{6.61685 \text{ in}}{7.854 \text{ in/rotation}} \approx 0.8425 \text{ wheel rotations}$$
$$0.8425 \text{ wheel rotations} \times \frac{53 \text{ motor rotations}}{1 \text{ wheel rotation}} \approx 44.65 \text{ motor rotations}$$
$$\frac{44.65 \text{ motor rotations}}{6700 \text{ motor rotations/min}} \approx 0.00666418 \text{ min}$$
$$0.00666418 \text{ min} \times \frac{60 \text{ sec}}{1 \text{ min}} \times \frac{1000 \text{ ms}}{1 \text{ sec}} \approx 399.85 \text{ ms}$$

8. Update the direction of the left wheel to backward, keep the right wheel direction forward
9. Enable the motors for 0.399 seconds to make a 90 degree turn
10. Disable the motors for 0.5 seconds (keep H-bridge from shorting)
11. Update the direction of the left wheel to forward, keep the right wheel direction forward
12. Repeat steps 6–11 three more times
13. Disable the motors

Once we are done with our algorithm, we can begin to code. The below code example satisfies the algorithm that we have created. But does it satisfy the customer requirements? Build the project using the code below and download it to the Sakura board. Make sure to connect the connectors to the pins defined in the code.

```
/*GR-SAKURA Sketch Template Version: V1.08*/
#include <rxduino.h>

#define directionA   2   //Port 2 pin 2 – motor A direction
#define enableA   3   //Port 2 pin 3 – motor A on/off
#define directionB   4   //Port 2 pin 4 – motor B direction
#define enableB   5   //Port 2 pin 5 – motor B on/off
#define Aforward   1
#define Abackward   0
#define Bforward   1
#define Bbackward   0
#define FORWARDTIME   2380   //forward delay in milliseconds
#define TURNTIME   400   //turn delay in milliseconds
#define PAUSE   500   //Pause between switching directions
#define ON   1
#define OFF   0
int i;   //counter variables
   //***********************************
   //setup input/output pins
   //
   //***********************************
   void setup() {
      pinMode(directionA,OUTPUT);
      pinMode(enableA,OUTPUT);
      pinMode(directionB,OUTPUT);
      pinMode(enableB,OUTPUT);
```

```
66.     }
67. }   //end program
```

Did the robot complete a 1 x 1 meter square? If the answer is yes then consider yourself lucky. If no, then it should not be a surprise. There are many variables that the above code does not consider. We use the rated speed for the motors, but it is more than likely that the RPM varies slightly from motor to motor. In fact, it could possibly be off by as much as 500 rpm. We also did not accommodate for or considered the weight of the robot, otherwise known as the payload. The more weight on the motors the slower they will rotate. How about the terrain? It would make a substantial difference in the rpm of the motors from riding on a smooth wooden surface or on a grassy field. How about slippage? It is quite possible for one of the wheels to slip slightly or even rotate faster than the other. To accommodate for our environment we will require feedback mechanisms, counters, and pulse width modulators. All this we will learn in Chapter 4, where we will attempt to utilize our knowledge to achieve the functionality dictated by our requirements.

3.9 RECAP

The GR-Sakura is one of the Gadget Renesas board series. It is based on RX63N series 32-bit MCU. The MCU has on-chip flash memory and enhanced communication functions, including an Ethernet controller and USB 2.0 Host/Function. The on-chip flash memory of RX63N is programmable by USB mass storage mode, and the on-chip flash memory is visible as a drive on your PC. This chapter presented the tools and processes to use the Sakura embedded board. The board is easy to program and use for many applications, including sensing applications and robotics.

3.10 REFERENCES

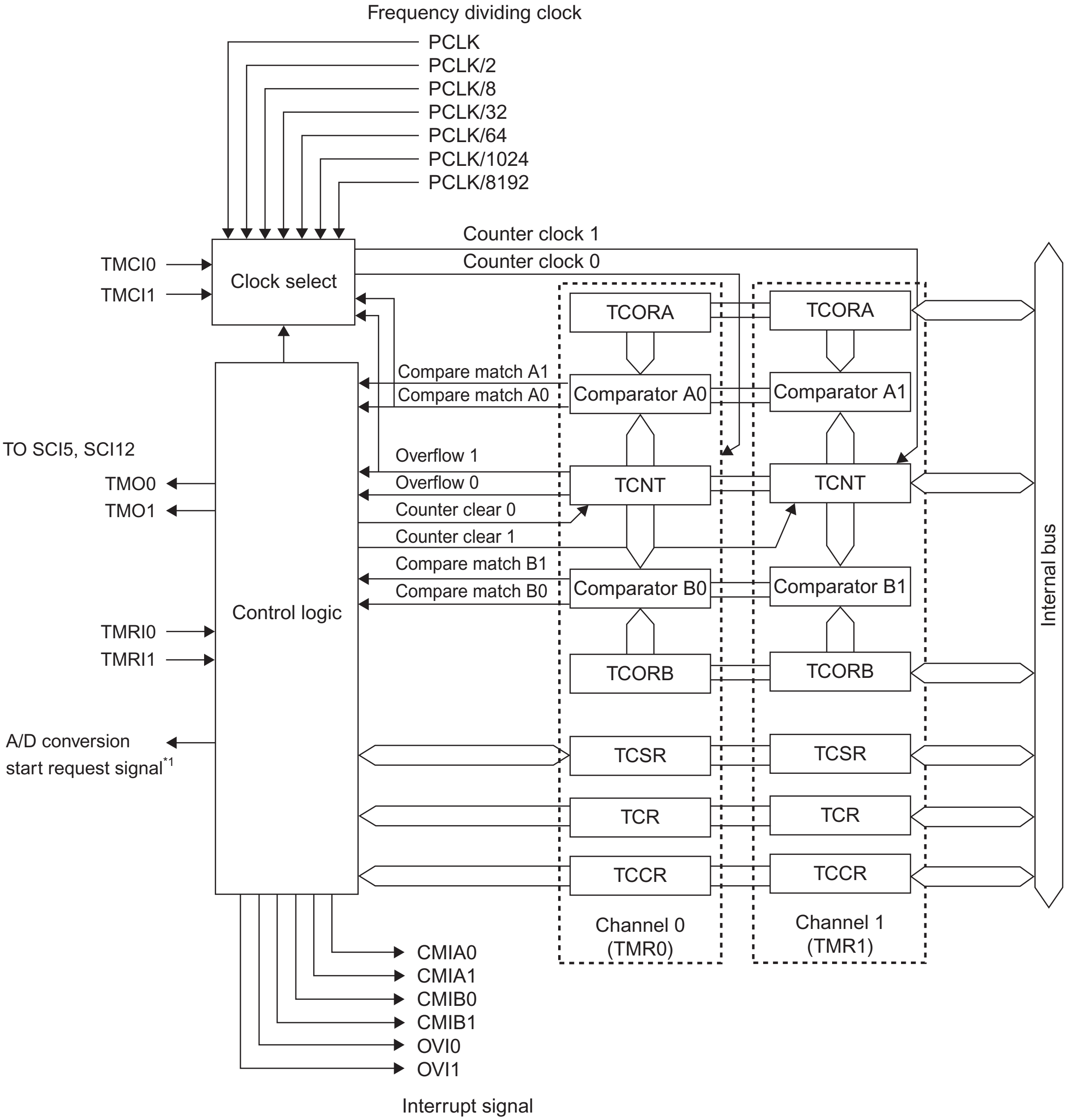
[1] Renesas Electronics, Inc. (February, 2013). *RX63N Group, RX631 Group User's Manual: Hardware, Rev.1.60.*

[2] Conrad, James M. (2013). *Embedded Systems: An Introduction using the RX63N Microcontroller.* Micrium Press.

[3] Digilent Inc. (August, 2012). *Motor Robot Kit (MRK) Reference Manual, Rev.*

[4] Digilent Inc. (February 28, 2012). *Digilent PmodHB5™ 2A H-Bridge Reference Manual, Circuit Rev D, Document Rev.*

[5] Shayang Ye. (April, 2010). *DC Carbon-brush motors, IG-22 Geared Motor Series: IG-22GP Type 01 & 02.*



TCORA:	Time constant register A	TCSR:	Timer control/status register
TCNT:	Timer counter	TCR:	Timer control register
TCORB:	Time constant register B	TCCR:	Timer counter control register

Note: * For the corresponding A/D converter channels, see section 40, 12-Bit A/D Converter (S12ADa), and section 41, 10-Bit A/D Converter (ADb).

Figure 4.2 Block diagram of TMR Unit 0 [1], page 1014.

4.2.1 Setting Up a Timer for Counting Events

Timer Count Register

The TCNT (Timer Counter) register holds the current timer value at any time after the timer has been configured. Whenever you want to know the value of the timer or counter you will read the value in this register. Also, when not currently operating the timer, you can load a value into this register and the timer will begin counting from that value when restarted. Note that in the 16-bit mode TMR0.TCNT and TMR1.TCNT (TMR2.TCNT and TMR3.TCNT as well) cascade into one 16-bit register. This holds true for the timer constant registers as well.

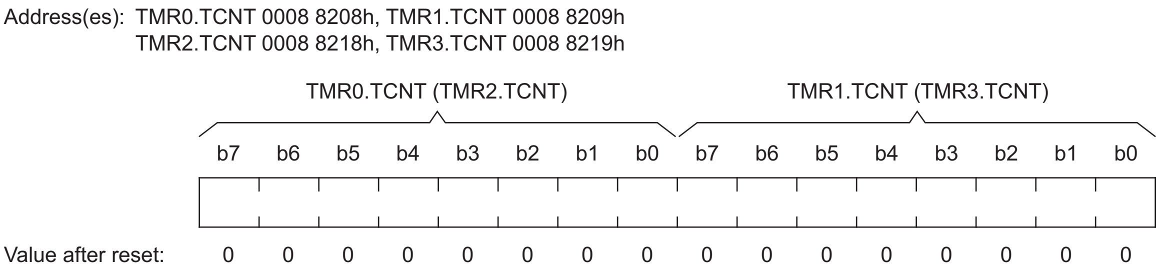


Figure 4.3 Timer Counter (TCNT) Register [1], page 1017.

The TCNT register is where the count is held. After the timer is started this register will increment every time a count is detected. If you want to know the current count, you can read this register. If the timer is stopped you can write a value to this register and it will begin counting from the written value when re-started.

Timer Counter Control Register

The Timer Counter Control Register (TCCR) controls where the timers count source comes from. Dependent on what value is set here, it will be determined if the count comes from the internal peripheral clock, a pre-scaled peripheral clock, an external count source, or from another timer overflowing. This register also enables the timer's interrupts on the peripheral level.

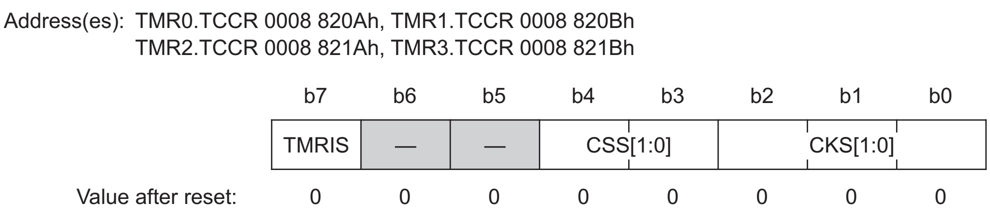


Figure 4.4 Timer Counter Control Register [1], page 1019.

BIT	SYMBOL	BIT NAME	DESCRIPTION	R/W
b2 to b0	CKS[2:0]	Clock Select*	See table below.	R/W
b4, b3	CSS[1:0]	Clock Source Select	See table below.	R/W
b6, b5	—	(Reserved)	These bits are always read as 0. The write value should always be 0.	R/W
b7	TMRIS	Timer Reset Detection Condition Select	0: Cleared at rising edge of the external reset	R/W
			1: Cleared when the external reset is high	

Note: * To use an external clock, set the Pn.PDR.Bi bit for the corresponding pin to "0" and the PORTn.PMR.Bi bit to "1". For details, see [1] section 21, I/O Ports.

Figure 4.5 TCCR (Timer Counter Control Register) description [1], page 1019.

CHANNEL	TCCR REGISTER					DESCRIPTION
	CSS[1:0]		CKS[2:0]			
	B4	B3	B2	B1	B0	
TMR0 (TMR2)	0	0	—	0	0	Clock input prohibited.
					1	Uses external clock. Counts at rising edge*[1].
				1	0	Uses external clock. Counts at falling edge*[1].
					1	Uses external clock. Counts at both rising and falling edges*[1].
	0	1	0	0	0	Uses internal clock. Counts at PCLK.
					1	Uses internal clock. Counts at PCLK/2.
				1	0	Uses internal clock. Counts at PCLK/8.
					1	Uses internal clock. Counts at PCLK/32.
			1	0	0	Uses internal clock. Counts at PCLK/64.
					1	Uses internal clock. Counts at PCLK/1024.
				1	0	Uses internal clock. Counts at PCLK/8192.
					1	Clock input prohibited.
	1	0	—	—	—	Setting prohibited.
	1	1	—	—	—	Counts at TMR1.TCNT (TMR3.TCNT) overflow signal*[2].

Figure 4.6 Clock input to TCNT and count condition [1], page 1020.

CHANNEL	TCCR REGISTER					DESCRIPTION
	CSS[1:0]		CKS[2:0]			
	B4	B3	B2	B1	B0	
TMR1 (TMR3)	0	0	—	0	0	Clock input prohibited.
					1	Uses external clock. Counts at rising edge*1.
				1	0	Uses external clock. Counts at falling edge*1.
					1	Uses external clock. Counts at both rising and falling edges*1.
	0	1	0	0	0	Uses internal clock. Counts at PCLK.
					1	Uses internal clock. Counts at PCLK/2.
				1	0	Uses internal clock. Counts at PCLK/8.
					1	Uses internal clock. Counts at PCLK/32.
			1	0	0	Uses internal clock. Counts at PCLK/64.
					1	Uses internal clock. Counts at PCLK/1024.
				1	0	Uses internal clock. Counts at PCLK/8192.
					1	Clock input prohibited.
	1	0	—	—	—	Setting prohibited.
	1	1	—	—	—	Counts at TMR0.TCNT (TMR2.TCNT) overflow signal*2.

Notes:
1. To use an external clock, set the PORTn.PDR.Bi bit for the corresponding pin to “0” and the PORTn.OPMR.Bi bit to “1”. For details, see [1] section 21, I/O Ports.
2. If the clock input of TMR0 (TMR2) is the overflow signal of the TMR1.TCNT (TMR3.TCNT) counter and that of TMR1 (TMR3) is the compare match signal of the TMR0.TCNT (TMR2.TCNT) counter, no incrementing clock is generated. Do not use this setting.

Figure 4.6 Clock input to TCNT and count condition [1], page 1020.—*Continued.*

Time Constant Register

The TCORA (Time Constant Register A) and TCORB (Time Constant Register B) are used to store constants to compare against the TCNT register. Every time the TCNT increments it is constantly being compared against either of these registers. When TCNT matches either of these registers, a compare match event occurs. Compare match events have many uses depending on what mode we are using the timer in.

Address(es): TMR0.TCORA 0008 8204h, TMR1.TCORA 0008 8205h
TMR2.TCORA 0008 8214h, TMR3.TCORA 0008 8215h

	TMR0.TCORA (TMR2.TCORA)								TMR1.TCORA (TMR3.TCORA)							
	b7	b6	b5	b4	b3	b2	b1	b0	b7	b6	b5	b4	b3	b2	b1	b0
Value after reset:	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

Figure 4.7 Time Constant Register A[1], page 1017.

Timer Control/Status Register

The TCSR (Timer Control/Status Register) register controls compare match output. Each timer has an output port assigned to it which is controlled via compare match events. This is one of many uses of the compare match events. When a compare match event occurs this register can set the output of the timer's port to 1 or 0, or toggle it. This register is used when we want the timer to control a pulse output.

Address(es): TMR0.TCSR 0008 8202h, TMR2.TCSR 0008 8212h

	b7	b6	b5	b4	b3	b2	b1	b0
	—	—	—	ADTE	OSB[1:0]		OSA[1:0]	
Value after reset:	x	x	x	0	0	0	0	0

Address(es): TMR0.TCSR 0008 8203h, TMR3.TCSR 0008 8213h

	b7	b6	b5	b4	b3	b2	b1	b0
	—	—	—	—	OSB[1:0]		OSA[1:0]	
Value after reset:	x	x	x	1	0	0	0	0

Figure 4.8 Timer Control/Status Register [1], page 1021.

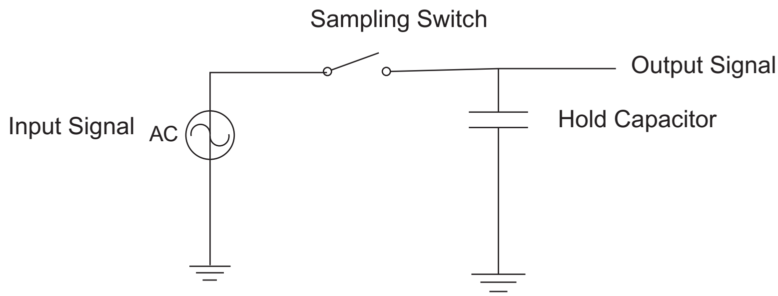


Figure 4.18 Sample and Hold Circuit.

Signal from the sample and hold circuit is then given to the comparator. The comparator compares the input signal with a reference signal and gives the digital output. The reference voltage of an ADC is the maximum analog voltage that can be converted by an ADC.

The digital value for a particular analog value can be found mathematically. This can be useful as a guide to see if the ADC output obtained is correct.

If V_{in} is the sampled input voltage, V_{+ref} is the upper end of input voltage range, V_{-ref} is the lower end of input voltage range, and N is the number of bits of resolution in ADC, the digital output (n) can be found using the following formula:

$$n = \left[\frac{(V_{\text{in}} - V_{-\text{ref}})(2^{\text{N}} - 1)}{V_{+\text{ref}} - V_{-\text{ref}}} + \frac{1}{2}\right]\text{int}$$

$$n = \left[\frac{(V_{\text{in}})(2^{\text{N}} - 1)}{V_{+\text{ref}}} + \frac{1}{2}\right]\text{int (if } V_{-\text{ref}} = 0)$$

Let us assume that the analog voltage to be calculated is 2.7 V and the 12-bit ADC has to be used. The digital value will be:

$$n = \left[\frac{(V_{\text{in}})(2^{\text{N}} - 1)}{V_{+\text{ref}}} + \frac{1}{2}\right]\text{int (Since } V_{-\text{ref}} = 0) = \left[\frac{(2.7)(2^{12} - 1)}{3.3} + \frac{1}{2}\right]\text{int} = \left[\frac{(2.7)(\mathbf{4095})}{3.3} + \frac{1}{2}\right]\text{int}$$

$$n = 3352_{10}$$

The GR-SAKURA has one 10-bit A/D converter unit and one 12-bit A/D converter unit. However, the GR-SAKURA is designed specifically to use as little real-estate as possible, hence there are not enough designated pins on the board to support all of the RX63N MCU functionality at the same time. There are six designated A/D pins (AN0 to AN5) that can only be used for the 12-bit A/D.

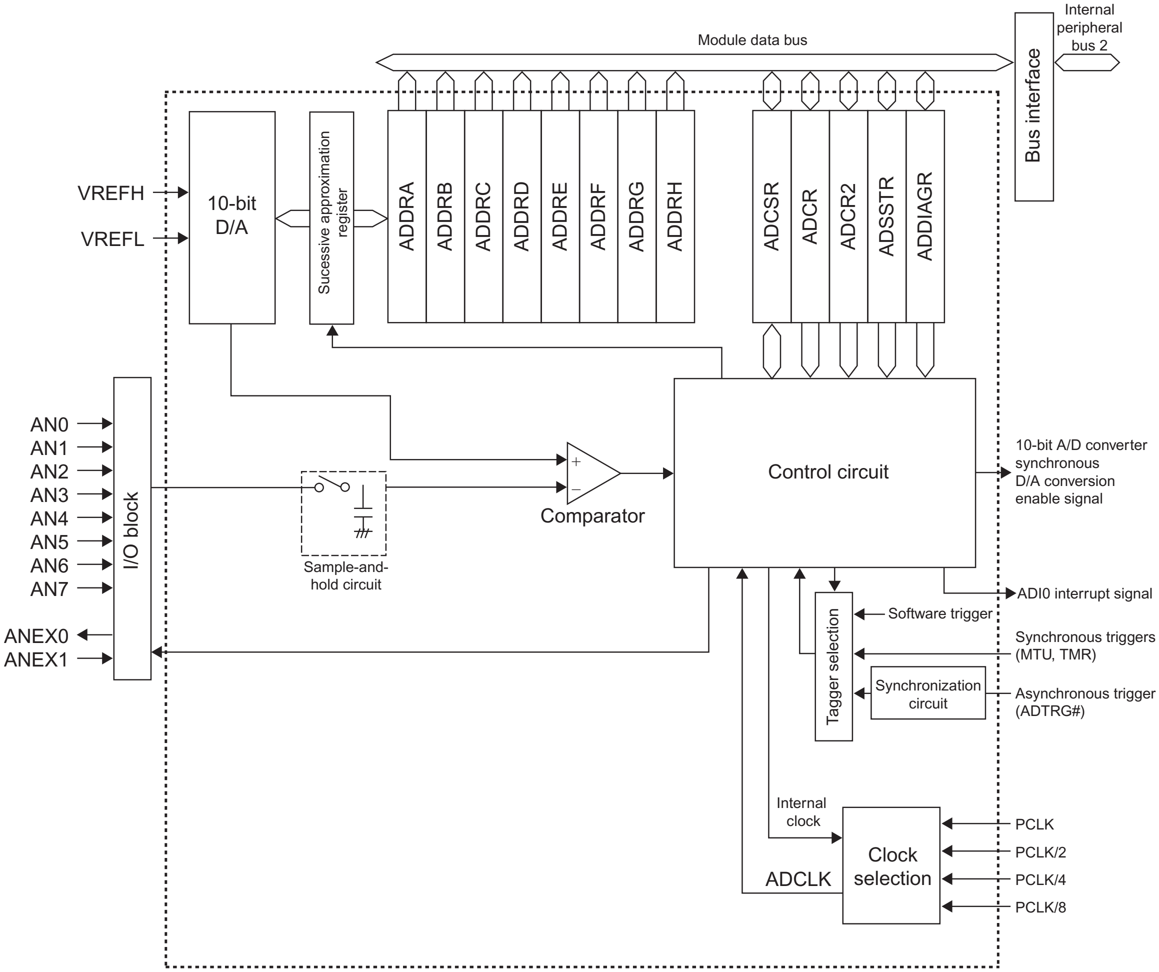
TABLE 4.3 GR-Sakura 12-bit A/D Converter Port Map [8].

CN15	PIN NUMBER 100 PIN LQFP	I/O PORT	BUS EXDMAC	TIMER (MTU, TPU, TMR, PPG, RTC, POE)	COMMUNICATIONS (ETHERC, SCIc, SCId, RSPI, RIIC, CAN, IEB, USB)	INTERRUPT	S12AD, AD, DA
AD0	95	P40				IRQ8-DS	AN000
AD1	93	P41				IRQ9-DS	AN001
AD2	92	P42				IRQ10-DS	AN002
AD3	91	P43				IRQ11-DS	AN003
AD4	90	P44				IRQ12-DS	AN004
AD5	89	P45				IRQ13-DS	AN005

The 10-bit ADC cannot be utilize with the defined A/D pins AN001-AN005. However, the GR-SAKURA does provide access to the 10-bit ADC using the pins shown in Table 4.4A.

TABLE 4.4A GR-Sakura 10-bit A/D Converter Port Map[8].

CN15	PIN NUMBER 100 PIN LQFP	I/O PORT	BUS EXDMAC	TIMER (MTU, TPU, TMR, PPG, RTC, POE)	COMMUNICATIONS (ETHERC, SCIc, SCId, RSPI, RIIC, CAN, IEB, USB)	INTERRUPT	S12AD, AD, DA
IO44	78	PE0	D8[A8/D8]		SCK12/ SSLB1		ANEX0
IO45	77	PE1	D9[A9/D9]	MTIOC4C/ PO18	TXD12/ SMOSI12/ SSDA12/ TXDX12/ SIOX12/ SSLB2/ RSPCKB		ANEX1
IO46	76	PE2	D10[A10/D10]	MTIOC4A/ PO23	RXD12/ SMISO12/ SSCL12/ RXDX12/ SSLB3/MOSIB	IRQ7-DS	AN0
IO47	75	PE3	D11[A11/D11]	MTIOC4B/ PO26/ POE8#	CTS12#/ RT S12#/ SS12#/ MISOB/ ET_ERXD3		AN1
IO48	74	PE4	D12[A12/D12]	MTIOC4D/ MTIOC1A/ PO28	SSLB0/ ET_ERXD2		AN2
IO49	73	PE5	D13[A13/D13]	MTIOC4C/ MTIOC2B	RSPCKB/ ET_RX_CLK/ REF50CK	IRQ5	AN3
IO50	72	PE6	D14[A14/D14]		MOSIB	IRQ6	AN4
IO51	71	PE7	D15[A15/D15]		MOSIB	IRQ7	AN5
IO42	80	PD6	D6[A6/D6]	MTIC5V/POE1#		IRQ6	AN6
IO43	79	PD7	D7[A7/D7]	MTIC5U/POE0#		IRQ7	AN7



ADDRA: A/D data register A
ADDRB: A/D data register B
ADDRC: A/D data register C
ADDRD: A/D data register D
ADDRE: A/D data register E
ADDRF: A/D data register F
ADDRG: A/D data register G
ADDRH: A/D data register H

ADCSR: A/D control/status register
ADCR: A/D control register
ADCR2: A/D control register 2
ADSSTR: A/D sampling state register
ADDIAGR: A/D self-diagnostic register

Figure 4.20 Block Diagram of the 10-bit A/D Converter [1], page 1684.

TABLE 4.5 List of 10-bit A/D Converter Registers [2], page 77.

ADDRESS	MODULE SYMBOL	REGISTER NAME	REGISTER SYMBOL	NUMBER OF BITS	ACCESS SIZE	NUMBER OF ACCESS STATES		RELATED FUNCTION
						ICLK ≥ PCLK	ICLK < PCLK	
0008 9800h	AD	A/D data register A	ADDRA	16	16	2, 3 PCLKB	2 ICLK	ADb
0008 9802h	AD	A/D data register B	ADDRB	16	16	2, 3 PCLKB	2 ICLK	
0008 9804h	AD	A/D data register C	ADDRC	16	16	2, 3 PCLKB	2 ICLK	
0008 9806h	AD	A/D data register D	ADDRD	16	16	2, 3 PCLKB	2 ICLK	
0008 9808h	AD	A/D data register E	ADDRE	16	16	2, 3 PCLKB	2 ICLK	
0008 980Ah	AD	A/D data register F	ADDRF	16	16	2, 3 PCLKB	2 ICLK	
0008 980Ch	AD	A/D data register G	ADDRG	16	16	2, 3 PCLKB	2 ICLK	
0008 980Eh	AD	A/D data register H	ADDRH	16	16	2, 3 PCLKB	2 ICLK	
0008 9810h	AD	A/D control/status register	ADCSR	8	8	2, 3 PCLKB	2 ICLK	
0008 9811h	AD	A/D control register	ADCR	8	8	2, 3 PCLKB	2 ICLK	
0008 9812h	AD	A/D control register 2	ADCR2	8	8	2, 3 PCLKB	2 ICLK	
0008 9813h	AD	A/D sampling state register	ADSSTR	8	8	2, 3 PCLKB	2 ICLK	
0008 981Fh	AD	A/D self-diagnostic register	ADDIAGR	8	8	2, 3 PCLKB	2 ICLK	

The width of the ADDRn (16-bit) is greater than the width of the ADC output (10-bit). To avoid reading wrong data, the output has to be aligned either to the right or left of ADDRn. This can be done by setting the ADCR2.DPSEL bit. This will be explained a little later.

4.3.2 Initializing the 10-bit A/D Converter

Module Stop Control Register A (MSTPCRA)

The module-stop control registers is a 32-bit register and can be used to place modules in and release modules from the module-stopped state. The several modules that realize frequency measurement are all stopped in their initial state. Releasing the modules from the stopped state makes operations for frequency measurement possible. Before we can utilize the 10-bit A/D converter, we would need to release the module from the stopped state by configuring bit 23 of the MSTPCRA[31:0] register.

Address(es): 0008 0010h

	b31	b30	b29	b28	b27	b26	b25	b24	b23	b22	b21	b20	b19	b18	b17	b16
	ACSE	—	MSTPA 29	MSTPA 28	MSTPA 27	—	—	MSTPA 24	MSTPA 23	—	—	—	MSTPA 19	—	MSTPA 17	—
Value after reset:	0	1	0	0	0	1	1	0	1	1	1	1	1	1	1	1

	b15	b14	b13	b12	b11	b10	b9	b8	b7	b6	b5	b4	b3	b2	b1	b0
	MSTPA 15	MSTPA 14	MSTPA 13	MSTPA 12	MSTPA 11	MSTPA 10	MSTPA 9	—	—	—	MSTPA 5	MSTPA 4	—	—	—	—
Value after reset:	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1	1

b23	MSTPA23	10-bit A/D Converter Module Stop	Target module: AD	R/W
			0: The module-stop state is canceled	
			1: Transition to the module-stop state is made	

Figure 4.22 Module Stop Control Register A (MSTPCRA) Description [1], page 282.

A/D Control/Status Register (ADCSR)

The Control/Status Register is used to select the input channels, start or stop A/D conversion, and enable or disable the ADI interrupt. The CH[2:0] register is used to select the analog channels which have to be A/D converted. The channels can be selected using the Table 4.6.

TABLE 4.6 Channel Selection [1], page 1690.

WHEN ADCR.MODE[1:0] = 00B				WHEN ADCR.MODE[1:0] = 10B OR 11B			
B2	B1	B0		B2	B1	B0	
0	0	0	AN0	0	0	0	AN0
0	0	1	AN1	0	0	1	AN0, AN1
0	1	0	AN2	0	1	0	AN0 to AN2
0	1	1	AN3	0	1	1	AN0 to AN3
1	0	0	AN4	1	0	0	AN0 to AN4
1	0	1	AN5	1	0	1	AN0 to AN5
1	1	0	AN6	1	1	0	AN0 to AN6
1	1	1	AN7	1	1	1	AN0 to AN7

When used as an analog sensor, the QTI can detect shades of gray on paper and distances over a short range if the light in the room remains constant. The QTI sensor has 2 inputs and one output. When W is connected to V_{dd} (5V) and B is connected to V_{ss} (GND), the R terminal's voltage will drop or rise based on the shade of the surface. If all you want to know is whether a line is black or white, the QTI can be converted to a digital sensor by adding a 10 kΩ resistor across its W and R terminals. After doing so, the QTI behaves similarly to the circuit in figure 4.28. When W is connected to Vdd and B is connected to V_{ss}, the R terminal's voltage will drop below 1.4 V when the IR transistor sees infrared reflected from the IR LED. When the IR LED's signal is mostly absorbed by a black surface, the voltage at R goes above 1.4 V [7].

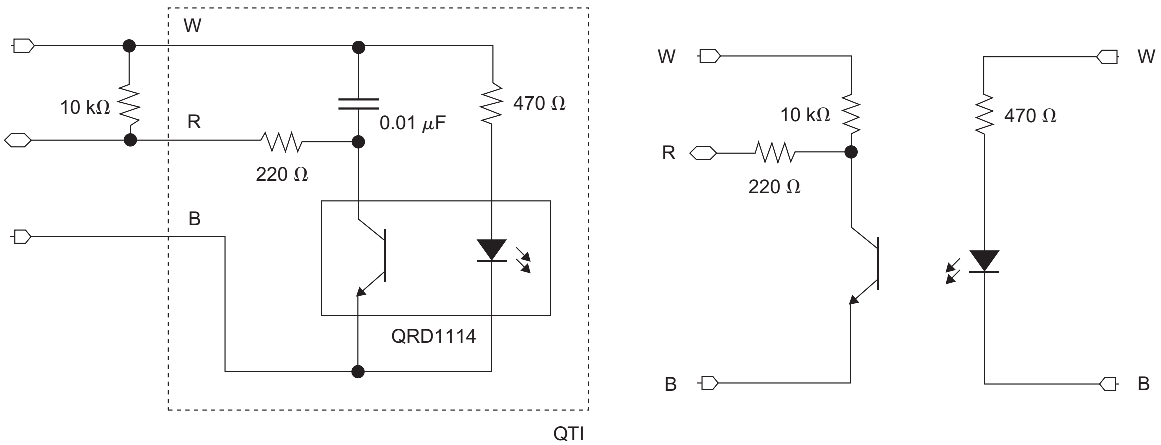


Figure 4.28 QTI sensor electrical characteristics using a 10K resistor [7].

Since we have made the design decision to use the QTI sensor, we have implied several derived requirements. (1) The surface of the environment will need to be white and (2) we will need to outline our borders in black. Can you think of any other requirements that can be derived from the design decision of using the QTI sensor to meet our initial set of requirements? Note that the QTI sensor needs to be very close to the surface/ground to get an appropriate reading.

Given the specification of the QTI sensor we know that our threshold voltage that will determine if the robot has reached the border will be 1.4V. We also know that our board V_{ref+} is 3.3V and V_{ref-} GND or 0V. Given this we can calculate the integer value for our threshold.

$$\left[\frac{1.4V(2^{10}-1)}{3.3V}+\frac{1}{2}\right]\text{int} = 434 = 0x1B2$$

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