Jonathan W. Valvano

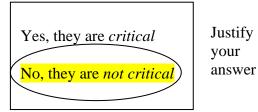
First:_____ Last:__

March 3, 2017, 9:00am-9:50am. This is a closed book exam, with one 8.5 by 11-inch crib sheet. You have 50 minutes, so please allocate your time accordingly. *Please read the entire quiz before starting*.

(15) Question 1. You are asked to consult on a project because they have weird and intermittent bugs. The system runs on a Freescale 9S12, which is nothing like the Cortex M, but you decide to look at it anyway. You see many read-modify-write accesses to output ports. To set bit 2, the software executes **PTT** |= 0x04; To clear bit 0, the software executes **PTT** &= ~0x01; To set bit 7, the software executes **PTT** |= 0x80; To investigate, you find this assembly code generated by the compiler.

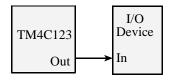
;PTT = 0x04	;PTT &= ~0x01	;PTT = 0x80;
BSET PTT,#4	BCLR PTT,#1	BSET PTT,#\$80

Do these read-modify-write accesses to Port T create critical sections? Circle your choice and justify



On most computers individual instructions execute atomically. Notice the access to the shared global requires just one instruction. It is not critical because the readmodify-write accesses are atomic.

(10) Question 2. You have connected a TM4C123 output pin to an unknown device, with 8-mA mode selected. Your software outputs a 1 to the pin, but your voltmeter measures only 2.5 V.



Is it broken? Specify *OK* or *Broken*:

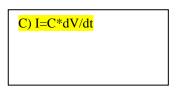
If OK, explain why. If Broken, show at least one parameter/equation not satisfied.

OK

It is OK, because the output voltage is larger than $V_{OH} = 2.4$ V

(5) Question 3. Consider an ideal capacitor. Which is correct? There is one answer, put letter in box.

- A) Voltage is directly proportional to current.
- B) Voltage is proportional to a change in current.
- C) Current is proportional to a change in voltage.
- D) At DC, the capacitor can be considered a short circuit.
- E) None of the above.



(10) Question 4. Let *N1 N2 N3 N4* be the values of four 16-bit signed decimal fixed-point numbers each with a resolution of 0.01 Assume **I1**, **I2**, **I3**, and **I4** are the corresponding integer parts. Write the body of the function that implements fixed-point math, N4 = N2*N1+N3. Minimize dropout, but don't worry about overflow.

int16_t Math(int16_t I1, int16_t I2, int16_t I3){ int16_t I4;

```
// step 1, write desired action: N4 = N3*N2+N1
// step 2, substitute definitions: I4/100 = I3/100*I2/100+I1/100
// step 3, solve for I4, factor, simplify:
I4 = (I1*I2)/100 + I3;
return I4;
```

return 14
}

}

(10) Question 5. Show the C code to create a signed 32-bit global variable that is shared between the main program and an ISR. For example, define **Count** in the correct manner for this use case.

```
int32_t volatile Count;
// adding static is ok, const is very wrong
void main(void){
    Init(); // Systick interrupts every 1ms
    while(1){
        Count = 1000;
        while(Count>0){}
        GPIO_PORTF_DATA_R ^= 0x02;
    }
}
void SysTick_Handler(void){
    Count--;
```

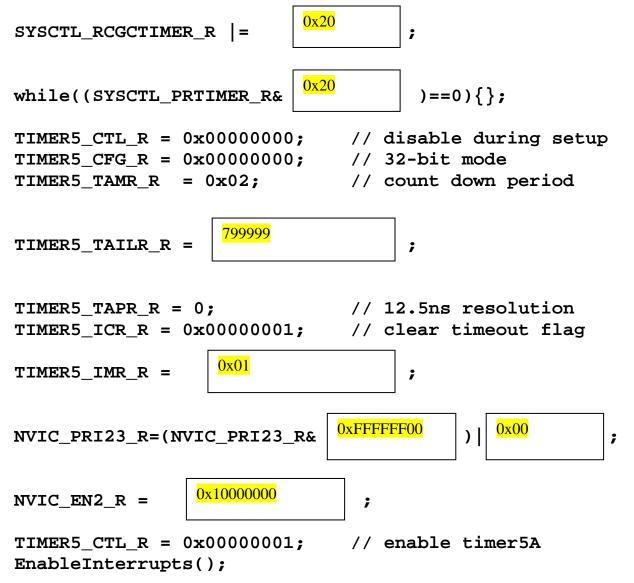
```
(10) Question 6. How much stack space does this ISR need?
Give your answer in bytes.
uint32_t Count=0;
void Timer5A_Handler(void){
   Count++;
   TIMER5_ICR_R = 0x00000001; // acknowledge timeout
}
```

8 registers are pushed, each is 4 bytes, 32 bytes needed

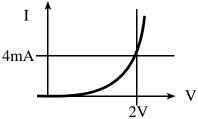
Count is not local, it is static; meaning it does not get placed on the stack Interrupts push R0,R1,R2,R3,R12,LR,PC,PSW on stack (5) Question 7. What is the response from the internet when a UDP packet is lost?

Nothing happens, if packets are lost, they are lost. UDP is best effort, but delivery is not guaranteed. Contrast with TCP, which will retransmit.

(15) Question 8) You are asked to configure Timer 5A to interrupt every 10 ms. The bus clock is 80 MHz. Put your answers in the boxes. Make Timer 5A an interrupt with the highest priority. Timer 5 priority is in bits 7,6,5 of PRI23 register. Timer 5A is interrupt 92, which is bit 92-64=28 of EN2.



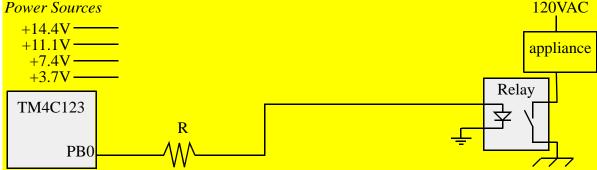
(15) Question 9. Interface a solid state relay to the microcontroller. A digital output on PB0 controls the relay. PB0 is an output with 8-mA selected. If PB0 is high, a 2V signal should be applied across the relay control, and the 120VAC switch will activate causing the appliance to turn on. If PB0 is low, no current should flow through the relay control, and the 120VAC switch will deactivate causing the appliance to turn off. The desired set-point to activate the relay is 2V, 4mA. The following graph plots the voltage current relation on the relay control.



You may use +3.7V, +7.4V, +11.1V, or 14.4V power. Decide whether to use no transistor (\$0.00), a 2N2222 (\$0.44), or a TIP120 (\$0.72). Select the least expensive circuit that will operate the relay. Show your work including resistance values. No software needed, just the hardware circuit.



The interface is a simple positive LED interface with no driver. It is ok to pick any V_{OH} between 2.4 and 3.3 V. At $V_{OH} = 2.4$ V, R = (2.4-2)/4mA = 0.4V/4mA = 100 ohms. At $V_{OH} = 3.3$ V, R = (3.3-2)/4mA = 1.3V/4mA = 325 ohms. So any resistance between 100 and 325 ohms is ok.



$V_{OL} = 0.4V, V_{OH} = 2.4V, \qquad V_{IL} = 1.3V, V_{IH} = 2.0V$ $31-3 \qquad 2-0 \qquad \text{Name}$ $4003.000 \qquad 31-4 \qquad 3 \qquad 2 \qquad 1-0$ $1003.000 \qquad 100 \qquad 100 \qquad 1000 \qquad 10000 \qquad 100000 \qquad 100000 \qquad 100000 \qquad 100000 \qquad 1000000 \qquad 1000000 \qquad 1000000 \qquad 10000000 \qquad 100000000$	$I_{OL} = 8 \text{mA},$	$I_{OH} =$	= 8mA,		$I_{IL} =$	2μΑ,	$I_{IH} =$	2µA,					
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44003.0048TARHTARLTIMER0_TAR_RAddress $31 - 29$ $23 - 21$ $15 - 13$ $7 - 5$ Name0xE000E400GPIO Port DGPIO Port CGPIO Port BGPIO Port ANVIC_PRI0_R0xE000E404SSI0, Rx TxUART1, Rx TxUART0, Rx TxGPIO Port ENVIC_PRI1_R0xE000E408PWM Gen 1PWM Gen 0PWM Fault $12C0$ NVIC_PRI2_R0xE000E401Timer 0AWatchdogADC Seq 3ADC Seq 2NVIC_PRI3_R0xE000E410Timer 0AWatchdogADC Seq 3ADC Seq 2NVIC_PRI5_R0xE000E414Timer 2ATimer 1BTimer 1ATimer 0BNVIC_PRI5_R0xE000E425CWide Timer 0BWide Timer 0ATimer 5BTimer 5ANVIC_PRI3_R0xE000E100FTimer0AUART1UART0EDCBANVIC_EN0_R0xE000E104FTimer5AUART1UART0EDCBANVIC_EN0_R0xE000E104FTimer5AUART1UART0EDCBANVIC_EN0_R0xE000E104GCOUNTOCLK_SRCINTENENABLENVIC_ST_CTRL_R0xE000E104G23-171615-3210NameSE000E014OO24-bit CURRENT value of SysTick counterNVIC_ST_CTRL_R	\$4003.0040									TAPS	SMR	TIMER0_TAPMR_	
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Address31 - 2923 - 2115 - 137 - 5Name0xE000E400GPIO Port DGPIO Port CGPIO Port BGPIO Port ANVIC_PRID_R0xE000E404SSI0, Rx TxUART1, Rx TxUART0, Rx TxGPIO Port ENVIC_PRIL0xE000E404SSI0, Rx TxUART1, Rx TxUART0, Rx TxGPIO Port ENVIC_PRIL0xE000E402ADC Seq 1ADC Seq 0Quad EncoderPWM Gen 2NVIC_PRI30xE000E410Timer 0AWatchdogADC Seq 3ADC Seq 2NVIC_PRI30xE000E414Timer 2ATimer 1BTimer 1ATimer 0BNVIC_PRI50xE000E45CWide Timer 0BWide Timer 0ATimer 5BTimer 5ANVIC_PRI23_R0xE000E102SysTickPendSVDebugNVIC_SYS_PRI3_R1Address30281965432100xE000E104FTimer0AUART1UART0EDCBANVIC_EN0_R0xE000E104FTimer0AUART1UART0EDCBANVIC_EN1_R0xE000E104IIIIIIINVIC_ST_CTRL_R0xE000E104IIIIIIII0xE000E104IIIIIII0xE000E108ITimer5AIIINVIC_ST_CTRL_RSE000E01000COUNTIIII </td <td>+ · · · · · · · · · · · · · · · · · · ·</td> <td></td> <td></td> <td></td> <td></td> <td></td> <td></td> <td colspan="6">31–16 15-0</td>	+ · · · · · · · · · · · · · · · · · · ·							31–16 15-0					
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OxE000E40C ADC Seq 1 ADC Seq 0 Quad Encoder PWM Gen 2 NVIC_PRI3_R 0xE000E410 Timer 0A Watchdog ADC Seq 3 ADC Seq 2 NVIC_PRI4_R 0xE000E414 Timer 2A Timer 1B Timer 1A Timer 0B NVIC_PRI5_R 0xE000E418 Comp 2 Comp 1 Comp 0 Timer 2B NVIC_PRI6_R 0xE000E45C Wide Timer 0B Wide Timer 0A Timer 5B Timer 5A NVIC_PRI3_R 0xE000E100 SysTick PendSV Debug NVIC_SYS_PRI3_R Address 30 28 19 6 5 4 3 2 1 0 Name 0xE000E100 F Timer0A UART1 UART0 E D C B A NVIC_EN0_R 0xE000E104 Imer5A <	0xE000E400	GPIO P	– 29 Port D	23 – 2 GPIO Port	t C	GPIO P	ort B	7 - GPIO P	– 5 ort A	N	ame VIC_PRI0_1	R	
OxE000E410Timer 0AWatchdogADC Seq 3ADC Seq 2NVIC_PRI4_ROxE000E414Timer 2ATimer 1BTimer 1ATimer 0BNVIC_PRI5_ROxE000E418Comp 2Comp 1Comp 0Timer 2BNVIC_PRI6_ROxE000E45CWide Timer 0BWide Timer 0ATimer 5BTimer 5ANVIC_PRI23_ROxE000ED20SysTickPendSVDebugNVIC_SYS_PRI3_RAddress3028196543210NameNameOxE000E100FTimer0AUART1UART0EDCBANVIC_EN0_R0xE000E104IIIIIIINVIC_EN1_R0xE000E108Timer5AIIINVIC_ST_CTRL_RAddress31-2423-171615-3210Name\$E000E0100OCOUNT0CLK_SRCINTENENABLENVIC_ST_CTRL_R\$E000E014024-bit CURRENT value of SysTick counterNVIC_ST_CURRENT_R	0xE000E400 0xE000E404	GPIO P SSI0, R	– 29 Port D Ix Tx	23 – 2 GPIO Port UART1, R	t C Rx Tx	GPIO P UARTO	ort B , Rx Tx	7 - GPIO P GPIO P	– 5 ort A	N N	ame VIC_PRI0_] VIC_PRI1_]	R R	
OxE000E414 Timer 1A Timer 1B Timer 1A Timer 0B NVIC_PRI5_R OxE000E418 Comp 2 Comp 1 Comp 0 Timer 2B NVIC_PRI6_R OxE000E45C Wide Timer 0B Wide Timer 0A Timer 5B Timer 5A NVIC_PRI3_R OxE000ED20 SysTick PendSV Debug NVIC_SYS_PRI3_R Address 30 28 19 6 5 4 3 2 1 0 Name 0xE000E100 F Timer0A UART1 UART0 E D C B A NVIC_EN0_R 0xE000E104 Imer5A Imer5A Imer5A Imer5A Imer5A NVIC_EN1_R 0xE000E108 Timer5A Imer5A Imer5A Imer5A Imer5A Imer5A NVIC_EN2_R Address 31-24 23-17 16 15-3 2 1 0 Name \$E000E010 0 O COUNT 0 CLK_SRC INTEN ENABLE NVIC_ST_CTRL_R \$E000E014 0 24-bit CURRENT value of SysTick counter <td>0xE000E400 0xE000E404 0xE000E408</td> <td>GPIO P SSI0, R PWM C</td> <td>– 29 Port D Ix Tx Gen 1</td> <td>23 – 2 GPIO Port UART1, R PWM Gen</td> <td>t C Rx Tx n 0</td> <td>GPIO P UARTO PWM F</td> <td>ort B , Rx Tx ault</td> <td>7 - GPIO P GPIO P I2C0</td> <td>– 5 ort A ort E</td> <td>N N N</td> <td>ame VIC_PRI0_1 VIC_PRI1_1 VIC_PRI2_1</td> <td>R R R</td>	0xE000E400 0xE000E404 0xE000E408	GPIO P SSI0, R PWM C	– 29 Port D Ix Tx Gen 1	23 – 2 GPIO Port UART1, R PWM Gen	t C Rx Tx n 0	GPIO P UARTO PWM F	ort B , Rx Tx ault	7 - GPIO P GPIO P I2C0	– 5 ort A ort E	N N N	ame VIC_PRI0_1 VIC_PRI1_1 VIC_PRI2_1	R R R	
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OxE000E45C Wide Timer 0B Wide Timer 0A Timer 5B Timer 5A NVIC_PRI23_R 0xE000ED20 SysTick PendSV Debug NVIC_SYS_PRI3_R Address 30 28 19 6 5 4 3 2 1 0 Name 0xE000E100 F Timer0A UART1 UART0 E D C B A NVIC_EN0_R 0xE000E104 Imer5A Imer5A Imer5A Imer5A Imer5A Imer5A Imer5A Imer5A 0xE000E108 Timer5A Imer5A Imer5A <td>0xE000E400 0xE000E404 0xE000E408 0xE000E40C 0xE000E410</td> <td>GPIO P SSI0, R PWM C ADC So Timer (</td> <td>– 29 Port D Ix Tx Gen 1 eq 1 DA</td> <td>23 – 2 GPIO Port UART1, R PWM Gen ADC Seq Watchdog</td> <td>t C Rx Tx 1 0 0</td> <td>GPIO P UARTO PWM F Quad En ADC Se</td> <td>ort B , Rx Tx ault ncoder aq 3</td> <td>7 - GPIO P GPIO P I2C0 PWM C ADC Se</td> <td>- 5 ort A ort E ien 2 eq 2</td> <td>N N N N</td> <td>ame VIC_PRI0_ VIC_PRI1_] VIC_PRI2_] VIC_PRI3_] VIC_PRI4_]</td> <td>R R R R R R</td>	0xE000E400 0xE000E404 0xE000E408 0xE000E40C 0xE000E410	GPIO P SSI0, R PWM C ADC So Timer (– 29 Port D Ix Tx Gen 1 eq 1 DA	23 – 2 GPIO Port UART1, R PWM Gen ADC Seq Watchdog	t C Rx Tx 1 0 0	GPIO P UARTO PWM F Quad En ADC Se	ort B , Rx Tx ault ncoder aq 3	7 - GPIO P GPIO P I2C0 PWM C ADC Se	- 5 ort A ort E ien 2 eq 2	N N N N	ame VIC_PRI0_ VIC_PRI1_] VIC_PRI2_] VIC_PRI3_] VIC_PRI4_]	R R R R R R	
OxE000ED20 SysTick PendSV Debug NVIC_SYS_PRI3_R Address 30 28 19 6 5 4 3 2 1 0 Name OxE000E100 F Timer0A UART1 UART0 E D C B A NVIC_EN0_R 0xE000E104 Image: Constraint of the state of the	0xE000E400 0xE000E404 0xE000E408 0xE000E40C 0xE000E410 0xE000E414	GPIO P SSI0, R PWM C ADC So Timer 0 Timer 2	– 29 Port D Ix Tx Gen 1 eq 1 DA 2A	23 – 2 GPIO Port UART1, R PWM Gen ADC Seq Watchdog Timer 1B	t C Rx Tx 1 0 0	GPIO P UARTO PWM F Quad En ADC Se Timer 1	ort B , Rx Tx ault ncoder eq 3 A	7 - GPIO P GPIO P I2C0 PWM C ADC Se Timer 0	- 5 ort A ort E ien 2 eq 2 B	N N N N N	ame VIC_PRI0_ VIC_PRI1_ VIC_PRI2_ VIC_PRI3_ VIC_PRI4_ VIC_PRI5_	R R R R R R R R	
Address 30 28 19 6 5 4 3 2 1 0 Name 0xE000E100 F Timer0A UART1 UART0 E D C B A NVIC_EN0_R 0xE000E104 Image: Constraint of the state of	0xE000E400 0xE000E404 0xE000E408 0xE000E40C 0xE000E410 0xE000E414 0xE000E418	GPIO P SSI0, R PWM C ADC So Timer 0 Timer 2 Comp 2	- 29 Port D Ix Tx Gen 1 eq 1 DA 2A 2	23 – 2 GPIO Port UART1, R PWM Gen ADC Seq Watchdog Timer 1B Comp 1	t C Rx Tx n 0 0	GPIO P UARTO PWM F Quad E ADC Se Timer 1 Comp 0	ort B , Rx Tx ault ncoder q 3 A	7 - GPIO P GPIO P I2C0 PWM C ADC Se Timer 0 Timer 2	- 5 ort A ort E den 2 eq 2 B B B	N' N' N' N' N'	ame VIC_PRI0_ VIC_PRI1_ VIC_PRI3_ VIC_PRI3_ VIC_PRI4_ VIC_PRI5_ VIC_PRI6_	R R R R R R R R R	
OxE000E100 F Timer0A UART1 UART0 E D C B A NVIC_EN0_R 0xE000E104 Image: Constraint of the state of t	0xE000E400 0xE000E404 0xE000E408 0xE000E40C 0xE000E410 0xE000E414 0xE000E418 0xE000E45C	GPIO P SSI0, R PWM C ADC So Timer 0 Comp 2 Wide T	- 29 Port D Ex Tx Gen 1 eq 1 DA 2A 2 2 Simer 0B	23 – 2 GPIO Port UART1, R PWM Gen ADC Seq Watchdog Timer 1B Comp 1 Wide Time	t C Rx Tx n 0 0	GPIO P UARTO PWM F Quad E ADC Se Timer 1 Comp 0	ort B , Rx Tx ault ncoder q 3 A	7 - GPIO P GPIO P I2C0 PWM C ADC Se Timer 0 Timer 2 Timer 5	- 5 ort A ort E den 2 eq 2 B B B	N' N' N' N' N' N'	ame VIC_PRI0_ VIC_PRI1_ VIC_PRI3_ VIC_PRI3_ VIC_PRI4_ VIC_PRI5_ VIC_PRI6_ VIC_PRI23	R R R R R R R R R R R	
OxE000E100 F Timer0A UART1 UART0 E D C B A NVIC_EN0_R 0xE000E104 Image: Constraint of the state of t	0xE000E400 0xE000E404 0xE000E408 0xE000E40C 0xE000E410 0xE000E414 0xE000E418 0xE000E45C	GPIO P SSI0, R PWM C ADC So Timer 0 Comp 2 Wide T	- 29 Port D Ex Tx Gen 1 eq 1 DA 2A 2 2 Simer 0B	23 – 2 GPIO Port UART1, R PWM Gen ADC Seq Watchdog Timer 1B Comp 1 Wide Time	t C Rx Tx n 0 0	GPIO P UARTO PWM F Quad E ADC Se Timer 1 Comp 0	ort B , Rx Tx ault ncoder q 3 A	7 - GPIO P GPIO P I2C0 PWM C ADC Se Timer 0 Timer 2 Timer 5	- 5 ort A ort E den 2 eq 2 B B B	N' N' N' N' N' N'	ame VIC_PRI0_ VIC_PRI1_ VIC_PRI3_ VIC_PRI3_ VIC_PRI4_ VIC_PRI5_ VIC_PRI6_ VIC_PRI23	R R R R R R R R R R R	
OxE000E104 UART2 NVIC_EN1_R 0xE000E108 Timer5A UART2 NVIC_EN1_R Address 31-24 23-17 16 15-3 2 1 0 Name \$E000E010 0 0 COUNT 0 CLK_SRC INTEN ENABLE NVIC_ST_CTRL_R \$E000E014 0 24-bit RELOAD value NVIC_ST_CURRENT_R \$E000E018 0 24-bit CURRENT value of SysTick counter NVIC_ST_CURRENT_R	0xE000E400 0xE000E404 0xE000E408 0xE000E40C 0xE000E410 0xE000E414 0xE000E418 0xE000E418 0xE000E45C 0xE000ED20	GPIO P SSI0, R PWM C ADC Se Timer C Timer 2 Comp 2 Wide T SysTick	- 29 Port D xx Tx Gen 1 eq 1)A 2A 2 2 iimer 0B	23 – 2 GPIO Port UART1, R PWM Gen ADC Seq Watchdog Timer 1B Comp 1 Wide Time PendSV	t C Rx Tx n 0 0	GPIO P UART0 PWM F Quad En ADC Se Timer 1 Comp 0 Timer 5	ort B , Rx Tx ault ncoder q 3 A B	7 GPIO P GPIO P I2C0 PWM C ADC Se Timer 0 Timer 2 Timer 5 Debug	- 5 ort A ort E den 2 den 2 den 2 B B B A	N' N' N' N' N' N' N'	ame VIC_PRI0_ VIC_PRI1_ VIC_PRI3_ VIC_PRI3_ VIC_PRI4_ VIC_PRI5_ VIC_PRI6_ VIC_PRI23	R R R R R R R R R R PRI3_R	
OxE000E108 Timer5A NVIC_EN2_R Address 31-24 23-17 16 15-3 2 1 0 Name \$E000E010 0 0 COUNT 0 CLK_SRC INTEN ENABLE NVIC_ST_CTRL_R \$E000E014 0 24-bit RELOAD value NVIC_ST_CURRENT NVIC_ST_CURRENT_R	0xE000E400 0xE000E404 0xE000E408 0xE000E40C 0xE000E410 0xE000E414 0xE000E418 0xE000E418 0xE000E45C 0xE000ED20	GPIO P SSI0, R PWM C ADC S Timer C Timer 2 Comp 2 Wide T SysTick	- 29 Port D xx Tx Gen 1 eq 1)A 2A 2 2 iimer 0B	23 – 2 GPIO Port UART1, R PWM Gen ADC Seq Watchdog Timer 1B Comp 1 Wide Time PendSV	t C tx Tx 10 0 er 0A	GPIO P UARTO PWM F Quad En ADC Se Timer 1 Comp 0 Timer 5 	prt B , Rx Tx ault ncoder q 3 A B 5	GPIO P GPIO P I2C0 PWM C ADC Se Timer 0 Timer 2 Timer 5 Debug	- 5 ort A ort E Gen 2 eq 2 B B B A A	N' 2	ame VIC_PRI0_J VIC_PRI1_ VIC_PRI3_J VIC_PRI4_J VIC_PRI5_J VIC_PRI6_J VIC_PRI23_ VIC_SYS_F 1	R R R R R R R R R PRI3_R	
Address 31-24 23-17 16 15-3 2 1 0 Name \$E000E010 0 0 COUNT 0 CLK_SRC INTEN ENABLE NVIC_ST_CTRL_R \$E000E014 0 24-bit RELOAD value NVIC_ST_RELOAD_R \$E000E018 0 24-bit CURRENT value of SysTick counter NVIC_ST_CURRENT_R	0xE000E400 0xE000E404 0xE000E408 0xE000E40C 0xE000E410 0xE000E414 0xE000E418 0xE000E45C 0xE000ED20	GPIO P SSI0, R PWM C ADC S Timer C Timer 2 Comp 2 Wide T SysTick	- 29 Port D xx Tx Gen 1 eq 1)A 2A 2 2 iimer 0B	23 – 2 GPIO Port UART1, R PWM Gen ADC Seq Watchdog Timer 1B Comp 1 Wide Time PendSV	t C tx Tx 10 0 er 0A	GPIO P UARTO PWM F Quad En ADC Se Timer 1 Comp 0 Timer 5 	prt B , Rx Tx ault ncoder q 3 A B 5	GPIO P GPIO P I2C0 PWM C ADC Se Timer 0 Timer 2 Timer 5 Debug	- 5 ort A ort E Gen 2 eq 2 B B B A A	N' 2	ame VIC_PRI0_ VIC_PRI1_ VIC_PRI3_ VIC_PRI3_ VIC_PRI4_ VIC_PRI5_ VIC_PRI6_ VIC_PRI23 VIC_SYS_F 1 B	R R R R R R R R R R R R R R R R R R R	
\$E000E010 0 0 COUNT 0 CLK_SRC INTEN ENABLE NVIC_ST_CTRL_R \$E000E014 0 24-bit RELOAD value NVIC_ST_RELOAD_R \$E000E018 0 24-bit CURRENT value of SysTick counter NVIC_ST_CURRENT_R	0xE000E400 0xE000E404 0xE000E408 0xE000E40C 0xE000E410 0xE000E414 0xE000E418 0xE000E45C 0xE000E100 0xE000E100 0xE000E104	GPIO P SSI0, R PWM C ADC S Timer C Timer 2 Comp 2 Wide T SysTick	- 29 Port D IX TX Gen 1 eq 1 DA 2A 2 C Timer 0B X 28	23 – 2 GPIO Port UART1, R PWM Gen ADC Seq Watchdog Timer 1B Comp 1 Wide Time PendSV	t C tx Tx 10 0 er 0A	GPIO P UARTO PWM F Quad En ADC Se Timer 1 Comp 0 Timer 5 	prt B , Rx Tx ault ncoder q 3 A B 5	GPIO P GPIO P I2C0 PWM C ADC Se Timer 0 Timer 2 Timer 5 Debug	- 5 ort A ort E Gen 2 eq 2 B B B A A	N' 2	ame VIC_PRI0_ VIC_PRI1_ VIC_PRI3_ VIC_PRI3_ VIC_PRI4_ VIC_PRI5_ VIC_PRI6_ VIC_PRI23 VIC_SYS_F 1 B	R R R R R R R PRI3_R 0 Name A NVIC_EN0 NVIC_EN1	
\$E000E010 0 0 COUNT 0 CLK_SRC INTEN ENABLE NVIC_ST_CTRL_R \$E000E014 0 24-bit RELOAD value NVIC_ST_RELOAD_R \$E000E018 0 24-bit CURRENT value of SysTick counter NVIC_ST_CURRENT_R	0xE000E400 0xE000E404 0xE000E408 0xE000E40C 0xE000E410 0xE000E414 0xE000E418 0xE000E45C 0xE000E100 0xE000E100 0xE000E104	GPIO P SSI0, R PWM C ADC S Timer C Timer 2 Comp 2 Wide T SysTick	- 29 Port D IX TX Gen 1 eq 1 DA 2A 2 C Timer 0B X 28	23 – 2 GPIO Port UART1, R PWM Gen ADC Seq Watchdog Timer 1B Comp 1 Wide Time PendSV	t C tx Tx 10 0 er 0A	GPIO P UARTO PWM F Quad En ADC Se Timer 1 Comp 0 Timer 5 	prt B , Rx Tx ault ncoder q 3 A B 5	GPIO P GPIO P I2C0 PWM C ADC Se Timer 0 Timer 2 Timer 5 Debug	- 5 ort A ort E Gen 2 eq 2 B B B A A	N' 2	ame VIC_PRI0_ VIC_PRI1_ VIC_PRI3_ VIC_PRI3_ VIC_PRI4_ VIC_PRI5_ VIC_PRI6_ VIC_PRI23 VIC_SYS_F 1 B	R R R R R R R PRI3_R 0 Name A NVIC_EN0 NVIC_EN1	
\$E000E014 0 24-bit RELOAD value NVIC_ST_RELOAD_R \$E000E018 0 24-bit CURRENT value of SysTick counter NVIC_ST_CURRENT_R	0xE000E400 0xE000E404 0xE000E408 0xE000E40C 0xE000E410 0xE000E414 0xE000E418 0xE000E45C 0xE000E100 0xE000E100 0xE000E108	GPIO P SSI0, R PWM C ADC Sc Timer C Timer 2 Comp 2 Wide T SysTich 30 F	- 29 Port D x Tx Gen 1 eq 1 DA 2A 2 c iimer 0B x 2 2 Timer5A	23 – 2 GPIO Port UART1, R PWM Gen ADC Seq Watchdog Timer 1B Comp 1 Wide Time PendSV	er 0A	GPIO P UART0 PWM F Quad En ADC Se Timer 1 Comp 0 Timer 5 6 UART1	brt B , Rx Tx ault ncoder q 3 A B 5 UART	GPIO P GPIO P I2C0 PWM C ADC Se Timer 0 Timer 2 Timer 5 Debug	- 5 ort A ort E ien 2 eq 2 B B A A 3 D	N' N' N' N' N' N' N' 2 C	ame VIC_PRI0_J VIC_PRI1_J VIC_PRI2_J VIC_PRI3_J VIC_PRI4_J VIC_PRI5_J VIC_PRI6_J VIC_PRI23_ VIC_SYS_F 1 B UART2	R R R R R R R PRI3_R 0 Name A NVIC_EN0 NVIC_EN1	
\$E000E018 0 24-bit CURRENT value of SysTick counter NVIC_ST_CURRENT_R	0xE000E400 0xE000E404 0xE000E408 0xE000E40C 0xE000E410 0xE000E414 0xE000E418 0xE000E45C 0xE000E100 0xE000E100 0xE000E104 0xE000E108	GPIO P SSI0, R PWM C ADC Sc Timer C Timer 2 Comp 2 Wide T SysTick 30 F 30 F 31-24	- 29 Port D x Tx Gen 1 eq 1 0A 2A 2 2 iimer 0B x 28 7 iimer5A 23-17	23 – 2 GPIO Port UART1, R PWM Gen ADC Seq Watchdog Timer 1B Comp 1 Wide Time PendSV	t C Rx Tx 10 0 er 0A 4 15-3	GPIO P UART0 PWM F Quad En ADC Se Timer 1 Comp 0 Timer 5 6 UART1 2	brt B , Rx Tx ault ncoder q 3 A B 5 UART	GPIO P GPIO P I2C0 PWM C ADC Se Timer 0 Timer 2 Timer 5 Debug	- 5 ort A ort E ien 2 eq 2 B B A A 3 D 0	N'' N''	ame VIC_PRI0_J VIC_PRI1_J VIC_PRI3_J VIC_PRI4_J VIC_PRI5_J VIC_PRI5_J VIC_PRI5_J VIC_PRI23_ VIC_SYS_F 1 B UART2 me	R R R R R R R R PRI3_R 0 Name A NVIC_EN0 NVIC_EN1 NVIC_EN2	
	0xE000E400 0xE000E404 0xE000E408 0xE000E40C 0xE000E410 0xE000E414 0xE000E418 0xE000E45C 0xE000E100 0xE000E100 0xE000E104 0xE000E108	GPIO P SSI0, R PWM C ADC Sc Timer C Timer 2 Comp 2 Wide T SysTick 30 F 31-24 0	- 29 Port D x Tx Gen 1 eq 1 0A 2A 2 2 iimer 0B x 28 7 iimer5A 23-17	23 – 2 GPIO Port UART1, R PWM Gen ADC Seq Watchdog Timer 1B Comp 1 Wide Time PendSV	t C 2x Tx 10 0 er 0A 4 15-3 0	GPIO P UART0 PWM F Quad En ADC Se Timer 1 Comp 0 Timer 5 6 UART1 QART1	brt B , Rx Tx ault ncoder q 3 A B 5 UART C IN	GPIO P GPIO P I2C0 PWM C ADC Se Timer 0 Timer 2 Timer 5 Debug	- 5 ort A ort E ien 2 eq 2 B B A A 3 D 0	N'' N'' N'' N'' N'' N'' N'' N'' N'' N''	ame VIC_PRI0_J VIC_PRI1_J VIC_PRI2_J VIC_PRI3_J VIC_PRI4_J VIC_PRI5_J VIC_PRI6_J VIC_PRI23 VIC_SYS_F 1 B UART2 me VIC_ST_CT	R R R R R R PRI3_R 0 NAME A NVIC_ENI NVIC_EN1 NVIC_EN2	
2N2222 V = 0.3V TIP120 V = 0.8V	0xE000E400 0xE000E404 0xE000E408 0xE000E402 0xE000E410 0xE000E414 0xE000E418 0xE000E418 0xE000E4020 Address 0xE000E100 0xE000E104 0xE000E108 Address \$E000E010 \$E000E010	GPIO P SSI0, R PWM C ADC Sc Timer C Timer 2 Comp 2 Wide T SysTick 30 F 30 F 31-24 0 0	- 29 Port D x Tx Gen 1 eq 1 0A 2A 2 2 iimer 0B x 28 7 iimer5A 23-17	23 – 2 GPIO Port UART1, R PWM Gen ADC Seq Watchdog Timer 1B Comp 1 Wide Time PendSV 19 Timer0A 19 Timer0A	t C Rx Tx 10 0 er 0A er 0A 15-3 0 24-bit	GPIO P UART0 PWM F Quad En ADC Se Timer 1 Comp 0 Timer 5 6 UART1 QART1 2 CLK_SI RELOAD	brt B Rx Tx ault ncoder q 3 A B 5 UART C IN value	GPIO P GPIO P I2C0 PWM C ADC Se Timer 0 Timer 2 Timer 5 Debug	- 5 ort A ort E ien 2 eq 2 B B A A 3 D 0	N'	ame VIC_PRI0_J VIC_PRI1_J VIC_PRI2_J VIC_PRI3_J VIC_PRI4_J VIC_PRI5_J VIC_PRI6_J VIC_PRI23 VIC_SYS_F 1 B UART2 me IC_ST_CT VIC_ST_REJ	R R R R R R R R R PRI3_R 0 Name A NVIC_EN0 NVIC_EN1 NVIC_EN1 NVIC_EN2 R R R R L_R LOAD_R	
12N2222 V $-0.3V$ IFTPT20 V $-0.8V$	0xE000E400 0xE000E404 0xE000E408 0xE000E402 0xE000E410 0xE000E414 0xE000E418 0xE000E418 0xE000E4020 Address 0xE000E100 0xE000E104 0xE000E108 Address \$E000E010 \$E000E010	GPIO P SSI0, R PWM C ADC Sc Timer C Timer 2 Comp 2 Wide T SysTick 30 F 30 F 31-24 0 0	- 29 Port D x Tx Gen 1 eq 1 0A 2A 2 2 iimer 0B x 28 7 iimer5A 23-17	23 – 2 GPIO Port UART1, R PWM Gen ADC Seq Watchdog Timer 1B Comp 1 Wide Time PendSV 19 Timer0A 19 Timer0A	t C Rx Tx 10 0 er 0A er 0A 15-3 0 24-bit	GPIO P UART0 PWM F Quad En ADC Se Timer 1 Comp 0 Timer 5 6 UART1 QART1 2 CLK_SI RELOAD	brt B Rx Tx ault ncoder q 3 A B 5 UART C IN value	GPIO P GPIO P I2C0 PWM C ADC Se Timer 0 Timer 2 Timer 5 Debug	- 5 ort A ort E ien 2 eq 2 B B A A 3 D 0	N'	ame VIC_PRI0_J VIC_PRI1_J VIC_PRI2_J VIC_PRI3_J VIC_PRI4_J VIC_PRI5_J VIC_PRI6_J VIC_PRI23 VIC_SYS_F 1 B UART2 me IC_ST_CT VIC_ST_REJ	R R R R R R R R R PRI3_R 0 Name A NVIC_EN0 NVIC_EN1 NVIC_EN1 NVIC_EN2 R R R R L_R LOAD_R	
$\begin{bmatrix} 21,2222 \\ V_{ce} &= 0.5V \\ V_{ce} &= 0.6V \\ V_{ce} &= 1.5V \\ V_{ce} &= 1.5V \\ V_{ce} &= 1.5V \\ V_{ce} &= 0.6V \\ V_{ce} &=$	0xE000E400 0xE000E404 0xE000E408 0xE000E40C 0xE000E410 0xE000E414 0xE000E418 0xE000E418 0xE000E4020 Address 0xE000E100 0xE000E104 0xE000E108 Address \$E000E010 \$E000E010	GPIO P SSI0, R PWM C ADC So Timer C Timer 2 Comp 2 Wide T SysTick 30 F 31-24 0 0 0	- 29 Port D x Tx Gen 1 eq 1 DA 2A 22 Timer 0B x 28 Timer 5A 23-17 0	23 – 2 GPIO Port UART1, R PWM Gen ADC Seq 1 Watchdog Timer 1B Comp 1 Wide Time PendSV 19 Timer0A 16 COUNT 24-bit CU	C Rx Tx 10 0 er 0A 15-3 0 24-bit JRREN	GPIO P UART0 PWM F Quad En ADC Se Timer 1 Comp 0 Timer 5 6 UART1 VART1 2 CLK_SI RELOAD T value of	ort B , Rx Tx ault ncoder q 3 A B 5 UART UART RC IN value SysTick	GPIO P GPIO P I2C0 PWM C ADC Se Timer 0 Timer 2 Timer 5 Debug 4 0 E 1 I IEN EN Counter	- 5 ort A ort E ien 2 eq 2 B B A A	N N N N N N N N N N N N N N N N N N N	ame VIC_PRI0_ VIC_PRI1_) VIC_PRI3_) VIC_PRI3_) VIC_PRI4_) VIC_PRI5_ VIC_PRI6_ VIC_PRI23 VIC_SYS_F 1 B UART2 IC_ST_CT IC_ST_CT IC_ST_CU	R R R R R R R R R PRI3_R 0 Name A NVIC_EN0 NVIC_EN1 NVIC_EN1 NVIC_EN2 R R R R L_R LOAD_R	

Parameters for the TM4C123 microcontroller, with 8-mA mode selected

$\begin{array}{c c} 2N2222 & V_{ce} &= 0.3V \\ V_{be} &= 0.6V \\ h_{fe} &= 100 \\ I_{ce} &= 500 \text{mA max} \end{array}$	$\begin{array}{c c} \text{TIP120} & V_{ce} &= 0.8V \\ \hline & V_{be} &= 1.5V \\ & h_{fe} &= 2000 \\ \hline & I_{ce} &= 5A \text{ max} \end{array}$
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