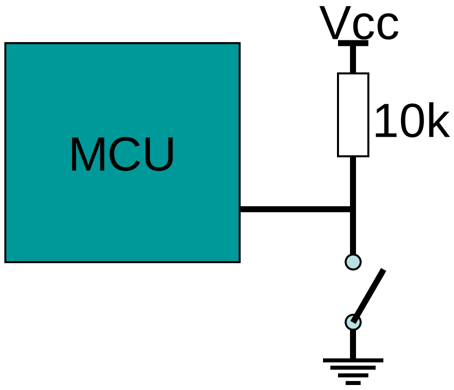
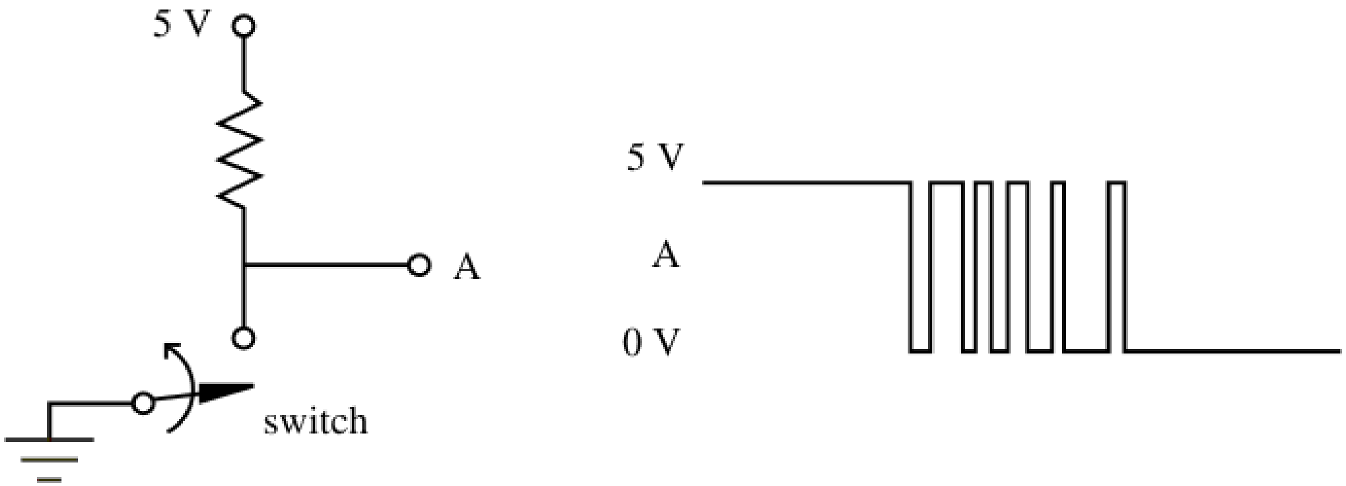
Hardware Interfacing (Input)

- Switches—Bouncing
  - A switch is a mechanical device that rarely opens/closes cleanly.



Any problems here?



Analog to Digital Conversion

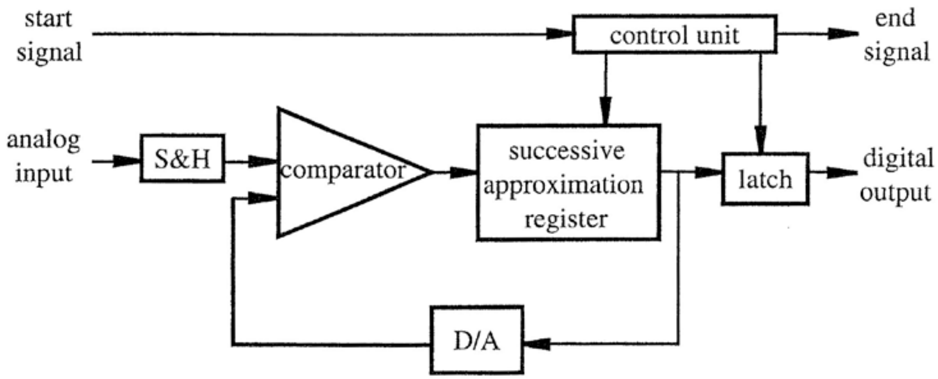
- Specifications—Resolution
  - Is a function of the range and the number of bits (N)

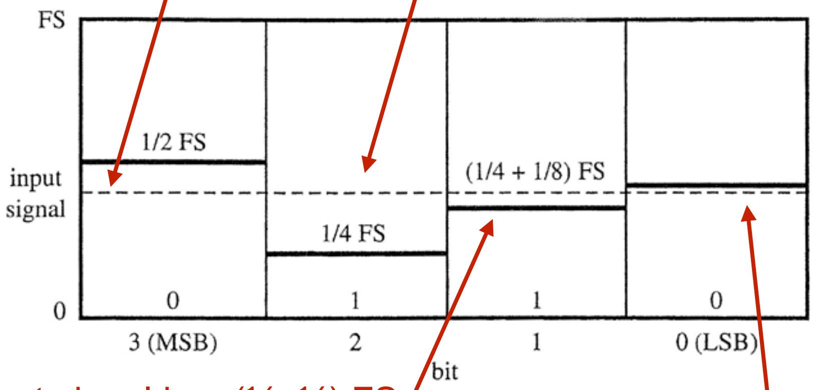
$$\text{Resolution} \equiv Q = \frac{\left(V_{max} - V_{min}\right)}{2^N} = \frac{\text{Range}}{2^N}$$

  - 12-bit resolution for 0-10V range: $\frac{10}{2^{12}} = \frac{10}{4096} = 2.44\text{mV}$
  - 16-bit resolution for -10-10V range: $\frac{20}{2^{16}} = 0.305\text{mV}$
- Quantization error
  - Due to finite resolution: $U_Q = \frac{1}{2}\left(\frac{\text{Range}}{2^N}\right)$

Analog to Digital Converters

- Successive Approximation
  - Relatively fast and inexpensive
  - Uses a D/A (DAC) in a feedback loop
  - Successively tests each bit
  - requires N steps to complete (typically 15-20 µs)





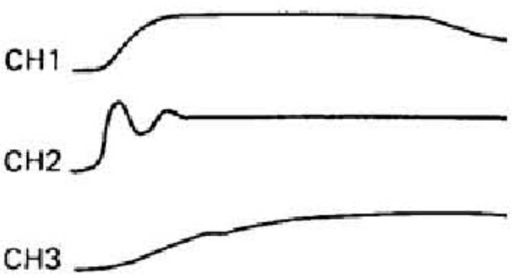
input signal is < ½ FS
(MSB =0)

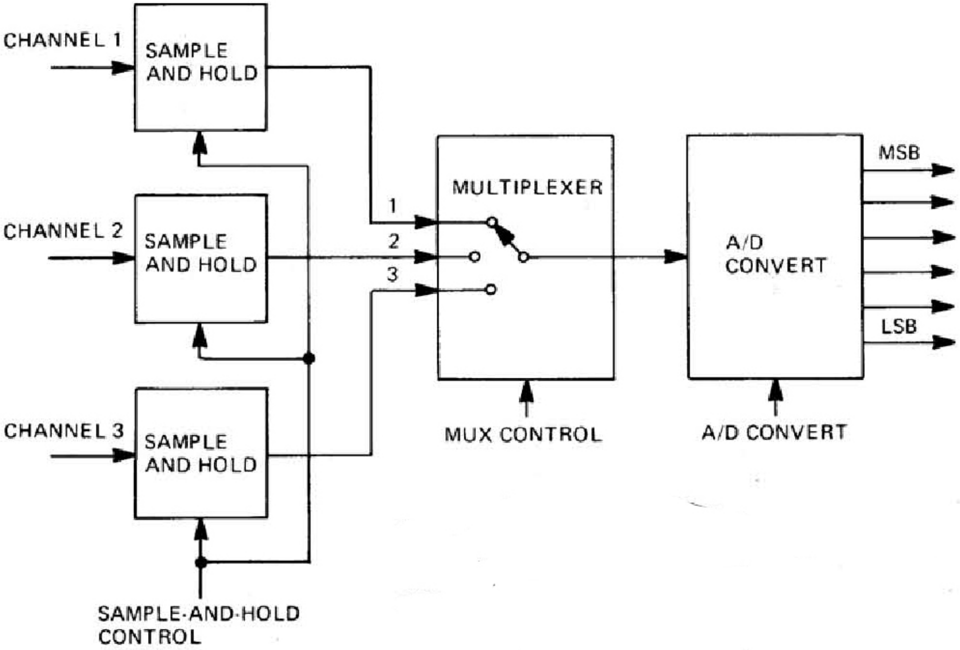
input signal is > ¼ FS
(2nd bit = 1)

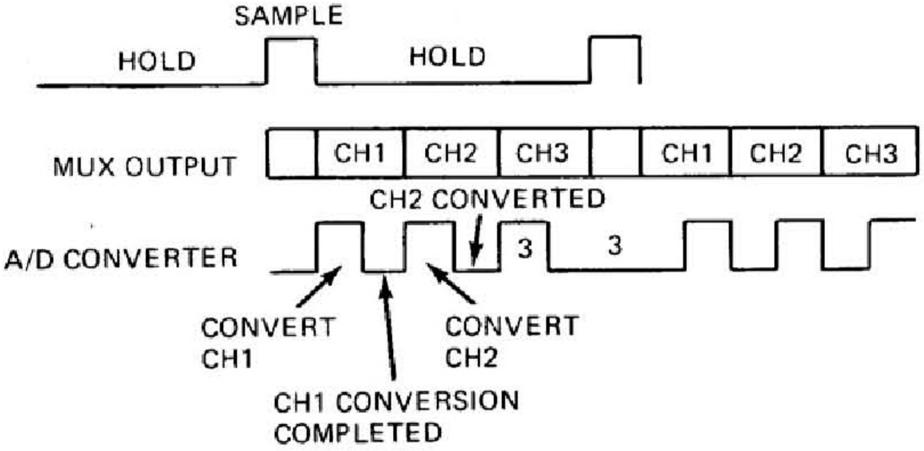
input signal is > (¼+⅛) FS
(3rd bit =1)

input signal is < (¼+⅛+$\frac{1}{16}$)FS
(LSB =0)

Multiplexers

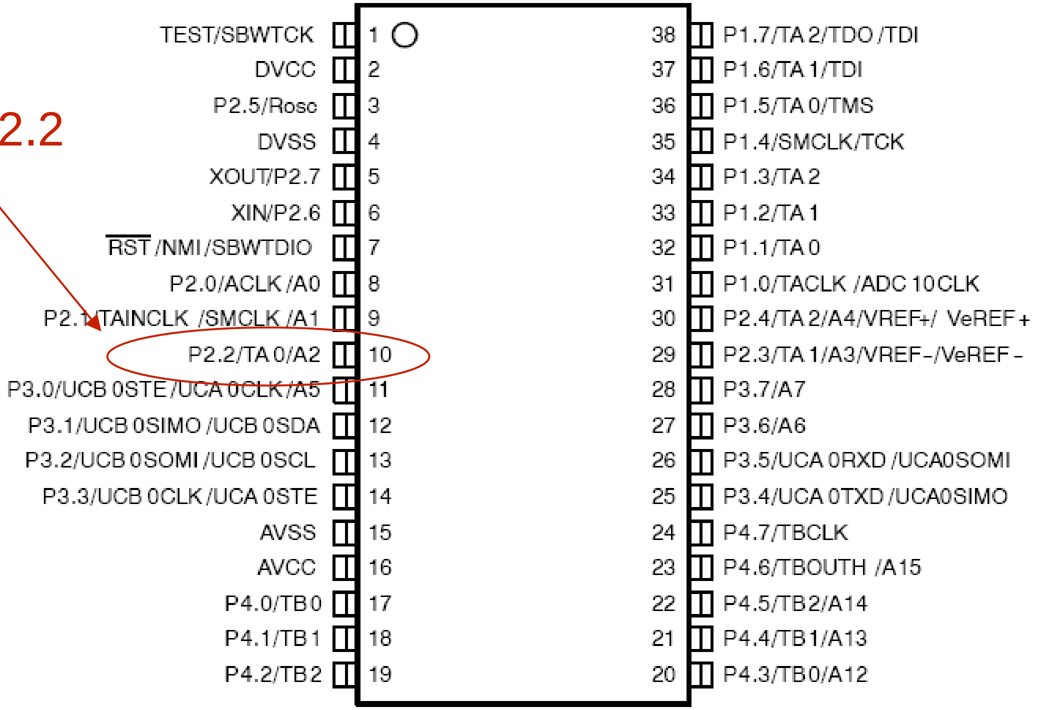




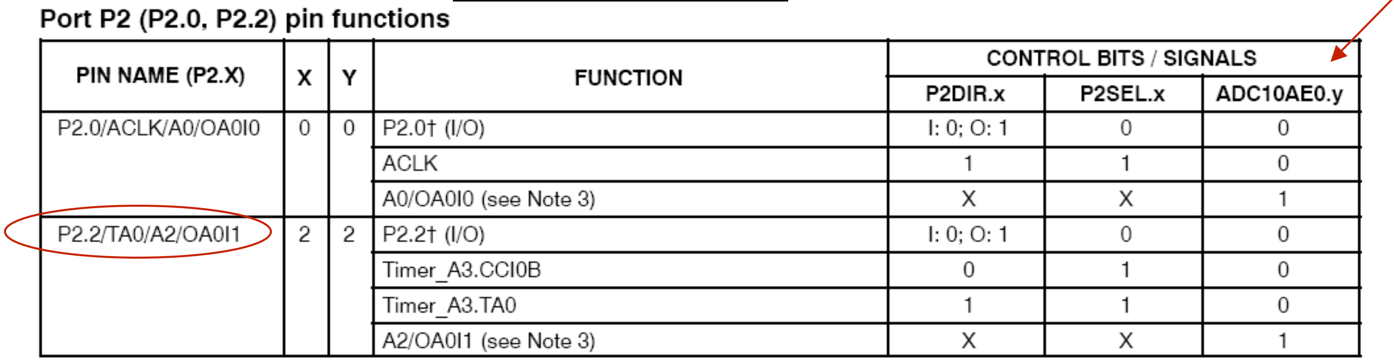


MSP430 ADC10

Multiplexed P2.2



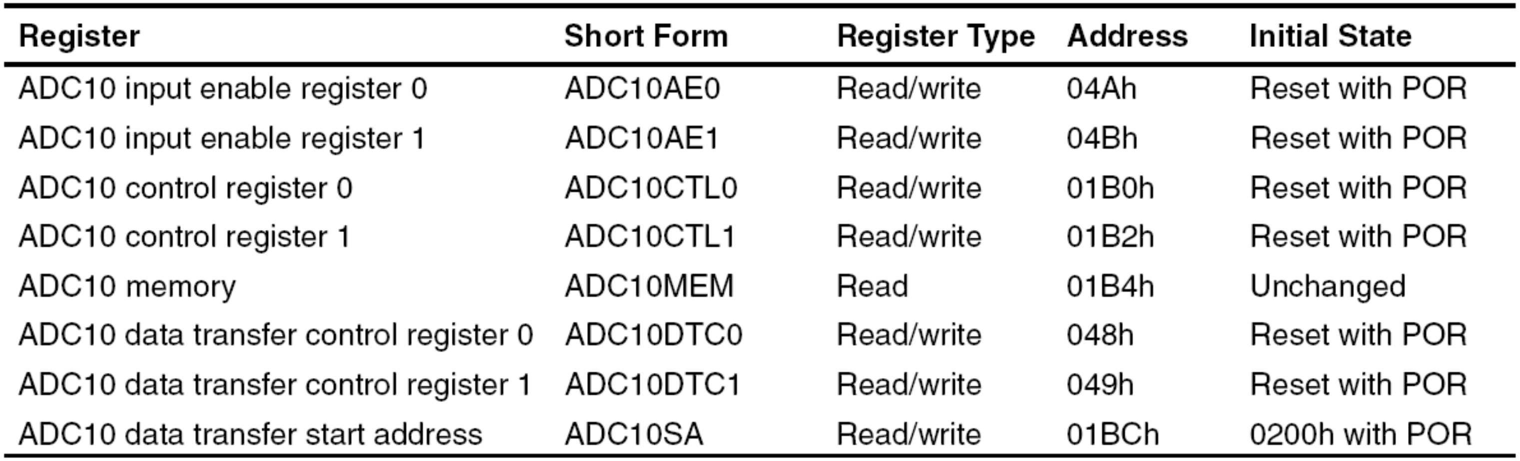
This table is found in the device datasheet



Port P2 (P2.0, P2.2) pin functions

PIN NAME (P2.X)	X	Y	FUNCTION	CONTROL BITS / SIGNALS		
				P2DIR.x	P2SEL.x	ADC10AE0.y
P2.0/ACLK/A0/OA0I0	0	0	P2.0† (I/O)	I: 0; O: 1	0	0
			ACLK	1	1	0
			A0/OA0I0 (see Note 3)	X	X	1
P2.2/TA0/A2/OA0I1	2	2	P2.2† (I/O)	I: 0; O: 1	0	0
			Timer_A3.CCI0B	0	1	0
			Timer_A3.TA0	1	1	0
			A2/OA0I1 (see Note 3)	X	X	1

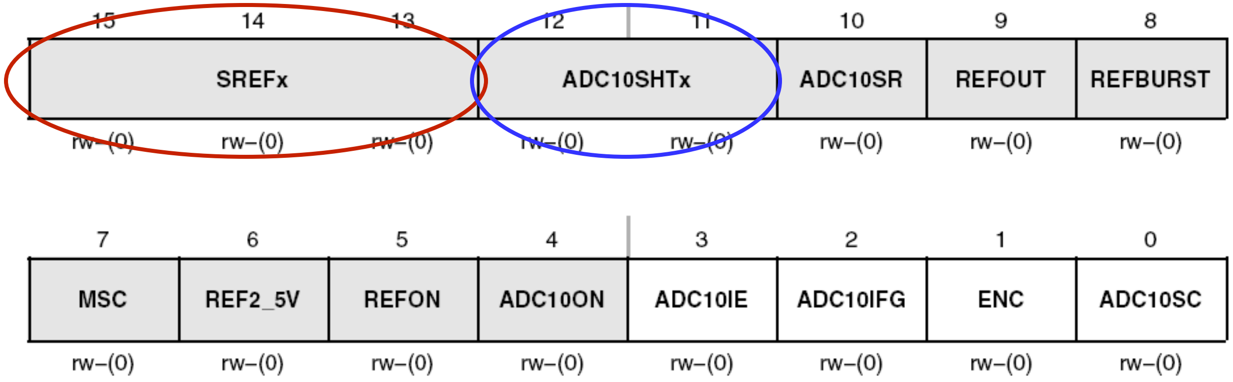
ADC10 Configuration



Register	Short Form	Register Type	Address	Initial State
ADC10 input enable register 0	ADC10AE0	Read/write	04Ah	Reset with POR
ADC10 input enable register 1	ADC10AE1	Read/write	04Bh	Reset with POR
ADC10 control register 0	ADC10CTL0	Read/write	01B0h	Reset with POR
ADC10 control register 1	ADC10CTL1	Read/write	01B2h	Reset with POR
ADC10 memory	ADC10MEM	Read	01B4h	Unchanged
ADC10 data transfer control register 0	ADC10DTC0	Read/write	048h	Reset with POR
ADC10 data transfer control register 1	ADC10DTC1	Read/write	049h	Reset with POR
ADC10 data transfer start address	ADC10SA	Read/write	01BCh	0200h with POR

- ADC10CTL0 & ADC10CTL1—ADC10 Control Registers
  - Used to configure how the ADC runs
- ADC10AE0 & ADC10AE1—Analog Input Enable Registers
  - Specifies which pins should be used for analog input
- ADC10MEM—Conversion Memory Register
  - This is where the conversion result is stored
- ADC10DTC0 & ADC10DTC1—Data Transfer Control Registers
  - Used to control direct memory transfer of conversion results
- ADC10SA—Start Address Register for Data Transfer
  - Specifies the starting address in memory where results are transferred

ADC10—ADC10CTL0 Control Register 0



15	14	13	12	11	10	9	8
SREFx			ADC10SHTx		ADC10SR	REFOUT	REFBURST
rw–(0)	rw–(0)	rw–(0)	rw–(0)	rw–(0)	rw–(0)	rw–(0)	rw–(0)

7	6	5	4	3	2	1	0
MSC	REF2_5V	REFON	ADC10ON	ADC10IE	ADC10IFG	ENC	ADC10SC
rw–(0)	rw–(0)	rw–(0)	rw–(0)	rw–(0)	rw–(0)	rw–(0)	rw–(0)

▨ Modifiable only when ENC = 0

SREFx	Bits 15-13	Select reference	
		000	$V_{R+} = V_{CC}$ and $V_{R-} = V_{SS}$
		001	$V_{R+} = V_{REF+}$ and $V_{R-} = V_{SS}$
		010	$V_{R+} = Ve_{REF+}$ and $V_{R-} = V_{SS}$
		011	$V_{R+} =$ Buffered Ve_{REF+} and $V_{R-} = V_{SS}$
		100	$V_{R+} = V_{CC}$ and $V_{R-} = V_{REF-}/\ Ve_{REF-}$
		101	$V_{R+} = V_{REF+}$ and $V_{R-} = V_{REF-}/\ Ve_{REF-}$
		110	$V_{R+} = Ve_{REF+}$ and $V_{R-} = V_{REF-}/\ Ve_{REF-}$
		111	$V_{R+} =$ Buffered Ve_{REF+} and $V_{R-} = V_{REF-}/\ Ve_{REF-}$

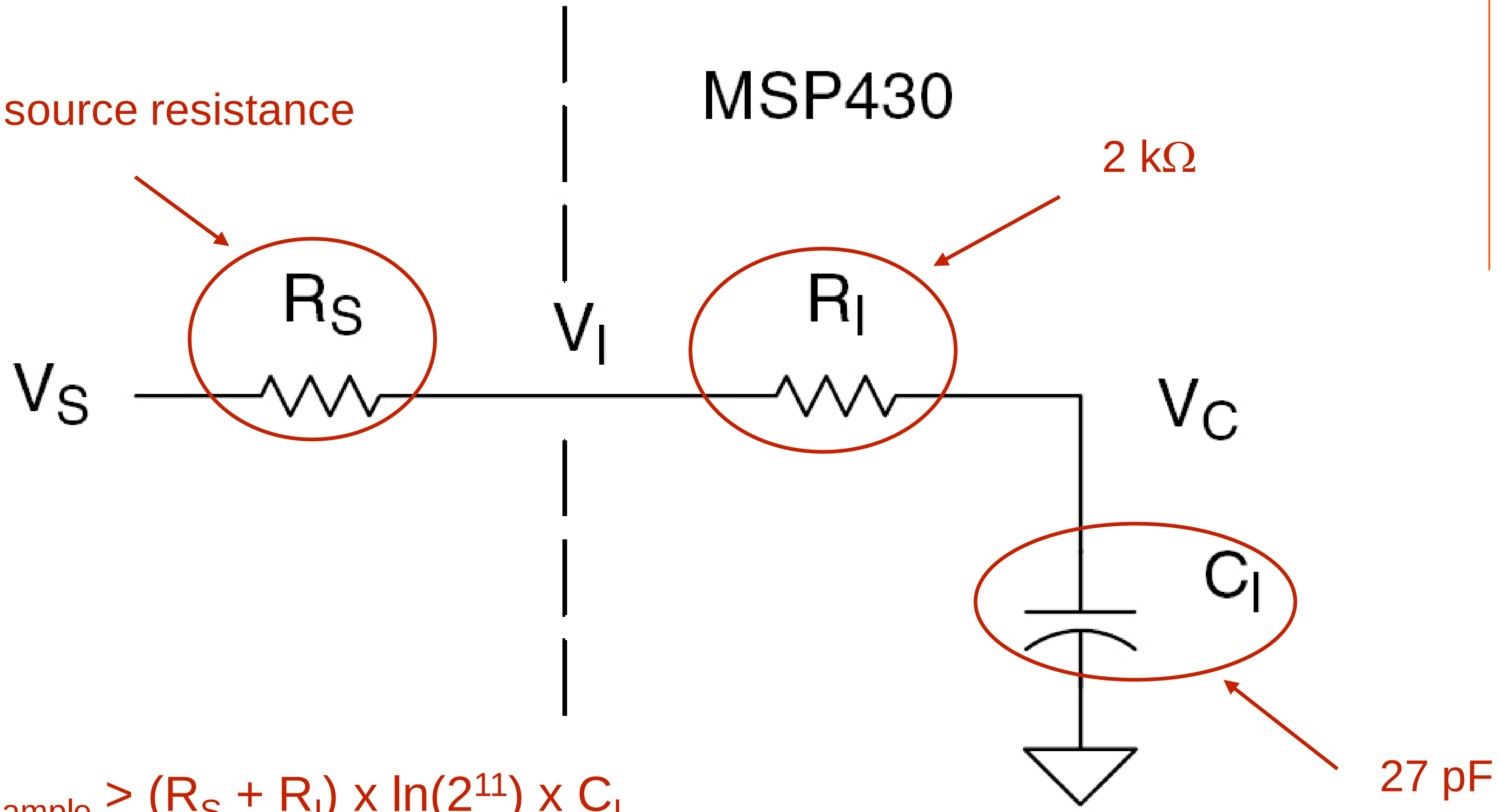
We must tell ADC10 what voltage reference source to use. For example, if we want to use the supply voltage and ground as the references, set bits 15-13 = %000 = SREF_0 (defined in header file).

ADC10 SHTx	Bits 12-11	ADC10 sample-and-hold time	
		00	4 x ADC10CLKs
		01	8 x ADC10CLKs
		10	16 x ADC10CLKs
		11	64 x ADC10CLKs

Set these bits to ensure accurate conversion voltage

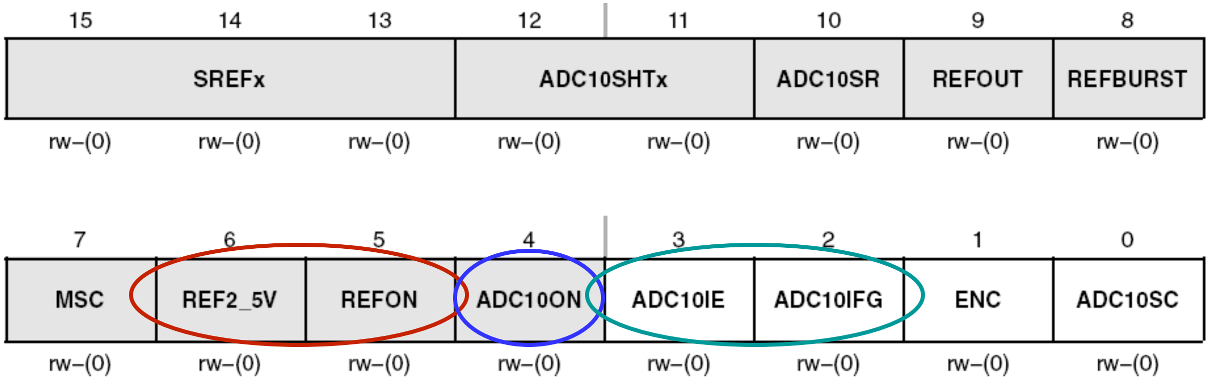
Sample and Hold

- Section 22.2.5.1 in MSP430x2xx Users Guide



$t_{sample} > (R_S + R_I) \times \ln(2^{11}) \times C_I$

ADC10—ADC10CTL0 Control Register 0



15	14	13	12	11	10	9	8
SREFx			ADC10SHTx		ADC10SR	REFOUT	REFBURST
rw–(0)	rw–(0)	rw–(0)	rw–(0)	rw–(0)	rw–(0)	rw–(0)	rw–(0)

7	6	5	4	3	2	1	0
MSC	REF2_5V	REFON	ADC10ON	ADC10IE	ADC10IFG	ENC	ADC10SC
rw–(0)	rw–(0)	rw–(0)	rw–(0)	rw–(0)	rw–(0)	rw–(0)	rw–(0)

▨ Modifiable only when ENC = 0

REF2_5V Bit 6 Reference-generator voltage. REFON must also be set.
0 1.5 V
1 2.5 V

REFON Bit 5 Reference generator on
0 Reference off
1 Reference on

Internal voltage reference control.

ADC10ON Bit 4 ADC10 on
0 ADC10 off
1 ADC10 on

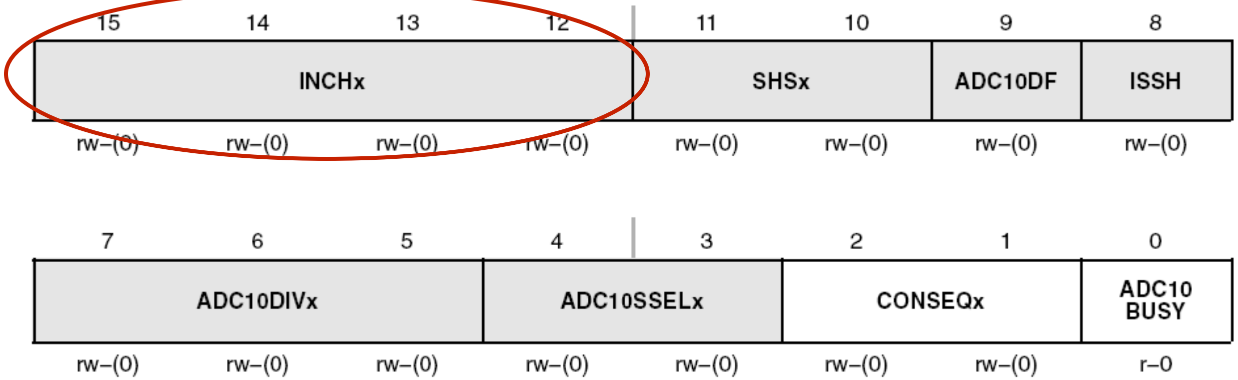
Don’t forget to turn the ADC on!

ADC10IE Bit 3 ADC10 interrupt enable
0 Interrupt disabled
1 interrupt enabled

ADC10IFG Bit 2 ADC10 interrupt flag. This bit is set if ADC10MEM is loaded with a conversion result. It is automatically reset when the interrupt request is accepted, or it may be reset by software. When using the DTC this flag is set when a block of transfers is completed.
0 No interrupt pending
1 Interrupt pending

You do want interrupts, don’t you?

ADC10—ADC10CTL1 Control Register 1



15	14	13	12	11	10	9	8
INCHx				SHSx		ADC10DF	ISSH
rw–(0)	rw–(0)	rw–(0)	rw–(0)	rw–(0)	rw–(0)	rw–(0)	rw–(0)

7	6	5	4	3	2	1	0
ADC10DIVx			ADC10SSELx		CONSEQx		ADC10 BUSY
rw–(0)	rw–(0)	rw–(0)	rw–(0)	rw–(0)	rw–(0)	rw–(0)	r–0

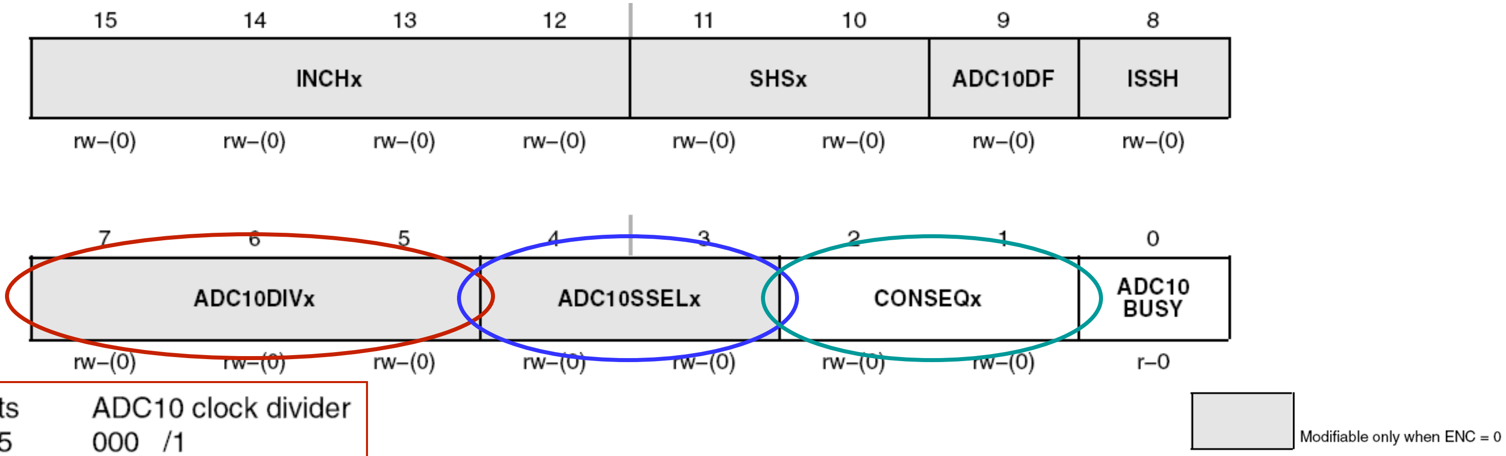
▨ Modifiable only when ENC = 0

INCHx Bits 15-12 Input channel select. These bits select the channel for a single-conversion or the highest channel for a sequence of conversions.

0000	A0
0001	A1
0010	A2
0011	A3
0100	A4
0101	A5
0110	A6
0111	A7
1000	Ve_{REF+}
1001	V_{REF-}/Ve_{REF-}
1010	Temperature sensor
1011	$(V_{CC} – V_{SS}) / 2$
1100	$(V_{CC} – V_{SS}) / 2$, A12 on MSP430x22xx devices
1101	$(V_{CC} – V_{SS}) / 2$, A13 on MSP430x22xx devices
1110	$(V_{CC} – V_{SS}) / 2$, A14 on MSP430x22xx devices
1111	$(V_{CC} – V_{SS}) / 2$, A15 on MSP430x22xx devices

Choose your channels.

ADC10—ADC10CTL1 Control Register 1



15	14	13	12	11	10	9	8
INCHx				SHSx		ADC10DF	ISSH
rw–(0)	rw–(0)	rw–(0)	rw–(0)	rw–(0)	rw–(0)	rw–(0)	rw–(0)
7	6	5	4	3	2	1	0
ADC10DIVx			ADC10SSELx		CONSEQx		ADC10 BUSY
rw–(0)	rw–(0)	rw–(0)	rw–(0)	rw–(0)	rw–(0)	rw–(0)	r–0

▨ Modifiable only when ENC = 0

ADC10DIVx	Bits 7-5	ADC10 clock divider	
		000	/1
		001	/2
		010	/3
		011	/4
		100	/5
		101	/6
		110	/7
		111	/8

Choose your clock rate.

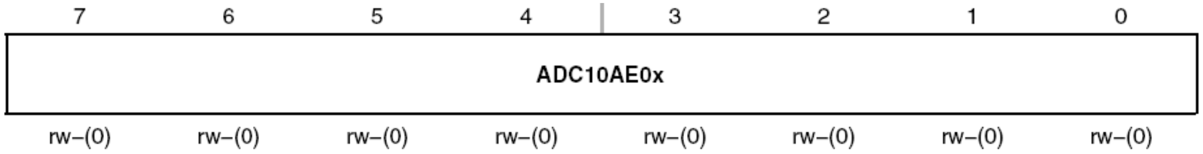
ADC10 SSELx	Bits 4-3	ADC10 clock source select	
		00	ADC10OSC
		01	ACLK
		10	MCLK
		11	SMCLK

Choose your clock.

CONSEQx	Bits 2-1	Conversion sequence mode select	
		00	Single-channel-single-conversion
		01	Sequence-of-channels
		10	Repeat-single-channel
		11	Repeat-sequence-of-channels

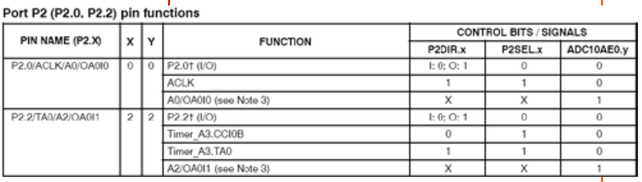
Specify your conversion sequence.

ADC10—ADC10AE0 A I Enable Control Reg 0



7	6	5	4	3	2	1	0
ADC10AE0x							
rw–(0)	rw–(0)	rw–(0)	rw–(0)	rw–(0)	rw–(0)	rw–(0)	rw–(0)

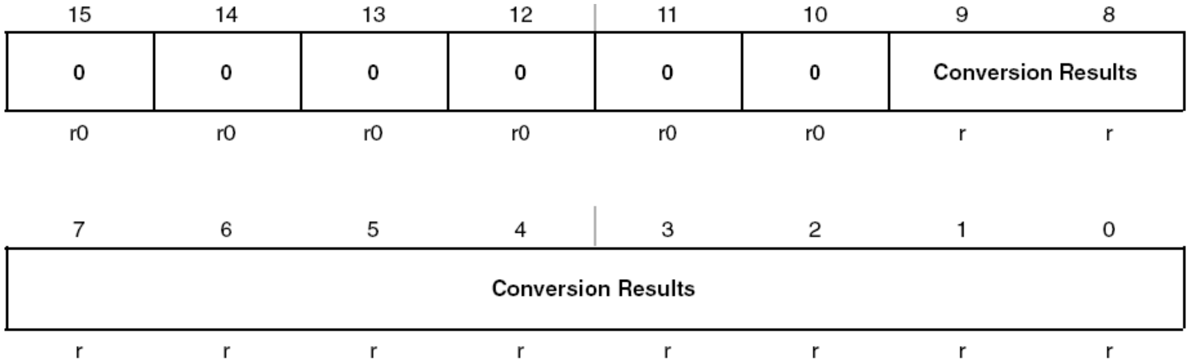
ADC10AE0x	Bits 7-0	ADC10 analog enable. These bits enable the corresponding pin for analog input. BIT0 corresponds to A0, BIT1 corresponds to A1, etc. 0 Analog input disabled 1 Analog input enabled



Port P2 (P2.0, P2.2) pin functions

PIN NAME (P2.X)	X	Y	FUNCTION	CONTROL BITS / SIGNALS		
				P2DIR.x	P2SEL.x	ADC10AE0.y
P2.0/ACLK/A0/OA0I0	0	0	P2.0† (I/O)	I: 0; O: 1	0	0
			ACLK	1	1	0
			A0/OA0I0 (see Note 3)	X	X	1
P2.2/TA0/A2/OA0I1	2	2	P2.2† (I/O)	I: 0; O: 1	0	0
			Timer_A3.CCI0B	0	1	0
			Timer_A3.TA0	1	1	0
			A2/OA0I1 (see Note 3)	X	X	1

ADC10—ADC10MEM Conversion Memory Reg

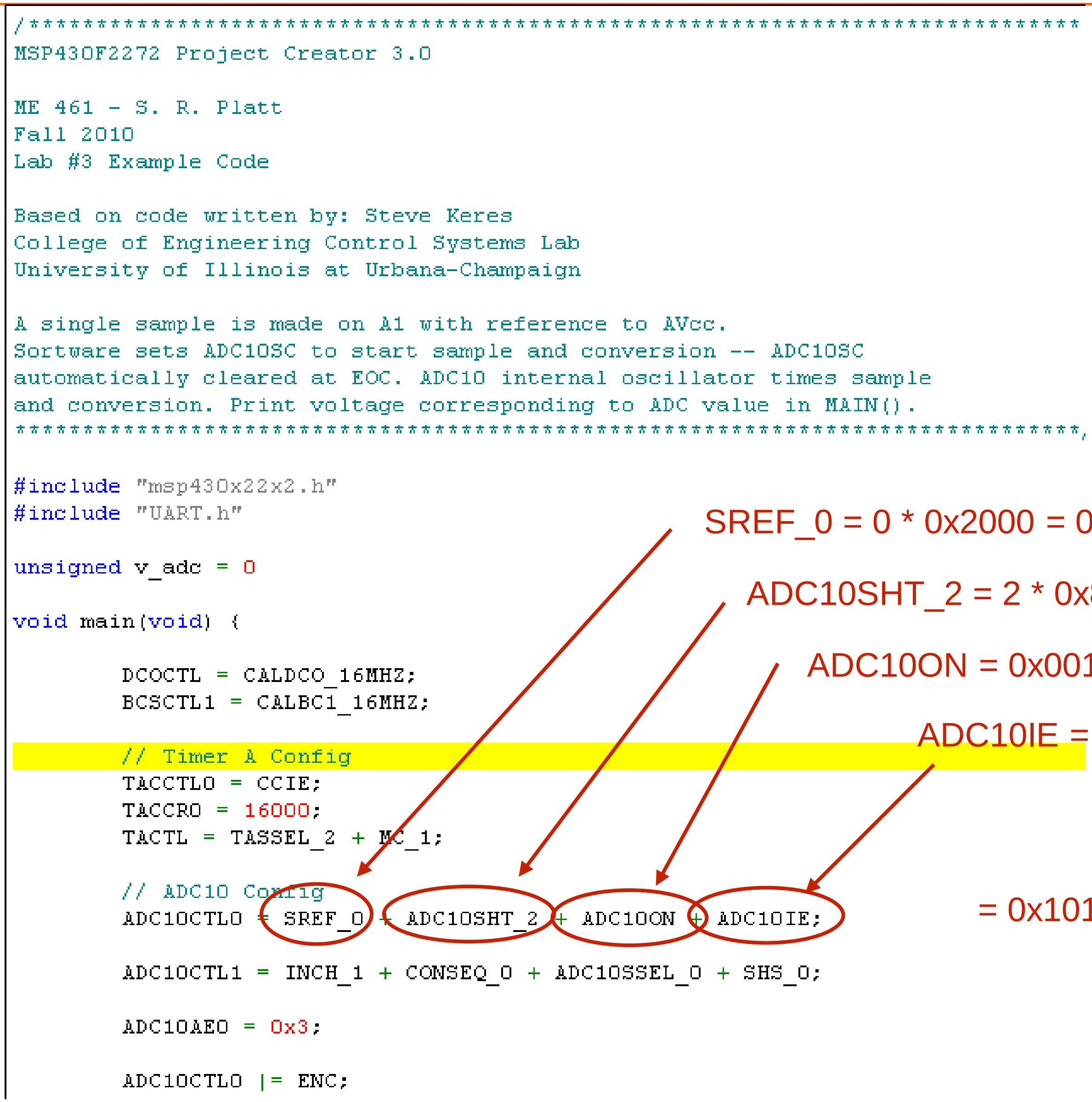


15	14	13	12	11	10	9	8
0	0	0	0	0	0	Conversion Results	
r0	r0	r0	r0	r0	r0	r	r

7	6	5	4	3	2	1	0
Conversion Results							
r	r	r	r	r	r	r	r

Conversion Results	Bits 15-0	The 10-bit conversion results are right justified, straight-binary format. Bit 9 is the MSB. Bits 15-10 are always 0.

MSP430 Analog to Digital Conversion



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/*************************************************************************
MSP430F2272 Project Creator 3.0

ME 461 - S. R. Platt
Fall 2010
Lab #3 Example Code

Based on code written by: Steve Keres
College of Engineering Control Systems Lab
University of Illinois at Urbana-Champaign

A single sample is made on A1 with reference to AVcc.
Software sets ADC10SC to start sample and conversion -- ADC10SC
automatically cleared at EOC. ADC10 internal oscillator times sample
and conversion. Print voltage corresponding to ADC value in MAIN().
*************************************************************************/

#include "msp430x22x2.h"
#include "UART.h"

unsigned v_adc = 0

void main(void) {

        DCOCTL = CALDCO_16MHZ;
        BCSCTL1 = CALBC1_16MHZ;

        // Timer A Config
        TACCTL0 = CCIE;
        TACCR0 = 16000;
        TACTL = TASSEL_2 + MC_1;

        // ADC10 Config
        ADC10CTL0 = SREF_0 + ADC10SHT_2 + ADC10ON + ADC10IE;

        ADC10CTL1 = INCH_1 + CONSEQ_0 + ADC10SSEL_0 + SHS_0;

        ADC10AE0 = 0x3;

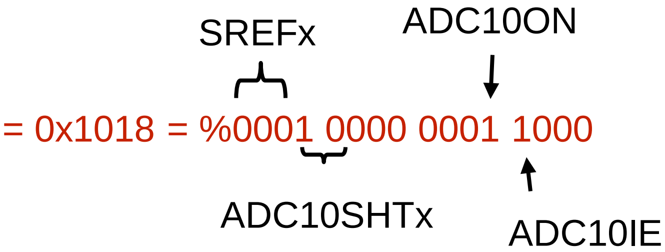
        ADC10CTL0 |= ENC;
```

SREF_0 = 0 * 0x2000 = 0x0000 (i.e., V_{cc} & V_{ss})

ADC10SHT_2 = 2 * 0x800 = 0x1000

ADC10ON = 0x0010

ADC10IE = 0x0008



SREFx

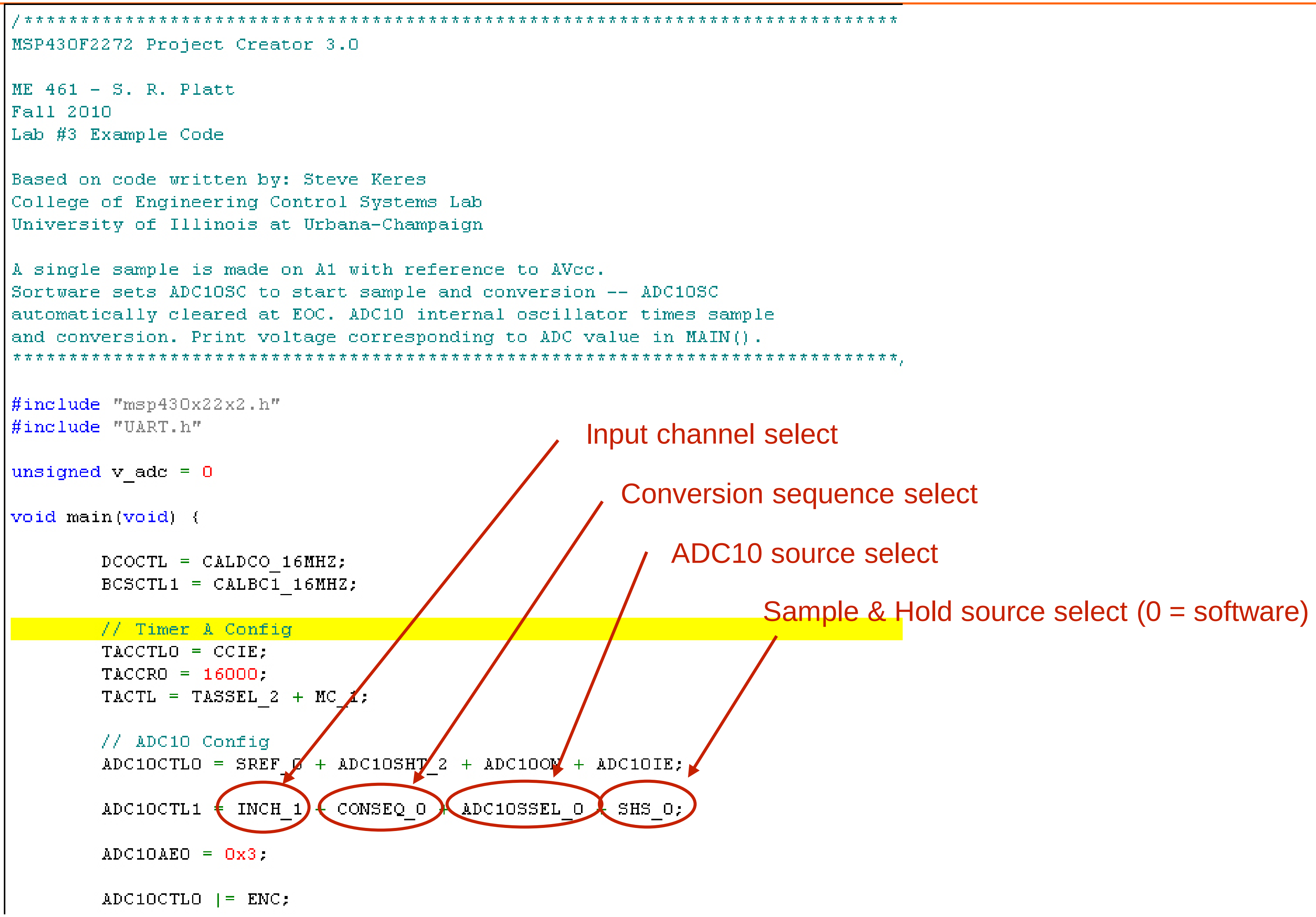
ADC10ON

= 0x1018 = %0001 0000 0001 1000

ADC10SHTx

ADC10IE

MSP430 Analog to Digital Conversion



```
/*****************************************************************************
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Software sets ADC10SC to start sample and conversion -- ADC10SC
automatically cleared at EOC. ADC10 internal oscillator times sample
and conversion. Print voltage corresponding to ADC value in MAIN().
*****************************************************************************/

#include "msp430x22x2.h"
#include "UART.h"

unsigned v_adc = 0

void main(void) {

        DCOCTL = CALDCO_16MHZ;
        BCSCTL1 = CALBC1_16MHZ;

        // Timer A Config
        TACCTL0 = CCIE;
        TACCR0 = 16000;
        TACTL = TASSEL_2 + MC_1;

        // ADC10 Config
        ADC10CTL0 = SREF_0 + ADC10SHT_2 + ADC10ON + ADC10IE;

        ADC10CTL1 = INCH_1 + CONSEQ_0 + ADC10SSEL_0 + SHS_0;

        ADC10AE0 = 0x3;

        ADC10CTL0 |= ENC;
```

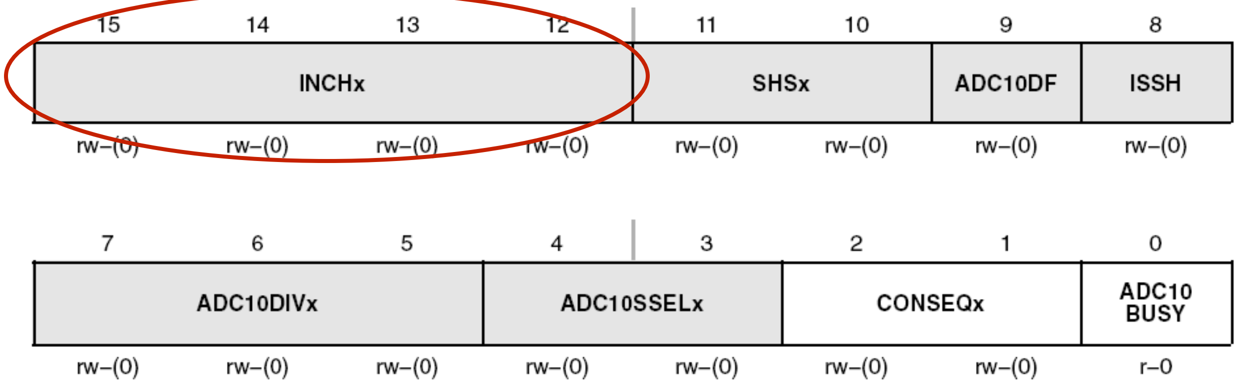
Input channel select

Conversion sequence select

ADC10 source select

Sample & Hold source select (0 = software)

ADC10—ADC10CTL1 Control Register 1



15	14	13	12	11	10	9	8
INCHx				SHSx		ADC10DF	ISSH
rw–(0)	rw–(0)	rw–(0)	rw–(0)	rw–(0)	rw–(0)	rw–(0)	rw–(0)

7	6	5	4	3	2	1	0
ADC10DIVx			ADC10SSELx		CONSEQx		ADC10 BUSY
rw–(0)	rw–(0)	rw–(0)	rw–(0)	rw–(0)	rw–(0)	rw–(0)	r–0

▨ Modifiable only when ENC = 0

INCHx	Bits 15-12	Input channel select. These bits select the channel for a single-conversion or the highest channel for a sequence of conversions.

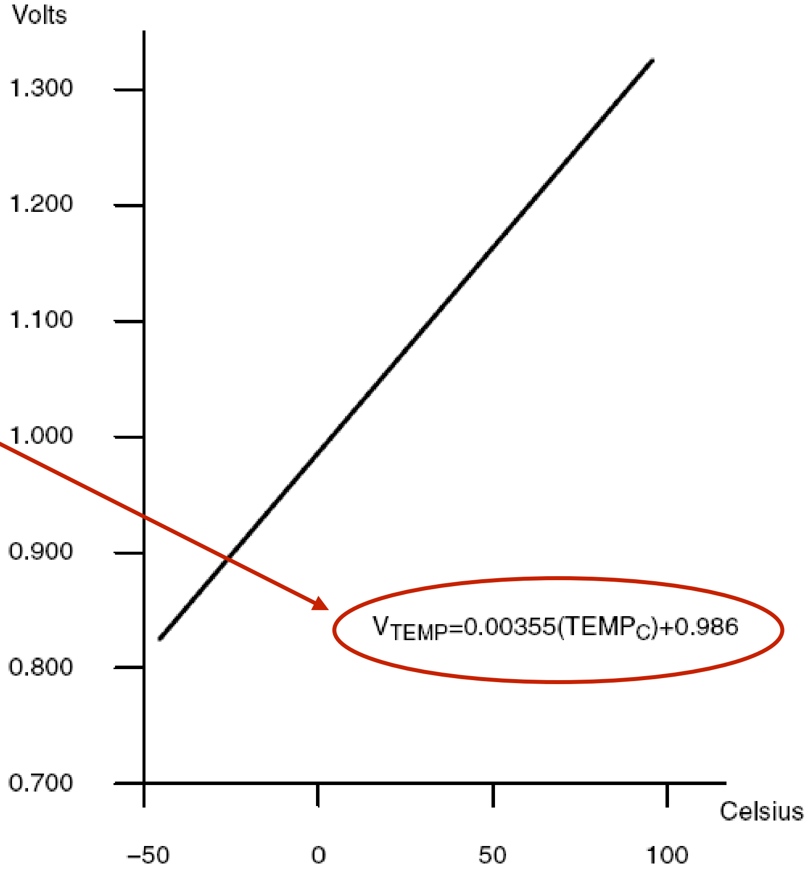
0000	A0
0001	A1
0010	A2
0011	A3
0100	A4
0101	A5
0110	A6
0111	A7
1000	Ve_{REF+}
1001	V_{REF-}/Ve_{REF-}
1010	Temperature sensor
1011	$(V_{CC} - V_{SS}) / 2$
1100	$(V_{CC} - V_{SS}) / 2$, A12 on MSP430x22xx devices
1101	$(V_{CC} - V_{SS}) / 2$, A13 on MSP430x22xx devices
1110	$(V_{CC} - V_{SS}) / 2$, A14 on MSP430x22xx devices
1111	$(V_{CC} - V_{SS}) / 2$, A15 on MSP430x22xx devices

Choose your channels.

Integrated Temperature Sensor

- Set INCHx = 1010
- Set $t_{sample} \geq 30\ \mu S$

Typical Temperature Sensor Transfer Function



“typical” response

In general, all sensors must be calibrated.

Do not trust the datasheets!