Data Conversion and Lab (17.368)

Fall 2013

Lecture Outline

Class # 11

November 14, 2013

Dohn Bowden

Today's Lecture Outline

- Administrative
- Detailed Technical Discussions
  - Microcontroller and Sensors
- Lab
  - Lab #4 … due TONIGHT … 11/14/13
  - Lab #6 (there is no Lab #5) … due 11/21/13 … NEXT WEEK
- Homework

Course Admin

Administrative

- Admin for tonight ...
  - Syllabus Highlights
  - Start/continue Lab #6
- **EXAM #2 is NEXT WEEK ... 11/21/13**

Syllabus Review

Week	Date	Topics	Lab	Lab Report Due
1	09/05/13	Introduction/Basic Data Conversion, Course Overview, Op Amps in Data Conversion		
2	09/12/13	Op Amp Lab	1	
3	09/19/13	Sample and Hold Lecture and Lab	2	
4	09/26/13	A/D Conversion Fundamentals and Lab	3	1
5	10/03/13	A/D Conversion Lab Continuation	3 con't	
6	10/10/13	**Examination 1**		
7	10/17/13	D/A Conversion Fundamentals and Lab	3	
8	10/24/13	D/A Conversion Lab Continuation	4	2
9	10/31/13	**V/F and F/V Conversion Lecture**	4 con't	
10	11/07/13	**Lab Only – No Lecture**	**6**	**3**
11	11/14/13	**Microcontroller and Sensors**	**6 con't**	4
12	11/21/13	**Examination 2**	Project	**6**
X	**11/28/13**	**No Class – Thanksgiving**		
13	12/05/13	Work on Course Project	Project	
14	12/12/13	Final Exam/Course Project Brief and Demonstration	Demo	

Detailed Technical Discussion

References …

Lecture material is covered in …

- Data Sheet for the PIC16F684
  - Located on the webpage

Microcontrollers
and
Microcontroller ADC Functions

General Overview …

General Overview

- The intent is not to teach microcontrollers ...
  - Rather ... introduce you to one of it's internal functions
- PIC microcontrollers are taught in detail in ...
  - Microprocessors A (17.383) and Microprocessors B (17.384)
- I am utilizing material/slides from those courses in this lecture
- Additionally ... I will not talk about programming the microcontroller

Embedded Systems …

Embedded Systems

- An ***embedded system*** is a combination of computer hardware and software, designed **to perform a dedicated function**
  - Examples ... microwave oven, digital watch, video game player
- The design of an embedded system to perform a dedicated function is in direct contrast to that of the personal computer
  - A personal computer is **not designed to perform a specific function**, rather it is able to do many things

Embedded Developer

- The embedded developer needs to understand ...
  - Hardware
  - Code
  - Peripheral interfaces

The Basics …

Basic Microcontroller facts

- What is a Microcontroller?
  - An inexpensive single chip computer
    - Single chip means ... that the entire computer lies within the confines of the integrated circuit
    - The microcontroller is capable of storing and running a program (its most important feature)

Basic Microcontroller facts

- Why use a Microcontroller?
  - Its ability to store and run unique programs makes it extremely versatile
  - A microcontroller can be programmed to make decisions and perform functions based on predetermined situations (I/O line logic) and selections
  - Its ability to perform math and logic functions allows it to mimic sophisticated logic and electronic circuits
  - Microcontrollers are responsible for intelligence in most smart devices on the consumer market

Basic Microcontroller facts

- The PIC Chip
  - Microchip's microcontrollers are commonly called PIC chips
  - Microchip uses PIC to describe its series of PIC microcontrollers
  - The PIC microcontroller was originally designed as a Peripheral Interface Controller (PIC) for a 16 bit microprocessor
    - It was essentially an I/O controller and was designed to be very fast
    - It had a small micro-coded instruction set
    - This design became the basis for the Microchip Technology's PIC family of microcontrollers

Hardware …

Getting to Know the Hardware

- Before writing software for an embedded system ...
  - You must be familiar with the hardware on which it runs
- Understand ...
  - General operation of the system
  - What the inputs are
  - What the outputs are
  - etc
- Initially you don’t need all the details of the hardware, but it is helpful

The Processor

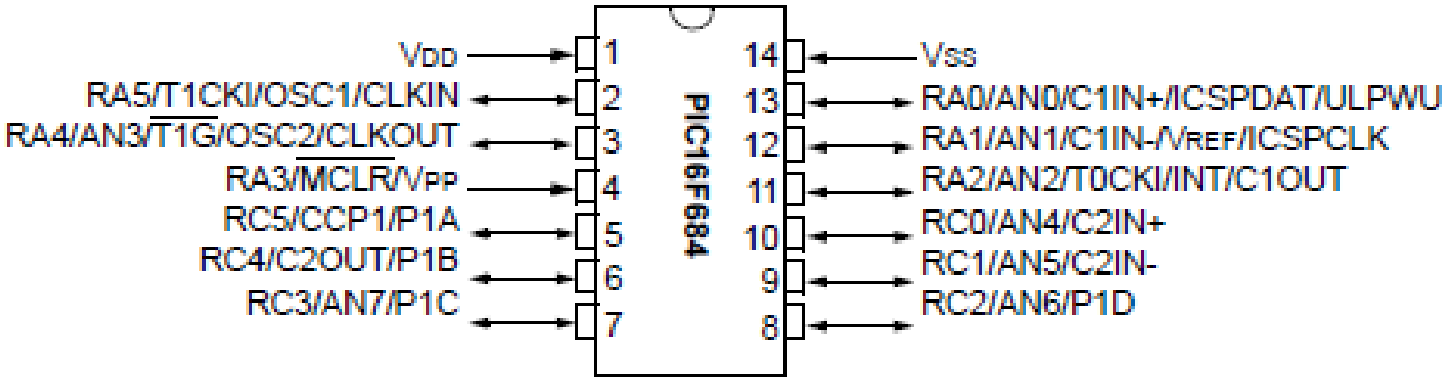
- Review the datasheets
- What internal functions does the processor have?
  - *ADC*?
  - *Comparators*?
  - Etc.
- What is connected to it?
- How does it communicate with those interfaces?
- Memory Mapping
- Initializing the processor

PIC Microcontroller of Interest to Us

- Microchip PIC microcontroller ...
    - PIC16F684
- The PIC16F684 is ...
    - A fourteen-pin microcontroller

PIC16F684 Pin Diagram

14-pin PDIP, SOIC, TSSOP

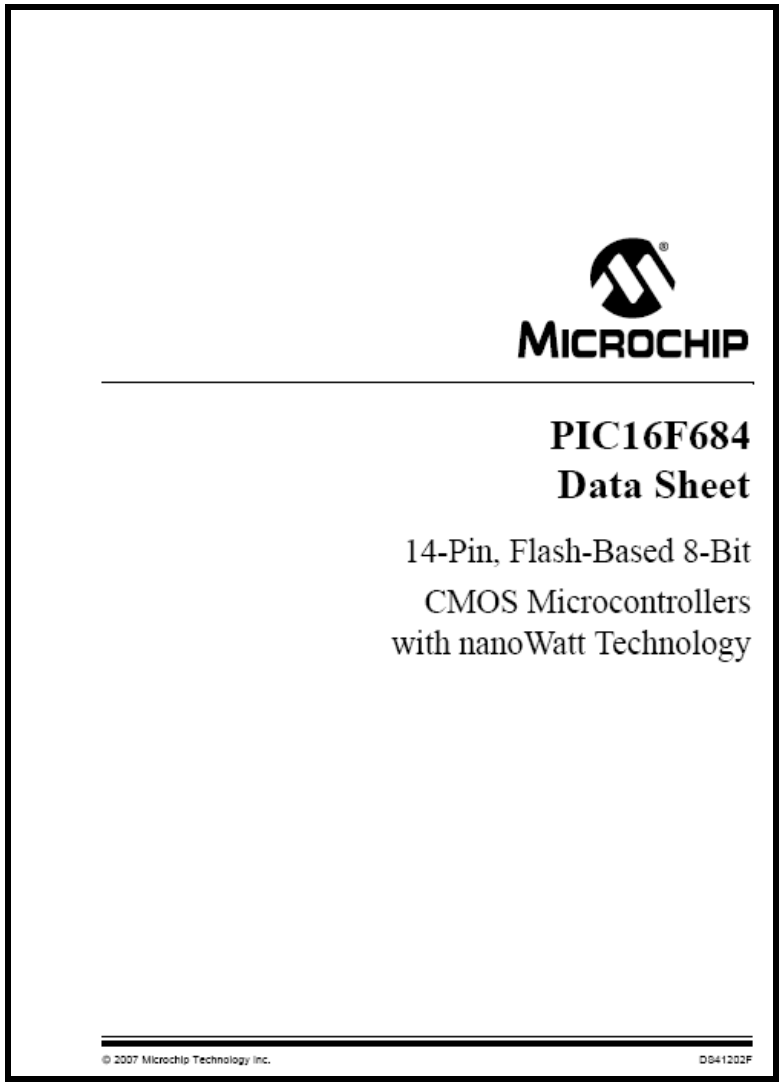


PICkit™ 3 – Used to Program the PIC

PICkit™ 3

- PICkit™ 3
- Provides
  - Programming
  - Evaluation
  - And development
- In one simple to use design

PIC16F684 Data Sheet



PIC16F684 Features

- 35 Instructions
- 8-level deep hardware stack
- 2048 Flash (words) Program Memory
- Interrupt capability
- 12 I/O pins with individual direction control
- *2 Comparators*
- *A/D Converter (10-bit resolution and 8 channels)*
- 2 Timers

PIC16F684 Features

Device	Program Memory	Data Memory		I/O	10-bit A/D (ch)	Comparators	Timers 8/16-bit
	Flash (words)	SRAM (bytes)	EEPROM (bytes)				
PIC16F684	2048	128	256	12	8	2	2/1

Analog Signals

- As we have discussed ... real world signals are analog
  - For example ... sensors
- We need to be able to take these signals and convert them to digital in order to be able to process them using the microcontroller
- The PIC16F684 is capable of performing the required conversion with it's built in analog to digital converter

The PIC16F684 Analog-to-Digital Converter

- Contains a Successive-approximation-register (SAR) type Analog to Digital converters
    - 10-bit resolution
- 8 channels
    - Meaning it can evaluate 8 different analog inputs
        - » One at a time

The PIC16F684 Analog-To-Digital Converter Module Specifics

ANALOG-TO-DIGITAL CONVERTER (A/D) MODULE

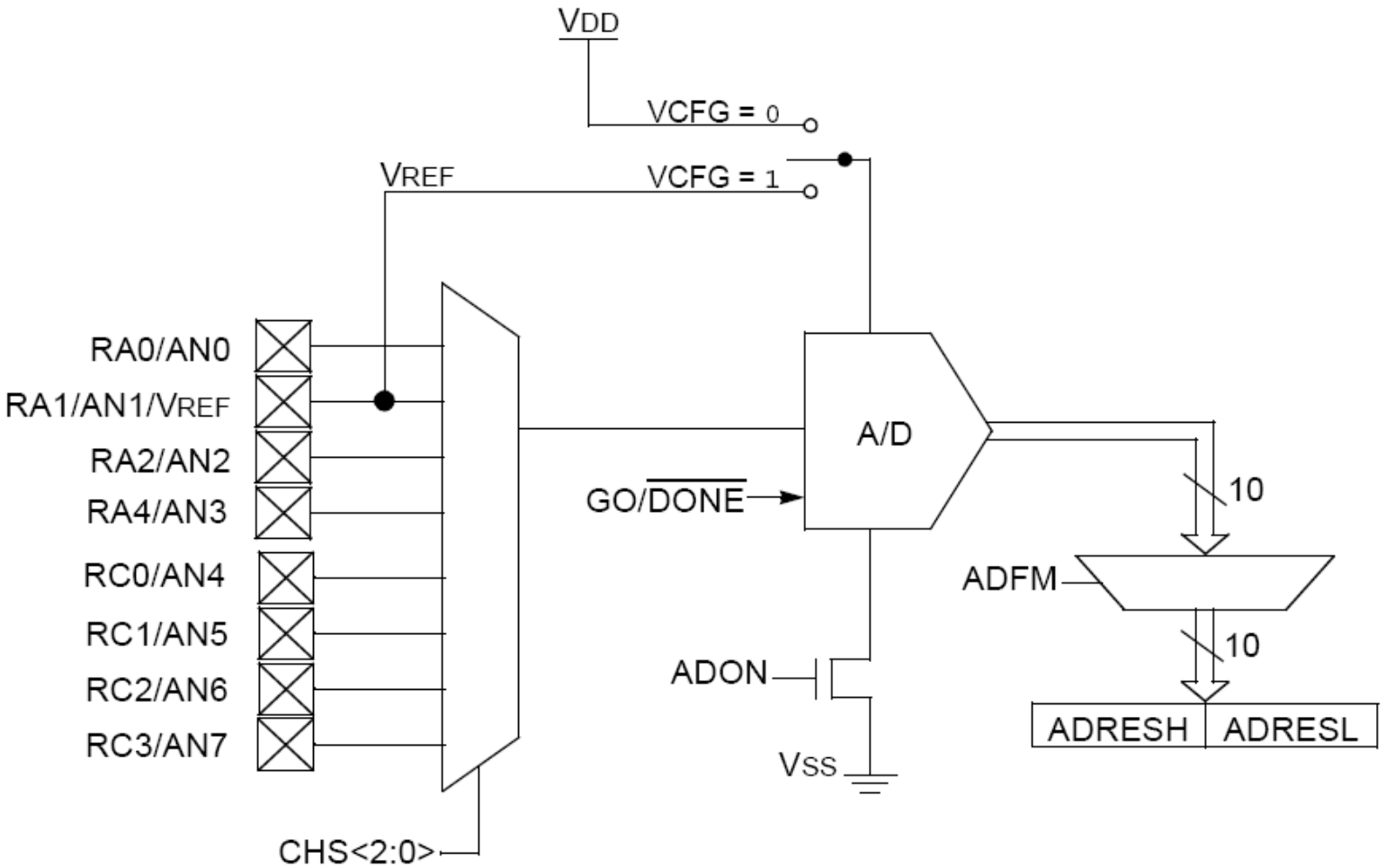
- The PIC16F684 Analog-to-Digital converter (A/D) allows
    - Conversion of an analog input signal to a 10-bit binary representation of that signal
- The PIC16F684 has eight analog inputs,
    - multiplexed into one sample and hold circuit
- The output of the sample and hold is connected to the input of the converter

ANALOG-TO-DIGITAL CONVERTER (A/D) MODULE (con't)

- The converter generates a binary result via successive approximation ... and ...
  - Stores the result in a 10-bit register
- The voltage reference used in the conversion is software selectable to either ...
  - VDD

  or
  - A voltage applied by the V_{REF} pin

A/D BLOCK DIAGRAM



Configuring The PIC16F684 A/D Module

- To use the feature we will need to configure the device
- To configure the PIC16F684 ... three registers need to be setup
  - ANSEL (Analog Select Register)
  - ADCON1 (A/D Control Register 1)
  - ADCON0 (A/D Control Register 0)

REGISTER 9-1: ANSEL – ANALOG SELECT REGISTER (ADDRESS: 91h)

R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1	R/W-1
ANS7	ANS6	ANS5	ANS4	ANS3	ANS2	ANS1	ANS0
bit 7							bit 0

bit 7-0: **ANS<7:0>**: Analog Select bits

Analog select between analog or digital function on pins AN<7:0>, respectively.

1 = Analog input. Pin is assigned as analog input(1).

0 = Digital I/O. Pin is assigned to port or special function.

Note 1: Setting a pin to an analog input automatically disables the digital input circuitry, weak pull-ups, and interrupt-on-change if available. The corresponding TRIS bit must be set to input mode in order to allow external control of the voltage on the pin.

Legend:			
R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'	
-n = Value at POR	'1' = Bit is set	'0' = Bit is cleared	x = Bit is unknown

ANSEL (Analog Select)

- Controls the operation of the A/D port pins
- Channel Selection (selects one of eight analog channels)
    - ANS0 through ANS7
- We must also set the corresponding TRIS bits to Input mode

Note:	Analog voltages on any pin that is defined as a digital input may cause the input buffer to conduct excess current.

REGISTER 9-3: ADCON1 – A/D CONTROL REGISTER 1 (ADDRESS: 9Fh)

U-0	R/W-0	R/W-0	R/W-0	U-0	U-0	U-0	U-0
—	ADCS2	ADCS1	ADCS0	—	—	—	—
bit 7							bit 0

bit 7: **Unimplemented:** Read as '0'

bit 6-4: **ADCS<2:0>:** A/D Conversion Clock Select bits

000 = FOSC/2
001 = FOSC/8
010 = FOSC/32
x11 = FRC (clock derived from a dedicated internal oscillator = 500 kHz max)
100 = FOSC/4
101 = FOSC/16
110 = FOSC/64

bit 3-0: **Unimplemented:** Read as '0'

Legend:			
R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'	
-n = Value at POR	'1' = Bit is set	'0' = Bit is cleared	x = Bit is unknown

ADCON1 (A/D Control Register 1)

- Bit 6-4 Conversion clock select bits
  - An accurate conversion requires a time of 1.6 μs or greater
  - There is no point making this too much longer
  - The internal oscillator provides a conversion time of approximately 4 μs, although this can vary between 2 and 6μs
    - We are using the internal oscillator, therefore we will use the A/D RC option (111)
- No other bits are used in this register

TAD VS. DEVICE OPERATING FREQUENCIES

TABLE 9-1: TAD VS. DEVICE OPERATING FREQUENCIES

A/D Clock Source (TAD)		Device Frequency			
Operation	**ADCS2:ADCS0**	**20 MHz**	**5 MHz**	**4 MHz**	**1.25 MHz**
2 TOSC	000	100 ns(2)	400 ns(2)	500 ns(2)	1.6 µs
4 TOSC	100	200 ns(2)	800 ns(2)	1.0 µs(2)	3.2 µs
8 TOSC	001	400 ns(2)	1.6 µs	2.0 µs	6.4 µs
16 TOSC	101	800 ns(2)	3.2 µs	4.0 µs	12.8 µs(3)
32 TOSC	010	1.6 µs	6.4 µs	8.0 µs(3)	25.6 µs(3)
64 TOSC	110	3.2 µs	12.8 µs(3)	16.0 µs(3)	51.2 µs(3)
A/D RC	x11	2-6 µs(1,4)	2-6 µs(1,4)	2-6 µs(1,4)	2-6 µs(1,4)

Legend: Shaded cells are outside of recommended range.

Note 1: The A/D RC source has a typical TAD time of 4 µs for VDD > 3.0V.

2: These values violate the minimum required TAD time.

3: For faster conversion times, the selection of another clock source is recommended.

4: When the device frequency is greater than 1 MHz, the A/D RC clock source is only recommended if the conversion will be performed during Sleep.

REGISTER 9-2: ADCON0 – A/D CONTROL REGISTER (ADDRESS: 1Fh)

R/W-0	R/W-0	U-0	R/W-0	R/W-0	R/W-0	R/W-0	R/W-0
ADFM	VCFG	—	CHS2	CHS1	CHS0	GO/$\overline{\text{DONE}}$	ADON
bit 7							bit 0

bit 7 **ADFM:** A/D Result Formed Select bit
1 = Right justified
0 = Left justified

bit 6 **VCFG:** Voltage Reference bit
1 = V_{REF} pin
0 = V_{DD}

bit 5 **Unimplemented:** Read as '0'

bit 4-2 **CHS<2:0>:** Analog Channel Select bits
000 = Channel 00 (AN0)
001 = Channel 01 (AN1)
010 = Channel 02 (AN2)
011 = Channel 03 (AN3)
100 = Channel 04 (AN4)
101 = Channel 05 (AN5)
110 = Channel 06 (AN6)
111 = Channel 07 (AN7)

bit 1 **GO/$\overline{\text{DONE}}$:** A/D Conversion Status bit
1 = A/D conversion cycle in progress. Setting this bit starts an A/D conversion cycle.
This bit is automatically cleared by hardware when the A/D conversion has completed.
0 = A/D conversion completed/not in progress

bit 0 **ADON:** A/D Conversion Status bit
1 = A/D converter module is operating
0 = A/D converter is shut-off and consumes no operating current

Legend:			
R = Readable bit	W = Writable bit	U = Unimplemented bit, read as '0'	
-n = Value at POR	'1' = Bit is set	'0' = Bit is cleared	x = Bit is unknown

ADCON0 (A/D Control Register 0)

- Bit 0
  - Turns on or off the A/D converter
    - 1 = On
    - 0 = Off
- Bit 4-2
  - Selects the channel to use (AN0 – AN7)
- Bit 6
  - Selects where the reference voltage is from
- Bit 7
  - Results format (right or left justified)

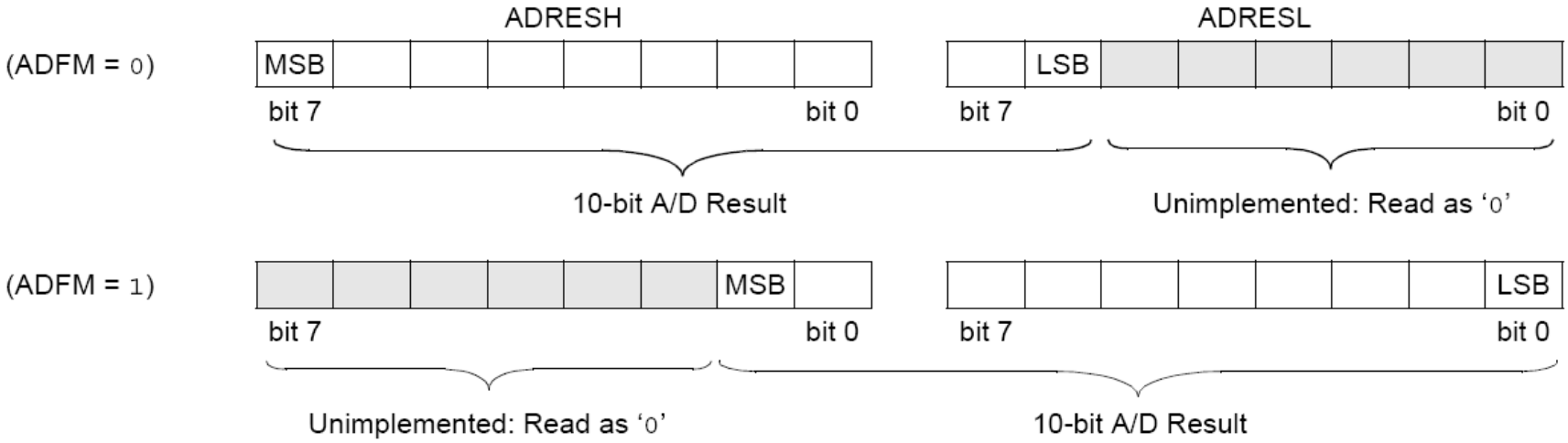
VOLTAGE REFERENCE

- There are two options for the voltage reference to the A/D converter ... either ...
  - VDD is used ... or ...
  - An analog voltage applied to V_{REF}
- The VCFG bit (ADCON0<6>) controls the voltage reference selection
  - If VCFG is set ... then the voltage on the VREF pin is the reference
  - otherwise, VDD is the reference.

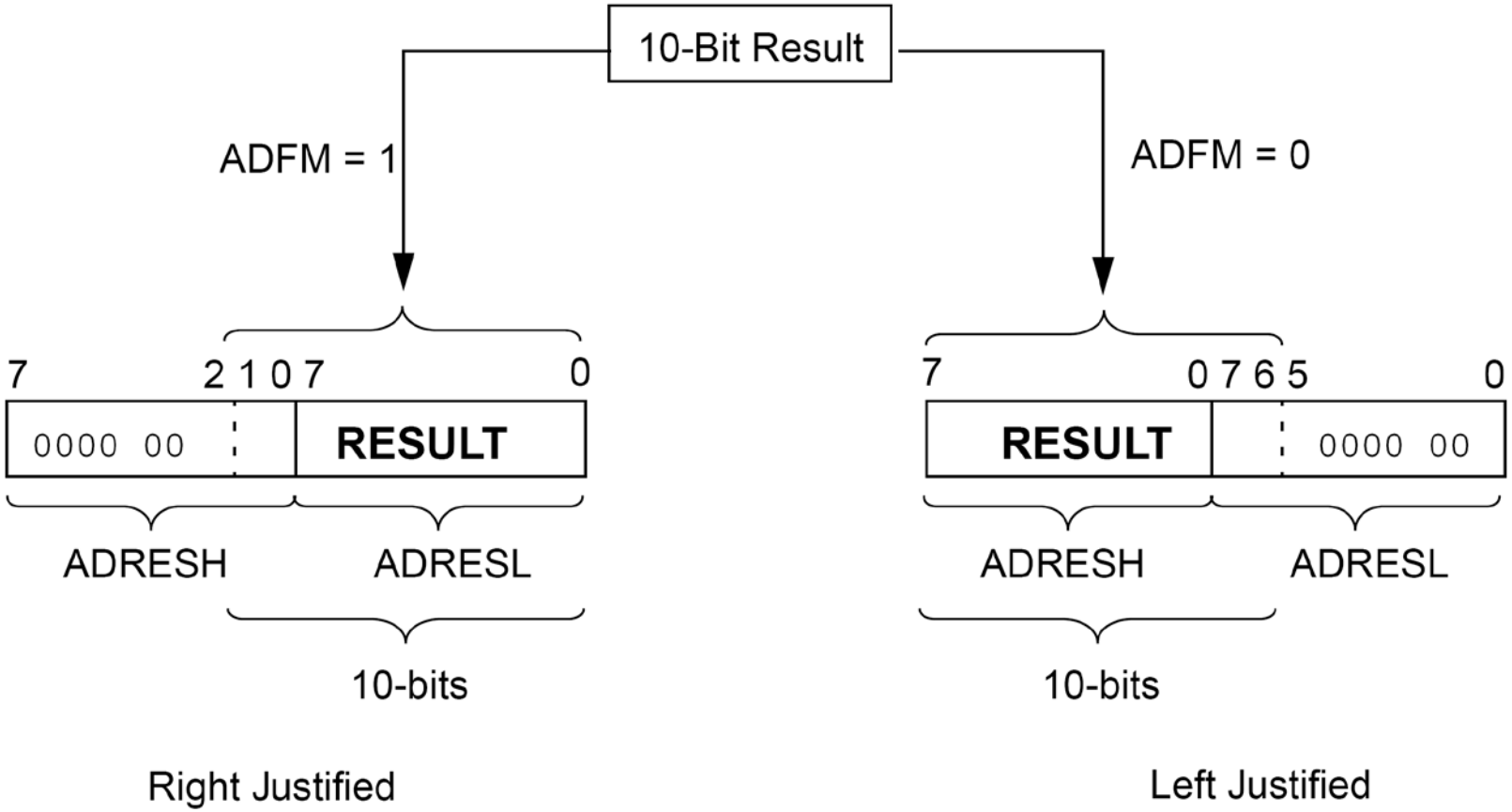
CONVERSION OUTPUT

- The A/D conversion can be supplied in two formats ...
  - Left ...
  - or right shifted
- The ADFM bit (ADCON0<7>) controls the output format
- The next slide shows the output formats

10-BIT A/D RESULT FORMAT



10-BIT A/D RESULT FORMAT



STARTING A CONVERSION

- The A/D conversion is initiated by setting the GO/DONE bit (ADCON0<1>)

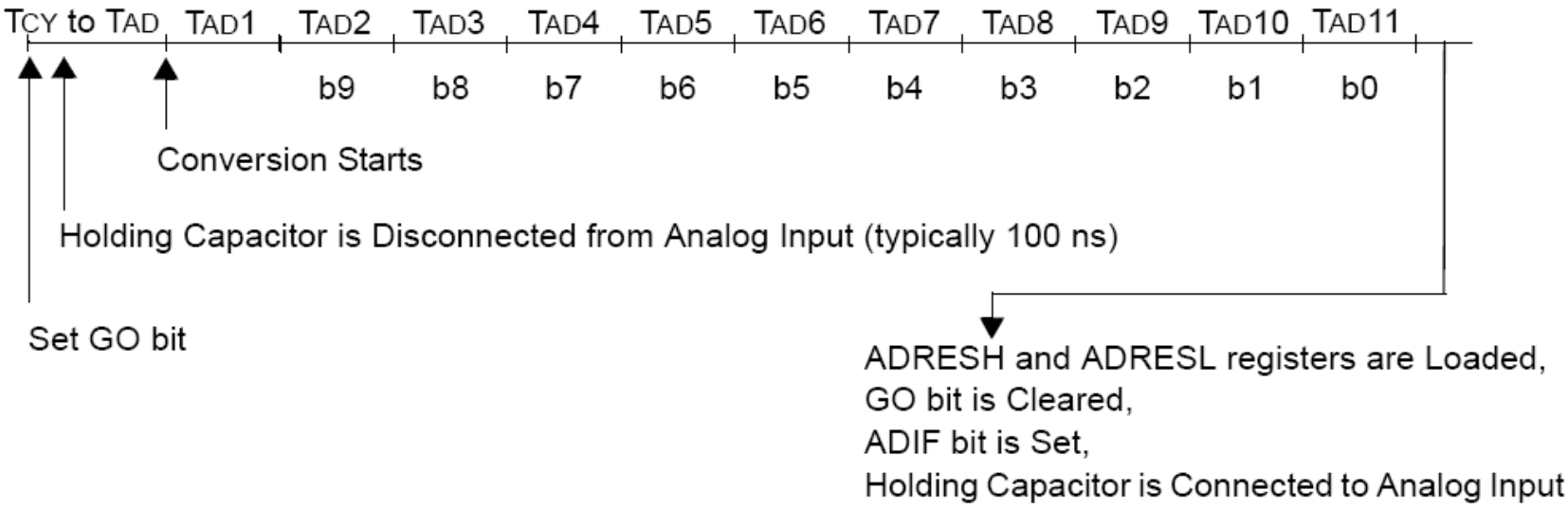
- When the conversion is complete, the A/D module ...

  - Clears the GO/DONE bit
  - Sets the ADIF flag (PIR1<6>)
  - Generates an interrupt (if enabled)

ABORTING A CONVERSION

- If the conversion must be aborted, the GO/DONE bit can be cleared in software.
- The ADRESH:ADRESL registers will not be updated with the partially complete A/D conversion sample ...
- Instead, the ADRESH:ADRESL registers will retain the value of the previous conversion
- After an aborted conversion ... a 2 TAD delay is required before another acquisition can be initiated.
- Following the delay, an input acquisition is automatically started on the selected channel

A/D CONVERSION TAD CYCLES



CONFIGURING THE A/D

- After the A/D module has been configured as desired ...
  - the selected channel must be acquired before the conversion is started
- The analog input channels must have their corresponding TRIS bits selected as inputs
- After this sample time has elapsed ...
  - the A/D conversion can be started

Steps to Follow for A/D Conversion

1. Configure the A/D module
2. Configure A/D interrupt (if desired)
3. Wait the required acquisition time
4. Start conversion
5. Wait for A/D conversion to complete
6. Read A/D Result register pair
7. For the next conversion ... go to step 1 or step 2 as required

Microcontroller Comparator Function

PIC16F684 Hardware

- Another analog interface function of the PIC16F684
  - Comparators

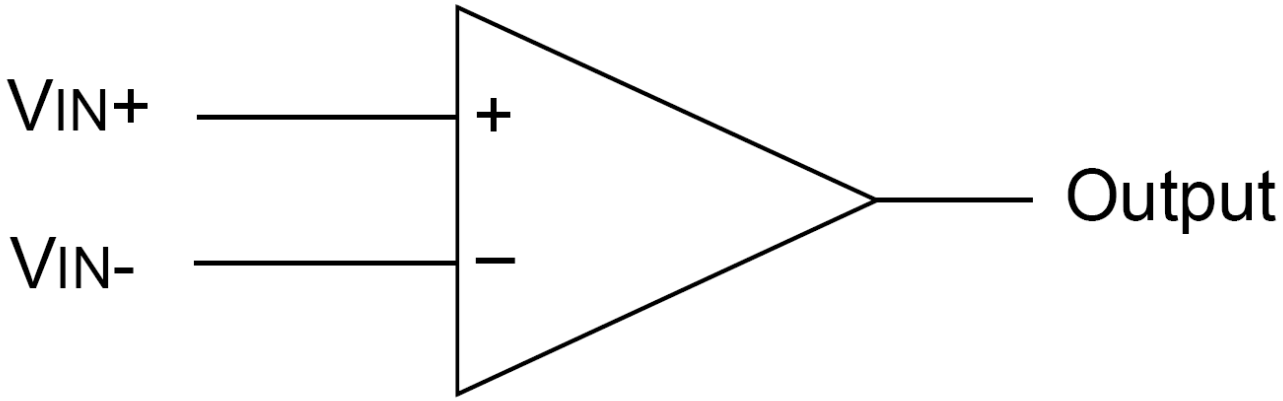
Comparator Fundamentals

- Compares the voltage level of two analog signals ... and ...
  - Identifies which signal is the largest

The PIC16F684 Comparator Module

- Dual comparators
- Multiple comparator configurations
- Comparator outputs are available internally/externally
- Programmable output polarity
- Interrupt-on-change
- Wake-up from Sleep
- Timer1 gate (count enable) – ONLY C2 CAN BE LINKED TO TIMER1
- Output synchronization to Timer1 clock input
- Programmable voltage reference

PIC16F684 Comparators



- When the analog voltage at VIN+ is < the analog voltage at VIN- ...
  - The output of the comparator is a digital low level

- When the analog voltage at VIN+ is > the analog voltage at VIN- ...
  - The output of the comparator is a digital high level

PIC16F684 Comparator Configuration

- There are eight modes of operation for the comparator
    1. Comparators Reset
    2. Three Inputs Multiplexed to Two Comparators
    3. Four Inputs Multiplexed to Two Comparators
    4. Two Common Reference Comparators
    5. Two Independent Comparators
    6. One Independent Comparator
    7. Two Common Reference Comparators with Outputs
    8. Comparators Off

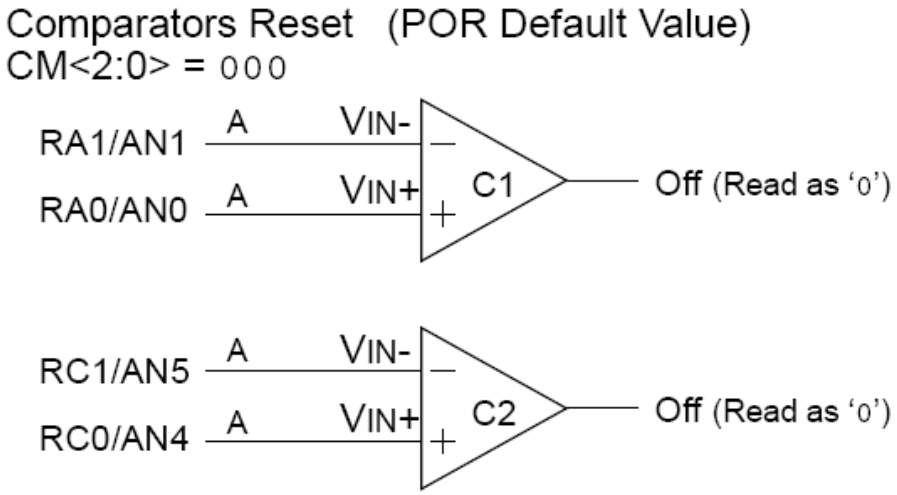
- The CM<2:0> bits of the CMCON0 register are used to select these modes

- I/O lines change as a function of the mode

PIC16F684 Comparator Modes of Operation (CMCON0) Register

1. Comparators Reset –
   `CM<2:0> = 000`
2. Three Inputs Multiplexed to Two Comparators –
   `CM<2:0> = 001`
3. Four Inputs Multiplexed to Two Comparators –
   `CM<2:0> = 010`
4. Two Common Reference Comparators –
   `CM<2:0> = 011`
5. Two Independent Comparators –
   `CM<2:0> = 100`
6. One Independent Comparator –
   `CM<2:0> = 101`
7. Two Common Reference Comparators with Outputs –
   `CM<2:0> = 110`
8. Comparators Off –
   `CM<2:0> = 111`

PIC16F684 Comparator Modes of Operation
Comparators Reset - CM<2:0> = 000

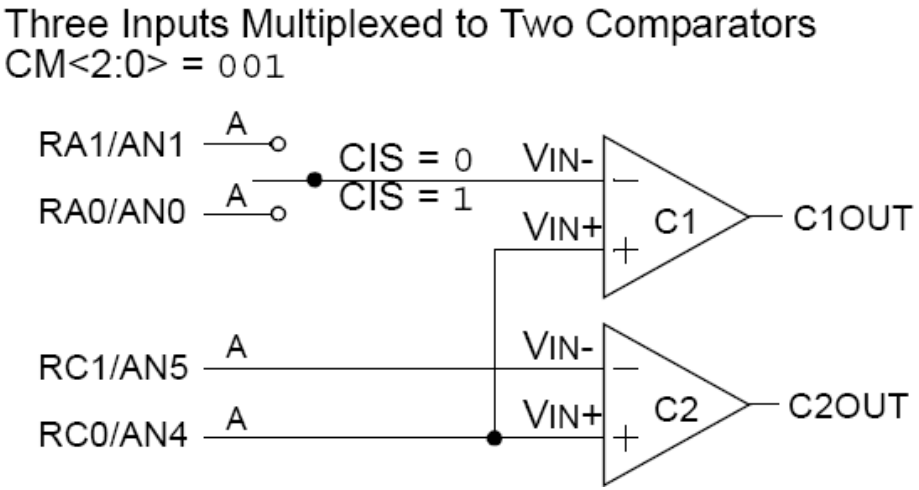


Legend: A = Analog Input, ports always read '0'
D = Digital Input

CIS (CMCON0<3>) is the Comparator Input Switch

PIC16F684 Comparator Modes of Operation

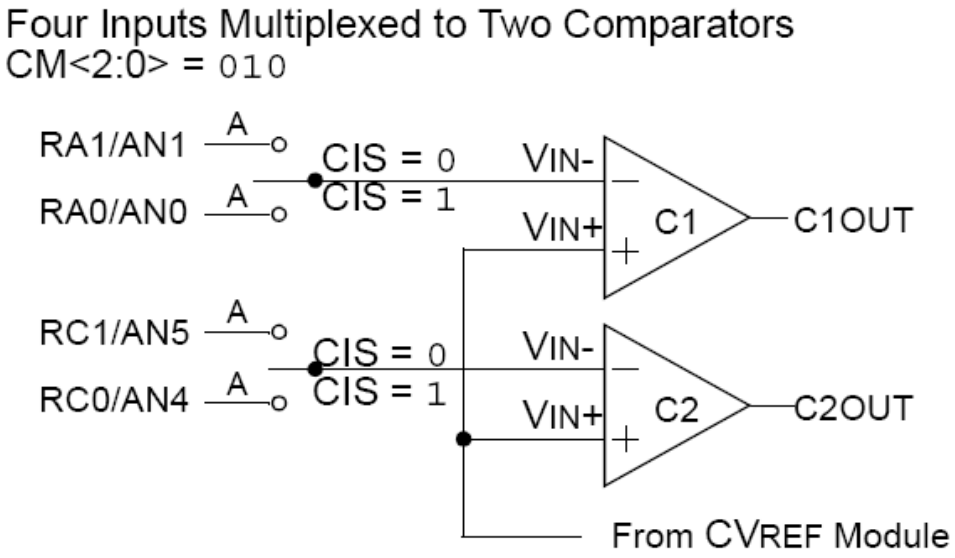
Three Inputs Multiplexed to Two Comparators – CM<2:0> = 001



Legend: A = Analog Input, ports always read '0'
D = Digital Input

CIS (CMCON0<3>) is the Comparator Input Switch

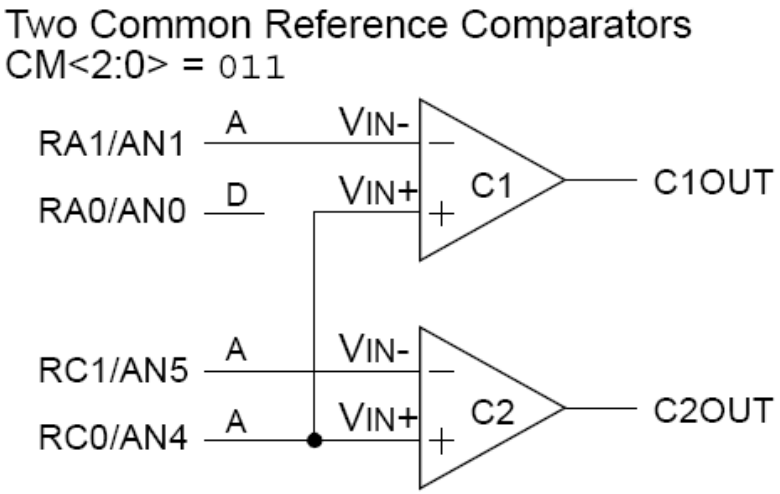
PIC16F684 Comparator Modes of Operation
Four Inputs Multiplexed to Two Comparators – CM<2:0> = 010



Legend: A = Analog Input, ports always read '0'
D = Digital Input

CIS (CMCON0<3>) is the Comparator Input Switch

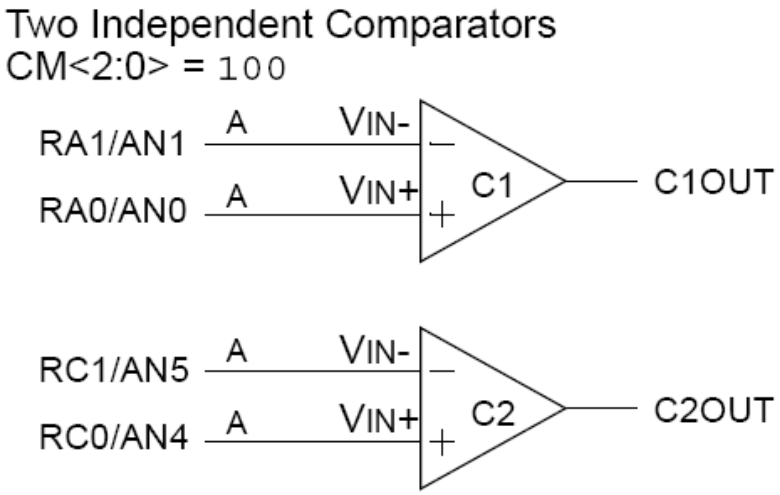
PIC16F684 Comparator Modes of Operation
Two Common Reference Comparators – CM<2:0> = 011



Legend: A = Analog Input, ports always read '0'
D = Digital Input

CIS (CMCON0<3>) is the Comparator Input Switch

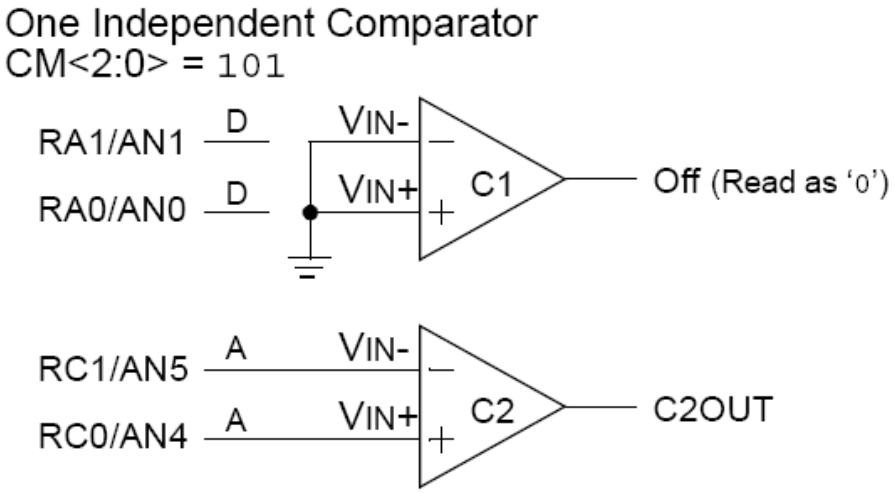
PIC16F684 Comparator Modes of Operation
Two Independent Comparators – CM<2:0> = 100



Legend: A = Analog Input, ports always read '0'
D = Digital Input

CIS (CMCON0<3>) is the Comparator Input Switch

PIC16F684 Comparator Modes of Operation
One Independent Comparator – CM<2:0> = 101

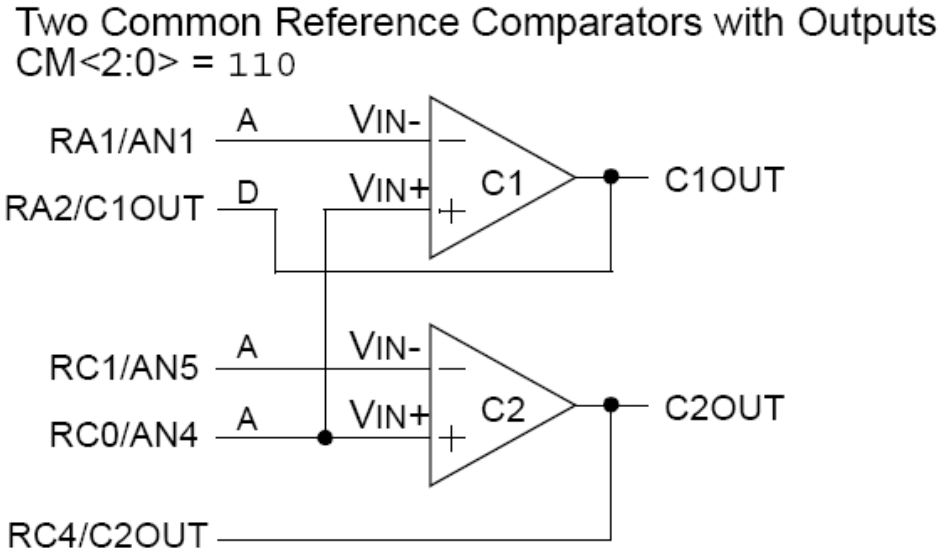


Legend: A = Analog Input, ports always read '0'
D = Digital Input

CIS (CMCON0<3>) is the Comparator Input Switch

PIC16F684 Comparator Modes of Operation

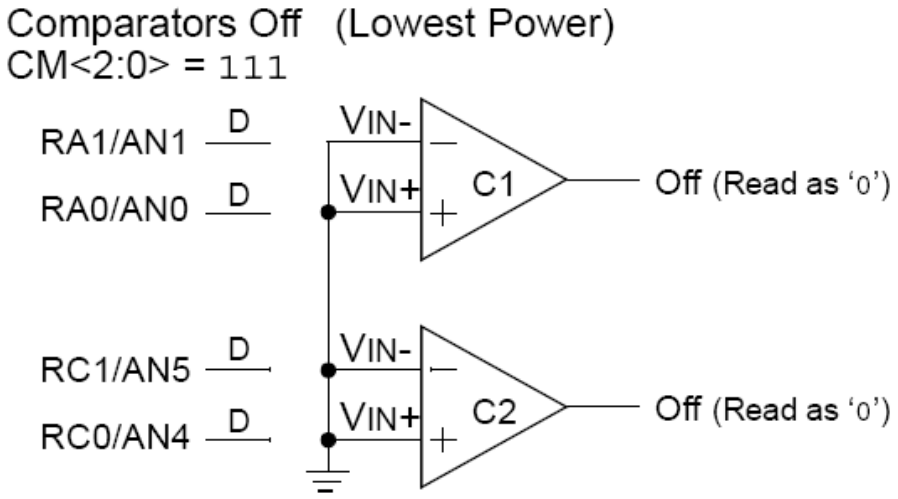
Two Common Reference Comparators with Outputs – CM<2:0> = 110



Legend: A = Analog Input, ports always read '0'
D = Digital Input

CIS (CMCON0<3>) is the Comparator Input Switch

PIC16F684 Comparator Modes of Operation
Comparators Off – CM<2:0> = 111



Legend: A = Analog Input, ports always read '0'
D = Digital Input

CIS (CMCON0<3>) is the Comparator Input Switch

In Summary …

Microcontroller Data Conversion Function

Summary

- The microcontroller can accomplish many of the functions that we have discussed this semester ...
  - Including ...
    - ADC
    - DAC
    - Comparators
- In many cases ... hardware configuration is much easier
- However ... software must be used in place of the hardware

Lab

Lab #5 ...

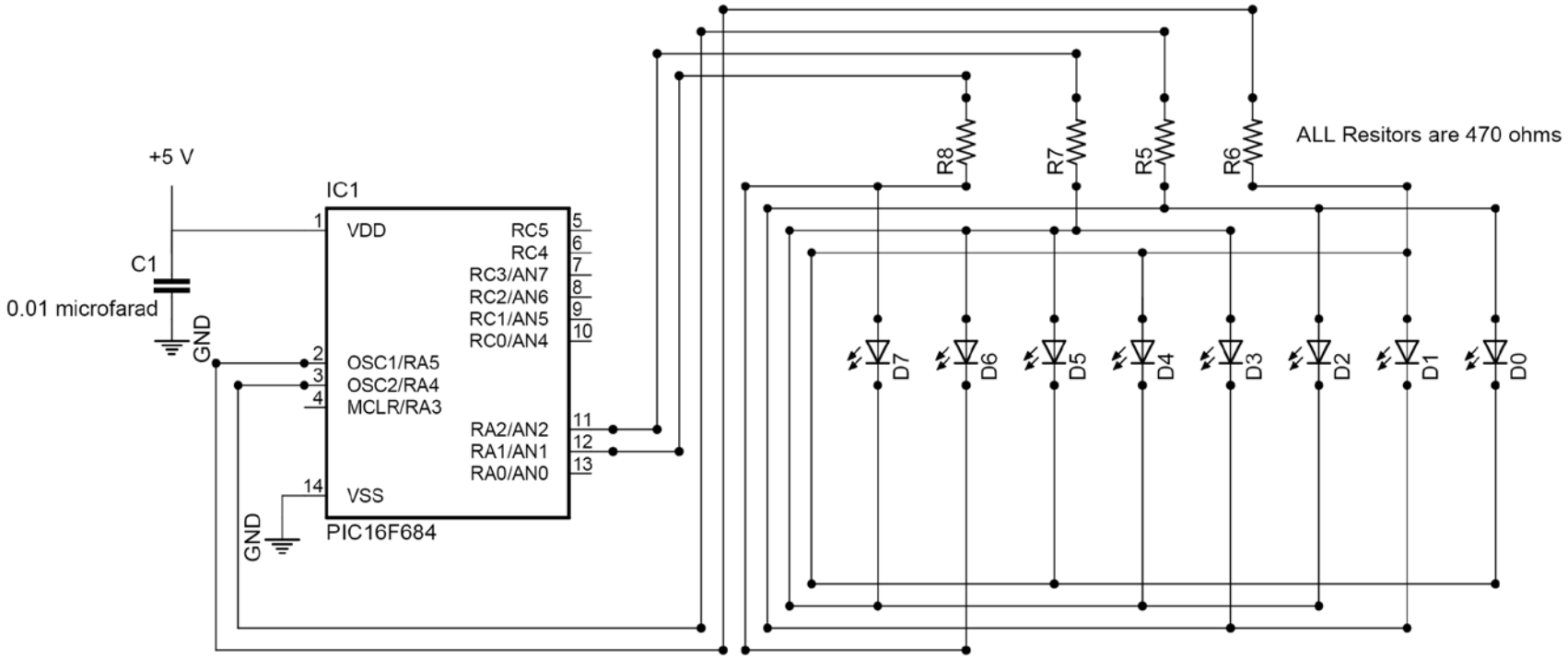
Lab # 5 – Overview

- Will compare the operation of the ADC0804 to that of the PIC16F684
- The PIC16F684 is pre-programmed
- Need to remember that ...
  - The ADC0804 is an 8 bit ADC
  - The PIC16F684 is a 10 bit ADC

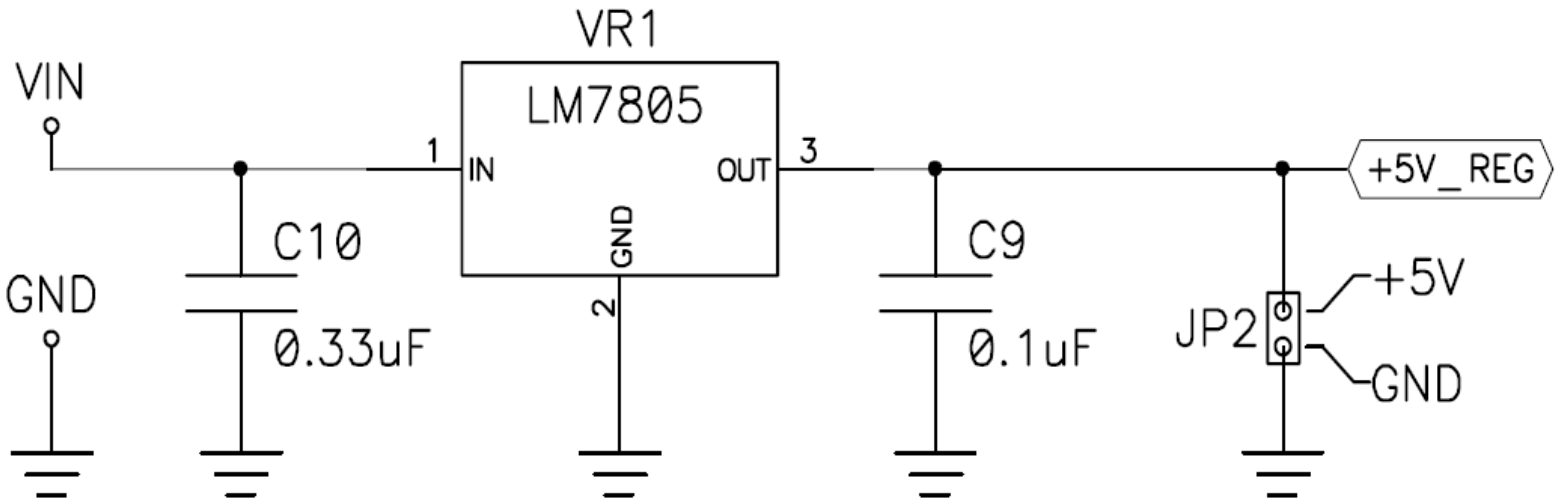
What the Pre-Programmed Code is doing …

- Set the initial conditions
- Lights corresponding LEDs (represents the binary equivalent of the analog voltage)
- While in an Endless Loop …
    - Checks to see if the A/D Conversion is complete
        - If it is … Then …
            - » Get the new conversion value
            - » Display the new value
            - » Start a new conversion
        - If still in the conversion
            - » Display the last result

PIC16F684 and LED Output Connections

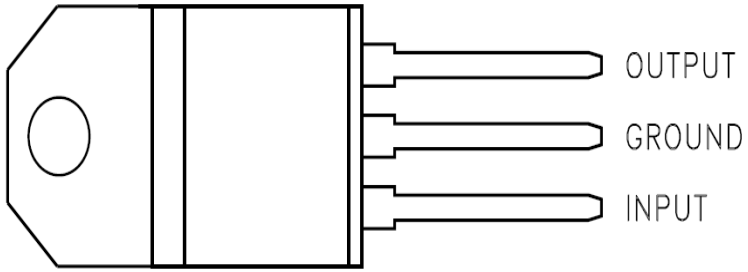


Voltage Regulator Circuit

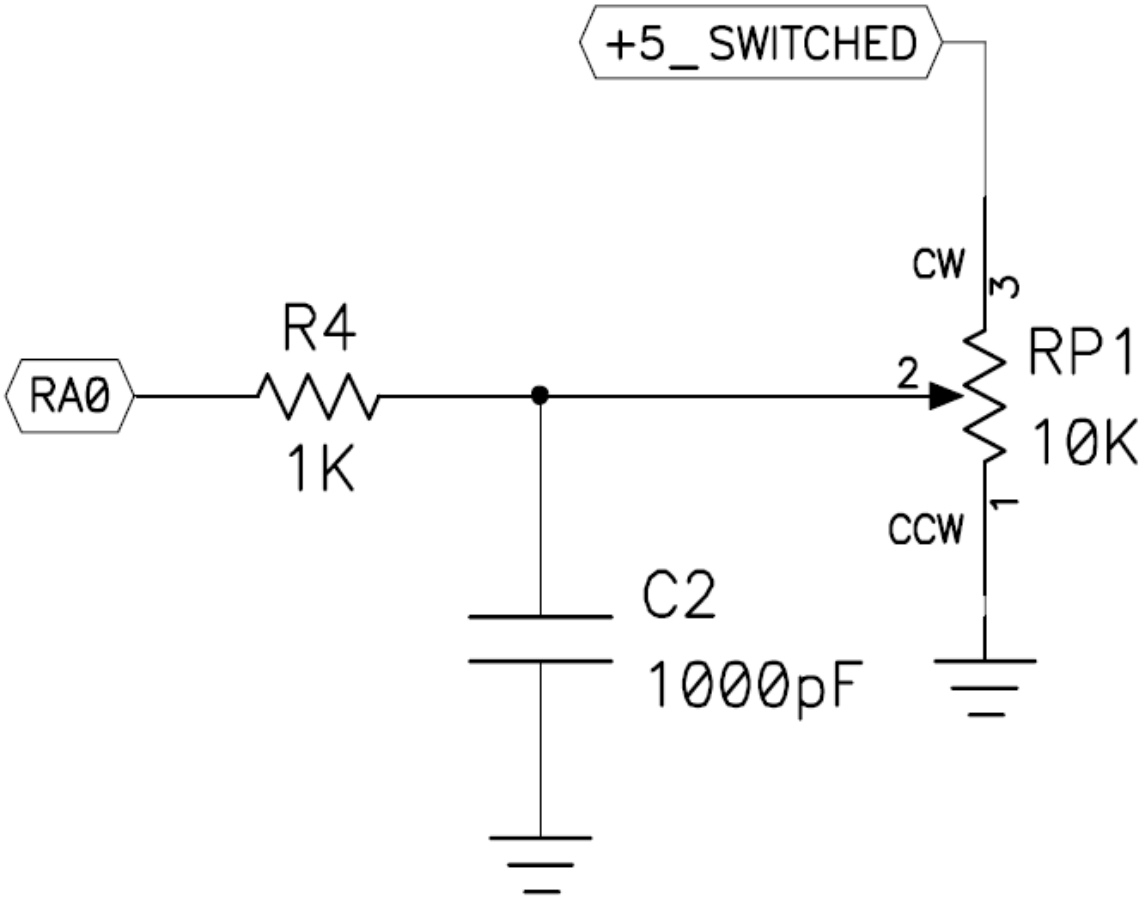


LM7805 Pin Connections - Top View

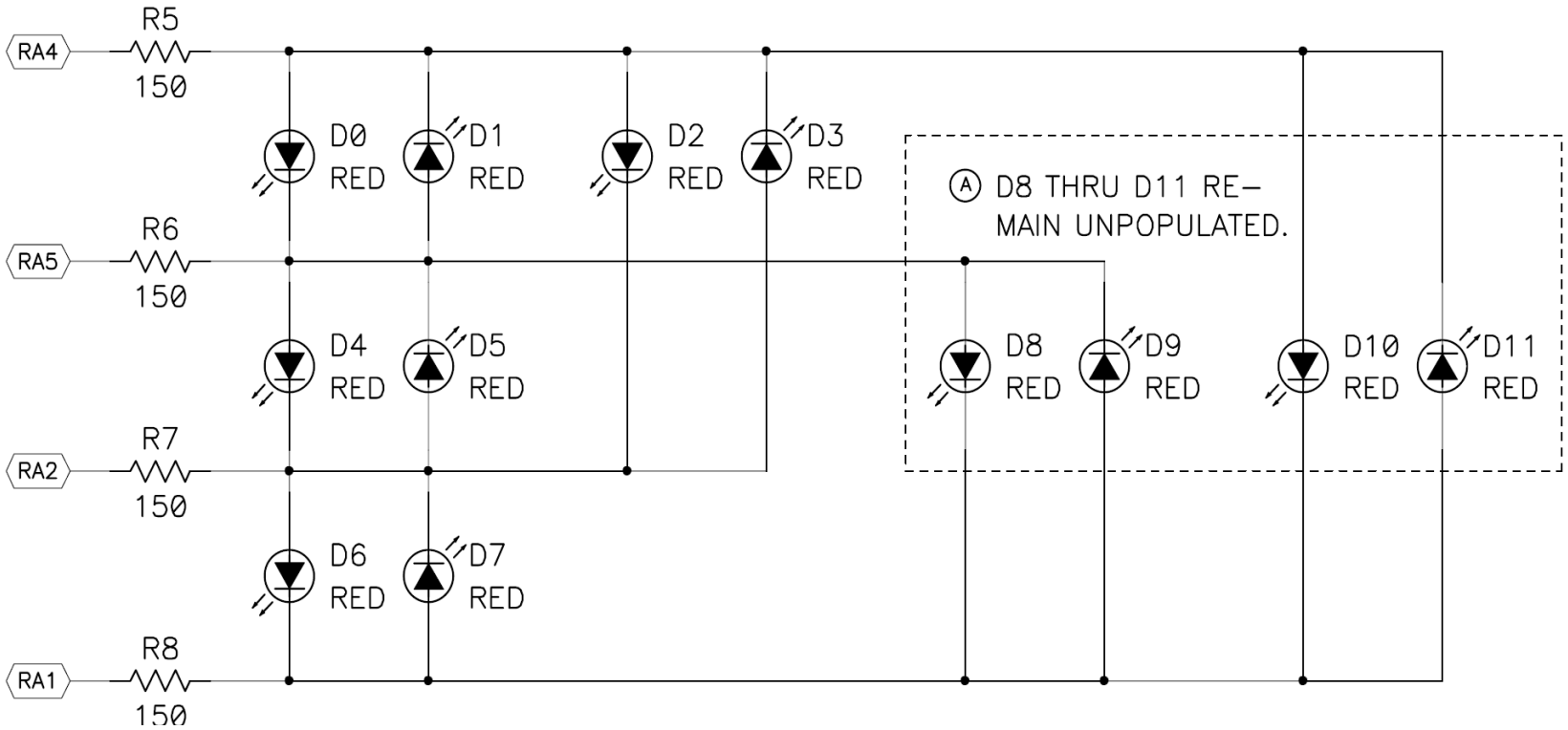
LM7805 Pin Connections - Top View



RA0 Analog Input



LED Connections



Lab #6 ...

Lab # 6 – Overview

- Voltage-to-Frequency conversion
- Frequency-to-Voltage conversion
- Input a signal into a VFC and convert it back via a FVC

- *READ THE DATA SHEET* ... this is one of the most informative data sheets I have used

Next Class

Next Class Topics

- Exam #2

Homework

Homework

1. Lab Reports are due as follows:

   a) Lab Report (#6) Due 11/21/13

   b) Course Projects

   c) Study for Exam!!!!

Time to start the lab …

Lab

- Start/continue with Lab #6

Questions?