

Using the HCS12 PWM

1. Choose 8-bit mode ($PWMCTL = 0x00$)
2. Choose high polarity ($PWMPOL = 0xFF$)
3. Choose left-aligned ($PWMCAE = 0x00$)
4. Select clock mode in $PWMCLK$:
 - $PCLK_n = 0$ for 2^N ,
 - $PCLK_n = 1$ for $2^{(N+1)} \times M$,
5. Select N in $PWMPRCLK$ register:
 - $PCKA$ for channels 5, 4, 1, 0;
 - $PCKB$ for channels 7, 6, 3, 2.
6. If $PCLK_n = 1$, select M
 - $PWMSCLA = M$ for channels 5, 4, 1, 0
 - $PWMSCLB = M$ for channels 7, 6, 3, 2.
7. Select $PWMPER_n$, normally between 100 and 255.
8. Enable desired PWM channels: $PWME$.
9. Select $PWMDTY_n$, normally between 0 and $PWMPER_n$. Then

$$\text{Duty Cycle } n = \frac{PWMDTY_n}{PWMPER_n} \times 100\%$$

Change duty cycle to control speed of motor or intensity of light, etc.

10. For 0% duty cycle, choose $PWMDTY_n = 0x00$.

Finding the Values to Set Up the PWM Clock

1. Find the number of 24 MHz clock cycles needed for desired PWM frequency:

$$\text{Cycles} = \frac{24 \times 10^6}{\text{PWM Frequency}}$$

2. Choose a value for PWMPERx, typically between 100 and 255

- To get an exact frequency, PWMPERx must divide evenly into the number of cycles found in 1.

3. Find the PWM clock period:

$$\text{PWM Clock Period} = \frac{\text{Total Cycles}}{\text{PWMPERx}}$$

4. Use either Clock Mode 0 or Clock Mode 1:

- (a) Clock Mode 0: Find N such that $2^N = \text{PWM Clock Period}$
- (b) Clock Mode 1: Find M and N such that $2^{N+1} \times M = \text{PWM Clock Period}$.

Suppose you want a 500 Hz PWM frequency. Then:

$$\text{Cycles} = \frac{24 \times 10^6}{500} = 48,000$$

Let's use PWMPERx = 250. Then

$$\text{PWM Clock Period} = \frac{48,000}{250} = 192$$

Because 192 is not a power of two, we cannot use Clock Mode 0 to get an exact frequency. For Clock Mode 1, we want

$$192 = 2^{N+1} \times M$$

We could do this with $N = 0$ and $M = 96$, $N = 1$ and $M = 48$, $N = 2$ and $M = 24$, and several other combinations.

Program to use the MC9S12 PWM System

```

/*
 * Program to generate a 500 Hz PWM on
 * on Port P Bits 0 and 1
 *
 * To get 500 Hz,  $24,000,000 / 500 = 48,000$ 
 *
 * Choose PWMPERx = 200, then  $48,000/200 = 240 = 2^4 \times 3 \times 5$ 
 *
 * Lots of ways to set up PWM to achieve this. One way is  $2^1 \times 120$ 
 * Choose Clock Mode 1, PCKA = 0, N = 0, PWMSCLA = 120
 *
 */
#include "hcs12.h"

main()
{
    /* Choose 8-bit mode */
    PWMCTL = 0x00;
    /* Choose left-aligned */
    PWMCAE = 0x00;
    /* Choose high polarity on all channels */
    PWMPOL = 0xFF;
    /* Select clock mode 1 for Channels 1 and 0 (no PWMSCLA) */
    PWMCLK = PWMCLK | (BIT1 | BIT0);
    /* Select PCKA = 0 for Channels 1 and 0 */
    PWMPRCLK = (PWMPRCLK & ~0x7);
    /* Select PWMSCLA = 96 for Channels 1 and 0 */
    PWMSCLA = 96;
    /* Select period of 200 for Channels 1 and 0 */
    PWMPER1 = 200;
    PWMPER0 = 200;
    /* Enable PWM on Channels 1 and 0 */
    PWME = PWME | 0x03;

    PWMDTY1 = 100; /* 50% duty cycle on Channel 1 */
    PWMDTY0 = 50; /* 25% duty cycle on Channel 0 */

    while (1)
    { /* Code to adjust duty cycle to meet requirements */ }
}

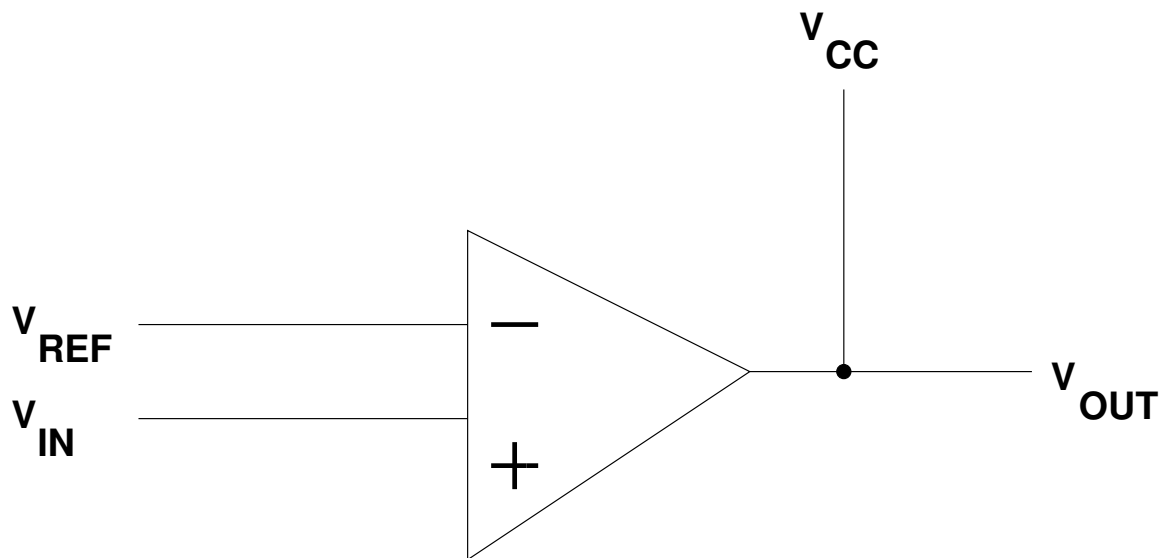
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Analog/Digital Converters

- An Analog-to-Digital (A/D) converter converts an analog voltage into a digital number
- There are a wide variety of methods used for A/D converters
Examples are:
 - Flash (Parallel)
 - Successive Approximation
 - Sigma-Delta
 - Dual Slope Converter
- A/D converters are classified according to several characteristics
 - Resolution (number of bits) — typically 8 bits to 24 bits
 - Speed (number of samples per second) — several samples/sec to several billion samples/sec
 - Accuracy — how much error there is in the conversion
- High-resolution converters are usually slower than low-resolution converters
- The MC9S12 has a 10-bit successive approximation A/D converter (which can be used in 8-bit mode)
- The MC9S12 uses an analog multiplexer to allow eight input pins to connect to the A/D converter

Comparator

- A comparator is used in many types of A/D converters.
- A comparator is the simplest interface from an analog signal to a digital signal
- A comparator compares two voltage values on its two inputs
- If the voltage on the + input is greater than the voltage on the - input, the output will be a logic high
- If the voltage on the + input is less than the voltage on the - input, the output will be a logic low

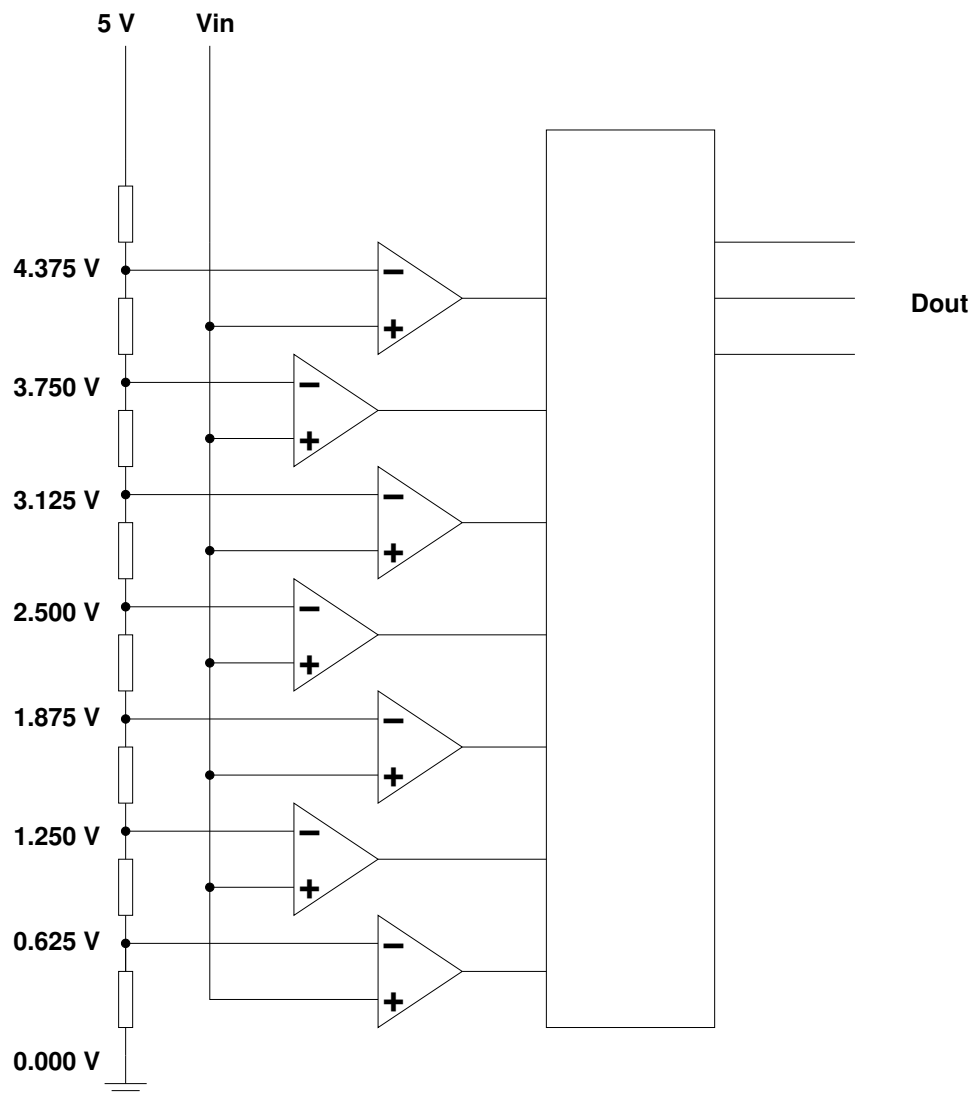


If $V_{in} > V_{ref}$ then $V_{out} = V_{cc}$

If $V_{in} < V_{ref}$ then $V_{out} = 0$

Flash (Parallel) A/D Converter

- A flash A/D converter is the simplest to understand
- A flash A/D converter compares an input voltage to a large number of reference voltages
- An n -bit flash converter uses $2^n - 1$ comparators
- The output of the A/D converter is determined by which of the two reference voltages the input signal is between,
- Here is a 3-bit A/D converter



Flash A/D Converter

- A B -bit Flash A/D converter requires 2^B-1 comparators
- An 8-bit Flash A/D requires 255 comparators
- A 12-bit Flash A/D converter would require 4,095 comparators
 - Cannot integrate 4,095 comparators onto an IC
- The largest flash A/D converter is 8 bits
- Flash A/D converters can sample at several billion samples/sec

A/D Converter Resolution and Quantization

- If the voltage input voltage is 3.2516 V, the lowest 5 comparators will be turned on, and the highest 2 comparators will be turned off
- The output of the 3-bit flash A/D converter will be 5 (101)
- For a 3-bit A/D converter, which has a range from 0 to 5 V, an output of 5 indicates that the input voltage is between 3.125 V and 3.750 V
- A 3-bit A/D converter with a 5 V input range has a quantization value of 0.625 V
- The quantization value of an A/D converter can be found by

$$\Delta V = \frac{V_{RH} - V_{RL}}{2^b}$$

where V_{RH} is the highest voltage the A/D converter can handle, V_{RL} is the lowest voltage the A/D converter can handle, and b is the number of bits of the A/D converter

- The MC9S12 has a 10-bit A/D converter. The typical voltage range used for the MC9S12 A/D is $V_{RH} = 5$ V and $V_{RL} = 0$ V, so the MC9S12 has a quantization value of

$$\Delta V = \frac{5 \text{ V} - 0 \text{ V}}{2^{10}} = 4.88 \text{ mV}$$

- The dynamic range of an A/D converter is given in decibels (dB):

$$DR(\text{dB}) = 20 \log 2^b = 20b \log 2 = 6.02b$$

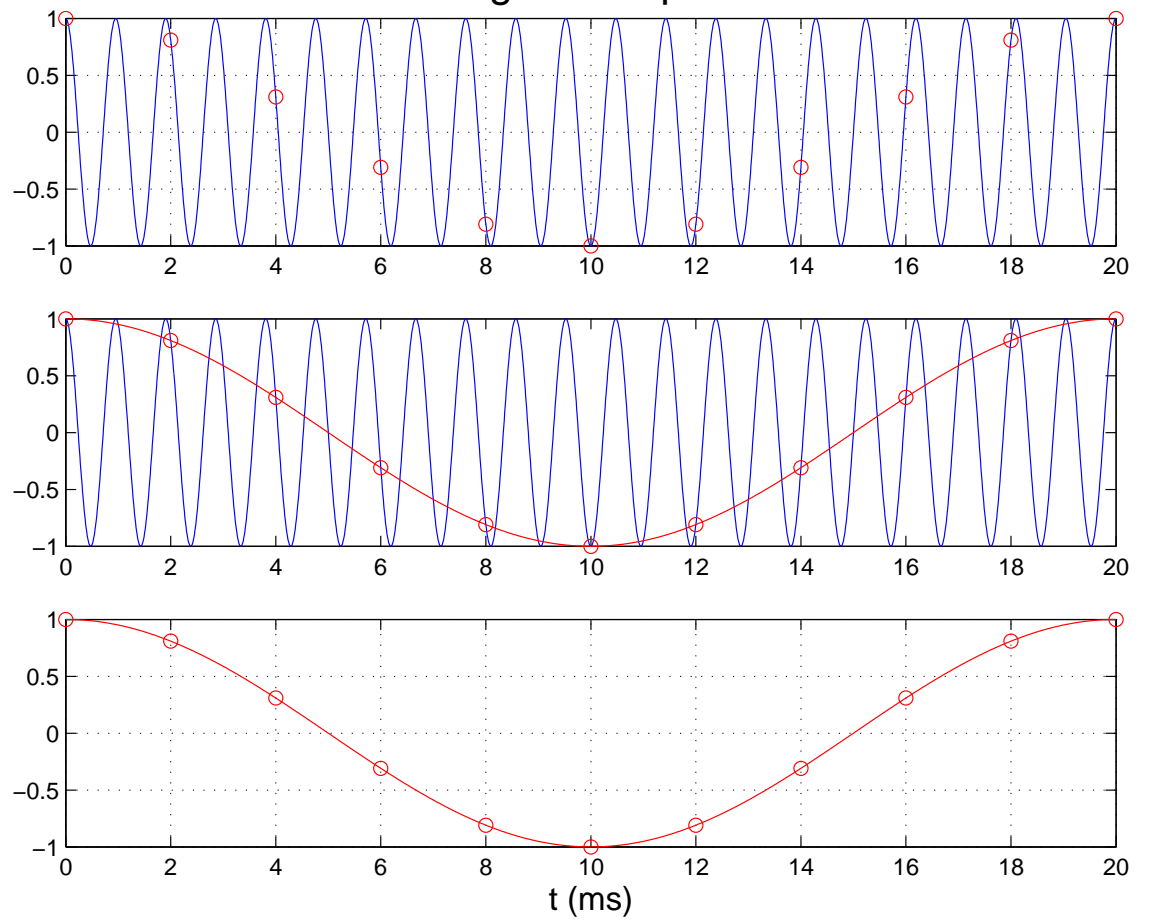
- A 10-bit A/D converter has a dynamic range of

$$DR(\text{dB}) = 6.02 \times 10 = 60.2 \text{ dB}$$

A/D Sampling Rate

- The rate at which you sample a signal depends on how rapidly the signal is changing
- If you sample a signal too slowly, the information about the signal may be inaccurate

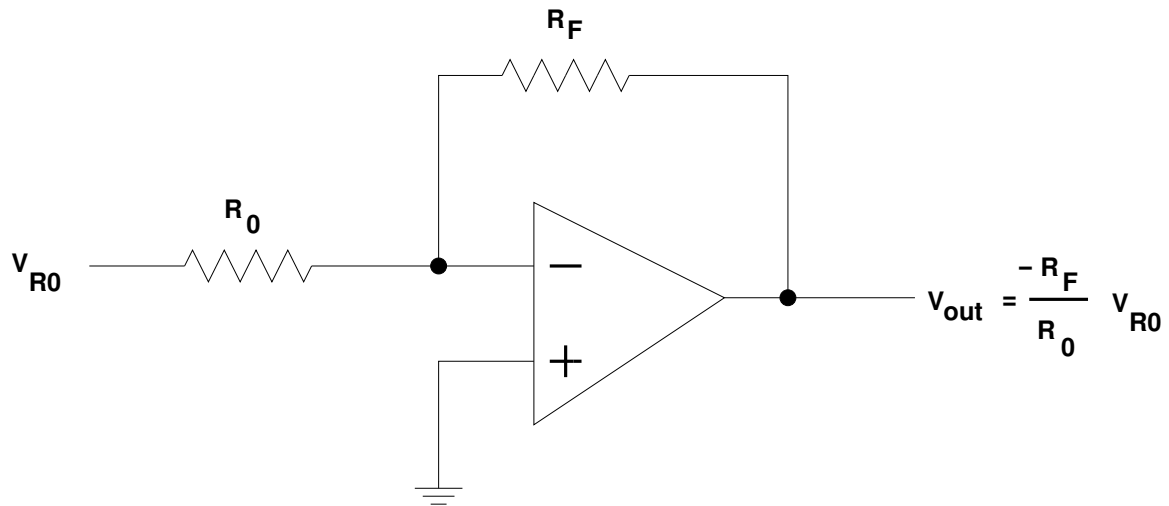
A 1050 Hz signal sampled at 500 Hz



- A 1,050 Hz signal sampled at 500 Hz looks like a 50 Hz signal
- To get full information about a signal you must sample more than twice the highest frequency in the signal
- Practical systems typically use a sampling rate of at least four times the highest frequency in the signal

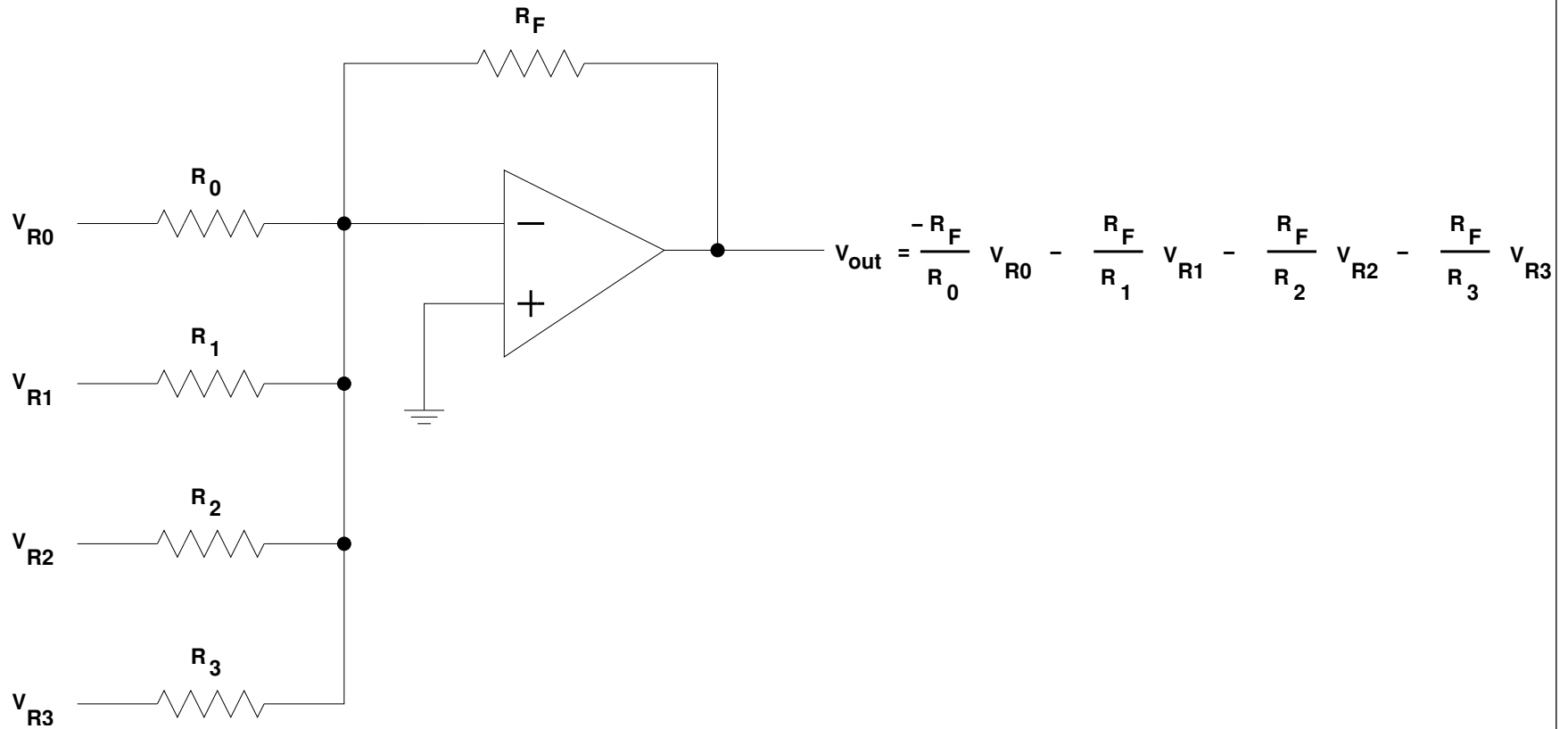
Digital-to-Analog (D/A) Converters

- Many A/D converters use a D/A converter internally
- A D/A converter converts a digital signal to an analog voltage or current
- To understand how most A/D converters work, it is necessary to understand D/A converters
- The heart of a D/A converter is an inverting op amp circuit
- The output voltage of an inverting op amp circuit is proportional to the input voltage:



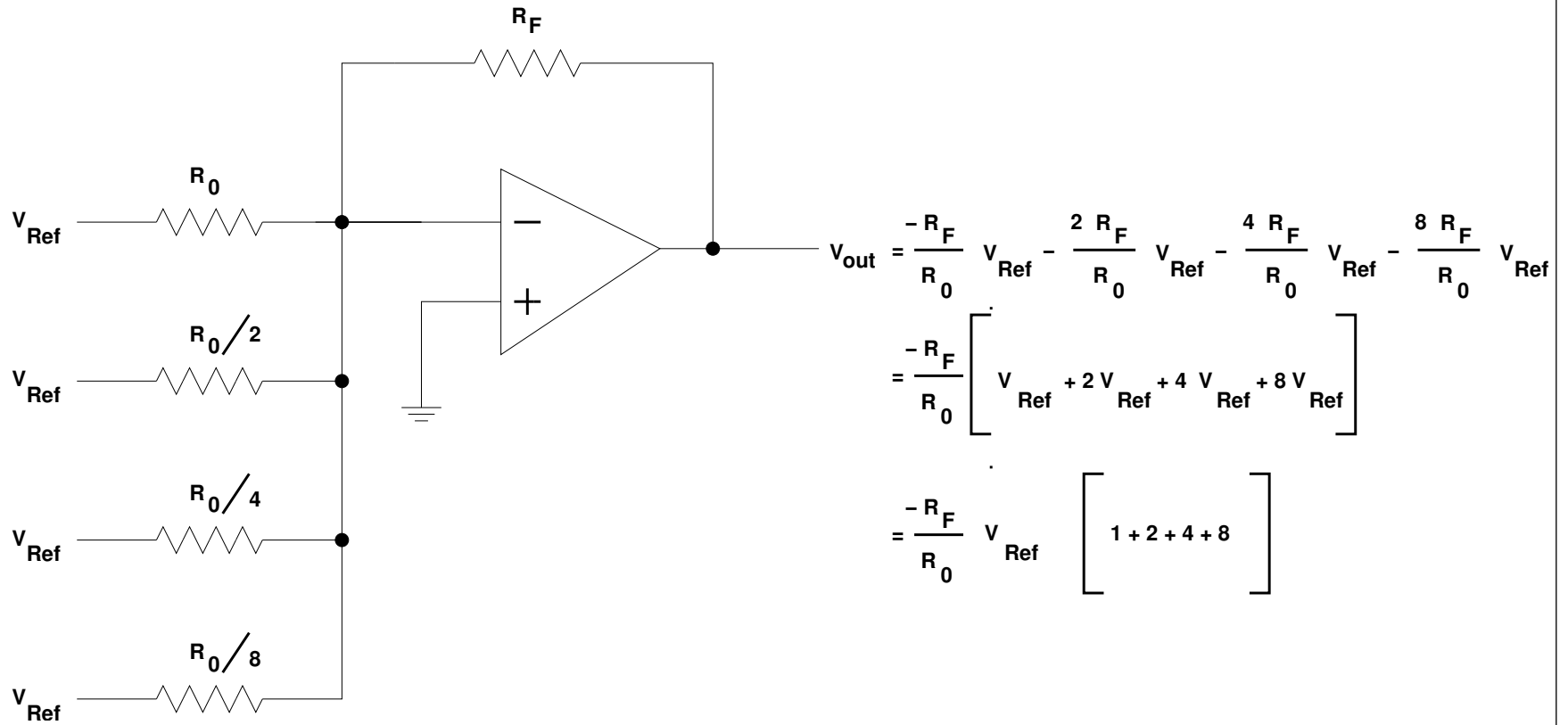
Digital-to-Analog (D/A) Converters

- An inverting op amp can produce an output voltage which is a linear combination of several input voltages



Digital-to-Analog (D/A) Converters

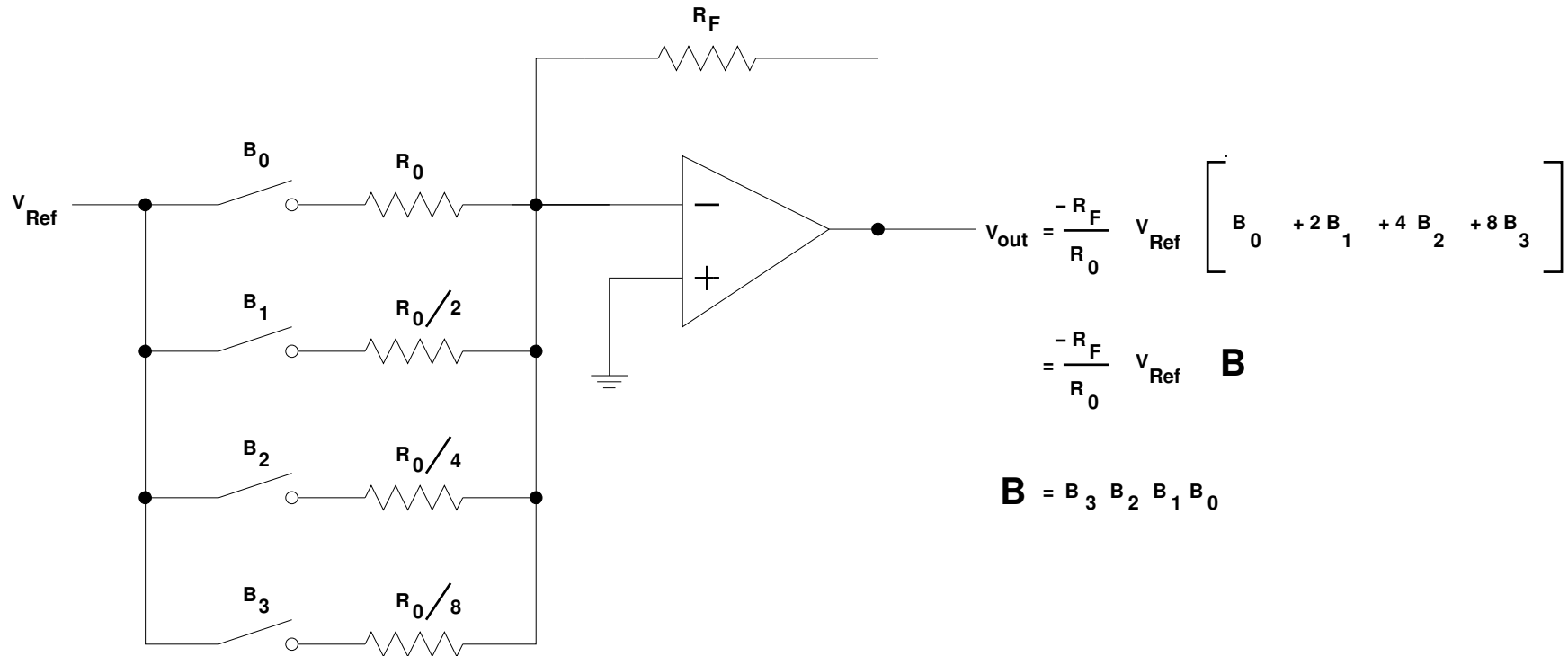
- By using input resistors which scale by factors of 2, a summing op amp can produce an output which follows a binary pattern



Digital-to-Analog (D/A) Converters

- By using switches on the input resistors, a summing op amp can produce an output which is a binary number (representing which switches are closed) times a reference voltage

4-Bit Digital-to-Analog Converter

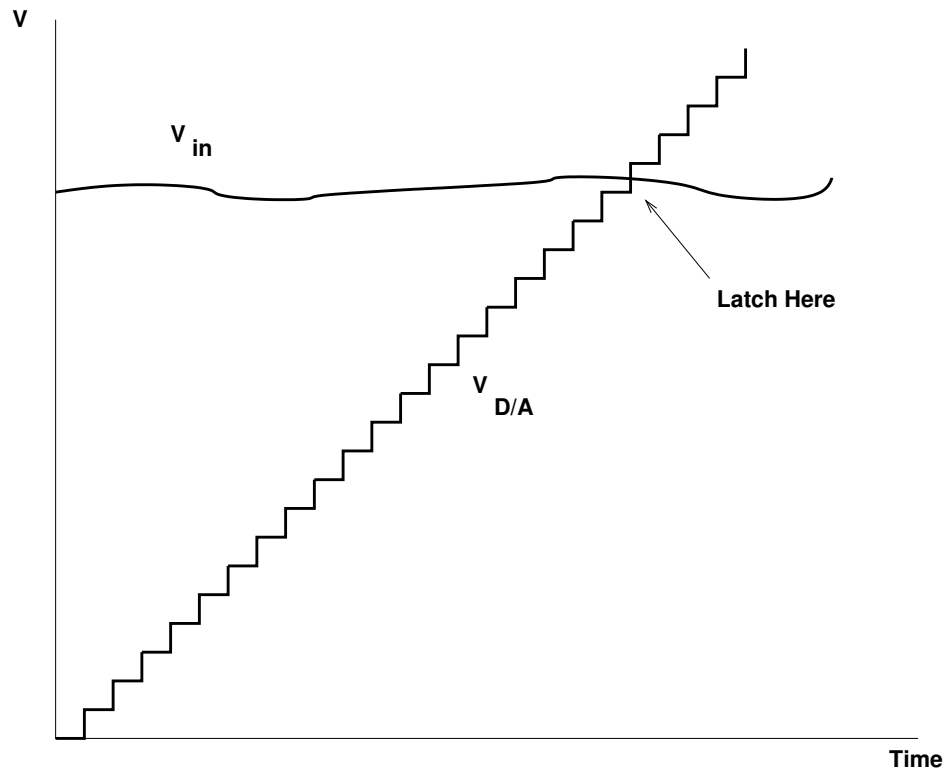
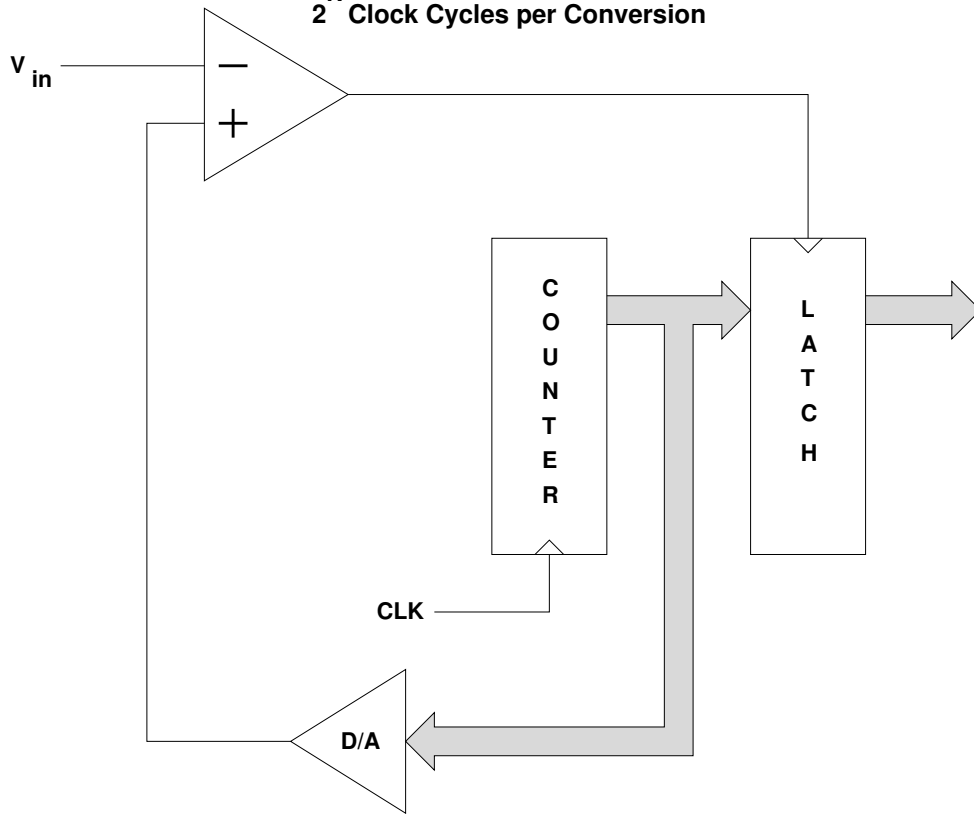


Slope A/D Converter

- A simple A/D converter can be constructed with a counter and a D/A converter
- The counter counts from 0 to 2^b-1
- The counter drives the input of the D/A converter
- The output of the D/A converter is compared to the input voltage
- When the output of the comparator switches logic level, the generated voltage passed the input voltage
- By latching the output of the counter at this time, the input voltage can be determined (with the accuracy of the quantization value of the converter)
- Problem with Slope A/D converter: Takes 2^b clock cycles to test all possible values of reference voltages

SLOPE A/D CONVERTER

2^N Clock Cycles per Conversion

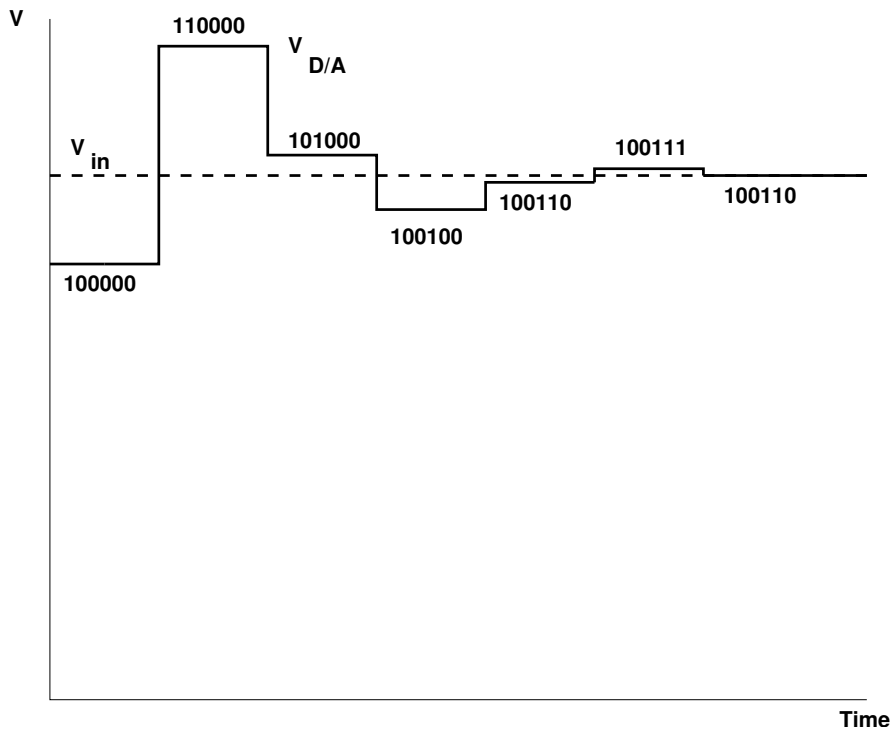
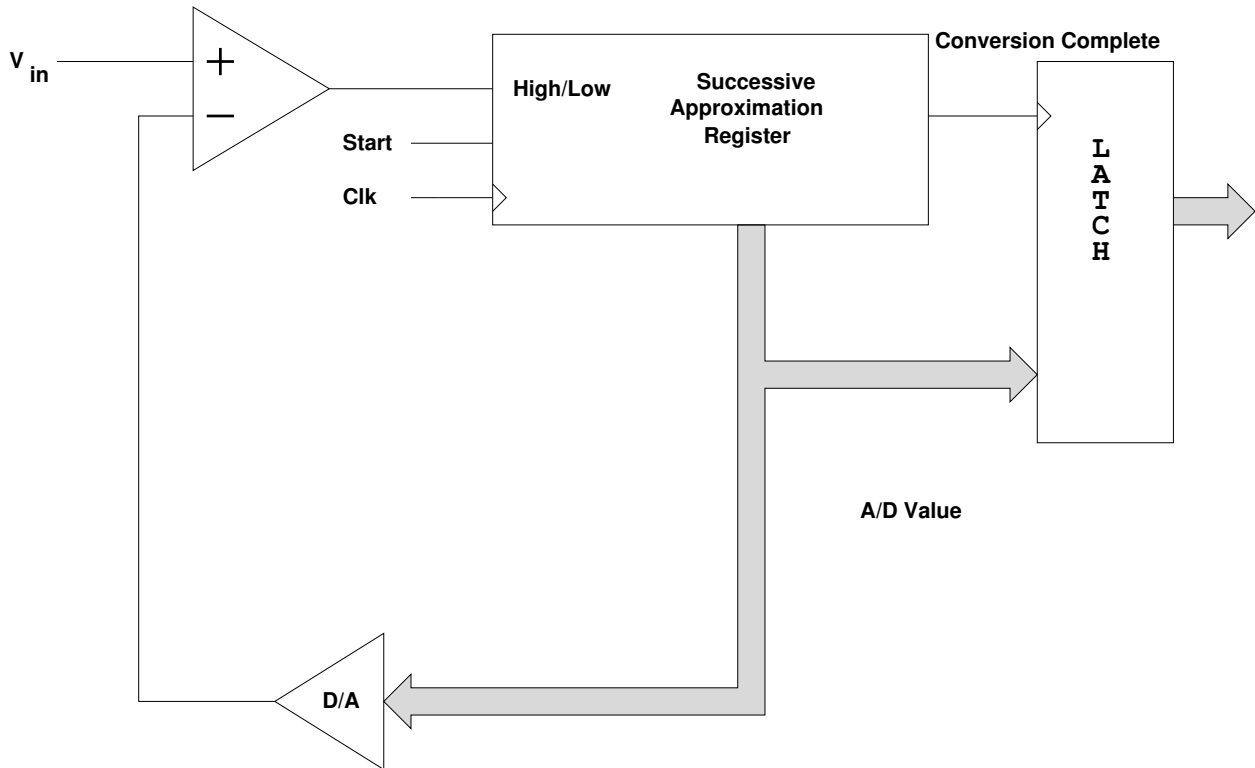


Successive Approximation A/D Converter

- A successive approximation (SA) A/D converter uses an intelligent scheme to determine the input voltage
- It first tries a voltage half way between V_{RH} and V_{RL}
- It determines if the signal is in the lower half or the upper half of the voltage range
 - If the input is in the upper half of the range, it sets the most significant bit of the output
 - If the input is in the lower half of the range, it clears the most significant bit of the output
- The first clock cycle eliminates half of the possible values
- On the next clock cycle, the SA A/D tries a voltage in the middle of the remaining possible values
- The second clock cycle allows the SA A/D to determine the second most significant bit of the result
- Each successive clock cycle reduces the range another factor of two
- For a B -bit SA A/D converter, it takes B clock cycles to determine the value of the input voltage

SUCCESSIVE APPROXIMATION A/D CONVERTER

N Clock Cycles per Conversion



Successive Approximation A/D Converter

- An SA A/D converter can give the wrong output if the voltage changes during a conversion
- An SA A/D converter needs an input buffer which holds the input voltage constant during the conversion
- This input buffer is called a Track/Hold or Sample/Hold circuit
- It usually works by charging a capacitor to the input voltage, then disconnecting the capacitor from the input voltage during conversion
- The voltage on the capacitor remains constant during conversion
- The MC9S12 has a Track/Hold amplifier built in
- SA A/D converters have resolutions of up to 16 bits
- SA A/D converters have speeds up to several million samples per second

SUCCESSIVE APPROXIMATION A/D CONVERTER

