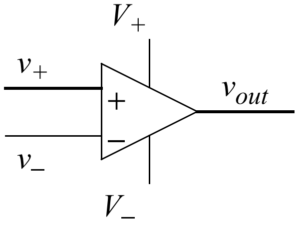
Physics 475, Laboratory 23
Digital-to-Analog Converters

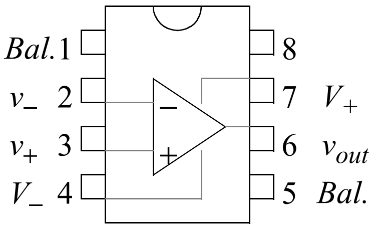
Overview

The purpose of these experiments is to study two ways of generating analog signals from a digital source.

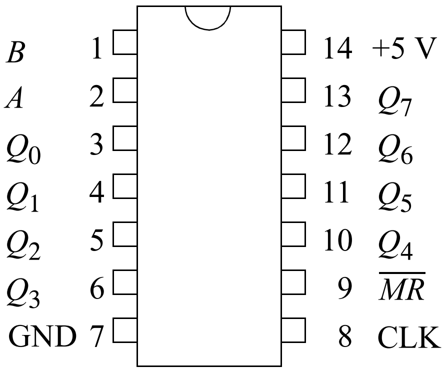
Components

The TL071 op-amp is an integrated circuit based on JFET inputs and bipolar transistor outputs (BIFET) and comes in an 8-pin dual in-line package (DIP). The connections for the chip looking down with the notch facing up is:



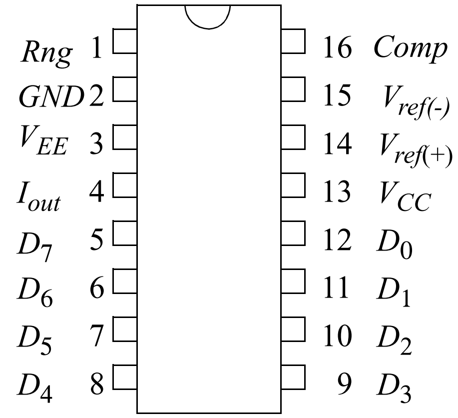


The 74LS164 is an 8-bit serial-in-parallel-out shift register with asynchronous master reset (MR). The input data is an AND of the *A* and *B* inputs, and the clock is positive-edge triggered. The pinouts are shown below.



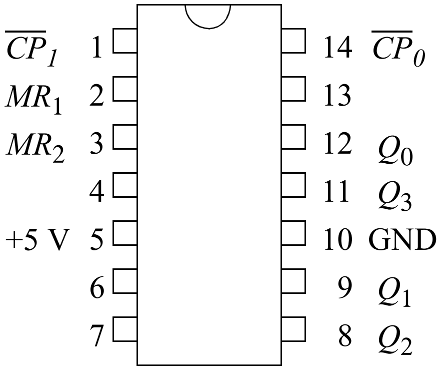
74LS164

The MC1408 is an 8-bit multiplying digital-to-analog converter using current switched and an R-2R ladder internally. Typical power supplies are V_{CC} = +5 V and V_{EE} = -15 V, and *Comp* is capacitively coupled to V_{EE}. There are 8 input data lines ($D_{0\text{-}7}$) where D_0 is the least significant bit (LSB) and D_7 is the most significant bit (MSB). The output current, I_0, is based on the difference between the reference voltages multiplied by binary number expressed in the input data. The pinouts are shown below.



MC1408

The 74HC93 is a 4-bit binary counter. Internally the circuit is two separate counters: a divide-by-2 counter counter using $\overline{\text{CP}}_0$ and Q_0 and a divide-by-8 counter using $\overline{\text{CP}}_1$ and $Q_{1\text{-}3}$. For full divide-by-16 operation, the clock is input at $\overline{\text{CP}}_0$, and Q_0 is wired to $\overline{\text{CP}}_1$. The pinouts are shown below.



74HC93

1. Summing Digital-to-Analog Converter

Connect a 74LS164 shift register to form a Johnson counter then use an op-amp to form the summing circuit in figure 1. Use $R_f = 10$ kΩ and a 10 kHz clock.

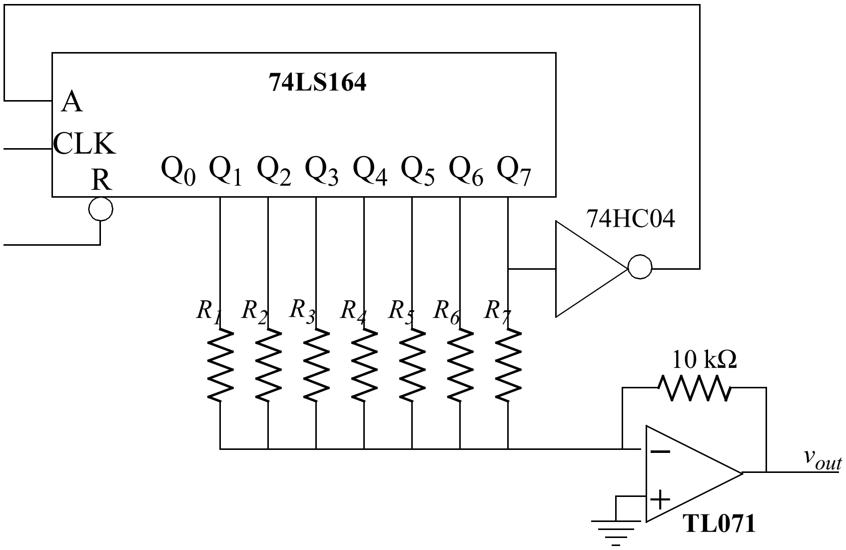


Figure 1: Sine Wave Synthesizer

Use the same resistor value for R_1 through R_7 and observe the output waveform on the oscilloscope. How does the freqency of the output wave compare to the clock frequency? Now replace those resistors with the following values:

$R_1 = 26.1$ kΩ (use 22 kΩ + 4.7 kΩ)
$R_2 = 14.1$ kΩ (use 6.8 kΩ + 6.8 kΩ)
$R_3 = 10.8$ kΩ (use 10 kΩ + 680 Ω)
$R_4 = 10$ kΩ
$R_5 = 10.8$ kΩ (use 10 kΩ + 680 Ω)
$R_6 = 14.1$ kΩ (use 6.8 kΩ + 6.8 kΩ)
$R_7 = 26.1$ kΩ (use 22 kΩ + 4.7 kΩ).

Observe the output signal again. How well does this match a sine wave?

2. Current Switch DAC

Connect an MC1408 digital-to-analog converter to a set of input switches and an output op-amp as in figure 2. Use 1 kΩ resistor SIP for all connections to power and an 8-pin DIP switch for the switches.

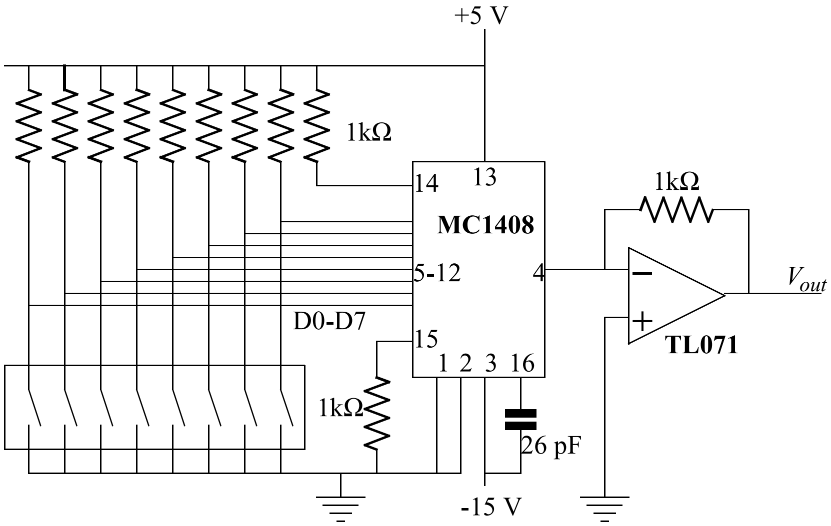


Figure 2: 8-bit Digital-to-Analog Converter

Measure the output voltage for the digital settings 00h and 01h with a DMM and determine the value of the least significant bit (LSB). Repeat for settings FEh and FFh and compare the LSB to the previous measurement. How well do they agree? Compare the output for 7Fh and 80h; is the difference still one LSB? Measure the output voltage for settings 01h, 02h, 04h, 08h, 10h, 20h, 40h, and 80h and plot the points to determine the linearity.

3. Counter-Driven DAC

Remove the switch inputs to the DAC from the circuit in figure 2. Tie the 4 least significant bits to ground, and hook the outputs of a 74HC93 4-bit counter to the remaining 4 inputs of the DAC so that the most significant bit of the counter corresponds to the most significant bit of the DAC. Use a 1 KHz square wave as the clock input to the counter and observe the output of the op-amp on an oscilloscope. How well does the wave form match a triangle wave? Are there any non-linearities in the steps? Increase the clock speed to 1 MHz and repeat the observations.