Analog-to-Digital Input-Output (A/D) Boards[1]

Perhaps counter-intuitively, most A/D converters are based on the use of Digital-to-Analog converters (D/A converters). A brief summary of both D/A and A/D converters is provided below.

D/A Converters: Several types of D/A converters exist, and (given the rapid rate of new developments in this field) new types of D/A converters will likely appear in the future. Only one type of D/A converter will be described here: the Binary-Weighted Resistance D/A Converter.

The circuit shown in Figure 1 illustrates the essential features of an 8-bit Binary-Weighted Resistance D/A converter. The circuit consists of the following elements:

(a) A constant reference voltage, V_{ref}

(b) A total of eight switches, labeled S_0, S_1, S_2,...S_7. Note from Figure 1 that these switches are labeled in ascending order from ***right to left***. Switch S_0 corresponds to the least-significant bit (LSB) in the 8-bit digital word, whereas switch S_7 corresponds to the most-significant bit (MSB). Also note that the reference voltage (V_{ref}) is applied across all eight switches.

(c) A total of eight resistances, ranging in value from $2^0R = R$ to $2^7R = 128R$. Note from Figure 1 that these resistances increase in value from ***left to right***. Resistance $2^7R = 128R$ is connected to switch S_0 and is associated with the LSB, resistance $2^6R = 64R$ is connected to switch S_1, resistance $2^5R = 32R$ is connected to switch S_2, etc, resistance $2^0R = R$ is connected to switch S_7 and is associated with the MSB.

(d) An operational amplifier ("op-amp") that produces a voltage proportional to the total current flowing from the circuit.

Again, Figure 1 shows an 8-bit D/A converter. A 12- or 16-bit D/A converter would involve 12 or 16 switches and resistances, respectively.

---

[1] This document is based primarily on: Khan, A.S., and Wang, X., STRAIN MEASUREMENTS AND STRESS ANALYSIS" (in particular, section 8.4), available from Prentice-Hall, ISBN 0-13-080076-7 (2001). A comparable discussion appears in Chapter 19 of the Shukla and Dally textbook.

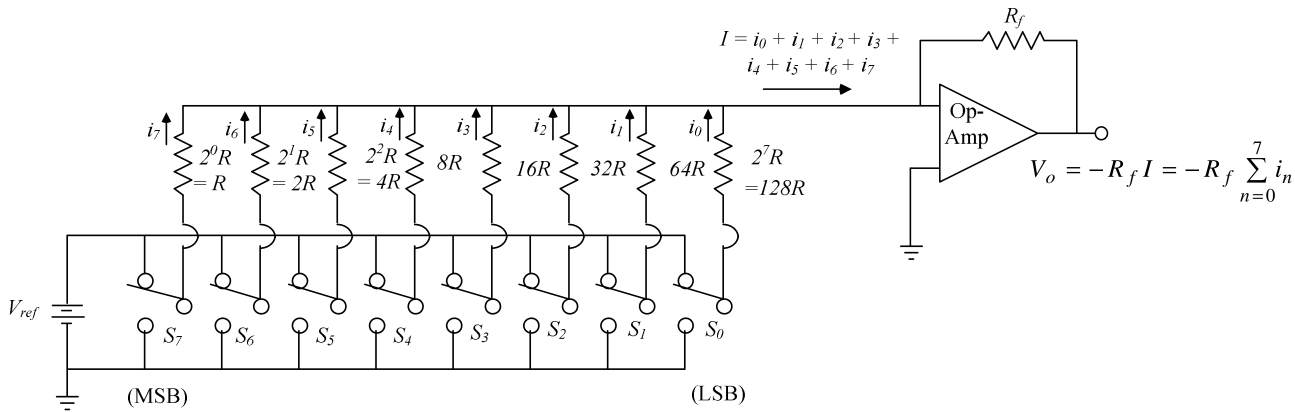

Figure 1: Switch positions corresponding to the 8-bit word: 1 1 1 1 1 1 1 1

The op-amp produces an (analog) output voltage given by $V_o = -R_f I$, where the value of current I depends on the positions of switches S_0-S_7. There are eight switches in this example (since an 8-bit word is being illustrated), and each switch can be thought of as a binary number, a_i, where $a_i = 0$ or 1. If $a_i = 0$ the switch is open, whereas if $a_i = 1$ the switch is closed.

In Figure 1 all switches are closed….Figure 1 illustrates the 8-bit word: 1 1 1 1 1 1 1 1. In this case current I equals the sum of the currents that pass through each switch: $I = i_o + i_1 + i_2 + i_3 + i_4 + i_5 + i_6 + i_7$.

Now consider Figure 2, which shows the circuit with only one switch closed (switch S_7). In this case the figure represents the 8-bit word: 1 0 0 0 0 0 0 0, and current $I = i_7$. Since the current passed to the op-amp in Figure 2 is much lower than in Figure 1, the output voltage of the op-amp in Figure 2 is much lower than in Figure 1….hence, the digital 8-bit word represented by the position of the 8 switches has been converted to an analog output voltage by the op-amp…the D/A conversion has been achieved.

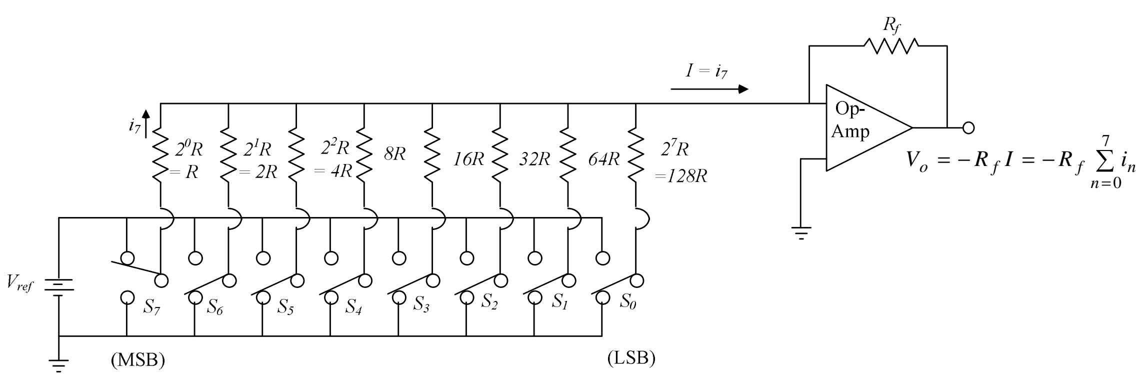

Figure 2: Switch positions corresponding to the 8-bit word: 1 0 0 0 0 0 0 0

As a third example, consider Figure 3 in which switches S_6 and S_0 are closed representing the 8-bit word: 0 1 0 0 0 0 0 1. In this case the total current $I = i_6 + i_0$, and the output voltage of the op-amp is between that produced in Figures 1 and 2.

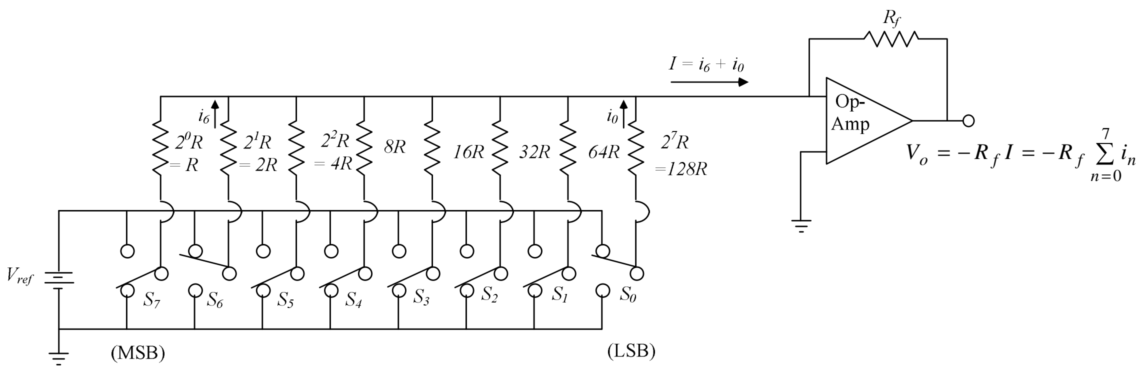

Figure 3: Switch positions corresponding to the 8-bit word: 0 1 0 0 0 0 0 1

To summarize, an 8-bit digital word that is to be converted to an analog voltage signal is generated by the computer. Switches S_0 through S_7 are opened/closed accordingly, resulting in the corresponding output current, *I*. This current is converted to an *analog voltage* by means of an op-amp….hence, the digital number (generated by the computer) has been converted to a corresponding (and distinct) analog voltage level, and D/A conversion has been achieved.

<u>Analog-to-Digital Conversion based on the "Successive Approximation Method"</u>

Several types of A/D converters exist, and (given the rapid rate of new developments in this field) new types of A/D converters will likely appear in the future. The "successive approximation" method is described here.

Referring to Figure 4, the vertical scale in the upper half of the figure represents both the analog input signal (to be converted) as well as a digital representation of the analog signal. The digital representation is shown in a heavy black line. The horizontal axis corresponds to *time*. Note that the analog voltage remains constant with time, but the digital representation changes with time, eventually converging to the analog voltage. The increments in time shown in Figure 4 (i.e, T_1, T_2, ...T_8) correspond to the time interval between "pulses" of the system clock. Figure 4 illustrates the conversion process based on an 8-bit word. The A/D conversion proceeds as follows (an 8-bit word is assumed):

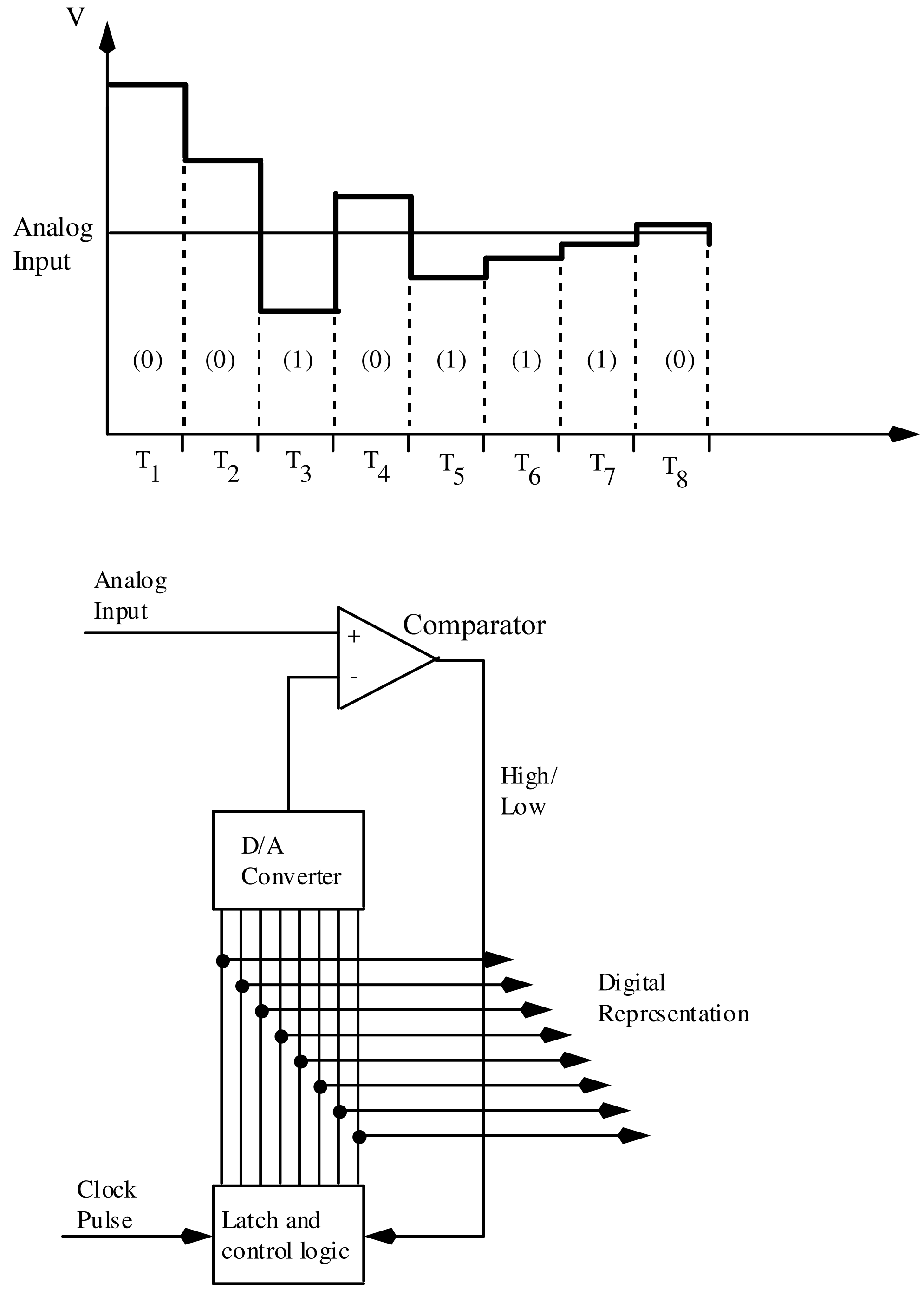

Figure 4: A/D converter based on the "gradually approaching" method

(a) The digital word: 1 0 0 0 0 0 0 0
is converted to an analog voltage signal by the D/A converter. That is, the MSB is set to "1", while all remaining bits are all set to "0".

(b) The analog voltage signal generated by the D/A converter (and corresponding to the digital word: 1 0 0 0 0 0 0 0) is compared to the analog input signal, by means of the "comparator". If the output from the D/A converter is less than the input signal, then digital representation of the input signal is less than the digital representation of the input analog voltage signal. In this case the setting of the MSB remains "1", and the converter proceeds to step (c). Conversely, if the output from the D/A converter is greater than the input signal, then digital representation of the input signal is less than

1 0 0 0 0 0 0 0

In this case, the setting of the MSB is set to "0", and the converter proceeds to step (c).

This comparison takes some time. Referring to Figure 4, the comparison occurs over the time interval T_1. During interval T_1 the MSB is "1", and the digital representation remains constant over this time. Figure 4 implies that after comparison the output from the D/A converter is found to be greater than the input signal, so the MSB is set equal to "0".

(c) The next bit is set to "1", and the digital word is converted to an analog voltage signal and compared to the input signal, again using the "comparator." For example, if the MSB was set to "0" in step b (as implied in Figure 4), then during step c the digital word

0 1 0 0 0 0 0 0

is converted to an analog voltage by the D/A converter and compared to the input signal. Referring to Figure 4, this comparison occurs over time interval T_2. If the output from the D/A converter is less than the input signal, then digital representation of the input signal exceeds 0 1 0 0 0 0 0 0, and the bit remains "1"; otherwise it is returned to "0".

Figures 4 imply that the "new" digital voltage signal again exceeds the input voltage, so the second bit is set to "0".

(d) Step c is repeated for all remaining bits. Figure 4 implies a digital word:
0 0 1 0 1 1 1 0

Notice that the total time necessary to perform and A/D conversion is dominated by:

(a) The time period between pulses of the system clock (i.e., time periods $T_1 \rightarrow T_8$ in Figure 4). The time period is a feature of the computer used to perform data acquisition and has decreased continuously for over three decades
(b) The word length used, which implies, for example, that the total time required to perform A/D conversion of a 16-bit word is longer than the time required for an 8-bit word.