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Stable, Low Cost Microcomputer Digital-To-Analog Instrument Control*

FRANK K. KING

Stanford Linear Accelerator Center

Stanford University, Stanford, California, 94305

ABSTRACT

Two methods of computer-controlling an electronic instrument are described. One method employs a computer having as few as two digital-to-analog converters. A second method is shown which can be used if a 16-line digital output is available. Features of either method include low cost, high accuracy and stability, low noise and ease of installation.

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A common way of implementing computer control of an electronic instruments is to purchase an "off the shelf" digital-to-analog conversion (DAC) unit, install it in the computer and connect it to the proper control point of the instrument circuit via a shielded cable (Figure 1). Potential problems with this scheme include 1) finding a reasonably priced DAC card for the computer being used, 2) obtaining sufficient resolution and stability from the unit chosen, 3) minimizing noise pickup on the control line connecting the computer and the instrument, and 4) curing ground loop problems which are likely to arise.

In this Note, we show that a high level of performance can be achieved at low cost using a computer equipped with as few as two DACs and a user-constructed instrument control board containing common components. The primary devices needed for the instrument control board are low voltage opto-isolators, common counter chips, a 16-bit DAC chip and, optionally, a high performance operational amplifier. If the host computer has a 16-line parallel output available the implementation is simplified and will be discussed below.

Referring to the block diagram (Figure 2), output lines from three computer DACs, which may be of low resolution ($<$ 12 bits), are connected, through opto-isolators, to four 4-bit counters which are cascaded to form a 16-bit counter. One DAC is used to toggle the clock input of the first 4-bit counter. The second DAC is used as a count reset line. The third DAC sets the direction of counting. If the computer contains only two DACs, bi-directional operation is not possible and the counters are hard wired to set the counting direction. The output states of the counters achieved when they are reset is determined by hard wiring the data input pins on each counter chip, usually to all zeros or ones.

The opto-isolators perform a very important function. They provide complete electrical isolation between the computer and the instrument. The ground connections on the light-emitting diode side of the opto-insulators are entirely separate from all ground and power supply connections on the photo-transistor side of the isolators and the rest of the circuit. Ground loops between computer and instrument can therefore be very effectively eliminated.

The four-bit counters are cascaded to create a 16-bit counter which is directly connected to the input of the controller 16-bit DAC chip. The standard output voltage range of this DAC can then be adjusted, in a final buffering stage, to cover any voltage and/or current conditions required to control the instrument. In some applications, a simple voltage divider using high quality resistors may be sufficient. Otherwise, a high performance operational amplifier is essential to maintain high stability and linearity, and low noise in the controller circuit.

One of our applications is the control of a VG Scientific ESCA 3 x-ray photoelectron spectrometer. An electron energy analyzer is typically scanned over some portion of the voltage range 0-2500 volts. With 16 bits of resolution we can set the analyzer to within 0.019 volts of the energy desired and move it in steps of 0.038 volts.

We mount the controller board containing all components shown in the block diagram (Figure 2) in the analyzer control unit. The lines coming from the computer DAC's enter the chassis through isolated BNC connectors to isolate the computer and instrument grounds. The power to run the controller circuit comes from the instrument power supply. In applications where the instrument is not capable of providing the necessary power, a separate power supply can be included on the controller DAC board. There are important advantages to mounting on the controller DAC board within the chassis of the instrument. The critical components can be maintained at a temperature as stable as that of the instrument for low drift of the controlling voltage. Since the distance between the controller DAC and the point where the controlling voltage is inserted into the circuit of the instrument is very short and contained entirely within the chassis of the instrument, very little noise is added to the control line. In our application the output of the energy analyzer control unit is stable to within a few hundreths of a volt over a period of months and the noise at the output is less than 20 mv peak-to-peak over the entire output range. This level of performance could not be easily achieved using a computer-installed DAC and a single control line.

The software to run the controller is straightforward to write (Appendix). Note that toggling a line implies that the computer DAC controlling that line (assumed to be at zero volts initially) is set to its full-scale output and immediately reset to zero volts. The duration of this pulse is sufficient to operate the counter chips. The first step is to toggle the reset line to set all counters to their initial state. The direction line (if used) is set (or cleared) to determine the direction of counting. The clock line is then toggled to step the counters, which set the input lines of the controller DAC, to the states corresponding to the desired output voltage. A new DAC voltage is reached either by setting the direction line and toggling the clock line to set the counters or by first resetting the counters and then clocking to the new value. The choice is determined by which method requires the fewest clock pulses. Maximum clock speeds are realized by writing the software which toggles the computer DACs in assembly language. We use a LSI 11/23 processor and a Data Translation DT2766 DAC board and achieve clock rates of 68 kHz, although this speed could be increased by using a faster processor. While the time needed to set the controller DAC to full scale may seem long (almost a full second in our case), it is not a real disadvantage in any application where the instrument is scanned over a portion of its range while data is being collected. We typically collect data while stepping our analyzer through a 20 volt range in 0.1 volt steps which require 30 μ sec/step. The time spent collecting the data at each step is at least several orders of magnitude greater.

The performance and cost of the installation is largely determined by the DAC chosen for the controller circuit. We use a Burr-Brown DAC71-CSB which provides good performance at low cost ($60). Improved linearity and reduced gain error and drift could be obtained from a high performance DAC such as a Burr-Brown DAC73-CSB ($400), if needed. The other components used are Sieman-Litronix opto-isolators IL-100, generic SN74193 U/D counters and a Datel-Intersil AM490-2 chopper-stabilized operational amplifier in the final buffering stage. The cost of this installation compares very favorably to that of 16-bit DAC units designed for installation in the computer. Assuming that such units are available for the computer being used, the cost of such a DAC unit can be $1000-$2000.

If the host computer, such as an IBM PC-AT with an IBM Data Acquisition and Control Adapter Card, has a 16-line parallel output available, the installation is slightly different (Figure 3). The counter stage is omitted and the 16 digital output lines are connected to the input of the 16 bit DAC through 16 opto-insulators. A flat ribbon cable is used to connect the computer to the instrument but the other features of the design remain. The controller board is mounted within the chassis of the instrument and the digital and analog grounds remain separate. The primary advantage of this method is increased speed because it is not necessary to reset or clock the counters to reach the desired output on the controller DAC. Instead, the 16 digital output lines are set simultaneously and the controller DAC output changes immediately.

Two similar methods of implementing computer control of a host of electronic instruments have been presented. Both provide significant improvements in performance at much lower cost than by simply installing a high resolution DAC unit in the host computer.

FIGURE CAPTIONS

Figure 1	Block diagram of common computer control configuration. Digital (D) and Analog (A) circuits share a common ground.
Figure 2	Instrument controller block diagram using a computer with low resolution DACs. Digital (D) and Analog (A) circuit grounds are isolated from each other.
Figure 3	Instrument controller block diagram using a computer with a 16 line parallel output. Digital (D) and Analog (A) circuit grounds are isolated from each other.
Appendix:	Computer program flow chart for instrument controller.

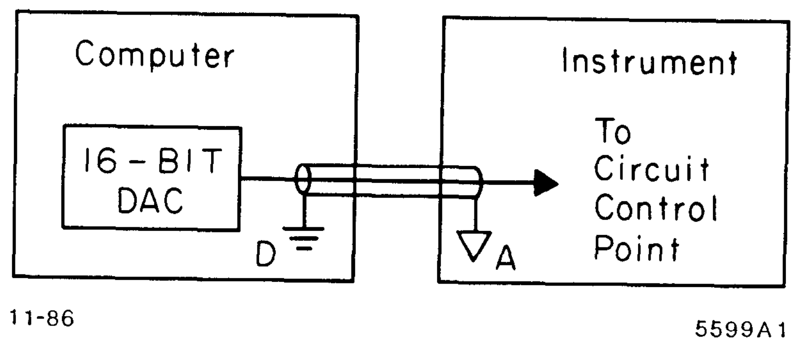
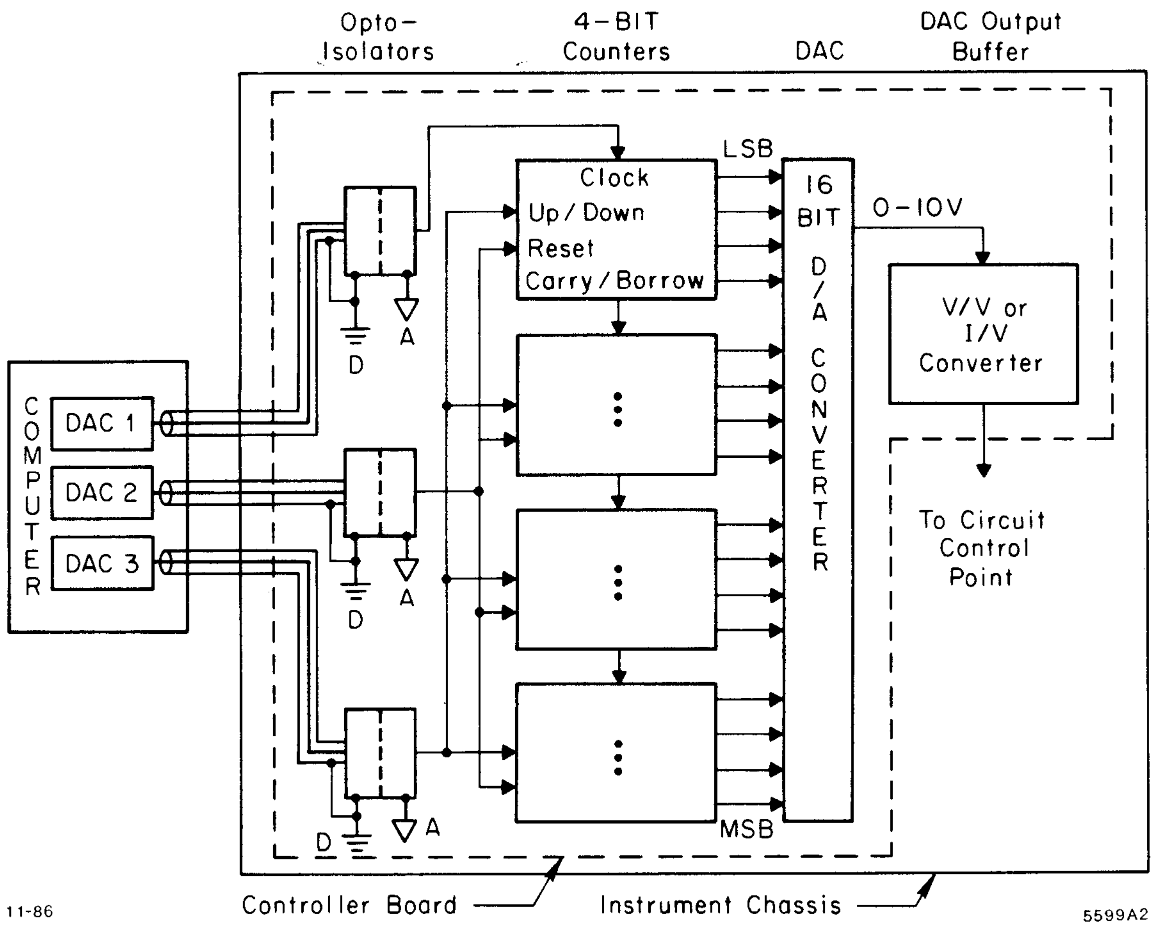

Computer
16-BIT
DAC
D
Instrument
To
Circuit
Control
Point
A
11-86
5599A1

Fig. 1



Opto-
Isolators
4-BIT
Counters
DAC
DAC Output
Buffer
LSB
Clock
Up/Down
Reset
Carry/Borrow
16
BIT
D/A
CONVERTER
0-10V
V/V or
I/V
Converter
To Circuit
Control
Point
COMPUTER
DAC 1
DAC 2
DAC 3
D
A
MSB
11-86
Controller Board
Instrument Chassis
5599A2

Fig. 2

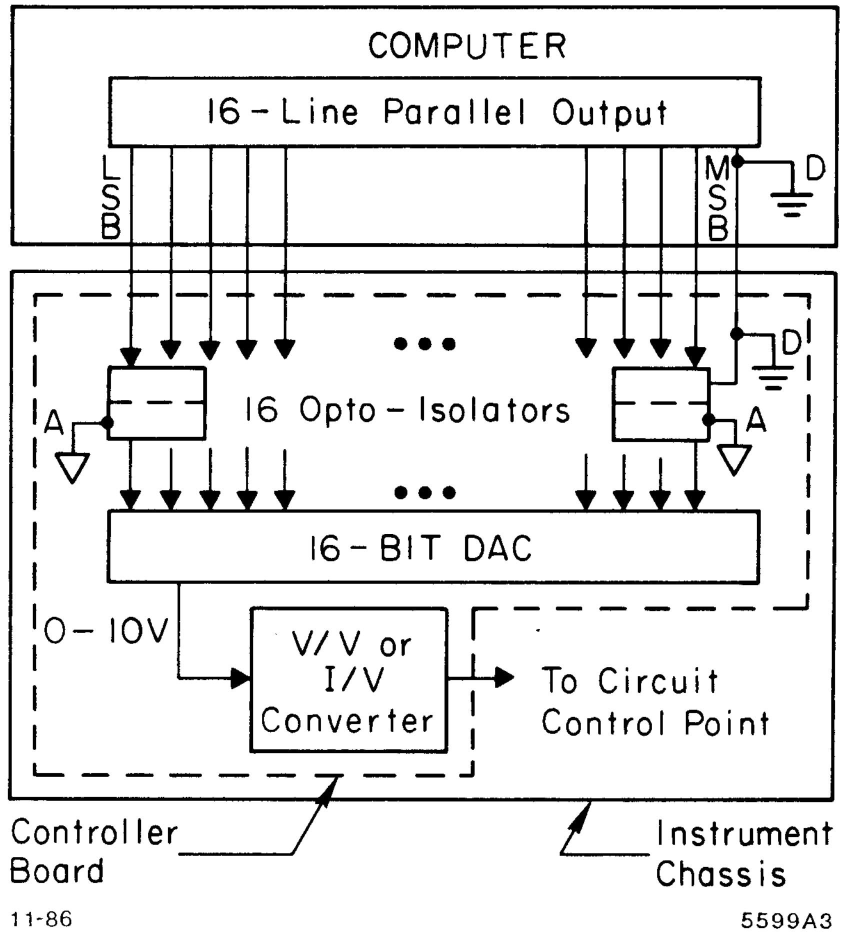
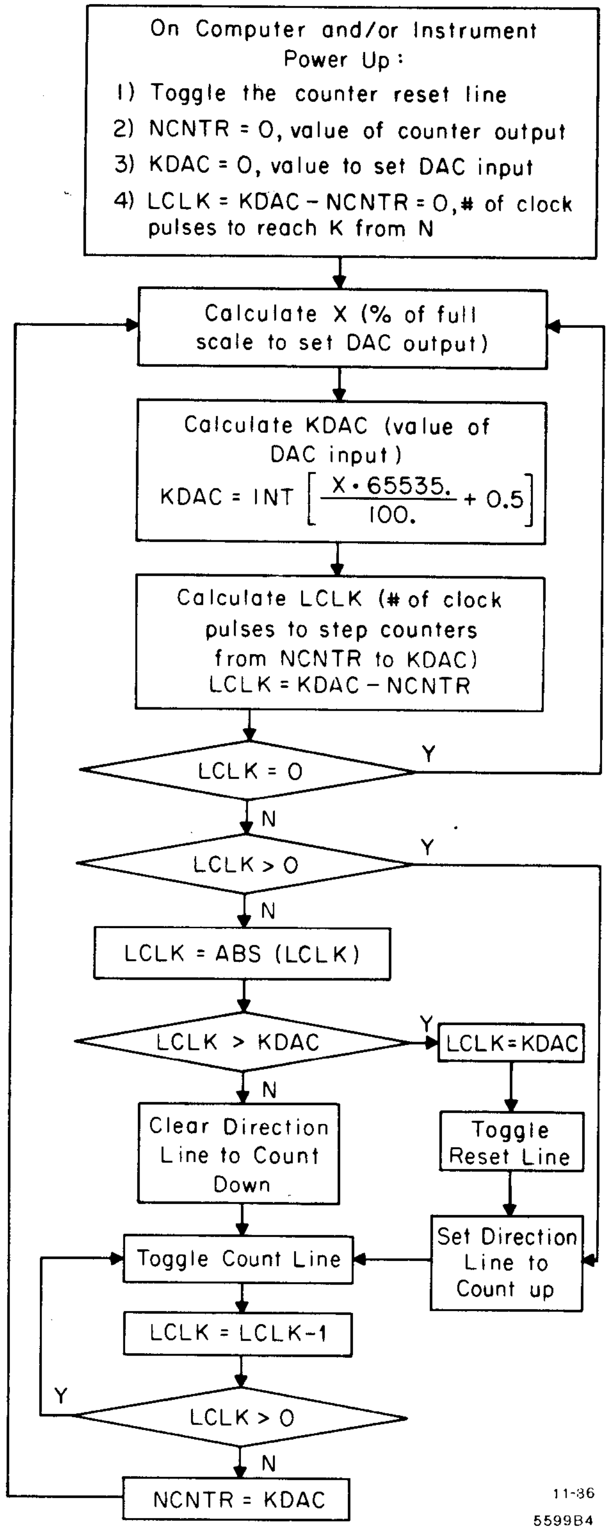

COMPUTER
16-Line Parallel Output
LSB
MSB
D
16 Opto-Isolators
A
D
A
16-BIT DAC
0-10V
V/V or
I/V
Converter
To Circuit
Control Point
Controller
Board
Instrument
Chassis
11-86
5599A3

Fig. 3


On Computer and/or Instrument Power Up:
1) Toggle the counter reset line
2) NCNTR = O, value of counter output
3) KDAC = O, value to set DAC input
4) LCLK = KDAC − NCNTR = O, # of clock pulses to reach K from N
Calculate X (% of full scale to set DAC output)
Calculate KDAC (value of DAC input)
KDAC = INT [X · 65535. / 100. + 0.5]
Calculate LCLK (# of clock pulses to step counters from NCNTR to KDAC)
LCLK = KDAC − NCNTR
LCLK = O
Y
N
LCLK > O
Y
N
LCLK = ABS (LCLK)
LCLK > KDAC
Y
N
LCLK=KDAC
Clear Direction Line to Count Down
Toggle Reset Line
Set Direction Line to Count up
Toggle Count Line
LCLK = LCLK-1
LCLK > O
Y
N
NCNTR = KDAC
11-86
5599B4

APPENDIX