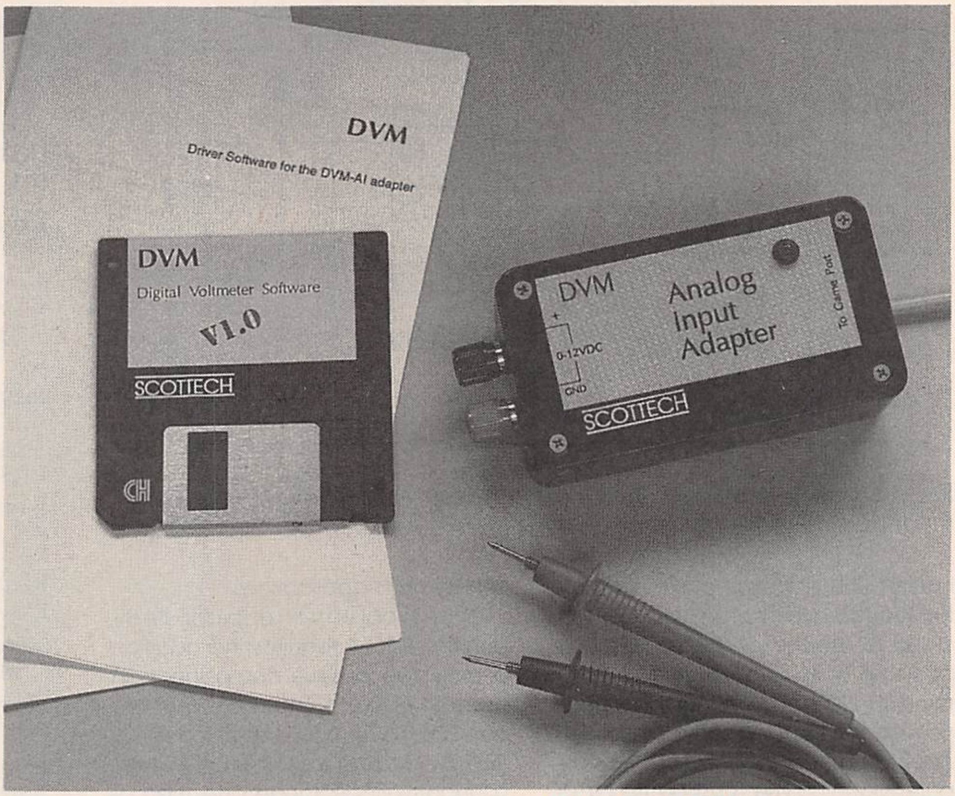
Add a DVM

BY SCOTT HENDERSHOT



to your PC

Turn your PC into a digital voltmeter for automated testing, to record readings over time, and more.

PC-based analog-to-digital (A/D) conversion is a hot topic these days. So there are numerous A/D adapter boards available for PC's. However, most of them seem to be geared toward digitizing waveforms in the megahertz frequency range and, as a result, cost megabucks. However, for many types of signals, high-speed, high-cost conversion is not necessary. For example, unless you are doing some special, research you probably do not need to take temperature measurements at 50,000 samples per second even if high resolution is a must.

So what data-acquisition technique will yield a cost savings by permitting slow, high-resolution analog-to-digital conversion? Voltage-to-frequency (or V/F) conversion, which is very useful for digitizing steady-state or slowly changing DC signals. Voltage-to-frequency conversion is seldom discussed in texts on analog-to-digital conversion, probably because of its generally slow conversion speed. However, it offers some important advantages over other techniques. For example, its inherent integration of the input signal makes it more immune to noise. Also, high-resolution is more easily obtainable with this form of conversion.

You can take advantage of all that by building the project presented in this article. It is a 0- to 12-volt analog-input adapter that uses the Analog Devices AD654 voltage-to-frequency converter IC. That IC has several features that make it very attractive to the experimenter including extremely low cost, low support-component count, and the ability to be powered by a single 5-volt supply. The circuit uses a PC's game port as the interface, has a resolution of 1 part in 12,000, and can be built for about 15 dollars.

As you read through this article you will probably see opportunities to customize this project for your own needs. Fortunately, there are many parameters that can be changed (which we'll explore in moderate detail) once you understand how each affects the overall system. The intent here is not to fully illustrate the AD654, but to present the basics of a complete A/D converter project and allow the experimenter to use it as a starting point for other designs.

The Circuit. Looking at the schematic diagram in Fig. 1, you will notice that there are only two active components: U1 and U2. Taking U1 first, it is an Analog Devices AD654, which is the actual analog-to-digital converter. More accurately, it is a voltage-to-frequency converter; it accepts an analog input voltage (the difference between its $-V_{in}$ and $+V_{in}$ inputs) and generates a squarewave. The chip was chosen for its ease of implementation. For example, it can be powered from a single supply such as the 5 volts available from a PC's game port. The full-scale input range can be set by a single resistor, and it has a linearity of 0.1% or better.

Integrated circuit U2 is an LM324 single-supply general-purpose op-amp with an input impedance of 250-megohms set up as a voltage follower. It provides input protection and bias-current compensation for the AD654. Other single-supply op-amps will also work, however the LM324 is readily available while others might be difficult to find.

As mentioned, the output of U1, and therefore the circuit, can be connected to any digital input on the PC. For example, one of the parallel-port

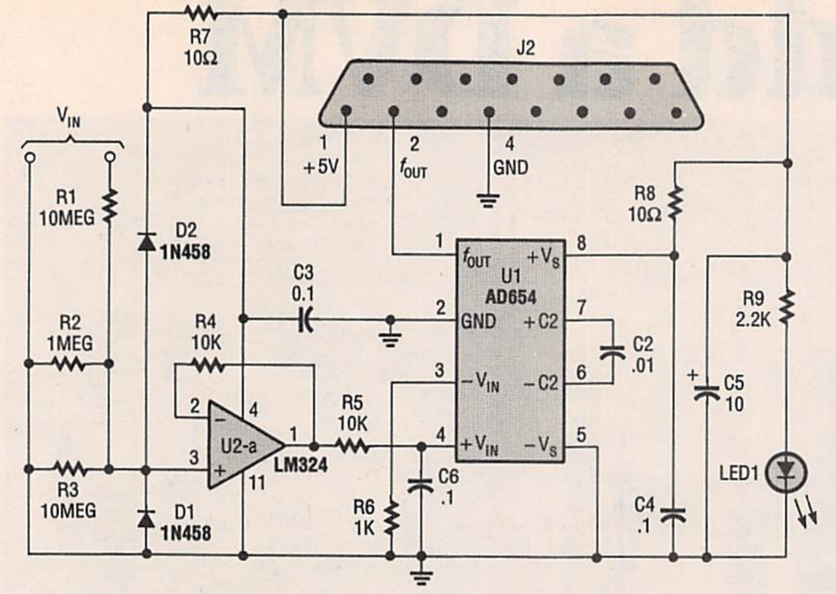


Fig. 1. Effectively, the adapter can be broken down into a voltage-to-frequency adapter with a signal-conditioner/protection-circuit at the front end.

handshaking inputs or one of the button inputs on the game port. We decided to use the game port (via J2) because of its 5-volt outputs. Bear in mind that the AD654 has an open-collector output capable of sinking about 10-mA. So the input of the computer port you use must be tied to 5 volts through a pull-up resistor residing either inside the computer or the adapter circuit. The inputs on the game port are tied high within the computer, so we don't need to worry about this. If you decide to use another input port (such as the parallel port), you will need to deliberately pull the signal line high.

The AD654 can accept input voltages of up to 4 volts less than the power supply. Since we will be using the PC's 5-volt supply, our maximum input voltage will be 1 volt. In order to extend this range to 12 volts, a voltage divider is used ahead of both U1 and U2 to scale the input down to 1 volt. Looking at the schematic you will see the divider is made up of R1, R2, and R3. Resistors R2 and R3 are in parallel and have a total resistance of 909,000 ohms. In series with the 10-megohm resistor that provides a 12:1 attenuation of the input signal. Component values are not critical and 5% types are okay to use. Any accuracy problems will be compensated for in software. Using the attenuator will reduce the input impedance to 10 megohms. This is about the same as most digital volt meters and should not be a problem for most applications.

Once supplied with appropriate input, the AD654 requires the addition of only two passive components in order to operate. These are a timing capacitor (C2) and a scaling resistor (R6). The scaling resistor sets the overall input-voltage range and the capacitor sets the full-scale frequency.

The scaling resistor converts the IC's input voltage to a current. That resistor must be selected to provide 1 mA of input current at the full-scale input voltage. For example, our full-scale input voltage will be 1 volt, so by Ohms law, the resistor needs to be 1k. You might be tempted to substitute another resistor to achieve some other full-scale voltage. That is fine as long as you observe the design parameters that follow.

The timing capacitor should be selected by using the following formula:

$$C = V/(10Rf)$$

where f is the full-scale frequency (10 kHz for our design), R is the scaling resistor, and V is the full-scale input voltage, which is 1 volt for our circuit. This sets the value of our timing capacitor, C2, at 0.01-µF. It is possible to design the circuit to operate at a higher frequency, but most PC's will not be able to keep up with the signal. This frequency is suitable for PC/XT and later machines.

The only other criteria for the capacitor is a stable temperature coefficient. The following types are recommended: polystyrene, NPO ceramic, and polypropylene. Other types are not recommended due to their poor temperature stability.

With the output of the AD654 connected to a TTL-input port and tied to 5 volts, it will generate a 0–5-volt square-wave. The frequency of the square-wave will be linearly proportional to the input voltage. The component values chosen will give us a 10-kHz square-wave at full scale. That

PARTS LIST FOR THE ANALOG-INPUT ADAPTER

SEMICONDUCTORS

U1—AD654 voltage-to-frequency converter, integrated circuit
U2—LM324 operational amplifier, integrated circuit
D1, D2—1N458, or 2N5089 diode
LED1—light-emitting diode

CAPACITORS

C1—not used
C2—0.01-µF polypropylene
C3, C4, C6—0.1-µF monolithic bypass
C5—10µF, 6-WVDC, Tantalum

RESISTORS

(All fixed resistors are ⅛-watt, 5% units unless otherwise indicated.)
R1, R3—10-megohm
R2—1-megohm
R4, R5—10,000-ohm
R6—1000-ohm
R7, R8—10-ohm, ¼-watt
R9—2200-ohm

ADDITIONAL PARTS AND MATERIALS

J1—not used
J2—Male DB-15 connector

Printed-circuit board or perfboard, 14-pin IC socket, 8-pin IC socket, connector hood, binding posts, hardware, solder, wire, etc.

The following are available from SCOTTECH (485 Old Ridge Road, Webster, NY 14580; Tel. 716-671-8783, FAX 716-787-2788): Software, $5.00; printed-circuit board, $12.00; a kit including software, circuit board, U1, C2, and the IC sockets, $25.00. Add $3.00 shipping with your order, and NY State residents must add 8½% sales tax.

The AD654 voltage to frequency converter is available from Newark Electronics (N. Ravenswood Ave., Chicago, IL 60640-4496; Tel. 312-784-5100)

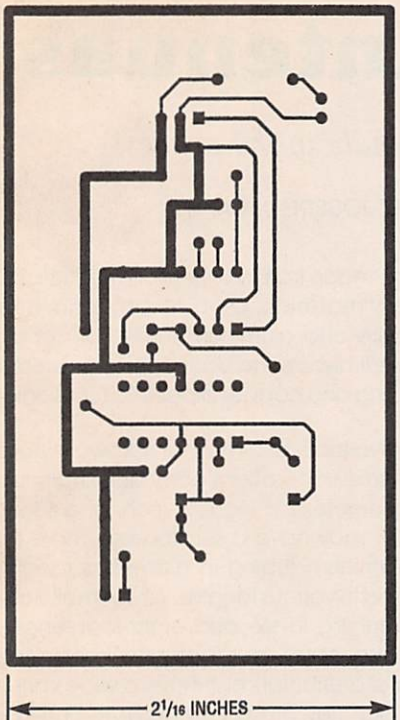


Fig. 2. It is recommended that you use this foil pattern for making your own adapter circuit board.

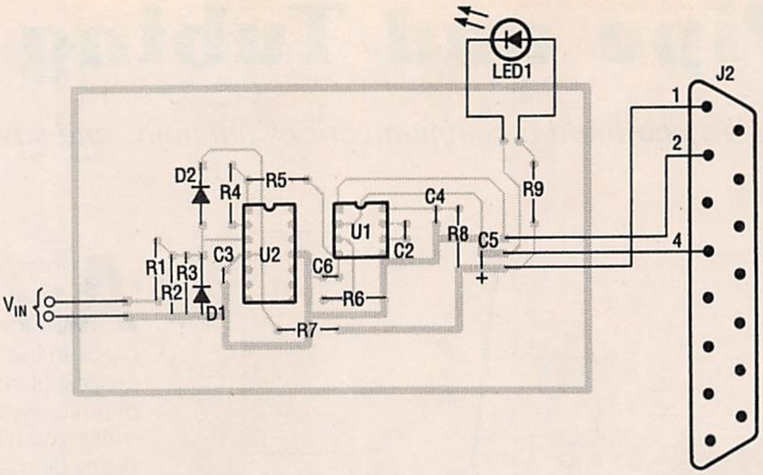


Fig. 3. If using a PC board based on the author's foil pattern, stuff it as shown here. Note the polarity of the diodes, C5, and LED1 as you proceed.

translates to 10 Hz per millivolt. Actually, because of the voltage divider, our scaling will be 0.833 Hz per millivolt. However, because of the way the software measures the voltage, it is not necessary to have a 1-to-1 correlation of Hz to millivolts.

Diodes D2 and D1 provide input protection in case of polarity reversal or over-voltage. These should be Schottky or low-leakage type diodes.

Resistor R5 provides bias current compensation to the AD654. Together with C6 they form a single-pole filter with a time constant of 1 millisecond. That helps suppress noise at the input to prevent false readings. Remember we are measuring voltage changes of only 100 microvolts.

A 10-μF tantalum capacitor (C5) at the point where the supply voltage enters the circuit quiets any power-supply noise to produce a clean square-wave output. The additional resistors and 0.1-μF monolithic capacitors shown in the schematic just decouple the IC's.

Software. Precise timing software is the key ingredient to using this technique on a PC. Most high-level languages are inadequate for microsecond timing so the software must be written in machine language. To spare you the agony of assembly-language programming, all of the necessary interface routines complete with manuals have been made available by the author (see Parts List). There are demo programs that show you how to call the data-acquisition routines from C and BASIC, and linkable object modules for both languages. There is also a quick library that can be loaded into the QuickBASIC environment.

A single call is all that is necessary to acquire a sample from the adapter. The functions return a floating point value that is already adjusted for the current calibration. The supplied functions have a conversion time of about 17 ms. That will provide about 60 samples per second. This sample rate was chosen to reduce the effects of 60-cycle noise. Each sample will last exactly as long as one cycle of a 60-Hz sinewave, therefore fully integrating any noise. The functions have been tested with Microsoft BASIC and QuickBASIC, Microsoft C and Quick C. I cannot guarantee their compatibility with other compilers.

Along with the sample programs, there is a program called DVM.EXE. This program is a digital voltmeter application. When run, it expects to find a square-wave signal on the button-0 input of the game port. If the signal is there, the program reads the frequency and displays the calculated voltage. Complete instructions for using DVM are provided with the software.

For convenience, all this software has been posted on this magazine's bulletin board. The telephone number is 516-293-2283 and the protocol is no parity, 8 data bits, and 1 stop bit. However, if you go this route you'll have to do without the manuals. [At the time this was being prepared for publication a Windows version of the software was due to be released. Contact Scottech for further information—*Editor*]

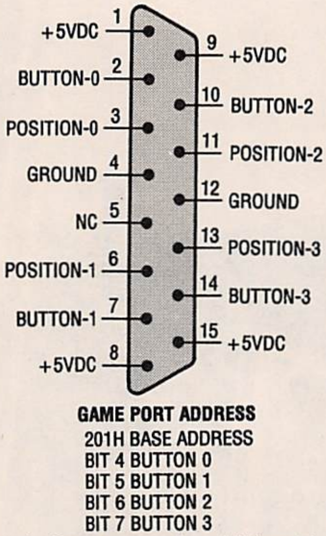


Fig. 4. You can use the additional button inputs on your PC's joystick port to receive data from multiple adapters.

Construction. The circuit should be constructed using a printed-circuit board. You can obtain one from the author (see Parts List for ordering information), etch your own using the pattern in Fig. 2, or design your own.

If you design your own PC board consider the following precautions.

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Analog devices recommends a guard ring around the timing capacitor for demanding applications. For this project, careful placement should be enough. Make sure the timing capacitor is placed as close to the AD654 as possible. They also recommend that you do *not* use a ground plane.

To stuff the board of Fig. 2, look at Fig. 3 and begin by installing the passive components. Then add the IC sockets. You may wish to hold off from soldering LED1 to the board until the case is prepared. This way you will be sure to cut the leads to the proper length. While that LED is optional, it indicates that power is present. If power is not present, you should not connect a signal to the inputs. Therefore, LED1 also provides an indication that it is safe to use the adapter.

After you have prepared a circuit board, you should build the interface cable. The cable should be constructed from a length of three-conductor cable. Keep the length to about six feet or less. Strip one inch of jacket from each end of the cable exposing the three wires. Strip one sixteenth inch from the ends of each of the wires. Solder the conductors to pins 1, 2, and 4 of the DB15 connector.

Cut two lengths of wire to about two inches in length. Strip 1/16 inch from each of the ends. These will connect the input terminals to the board. Drill two 1/8-inch holes in one end of the case about one inch apart for mounting the terminals. Drill a 1/4-inch hole in the opposite end for the interface cable. Feed the interface cable through the 1/4-inch hole and solder the conductors to the appropriate pads on the circuit board. I like to drill holes in the board on either side of the cable so I can use a cable tie to secure the cable to the board.

Once everything is in place, I recommend using a flux stripper on the solder side of the board to be sure it is clean and free of contamination. Residual flux can cause shorts and problems that are difficult to debug at a later time.

With the power off, plug the interface cable into the game port. Turn the computer on. Check for the proper voltage and polarity on the board. Remember the button-0 input of the game port has a pull-up resistor on it, so there will be +5 volts present on that signal line. If the voltages check out turn the computer off, unplug the interface cable and insert the AD654 and LM324 into their sockets. Plug the interface cable in and turn on the computer. If you have an oscilloscope, check for a square-wave on pin 1 of the AD654. If you do not have a scope, you can use a logic probe or frequency meter. If there is no signal on pin 1 then there is a problem with the board or perhaps the interface cable. Turn the computer off and double check the circuit against the schematic and then check the wiring of the interface cable to find any errors.

If the circuit checks out then run the DVM program. If the program finds a square-wave on the button-0 input, it will begin to display values on the screen. If the signal is not present, the program will display a message and abort.

Once the circuit is functioning correctly you can secure the circuit board in the case and connect the input wires to the terminals. That's all there is to it; your circuit is now ready for use.

Going Further. There are 4 digital inputs on the game port so you can have up to 4 Analog Input Adapters connected at the same time. You can easily construct a circuit board that distributes power and ground to the attached adapters. Remember to connect the signal lines to different button inputs on the port. Refer to the pinouts in Fig. 4 for the proper connections and input addresses for the game sport connector. ■