BUILD A
DIRECT-DRIVE TURNTABLE

BY GEORGE MEYERLE

A HI-FI turntable isn't something you would ordinarily expect to see as a construction project in an electronics magazine, but here's a turntable system you *can* build yourself. It's chock full of electronics, and its direct-drive design is the apple of the audiophile's eye today. In addition, it features two remarkable innovations: an automatic pitch control and a direct-readout meter for checking speed accuracy.

FEATURES AUTOMATIC PITCH CONTROL AND METER-READOUT "STROBE"

Unlike turntable designs which use idler-rim drive or belt drive, the direct-drive turntable does not employ speed-reducing devices to rotate the platter. Consequently, there are no idler wheels to flatten or belts to fray and stretch over a period of time. The servo-controlled motor, operating directly at a precise speed of 33 1/3 or 45 rpm, connects directly to the platter. Such a slow rotational speed reduces vibration and rumble. At 33 1/3 rpm, the main rumble frequency is below 10 Hz. Direct drive also permits use of a single bearing, reducing wow, flutter and rumble caused by multiple bearings.

Using electronic circuitry to control a direct-drive motor produces a host of benefits. For example, speed accuracy is maintained even in the face of line frequency changes, which can occur from time to time. Moreover, you can adjust the pitch higher or lower. And should there be an unusually heavy force applied to the platter of this turntable while it's rotating — say, by a record-cleaning brush — you can quickly achieve precise speed by switching on the *automatic* pitch control.

About the Circuit. The turntable employs a direct-drive brushless dc motor that has one main sleeve bearing and

PARTS LIST

C1—4.7-μF, 10%, 10-volt electrolytic capacitor
C2—0.015-μF, 10%, 50-volt polyester film capacitor
C3—47-μF, 10%, 10-volt tantalum capacitor
C4—1-μF, 10%, 10-volt tantalum capacitor
C5,C6—330-μF, 10-volt electrolytic capacitor
C7,C9—220-μF, 35-volt electrolytic capacitor
C8—1000-μF, 35-volt electrolytic capacitor
C10—100-pF, 50-volt disc capacitor
C11—0.047-μF, 10%, 50-volt polyester film capacitor
C12—0.22-μF, 10%, 50-volt polyester film capacitor
D1 through D5,D8—1N4148 diode
D6,D7—100-volt, 1-ampere rectifier diode (1N4002 or similar)
IC1—MC1732CL integrated circuit (Motorola)
IC2,IC3—747 operational amplifier integrated circuit.
J1,J2—Dual phono jack assembly
M1—Zero-center, ±75-μA meter movement
The following resistors are ½-watt unless otherwise noted:
R1,R2,R3,R31—100,000 ohms, 10%, carbon film
R4—220,000 ohms, 10%, carbon film
R5,R6,R35—12,000 ohms, 10%, carbon film
R7—10,000 ohms, 2%, metal film
R8,R12,R16—300,000 ohms, 2%, metal film
R9,R11,R32,R33—330,000 ohms, 10%, carbon film
R10,R13—1200 ohms, 10%, carbon film
R14—1000 ohms, 2%, metal film
R15—22,000 ohms, 2%, metal film
R17—22,000 ohms, 10%, carbon film
R18,R22,R27—560 ohms, 10%, carbon film
R19—2400 ohms, 2%, metal film
R20—390 ohms, 2%, metal film
R28—10 ohms, 10%, carbon film
R29—200 ohms, 2%, metal film
R30—2700 ohms, 2%, metal film
R34—6800 ohms, 2%, metal film
R21,R26—10,000-ohm trimmer potentiometer
R23,R24—2500-ohm trimmer potentiometer
R25—39-ohm, 10%, 5-watt resistor
R36—2500-ohm potentiometer
S1—3-pole, 3-position rotary switch (or toggle equivalents)
S2—Spst switch
T1—16-volt, 100-mA wall-plug transformer with line cord
Misc.—Direct-drive, brushless dc motor with integral circuit board assembly; printed circuit board for control circuit; motorboard; turntable base; control panel; acoustic-isolator springs (8); wire nuts (6); control knobs (3); 6-32 × 1″ machine screws and nuts (3); No. 6 × ¼″ woodscrews (2); double-sided tape; hookup wire; solder; etc.

Note: The following items are available from Netronics Research & Development Ltd., 333 Litchfield Rd., New Milford, CT 06776: Complete turntable kit, including all parts and Audio-Technica Model AT-1005II universal tonearm No. 450D for $159.95; complete kit less tonearm (motorboard minus tonearm holes) No. 350D for $130.00 plus $3.00 postage and handling; dust cover for above No. 40-004 for $12.00 plus $1.50 postage and handling; motor with cast platter and rubber mat No. 99-001 for $65.00; control circuit pc board No. 99-007 for $5.90; meter movement No. 99-004 for $6.50. auto pitch control switch (S2) No. 99-004 for 90¢. When ordering complete kit, add $2.50 for postage. Connecticut state residents, please add sales tax.

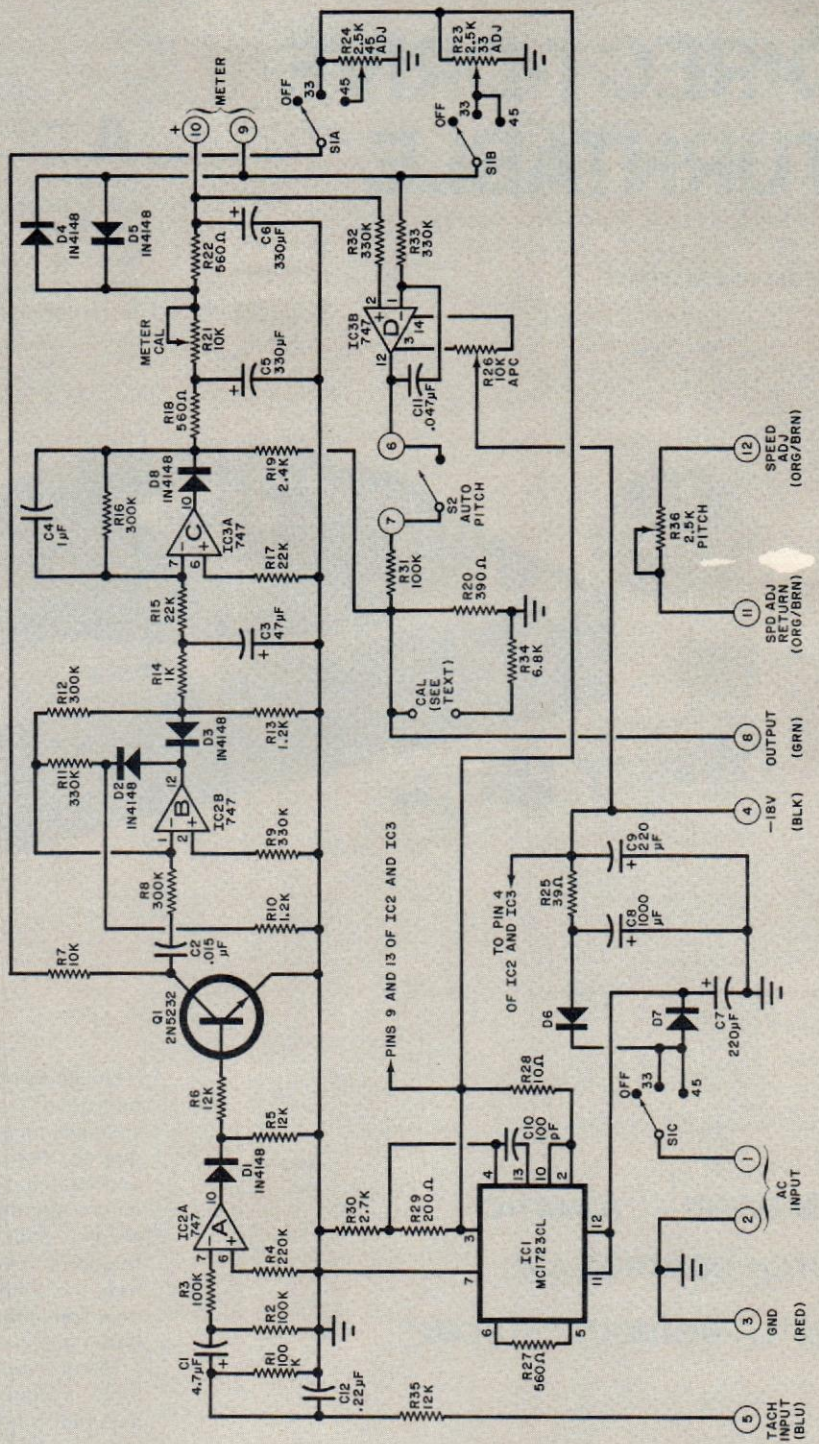


Fig. 1. The control circuit for the turntable motor. The tachometer signal is converted to square waves, differentiated and fed back to the motor. The oscillator and filter for the power supply are also located on the control board assembly.

a ball-type bottom bearing. A preassembled 11-transistor circuit board is housed inside the motor's case. It is connected to an external electronic control circuit board assembly via a color-coded cable system. The circuit assembly inside the motor housing contains all of the circuitry required to rotate the motor and provides a means by which the accuracy of the motor's speed can be monitored.

The motor's brushless action is accomplished by using a high-frequency oscillator, the output of which goes to a series of commutator coils that initiate and sustain motor rotation. A tachometer coil assembly generates a signal that is a function of the speed of the motor's rotor. This control signal is fed back to the speed control circuit to provide constant regulation.

The external control circuit is shown in Fig. 1. The tachometer signal from the motor goes to stage A (*IC2A*), which converts the pulses into square waves. The positive-going portions of the square waves go through *D1* and *Q1*. The circuit associated with stage B (*IC2B*) differentiates the square wave and, due to *D3*, passes the negative portions to *R14*, *C3*, *R15*, and *C4*, all of which are associated with the precision rectifier made up of stage C (*IC3A*). The output of stage C is, therefore, proportional to the speed of the motor. Independent of temperature or line voltage, this output is then coupled back to the motor control board through *R19*. Once the motor has been set to a desired speed, via *R36*, the electronic feedback system tracks to maintain this speed.

A zero-center meter movement is connected between the output of stage C and the rotor of 33 1/3-rpm potentiometer *R23*. When this potentiometer and PITCH potentiometer *R36* have been properly set, the direct-drive motor locks onto exactly 33 1/3 rpm and the meter's pointer remains at the zero-center index mark on its scale.

If for any reason, such as record loading or other sources of friction, the speed of the motor deviates from 33 1/3 rpm, the meter will begin to indicate off the zero mark. The meter itself is calibrated for a ±5% motor speed deviation range (both sides of the zero index mark). You can compensate for speed changes by operating the speed adjust potentiometer and recentering the meter's pointer. However, there is a far easier and faster way to accomplish the same end that makes this turntable different from other turntables.

Stage D in the control system is what sets this turntable apart. Note that op amp *IC3B* is connected as a differential amplifier directly across the meter terminals. Because this stage has a gain of about 20,000 and is operated wide open, a change of only a few millivolts at its input ports generates a maximum output. The change in millivolts will barely be revealed by the meter's pointer, which will remain virtually fixed at the zero mark.

If *S2* is closed (AUTO PITCH CONTROL ON), the output of stage D will be fed to the motor speed control board for instant use. The correction factor in this mode is so fast that it insures an almost perfect pitch. Even the slightest change in motor speed is immediately corrected automatically and the motor will rotate at a predetermined speed to keep the meter's pointer on zero center and the inputs to the differential amplifier will be exactly the same.

With automatic pitch control switch *S2* set to OFF (open), speed adjust potentiometer *R36* can be used to fine tune the turntable speed for exact pitch, slightly above or below 33 1/3 rpm, if there have been any slight frequency changes during the manufacturing stage between the original recording and the final retail disc. You can also tune a disc for your own instrument if you wish to play along with the music.

Note that only the rectifier/filter part of the power supply is on the control circuit board assembly. The 16-volt transformer plugs into a wall outlet and only the low ac voltage is routed to the turntable's electronics package. This insures a very low hum level to be picked up by the phono cartridge.

This turntable employs a second set of acoustic isolators that are resonant about 2 Hz below the resonant frequency of the main platter system. The result is excellent isolation from acoustic coupling sometimes experienced from loudspeakers.

Construction. The actual-size etching guide and components placement guide for the printed circuit board to be used in the turntable are shown in Fig. 2. Mount the components on the board exactly as shown, taking care to properly orient the electrolytic capacitors, diodes, transistor, and IC's. Use a low-wattage soldering iron with fine tip and apply only enough heat to assure good electrical and mechanical connections. Carefully inspect each solder connection for cold soldering and solder bridges between closely spaced conductors. When you are satisfied that the board is properly wired and soldered, temporarily set it aside.

The motorboard, which measures roughly 17" × 10" (43 × 25 cm), consists of two ¾" (1.9-cm) thicknesses of high-density particle board glued firmly together to form a monolithic sandwich. The upper layer of the sandwich has a 5" (12.7-cm) hole cut into it, while the lower layer has a 3½" (8.9-cm) hole centered within the hole in the upper layer. The motor drops into the motorboard through the top hole, its mounting flange resting on the lower layer's upper surface. Then three 6-32 × 1" machine screws and nuts anchor the motor into place. Mount the tonearm and its rest post in their respective locations on the right side of the motorboard. Slip the turntable platter onto the motor's spindle and check to make sure that it rotates without brushing against the motorboard.

The base of the turntable must be large enough to accommodate the motorboard and leave enough room to house the control electronics package in front. It must also be deep enough to clear the motor or permit the rear end of the motor's housing to sit in a cutout in the bottom panel.

Use #6 woodscrews to mount four isolation springs near the corners of the motorboard. Turn over the base and, in like manner, mount four more isolation springs near each corner of the base.

Mount the AUTO PITCH CONTROL *(S2)* at the left end of the control panel. Then, using double-sided tape, mount

SPECIFICATIONS

Wow	0.02% rms (weighted)
Flutter	0.04% rms (weighted)
Rumble	−60 dB RIAA/RRLL
Drift (APC on)	0.01%
APC accuracy	0.01%
Speed control	±5% (33 1/3 & 45 rpm)
Suspension	Dual resonant
Motorboard weight	5½ pounds (2.5 kg)
Platter	180 kg/cm² moment of inertia, non-ferrous
Pitch control	Five-turn, three-ball planetary potentiometer for precision accuracy

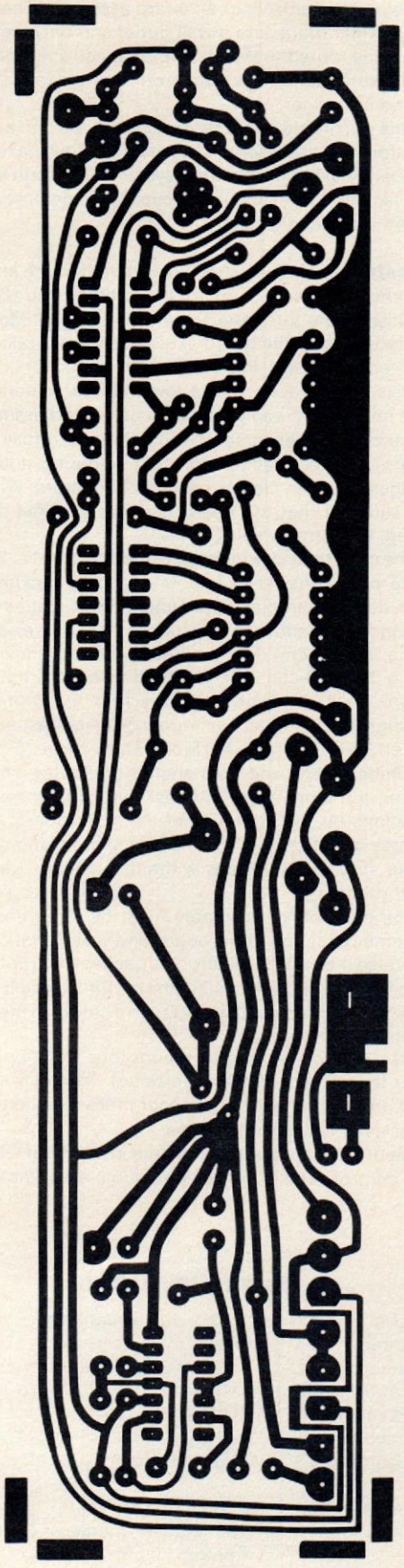
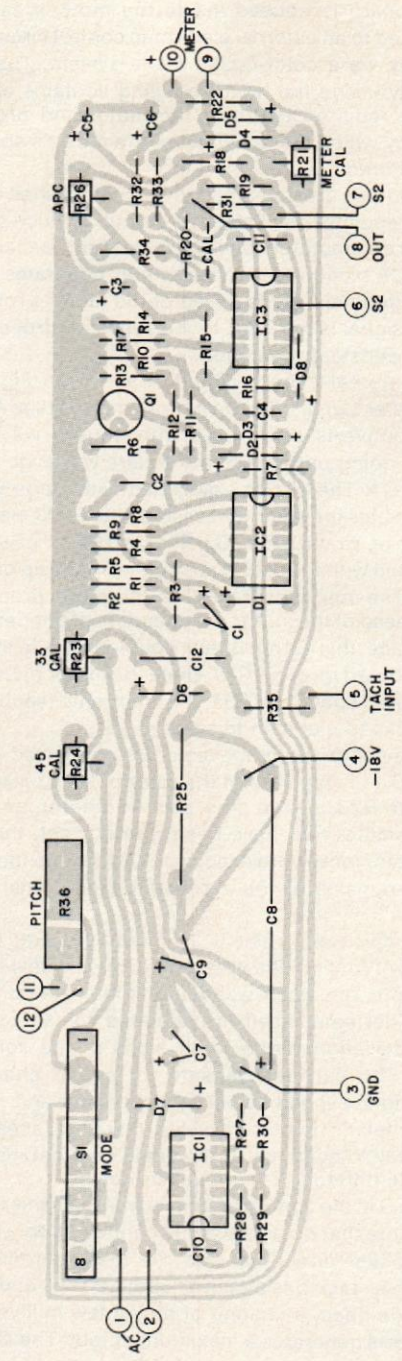


Fig. 2. Etching and drilling guide for the turntable is shown above. Component layout is above right.



the meter movement in a rectangular cutout in the control panel so that its scale is easy to read. This done, mount the control circuit board assembly to the panel via the PITCH control *(R36)* and MODE switch *(S1)*. Check to make sure that the adjustment slots of the 33 *(R23)*, 45 *(R24)*, and APC *(R26)* trimmer potentiometers line up with the holes in the control panel.

Referring back to Fig. 1 and Fig. 2, complete wiring the system. Do *not* solder the wires coming from the motor housing directly to the pc board pads. Instead, solder lengths of prepared hookup wire (preferably color coded for easy identification) to the board, twist together the free ends of the hookup wires and the appropriate motor wires, and screw onto each twisted connection a wire nut. Solder a 1" (2.54-cm) long piece of solid bare wire to the pads marked CAL on the circuit board. Then solder the leads from the outboard low-voltage transformer's output to the pads marked AC.

Next, connect and solder the cartridge leads coming

TEST RESULTS
A Hirsch-Houck Labs Report

The turntable performance was exactly what you would expect of a first-quality unit. Checks with a frequency counter confirmed that the indicated nominal speeds were exact, within the ±0.1% accuracy of our four-digit counter's display. The meter indications for vernier speed control were within 5% of full-scale and on the nose at the zero-center index mark. Line voltage variations had absolutely no effect on the speed of the turntable or meter indications.

The unweighted rms wow was 0.02%, essentially the residual of our test record and meter. The flutter measured 0.04%. The unweighted rumble was −31 dB, principally in the lateral plane. With RRLL audibility weighting, the rumble was −58 dB.

The turntable took a little longer to reach its final speed than do most turntables. We timed it at about 7 seconds to come up to 33 1/3 rpm and 11 seconds to come up to 45 rpm. With the AUTO PITCH CONTROL set to ON, the turntable required about 14 seconds to reach a locked-in condition at both speeds.

The turntable's unique double-suspension isolation system proved to be very effective in preventing acoustic feedback. We confirmed this when we made our standard test for isolation from the mounting surface, as a function of frequency. This was by far the best turntable we have tested in this manner. Its most sensitive point was at about 35 Hz—at least as good as the best turntable we previously tested. Its isolation at higher frequencies, where most acoustic feedback problems occur, was typically 20 to 40 dB better than other turntables.

User Comment. Without considering cost, our tests revealed that this turntable performs essentially on a par with other direct-drive, commercially made turntables. Its wow, flutter, and rumble are as good as most direct-drive turntables and better than most belt-driven units.

The turntable's speed stability was exceptionally good, with none of the warm-up drift that is typical of direct-drive or other electronically controlled turntables. This drift is usually small enough to be negligible, but in the case of this turntable it was undetectable. The range of the PITCH control is greater than average, and we especially like the APC system. It gives the user the rock-stable, accurate frequency of a synchronous motor with the advantage of being able to set the "synchronous" speed to one's own taste.

The chief drawback to the turntable was the long start-up time. On the other hand, the platter can be left running while changing records or stopped manually at any time. Hence, there is no need to shut the turntable off during a playing session. Because of the soft base suspension, one must be careful when operating the controls to avoid jarring the motorboard. But in normal operation, the tonearm's finger lift or cueing lever are the only active controls, and they pose no problems in this regard.

We did not perform tests on the Audio-Technica tonearm that was mounted on the turntable's motorboard. From past experience with it, we know that this is a smooth-handling tonearm that should be compatible with any good phono cartridge. The turntable can accommodate any separate tonearm, of course.

This turntable gives every audiophile the opportunity to own a truly state-of-the-art direct-drive disc player for a fraction of the usual cost by allowing him to wire the electronics and assembling the mechanical section.

out of the base of the tonearm assembly to the lugs on a two-phono-jack assembly and mount the jack assembly on the bottom of the turntable's base. Mount a phono cartridge in the tonearm's cartridge shell.

Setup and Use. Set the motorboard assembly into the base so that it rests on its isolation/support springs. Slip onto the motor's spindle the turntable platter and rubber mat. Place a bubble level on the platter to make sure that it is level.

Preset all potentiometers on the control board to their mid-positions. Plug the turntable's line cord into an ac outlet and set the MODE switch to 33 and the AUTO PITCH CONTROL switch to OFF. Illuminate the strobe pattern on the edge of the turntable platter with a fluorescent or neon light source. Adjust the 33 control on the bottom of the motor housing so that the second set (from the bottom) of strobe marks is approximately stationary. Then adjust the PITCH control until the pattern is exactly stable. Adjust the 33 CAL *(R23)* control so that the meter's pointer rests on the zero index on the scale.

Set the MODE switch to 45 and adjust the 45 CAL *(R24)* control until the bottom set of strobe marks on the platter are stationary. Put the MODE switch back in the 33 position and set the AUTO PITCH CONTROL to ON. Adjust the APC calibration control *(R26)* for a zero indication on the meter. Set the AUTO PITCH CONTROL to OFF.

Lightly twist together the two bare calibration wires on the circuit board. This will speed up the motor by 5%. Adjust METER CAL potentiometer *R21* (this pot is not accessible through a hole in the front panel) until the meter's pointer indicates exactly +5%. Untwist the calibration wires and orient them so that they do not touch each other or any part of the circuit.

(Note: The calibration procedure is best performed during the hours when commercial power demands are at their lowest, such as during a weekend. This will insure that the power-line frequency is at its closest to the ideal 60 Hz.)

Turn off the power by setting the MODE switch to OFF and disconnect the power from the ac receptacle. Remove the turntable platter and mat. Then fit the control panel in place in the turntable's base and fasten it down with two No. 6 woodscrews. Reinstall the platter and mat and check again with the bubble level to make certain the turntable is level. If necessary, repeat the adjustment procedure from the point where you trim the PITCH control to obtain an exactly stable 33 1/3 rpm speed when viewing the strobe marks on the platter.

Put the turntable where you want it in your system and connect the feed cables between it and your audio amplifier. Check again to make sure the turntable is level. It is now ready to be used for playing discs.

Whenever you turn on the turntable from a cold start or switch from one speed to another, wait about 10 seconds for the speed to stabilize before lowering the tonearm onto the disc's surface. (Monitor the meter; when the pointer rests on the zero, or center, index, the turntable is operating at the proper speed.)

The most convenient way of operating the turntable is by leaving it in the automatic mode. In this mode, the speed of operation will be as close to perfect as your calibration can make it. When the turntable is operated on automatic, the assumption is that the disc was cut at an exact 33 1/3- or 45-rpm speed. If you find that the pitch appears to be off, however, you can set the AUTO PITCH CONTROL to OFF and bring it back on-pitch by adjusting the PITCH control. You can adjust for up to ±5% pitch error in this manner. ◈

(Editor's Note: The author is pursuing patent protection for concepts described in this article. However, readers may build it for personal use.)