Build the Lawn Ranger

Now you can sit back and watch your lawn mower cut the grass by itself!

Raymond Rafaels

PICTURE THIS—YOU'RE SITTING IN A HAMMOCK ON A WARM SUNDAY afternoon listening to your favorite radio station. You watch in amusement as your personal robot completes the last of your weekly chores. Only a dream? Not any longer, because now you can build a personal robot that can perform the world's most dreaded chore—lawn mowing. In the next few issues of **Radio-Electronics**, we will explain how you can build the Lawn Ranger, a patented battery-powered robot that can cut grass automatically while you and your friends watch in amazement.

The Lawn Ranger is *not* a remote-control lawn mower. It is a robot that can actually "see" the grass while it cuts. It may seem hard to believe, but the Lawn Ranger really can cut grass by itself. You may have already seen the Lawn Ranger on television or in periodicals such as the New York Times, USA Today, Machine Design, or others. Now, you can easily build and use the Lawn Ranger for your yard, or even start your own lawn maintenance business.

General description

The design of the Lawn Ranger is surprisingly simple. It consists of an aluminum frame, two electric cutting motors, two electric drive motors, a plastic top, a sensor assembly, two 12-volt batteries, and an electronic control system.

The metal frame provides the basic structure of the robot and is composed of ¼-inch thick 9091 aluminum. Attached to the frame are two caster wheels located in the front, and two geared drive wheels located in the rear. Each drive wheel is connected to a 24-volt DC gear motor through a spur-gear interface. That "direct drive" approach allows the robot to be propelled by a durable drive system that does not rely on chains or belts.

The Lawn Ranger uses four permanent-magnet 24-volt DC motors. The two drive motors come with an internal gear box for speed reduction. The two cutting motors are synchronized by a timing belt to prevent the blades from coming in contact with each other.

The red top is molded from sturdy ABS plastic. For safety, a pressure sensitive bumper switch is attached to its outer edge. That switch will automatically shut the Lawn Ranger off if it comes in contact with trees or other obstacles. An additional pushbutton shut-off switch is mounted on top of the robot for easy access by the operator.

The sensor assembly consists of 15 infra-red sensors mounted in front of the Lawn Ranger. Those sensors "see" your grass and provide critical

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navigation information to the electronic control system.

Two 12-volt deep-cycle batteries allow the Lawn Ranger to operate for approximately 2–3 hours on a single charge. Since the robot is 100% battery powered, there is no need for gasoline, oil, or the periodic maintenance associated with gasoline-powered engines. Battery power also allows the Lawn Ranger to run very quiet and clean.

Electronic control system

The electronic control system is composed of four printed circuit boards; the CPU, motor controller, power, and motherboard. Each board uses readily available off-the-shelf electronic components.

The CPU board contains a Z80 microprocessor and is the central "brain" of the Lawn Ranger. The board receives information from grass sensors that are designed to detect the position of cut and uncut grass located beneath the robot. The Z80 microprocessor continually processes the sensor data and calculates the correct steering path for the Lawn Ranger to follow.

The motor-controller board is used to control the speed of the drive motors. Velocity information from each drive wheel is fed back to that board in order to keep the Lawn Ranger's speed constant, even when climbing hills. Steering is accomplished by changing the speed of each rear drive wheel. For example, if the right wheel spins faster than the left, the robot will turn to the left—just like a tank. The motor-controller board also contains the circuitry that is used to amplify the grass-sensor signals.

The power board contains DC/DC converters that convert the battery voltage to +5-, +10-, +30-, and −10-volts DC. The board also contains power MOSFET's that are used to control the motors.

The motherboard provides the interconnection between the boards listed above. Each board plugs into the motherboard via an edge connector in order to facilitate the assembly and test of the electronic control system.

Operation

Figure 1 illustrates the path that the Lawn Ranger would follow on a typical lawn. The operator must first manually steer the robot around the perimeter of the yard (while cutting grass) and around any obstacles within that area with the manual control unit. The manual control unit is a hand-held device that plugs into the rear of the mower with a 5-foot cable. The initial border cut around the yard is used by the Lawn Ranger for navigation, as it will steer along the border while it cuts grass. Because the mower will search for high grass, it will move away from any area that has been previously cut. That feature allows the robot to move around trees and other obstacles that are surrounded by cut grass. After all the borders are cut, you unplug the manual control unit, switch the mower into its automatic mode, and then watch it finish the job as you relax and enjoy a cold drink!

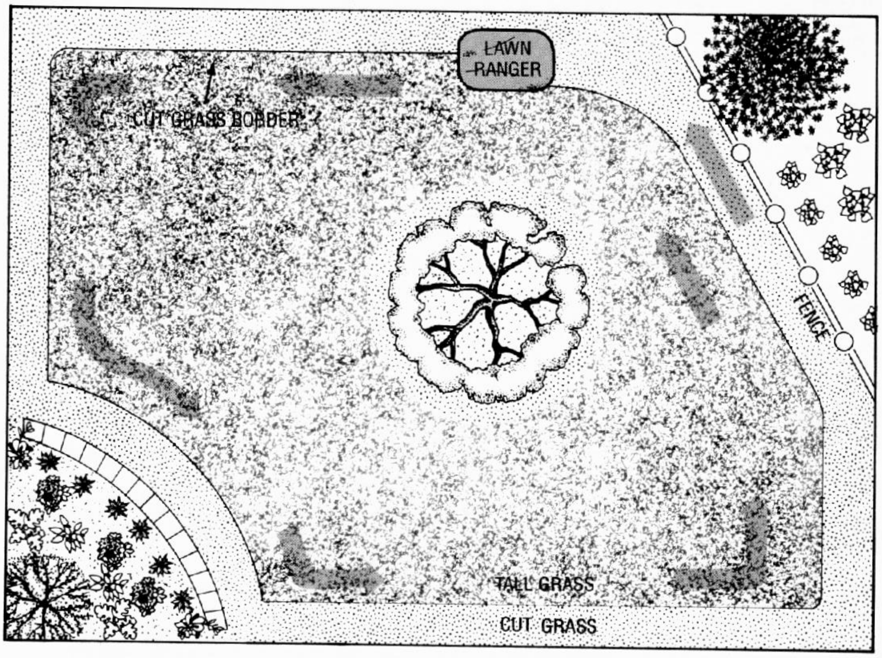

FIG. 1—THE LAWN RANGER WOULD FOLLOW this path on a typical lawn. The operator must first manually steer the robot around the perimeter of the yard (while cutting grass) and around any obstacles within that area using the manual control unit.

Safety

There are several safety features that have been added to the robot in addition to the shut-off switches. There are special cutting blades (see Fig. 2) that freely pivot at the end of the round blade disks. The centrifugal force created by the spinning disks causes the blades to swing outward where they will hold their position while cutting grass. But if the blades hit a solid object, they will give, thus reducing the cutting force and risk of serious injury. However, even with that feature, the blades are extremely dangerous and should be treated as such.

Warning: just like any lawn mower, never leave the powered unit unattended. Also, make sure that an adult is always present while the mower is in operation. Always keep hands and feet away from the mowing deck, and make sure cutting area is free of people, animals, and debris. Never let children or animals ride on top of the robot.

Grass sensors

A close-up shot of the grass sensors is shown in Fig. 3. As you can see, the sensor consists of two protruding plastic prongs that contain an infrared light source (an IR LED) and a detector (a photo transistor). Fifteen of those sensors are placed in a row across the front of the Lawn Ranger. A partial schematic diagram of the sensor assembly is shown in Fig. 4. The sensors are spaced approximately 2 inches apart as measured from the center of each sensor.

The LED's of each sensor are connected in series. Light from each LED will cause its respective phototransistor to conduct and the emitter voltage to rise to +5-volts DC. When a piece of tall grass passes between an LED and detector, the phototransistor will stop conducting and the emitter voltage will change from a digital "1"

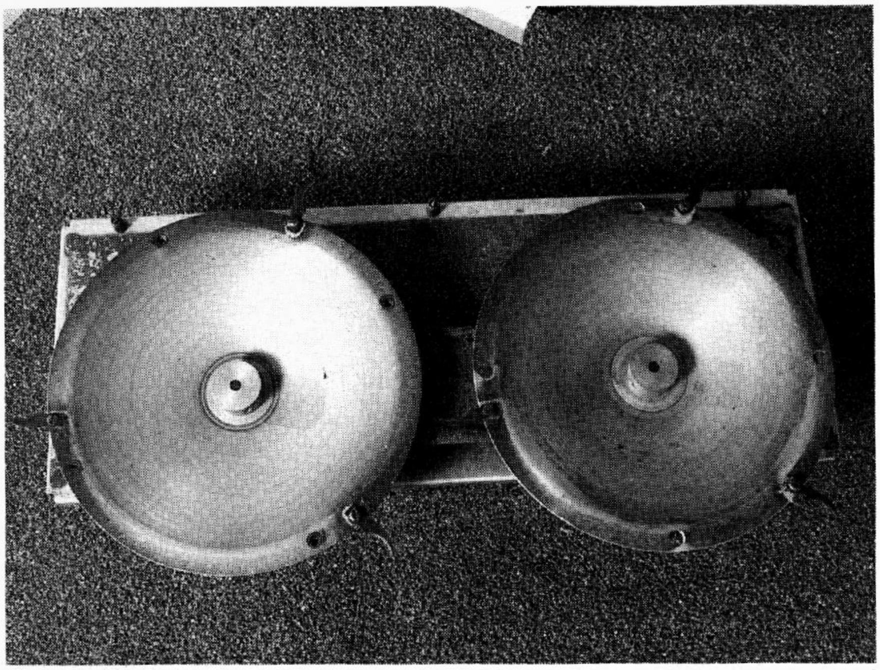

FIG. 2—THERE ARE SPECIAL CUTTING BLADES that freely pivot at the end of the round blade disks.

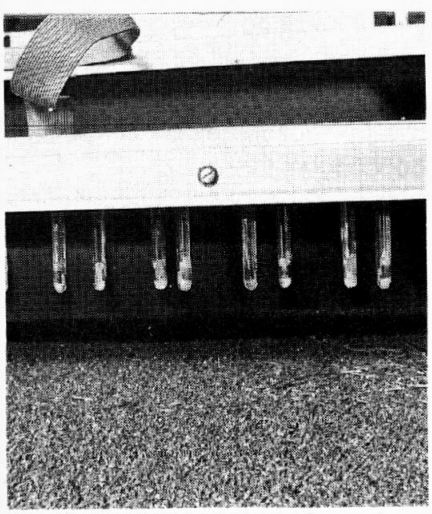

FIG. 3—THE GRASS SENSORS contain an infra-red light source and a detector.

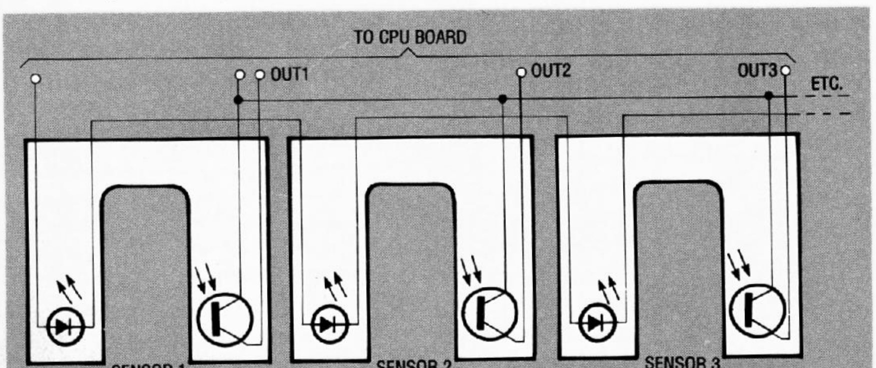

FIG. 4—SCHEMATIC DIAGRAM of the grass-sensor assembly.

(+5 volts) to "0" (0 volts). Since cut grass is not tall enough to pass between the sensors, the sensor outputs will remain at +5 volts. The digital information from each sensor is sent to the motor-controller board for amplification and then forwarded to the CPU board for processing.

Computer program

The computer is used to locate the position of the cut-grass border as it passes beneath the mower. The location of the border will allow the lawn ranger to decide if it should steer left, right, or straight ahead.

As each grass sensor detects grass, it will output a digital "1" (high grass) or a "0" (cut grass or no grass). The computer will sample every sensor several times per second, and then store the information in memory. Table 1 illustrates a memory dump that contains five samples of grass-sensor data.

In Table 1, the actual edge of the cut-grass border is located between sensors 8 and 9, with tall grass positioned between sensors 1–8, and cut grass between sensors 9–15. The tall-grass region (sensors 1–8) will record a large number of 1's as the tall grass flows through the sensors (1's will periodically be recoded in the cut-grass region due to stray uncut blades of grass).

In order to calculate the correct position of the cut border edge, the computer program will add the number of "1" tallies for each sensor. If the number is greater than or equal to 2, the computer will store the final value of 1. If the summed value is less than 2, then a value of 0 is stored. For example, the final value stored for the first five data samples in Table 1 would be 111111110000000. Now, it is very easy to detect the location of the grass border. It is simply identified by the point where the string of 1's end. A simplified flow chart of the computer program is shown in Fig. 5.

CPU board

Figure 6 is a schematic diagram of the CPU board. The CPU board is responsible for processing the sensor data and calculating the correct steering direction. It consists of a Z80 microprocessor (IC1), two parallel I/O chips (IC9 and IC10), a 4K × 8-bit EPROM (IC6), two 4K × 4-bit RAM chips (IC7 and IC8), and glue logic (IC2 through IC5). The CPU was chosen in order to keep the parts count low and the price within the budget of hobbyists.

The clock for the Z80 is generated by three inverters contained on IC2. A 2-MHz crystal is used to ensure that a steady timing frequency is maintained over ambient temperature changes. The clock output (pin 6 of IC2) is tied to the Z80 microprocessor and to pin 25 of IC9 and IC10. Power-on reset is accomplished with an RC delay circuit made up of R4, C12 along with IC5-d, which is used as a buffer for the delay circuit. The RST line will reset two latch circuits upon power up.

The first latch circuit consists of IC4-a, IC4-b, IC3-b, and IC3-c, and the second circuit by IC4-c and IC4-d. The latches are used to store the START and FULL STOP signals. Those signals command the Lawn Ranger to move forward and turn off, respectively. When the robot moves for-

TABLE 1—GRASS SENSOR DATA

	Byte 1								Byte 2						
	Sensor #														
Sample #	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	1	1	0	1	0	1	0	1	0	1	0	0	0	1	0
2	1	0	1	1	1	1	1	1	0	0	0	0	0	0	0
3	0	1	0	0	1	1	1	0	1	0	0	0	1	0	0
4	1	0	1	0	0	1	1	1	0	0	0	0	0	0	0
5	0	1	0	1	0	0	1	0	0	0	0	0	0	0	0

ward, the START signal will turn Q1 on and bring the STOP MOVE line low. When the robot shuts down, pin 8 of IC4-c and pin 6 of IC3-d will go low. That deactivates the input power relay.

Input/output

The CPU board uses two Z8420 parallel input/output or PIO chips labeled IC9 and IC10. Each chip has two 8-bit I/O ports that are software programmable. Bit 7 of Port B on IC10 is programmed as an output. That output line provides a gating pulse that is used to sample the sensor data. When the line goes high, the sensors are enabled and sensor information is passed to the motor-controller board for amplification. After the sensor data is amplified, it is sent to IC10 on the CPU board.

The bits of Ports A (0–7) and B (0–6) of IC10 are defined as inputs that are used to receive the sensor data. IC10 transfers the information to the Z80 microprocessor over the data bus for processing.

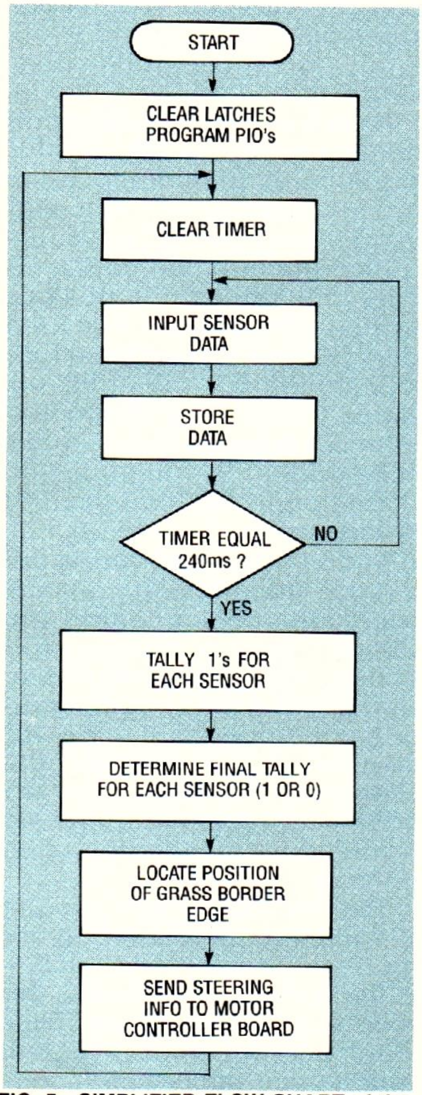

FIG. 5—SIMPLIFIED FLOW CHART of the computer program.

CPU construction and test

It is recommended that you use a PC board for the CPU, and you can either purchase one from TSI (it's a plated-through board that's hard to make—see ordering information), or you can make one from the artwork provided in PC Service. Also, the 2732A EPROM is preprogrammed and is available only from TSI. Using the parts-placement diagram of Fig. 7, first solder the IC sockets to the board, then solder the remaining components. Then, carefully push all the IC's into their respective sockets. And remember, that some of the IC's are CMOS, which must be handled carefully. Figure 8 shows a fully assembled CPU board.

Apply +5 volts to TP4 and ground to TP6. Place a scope probe at pin 34 of IC10; the scope should display a 1-kHz square wave. If you don't have a scope, verify that the voltages on pins 9, 10, 12, 13, 14, and 15 of IC9 read 0-volts DC. Now, as you temporarily ground pin 15 of IC10, recheck IC9 for 5 volts on pins 10, 13, 14, and 15, and 0 volts on pins 9 and 12.

If your board passes those tests, it

All resistors are ¼-watt, 5%, unless otherwise indicated.
R1, R2—1000 ohms
R3–R7, R12, R15, R17—2200 ohms
R8—not used
R9, R10, R19, R20—3300 ohms, SIP
R11, R18—3300 ohms
R13—22,000 ohms
R14—470,000 ohms
R16—47,000 ohms
R21—120 ohms

Capacitors
C1, C12—100 µF, 25 volts, electrolytic
C2, C3, C5–C9, C11, C13, C15, C16, C18—0.1 µF, ceramic
C4—56 pF, ceramic
C10—10 µF, 16 volts, electrolytic
C14—not used
C17—1 µF, 35 volts, electrolytic

Semiconductors
IC1—Z84C00-4PS microprocessor
IC2—74HCT04 hex inverter
IC3—74LS08N quad 2-input AND gate
IC4—74LS00N quad 2-input NAND gate
IC5—74LS32N quad 2-input OR gate
IC6—2732A 4K×8 EPROM (must be purchased from TSI)
IC7, IC8—2114L-2 1K×4 RAM
IC9, IC10—Z84C20-4PS parallel I/O
D1—1N4148 diode
Q1—2N3904 NPN transistor

Other components
XTAL1—2-MHz crystal
J5—10-pin IDC connector
S1—7-position DIP switch
TP1–TP6—individual pins or scraps of component leads

Miscellaneous: IC sockets

Note: The following items can be purchased from Technical Solutions, Inc., P.O. Box 284, Damascus, MD 20872 (301) 253-4933: PC boards for the CPU, motor-controller, power board, and motherboard, $39 each; programmed EPROM, $39 (contains computer program and firmware license); grass sensors, $8.99 each; hand-held manual controller kit, $39; full CPU-board kit, $129 (includes EPROM, PC board, and all parts); full kit for motherboard, $69 (contains PC board and all parts); kit for power board, $149 (contains PC board and all parts except DC/DC converters); full kit for motor-controller board, $169 (includes PC board and all parts); Lawn Ranger demo VHS tape, $19 (refundable for orders of $100 or more). Please add $8.00 for S/H (U.S. orders). Maryland residents add sales tax.

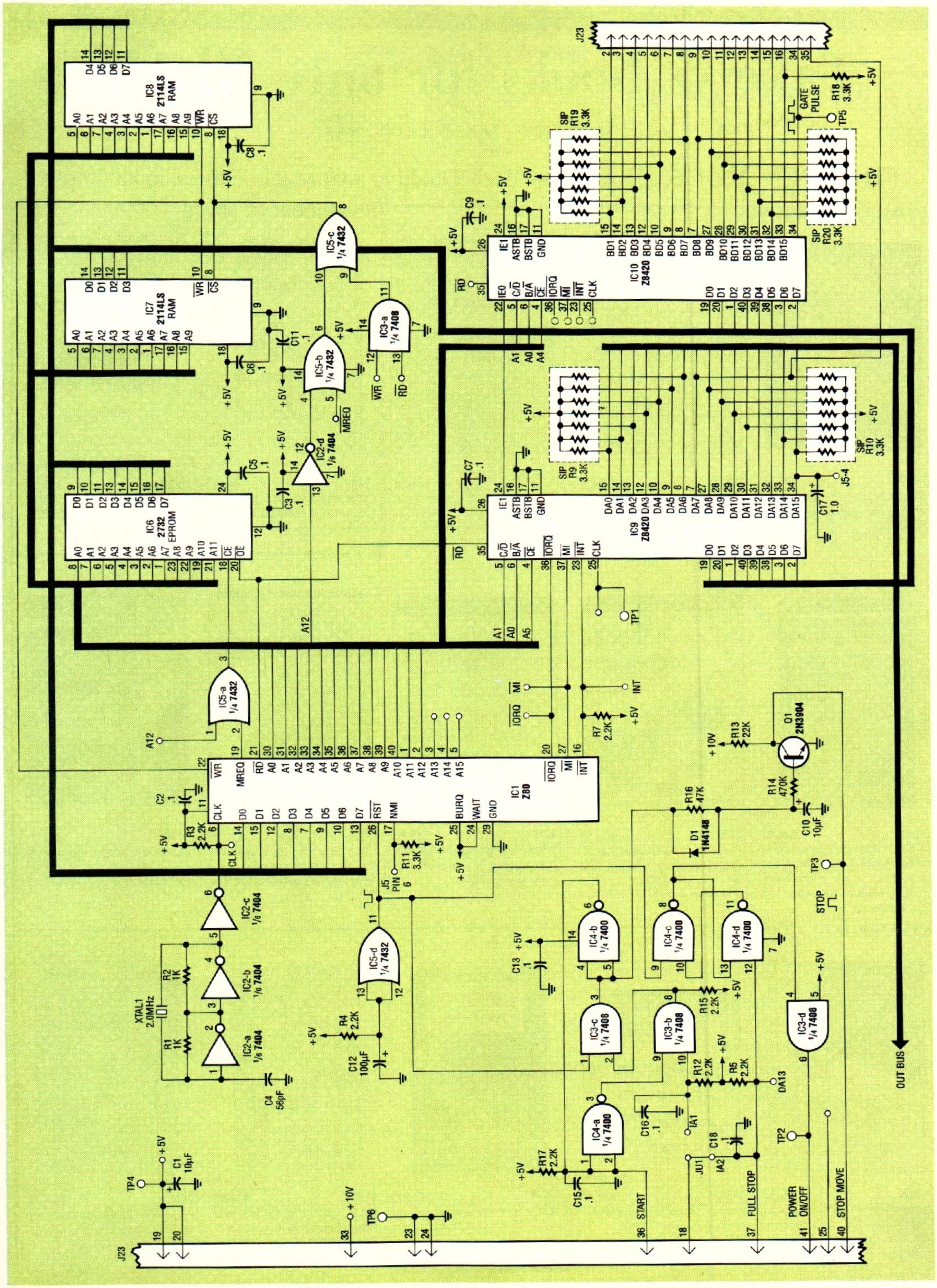

FIG. 6—SCHEMATIC DIAGRAM of the CPU board. Its purpose is to input all sensory information, and then tell the Lawn Ranger where to go.

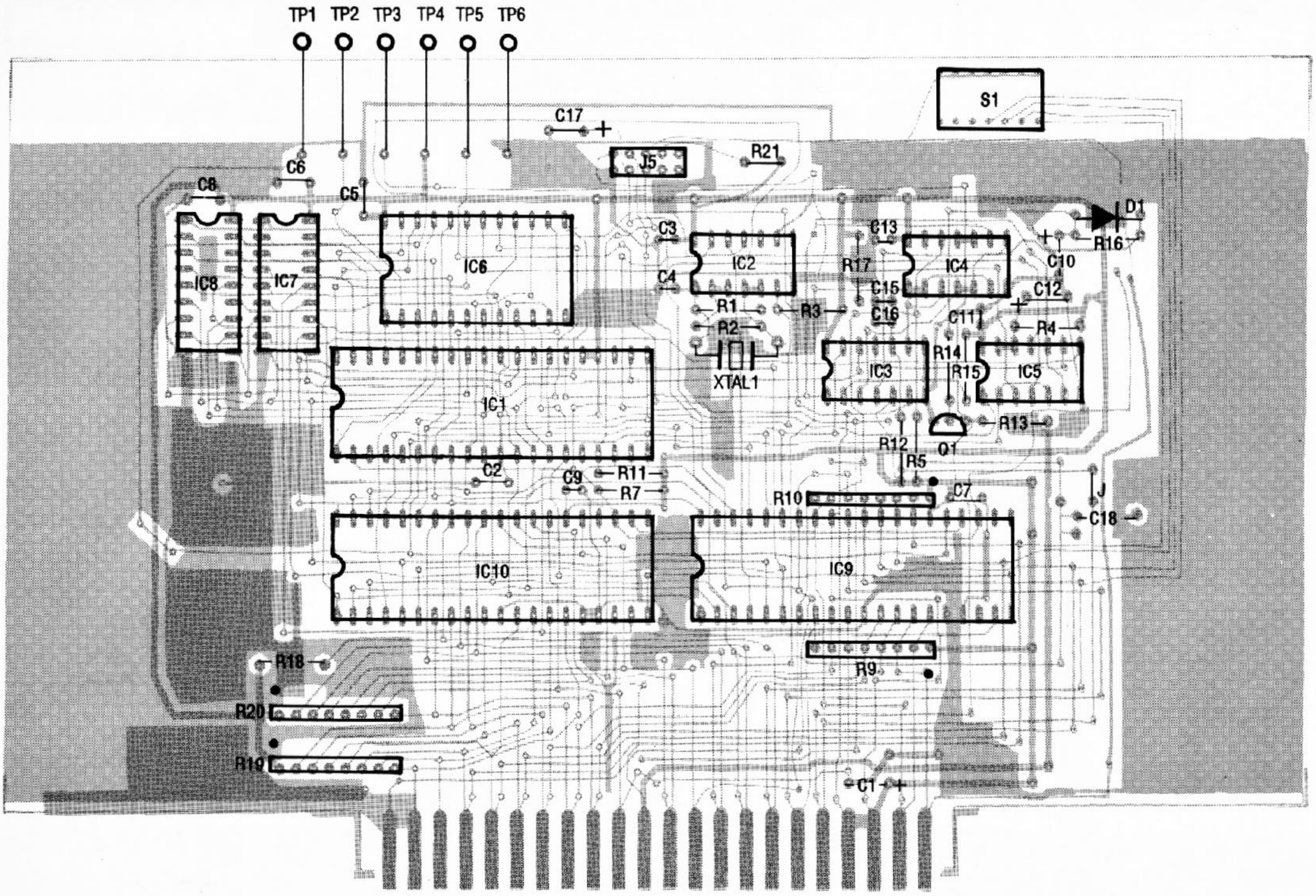

FIG. 7—ASSEMBLE THE COMPONENTS according to this parts-placement diagram.

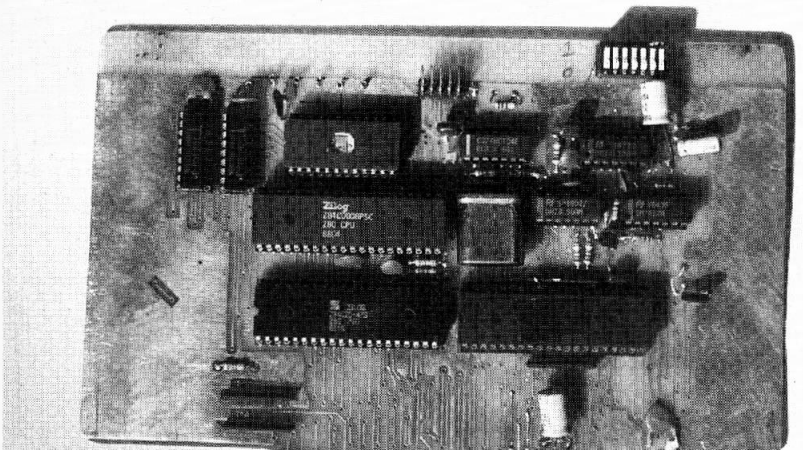

FIG. 8—FULLY ASSEMBLED CPU BOARD.

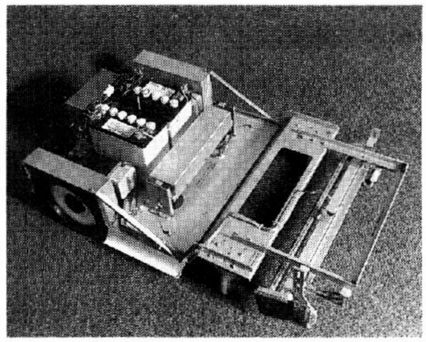

FIG.9—THE COMPLETE LAWN RANGER unit. We will get to the mechanical assemblies in later issues.

should be functioning properly. More extensive testing of the CPU can be performed after the motor controller, power board, and motherboard are assembled and tested.

Still to come

In the next couple of issues of **Radio-Electronics** we will explain how you can finish building the Lawn Ranger. As far as the electronics portion goes, we've still got to build the motor-controller board, the power board, and the motherboard, which holds all of the other boards together. Then we have to build and wire the sensor assembly, put together the mechanical frame, and connect everything together.

By the way, for a sneak preview look "under the hood," of what the Lawn Ranger will eventually look like, Fig. 9 shows the complete mechanical assembly, without the cover. You can see that everything fits together in a nice, compact package.

For those of you who still doubt the Lawn Ranger's capabilities, a VHS demo tape can be purchased, showing the unit in action; it's sure to make you a true believer. The cost of the tape is refundable with an order (see the Parts List for details). **R-E**

Build the Lawn Ranger

This month we discuss the motor-controller board.

Raymond Rafaels

LAST MONTH WE INTRODUCED YOU TO THE LAWN RANGER, THE world's first personal robotic lawn mower. For those of you who missed last month's issue, the Lawn Ranger is a computerized robot that can cut grass by itself. All you have to do is cut a boundary around the perimeter of your yard and around any obstacles using the manual controller, switch the mower to automatic, and watch in amazement as it completes the job.

Control system

Let's quickly review the block diagram of the electronic control system shown in Fig. 1. The grass-sensor assembly is used to detect the position of cut and uncut grass that lies beneath the Lawn Ranger. That information is amplified on the motor-controller board and then forwarded to the *C*entral *P*rocessing *U*nit (CPU). The CPU will calculate the steering direction and send it to the motor-controller board. The motor-controller and power-switching circuitry will steer the robot in the direction defined by the CPU by varying the speed of the rear drive wheels. If the right wheel is made to spin faster than the left wheel, the robot will steer to the left—just as a tank works.

Motor-controller board

Figure 2 shows a block diagram of the motor-controller board, which is used to control the speed of each drive wheel and to amplify the grass-sensor signals. The motor-speed control circuitry contained on the board is designed to increase or decrease power to the drive motors based upon the drive motor's actual speed. The circuitry has three major sections: the D/A converter, velocity-feedback loops, and *P*ulse-*W*idth *M*odulators (PWM).

The D/A converter converts the Z80 microprocessor's digital steering command into an analog voltage. The D/A converter, hand-held manual controller, and speed-set adjustment provide steering reference signals to the velocity-feedback loops.

There are two feedback loops: one for the right wheel, and one for the left. The loops are designed to "lock on" to the reference-signal input and provide a constant motor speed. The D/A and the manual-controller outputs are designed to slow down the left or right wheel for steering purposes. When the robot is steering straight, the D/A and manual-control outputs will be zero and both drive wheels will spin at the same speed. If the actual wheel speed (from the velocity-feedback signal) is equal to the desired wheel speed, the error voltage will be zero. When the wheel speed is too slow, the velocity-feedback signal will cause the error voltage (reference input minus the feedback) to increase and additional power will be delivered to the drive motors. If the wheel speed is too

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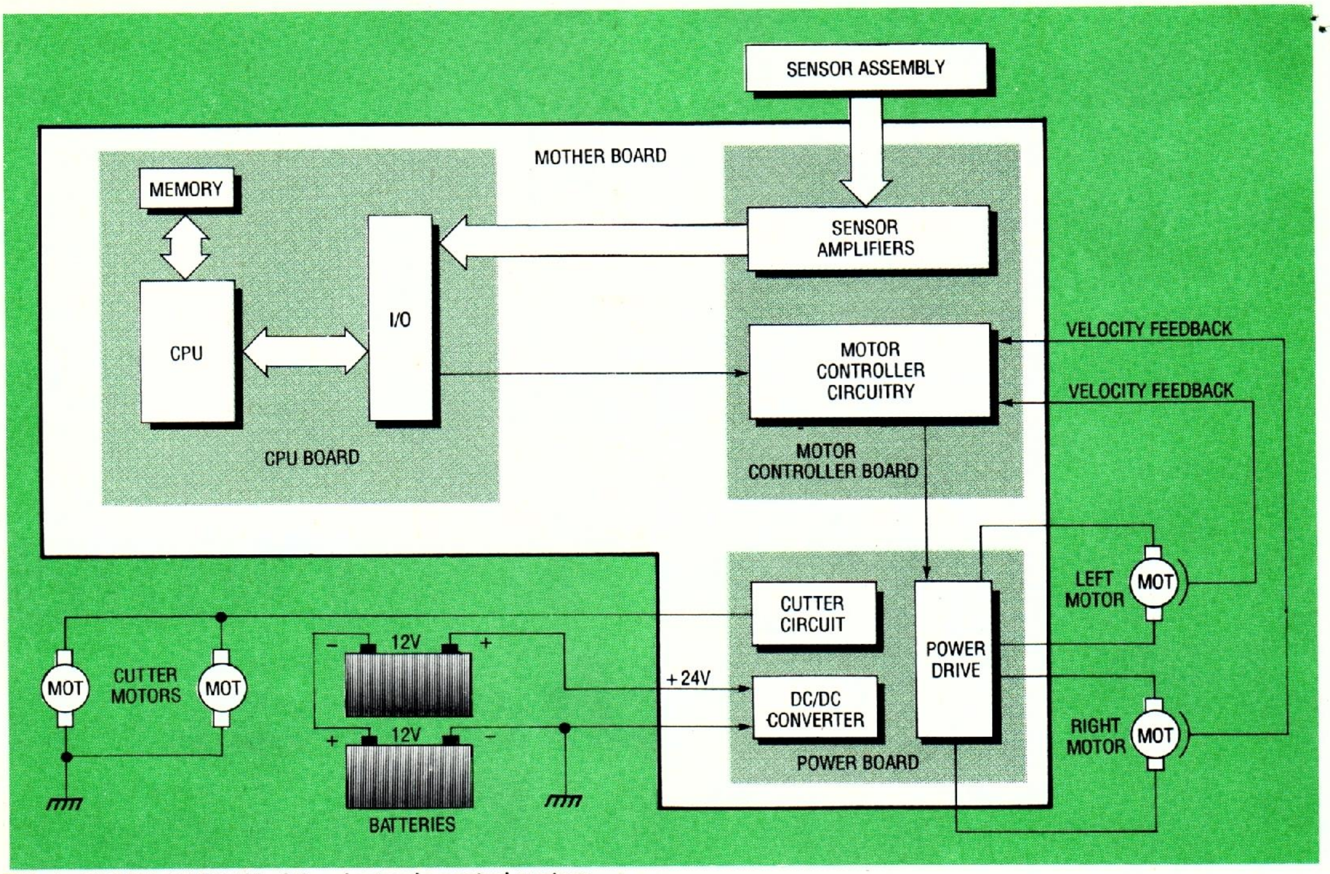

FIG. 1—BLOCK DIAGRAM of the electronic control system.

fast, the velocity-feedback signal will cause the error voltage to decrease and less power will be delivered to the drive motors.

The PWM circuitry is used to achieve high-efficiency power amplification. The technique allows the +24-volt supply to be switched (applied and then removed) from the drive motors for the sake of increased efficiency. The "on" and "off" times are precisely controlled and the effect on the motors is the same as if a lower voltage were continuously applied to them.

PARTS LIST

MOTOR-CONTROLLER

All resistors are ¼-watt, 5%, unless otherwise indicated.

R1, R93—two 16-ohm, 1-watt resistors in parallel
R2, R16, R28, R41—22,000 ohms
R3, R17, R21, R25, R43, R55, R56, R59, R60, R73, R83, R86, R90—100,000 ohms
R4, R5, R18, R19—2200 ohms
R6, R30, R38, R39, R44, R45, R47, R50, R108, R110, R112, R115—1 megohm
R7—806,000 ohms, 1%
R8—402,000 ohms, 1%
R9, R26, R27, R52—200,000 ohms, 1%
R10—150,000 ohms
R11, R23, R46, R53, R54, R62, R65, R69, R72, R75, R78, R79, R84, R89—10,000 ohms
R12—499,000 ohms, 1%
R13—180,000 ohms
R14—604,000 ohms, 1%
R15—4500 ohms, 1%
R20—2.7 megohms
R22, R36, R48—220,000 ohms
R24—82,000 ohms
R29—680,000 ohms
R31–R35, R37, R104–R106, R117–R200—not used
R40, R42—68,000 ohms
R49—820,000 ohms
R51, R57, R109, R111, R113, R114, R116—8200 ohms
R58, R61—39,000 ohms
R63, R64, R81, R82, R94—1000 ohms, 1%
R66, R68, R74, R87—270 ohms
R67, R70, R77, R80—3300 ohms
R71, R76, R85, R88—2700 ohms (with 0.1 µF capacitor in parallel, see text)
R91, R92, R107—jumper
R95, R98, R102—3900 ohms, 8-pin SIP resistor network
R96, R97, R99–R101, R103—2200 ohms, 8-pin SIP resistor network
R201, R202—2000 ohms, potentiometer
R203—10,000 ohms, potentiometer

Capacitors

C1, C5, C7, C10, C11, C16, C18–C21, C26, C42, C47–C51—0.1 µF, 50 volts
C2, C4, C8, C15, C43–C45—0.01 µF, 25 volts, disc
C3, C9, C27–C41—1 µF, 35 volts, electrolytic
C6, C17, C46—100 µF, 35 volts, electrolytic
C12–C14, C22—0.002 µF, 25 volts
C23–C25—10 µF, 16 volts, electrolytic

Semiconductors

IC1, IC12–IC14—74LS14N hex inverter
IC2—74LS74N D-type latch
IC3, IC11—not used
IC4, IC7—LM324 op amp
IC5, IC6—LM2907N-8 frequency-to-voltage converter
IC8—LF13202 analog switch
IC9, IC10—UC3637N pulse-width modulator
IC15, IC18—LM339 comparator

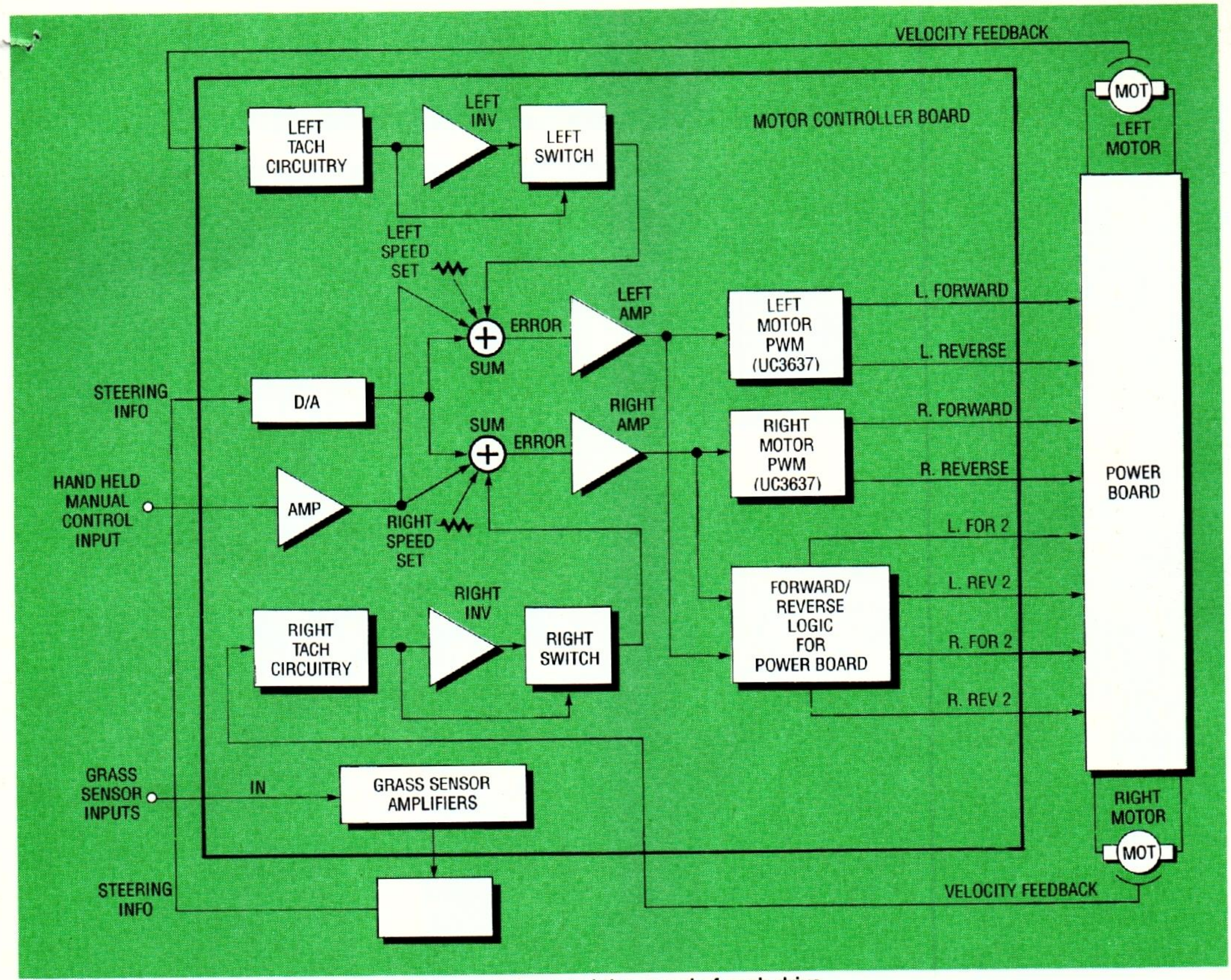

FIG. 2—THE MOTOR-CONTROLLER BOARD is used to control the speed of each drive wheel and to amplify the grass-sensor signals.

IC16, IC17—ULN2081A transistor array
IC19, IC20—OPB822S dual opto module
D1–D3, D6–D11, D13, D15, D17, D20–D22—1N4148 diode
D4, D5, D12, D14, D16, D18, D19—not used
Q2, Q3, Q5, Q6, Q8, Q9, Q11–Q16—2N3904 transistor
Q1, Q4, Q7, Q10—2N3906 transistor

Other components
J1—20-pin IDC connector
J2—not used
J3—10-pin IDC connector
J4—16-pin IDC connector

Miscellaneous: PC board, IC sockets (two 8-pin, nine 14-pin, three 16-pin, and two 18-pin), jumper wire, solder, etc.

MOTHERBOARD

PC board; P21, P23—44-pin edge connector; P22—50-pin edge connector

Note: The following items can be purchased from Technical Solutions, Inc., P.O. Box 284, Damascus, MD 20872 (301) 253-4933: PC boards for the CPU, motor-controller, power board, and motherboard, $39 each; programmed EPROM, $39 (contains computer program and firmware license); grass sensors, $8.99 each; hand-held manual controller kit, $39; full CPU-board kit, $129 (includes EPROM, PC board, and all parts); full kit for motherboard, $69 (contains PC board and all parts); kit for power board, $149 (contains PC board and all parts except DC/DC converters); full kit for motor-controller board, $169 (contains PC board and all parts); Lawn Ranger demo VHS tape, $19 (refundable for orders of $100 or more). Please add $8 for S/H (U.S. orders). Maryland residents add sales tax.

D/A converter

Figure 3 shows a detailed schematic diagram of the motor-controller board. The D/A circuit uses op-amp IC4-b, which is basically an inverting summing amplifier that adds the voltages from data bits DA0–DA5. The lower the amplifier input resistance, the higher the gain for that particular data bit line. The resistance (and gain) used to couple the six data lines to the input of the summing amplifier will vary by a factor of two. For instance, the resistance at DA0 (R12 and R20) will be twice as large as the resistance at DA1 (R6 and R14), which will be twice as large as DA2 (R7), etc. That allows the magnitudes of each binary number to be properly weighted with respect to each other. A small bias voltage is applied through R13 and R203 into the summing junction to force the D/A output to swing both positive and negative. Potentiometer R203 will adjust the level of the D/A

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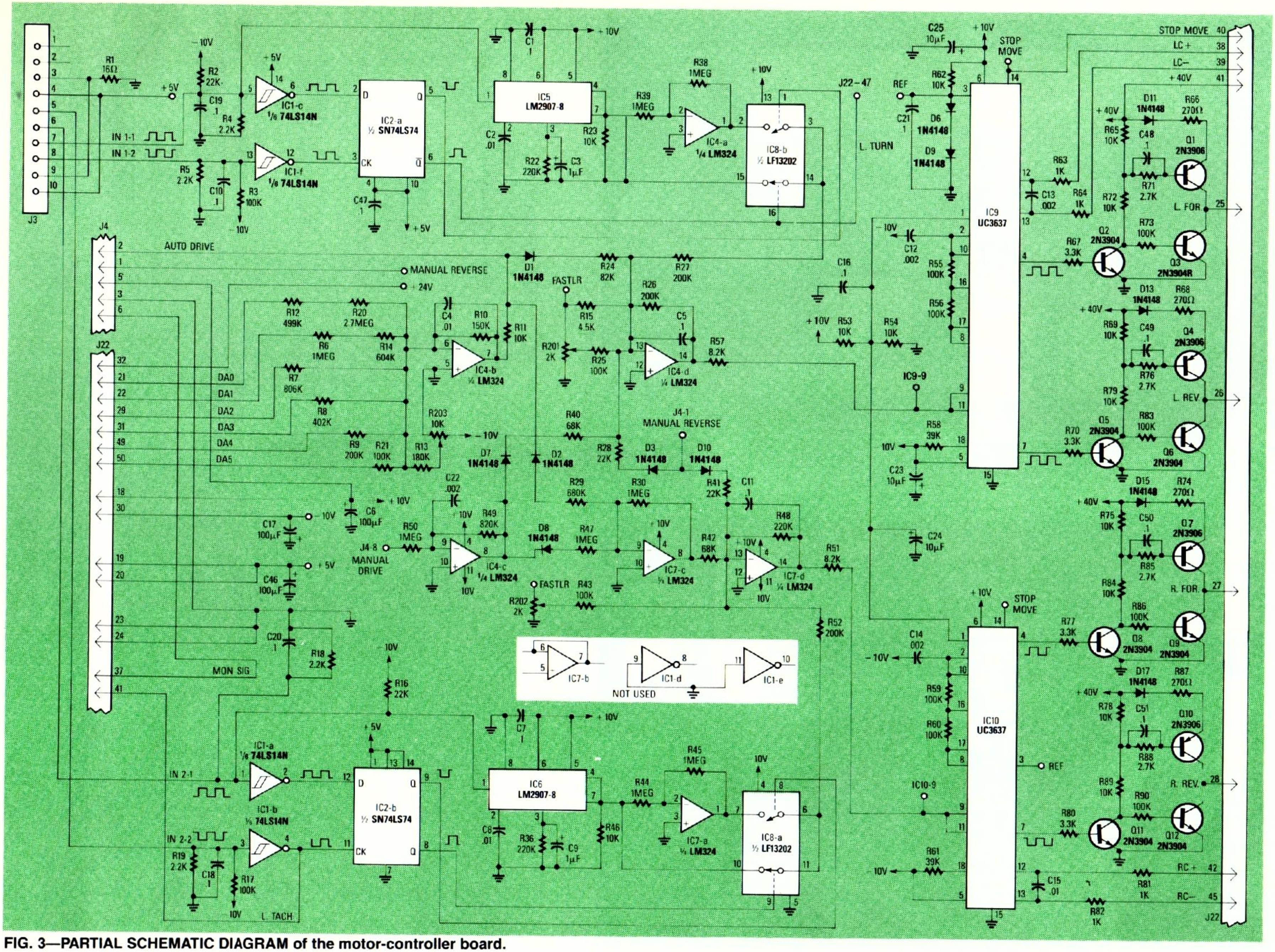

FIG. 3—PARTIAL SCHEMATIC DIAGRAM of the motor-controller board.

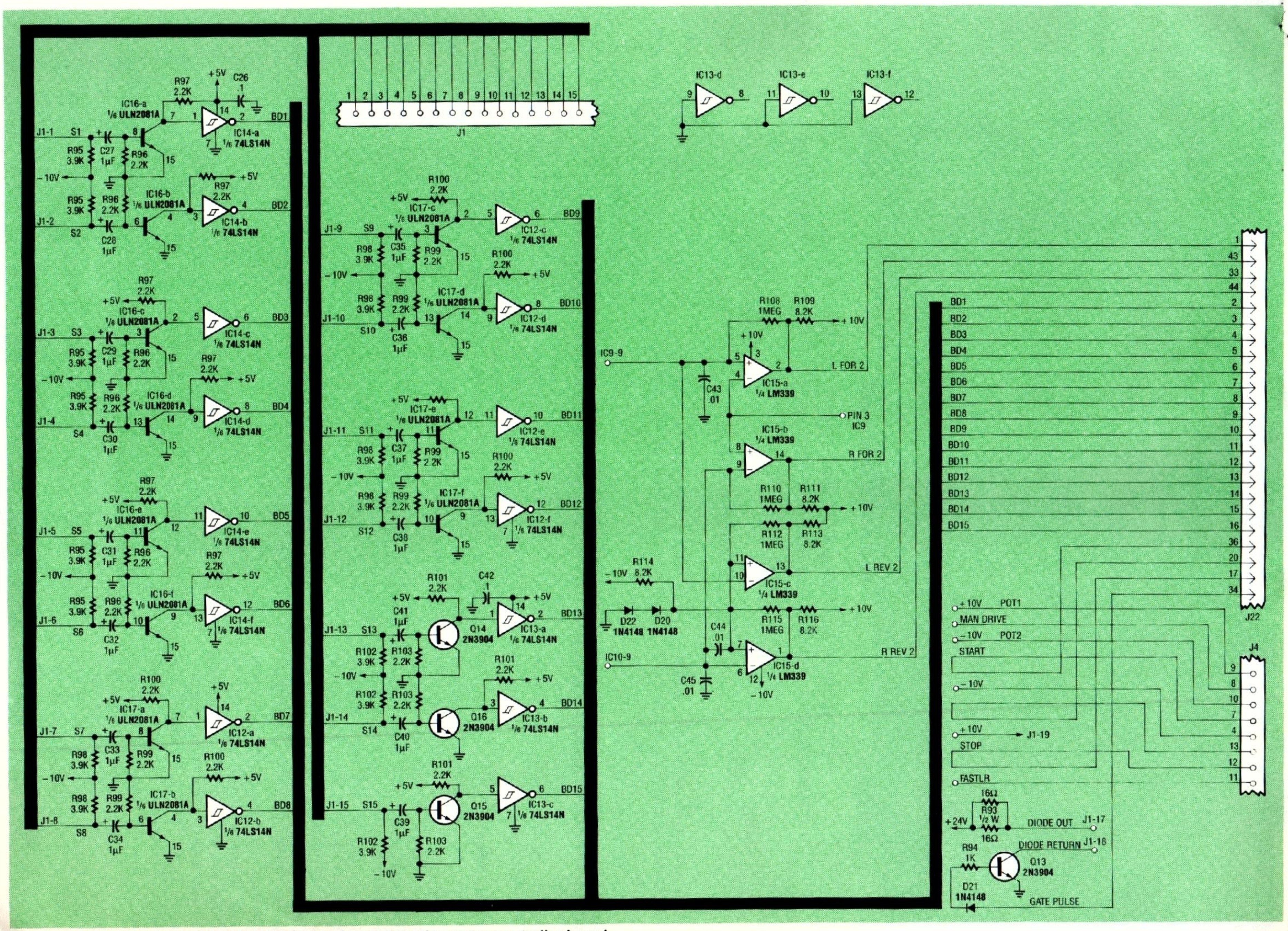

FIG. 4—THE GRASS-SENSOR AMPLIFIERS are located on the motor controller board.

LAWN MOWER

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output (pin 7 of IC4-b) in the positive direction by a few volts. Capacitor C4 is used to create a low-pass filter at the output stage of the D/A circuit. The D/A circuitry and the manual-control input (J4 pin 8) provide the steering input reference to the velocity-feedback loops.

Velocity-feedback loops

Each loop consists of a summing junction, amplifier, PWM, velocity feedback, tachometer circuitry, and inverter/switch. Since the right and left velocity-feedback loops are basically identical, we will discuss the details of the left velocity loop only. Op-amp IC4-d acts as the summing junction and amplifier. The steering reference signals are coupled to the op-amp's inverting input (pin 13) through resistors R24–R28 and R40. Capacitor C5 is used to create a low-pass filter at the amplifier's output (pin 14). After the signals are added and amplified, they are passed through R57 to IC9, a UC3637 *P*ulse *W*idth *M*odulator (PWM) IC, that sends PWM signals to the power board for running the drive motors.

Also contained on the motor-controller board are the grass-sensor amplifiers, which are shown in Fig. 4—

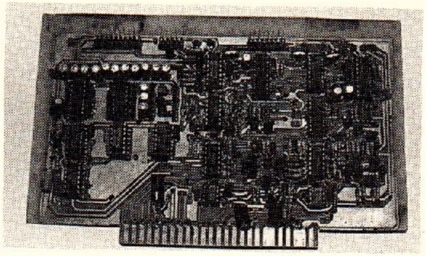

FIG. 5—THE MOTOR-CONTROLLER board fits in one of the motherboard's slots.

we will discuss them shortly. A photograph of the motor-controller board is shown in Fig. 5.

Within the motor housing is a chopper wheel that is used for sensing wheel (and motor) speed. The chopper wheel is shown in Fig. 6. The wheel has gear-like teeth that move through a dual opto-interrupter module as shown in Fig. 7. As the teeth

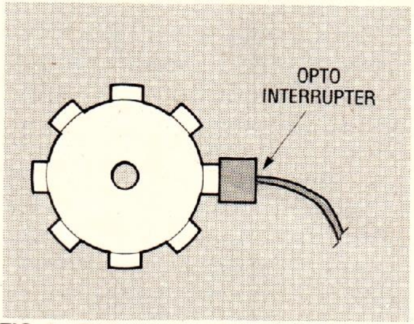

FIG. 6—THE CHOPPER WHEEL has gear-like teeth that move through a dual opto-interrupter module.

move through the opto module, they'll intermittently break the two light beams causing the module's internal phototransistor to turn on and off. The process creates two square-wave outputs, IN I-1 and IN I-2, that have pulse widths that are proportional to the speed of the chopper wheel, motor, and drive wheel. Since one light beam is broken before the other, IN I-2 will always lead IN I-1 in phase by 90 degrees when the motor is in moving in the forward direction. Figure 8 shows the two square-wave outputs from the dual opto-interrupter module. When the wheel spins in the reverse direction, the phase of the two square waves will switch. In that case, the square wave at IN I-1 will lead in phase by 90 degrees. That tells the motor-controller circuitry if the drive wheels are moving forward or backward.

The square-wave outputs for the left drive motor are fed to the motor controller board via J3, pins 7 and 8. The signals are buffered by inverters IC1-c and IC1-f and then sent to D-type flip flop IC2-a. The flip flop is used to determine motor direction; forward or reverse. Since the flip flop clocks in data during the 0-to-+5-volt transition at pin 3, 0 volts will be indicated at the Q output (pin 5) when the motor is moving forward. Conversely, +5 volts will be at the Q output when the motor is in reverse.

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LAWN MOWER

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The square-wave signal IN 1-1 is tapped off IC1 pin 5 and sent to IC5, a frequency-to-voltage converter that produces an analog voltage that represents wheel velocity from the square-wave frequency. The analog switch IC8, which is controlled by IC2-a, is used to select the forward and reverse velocity-feedback signals. When the motor spins in reverse, the velocity-feedback loop requires an inverted signal in order to maintain negative feedback; that inverted signal is produced by IC4-a.

Pulse-width modulators

The pulse-width-modulator function is performed by two UC3637 PWM IC's, IC9 and IC10. Pins 9 and 11 are the input to the PWM IC's, pin 4 is the "forward" output signal, and pin 7 is the "reverse" output signal. When the left wheel is moving forward, the analog input voltage to pins 9 and 11 will vary between +0.7 volts

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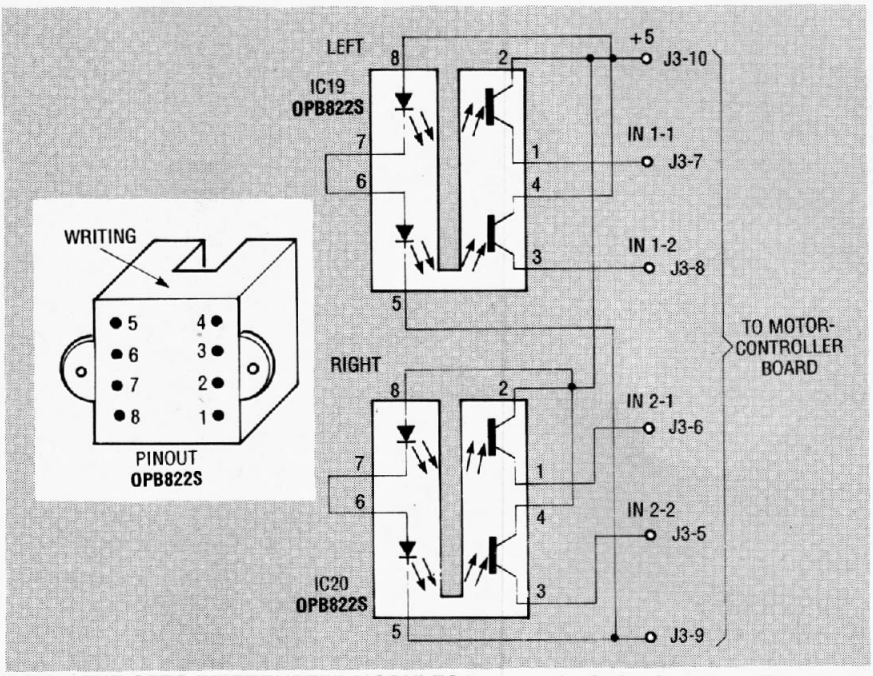

FIG. 7—THE OPTO-INTERRUPTER MODULES keep track of wheel movement.

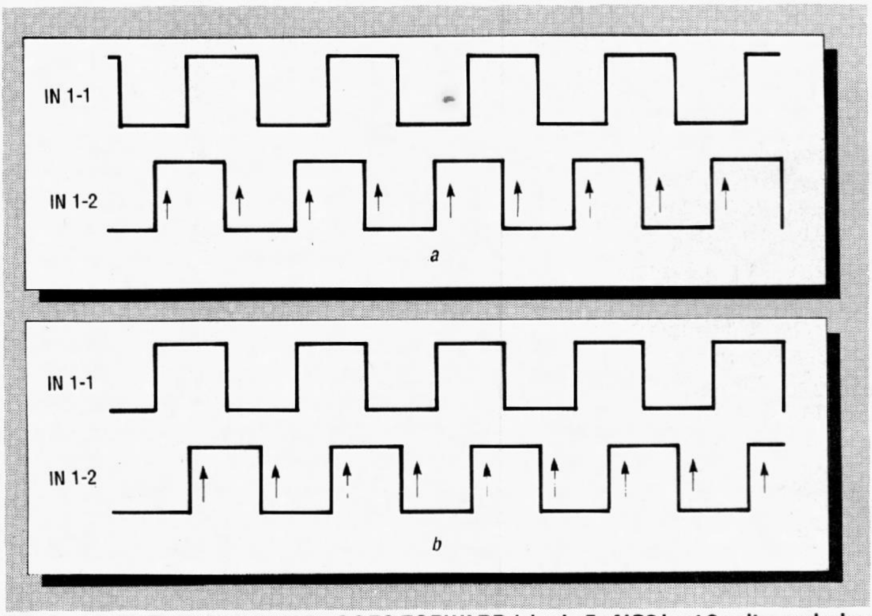

FIG. 8—WHEN THE LEFT WHEEL GOES FORWARD (*a*), pin 5 of IC2 is at 0 volts, and when the left wheel goes in reverse (*b*), pin 5 is at 5 volts.