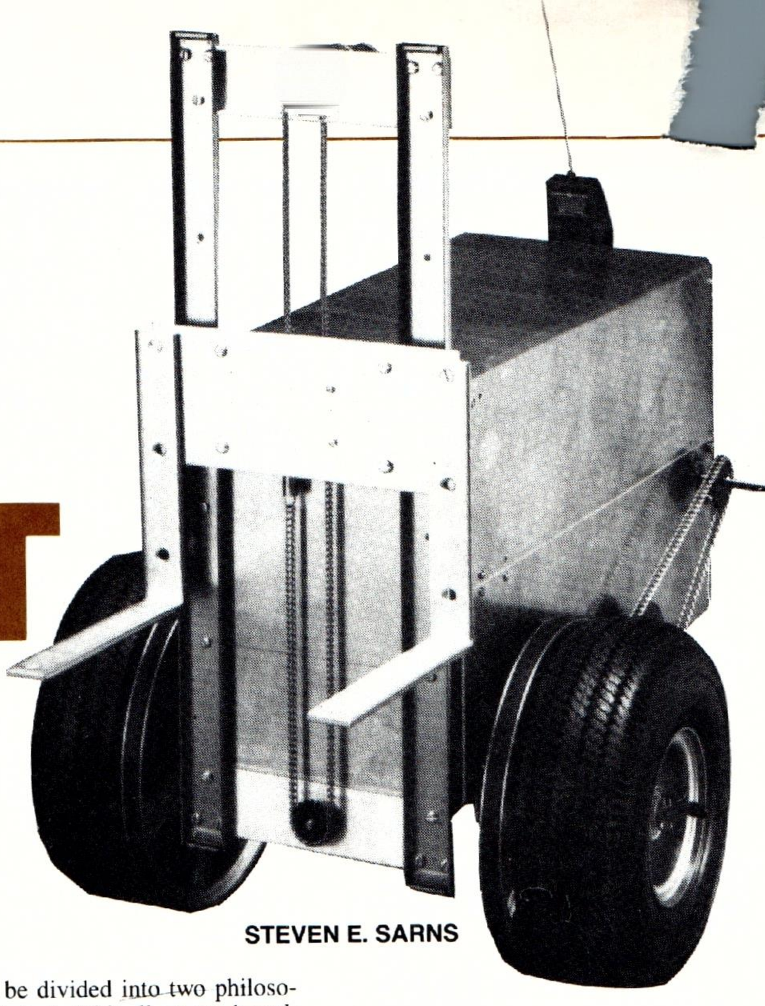
BUILD THIS

R-E ROBOT

An in-depth look at the robot's control electronics.



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Part 6 THIS MONTH WE TURN our attention to the robot's control electronics. All of the power and control circuits for the unit are located on a single control PC board. That includes the regulated power supplies, a "sleep" circuit to periodically start the robot's activities, a 16-channel 8-bit analog-to-digital converter, digital I/O as required, and the controllers for the two drive motors. The control board has a user connector, PL1, with 8 digital outputs, 4 digital inputs, and 8 analog inputs. A pinout of the user connector is shown in Table 1.

In addition, a simple 8-bit "RERBUS" (*R-E Robot BUS*) expansion bus, PL3, provides a method of integrating more elaborate projects into the robot's architecture. A pinout of the RERBUS connector is shown in Table 2.

Control architecture

There is an old Chinese proverb that says: "There are more ways than one to skin a cat...as long as you kill it first." So it is with the design of a sophisticated electronics project like the R-E Robot. We know many of the capabilities that we would like in the finished unit. We may even know the specific circuit-design approach that we will use. We also probably have several "gray areas" where not enough time has been spent at the test bench to convince ourselves that our first attempt will work.

There is also the future to consider: How are unforeseen changes in the design of the robot or its applications going to be accommodated? We are faced with a multitude of design decisions that will determine the character of the electronics.

The architectural design of the electronics can be divided into two philosophies: One is to build it all on one board; the other is to adopt a bus-oriented approach. The main advantage of the single-board approach is minimized cost. However, all risks are greater with that approach. Errors in design as well as adding future options or upgrades will all require a complete re-design. The bus approach will allow future expansion, but at an increased total system price (more boards to build).

The design approach used in the robot is therefore a combination of those two approaches. A single control board has

TABLE 1—USER-CONNECTOR PIN OUT (PL1)

Pin number	Function
1	+5 volts
2	+5 volts
3	analog channel 0
4	analog channel 7
5	analog channel 1
6	analog channel 3
7	analog channel 6
8	analog channel 5
9	analog channel 2
10	DO out
11	analog channel 4
12	D4 out
13	battery (unswitched)
14	D1 out
15	robot awake
16	D2 out
17	D4 in
18	D3 out
19	D5 in
20	D5 out
21	D6 in
22	D6 out
23	D7 in
24	D7 out
25	ground
26	ground

TABLE 2—RERBUS PIN OUT (PL3)

Pin number	Function
1	+5 volts
2	+5 volts
3	$\overline{WR}$
4	D7
5	$\overline{RD}$
6	D6
7	A1
8	D5
9	A0
10	D4
11	A2
12	D3
13	A3
14	D2
15	analog channel 15
16	D1
17	analog channel 14
18	D0
19	ground
20	ground
21	high-current ground (SPG)
22	high-current ground (SPG)
23	battery (switched)
24	battery switched)

PARTS LIST

All resistors ¼-watt, 5%, unless otherwise noted
R1, R4, R6, R7—not used
R2, R12, R16, R18–R20, R22, R23, R26–R28, R30, R34, R36, R37, R39, R41, R44—10,000 ohms
R3—62,000 ohms
R5, R9—15,000 ohms
R8—4700 ohms
R10—220 ohms
R11, R35, R42, R43—1000 ohms
R13, R14—1 megohm
R15, R38—47 ohms
R17, R24, R40—100 ohms
R21, R29—0.1 ohms, 5 watts, 1%
R25, R31–R33—100,000 ohms

Capacitors
C1, C2, C4, C5, C13–19, C22, C25, C27, C31—0.1 µF, monolithic ceramic
C3—100 pF, 50 volts, ceramic disc
C6, C10, C21, C30—2.2 µF, 50 volts, ceramic disc
C7—0.002 µF, 50 volts, ceramic disc
C8—330 pF, 50 volts, ceramic disc
C9—0.047 µF, 50 volts, ceramic disc
C11, C12—2200 µF, 25 volts, electrolytic
C20, C23, C24, C26—10 µF, 16 volts, electrolytic
C28, C29—not used

Semiconductors
IC1, IC2—4051 multiplexer
IC3, IC6—74LS541 octal buffer/line driver
IC4—74LS377 octal D-flip-flop
IC5—ADC0804 8-bit A/D converter
IC7, IC8—74LS374 octal D-flip-flop
IC9—L296 switching regulator (SGS)
IC10—74LS645 octal three-state bus transceiver
IC11—74LS125 quad three-state buffer
IC12—74LS266 quad 2-input exclusive NOR gate
IC13, IC14—8253 programmable interval timer
IC15—74LS32 quad 2-input OR gate
IC16—74ALS520 8-bit comparator
IC17—74LS164 8-bit serial-in/parallel-out shift register
IC18—74LS393 dual 4-bit binary ripple counter
IC19—74LS138 1-of-8 decoder
IC20—LM358 dual op-amp
IC21—74LS259 8-bit addressable latch
IC22—ULN2003 Darlington array
IC23, IC25—4046 PLL
IC24—74LS00 quad 2-input NAND gate
IC26—4060 14-stage ripple counter
IC27—4078 8-input NOR/OR gate
IC28, IC29—dual D-flip-flop
IC30—LM340-12 12-volt regulator
Q1, Q5—2N3906 PNP transistor
Q2, Q6—TIP29A NPN transistor
Q3, Q7—2N3772 NPN transistor
Q4—2N3904 NPN transistor
SCR1—C106Y1 (GE) SCR
D1, D3, D4, D9, D10—1N4001 rectifier
D2, D5, 1N5400 rectifier
D6, D7—1N4148 switching diode
D8—1N754 6.8-volt Zener diode
D11—8R05 Schottky diode (SGS)

Other Components
L1—300 µH
RY1–RY5—DPST relay, 12-volt coil, Fujitsu FBR-631D012 or equivalent
PL1, PL3—26-conductor plug, dual row, 0.025-inch spacing
PL2, PL6—10-conductor plug, dual row, 0.025-inch spacing
PL4—60-conductor right-angle plug, dual row, 0.025-inch spacing
PL5—2-conductor plug, single row, 0.025-inch spacing
TS1—6 connector terminal strip
B1—see text

Miscellaneous: PC board, IC sockets, heat sinks (Thermalloy 601 or equivalent for IC9, Thermalloy 286 or equivalent for IC30), mounting hardware, nuts, bolts, wire, solder, etc.

been designed that provides (together with the RPC—*R*obotic *P*ersonal *C*omputer) all of the functions required by the basic robot. The control board also provides two easy expansion opportunities—the user and RERBUS connectors—in addition to the RPC computer bus.

Before we get to the actual construction of the control board, let's look at some of the control and power circuits in detail. Refer to the schematic in Fig. 1 as we proceed. Note that the power and ground connections for the IC's are not shown in the schematic; where applicable, they are listed in Table 3.

Power supplies

Power-supply considerations are one of the toughest problems in robot design. Questions like the following must be considered and answered: Should the battery charger be onboard or remote? Should multiple supplies be provided? What range of DC inputs are to be accommodated? Should the power supplies be on a separate board?

The design we have chosen is an attempt to provide maximum flexibility for the user yet still use just a single, economical control board.

The 5-volt DC supply is the first section we will focus on. The expected current draw is about 3 amperes. If we use a linear regulator, more battery power will be wasted as dissipated heat than will be delivered to the computer and control circuitry; efficiency will be 21% at best! A switching regulator is called for.

The new SGS L296 switching regulator is ideal for our application; further, it is easy to use. The input voltage range is 8- to 50-volts DC, which allows us to use either one, two, or three 12-volt auto batteries in series to power the robot. The IC is capable of supplying a 5-amp output with full short-circuit and crowbar protection. The crowbar feature provides peace of mind. If anything in the power-supply circuit should fail and put more than 5.5 volts on the 5-volt DC bus, the SCR will trigger, short circuiting the bus to ground.

Speaking of ground, our design requires some special considerations. We will be switching up to 30 amperes at the motor controllers while trying to measure analog inputs as low as 20 mV. Meanwhile, our microprocessor system will be cooking along at 8 MHz. As you can see, we have created an ideal breeding ground for glitches, spikes, ground loops, cross coupling, and other mysterious bugs that can bring our system to its knees. Therefore, the concept of a *S*ingle *P*oint *G*round" (SPG) must be understood and used in our design.

If we simply connect everything labeled "ground" together on our PC layout, we will have ignored the fact that even the copper interconnections have

TABLE 3—IC POWER AND GROUND CONNECTIONS

IC number	Device type	Power pin number	Ground pin number
IC1, IC2	4051	16	8
IC3, IC6	74LS541	20	10
IC4	74LS377	20	10
IC5	ADCO804	20	10
IC7, IC8	74LS374	20	10
IC10	74LS645	20	10
IC11	74LS125	14	7
IC12	74LS266	14	7
IC13, IC14	8253	12	24
IC15	74LS32	14	7
IC16	74ALS520	20	10
IC17	74LS164	14	7
IC18	74LS393	14	7
IC19	74LS138	16	8
IC20	LM358	8	4
IC21	74LS259	16	8
IC23, IC25	4046	16	8
IC24	74LS00	14	7
IC26	4060	16	8
IC27	4078	14	7
IC28, IC29	74LS74	14	7

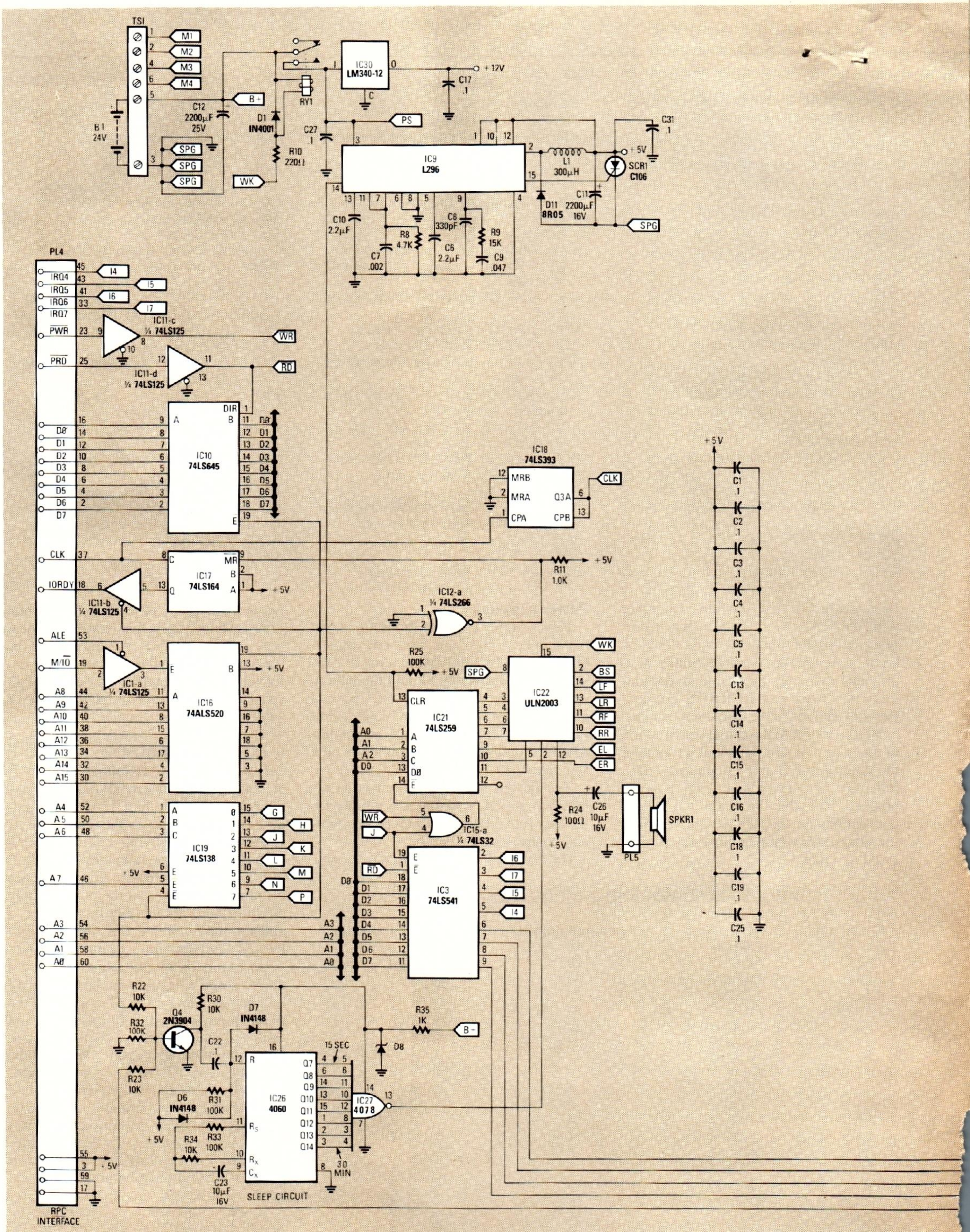
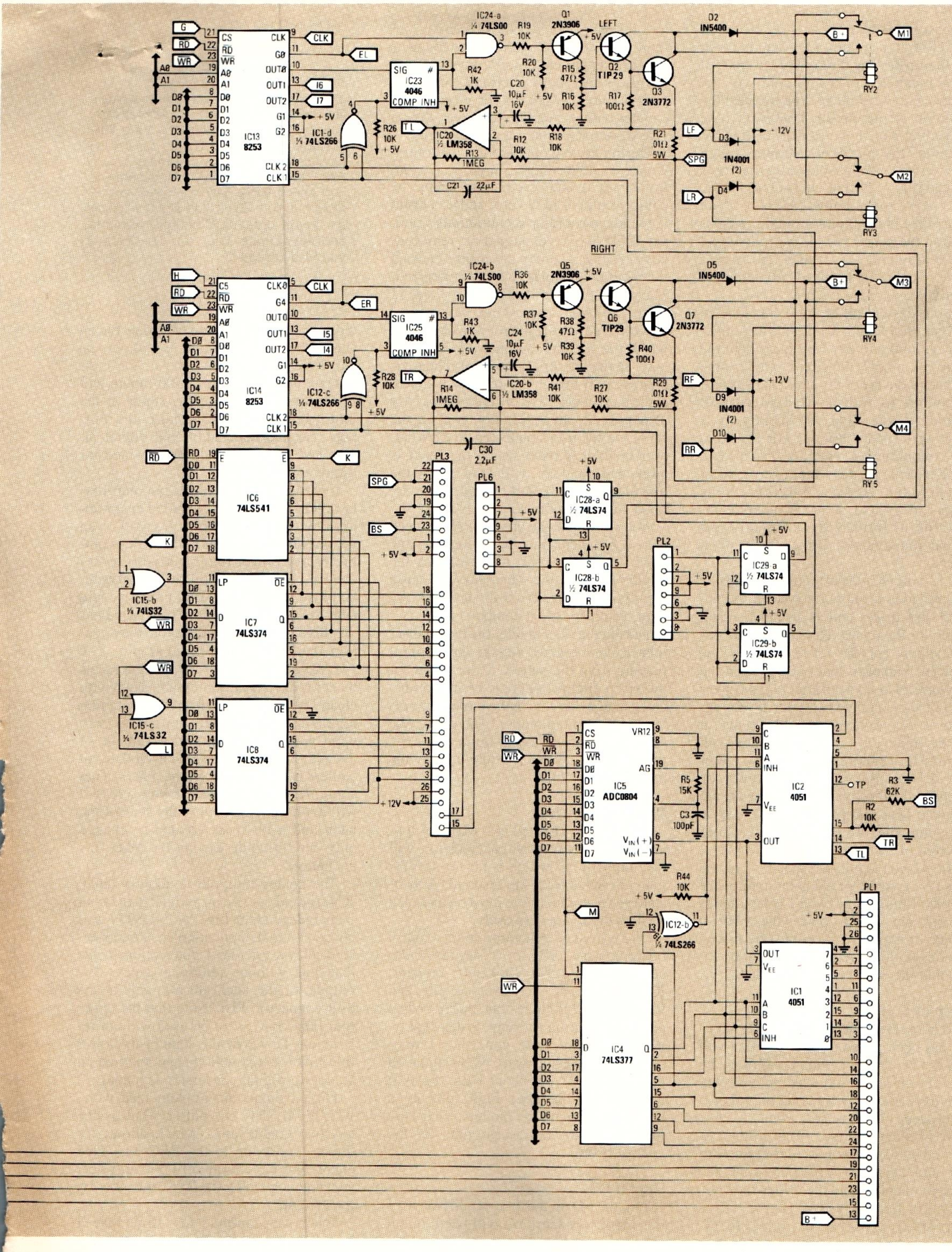


FIG. 1—THE R-E ROBOT'S CONTROL BOARD. Where applicable, power and ground connections for the IC's are listed in Table 3.


IC13 8253
IC14 8253
IC24-a ¼ 74LS00
IC24-b ¼ 74LS00
IC23 4046
IC25 4046
IC20 ½ LM358
IC20-b ½ LM358
IC1-d ¼ 74LS266
IC12-c ¼ 74LS266
IC12-b ¼ 74LS266
Q1 2N3906
Q2 TIP29
Q3 2N3772
Q5 2N3906
Q6 TIP29
Q7 2N3772
LEFT
RIGHT
D2 IN5400
D5 IN5400
D3 D4 1N4001 (2)
D9 D10 1N4001 (2)
RY2
RY3
RY4
RY5
M1
M2
M3
M4
IC6 74LS541
IC7 74LS374
IC8 74LS374
IC15-b ¼ 74LS32
IC15-c ¼ 74LS32
IC28-a ½ 74LS74
IC28-b ½ 74LS74
IC29-a ½ 74LS74
IC29-b ½ 74LS74
IC5 ADC0804
IC2 4051
IC1 4051
IC4 74LS377
PL1
PL2
PL3
PL6

some, albeit small, resistance. In a normal, all-digital system, a few hundreths of a milliamp flowing through a resistance of a few hundreths of a milliohm will not produce enough voltage drop to affect the operation of the circuit. However, if we are dealing with amperes instead of milliamperes, the problem becomes much more serious. We must identify the traces that carry large currents and connect those directly to some common point. That point is the single point ground, noted as SPG on the schematic. If we follow that rule throughout the design, the opportunities for ground-related problems are greatly decreased.

In our design, all of the points labeled SPG are tied together only at the single-point ground and nowhere else. If in the future you modify the circuit or add some peripheral device or circuit to the system, remember to return all high-current grounds to the SPG. Frequently, it is tempting to do otherwise. For instance, when mounting a regulator that uses a TO-220 package, it is tempting to connect the tab to the chassis and to connect the chassis to ground at some other point. Don't do it! Insulate the tab and tie the ground pin directly to the single point ground.

A 12-volt DC linear regulator, IC30, is also provided to supply power for the optional disk drives and as an independent supply for the relays. Having an independent supply for the relays prevents the inductive kickback that occurs when the relays are released from affecting the operation of the computer system. If the regulator is used only to power the relays, it can be mounted on the PC board with minimal heat sinking; if it will also power disk drives, the regulator should be mounted on the robot chassis to ensure adequate heat dissipation. We'll look at that again when we get to the actual construction of the board.

The 12-volt regulator specified in the Parts List is rated for a maximum input of 35 volts. If more than two 12-volt batteries in series are used to power the robot, a voltage-dropping resistor must be placed in series with the regulator's input to ensure that the rating is not exceeded.

Sleep circuit

To conserve battery power, a sleep circuit has been added to the robot that will shut it down when certain conditions are met. The circuit includes a timing mechanism to periodically wake up the robot.

The sleep circuit is built around IC26, a 4060 14-stage counter. The counter is clocked by its internal oscillator. Resistor R34 and capacitor C23 determine the clock frequency; with the values shown in Fig. 1 that frequency is 10 Hz.

A 4078 8-input OR gate, IC27, monitors the outputs of the 4060. Any time that all of the counter's outputs are all low, the OR gate activates the main power relay, RY1. Activating that relay connects the batteries to the power converters and energizes the robot's electronics and computer system. When one or more of the counter outputs are high, however, the OR gate de-activates the main power relay.

During normal operation, IC16 continuously resets the counter anytime the control board is addressed. That keeps the counter outputs all at zero, and as a result the main power relay is continuously activated. If the reset signal is removed, however, the counter advances, causing the main power relay to be de-energized. Therefore, the robot can be put to "sleep" simply by not addressing the control board. Once asleep, the robot will awaken when the counter outputs all return to zero. In the interim, if the control board is addressed by the RPC, a pulse will appear at the base of Q4, reseting the counter. It is also possible to externally awaken the robot via the user connector, PL1. Whatever method is used, when the robot is awakened the RPC will load all of the operating software and execute a pre-defined software routine.

You can adjust the duration of the sleep period by increasing or decreasing the clock frequency. The 10-Hz rate of the circuit shown in the schematic will cause the robot to be energized about once every hour, using specified components.

During the sleep mode, the main power relay is de-energized and the only current flowing from the battery is the power for the sleep circuit (a couple of milliamps) and leakage currents in the motor controllers (a few microamps). Therefore, the battery life during sleep is limited more by the battery's internal leakage than by the robot's power drain.

The RPC interface

The RPC is clocked at 8 MHz. A typical I/O access cycle at that clock rate will take only 12 ns, which is far too fast for many peripheral IC's to respond. A wait-state generator therefore must be included to slow the I/O access cycle.

The wait-state generator on the control board consists of IC16, a 74ALS520 decoder; IC17, a 74LS164 shift register; IC12, a 74LS266 exclusive NOR gate; and IC11, a 74LS125 three-state buffer. When an address within its range is detected by IC16, the wait-state generator immediately places a not-ready ($\overline{\text{RDY}}$) signal on the RPC bus. After about 1 μs, the shift register's output goes high, placing a ready (RDY) signal on the bus. That 1-μs interval is now the access time for the control board.

Digital I/O

Digital I/O is the first requirement of our robotic system. We will need digital outputs to enable the two motor controllers, four more to set forward or reverse direction of each motor, and one for an audio "beep." Four more digital outputs will be required to select the analog-multiplexer channel. Four digital inputs will be required to monitor the status of the motor controller's terminal-count outputs. Beyond that, additional digital inputs and outputs should be provided for future applications.

It is vital that the direction-control relays, RY2–RY5, not be enabled on power-up. Otherwise, the robot will set off on an uncontrolled jaunt until the RPC completes its power-on initialization sequence, loads the application software, and assumes control. That process could take as long as 30 seconds. That means that IC21, the latch used to store the direction data, must have a clear pin. The 74LS259 used for that application meets that criteria; it is an addressable latch with clear. The reset output from the switching regulator initializes all outputs to zero upon power up. An added advantage of the addressable latch is that each data-bit address is independent of the others. That simplifies software because now a record will not have to be kept of the state of the latch and a bit mask created to change only one bit while leaving the other bits unchanged.

The analog-multiplexer-address latch, IC4, should operate on parallel data rather than independent bits. A 74LS377 was chosen for that application because its design allows for direct connection to the data bus without additional gates. The outputs of the latch are available at the user connector, PL1. Note that the upper four bits, Q4–Q7, can be used without restriction. However, the state of the lower four bits (Q0–Q3) will change anytime an analog-to-digital conversion is made.

Digital inputs are implemented using IC3, a 74LS541 bus buffer. That device has two enable pins, which allows for direct connection to the RPC bus. One enable pin is controlled by a chip-select signal generated by the RPC, the other by the $\overline{\text{RD}}$ line.

When we continue next time, we'll look at the analog-to-digital converter, the RERBUS interface, and more. **R-E**

SOURCES

The following are available from Vesta Technology, 7100 W 44th St., Wheatridge, CO 80033 (303-422-8088): Bare RE-Robot controller board, $41; assembled and tested RE-Robot controller board, $200; bare RPC board, $41; assembled and tested RPC, fully populated for the robot function, $294. Add $8.00 shipping per board ordered. Colorado residents add appropriate sales tax. Mastercard adn Visa accepted.

PC SERVICE

BECAUSE THE CIRCUIT BOARD FOR THE robotics-control computer will not fit on the pages of Radio-Electronics, the component side is shown here half sized. The solder side of the board will be shown next month. For those interested in receiving full-size photostats of both sides of the board, simply send a self-addressed, stamped envelope to:

Radio-Electronics
Dept PC
500-B Bi-County Boulevard
Farmingdale, NY 11735