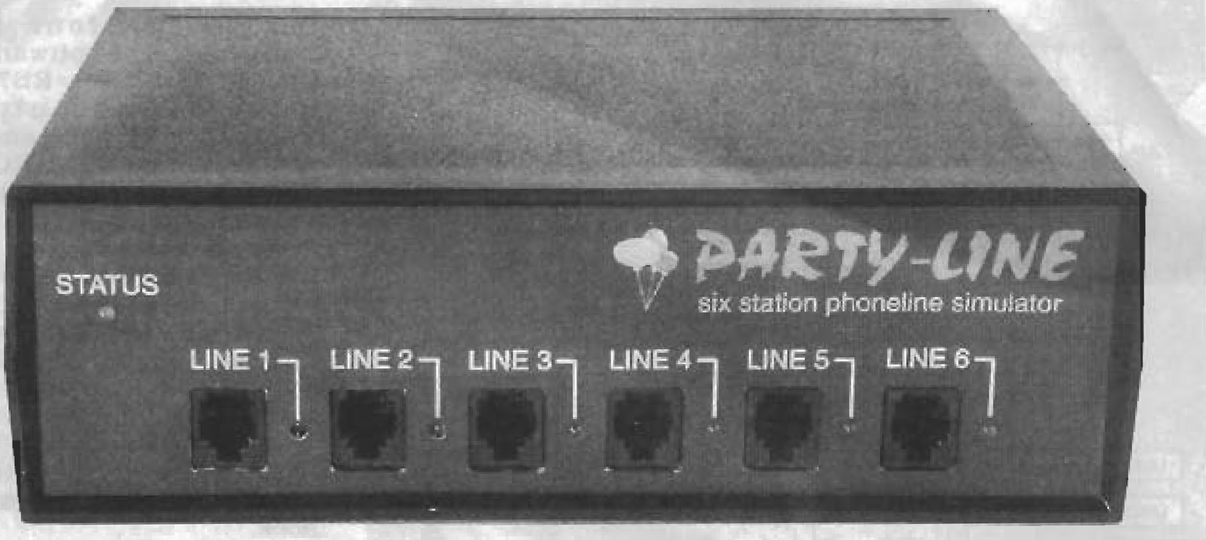

BUILD THE PARTY LINE

Construction and configuration details for a super-slick phone-line simulator.

THOMAS E. BLACK

LAST TIME WE PRESENTED AN OVERview of Party Line, an inexpensive phone-line simulator that provides authentic dial, ring, and busy signals, supports Caller ID and Distinctive Ringing, and can even be used as the hub of a six-line intercom system. For a detailed description of features and functions, as well as an overview of how it works, see last month's issue.

This month we'll dive right into the details of how it works. Recall that the circuit consists of five major sections: Input, step-up, microcontroller, DTMF decoder and call-progress generator, and power. Also, there are three separate grounds (analog, digital, and high-current), which unite at the power supply.

MCU circuit and software

Figure 3 shows the microcontroller (MCU) portion of the circuit. A PIC16C57 provides all system intelligence. The PIC is a member of Microchip Technology's family of high-performance, low-cost, 8-bit microcontrollers. Features include 2K of ROM, 72 bytes of RAM, 20 digital I/O pins, and very low power consumption—all in a compact 28-pin package. For more information on the PIC family, contact Microchip Technology, Inc., 2355 West Chandler Blvd., Chandler, AZ 85224-6199. Tel: (602) 963-7373, Fax: (602) 899-9210.

The MCU's internal ROM holds the software—more accurately, *firmware*—that controls Party Line. (Firmware is nonvolatile, which means that it isn't lost when power is turned off). Firmware-controlled functions such as Ring Generation, Tone Detection, and Relay Control are event-driven, so all features work together seamlessly. Unlike simple loop-controlled programs, Party Line's design uses a time-based task scheduler to control hardware operation.

Programming the microcontroller with the Party Line firmware requires special equipment. If you don't have access to the requisite equipment, pre-programmed MCUs are available as mentioned in the Parts List.

The firmware is copyright protected and is not public domain—it cannot be freely copied or distributed. However, you can use the PL6.OBJ software in your personal project at no charge just by downloading it from the Gernsback BBS. You will find it under the name PL6.ZIP. Please review the Hobbyware information included in the companion README.TXT file for full details about using the firmware in your personal project.

Time and date

Time information broadcast by the Caller-ID function comes from a software-maintained 24-hour clock. Unlike your personal computer, Party Line does not use a dedicated chip to maintain time. Instead, a one-second counter is obtained using the MCU's internal counter and dividing the oscillator frequency. The hour and minute data is derived from the counter. The real

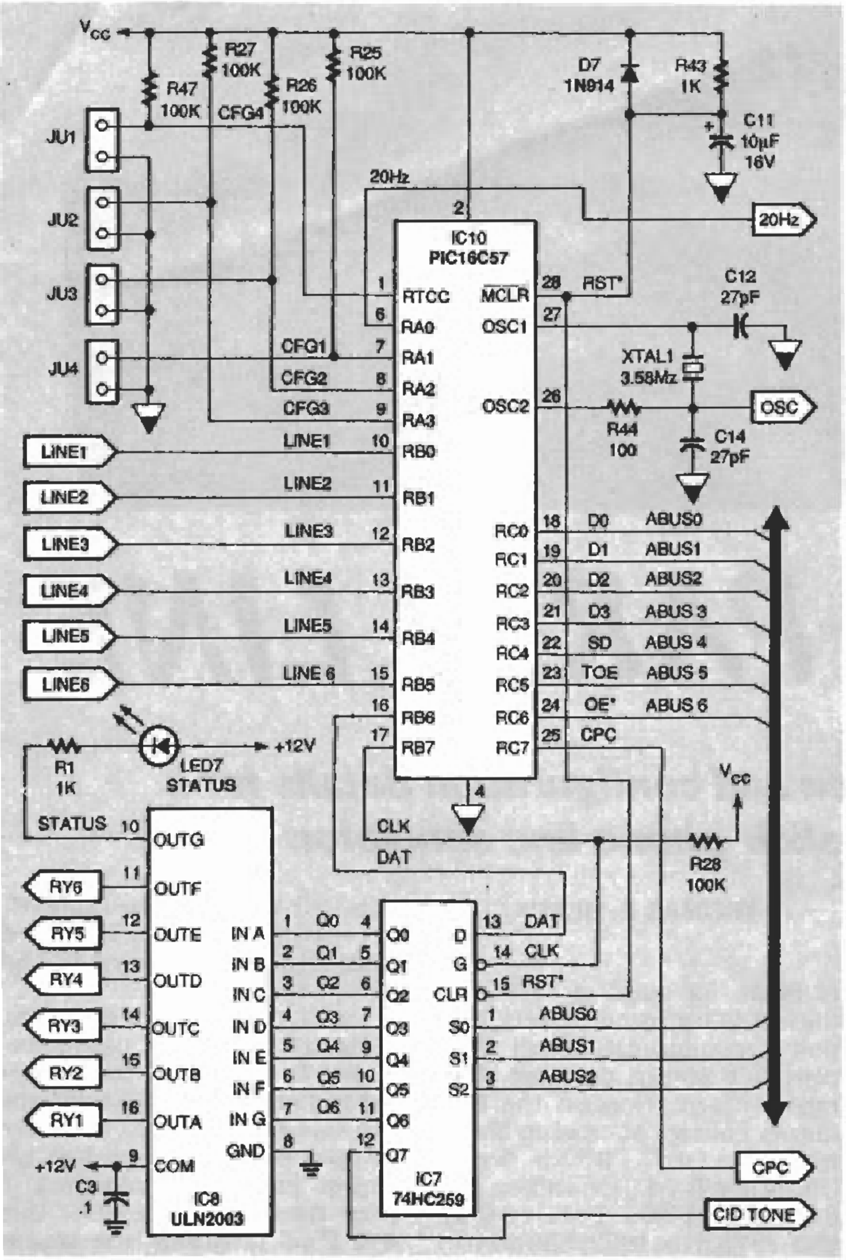

FIG. 3—THE MICROCONTROLLER reads line status from all six stations and controls their connections to the talk and ring circuits.

time clock function has been included so that you can experiment with Caller-ID products, but the clock is not designed as a precision timepiece; it may gain or lose a few seconds each day.

Unfortunately, because of limited ROM space, we were unable to include a date-tracking function. Thus, if you want the Called-ID date display to show the correct date, you must manually update the date on a daily basis.

Because the time (and date) information is stored in the MCU's volatile RAM, it will be lost whenever the MCU resets, such as when AC power is lost. The default date is Jan 1, and the default time is 12:00 am.

I/O control

The MCU's I/O lines monitor the hookswitch- and DTMF-decoder signals, operate the six line relays, and control the call-progress tone generator.

The twenty I/O lines consist of three port groups, A, B, and C. Ports B and C have eight lines apiece (RB0–RB7 and RC0–RC7, respectively), and Port A has four lines (RA0–RA3). The software configures RA0, RB6, RB7, and RC5–RC7 as outputs; RA1–RA3, RB0–RB5, and RC4 as inputs; and RC0–RC3 are used bidirectionally. A special MCU input signal, RTCC, is normally used as a counter input, but a software trick allows it to be used as an additional input port for configuration control.

In conjunction with RTCC, the RA1–RA3 inputs determine start-up configuration values, and RB0–RB5 monitor the optoisolated loop detectors that indicate when a phone goes off-hook.

The RC0–RC3 lines form a miniature data bus for reading DTMF codes from IC15 (Fig. 7), writing call-progress tone codes to IC14, and writing relay codes to IC7, an eight-bit addressable latch. In addition, MCU outputs RB6, RB7, RC5, and RC6 form the control signals for the bus; their job is to ensure that the correct data is read from or written to the right place at the right time. For example, to output a bit to the addressable latch (IC7), you would place data (0 or 1) on MCU signal RB6, the address (0–8) of the desired latch on RC0–RC2, and then toggle RB7 low.

Control line RC5 triggers a read of DTMF values from IC15, and RC6 latches call-progress tone codes into IC14. The RC4 input is normally low; the DTMF decoder drives it high when it detects a valid signal.

The last I/O bit to discuss is RA0. Its job is to provide the 20-Hz ring signal used by the step-up circuit. Low-end telephone simulators often use a 60-Hz ring signal because it is easily derived from the AC power line. However, some phone equipment will not operate correctly with a 60-Hz signal. To ensure compatibility, we use an accurate, software-generated ring signal.

The ring signal generated by the MCU must be isolated and stepped up to drive the telephone line talk circuit. As shown in Fig. 4, the high voltage is generated by push-pull

Continued on page 71

PARTY LINE

continued from page 36

power transistors Q1 and Q2, which in turn drive step-up transformer T1. Note that T1 is used "backward:" its low-voltage secondary is driven, and its output is derived from the high-voltage primary. The output of T1 is about 90 volts AC. Ideally, that output would be a clean sine wave. Although most equipment will not be bothered by the harmonics present in the T1 output, there is a possibility that some might be.

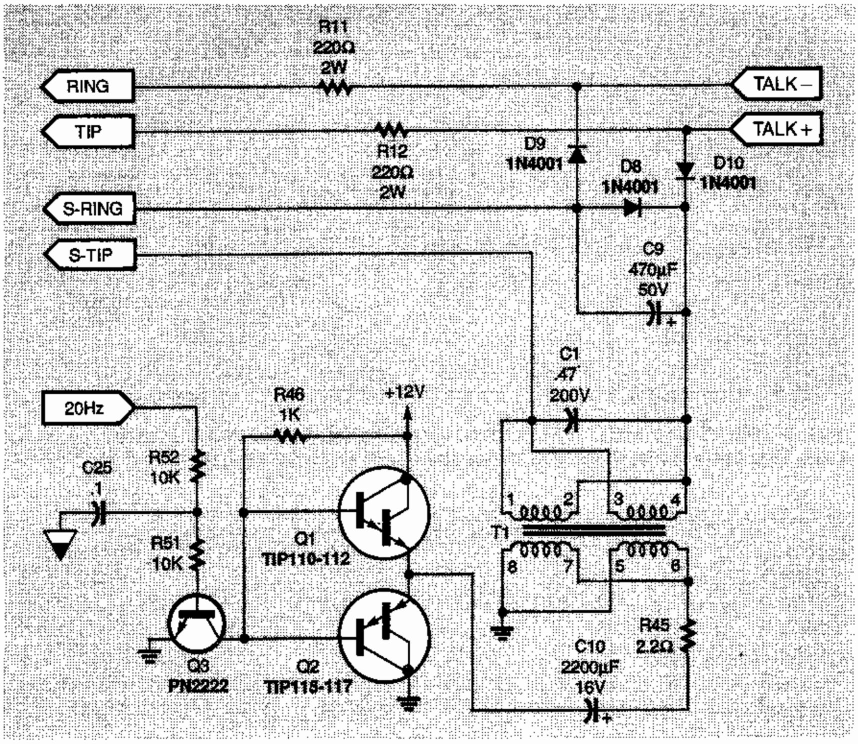

FIG. 4—THE STEP-UP CIRCUIT creates a 90-volt AC ring signal by driving transformer T1 via push-pull amplifier Q1 and Q2. The 20-Hz signal is generated under software control by the microcontroller.

Caller ID modulator

Caller-ID delivers its information in a 1200 bit-per-second (bps) serial modem-tone format formally known as Bell 202. Under Bell 202, a high is a 1200-Hz tone, a low is a 2200-Hz tone, and the nominal signal level is −13.5 dBm.

Party Line uses a clever technique to reproduce these modulated tones. Instead of a traditional hardware-based solution, a software process called *bit-banging* creates the tones. Bit-banging can often both improve reliability and reduce cost in comparison with hardware methods. Under MCU control, the high bit of addressable latch IC7 (returning to Fig. 3) is used to create the Caller-ID (CID) tone.

In operation, Party Line waits for the first ring, temporarily removes the caller's phone from the talk path (via the line relays), then carefully manipulates IC7's Q7 output to con-

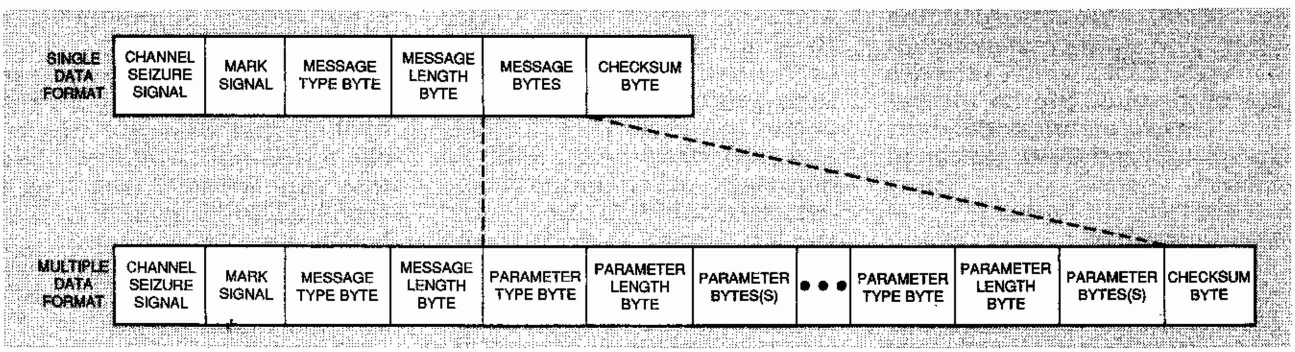

FIG. 5—CALLER-ID MESSAGE FORMATS ARE VERY SIMILAR. The Single Data Message Format includes a single message; the Multiple format inserts multiple messages in the parameter block used by the simple message.

TABLE 4—CALLER ID MESSAGE FORMAT

Message	Description
Power Ring	Not shown. The first ring is called the power ring. It is used to get the attention of the Caller-ID receiver. The ring is followed by 500 ms of silence.
Channel Seizure	Sync bytes, consisting of 30 ASCII U's (250 ms duration).
Mark Signal	1200-Hz marking tone, 150 ms duration.
Message	Message (or parameter) type, length, message bytes, and checksum.
Post-Msg Mark	After message data, an 80 ms mark tone is sent (optional).
Post-Msg Silence	All tones must end at least 475 ms before the next ring.

struct the modulated tones. Although the required frequencies are fairly low, the software keeps the MCU quite busy while generating the tones.

There are two CID data formats, as shown in Fig. 5. The two are very similar, except that the expanded format essentially embeds multiple data items in the position of the single data item of the simple format. Table 4 outlines the meaning of each field of the message.

CID data is transmitted unidirectionally. In addition, the receiver makes no attempt to acknowledge message receipt. Those limitations prevent the receiver from recovering from an erroneous transfer, so even minor transmission errors usually cause the loss of all CID information.

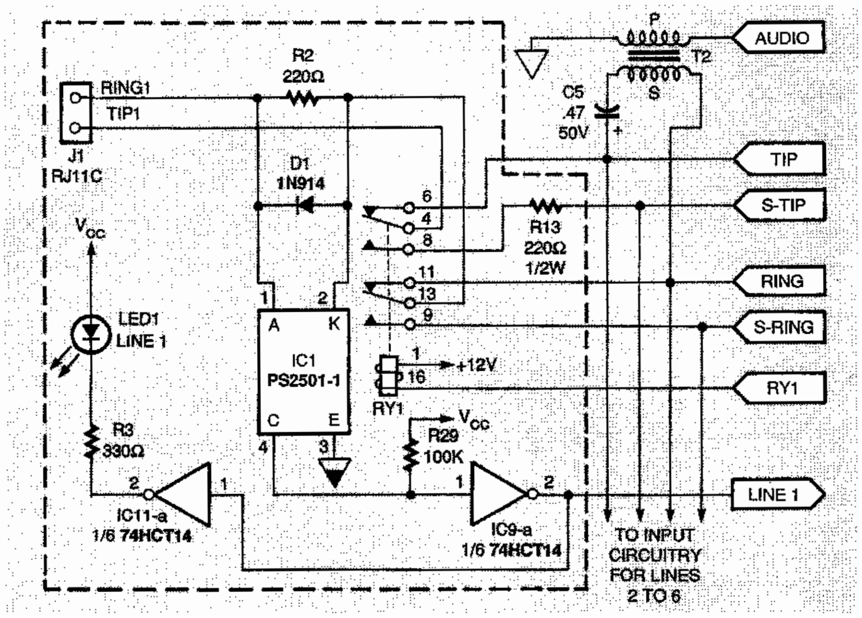

FIG. 6—INPUT CIRCUITRY: Note that everything inside the dashed lines repeats for each input line. Table 6 correlates the parts across all six circuits.

TABLE 6—LINE INPUT COMPONENTS

Line 1	J1	R2	D1	IC1	LED1	R3	IC11-a	R29	IC9-a	RY1	R13
Line 2	J2	R4	D2	IC2	LED2	R5	IC11-b	R30	IC9-b	RY2	R14
Line 3	J3	R16	D3	IC3	LED3	R17	IC11-c	R31	IC9-c	RY3	R15
Line 4	J4	R6	D4	IC4	LED4	R7	IC11-d	R32	IC9-d	RY4	R18
Line 5	J5	R8	D5	IC5	LED5	R9	IC11-e	R33	IC9-e	RY5	R19
Line 6	J6	R10	D6	IC6	LED6	R21	IC11-f	R34	IC9-f	RY6	R20

Relay drive

Returning again to Fig. 3, a ULN2003 drives the line-control relays. That IC has an array of seven independent high-gain Darlington NPN transistors, each of which includes an internal diode to prevent EMF damage.

Whenever one of IC8's inputs goes high, the corresponding output provides a return path for the coil of the corresponding relay. The seventh Darlington controls LED7, which provides status display. Status indications corresponding to different operating conditions appear in Table 5.

Input circuitry

Figure 6 brings together several strands of the circuit sections that have been discussed so far. Note that only one of six identical circuits is shown (the part within the dashed lines); Table 6 shows corresponding part numbers for all six stations. Note that there is only one set of audio-coupling devices (C5 and T2) for all six stations. Also, the four lines carrying tip and ring signals form a mini "bus" to which all stations attach in parallel. In contrast, each station has its own line-active indicator (e.g., LINE1) and relay driver (e.g., RY1). As discussed earlier, the LINEx signals drive the MCU directly, and the RYx signals come from the ULN2003 shown in Fig. 3.

TABLE 5—LED STATUS

State	Description
Steady On	Power is on and unit is ready
Flashing	Station is ringing
LED Off	DTMF digit is being dialed

Each station contains a loop detector circuit based on an optoisolator. The optoisolator (IC1) acts as a normally open switch that closes when a telephone goes off-hook. When that happens, current will flow through the optoisolator's input, which in turn forces its output low. That signal is then buffered and inverted by one section of a hex Schmitt trigger (IC9-a), and it is that signal that informs the MCU that a station is active. That same optoisolated and buffered signal also drives an LED (LED1) that provides visual indication when a station is active. If a telephone is plugged in, the indicator also flashes during the ring cycle. If a telephone is not plugged in, the indicator does not flash.

The loop detector circuit can detect a phone that goes off-hook during an active ring cycle, a desirable function called *ring trip.* Without ring trip, a very loud 20-Hz buzz would be heard when you answered a ringing phone. Ring trip is commonly available only on expensive phone-line simulators.

When a phone line is idle, the corresponding relay is energized. That removes each idle station from the talk path (Tip and Ring) and places it across the ring circuit (S-Tip and S-Ring) in preparation for a future ring cycle. During the active portion of a ring cycle, the MCU removes all idle stations—except for the station that is ringing—from the T1 circuit, and places them on the talk path. If you listen carefully, you can hear the relays deenergize during the ring cycle.

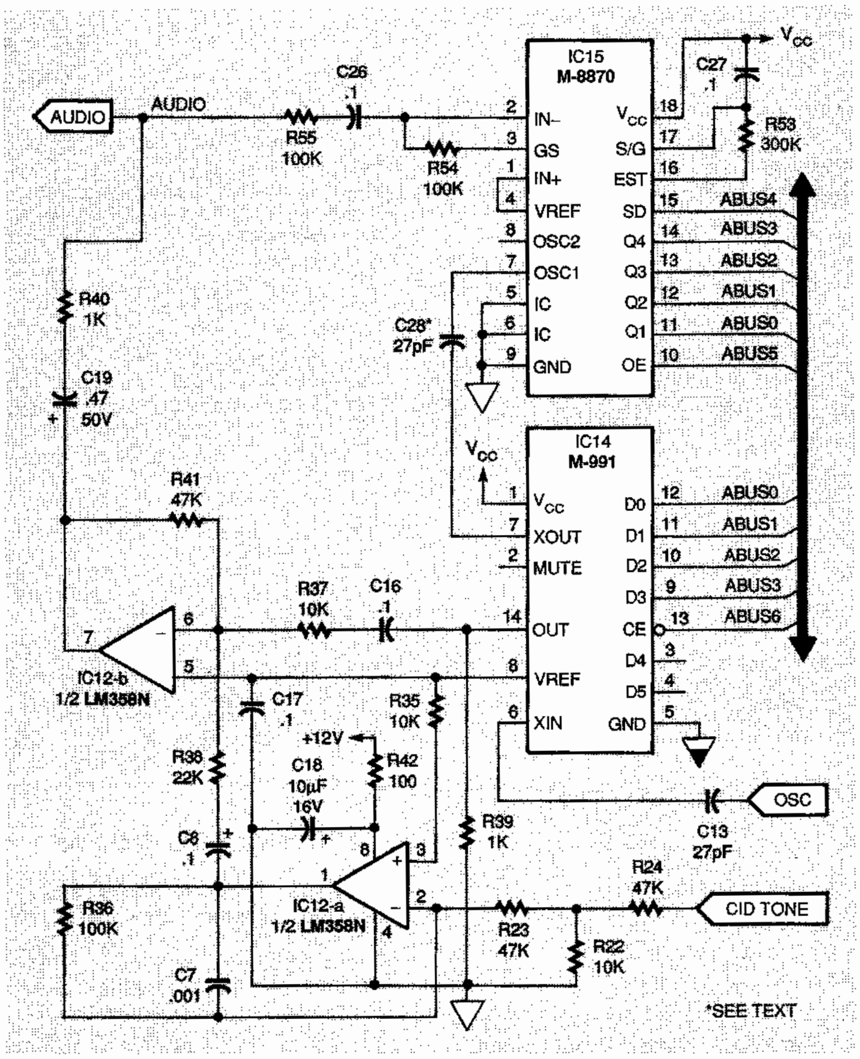

FIG. 7—TONE DETECTION AND GENERATION: IC14 generates one of several call-progress tones as determined by the binary input on its D0–D5 inputs. IC15 decodes DTMF tones and delivers them to the MCU via the 6-bit bus.

TABLE 7—DTMF CODES

Digit	D3	D2	D1	D0
1	0	0	0	1
2	0	0	1	0
3	0	0	1	1
4	0	1	0	0
5	0	1	0	1
6	0	1	1	0
7	0	1	1	1
8	1	0	0	0
9	1	0	0	1
0	1	0	1	0
*	1	0	1	1
#	1	1	0	0

When a station goes off-hook, the MCU deenergizes the associated line relay, which places that station on the talk path. Unless you like talking to yourself, at least two stations must be off-hook for you to carry on a conversation.

Tone decoding

Figure 7 shows how Party Line decodes incoming DTMF signals, encodes outgoing call-progress tones, and filters the MCU-generated 20-Hz ring signal.

Through use of a highly integrated DTMF tone receiver, decoding the dialed phone number is simple. Party Line uses the popular M-8870 (IC15), which is made by Teltone Corporation, Mitel Semiconductor, and others. The M-8870 decodes only DTMF telephone codes; it ignores rotary and pulse dialed digits. Because the M-8870 is crystal controlled, there are no adjustments to make. The IC incorporates switched-capacitor filtering to separate groups of tones.

Table 7 shows the binary code delivered by each telephone key. The DTMF encoding standard defines up to sixteen dual-tone combinations, but standard phones generate only twelve of them. The twelve keys appear in a matrix measuring four rows by three columns; those in a given row or column have one tone in common. Table 8 shows the row-column arrangement along with corresponding tones. Note: In 16-digit DTMF, there is an eighth tone (1633 Hz), which is not shown.

For example, if you press the "3" key, the phone generates 697- and 1477-Hz tones. Seven frequencies are involved in standard DTMF generation, and they are separated into two groups. The row information is called the low group; it has frequencies 697–941 Hz. The column information is called the high group; it has frequencies 1209–1477 Hz.

The codes get to the Microcontroller via bus lines ABUS0–ABUS3. The MCU periodically monitors bus line ABUS4; when it goes high, the MCU then reads the binary code from IC15. The software must decide if the tone code is new, because holding down a key will cause the tone code to be read about two hundred times per second. The software records the dialed digits as they are entered; when enough digits have been entered, the MCU starts ringing the station corresponding to the dialed number.

TABLE 8—DTMF TONES

	High Group		
Low Group	Column 0 1209 Hz	Column 1 1336 Hz	Column 2 1477 Hz
Row 0, 697 Hz	1	2	3
Row 1, 770 Hz	4	5	6
Row 2, 852 Hz	7	8	9
Row 3, 941 Hz	*	0	#

PARTS LIST

All resistors are ¼-watt, 5%, unless otherwise noted.
R1,R39,R40,R43,R46—1000 ohms
R2,R4,R6,R8,R10,R16—220 ohms
R3,R5,R7,R9,R17,R21,R48—330 ohms
R11,R12—220 ohms, 2W, 5%, metal oxide
R13–R15,R18–R20—220 ohms, ½W
R22,R35,R37,R50–R52—10,000 ohms
R23,R24,R41—47,000 ohms
R25–R34,R36,R47,R54,R55—100,000 ohms
R38—22,000 ohms
R42,R44—100 ohms
R45—2.2 ohms
R49—470 ohms
R53—300,000 ohms

Capacitors
C1—0.47uF, 200V, metalized polyester
C2–C4,C6,C8,C15–C17,C25–C27—0.1uF, 50V, monolithic, radial
C5,C19,C20—0.47uF, 50V, electrolytic, radial
C7—0.001uF, 50V, polyester, radial
C9,C24—470uF, 50V, electrolytic, radial
C10—2200uF, 16V, electrolytic, radial
C11,C18,C22,C23—10uF, 16V, electrolytic, radial
C12–C14,C28—27pF, 100V, COG ceramic
C21—1000uF, 25V, electrolytic, radial

Semiconductors
D1–D7—1N914 signal diode
D8–D13—1N4002 rectifier, 1A, 100V
BR1—50V, 1A, W005 or equiv.
LED1-LED7—Green LED, 3mm
Q1—TIP110 NPN Darlington transistor
Q2—TIP115 PNP Darlington transistor
Q3—PN2222A NPN transistor
IC1–IC6,IC13—Optoisolator, NEC PS2501-1 or equiv.
IC7—74HC259 or 74HCT259 addressable latch
IC8—ULN2003 Darlington array
IC9,IC11—74HC14 or 74HCT14 hex inverter
IC10—PIC16C57-XT/P 8-bit Microcontroller, Microchip Tech.
IC12—LM358N dual low-power op-amp
IC14—M-991 Call progress tone generator, Teltone Corp.
IC15—M-8870 DTMF decoder, Teltone Corp.
IC16—LM317T adjustable regulator
IC17—LM7812 or LM78M12, 12V regulator
IC18—LM7805 or LM78M05, 5V regulator

Other components
F1—0.5A, 5 × 20mm fuse
J1–J6—Modular RJ11, 6/2 or 6/4 receptacle, PCB Mount
J7—1 × 3, 0.1-inch female header
JU1-JU4—4 × 2, 0.1-inch pin header with shorting blocks
JU5—See text
P1—1 × 3 0.1-inch pin header
XTAL1—3.5795 MHz, HC18
RY1–RY6—DPDT, 12V, DC, 16–20mA coil, DIP package (OMRON G6A-234P-ST15-US-DC12 or equiv.)
T1—Transformer, split bobbin, dual 115-VAC to dual 6.3-VAC, 2.5VA (Prem SPW401D, Magnetek/Triad FS12-200, or equiv.)
T2—Telephone coupling transformer, 600:600 (PREM SPT130, Mouser TL016, or equiv.)
T3—Power transformer, 28VAC center tapped, 300mA

Miscellaneous
IC sockets, 4/40 hardware, TO-220 heatsinks (2 each for IC17 & IC18), AC power cord, 2.5-inch H × 8-inch W × 6-inch L plastic enclosure, PC board, IC sockets, solder, wire, etc.

TABLE 9—CALL PROGRESS CODES

Tone	Frequency	D3	D2	D1	D0
Dial	350/440	0	0	0	0
Special	400/off	0	0	0	1
Alert	440/off	0	0	1	0
Ring	440/480	0	0	1	1
Busy	480/620	0	1	1	0

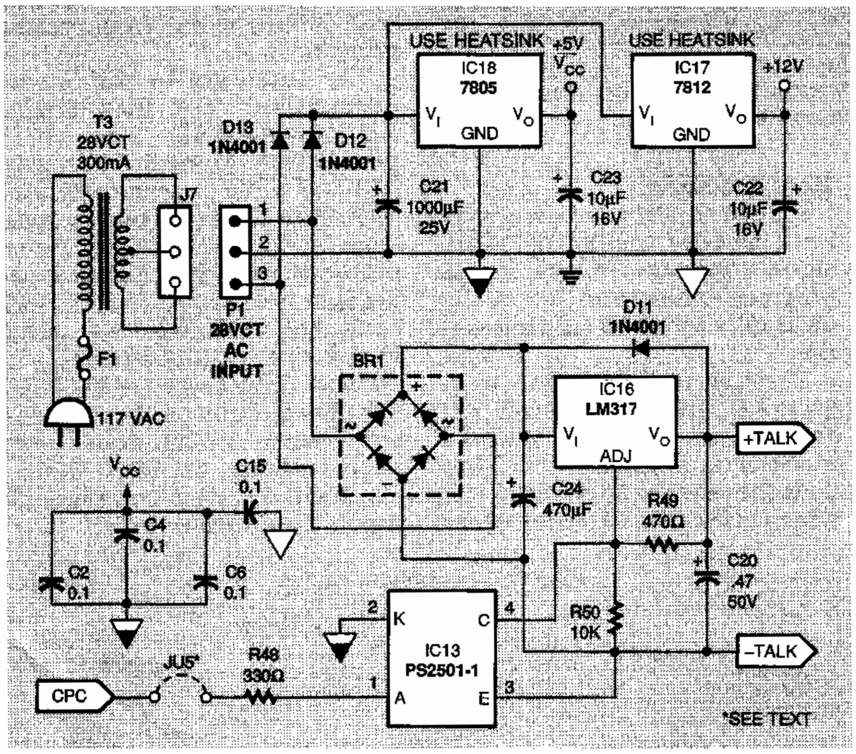

FIG. 8—A CONVENTIONAL POWER SUPPLY provides +5 and +12 volts DC. Note that IC16 can be turned off, thus disabling the talk circuit, if the input labeled CPC goes high. That happens under MCU control.

ORDERING INFORMATION

The following items are available from Digital Products Company, 134 Windstar Circle, Folsom, CA 95630, Voice: (916) 985-7219 Fax: (916) 985-8460. E-mail: DigProd@aol.com
KITS: Parts kit including printed-circuit board, programmed microcontroller, relays, transformers, IC's, resistors, capacitors, documentation, etc., less enclosure: ($199.95). Enclosure kit includes plastic case, drilled front panel, mounting screws, etc. ($32.95). Hard-to-obtain IC's, including M-8870, M-991, ULN2003, 74HC14 (2), 74HC259, PS2501-1 (7): ($31.25). Line transformers (T1, T2) and relays (RY1–RY6): ($48.50), power transformer kit with T3 (120VAC only), fuse, AC cord: ($14.75).
PARTS: Printed Circuit Board #PL6-001: ($34.95). Programmed PIC16C57 ($22.00). Complete documentation with schematic: ($7.25).
U.S. orders add $8 S/H for Kits, or $5 for Parts. Canadian orders add $14 for Kits, $9.50 for Parts. Write or fax for shipping information to other countries.
Prices shown in USA dollars. Remit U.S. funds only. CA residents add local sales tax. Money orders, checks, MasterCard, Visa, American Express, and Discover Card accepted. Personal and company checks require bank clearance before shipment and may delay orders 2–3 weeks. Prices and terms subject to change without notice.

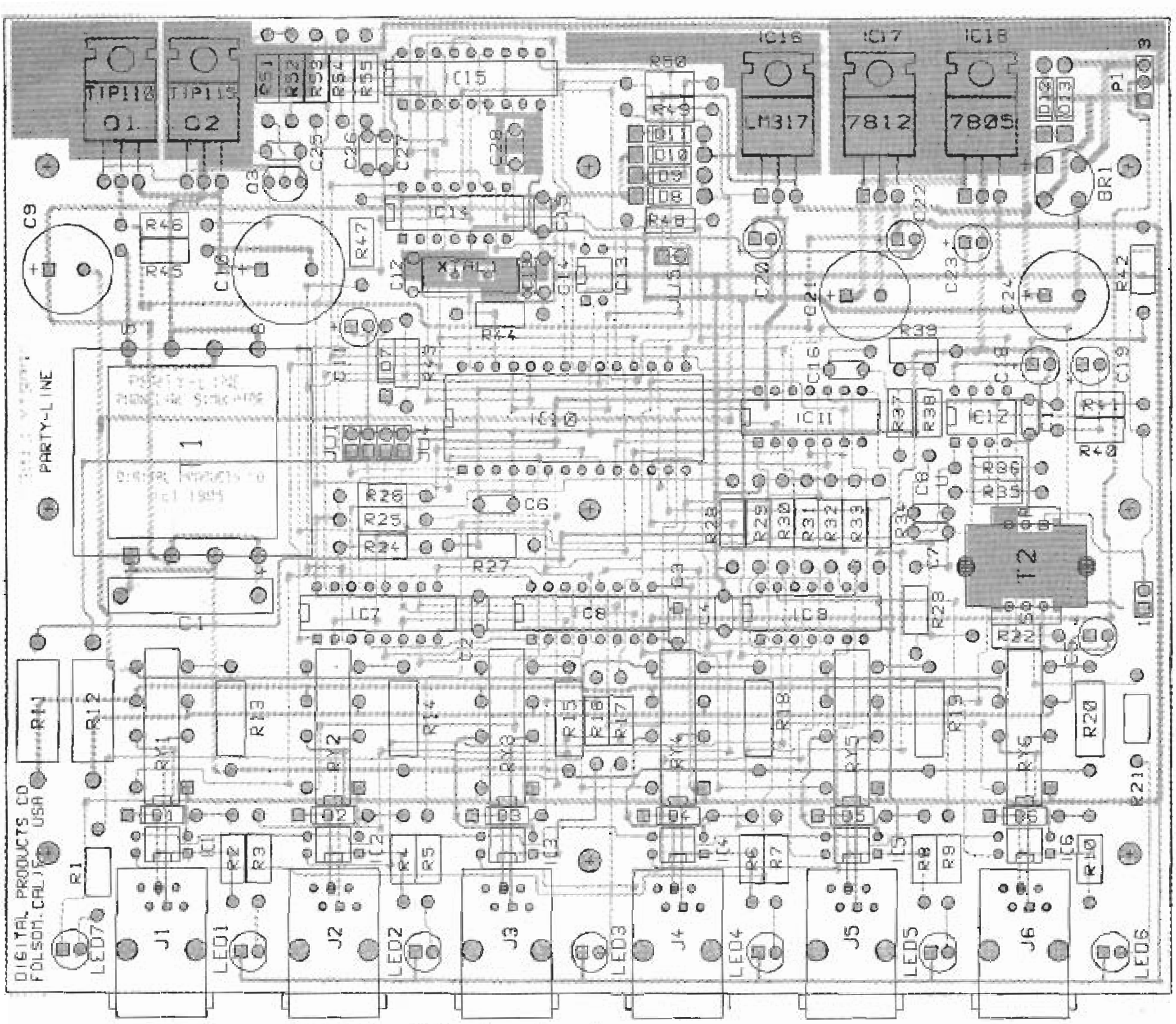

FIG. 9—PARTS PLACEMENT DIAGRAM: Mount all parts as shown here.

Call progress tones

The phone company considers sounds such as dial tone, busy, and ringing to be comfort tones that are present only to confirm the progress of the telephone call. Although foreign countries use similar tones, they often vary slightly from those heard in the U.S. Teltone's M-991 Call Progress Tone Generator (IC14) generates Party Line's call-progress tones. Table 9 lists several of the four-bit codes that the M-991 responds to. Some tones consist of a single, simple tone; others consists of several frequencies mixed together.

The M-991 makes generating the tones easy, but knowing when to generate them requires some intelligence. For example, busy tone signals must be gated on and off on a periodic basis. The MCU disables the IC when necessary by setting the chip-enable line (pin 13) of IC14 high. Because the four-bit codes are latched at the falling edge of $\overline{CE}$, the MCU's RC0–RC3 lines can be freed immediately for use by the DTMF receiver or relay control. Party Line's task-based software handles all those time-sensitive operations.

CID filtering

The MCU-generated CID information initially appears in squarewave format, which is unacceptable as a Caller-ID signal. Hence it must be converted to a sine wave; doing so is the job of active filter IC12-a. The op-amp is configured as a simple low-pass filter, with a roll-off frequency slightly higher than the highest frequency we need to send.

Although the filtered tones are not true sine waves—they look more like shark fins—they are quite acceptable to most Caller-ID products, which by design must be tolerant of signal anomalies, since in actual operation all phone lines introduce some noise and distortion.

Power supply

The power-supply schematic appears in Fig. 8. It contains three sections: two fixed-voltage 78xx regulators for powering the digital and analog circuits,