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A Simple Internet VoIP Board

A pair of these boards will provide a full duplex Internet audio link

This article describes a full duplex Internet audio board (a "VoIP" board) using a PIC® microcomputer and a Lantronix XPORT Ethernet module. This board sends and receives (approximately) 16 user datagram protocol (UDP) packets per second, with 512 payload bytes per packet. Each payload byte expresses an 8 bit audio sample, taken 8000 times per second.

The message format of 8 bits per sample and 8000 samples per second was as a matter of convenience and simplicity, and is *not* compatible with any common VoIP standard. Indeed, "VoIP" is actually a "buzz word" and does not really identify any "formal" internet protocol. Several audio formats are commonly used on the internet, but none seem to be predominant.

Two boards will provide a basic (two way) point-to-point Internet audio system, like an intercom or telephone. For bench tests, two boards can communicate directly with each other using an Ethernet crossover cable. The lead photo shows my test setup. (There is more about this later.) No provisions are made for broadcasts to multiple listeners. The IP addresses and ports of both locations must be identified and programmed into both XPORT modules, at the time of installation. The intention here is to describe a minimal system that can provide a foundation for more sophisticated internet-linked devices.

Details are provided here for construction, but achieving an Internet link will also require knowledge of local area network (LAN) principles, (configuring routers, switchers and so on) to provide a clear path to the Internet for each module. In general, a static IP address for the gateway computer will also be required, at both ends of the link. These topics are beyond the scope of this article and every LAN situation is different, so if you are not familiar with networking, consider enlisting the help of a friend with LAN experience.

The author's test-bench setup for testing a pair of the VoIP boards.

The Lantronix XPORT Module

The Lantronix XPORT module looks like a large RJ45 jack, but it actually contains its own microcomputer, which provides all the "intelligence" required for the Internet link. The module is quite flexible, and can be configured using a utility "Device Installer" program from Lantronix.

Interface with the PIC microcomputer is done with a full duplex serial port, similar to an RS232 port. The Lantronix port uses 3.3 V logic signal levels and positive logic polarity, but genuine RS232 signals are bipolar (3 to 15 V) and use negative logic polarity.

The VoIP Board

The PIC microcomputer is a socket-mounted 28 pin DIP device that can be re-programmed with a PicStart Plus programmer. The board has an LM386 (receive) speaker amplifier, and an op amp microphone amplifier for transmit. Trimpots are provided to adjust audio levels for both transmit and receive. See Figure 1. The schematic diagram for the VoIP board is shown in Figure 2.

The XPORT module requires 3.3 V dc for power, provided here by a switching regulator for good efficiency and reduced heating. The PIC uses a separate 5 V dc regulator. The supply load ranges from 1.6 W (12.6 V dc, idle/silent) to nearly 5 W with full speaker volume. Digital inputs to the XPORT module are tolerant of 5 V PIC output signals, but a 74CX07 chip is employed to translate 3.3 V XPORT output signals to 5 V levels for the benefit of the PIC inputs.

The circuit board is a double-sided board. Figure 3 is the top of the board and Figure 4 is the bottom pattern. I used the ExpressPCB CAD tool to lay out the circuit board. I created "two up" artwork to create a pair of boards, but only one half of the artwork is shown here. Figure 5 is the parts placement overlay.

The PIC Software

The PIC assembly code is fairly simple, yielding about 250 program bytes. TMR0 is configured to generate interrupts 8000 times per second, crystal controlled. The PIC UART communicates to and from the XPORT module at 115.2 K baud. Microphone audio is digitized by the 10-bit ADC, (the bottom 2 bits are ignored) and the PIC pulse width modulation (PWM) module, operating at 78.25 kHz, is used to generate PWM speaker audio. The ADC input is dc biased at mid supply (2.50 V) to allow for both positive and negative excursions of the microphone signal. As a result, audio "silence" will be expressed with a byte value of 0×80 (which is mid supply).

Interrupts are generated by TMR0 and the UART receiver. The program is 100% "interrupt driven," and there is no "main program loop."

Audio packets (UDP messages) are sent at an average rate of 15.625 packets/second, with 512 "payload" bytes of (8 bit) audio in each packet. Individual transmit audio bytes are sent to the Lantronix module immediately after they are measured with the ADC. The XPORT module has its own TX data buffer that is configured (in this design) to hold 512 bytes. Once that buffer is full, the XPORT module "triggers" and sends a VOIP packet.

For receiving, a 2 K byte RAM buffer in the PIC chip (2048 bytes) is used to store and hold the arriving VoIP bytes before speaker playback. Separate READ and WRITE memory pointers (FSR0 and FSR1) allow READ and WRITE operations to be performed in different parts of the RAM buffer, simultaneously. The average speed of both READ and WRITE operations is 8000 bytes/second. (crystal controlled)

The speed of READ operations (for speaker playback) is constant, and equal to 8000 bytes per second, but WRITE operations occur at 11,520 bytes per second, whenever UDP data is arriving from the XPORT module. There is some "idle time" between arriving UDP packets, which brings the average WRITE speed down to 8000 bytes per second.

The READ and WRITE pointers (FSR0 and FSR1) are initialized with 1 K of address separation, (50% of buffer capacity) but

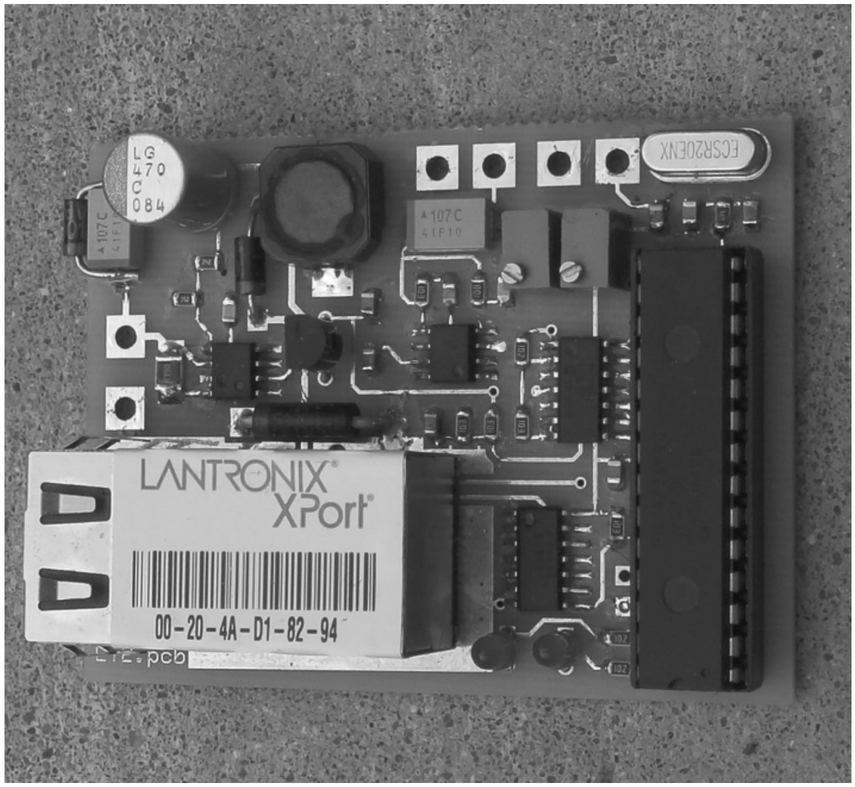

Figure 1 — This photo shows one of the completed VoIP boards. The Lantronix XPORT module is clearly visible.

this separation increases and decreases constantly because of the varying WRITE speed. Because the average READ and WRITE speeds are equal, (and the buffer is large enough to accommodate the variations of WRITE speed) the two address pointers (FSR0 and FSR1) normally will never "overrun" each other. (If they did, it would yield garbled audio.)

The RAM buffer therefore provides a way to compensate for these READ/WRITE speed differences and variations, but it also compensates for variations of UDP packet travel times — successive UDP packets can travel at different speeds through the Internet, yielding a variation of arrival time as great as 30 milliseconds, measured from one packet to the next. The RAM buffer has enough capacity to hold 256 milliseconds of audio, and therefore it can accommodate these variations, as well.

In reality, the average READ/WRITE data rates are controlled by two separate crystals, (one at each end of the link) and minor differences between these two crystals will gradually accumulate (in the memory pointer values) and eventually cause an "overrun" between the READ and WRITE areas of the buffer RAM.

To deal with this, a few lines of PIC code constantly check the address difference between the two pointers, and if the separation distance ever gets "too close for comfort", (equal to 32 ms or less) the WRITE pointer address is re-initialized to a value with 1 K of address separation from the READ pointer address. This will cause a slight "glitch" in the playback audio (less than 100 ms) perhaps once every 5 to 10 minutes.

As a result of the normal operation of the RAM buffer, speaker audio is delayed by a typical value of 128 ms, but the delay can actually range from 32 to 224 ms. Delays smaller than 32 ms or greater than 224 ms will trigger an automatic "adjustment" of the WRITE pointer address.

Once a buffer byte is read and sent to the PWM for speaker playback, the value of the buffer byte is set to 0 × 80, to "erase" the byte. (0 × 80 = "no audio")

The XPORT Module: More Information

General information about the XPORT module is available on the Lantronix website: **www.lantronix.com/device-networking/embedded-device-servers/xport.html**. In particular, the Quick Start Guide (**www.lantronix.com/pdf/XPort_QS.pdf**) and Users Guide (**www.lantronix.com/pdf/XPort_UG.pdf**) are worth viewing.

The (utility) ***Device Installer*** program is

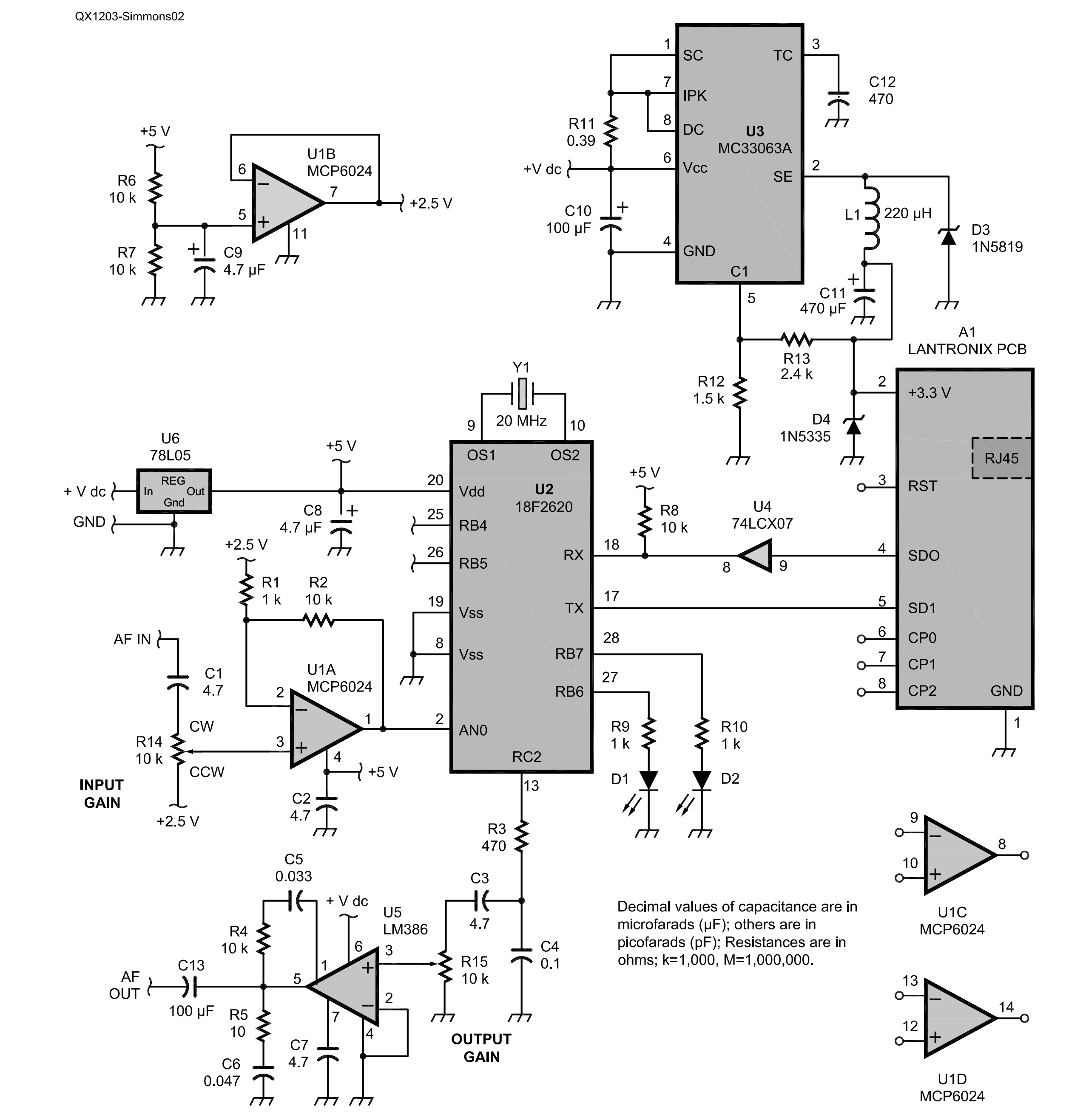

Figure 2 — Here is the schematic diagram of the VoIP module.

available here: **http://ltxfaq.custhelp.com/app/answers/detail/a_id/644**. Instructions about installing and running the ***Device Installer*** program are in the Quick Start Guide.

The Device Installer Program

The ***Device Installer*** program is used for several Lantronix products, not just the XPORT module. Some features in the ***Device Installer*** program, therefore, will not be applicable to the XPORT module (just ignore them).

Furthermore, the ***Device Installer*** program is a bit "buggy" in a few respects — if a parameter is changed in the XPORT module, you must click the APPLY SETTINGS button and wait several seconds for the new settings to be applied, before switching to a different display page. Checking to verify the new parameter settings have really been installed in the XPORT module will usually reveal that NO CHANGE has occurred, but this is a false display. The browser used in the

NOTE: All part numbers are DigiKey unless noted otherwise. Quantities are for a single VoIP module. Quantities must be doubled to make 2 boards for a complete link.

Component	Description	Part No.	Unit Price
	Circuit board	EXPRESSPCB	$10.89
A1	Lantronix XPORT	515-XP1001001-04R (Mouser)	$49.00
C1, C2, C3, C7, C8, C9	4.7 µF 0805	PCC2321CT-ND	$0.25
C4	0.1 µF 0805	478-1395-1-ND	$0.05
C5	33 nF 0805	478-1389-1-ND	$0.09
C6	47 nF 0805	478-1391-1-ND	$0.11
C10, C13	100 µF	478-1723-1-ND	$1.30
C11	470 µF	493-3114-ND	$1.73
C12	470 pF 0805	478-1324-1-ND	$0.09
D1, D2	LED T-1	67-1064-ND	$0.10
D3	1N5819	1N5819FSCT-ND	$0.68
D4	1N5335	1N5335BGOS-ND	$0.44
L1	220 µH	495-1801-1-ND	$1.82
R1, R9, R10	1.0 kΩ 0805	P1.0KACT-ND	$0.04
R2, R4, R6, R7, R8	10 kΩ 0805	P10KACT-ND	$0.04
R3	470 Ω 0805	P470ACT-ND	$0.04
R5	10 Ω 0805	P10ACT-ND	$0.04
R11	0.39 Ω 1210	RHM.39SCT-ND	$0.32
R12	1.5 kΩ 0805	P1.5KACT-ND	$0.04
R13	2.4 kΩ 0805	P2.4KACT-ND	$0.04
R14, R15	10 kΩ Trim Pot	490-2970-ND	$1.84
U1	MCP6024	MCP6024-I/SL-ND	$2.08
U2	18F2620	PIC18F2620-I/SP-ND	$7.68
U3	MC33063A	296-17763-1-ND	$0.68
U4	74LCX07	74LCX07M-ND	$0.51
U5	LM386	LM386M-1-ND	$0.94
U6	78L05	296-1365-1-ND	$0.40
Y1	20 MHz	XC1723-ND	$0.55

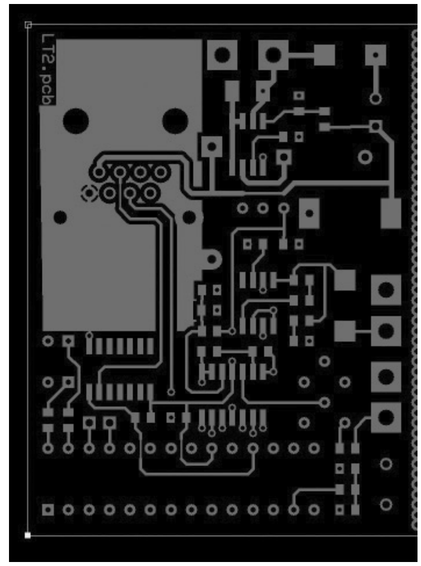

Figure 3 — This is a top view of the circuit board. The Lantronix XPORT module will be positioned over the large ground screen block at the top left corner.

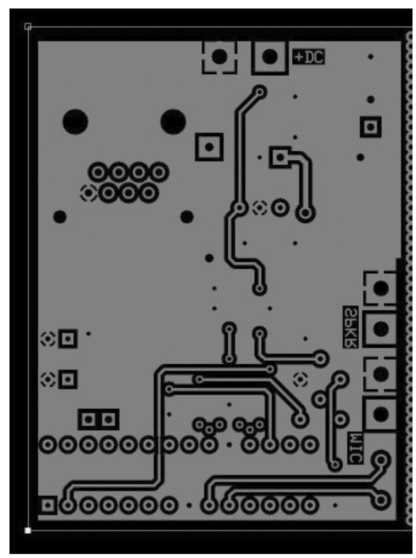

Figure 4 — This is an X-ray view of the bottom of the circuit board. Note the location for the Lantronix XPORT module in the upper right corner.

Device Installer program does not "refresh" properly, (even though a REFRESH button is provided) and typically the parameters truly have been changed. The only way to verify that the new parameters are properly installed in the XPORT module is to completely shut down (close) the ***Device Installer*** program and restart it. This flushes the browser's cache memory.

When the ***Device Installer*** program starts up, it conducts a search to find XPORT modules, but if multiple network interfaces are available, it might look in the wrong direction. It is prudent to disable or disconnect all network connections except the one to the XPORT module, while using the ***Device Installer*** program.

Configuring the XPORT Module

After installing the ***Device Installer*** program on your computer, and with the foregoing warnings about the program's "peculiarities" in mind, follow the instructions in the Quick Start Guide to begin the configuration process for the Lantronix XPORT module.

Some additional changes must be made after you have finished all the steps described in the Quick Start Guide. The information provided below will allow two VoIP modules to connect directly to each other with a cross-over cable, for bench tests.

Start up the ***Device Installer*** program, establish contact with the XPORT module, open up the web interface for the module and make the following changes:

NETWORK: Use static IP address

IP Address: 192.168.1.65 for board number 1

IP Address: 192.168.1.70 for board number 2

SERVER: MTU size = 512 (both boards)

CH 1 SERIAL SETTINGS: Baud rate = 115200 (both boards)

CH 1 CONNECTION: Protocol = UDP (both boards)

Datagram Type = 01(both boards)

Local Port = 10001 (both boards)

Remote Port = 10001 (both boards)

Remote Host = 192.168.1.70 for board number 1

Remote Host = 192.168.1.65 for board number 2

Shut down the ***Device Installer*** program and restart it. Examine the parameters to verify they have all truly been entered properly and saved in the XPORT module. Do this for both VoIP boards.

Bench Testing the VoIP Boards

At this point, hook up the two VoIP boards as shown in Figure 6, to test their operation. The two speakers shown in the diagram will allow you to verify the operation. The lead photo shows the test setup on my workbench. If everything is working properly, you will hear speaker audio in both speakers. Speaker audio in the receiving board will be delayed several dozen milliseconds, yielding a distinct "echo" quality to the sound. You can adjust the audio levels with the trimpots to equalize the speaker levels, which will maximize the "echo" effect.

Setting Up an Internet Link

This topic is beyond the expertise of the author, and the scope of this article. Some people reading this article will have a very good idea what must be done, but others will not — for the latter folks, enlist the help of someone well-versed in the black art of setting up computer LANs.

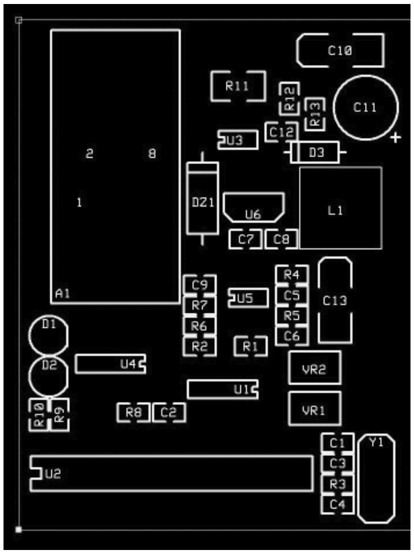

Figure 5 — The parts placement screen pattern shows the various circuit components.

Please note "machine level" IP addresses (IPv4) presently consist of 4 individual bytes. (6 byte addresses for IPv6 are coming in a few years) These bytes are written as individual numbers, in decimal notation with leading zero suppression, delimited by decimal points. The range of possible IP addresses runs from "0.0.0.0" to "255.255.255.255". This yields almost 4.3 billion possible addresses.

IP port numbers (at the machine level for IPv4) consist of a 2 byte unsigned integer, expressed in decimal notation as a single number. Therefore the possible range of port number runs from "0" to 65535".

Each IP address has 65536 possible port numbers associated with it. By analogy, an IP address is like a telephone number, and the port number is like an "extension number" available at that phone number.

Basically, a clear pathway directly between the Lantronix module and the Internet must be created in the LAN. This will require selecting an IP port number for the Lantronix module, one that is "free" and not being used by any other computers in the LAN. The port number should lie between 49152 and 65535, and definitely avoid port numbers below 1024, which are pre-defined in the Internet community as "well known" ports.

Once a suitable port number is identified, the gateway computer (the switcher or router that connects the LAN to the Internet) can be programmed to pass all traffic using that port directly to/from the Lantronix module. This is called "port forwarding."

The Internet address ("worldwide web" address) for the LAN gateway computer cannot be independently selected, its value is "dictated" by the ISP (Internet Service Provider), which provides the external Internet connection to the LAN. This address must be identified, because it will be used to program the Lantronix module at the other end of the link. (The port number will also be required.)

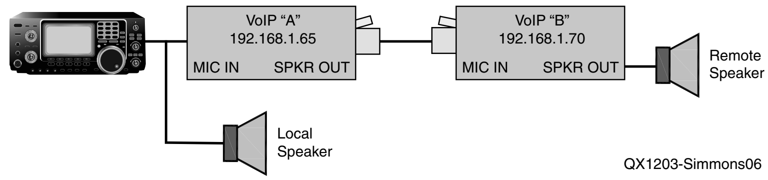

Figure 6 — This block diagram shows the setup used to test a pair of the VoIP circuit boards.

For reliable operation, the IP address should be a "static" address (one that never changes) and static addresses can be provided (rented) from ISP companies for a monthly fee. Most end-user IP addresses are "dynamic" (temporary), and can change at any time, with no warning. Generally, these addresses only change whenever a user (the LAN gateway computer) "signs off" from an Internet connection, but if this never happens, a dynamic address might remain constant and never change for weeks or months. In contrast, a static IP address is guaranteed to never change.

All these actions will involve some "configuration" work with the switcher or router that provides the Internet connection for the LAN (the "gateway" computer). If the switcher/router also has a firewall program, it might also be necessary to instruct the firewall to "make an exception" for any Internet traffic to or from the specific port assigned to the Lantronix module. ("Don't interfere" with traffic to or from the Lantronix module.)

The CAD Files and Parts List

The schematic and PCB CAD files were created with ExpressPCB, which provides free CAD tools to do this kind of work. The ExpressPCB CAD tool has a feature for directly ordering the PC boards via the Internet, with a credit card. (This option is in the LAYOUT menu.)

Use the ExpressPCB "MiniBoard" service when ordering the boards. This is their most economical service, but orders are limited to 3 identical boards measuring 2.5 × 3.8 inches, which will yield enough modules for 3 complete links (6 VoIP modules). Each ExpressPCB board holds 2 VoIP modules, with a line of closely-spaced VIAs separating them. The VIAs serve as "perforations" that allow the two modules to be manually "broken apart" into separate boards.

You can get the CAD tools to view the files and order the circuit boards at the ExpressPCB website: **www.expresspcb.com/**

The CAD files for these circuit boards (schematic and PCB) are available for download from the ARRL *QEX* files website.[1]

The PC board itself should be ordered using the ExpressPCB "MiniBoard" service, which will yield enough boards for 3 complete Internet links.

Credits

This module was developed and tested in collaboration with John Piri, WD6CSV, and GTMR Corporation. They have both kindly granted permission to report the results in this article, in exchange for honorable mention. You can visit the GTMR company website at: **www.gtmrinc.com/**.

The author maintains a website with information about some of his other projects, mostly related to radio direction finding and hidden transmitter hunting. Visit this website at: **www.picodopp.com**

[1]The ExpressPCB files as well as the Assembly language program code are available for download from the ARRL QEX files website. Go to **www.arrl.org/qexfiles** and look for the file **3x12_Simmons.zip**.

Bob Simmons, WB6EYV, was first licensed as a novice in 1964 at age 13, and remained licensed (more or less) constantly ever since. He also earned a commercial FCC license in 1967. He served Naval Reserve duty as a radar technician (ETR2) with about 6 months of total sea time. He spent several years of civilian work in nautical and marine electronics in Los Angeles harbor, as well as doing some land mobile radio work, followed by 5 years in flight line avionics, working on business jets. He moved to Santa Barbara, CA in 1992 and worked on vacuum deposition systems for 5 years, and held assorted odd engineering jobs at other times. Presently, Bob is self employed and runs a website making and selling radio direction finding equipment and modules, with a majority of his "new" work spent creating embedded software / hardware and developing technologies to enable Internet-linked remote DF stations. His primary interest is developing and applying new technologies to old problems, and pushing the DF "art" forward.

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