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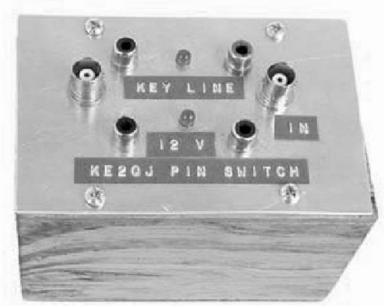


A Fast TR Switch

Here are two approaches to integrating a separate receiver into your equipment lineup.

Some time ago I purchased an ICOM PCR1000 receiver. This very small radio is representative of a new class of radios offered by ICOM, Ten-Tec and others. The radio has no controls on the panel. In fact, there scarcely is a panel. It is controlled entirely by a computer over an RS-232-C connection, and virtual controls appear on the computer display. The mouse or keyboard can be used to set frequency, volume and mode, and perform all the normal radio functions.

The PCR1000 is a versatile receiver. It covers 100 kHz through 1.3 GHz, except for cellular telephone frequencies. Modes include AM, FM, SSB and CW. Aftermarket *Bonito* software (now supplied with the radio) adds DSP filtering functions and modes like RTTY, FAX, SSTV and PSK31 that are not offered on older transceivers. The UT-106 DSP hardware option adds an automatic notch filter and noise reduction.

I was interested in using the PCR1000 in my ham station, along with a separate transmitter. Although the radio will function with a chunk of wire for an antenna, it hears much better with a resonant antenna. The input is matched to 50 Ω. An obvious choice would be to use it with the antenna used for transmitting, but to do that I needed to make some kind of TR switch.

Some measures must be taken to disconnect the receiver from the antenna when the transmitter is operating. Otherwise the transmitter power will surely damage the front end. Even connecting the receiver to a full size matched antenna in the vicinity of a kilowatt transmitter on another antenna could destroy the input stages, so I needed a fast acting TR switch to isolate the receiver from the powerful transmitted signal. This article describes the development of two TR switches, one using a reed relay and the other PIN diodes.

The Reed Switch

The first switch I developed for this purpose employed a low-power RF reed relay from Wabash Magnetics,[1] as shown in Figure 1. The relay (K1) is "T'd" onto the line connecting the transmitter or transceiver and the linear amplifier. When the reed relay contact closes, it connects the external receiver antenna input in parallel with the transceiver. This T configuration costs perhaps 3 dB, or half an S-unit, in received signal strength.

Since the switch is exposed to the high power RF only in the open condition, a common reed relay could probably be used. If a relay had been used to isolate the transmitter, it would have had to pass approximately 100 W. In this case a true RF reed is required since the iron reed in a common switch is lossy at radio

[1]Notes appear on page 59.

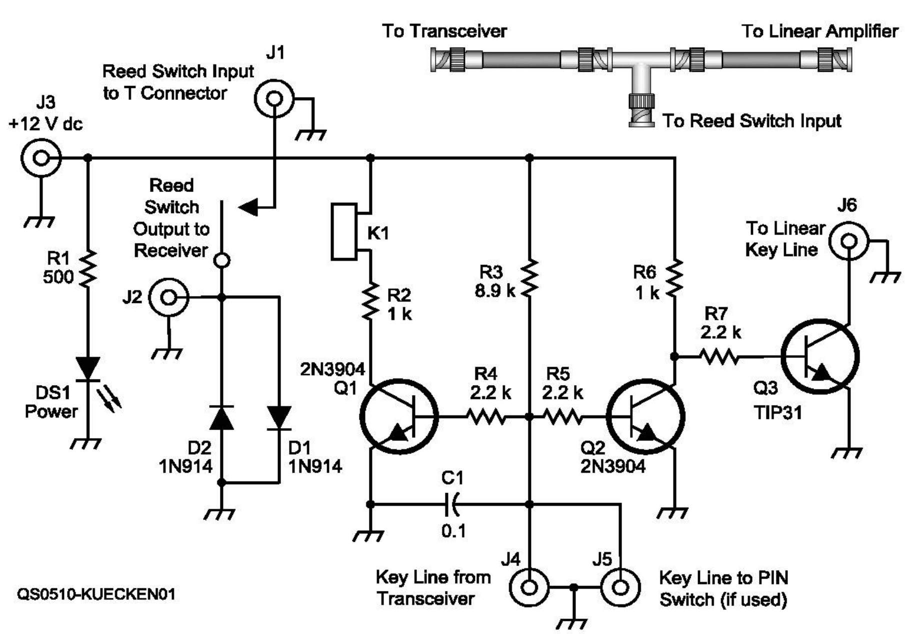


Figure 1—Schematic and parts list for the reed relay TR switch. Resistors are 1/4 W.

D1, D2—High speed switching diode, 1N914 or equivalent.
DS1—LED.
J1, J2—Chassis mount BNC connectors.
J3-J6—Chassis mount phono connectors.
K1—SPST normally open reed relay with 12 V coil. See text and Note 2.
Q1, Q2—Small signal PNP transistor, 2N3904 or equivalent.
Q3—NPN power transistor, TIP31 or equivalent.

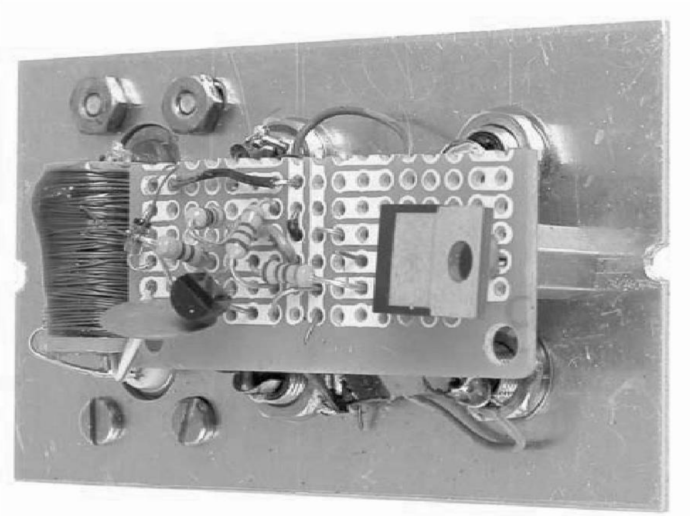


Figure 2—Interior of the reed switch. The connectors all mount on a small aluminum plate which fits the wooden enclosure shown in the title photo. The reed relay is mounted directly to the input and output connectors. The control circuitry is on a RadioShack project board. Component layout is not critical.

frequencies and will heat up. If it heats to the Curie point (the temperature at which a material loses its magnetic properties), it will drop open and present an extreme SWR to the transmitter.

The key line on my Ten-Tec Omni C transceiver goes low on transmit. Looking at Figure 1 you can see that with the key line high, both 2N3904s are biased on and K1 is closed and the TIP31 is turned off. When the key line goes low on transmit, the 2N3904s are cut off, K1 opens to disconnect the receiver, and the TIP31 saturates and keys the linear. I needed the TIP31 because the load of the 2N3904 control transistors was enough to key my Ameritron AL-80A linear even with the switch in the receive mode. D1 and D2, the set of back-to-back diodes across J2, represent a safety measure against transmitter startup transients (more on this later).

Reed Switch Construction

Figure 2 shows the inside of the reed switch. The reed itself is a glass cylinder about 3/32 inch in diameter that is covered with a coil of wire. The winding is adequate to permit closing of the reed with about 5 mA of current. The transistor drives about 10 mA through the coil. The reed switch (green) bridges directly between the two BNC chassis connectors. An external BNC T adapter is used to connect the transceiver and the linear amplifier and clips on the input chassis connector. The PCR1000 auxiliary receiver is fed through the other chassis connector. I built the control circuitry on a RadioShack project board.

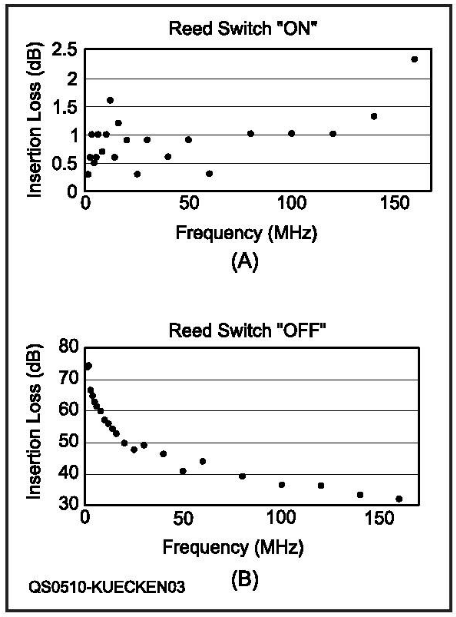


Figure 3—Insertion loss measured with the reed switch ON (A) and OFF (B).

The assembled switch in its wooden case can be seen in the title photo. There is a single key line input (J4) and two key line outputs (J5 and J6). One output (J5) is in parallel with the transceiver key line and goes to the PIN switch (if used). The output from Q3 goes to a tune-up interlock and then to the linear amplifier key line. I used phono connectors and shielded cable for the 12 V supply and the key lines to avoid RF pickup in the control circuitry. The extra phono connector is wired in parallel with the 12 V jack to provide convenient power for another device such as the PIN switch described later. This version does not have the POWER LED (DS1).

Figure 3 shows the measured insertion properties of the reed switch. Insertion loss with the switch on is very low, and the loss (isolation) with the switch off is quite respectable.

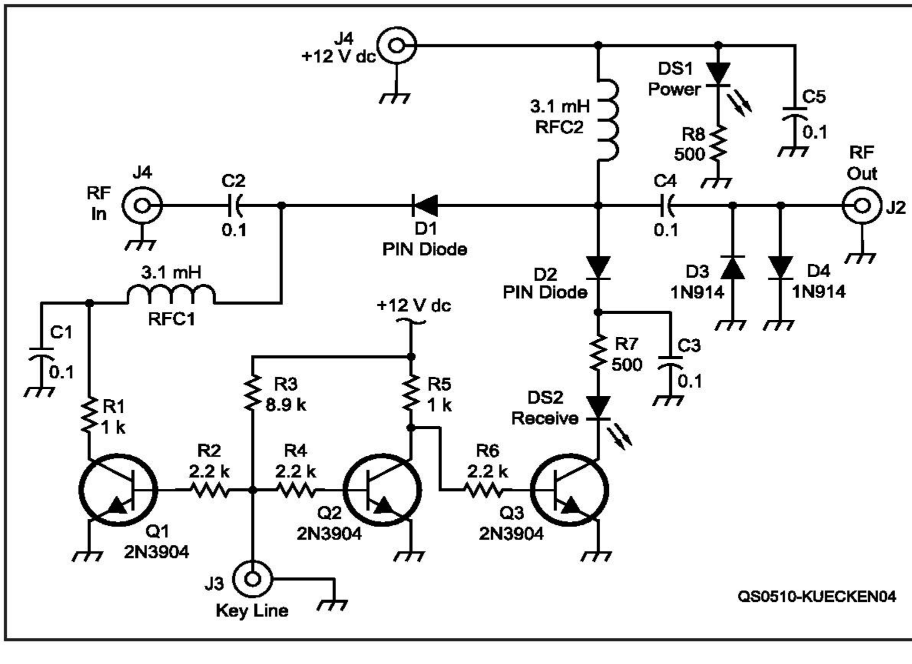


Figure 4—Schematic and parts list for the PIN diode TR switch. Resistors are 1/4 W.

C1-C5—0.1 µF ceramic capacitor.
D1, D2—PIN diode (see text and "Alternative Parts" sidebar).
D3, D4—Switching diode, 1N914 or equivalent.
DS1, DS2—LED.
J1, J2—Chassis mount BNC connector.
J3, J4—chassis mount phono connector.
Q1-Q3—Small signal PNP transistor, 2N3904 or equivalent.
RFC1, RFC2—3.1 mH RF choke, 225 turns 30 gauge enameled wire wound on a 5/16 inch diameter, 5/8 inch long plastic tube. See text.

The PIN Switch

After building the reed switch, I decided to try another approach. Figure 4 shows the schematic diagram of a fast TR switch that I built with PIN diodes. The PIN diode is a special kind of silicon diode that is capable of passing RF when forward biased, making it ideal for use in RF switches. See the sidebar "About PIN Diodes."

Note that Q1-Q3 are all operated in a digital mode—they are all either cut off or saturated. They do not operate in a linear mode. In the receive condition the key line is open and Q1 is biased ON. This biases the PIN diode D1 ON, connecting the receiver to the input terminal. When Q1 is ON, Q2 is biased ON and Q3 draws no current through the shunt element. Thus the shunt PIN diode, D2, is OFF.

When the transceiver is keyed OFF, the key line pulls the base of Q1 low, cutting off the forward bias to D1, switching it OFF. The low line also turns Q2 OFF. This causes Q3 to saturate and forward bias D2, which shorts the feedthrough signal to ground.

I built the original switch using Unitrode diodes with a rating of 100 V and a carrier lifetime on the order of 5 µs. The parts I used are no longer available (see the sidebar, "Alternative Parts"). Note that the 100 V rating makes these PIN diodes marginal for direct connection to the output of a 100 W transmitter. More on this later.

I measured the effect of the bias current on the Unitrode diodes used for the series and shunt elements individually. For the series diode, insertion loss ranged from 0.9 dB with 3 mA of bias current to 1.2 dB with 7 mA. For the shunt diode, insertion loss ranged from 42.9 dB with 3 mA bias current to 52.9 dB with 15 mA. The test setup consisted of a Hewlett Packard signal generator for the signal source and a Tektronix spectrum analyzer with a well matched 50 Ω input for the measuring device. A low-SWR RF bypass switch I developed for an earlier project for *ARRL Antenna Compendium Vol 5* switched the signal directly to the spectrum analyzer or through the device under test.[2]

PIN Switch Construction

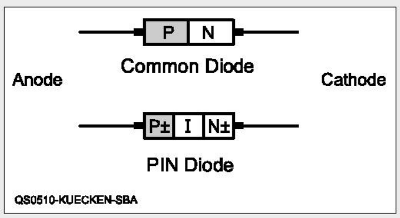
Figures 5 and 6 show the construction details of the PIN diode switch. D1-D4, RFC1-RFC2 and C1-C5 mount on a piece of double-sided Teflon-fiberglass circuit board that I had on hand. (Regular G-10 or FR-4 board would work just fine here too.) To make pads for component mounting, I cut gaps in the foil on one side. The far side foil was left intact as a continuous ground plane. Jumpers were soldered to connect ground areas on the top to the solid ground plane. An etching pattern is available from the ARRL Web site.[3]

Originally, I built the switch with surface mount capacitors. I was interested in using these tiny capacitors because they have no leads and should have very high resonant frequencies in the circuit. Unfortunately, several of the capacitors failed in the course of measurements. After a bit of exasperation, I realized that the thin circuit board was flexing and breaking the capacitors. I switched to the conventional ceramic capacitors shown in the photos.

Perhaps the most visible part of the assembly is the pair of RF chokes. These are wound on a 5/16 inch diameter plastic tube between a pair of 1 inch fiberglass washers. The washers were epoxied on the ends of the tube about 5/8 inch apart and

About PIN Diodes

The PIN diode is constructed with a layer of intrinsic (undoped) semiconductor material between very highly doped P type and N type material called P+ and N+. This contrasts with a normal high speed switching diode such as the 1N914 which has a simple PN junction.



An ordinary PN junction diode can be used to switch RF currents on and off. In order to completely close off the current, the diode must be reverse biased with a voltage equal to the peak RF voltage to be blocked. For example, to block an RF signal of 10 V p-p, the diode anode must be 10 V dc more negative than the cathode. If the diode is to remain turned on for the complete RF cycle, the dc bias current must exceed the RF current. For example, if the diode is expected to pass 0.1 A of peak RF, it must have a forward bias of at least 0.1 A dc.

The behavior of the PIN diode is notably different. Because of the intrinsic layer, the RF takes a significant time to travel between the P+ and N+ regions. The delay characteristic is important for RF switching. The PIN diode is normally OFF for RF and only requires a bias to turn ON. If the length of an RF cycle is shorter than this delay and the diode is not forward biased, the current flow will be negligible and the diode will appear to be OFF. If a forward bias current is applied, some RF current will flow and the diode switch will be ON.

Over a limited range, the diode acts like a current controlled resistor to RF. Resistance decreases with increasing bias current. Used in conjunction with a fixed resistor, the PIN diode can be used to construct an electronically controlled RF attenuator.

The capacitance of the diode itself and the diode package will permit some RF feedthrough current in the OFFcondition. Feedthrough in the OFF condition will always be greater than zero, so a switch intended to provide high levels of isolation will frequently have two PIN diode elements. A series element (D1 in Figure 4) disconnects the switch from the source, and a shunt element (D2 in Figure 4) shorts out most of the feedthrough signal. When the switch is ON, the series element will be biased ON and the shunt element will be unbiased and OFF. Conversely, when the switch is OFF, the series element will be unbiased and OFF and the shunt element will be biased ON to short out the feedthrough signal.

Alternative Parts

The Unitrode PIN diode product line was purchased by Microsemi* more than 10 years ago, and the parts that I used in the prototype are no longer available.

Several parts in the current Microsemi product line would work well in this switch. Their GC4432 diode, which has a 300 V breakdown rating, would be especially suited to the series position (D1). The GC4412, which has a smaller ON resistance of 0.4 Ω would work for the shunt position (D2). The carrier lifetimes are a bit smaller, at 1.5 and 0.7 µs, than the Unitrode part. With its 300 V breakdown, the GC4432 could be directly connected to a 100 W transceiver output provided that the SWR on the line is modest. The GC4495 part, with a 1000 V breakdown, should be capable of switching the output of the 1.5 kW linear.

An excellent reference, *The PIN Diode Circuit Designer's Handbook*, is available for download at **www.microsemi.com/literature/pinhandbook.pdf**. This 137 page *Handbook* contains a wealth of information on PIN diodes and their applications. It includes several design examples of interest to hams, and even one featuring an Amateur Radio TR switch.

*Microsemi, 75 Technology Dr, Lowell, MA 01851, tel 978-442-5600, **www.microsemi.com**.

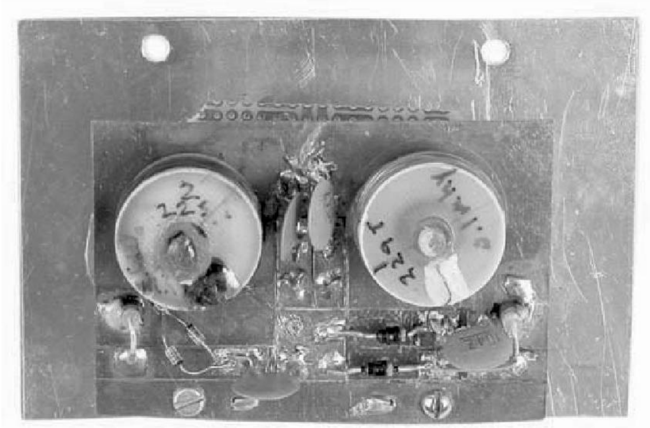


Figure 5—Construction details of the PIN diode TR switch. The capacitors, RF chokes (upper half) and PIN diodes (lower right) mount on a piece of PC board material. Mounting pads for components are created by cutting away the foil with a sharp knife. The back side is left intact.

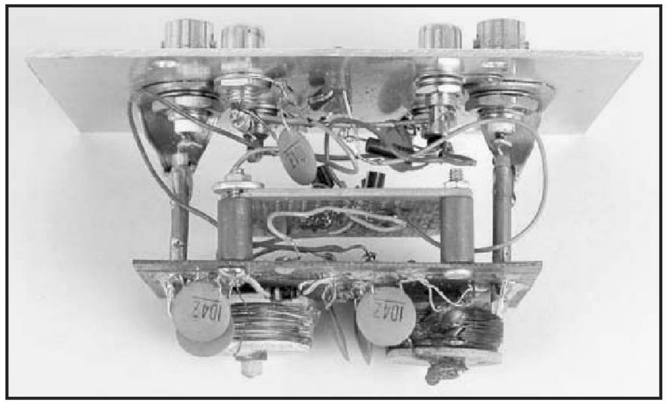


Figure 6—Another view inside the PIN switch. The control circuitry is on a RadioShack project board secured under the diode board. Short lengths of 0.141 inch 50 Ω semi-rigid coax connect the BNC jacks to the diode board and provide mechanical support.

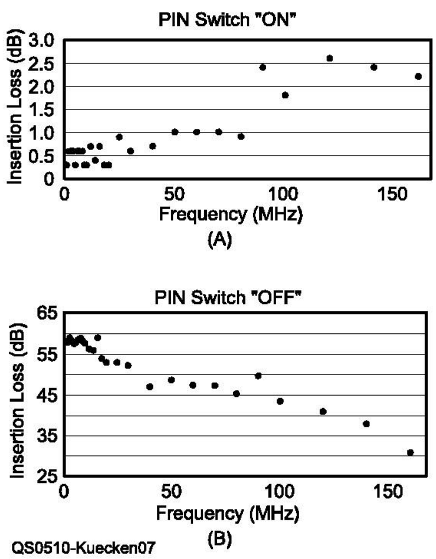


Figure 7—Insertion loss measured with the PIN diode switch ON (A) and OFF (B).

225 turns of 30 gauge wire wound on. Gray fingernail polish holds the windings in place. A small wooden shaft holds the choke to the board. The chokes measure 3.1 mH and provide plenty of isolation for RF at the lowest frequency of 1.8 MHz.

Figure 6 shows additional details. The transistors and resistors are mounted on a RadioShack project board on spacers under the diode board. Short pieces of semi-rigid coaxial cable run from the BNC connectors to the RF board and also provide mechanical support. The outer conductor is soldered to brass tabs, providing a ground connection. The title photo shows the switch mounted in the wooden case.

Figure 7 shows the insertion loss of the switch in the on and off conditions. Insertion loss is quite low when the switch is on, and isolation is pretty good when it is off.

The PIN switch alone has enough isolation to protect the receiver. However, as noted earlier, the 100 V rating on the PIN diodes is marginal for direct connection to a 100 W transmitter. On a 50 Ω line, 100 W corresponds to 70.7 V RMS and 100 V peak. With any significant SWR the voltage on the line can easily exceed the 100 V peak level.

I usually use the PIN switch along with the reed switch. The reed switch output, J2, connects to the PIN switch input at J1. The PCR1000 connects to J2, the PIN switch output. The PIN switch key line, J3, connects to J5 on the reed switch. The combination of reed and PIN switches provides a very high degree of isolation for the receiver and solves the problem of marginal diode ratings. With better diodes (or at low power levels with the 100 V diodes), the PIN switch alone would be fine.

Surprises

Initial measurements with a Tektronix 100 MHz real time sampling oscilloscope held a few surprises. I learned that the key line and the RF output of my Ten-Tec Omni C are not exactly synchronized. The key line goes low about 3.5 ms *after* the RF comes on and there is some relay bounce on the key line. Because of this delay, there is some RF present at the output of the TR switch until the key line closes. Oscilloscope screen shots showing the switch output under various conditions are available from the ARRL Web site in the template package described in Note 3. Other transceivers may or may not exhibit similar behavior.

Referring back to Figures 1 and 4, the set of back-to-back 1N914 diodes across the switch output line clip the RF leak-through down to a single diode drop. They represent a safety measure against startup transients. Unfortunately, they can be a source of intermodulation distortion in the presence of strong received signals. With a slightly more sophisticated arrangement, I could derive the key line signal from the RF switch circuitry so that the transceiver would be keyed only after the switching had taken place. This may be the next project.

Notes

[1] Wabash Magnetics, Control Products Group, 1450 First St, Wabash, IN 46992, **www.kurz-kasch.com**. Reed relays suitable for use in the TR switch are available from a number of sources, including Surplus Sales of Nebraska (**www.surplussales.com**) and Ocean State Electronics (**www.oselectronics.com**).

[2] J. Kuecken, "A High-Efficiency Mobile Antenna Coupler," *ARRL Antenna Compendium Vol 5* (Newington: 1996), pp 182-188. Available from your local dealer, or from the ARRL Bookstore, ARRL order no. 5625. Telephone toll-free in the US 888-277-5289, or 860-594-0355, fax 860-594-0303; **www.arrl.org/shop/**; **pubsales@arrl.org**.

[3] A template package including the PIN switch RF board etching pattern and additional oscilloscope screen shots is available from the ARRL Web site at **www.arrl.org/files/qst-binaries/kuecken1005.zip**.

Jack Kuecken, KE2QJ, is a consulting engineer in antennas, transmission line devices and instrumentation. He has published 14 books and numerous technical articles, including seven contributions to volumes 3-6 of The ARRL Antenna Compendium *series. His book* Antenna and Transmission Lines *is available through MFJ Enterprises. You can reach Jack at 2 Round Trail Dr, Pittsford, NY 14534 or* **ke2qj@aol.com**.