INTRODUCTION

The TAK-40 transceiver is designed specifically for the ARRL Homebrew Challenge contest. The following is a list of the criteria for the contest and a brief description of how the TAK-40 meets the requirements:

The station must include a transmitter and receiver that can operate on the CW and voice segments of 40 meters. The TAK-40 covers 7.0 to 7.3 MHz.

It must meet all FCC regulations for spectral purity. All spurious emissions from the TAK-40 are at least 43 dB below the mean power of fundamental emission.

It must have a power output of at least 5 W PEP. The TAK-40 generates at least 5 watts PEP for voice and CW modes. The ALC can be set as high as 7 watts.

It must operate from either 120 V ac mains or a 13.8 V dc power supply. The TAK-40 operates on a 13.8 VDC supply and draws less than 0.2A during receive and less than 3A during transmit.

It can be constructed using ordinary hand tools. Construction of the TAK-40 uses all leaded components and assembly only requires hand tools, soldering iron, and an electric drill (helpful but not strictly necessary).

It must be capable of operation on both voice and CW. The TAK-40 operates lower and upper sideband (USB and LSB) as well as CW. USB was included to allow the TAK-40 to easily operate in digital modes like PSK-31.

Parts must be readily available either from local retailers or by mail order. No "flea market specials" allowed. The TAK-40 is constructed from materials available from Digikey, Mouser, Jameco and Amidon.

Any test equipment other than a multimeter or radio receiver must either be constructed as part of the project or purchased as part of the budget. The TAK-40 only requires a multimeter for construction, extensive built-in setup functions are included in the software including a frequency counter to align the oscillators and a programmable voltage source for controlling the oscillators.

Equipment need only operate on a single band, 40 meters. Multiband operation is acceptable and encouraged. The TAK-40 operates on the 40 meter band.

Frequency control can be by VFO or crystal control. Some method of variable tuning is encouraged. If crystal controlled, only a single crystal must be included in the $50. The TAK-40 has dual VFO's with memory functions including VFO to Memory and Swap VFO and Memory. Each VFO has it's own memory and the current VFO setting is retained during power off.

The total cost of all parts, except for power supply, mic, key, headphones or speaker, and usual supplies such as wire, nuts and bolts, tape, antenna, solder or glue must be less than $50. The total parts required to built the TAK-40 is $49.50

The TAK-40 also includes some features that make it very smooth to operate:

- LSB operation – interoperable with 99% of the voice communications on 40 meters
- Automatic Gain Control – regulates the audio output for strong and weak signals
- S-Meter – simplifies signal reports
- Digital frequency readout – reads the operating frequency to 100 hz
- Dual Tuning Rates – fast for scanning the band and slow for fine tuning
- Large tuning knob – just like commercial rigs

- Speech Processor - get the most from the 5 watt output
- Automatic Level Control – prevents overdriving the transmitter
- TX power meter – displays approximate power output
- Bootloader – accepts firmware updates via a computer (cable and level converter optional)

CIRCUIT DESCRIPTION

The TAK-40 transceiver is designed on 4 modules; the digital section/front panel, the variable frequency oscillator (VFO), the intermediate frequency (IF) board, and the power amplifier (PA). The overall design is a classic super-heterodyne with a 4 MHz IF and a 3 to 3.3 MHz VFO. The same IF chain is used for TX and RX by switching the oscillator signals between the two mixers. Figure 1 shows the block diagram of the TAK-40 transceiver.

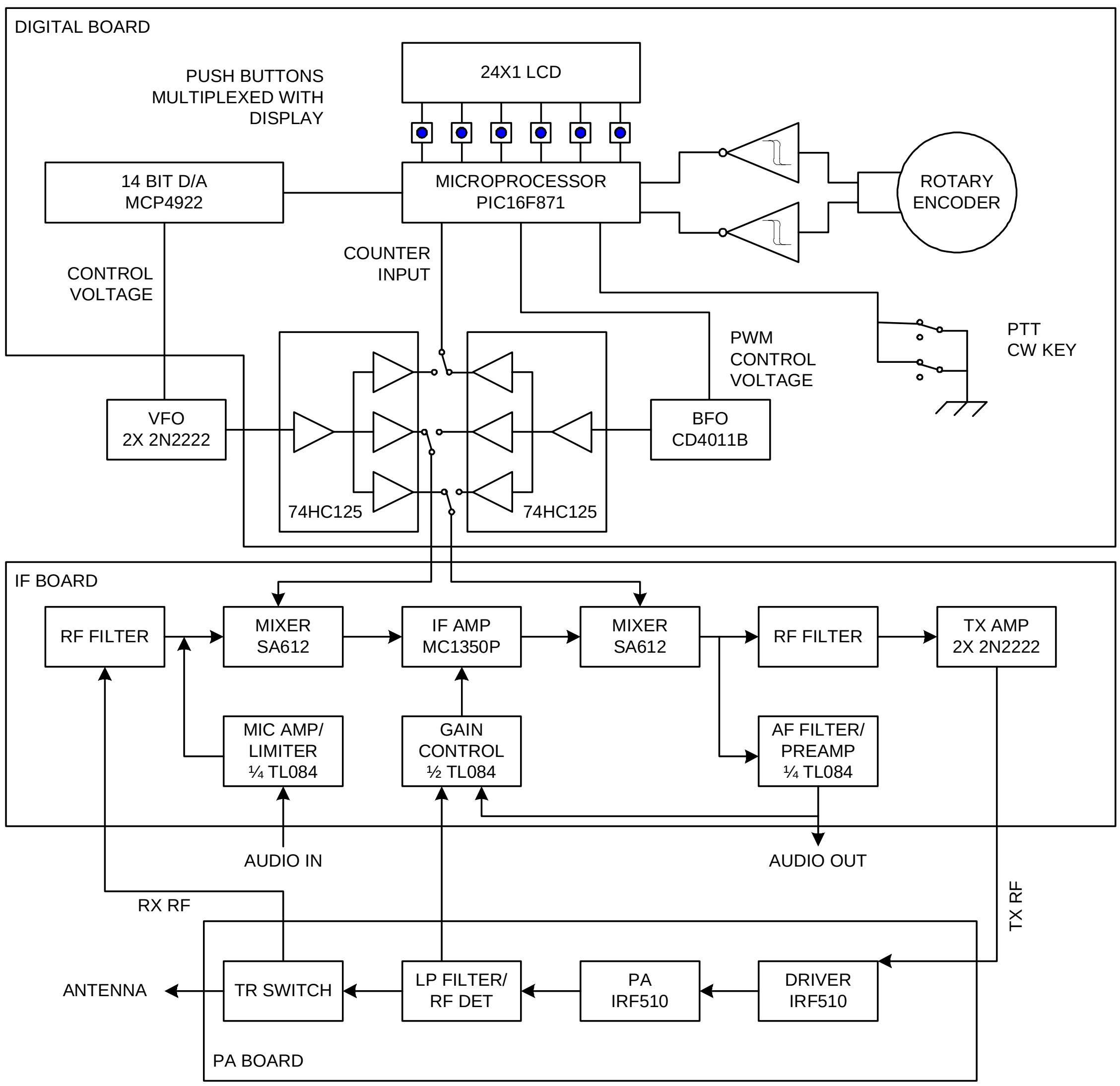

Figure 1: TAK-40 Block Diagram

Digital Board (100 Series parts) – The digital board contains the microprocessor, front panel controls, LCD, the digital to analog converter for the VFO, the beat frequency oscillator (BFO) and the oscillator switching matrix. The front panel switched are multiplexed on the LCD control lines for economy so the display will not update when a button is pressed. The BFO is a voltage controlled oscillator (VFO) using a ceramic resonator (Y101) as a tuned circuit. The pulse width modulator (PWM) output from the microprocessor is filtered (R124, C114, R131, C108) and used as the control voltage for the BFO. The microprocessor (U105) varies the BFO frequency for upper or lower sideband modulation. The microprocessor is also used to stabilize the BFO, if the BFO varies more than 10 Hz from the set frequency, the microprocessor adjusts the PWM to correct the BFO frequency.

The digital board also contains the switching matrix for the VFO and BFO (U106,U107). The NE-612 mixers on the IF board work nicely when driven with square waves and aren't sensitive to duty cycle. One section of each tri-state buffers (74HC125's) is used to convert the output of the VFO anf BFO to a square wave and the remaining sections control which oscillator goes to which mixer and which oscillator is applied to the frequency counter. The counter counts the VFO then the BFO and adds the result to calculate the operating frequency. The 20 MHz oscillator (OSC101) the runs the microprocessor is accurate to 100 PPM so the frequency displayed may be as much a 1 kHz off don't operate within 1 kHz of the band/segment edge just to be sure.

The digital to analog converter (DAC) (U103) used to drive the VFO is a Microchip MCP4922 dual 12 bit DAC. The ouputs of each converter are coupled with an 8:1 resistive divider (R116, R117) effectively creating a 15 bit DAC. Since the band is split into two 150 kHz sections this results in approximately 10 Hz steps. Actually since the tuning is not linear steps at the bottom of each band are slightly larger than steps at the top. Figure 2 shows the schematic for the digital board.

IF Board (200 Series parts) – In receive mode RF is filtered in an impedance matching RF filter (C254, L208, C240, C235, L207, C234, C226), applied to the first mixer and mixed (U201) with the VFO signal to result in a 4 MHz IF which is filtered in a 6 element crystal ladder filter (Y201-206) with a bandwidth of a bit more than 2 kHz. The signal is then amplifier with a MC1350P IF amp (U202) and applied to the second mixer (U203) and mixed with the BFO signal to produce audio. The audio is filter and amplified to drive a set of computer speakers. Audio is also used to generate an AGC signal for the IF amp and the S-meter. The audio derived AGC pops and clicks a bit but it's an improvement over manual gain control and there is an provision for adding a manual gain control (I just couldn't fit the pot and knob in the $50 budget). All audio and AGC functions are handled by a quad op-amp (U204).

In transmit mode, microphone audio is amplified and limited (soft-clipped) then applied to the first mixer and mixed with the BFO to create a 4 MHz IF signal. The IF is filtered, amplified (just like received signals) and sent to the second mixer to be mixed with the VFO to create an RF signal. The RF signal is filtered by an identical filter to the RX input filter, and two stages of amplification bring the TX signal to 2 volts peak-to-peak. There is a manual TX gain control setting and the RF detector on the PA board reduces the IF gain for automatic level control (ALC) on transmit.

TX and RX signals are diplexed into and out of the mixers so no switching is necessary. Switches are used to mute the RX audio during transmit and a diode RF switch is used at the input to the RX filter to protect the input during transmit. Figure 3 shows the schematic for the IF Board.

VFO Board (300 Series parts) – The VFO circuits is a straight forward Colpits oscillator (Q301) with an emitter follower buffer (Q302). Tuning is achieved by varying the reverse bias on a MV209 (D302) varactor diode. A second MV209 (D301) is used to switch between the lower and upper 150 kHz sections of the band (originally intended for CW and Voice segments but the FCC messed that up). There are no expensive trimmer caps to set the range, tuning is achieved by winding too many turns on the inductor (L301) the removing turns until the correct tuning range is achieved. The VFO drifts a bit for the first ½ hour but eventually settles down. Figure 4 shows the schematic for the VFO Board.

PA Board (400 Series parts) – The driver (Q401) and PA (Q402) are located on the PA board. Both stages use an IRF-510 MOSFET which is overkill for the driver but I couldn't find a better device for $0.69. The gate voltage is pulled down during receive to reduce current draw and heat. The PA is biased class A and can produce 7 or 8 watts. The RF detector (R405, R406, D403 and C413) simply measures the RF voltage at the output so it's only accurate into a 50 ohm load. No VSWR protection is included and it is possible to damage the PA transistor with prolonged operation in to a poorly matched antenna system. A tuned T/R switch (C412, D404, D405, L405) isolated the receiver input during transmissions. Figure 5 shows the schematic for the PA Board.

Chassis – Fortunately the TAK-40 requires relatively little chassis wiring. A small harness for the LCD and push button switches, cable for the rotary encoder audio in and out and key line wiring are all that is required for the front panel. The IF Board connects to the VFO, IF and PA boards for control and metering and two RF lines run between the IF and PA boards. Figure 6 shows the chassis wiring schematic.

CONSTRUCTION

OK the best way to build this radio would be to buy the printed circuit boards (PCB) but it won't fit in the $50 budget. I've included files that you can send to expresspcb.com and they will send you two complete sets of boards for just over $100. I suspect that if you got a part time job mowing lawns and saved up enough money to order the PCBs you would complete the radio sooner that if you built it using any other technique and with a higher probability of success. Be that as it may, to build the TAK-40 for less than $50 we'll have to resort to more creative techniques. Perfboard is expensive! Deadbug style is messy and difficult to rework/troubleshoot so I've used a different approach in the prototype.

Print out the mechanical files for each board. Each drawing includes a parts placement, hole position, top copper and bottom copper drawing. Cut out the hole drawing and stick it to the copper side of the copper clad PCB using glue stick or print it on a self sticking label. Make sure that the printer is print 1:1 using the dimensions of the board shown on the drawings. Mark each hole with a center punch (hammer and nail works file) then remove the drawing and drill all of the holes. Then refer to the top copper drawing and mark every hole that does not connect to the ground plane with a Sharpie then touch each hole with a larger diameter drill bit to remove the copper but don't go all the way through. Then using the parts placement drawing, the bottom copper drawing and the schematic, build the board. Take care not to short the non-grounded component leads to the copper on the and directly solder component leads that need to be grounded. The technique results in a good ground, short signal runs and solid mounting.

I built the prototype on a wooden frame and printed the front panel on photo paper in an inkjet printer. The tuning knob was made by using a hole-saw to make a circular wooden slug, drilling and tapping the sides for set screws and cutting off 6-32 screws to use as set screws. The encoder is made from rebuilding a potentiometer with the guts of a wheel mouse (see sidebar). I mounted the VFO board in an Altoids tin for three reasons; mechanical stability, electrical shielding and it not really a cool home brew if part of it isn't in a food container.

Separate the inductors L101, L201, L202, L204, L207, L208, and L405 from the PCB by 1/4 " because close proximity of the copper ground plane seems to detune the tuned circuits. Scrape the copper from under the toroidal inductore, L301, L401, L402, L403 and L404. Radioshack sells a pack of magnet wire that includes #22 and #26 enameled wire. To make bifilar windings twist two conductors using a clamp on one end and a drill or Dremel tool to twist the wire. It's very important to get 8 to 10 twists per inch in the wire before it goes on the core. The driver Q401 doesn't need a heat sink but the final transistor Q402 needs about 30 sq in of aluminum or copper attached to the heat sink tab. I used copper flashing but aluminum cake pans, soda cans anything you can find to spread the heat will work.

ADJUSTMENTS

After completion of the digital board and front panel the microprocessor can be powered up and the BFO aligned. Carefully recheck all connections looking for shorts and wiring errors and apply power. The display should show a frequency around 4 MHz. Powering the TAK-40 while holding the SWAP/SETUP button places the TAK-40 in setup mode. Repeatedly pressing the SWAP/SETUP toggles between the 5 setup modes. Here is a summary of the setup modes in the order they appear:

1. LSB BFO setup, the left portion of the display shows the frequency of the BFO at 100 Hz and the right portion shows the BFO setting at 10 Hz resolution. The main tuning knob adjusts the BFO setting (right display). Pressing SELECT stores the setting and updates the BFO. The microprocessor stabilizes the BFO frequency by counting the frequency with 10 Hz resolution and adjusting the BFO as necessary.
2. USB/CW BFO setup, works the same as LSB but adjusts the setting for USB and CW modes.
3. VFO A range test, the left portion of the display shows the VFO frequency and the main tuning knob adjusts the VFO frequency. This is useful when adjusting the VFO circuit and verifying the tuning range.
4. VFO B range test, same as VFO A test but displays the upper frequency range.
5. BFO range test, the right portion of the display shows the BFO frequency and the main tuning knob adjusts the BFO frequency. Useful for setting VR102 to make sure the BFO tuning range is 3.995 to 4.005 MHz.

Once the digital board is working properly, assemble, inspect and connect the VFO board to the digital board. Adjust the number of turns on L301 for 3.000 to 3.150 MHz in VFO A test #3 and 3.150 to 3.300 MHz in VFO B test #4.

Then build the IF board and wire it to the mic and speaker jacks and the digital board. Connect a set of amplified computer speakers and a 40 meter antenna to the RF in of the IF board and you should be able to receive signals.

Build the PA board and connect it to the IF board and digital boards, follow the alignment procedure and your ready to operate.

There are 5 pots to adjust to align the TAK-40 (VR101 is not used):

VR102 – sets the BFO range use setup mode 5 above to display frequency of the BFO and rotate the main tuning knob CW until the frequency stops increasing. Set VR102 for a BFO of 4.006 MHz. Rotate the main tuning knob CCW until the BFO stops decreasing and verify that the BFO tunes below 3.995 MHz.

VR201 – sets the AGC threshold with no signal applied to the TAK-40 adjust VR201 for 2.5 VDC at pin 4 of the microprocessor (U105).

VR401 – sets the PA Bias set for 600 mA current draw LSB mode key down, VR 203 set to minimum

VR203 – sets the TX drive level set for 7 watts (3.7 VDC at pin 7 of U105) into 50 ohms CW mode with VR202 set to minimum (wiper toward R227).

VR202 – sets the ALC adjust to reduce CW output to 6 watts (3.4 volts at pin 7 of U105) into 50 ohms.

OPERATION

Operating this radio is a breeze, the receiver is not super sensitive but it seems relatively impervious to strong signals. The rule of thumb I use is of the noise level increases when the antenna is plugged in, the receiver is sensitive enough given the current operating environment. With a GAP Triton on the roof of my Baltimore row house the TAK-40 receiver works just fine. Don’t scoff at 5 watts either, do a little math a 5 watt transceiver is 13 dB below a 100 watt unit so if you hear a signal from a 100 watt transmitter that’s 20 or 30 dB above the noise, the other operator will hear you just fine.

My on the air experience is that most operators can't believe that it's only 5 watts. I worked 15 states on LSB in about a 2 week period. Lot's of phone operators use more than 100 watts but you can work then as well and they are usually excited about working a QRP station especially homebrew. CW is even easier. Fewer stations run high power and less S/N ratio is required. Just listen for a station calling CQ or a QSO ending and give a call. I haven't tried PSK31 yet but I expect good results there as well. Don't expect to sit on a frequency, call CQ and rake in the DX, but practice, patience, good operating skills and lots of listening, will be rewarded with plenty of ham radio action.

Controls – Here is a brief summary of the front panel controls and what they do. The switches are multiplexed with the LCD lines so if you hold down a switch the display won't update. Normal operation resumes when the switch is released. It's also possible that pressing a switch may corrupt an important bit if display data just cycle the power and LCD will recover.

- Main Tuning Knob – used to adjust the frequency, can be programmed for left or right hand operation by swapping the A and B encoder lines
- SELECT – used in setup mode, also for future expansion (CW keyer, RIT, PBT) and other function if the software developer ever gets going. Holding the SELECT button down during start-up puts the TAK-40 in bootloader mode ready to accept new firmware.
- MODE – selects LSB, USB or CW, current setting retained during power off.
- RATE – selects fast or slow tuning speeds, defaults to slow on power up.
- VFO A/B – selects 7.0 to 7.15 MHz range or 7.15 to 7.3 MHz range.
- V to M – stores the current frequency in memory
- SWAP – swaps the current and memory frequencies. Holding SWAP during power up places the TAK-40 in setup mode.

ACKNOWLEDGEMENTS

All circuitry used in the TAK-40 was designed specifically for use in the TAK-40. I looked a many designs on the internet and in printed sources but no circuits were taken directly from any specific source. The most valuable tools were manufacturers' data sheets, the ARRL handbook and the Internet.

TAK-40 ENGINEERING CHANGE ORDERS

Revised: **July 23, 2008**
Previous revision was dated July 9. Changes appear in blue.

Some errors have been found on the TAK-40 printed circuit boards. Here's what they are, and what we think you should do about them.

ALERT

U106 and U107 should both be 74HC125 chips. DO NOT INSTALL 74**AC**125. This chip will not function correctly. Contact wb9lbi@portcars.org by July 31, 2008, for replacement chips.

Do not confuse these chips with U102, a 74HC14 chip.

SILK SCREEN ERRORS

We recommend that you manually fix the labels for these components, before doing any other work on your project.

- C104 mislabeled as C124.
- Label for C401 obliterated upon PC board separation
- C414 mislabeled as C415
- C221 mislabeled as C22, located between L201 and L202
- J105 mislabeled as H2
- L207 is mislabeled as R207. L207 is on the left side of the board between C234 and C240. R207 (which is marked correctly) is on the upper right between C210 and C217.
- R118 mislabeled as R188
- R211 (near pin 1 of U206) is not marked on silk screen.
- R214 (near base of Q201) is not marked on silk screen.
- R239 (to the right of C222) is not marked on silk screen
- R233 (below Q204) is not marked on silk screen.
- R305 (adjacent to C311) mislabeled as R1
- R405 mislabeled as R406
- R406 mislabeled as R405
- U102 mislabeled as U3
- ECO regarding mislabeling of R208, and R209 has been rescinded. Leave these parts labeled as delivered.

UNUSED COMPONENTS

The following components should not be installed

- VR101. Install 100K resistor in its place.
- R252, which connects between pins 4 and 5 on U201, is not present
  on the schematic. Recommendation: Do not install. This was an attempt to improve the mixer balance and it didn't work out. (From WA2EUJ)
- C109: Recommendation: Do not install.
- Pin 6 on J105 is not connected to ground. Recommendation: Do nothing. Pin 2 is grounded, pin 6 is redundant.
- R109 connects to J101 Pin 15, which is unused. Installation of R109 is optional.

MISSING COMPONENTS

C255, which connects to the collector of Q201, is missing from the
PCB design (present on the schematic).
Recommendation: Solder C255 across L203 prior to installation. Remember not to get L203 too close o the ground plane. (from WA2EUJ)

C415 missing, C414 mislabeled C415. Recommendation: Change label to C414.

C415 missing from board. Install across R403 prior to installation.

R210 is not on schematic, although it is on the Bill of Materials.

WIRING CHANGES

Upper contact of VR201 is grounded, should be floating.
Recommendation: using an Exacto knife, cut the traces to ground around the upper pin before installing VR201.

R227 (4.7K) connects to upper contact of VR203, should connect to wiper.
Recommendation: Do nothing. This is correct per the latest (June 1) version of the schematic.

Cathode of D208 does not connect to Cathode of D209.
Recommendation: Install a jumper between these two points.

VR202 connects to J201 pin 10. Should connect to pin 9 on J201.
Recommendation: Cut trace, install jumper from VR202 to J201 pin 9.

C248 (minus side) floating. Should connect to drain of Q208, also floating. Recommendation: Install jumper to between the pins on C248 and Q208 that aren't connected to anything else.

Collector of Q301 not connected to +5V. Recommendation: Jumper to ungrounded side of C310.

C413 is not grounded. Recommendation: Jumper nearest pin of C413 to cathode of D403. Jumper the other side of C413 to ground.

Pin 14 on U104 not connected to +5V**.** Recommendation: Jumper U104 Pin 14 to non-grounded side of C106.

R122 is not connected to +5V. Recommendation: Jumper R122 pin (next to C110) to the empty hole where C109 was supposed to be.

Pin 12 on U103 is not grounded on board. Recommendation: Install jumper to center pin of VR101 (VR101 is unused).

RMCLR (next to C108, looks a resistor on the silk screen) must be jumpered for transceiver to operate. A wire jumper will allow this. If you intend to enable in-circuit reprogramming of the PIC (recommended), a resistor should be installed. Recommendation: Install a resistor of value 1K to 10K ohms across RMCLR.

U102 Pin 7 not grounded. Recommendation: Install jumper across top of board from U102 Pin 7 to U103 Pin 12.

U105 Pins 12 and 31, and JPRGM Pin 3 not grounded, although they appear to be grounded. Recommendation: Jumper one of these pins (your choice) to ground side of OSC101. This fixes all three.

J106 not grounded. Jumper J106 Pins 2 and 4 to U106 Pin 7.

R121 (10K ohms) needs to be connected to +5V, Jumper R121 to U106 Pin 14.

U104 has floating pins, which is bad practice. Jumper Pins 8 and 9 to U104 Pin 7.

SUBSTITUTIONS

R303 may be dropped to 100 Ohms. Try this if the VFO does not oscillate.

Q204, Q206, Q207, Q208, Q303 may utilize either 2N7000 or BS170 transistors. The pin configurations are different for each transistor.

If running cables to the front panel longer than 6 inches, R101 through R108 may be replaced with 1000 ohm resistors.

MISCELLANEOUS

Y101 is the ceramic resonator (looks like a capacitor), not a 4 MHz crystal.

R217 should be 390 ohms. It is on the Bill of Materials with two different values.

R214 should be 4700 ohms. It is on the Bill of Materials with two different values.

R117 should be 910 ohms. It is on the Bill of Materials with two different values.

R121 should be 10K ohms. It is NOT on the Packing List. See also note in the Wiring Changes section regarding jumpers.

R208 is 100 ohms, and located next to Q202. Misidentified on schematic as R209.

R209 is 560 ohms, and located adjacent to U201. R209 appears on schematic twice.

R113 (1M ohms) is on the parts list twice under two values. However, this value is not critical; 100K ohms has been tried and works well.

R221 (3.3K ohms) is not on the parts list. It was not included with your kit.

R223 (1000 ohms) is not on the parts list. It was not included with your kit.

R227 (4.7K ohms) is not on the parts list. It was not included with your kit.

R244 (3.3K ohms) is not on the parts list. It was not included with your kit.

R251 (100K ohms) is not on the parts list. It was not included with your kit.

R403 (22 ohms) is on the schematic and packing list twice. It is correctly marked on the circuit board.

R404 (1000 ohms) is correctly labeled on the circuit board. This resistor is mislabeled as R403 on the schematic and parts list.

C209 (0.1 uf) is not on the parts list. It was not included with your kit.