

The TAK-40 SSB CW Transceiver



We are excited to introduce this winner of the first ARRL Homebrew Challenge competition!

Jim Veatch, WA2EJ

This transceiver was 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:¹

- *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 W PEP for voice and CW modes. The ALC can be set as high as 7 W if desired.*

- *It can be constructed using ordinary hand tools. Construction of the TAK-40 uses all leaded components, and assembly requires only 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 upper and lower sideband (USB and LSB) as well as CW. USB was included to allow the TAK-40 to easily operate in digital modes such as PSK31.*

- *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 across the 40 meter band.*

- *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 cost of the parts required to build the TAK-40 is \$49.50.*

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

- 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.

- Speech processor — get the most from the 5 W output.

- Automatic level control — prevents overdriving the transmitter.

- Transmit 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 to be constructed on four modules:

- Digital section and front panel.

- Variable frequency oscillator (VFO).

- Intermediate frequency (IF) board, and

- Power amplifier (PA).

The overall design is a classic superheterodyne with a 4 MHz IF and a 3 to 3.3 MHz VFO. The same IF chain is used for transmitting and receiving by switching the oscillator signals between the two mixers. Figure 1 shows the block diagram of the TAK-40 transceiver. Each board is described below. Detailed schematics, board layout and parts list are on the *QST* article details Web site.²

Digital Board

The digital board contains the microprocessor, front panel controls, liquid crystal display (LCD), the digital to analog converter for the VFO, the beat frequency oscillator (BFO) and the oscillator switching matrix. Figure 2 is the schematic of the digital board with components numbered in the 100 range. The front panel switches are multiplexed on the LCD control lines for economy so the display will not update when a button is pressed.

¹Notes appear on page 37.

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 buffer (74HC125) is used to convert the output of the VFO and BFO to a square wave. 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) that runs the microprocessor is accurate to 100 PPM, so the frequency displayed may be as much as 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 outputs 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.

IF Board

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. This signal is filtered in a 6-element crystal ladder

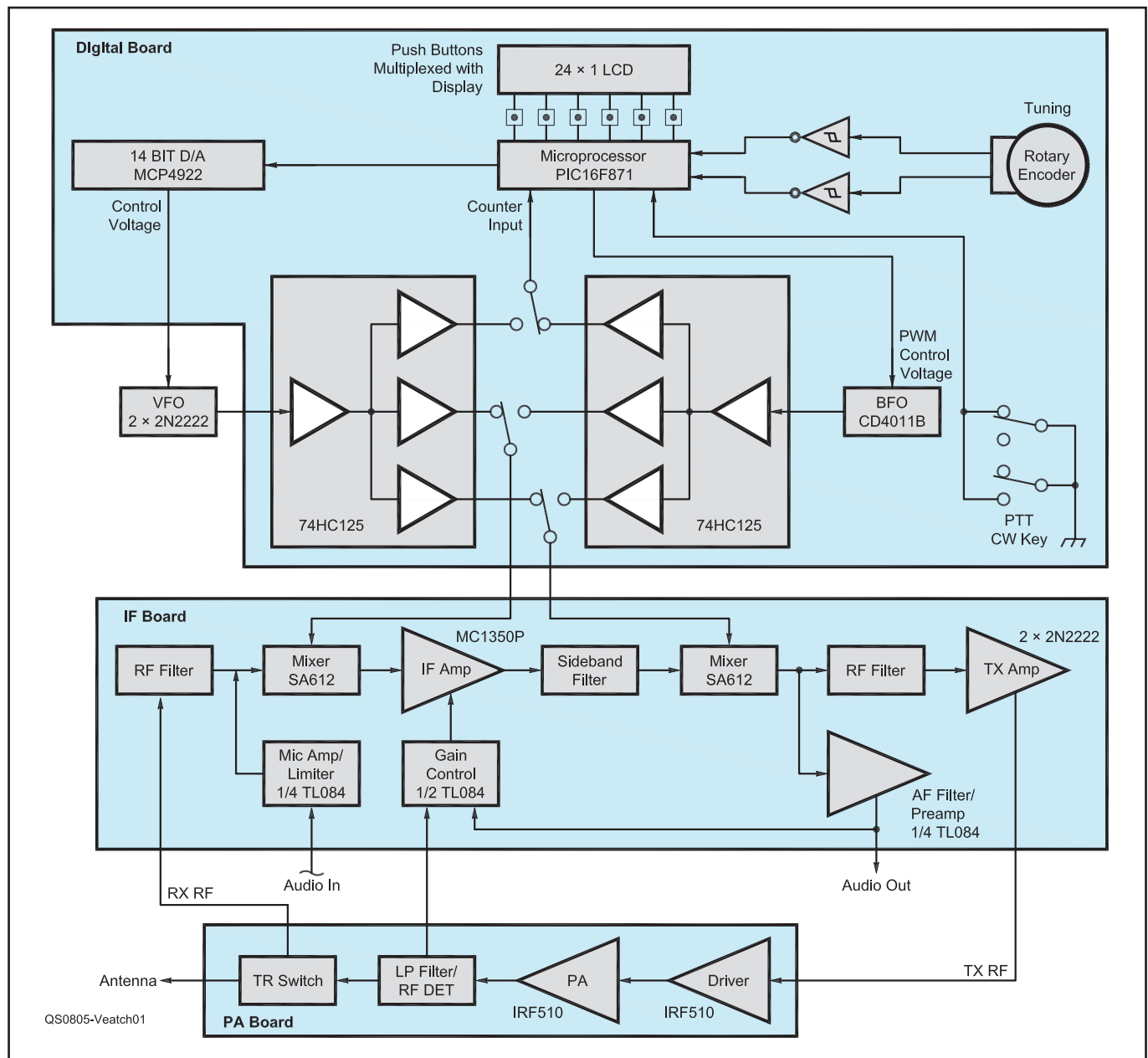


Figure 1 — Block diagram of TAK-40, Homebrew Challenge winner. This radio includes many more features and capabilities than we expected to find in a \$50 radio! All schematic diagrams and a parts list can be found at www.arrl.org/files/qst-binaries/.

filter (Y201-Y206) with a bandwidth of a bit more than 2 kHz. The signal is then amplified by an MC1350P IF amplifier (U202). The amplified signal is applied to the second mixer (U203) and mixed with the BFO signal to produce the receive audio.

The audio is filtered 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. There is a provision for adding a manual gain control (it didn't fit into the 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 as with the 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 a filter identical to the receive input filter. This is followed by two stages of amplification to bring the transmit signal to 2 V_{pp}. There is a manual transmit gain control setting and the RF detector on the PA board reduces the IF gain for automatic level control (ALC) on transmit.

Transmit and receive signals are diplexed into and out of the mixers so no switching is necessary. Switches are used to mute the receive audio during transmit and a diode RF switch is used at the input to the receive filter to protect the input during transmit. Parts on the IF board are numbered in the 200 range.

VFO Board

The VFO circuit is a straightforward Colpitts 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. There are no expensive trimmer caps to set the range. Tuning is achieved by winding too many turns on the inductor (L301), then removing turns until the correct tuning range is achieved. The VFO drifts a bit for the first ½ hour but eventually settles down. Parts on the VFO board are numbered in the 300 range.

PA Board

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 to 8 W output. The RF detector (R405, R406, D403 and C413) simply measures the RF voltage at the output so it's only accurate into a 50 Ω load. No protection is provided for excessive SWR conditions. Thus it is possible to damage the PA transistor with prolonged operation into a poorly matched antenna system. A tuned TR switch (C412, D404, D405 and L405) isolates the receiver input during transmissions. Parts on the PA board are numbered in the 400 range.

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 are required for the front panel. The IF board connects to the VFO, IF and PA boards for control and metering. Two RF lines run between the IF and PA boards.

Construction

The best way to build this radio would be to buy the printed circuit boards (PCB) but this approach won't fit within the \$50 budget. I've included files in the Web *QST* binaries package (see Note 1) that can be sent to expresspcb.com. 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 than 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 printing a 1:1 size ratio 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. Refer to the top copper drawing and mark every hole that does not connect to the ground plane with a fine point permanent marker. Next touch each hole with a larger diameter drill bit to remove the copper but don't go all the way through. 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 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. See Figure 2. 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 binaries package). I mounted the VFO board in an Altoids tin for three reasons: mechanical stability, electrical shielding and it is only a cool homebrew radio if part of it is in a food container.

Separate the inductors L101, L201, L202, L204, L207, L208 and L405 from the PCB by ¼ inch because close proximity of the copper ground plane seems to detune the tuned circuits. Scrape the copper from under the toroidal inductors 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 in² of aluminum or copper attached to the heat sink tab. I used copper flashing but aluminum cake pans, soda cans or 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 SWAP/SETUP toggles between the five setup modes. Here is a summary of the setup modes in the order they appear:

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.

USB/CW BFO Setup

This is the same as the LSB setup, above, but adjusts the setting for USB and CW modes.

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.

VFO B Range Test

Same as VFO A test but displays the upper frequency range.

BFO Range Test

The right portion of the display shows the BFO frequency and the main tuning knob adjusts the BFO frequency. This is 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.

Final Assembly

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 INPUT



Figure 2 — Close-up of the TAK-40 front panel.

port 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 you're almost ready to operate.

Final Tune Up

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

- VR102 — sets the BFO range. Use setup mode 5 above to display the BFO frequency and rotate the MAIN TUNING knob clockwise until the frequency stops increasing. Set VR102 for a BFO frequency of

4.006 MHz. Rotate the MAIN TUNING knob counterclockwise 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 V dc at pin 4 of the microprocessor (U105).

- VR401 — Sets the PA bias. Adjust for 600 mA current draw LSB mode key down, VR203 set to minimum.

- VR203 — Sets the transmit drive level. Set for 7 W (3.7 V dc at pin 7 of U105) into 50 Ω on CW mode with VR202 set to minimum (wiper toward R227).

Homebrew Challenge Results are In!

Joel R. Hallas, W1ZR
QST Technical Editor

The Homebrew Challenge was a contest announced in *QST* for August 2006 and updated in October 2006. Entrants were required to submit a home constructed voice and CW, 5 W minimum output radio by August 1, 2007. The radio had to be reproducible from no more than \$50 of new parts.

In October 2006, by popular demand, we offered a second category to the competition, allowing the use of a PC as part of the control, display or processing function as well as using it to program a microprocessor.

We are pleased that we had four entries that passed the documentation and price confirmation check. They also went through an ARRL Laboratory evaluation to make sure that they met all the ARRL and FCC technical requirements before being subjected to a thorough operational evaluation by ARRL staffers.

We have two winners to announce,

one in each category. The PC supported winner was Jim Veatch, WA2EJJ, who gathered the most points in the evaluation by our judges and is the author of this article describing his radio. In a way his radio could be considered a contender for the other award as well, since he has agreed to provide his firmware onto builders' processors at no cost if they don't have the requisite programming capabilities. The winner with a radio totally without use of a PC is Steve Weber, KD1JV, who came in close behind in overall scoring by the judges. His radio will be described in a subsequent article.

In addition to the winners above, entries were received from Dave Cribbe, NM0S, and Doug Pongrance, N3ZI. We enjoyed exploring and operating each radio. Each had its strong points and unique features, making selection difficult. Each judge spent many hours operating, comparing and scoring the radios based on their technical profi-

ciency as well as operating features and reports from distant stations.

We thank the judges for contributing their time to this effort. They were W1AW Station Manager Joe Garcia, NJ1Q; ARRL Lab Manager Ed Hare, W1RFI; Contest Branch Manager Sean Kutzko, KX9X; *QEX* Editor Larry Wolfgang, WR1B, and me. All the judges, with the exception of me, had considerable experience operating low power (QRP) radios in contests and other venues. Ed Hare has served as a judge for various QRP equipment contests (ARCI) and noted these entries stood well in comparison to many he has judged previously.

We also thank ARRL Lab Engineer Michael Tracy, KC1SX, for fitting in HBC testing between product review evaluations and his other responsibilities, as well as for helping set up the operational evaluation suite in the newly renovated W1HQ/W1INF Headquarters Operators Club station.

■ VR202 — Sets the ALC. Adjust to reduce CW output to 6 W (3.4 V dc at pin 7 of U105) into 50 Ω.

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 if 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 W either. Do a little math. A 5 W transceiver is 13 dB below a 100 W unit, so if you hear a signal from a 100 W transmitter that's 20 or 30 dB above the noise, the other operator should hear you just fine.

My on the air experience is that most operators can't believe that it's only 5 W. I worked 15 states on LSB in about a two week period. Lots of phone operators use more than 100 W, but you can work them 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 signal to noise 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.

Practice, patience, good operating skills and lots of listening, however, 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 the display shows strange looking data, just cycle the power and the LCD will recover.

MAINTUNING knob — Used to adjust the frequency. It 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 functions 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 following power off.

RATE — Selects fast or slow tuning speeds. It 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.


Acknowledgments

All circuitry used in the TAK-40 was designed specifically for use in the TAK-40. I looked at 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.

Notes

¹This project was named for three people who put up with years of basement radio development: Theresa, Ashley and Kensi.

²www.arrrl.org/files/qst-binaries/.

Jim Veatch, WA2EJ, holds an Amateur Extra class license and has been a ham since 1976. Jim has degrees in electronic technology and electrical engineering. He spent 12 years engineering long range HF and VHF sites for air-to-ground voice communications around the world. He is currently employed by L3 Communications developing RF direction finding systems. Jim is active on HF and 2 meters and is a volunteer in the Baltimore City RACES organization. He can be reached at 1704 Bolton St, Baltimore, MD 21217 or at wa2euj@arrrl.net. 

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Figure A — Judge Larry Wolfgang, WR1B, operating one of the four Homebrew Challenge Contest radios at W1HQ. Left to right are the radios of KD1JV, WA2EJ, N3ZI and NM0S.

Strays

US HOUSE RESOLUTION HONORS FIRST RESPONDERS, HAMS

◇ House Resolution 851, passed in December by the 110th Congress, which praised the work of first responders during the severe storms that struck Oregon and Washington in early December, included the following:

Resolved, That the House of Representatives —

(1) honors the citizens of the Pacific Northwest for their courage in facing the storm and efforts in helping their neighbors in a time of great need;

(2) honors the National Weather Service, State and local police officers, fire fighters, local rescue personnel, other first responders, and amateur radio operators for their efforts in the face of the severe storm;

(3) extends its thoughts and prayers to those whose lives have been devastated, and who have lost their housing, transportation, communications, water, heat, or electricity; and

(4) extends its profound and deepest sympathies to the families and friends of those who perished.

H Res 851 was introduced by Rep David Wu (D-OR) and received bipartisan support.