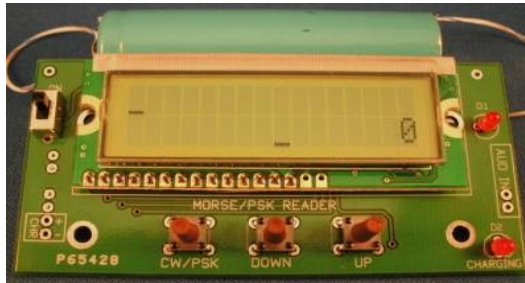


## OK1IAK Morse/PSK Reader



The OK1IAK/KD1JV Morse/PSK reader is a small, low power device which will decode and display Morse, PSK31 or PSK63 digital signals. The small size and low power requirements make it ideal for portable use and is an excellent companion to the ATS-4 rig which can transmit PSK31 using a paddle, eliminating the need for a PC. The reader can be powered by either a single Li-ion battery cell or three "AAA" batteries. A Li-ion battery charger is included on board.

### Specification:

Operating modes: CW, PSK31, PSK63  
Audio input: Accepts 0-3kHz, 1.5Vpp maximum with dynamic range 50dB.  
Center frequency: Fixed at 625Hz  
PSK31 AFC locking range: +5Hz  
PSK63 AFC locking range: +-10Hz  
Filter bandwidth, CW & PSK63: -3dB @ 70Hz, -50dB @ 150Hz  
Filter bandwidth, PSK31: -24dB @ 50Hz, -38dB @ 100Hz  
Display: 2x16 character HD44780-U compatible  
Tuning indicator: Bar graph, 56 steps, 1dB resolution  
Power supply: 2.75-6V, 3.5mA (CW LED on), 2.5mA (CW LED off)  
Charger power supply: 5V, 300mA

### Limitations:

The Reader uses a general purpose TI MSP 16 bit microprocessor with limited RAM, running at a modest 5 MHz clock instead of a high power DSP chip. The use of the MSP processor results in the very low power requirements, but does pose some limitations. These are:

- Fixed frequency filter. The filter is centered at 625 Hz. Therefore, a signal must be tuned to this frequency to be decoded. A minimal tuning step of 10Hz is required to decode PSK31.
- PSK31 / PSK63 automatic frequency control (AFC) only locks +5Hz from the center of 625Hz in PSK31 mode, +-10Hz in PSK63 mode. AFC does not follow the received signal if it drifts out of the locking range. Fairly stable transceivers on both sides are required.
- Bar graph indicator is provided to aid tuning. It is a little bit challenging to tune into PSK31 signal using the bar graph compared to clicking on waterfall when using PC.
- Although SSB band width receiver can be used, the use of narrow band receiver filter (such as for CW) will aid in tuning in signals as they peak in the filter and reduce wide band noise.
- Strong adjacent signals (closer than 60Hz to the center) can cause interference to decoding weak signals
- No squelch was implemented. In both CW or PSK modes, when no signal is presented the decoder prints garbage. To some extent it makes the decoder work with lower S/N values, but the operator is expected to listen to the signal and filter the garbage himself.

### Operation:

When first turned on a "splash" screen will appear on the display. The display will first read:

```
CW/PSK dcdv v1.0  
by OK1IAK/KD1JV
```

After about 1 second, the bottom line of the display will show the battery voltage [Battery X.XX V] Battery voltage is only displayed on initial power up. In operation, the decoded characters will start in the upper right of the top line and continue down on the second line until the 8<sup>th</sup> character. The 8 character spaces on the bottom right are used to display a signal level bar graph and an "AFC" number used when tuning PSK signals.

## Operating mode selection:

The "Menu" toggles through CW and PSK modes. The mode is advanced when the switch is closed and the selected mode is displayed until the switch is released.

## CW mode:

In the CW mode, the up down button select the length of an impulse noise filter, which has a direct influence on maximum decoded Morse code speed. Lower numbers indicates shorter filter and higher maximum WPM. Higher number indicates longer filter and lower maximum WPM, but better impulse noise filtering. If you get lot of E's and T's decoded, then your filter length is probably too short. Filter length 8 works well at 18WPM. The LED to the right of the display will blink with incoming signals. The bar graph can be used to help tune in signals.

The decoder expects reasonably timed Morse code. The decoder estimates an average dot length. Mark shorter than two dots is considered to be dot, longer than two dots is a dash. Inter symbol space is expected to be shorter than two dots. If the code is sent with left foot (QLF), the decoder will not decode it correctly.

## PSK modes:

In the PSK modes, the down button switches between PSK31 and PSK63. The up switch has no function. Use the bar graph to help tune in a signal. The number on the lower right of the display is an "AFC" reference. 0 is shown when the signal is centered in the pass band of the filter at 625 Hz. 1-4 indicates the filter center is 1-4Hz above audio signal. 9-6 indicates the the filter center is 1-4Hz below the audio signal. In PSK63 mode the AFC offset is multiplied by 2.

First tune the signal to get maximum bars on the bar graph. This can be little bit challenging when there is a lot of QRM or QRN. Impulse noise makes the bar graph jump up and down. Once the signal is tuned to maximum bars, the decoder may still print garbage. The AFC locking range for PSK31 is +-5Hz. If the tuning step of your radio is 10Hz, the decoder will decode only at a single particular frequency. One usually needs to try blindly one or two 10Hz tuning steps up or down from the maximum perceived bars before the signal is tuned in with sufficient precision and the decoder starts to print the real text.

Specific to ATS-4. Tuning step of the ATS-4 in PSK mode is 5Hz. If you are answering PSK31/63 call, use the AFC indicator to tune as close as possible to the center of the received signal. In PSK31 mode with 5Hz tuning step one shall be able to tune in with precision of +-2.5Hz. The AFC indicator shall show values between 8-9 or 0-2. If not tuned precisely enough, the decoder will still read, but the other side may miss your signal.

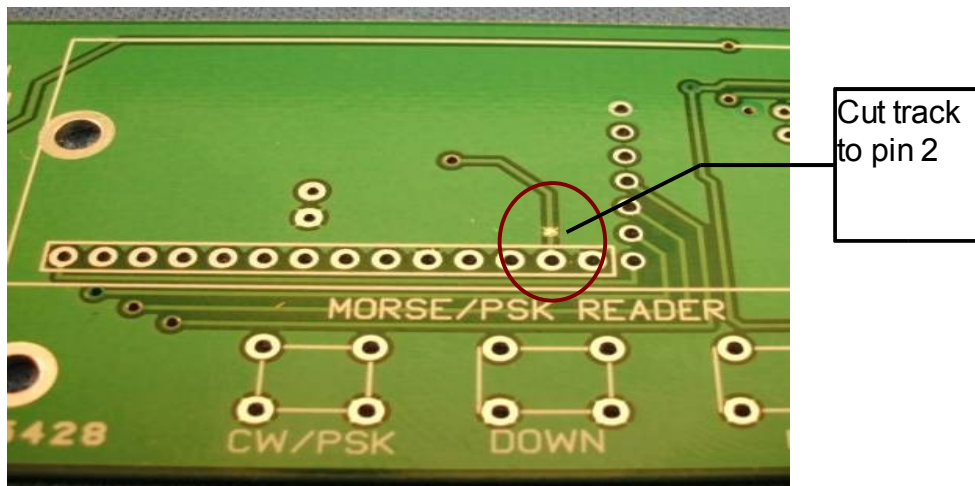
## The bar graph:

The bar graph is comprised of 7 characters comprised of 8 bars each, for a total of 54 steps. Each bar represents 1 dB of signal. If the range is exceeded, the bars will change to "!" indicating overload. When an overload condition occurs due to too large an input signal, harmonics will be produced in the A/D converter, which will affect the decoding

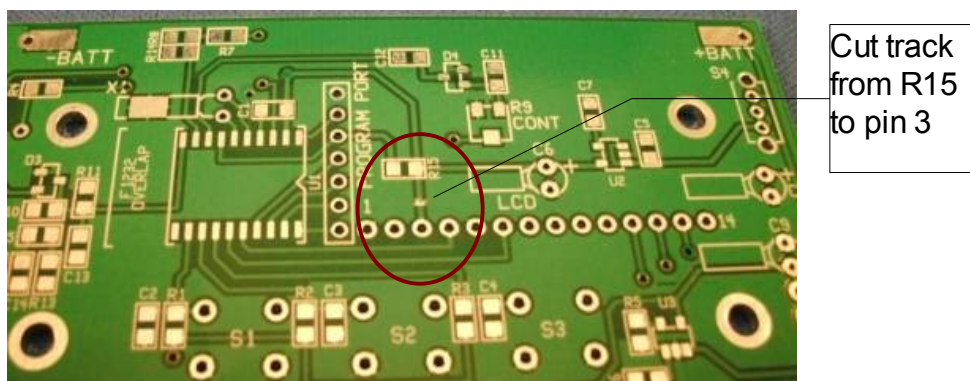
Board fix:

The connections to pins 2 and 3 of the display are reversed and this must be corrected by cuts and jumps. The cuts are best made now before any parts are mounted. Note: depending on when your kit was shipped, these cuts may have been made for you. If they have, it is a good idea to use an ohm meter to check to see if they were made properly and are truly “open”.

Top side: Cut track going to pin 2 of display header pads.

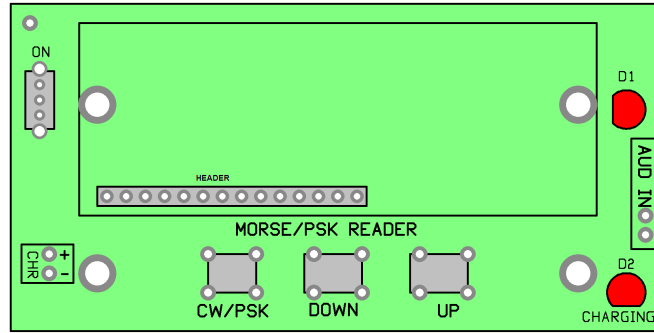


Bottom Side: Cut track going to pin 3 of display header pads.





## Top side parts



- D1, D2 – short lead goes into hole on flat side of part outline
- S4, slide switch
- 14 pin SIP pin header – long pins go into board. The pins sticking out the bottom of the board can be clipped short to reduce the profile of the board and to reduce the risk of them shorting to something.
- S1, S2, S3 – TACK switches
- LCD display module. Note that there are two unused pads on the display, the two end ones on the right side of the row. First solder only one pad to the header, then make sure the display is parallel to the board before soldering the rest of the pins. Spacing the display from the board with a # 4 nut and screw in the mounting holes will help keep the display spaced properly and parallel to the board.

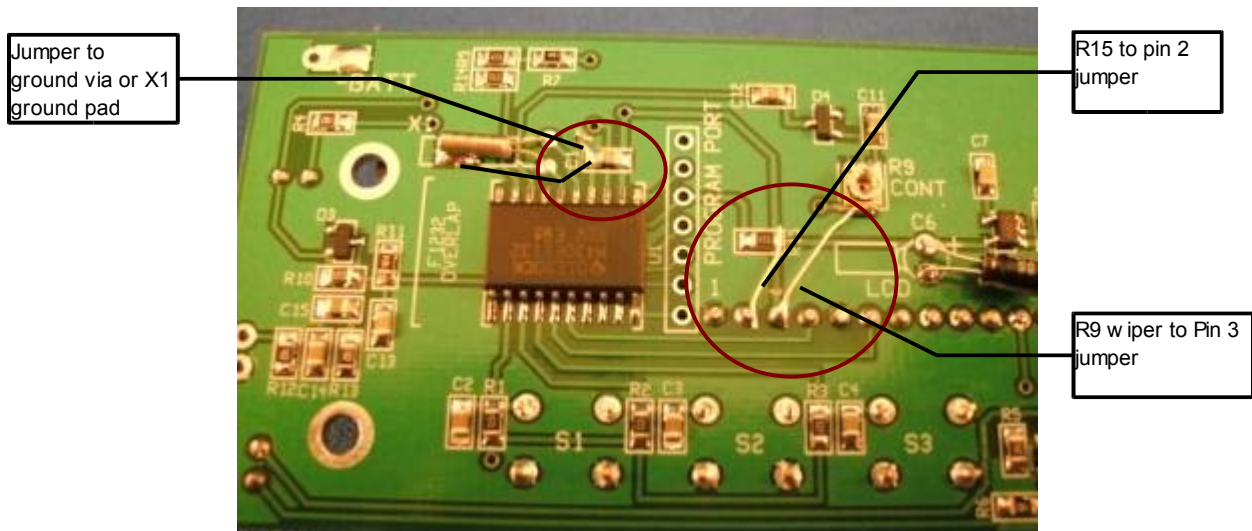
### Board fixes:

Three things must be now done to fix the board.

1. Connect a jumper from the C6 side of R15 to pin 2 of the display header pins
2. Connect a jumper from the wiper of R9 to pin 3 of the display header pins.
3. Connect a jumper from the end of C1 on X1 side to the ground plane.

Electrolytic capacitor lead clipping can be used for the jumpers.

Scrape away some of the solder mask around ground via near end of C1 to make solder connection to. Or use short length of magnet wire to jumper over to ground pad at X1.



Assembly is now complete.

## INSPECT YOUR SOLDER CONNECTIONS!

Before applying power to the board, **first make sure there are no shorts between the battery + and ground.** This would most likely happen between pins 2 and 3 of U3, the battery charger chip. Also check for a short between pins 2 and 3 of U2, the battery input to the regulator. If there is a short in either place, a high current capacity battery will fry the tracks connecting to these points and possibly damage the battery. It is also a good idea to inspect the solder connections to all the chip resistors and capacitors to make sure you didn't forget to solder one end of the part.

### Audio input connections:

Audio is connected to the "AUD IN" pads. You have several options here. Two stereo 3.5 mm jacks are included with the kit. These can be wired in parallel to provide an audio in and an audio out jack so headphones can be used to monitor the signals. This is needed for tuning the rig. Another option is to clip one or both ear buds off a cheap set of headphones and hard wire the cord to the board which can be plugged directly into the rig. This would eliminate the need for a separate jumper cable with plugs on both ends. If only one ear bud is clipped off, the other one can be used to monitor the signals, thus eliminating the need for a separate set of headphones. In case you use very sensitive ear buds, you need to be careful not to attenuate the signal for decoder too much. If the bar graph does not flicker on radio background noise, you may need to increase radio volume and attenuate signal into the ear buds with serial resistor of 50-100 Ohm.

### Battery selection:

The Morse/CW reader board can be powered with either a single Li-ion cell or three "AAA" batteries. Reverse battery protection is not included in the circuit, so you need to be very careful to hook the battery up the correct way. Protection is not included as to allow using every last drop of energy in the battery, going down to 0.9V per primary cell. If you plan to integrate the reader circuit into your transceiver, make sure the decoder will not be powered with higher voltage than 6V. If you need to power it with higher voltage, an external 5V linear regulator is recommended.

If you choose to use a Li-ion battery, you can use either a cylindrical or a flat, rectangular type. The AHr rating does not have to be high, as the reader only draws a few milliamps. A 350 maHr battery would be fine. Which type you choose will depend a lot on how you package the reader. Using a small flat battery or single AA/AAA sized cylindrical Li ion cell allows packaging the reader into an Altoids tin. Low cost Li-ion batteries are available from a number of dealers on the internet. Look for types with the built in protection circuit. One place which looked to have a good selection at very reasonable prices is [www.all-batteries.com](http://www.all-batteries.com) Another option is [http://www.sparkfun.com/commerce/product\\_info.php?products\\_id=341](http://www.sparkfun.com/commerce/product_info.php?products_id=341) , which includes protection circuit

The Lithium batteries are known to be dangerous and many builders fear them. They are reasonably safe if handled with respect. Li-ion/Li-Pol batteries shall not be overcharged, undercharged, shorted, mechanically deformed or punched. The Li-Pol cells enclosed in aluminum foil sacks are quite fragile, cylindrical Li-ion cells are more sturdy. If you plan to use Li-Pols, make sure you build the decoder into a sturdy box. If the battery shows any marks of physical damage or if the aluminum sack of the Li-Pol cell bloats, the battery shall not be used. Drop it into salt water overnight to discharge fully and dispose off the battery properly.

The decoder does not have undercharge protection. Only voltage readout on startup is provided, which is based on controller internal reference. Check the precision of the voltage readout against your DVM. Don't discharge your Lilon/LiPol battery below 3V. Do not forget to switch the decoder off, otherwise the battery will be discharged and destroyed. This may take time because the decoder draws so little, but eventually it will happen. There are Lilon/LiPol protection circuits on the market, which disconnect the battery when its voltage drops below 2.5V. There are Lilon cylindrical cells sold, which have the protection circuit built in. If you happen to discharge the battery below 2.5V and the charger circuit refuses to recharge it, the battery may be saved by charging with very low current like couple of mA up to 3V, when the battery may be fully charged with the built in charger. The battery will likely lose some of its capacity. If the LiPol battery sack is inflated, don't use it.

### The built in charger:

Maximum charge rate is set by R5 to 250 ma. The "preferred" fast charge rate for Li-ion cells is 1C and not to exceed 2C. The value of R5 needed for other charge rates can be calculated by  $1000 / K \text{ ohms} = \text{ma}$ . Charger input voltage is 5 volts and not to exceed 6 volts. A USB port can be used to supply the charger voltage or most any 5V output chargers for cell phones and the like which you might have. Since there are any number of charger plugs used, a jack is not supplied. **Charging progress is indicated by single LED. The LED is lit while charging, it shuts off when the battery is fully charged.**

## Packaging the decoder:

It was hoped the decoder would fit into an Altoids tin, and it can be made to fit, though it is tight and not much room for the jacks and battery. Using a single flat Li-Pol cell mounted under the board or AA/AAA sized cylindrical Li-ion cell on the side of the board will likely fit. The control switches (except the on/off switch) have actuator arms long enough so the board can be mounted behind a panel. **To keep the price of the kit down, we used a low cost display, that does not have the usual metal frame covering the connection between the display glass and circuit board. The connection strip looks quite fragile.** No matter what you use for an enclosure, you should include a clear plastic window to protect the display. Mounting hardware is not included as what you need will depend on how and what you mount it in. Although 4 mounting holes are supplied, only the two next to the switches really need to be used.

Two ideas, that we did not have chance to try yet. Hammond manufactures clear acrylic boxes. 1591ATCL has about the same dimensions as the Altoids tin. Hammond also manufactures clear acrylic lids for their black ABS boxes. 1591MSBK or 1591MSGY is the order number for ABS box, 1591LC is the lid. The transparent box will be cheaper than the ABS box and separate acrylic lid. Mouser stocks Hammond products. <http://www.specialtybottle.com> stocks hinged tins slightly bigger than Altoids with clear acrylic window on the lid. Look for THN8 order code. The same lid is stocked by The Four State QRP group <http://www.wa0itp.com/cleartoptin.html>

## Powering up:

Set the contrast trimmer to the middle. Switch the decoder on. Set the contrast trimmer to make the display background just barely gray. Congrats, you are ready to try it on the air.

## Theory of operation:

Standalone CW reader devices are usually equipped with audio amplifier chain, active op-amp filter, tone decoder chip (LM567 or XR2211) and controller. This kit follows a different approach. External analog circuits are replaced by digital signal processing algorithms inside the controller chip. This approach not only makes the circuit much simpler and cheaper, but also saves battery power. Digital circuit does not need any adjustment and is independent of component values, temperature and battery voltage. FIR (Finite Impulse Response) filters do not ring. Ringing spreads signal marks and noise impulses in time making CW decoding particularly difficult.

The decoder runs from 2.7V low quiescent current, low drop voltage regulator. This allows the decoder to suck every drop of energy from 3 primary cells and allows for single Lilon, LiPol or LiFePO4 cell. The voltage regulator shall not be powered with higher input voltage than 6V.

The MSP430 controller is specifically designed for very low power. MSP430F1132 has 8kB program memory and 256B of RAM. The controller is clocked by internal oscillator, running at about 5MHz. There is no hardware multiplier, which makes development of DSP algorithms on this architecture challenging. All multiplications are performed using shift / add operations. A PC program was written to generate assembler source code for optimized FIR filters using only shift / add operations and digital filters occupy most of the program and data memory of the controller.

Input signal at earphone level is connected to the A/D converter of the controller. A minimal R/C filter is placed between the audio in and A/D converter input to help reduce high frequency and impulse noise. The A/D converter has a resolution of 10 bits and a span of 0-1.5V. 10 bits of resolution correspond to 60dB maximum dynamic range. The A/D input is biased to 0.75V by an external resistor network. The rest of the signal processing is done by firmware.

The controller uses a 40 kHz oscillator for timing the signal sampling and for CW / PSK decoding. The audio signal is sampled 40,000x per second. Every 8 samples are averaged, which provides a frequency roll off at higher audio frequencies (see Figure 1) and decimates sample rate to 5,000 samples per second. Oversampling / averaging also improves dynamic range.

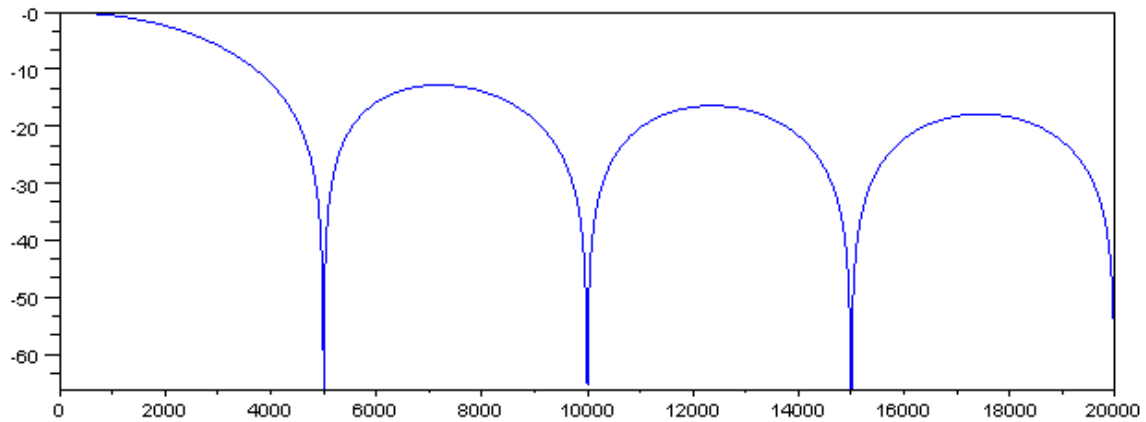


Figure 1: Frequency roll off (dB/Hz) when 8 values are averaged at 40ksamples / second

At the next step the signal is mixed with quadrature (I/Q) oscillator running at 625Hz, low pass filtered with 51 tap FIR filter and 16x decimated, resulting in an I/Q data stream of 312.5 samples per second, see green curve on Figure 2 and 3 for frequency response. Sample rate after 16 decimation is exactly 10x faster than PSK31 baud rate, or 5x faster than PSK63 baud rate. What was centered at 625Hz before mixing is now centered around zero. Quadrature (I/Q) signal representation allows to maintain full information of a narrow band signal at much lower sample rate, significantly reducing processing requirements. Filters on Figure 2 and 3 are centered around 0Hz. To visualize the frequency response at 625Hz, one needs to mirror the frequency response curve below and above the new center frequency. The resulting filter bandwidth is 2x wider than how it looks like in baseband.

The baseband I/Q stream at 312.5 samples per second is filtered once more with FIR filter of 17 taps, see blue curve on Figures 2 and 3. Resulting signal has 3dB bandwidth of 70Hz and suppression >50dB at 150Hz. This signal is fed to the CW or PSK63 decoder, but it would be still too wide for PSK31.

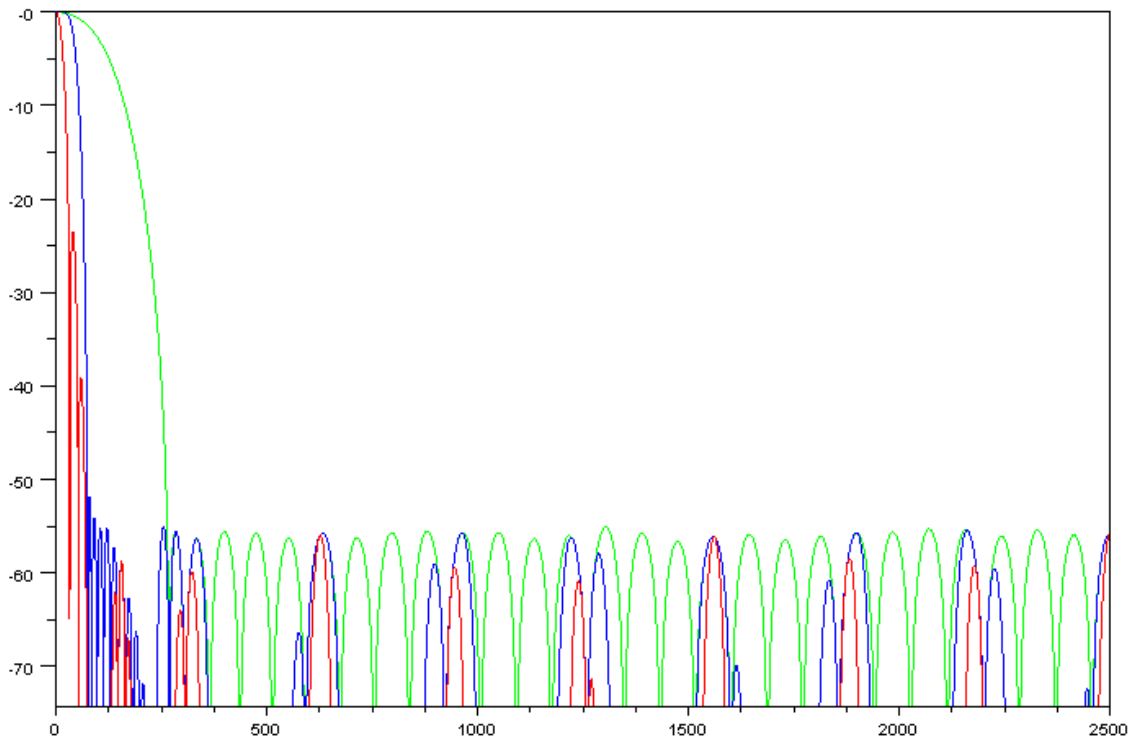


Figure 2: Frequency response (dB/Hz) of FIR1 (green), FIR1+FIR2 (blue) and FIR1+FIR2+FIR3 filters (red)



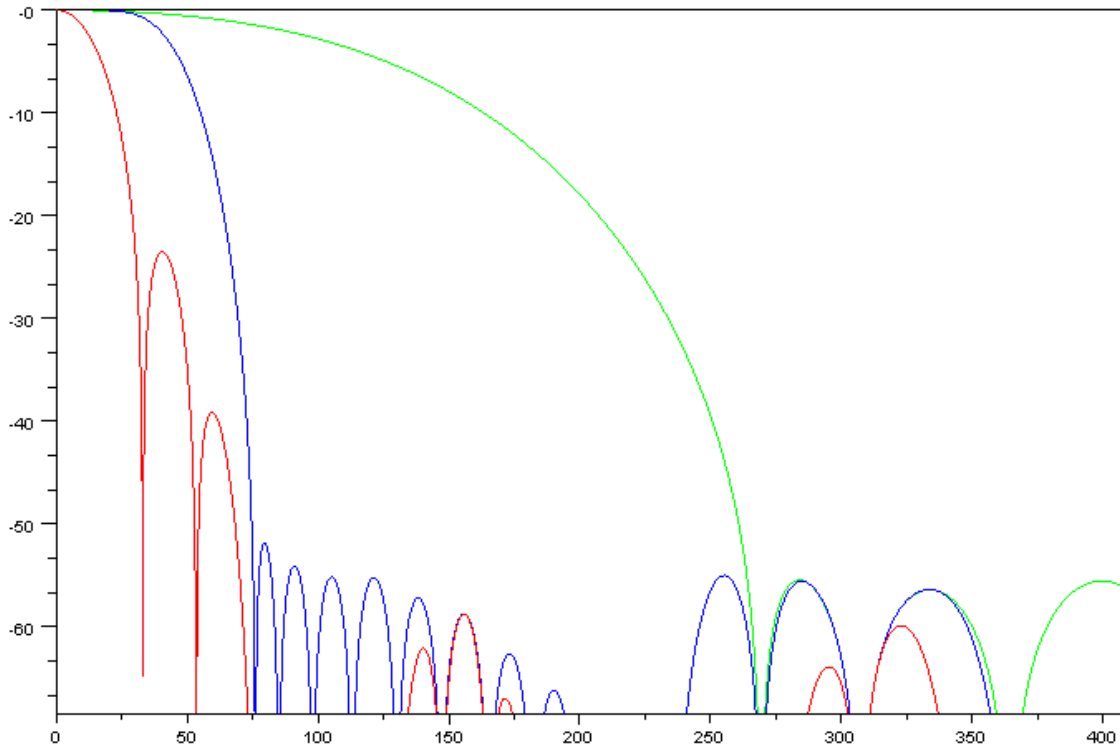


Figure 3: Close in of frequency response (dB/Hz) of FIR1 (green), FIR1+FIR2 (blue) and FIR1+FIR2+FIR3 filters (red)

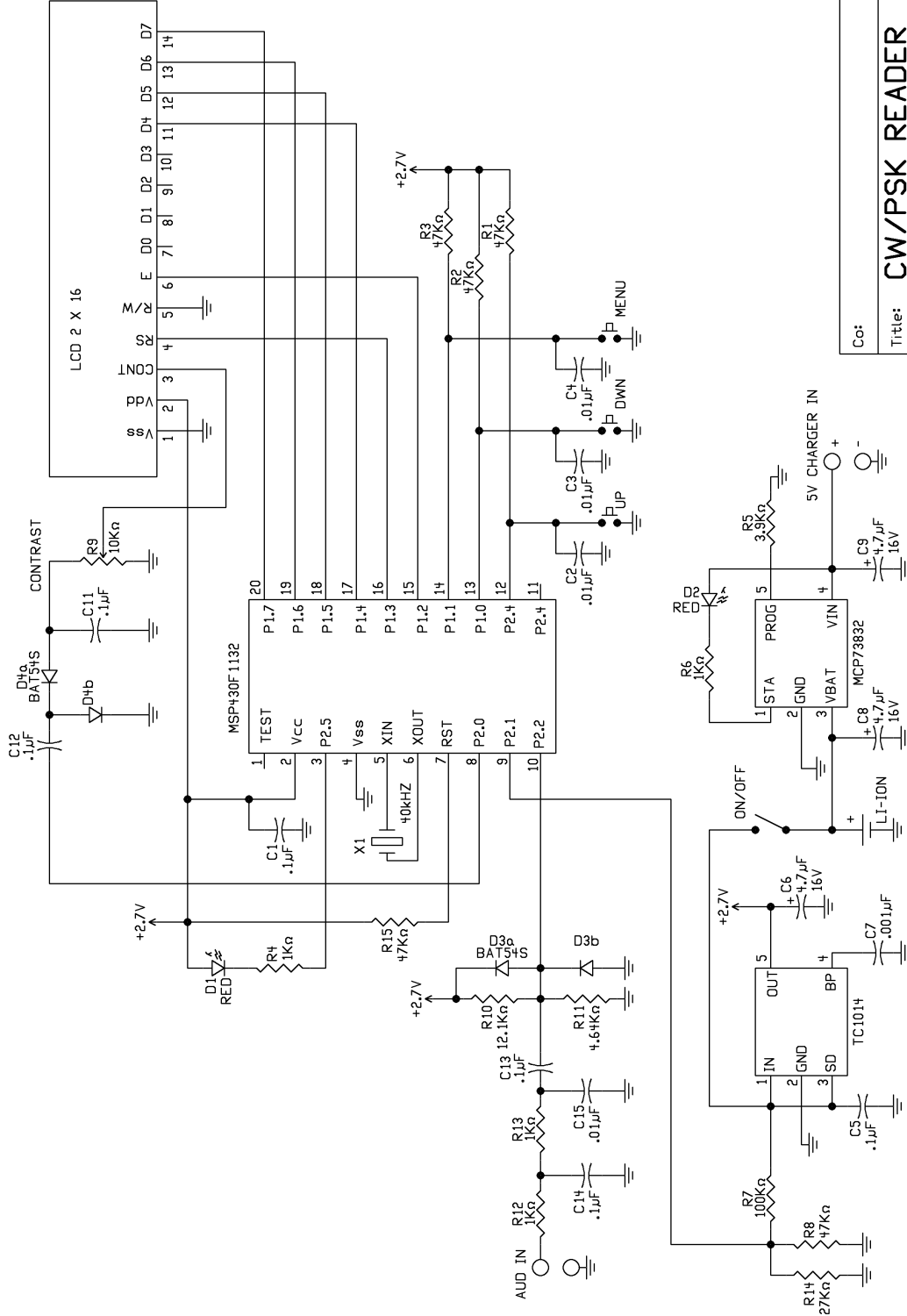
In the case of PSK31, the I/Q signal is further 2x decimated and filtered by an additional FIR filter with 8 taps. This filter is kept short mainly because of the lack of RAM. Still, it provides respectable roll off being less than 2x wide than the average PC sound card implementation when used in white noise. The close in roll off is less than ideal, making this decoder susceptible to QRM from very close strong signals.

In PSK31 or PSK63 mode, the bit sync is recovered from the amplitude envelope and phase difference is calculated between successive symbols. The phase difference of an ideally tuned clean signal will be either 0 or 180 grades. If the tuning is not exact, the phase difference will be skewed. The decoder uses this information to recover a close in AFC estimate. The PSK decoder works very much the same way as in Digipan or PocketDigi.

In the CW mode, an amplitude envelope is calculated from the filtered I/Q signal and fed into a moving average filter to filter out noise spikes. The length of the circular buffer is configurable by the operator. Filtered amplitude envelope is sliced at  $\frac{1}{2}$  between the maximum and minimum of the amplitude envelope averages and lengths of marks / spaces are measured.

The CW decoder measures lengths of two successive marks. If one of them is roughly 3x longer than the other one, the sum of them is stored into a circular buffer length of 8. The average dot length is calculated as an average of this circular buffer. This algorithm adapts quite well to changes of speed.

HD44780-U compatible 2x16 text display is connected to the controller using 4-bit write only interface. The display controller may be operated from 2.7V, but the LCD display backplanes need more than that. One needs to provide voltage about 4.1V between the Contrast and VDD pin of the display. 40kHz square signal is generated by the controller, which drives negative voltage pump.



Co:	
Title:	CW/PSK READER
Board:	DECODER
Author:	KD1JV/AB2ZA
Date:	3/29/10
Revision:	A
Size:	A
Sheet	1 of 1