Construction Information

This document provides useful information for building, testing, and calibrating the receiver. It also has a section at the end describing construction of the loopstick antenna.

1. Parts

SA602A

NE602A can also be used. An SA612A is very similar, and should work as well.

MA198CT

This is a dual diode in a SOT-23 (surface mount) package. It was chosen because it has fairly low leakage, but 1N4148's will usually work fine.

MVAM109

Motorola no longer makes this part, but some vendors still have stock on hand. One builder from Japan found a suitable substitute from Toshiba (1SV149). A Philips BB112 has also been suggested as a possible substitute. Another possibility is to use an NTE618 (MVAM115 replacement), which is available from Mouser. This part has higher capacitance than the MVAM109, but by changing C11 to 150pf, should work OK.. I've only tested the circuit with the MVAM109.

PIC16C76

This part was originally chosen over the 16C73A because of a documented problem with running the UART baud generator at the required rate. It appears this problem has been fixed in the 16C73B part. I will attempt to get the software to run on this lower cost processor. If cost is a major issue, a one time programmable (OTP) 16C76 could be used, which saves over $5. The windowed version specified in the parts list can be erased and reprogrammed if software changes occur.

2. Packaging, Connectors, Power Source

All external connectors, controls, indicators, and power supply circuitry is separate from the receiver PCB to keep the PCB as small as possible and allow maximum flexibility in packaging, interfacing, and power source. The PCB does have pads to accept 1.25mm pitch connector headers to allow easy PCB separation from case mounted connectors and power supply if this is desired. Not using these connectors will save over $5 in parts and make initial assembly easier since the socket pins for these connectors are *really* small and not easy to crimp or solder.

Good choices for antenna and GPS data cable connections are 2.5mm or 3.5mm stereo phone jacks. Shielded cables should be used between the receiver and antenna, and to the GPS. As long as these runs are short within the DGPS case, shielded wire won't be necessary between the connectors and PCB.

The board requires a +5V power source. A 9V battery and the LP2950 regulator circuit is fairly small & light, and should run the receiver for about 60 - 70 hours.

3. Parts Preparation

Important ! Some of these steps need to be done before mounting parts on the circuit board.

PCB From FAR Circuits

- Before mounting any parts on the PCB, check it carefully for shorts, especially where traces run between IC pins. Other areas with narrow gaps are the connector pins and some of the transistors. Checking for gaps along the narrower traces is also a good idea. The time spent looking for small PCB defects can potentially save a LOT of grief later on.

- Check for missing holes. The following holes were not drilled on the sample I received: U5-19, J3, and ground trace holes opposite U5-22,23 (below U6-5). These can be drilled out with a 0.028" (#70) drill bit. The T2 primary center pin was not drilled either, but this can be left as-is, since that pin gets cut off before mounting anyway. There were also a couple of extra holes in the ground traces near the transformers and above U5, but these can be ignored.
- Cut off the center tap (middle) pin on the primary windings of T2 and T3.

PCB From Andrew Wilkinson

- The primary center tap pins for all transformer need to be cut off.
- The holes for the shield tabs on T4 are too small. The tabs can either be trimmed to fit the holes, or the holes can be drilled out to the proper size.
- Carefully scrape the solder mask off the traces where D2 (surface mount diode) attaches to the bottom of the board. Be careful not to cut the traces. An alternative is to solder a pair of clipped resistor leads into the holes adjacent to U1, then solder the diode vertically to the wires.

Transformers

Remove the capacitors from T2 and T4, which are the small ceramic cylinders recessed in the bottom. This is most easily accomplished by breaking and removing the ceramic center with a small screwdriver. The capacitor ends can be left in place, but if they are removed, be careful not to pull the wires away from the pins, as this may sever the connection to the windings.

PIC Microcontroller

The PIC microcontroller needs to be have the software programmed into it. If the PIC is not socketed, this needs to be done before the device is soldered to the PCB.

Loading the software into the PIC is done using a *device programmer*, and there are a number of commercial and hobby grade programmers available to do this. If you don't have access to an existing programmer, several "build-your-own" projects are published on the web. A good place to start looking is at ftp://ftp.mcc.ac.uk/pub/micro-controllers/PIC/piclinks.html.

The file "dgps.hex" is all that is needed by a programmer to program the software into the PIC, and is included in the documentation archive.

4. Assembly Tips

- Stuffing the board is most easily accomplished by using the parts list and layout drawing (or silk screen on Andrew's PCB) as references. All axial parts (resistors, diodes, inductors) are placed vertically.
- It’s probably a good idea to use a socket for the PIC so software upgrades can be easily done, but socketing the rest of the IC’s isn’t really necessary if a PCB is used, and may slightly degrade long term reliability of the unit.
- Following anti-static practices is always a good idea when handling the semiconductors, and for handling the board once the IC’s are installed. Assembling the passive parts first makes this easier.
- Leave C5 out. This will facilitate tuning the RF amp’s bandpass filter. Don’t put the PIC in it’s socket until after the filter is tuned.
- Leave R19 out to allow testing active filter.
- On Andrew's PCB, no components are installed in R7, R8, or C8. Install a jumper in place of R7. Q3 (2N5210) must also be installed rotated 180 degrees from the orientation shown on the silk screen overlay.
- Make sure transformers with cut primary center tap pins get oriented correctly. The T2 primary side is adjacent to T1, while the T3 primary side is away from T2. On Andrew's PCB, the silk screen has a white dot under the clipped pin.
- The PCB layout was done so that all 1N4148 diodes are oriented with the cathode (band) side down when they are mounted as shown in the layout drawing.

- The surface mount diode (D2) is meant to be mounted on the bottom of the board. The PCB has an extra set of pads / holes if through hole parts are substituted. Leave the outer set of holes free for mounting R41.
- Single sided PCB's requires eight jumpers. W5 (R19 to C22) carries a low level signal and should be routed to minimize crosstalk, which can be done by having the wire overlay the +VA power distribution trace.
- Double sided PCB's require three jumpers: W1, W4, and W8 (in place of R7).

5. Testing and Calibration Tips

5.1 Calibration Aids

A simple buffer circuit is shown in the HW Description document (figure 2) that can allow the receiver's local oscillator to be used as a signal generator for tuning the antenna preamp and RF bandpass filter. The input is connected to the R10 / Q4-D node on the receiver. L1 is a single turn of wire that slips over the plastic tube holding the loopstick antenna rod. L1 and the series 6.8k resistor can be omitted if not needed. The circuit can derive it's power from either an external source or from the receiver. The supply voltage is not critical.

5.2 Initial Power-up

The board requires a source of regulated +5.0 ± 0.25 VDC power. One way to initially test for major problems is to power the board up through a DMM set up for measuring current. Current limiting is a good idea, and the LP2950 will do this adequately. Current consumption (with or without the PIC) will typically be < 10 mA.

5.3 Bandpass Filter Tuning

Tuning the bandpass filter requires the use of a signal generator and an oscilloscope, and the ability to control the signal frequency to within 1 kHz or so. Since there is a lot of interaction between the three filter sections, tuning is simplified quite a bit by isolating the stages and tuning T1 and T3 separately. The following procedure can be used. When connecting the function generator to the board, a 0.1 uF DC blocking capacitor should be used. Note that measured signal levels are approximate.

1. If C5 is installed, temporarily remove it. Solder short wires into the holes where C5 mounts to be used as temporary test points. Solder temporary shorting wires from each primary pin on T2 to ground (these are the pins connected to T1 and T3).
2. Apply power to the receiver.
3. Set the signal generator to output 304 kHz at approximately 50mV p-p and apply the signal to the receiver's antenna input (through DC blocking capacitor).
4. Adjust T1 for maximum amplitude on the secondary of T1 (C5 test point wire). The measured signal should be around 300mV p-p.
5. Remove the signal from the antenna input and apply it to the other C5 test point wire (secondary / input of T3).
6. Measure the signal at Q3’s emitter (R9), and adjust T3 for maximum amplitude. The signal frequency should still be 304 kHz. It's best if U3 (SA602) is installed before making this or subsequent adjustments.
7. Install C5, remove the temporary shorts from T2 to ground, and reconnect the signal source back to the antenna input. The amplitude should be set to around 25 mV p-p.
8. Adjust T2 for optimum bandpass response over the 283 kHz to 325 kHz range. The goal is to obtain output amplitudes at the edges (283 kHz, 325 kHz) that are within 75% of the average level within that range. Minor peaks and dips in amplitude between 283 kHz and 325 kHz are normal, but the lowest point shouldn’t be less than half the highest. Sharp amplitude roll-offs should begin to occur within 10 kHz of the edges. The output signal should be around 500 mV p-p.

5.4 Local Oscillator Adjustment

T4 is adjusted so the control voltage on D1 ranges from about 1.7 to 3.4 volts for the tuning range of 285 kHz to 325 kHz, respectively. Adjustment can be done by selecting a station frequency of 300 kHz and then setting T4 so the voltage measured across C17 is 2.4 volts.

Proper lock of the PLL synthesizer and good stability requires a solid, stable signal to U4-8. The buffer/amp driving this pin is somewhat sensitive to component tolerances and noise. I apologize for this marginal design solution, but I was trying to keep the circuit low power and simple. The signal at U4-8 should be at least 0.7V p-p (1.0 - 1.2V p-p is typical). If this signal is too small, try changing the value of R11 up or down. If all else fails, a cascode configuration (see Q1, Q2) could be used. Random frequency jitter can occur if the signal is a little noisy. This is most easily detected by listening to the audio monitor while inputting a steady signal at the antenna input from an external signal generator set to the tuned frequency. A steady tone indicates stable PLL lock. If jitter is observed, changing C14 from 47pf to 100pf may help, but at the expense of increasing the buffer's high frequency roll-off, and signal amplitude at the upper frequencies.

The amplitude of the signal at the gate of Q4 should be between 200 and 300 mV p-p.

If no oscillation is observed, one possibility is that the polarity of one of the transformer windings is reversed. The easiest thing to try first is to use a different transformer (swap with T2).

5.5 500 Hz Active Bandpass Filter Test

This step isn't required, but will verify correct operation of that circuit block.

1. Verify the '+' reference voltage (R34/R35 divider) is within 50 mV of 1/2 +VA. This is tighter than the worst case 5% tolerance limits of the resistors would provide, but resistors from the same manufacturing lot usually match pretty closely.
2. R19 must be isolated from U3-5 to allow injecting a signal into R19. The signal generator output impedance must also be 2K ohms or less. If necessary, place a 1K resistor across the output.
3. Set the signal generator to output 500 Hz at 25mV p-p and connect it to the side of R19 that would normally be connected to U3-5.
4. The signal at U1-7 should be approximately 760mV p-p.
5. The -3dB (540 mV p-p) points should be at about 400 Hz and 600 Hz, and the response should be fairly flat ($\pm$ 50mV) between the end roll-off points.
6. Observe the signal at U1-8. The total gain should be about 3000 when the input signal is < 300 μV, but should begin to clip at around 1V p-p for input levels above that. The comparator output (U2-1) should also start transitioning before clipping begins.
7. Set the input signal level to 0. The output at U1-8 should typically have a noise level < 200 mV p-p, and should be below the hysterisis of the comparator (no level changes at U2-1).

6. Loopstick Antenna

The key to good antenna performance is to get a fairly close match between the inductance of the loopstick and the inductor in the receiver’s local oscillator so the resonant frequency of the antenna follows that of the tuned station. When using the Amidon R33 rod (see parts list), this will be around 90 turns. The use of litz wire will give best results, but 28 AWG magnet wire will work adequately. It’s also a good idea to use MVAM109’s from the same manufacturing lot to improve the odds of good parameter match.

A plastic tube should be used to protect the rod. ½” CPVC (5/8” OD) water pipe provides a snug fit. The amplifier can be built to fit into the same tube as the rod, or in a slightly larger tube, and positioned so it extends off of one of the rod ends. Wrapping the tubing around the amplifier with a thin copper sheet or foil provides shielding, and also provides a good gripping surface that allows the body to serve as a ground when holding the antenna, reducing interference from the GPS and other sources.

1. First wrap the rod with a couple of layers of electrical tape, then wind 92 turns of wire, leaving a space between windings about equal to the wire diameter. The goal is to get the 92 turns to have a length of around 3 inches (+/-1/2" is OK). Leave several inches of wire at one end to allow adding additional turns if necessary, and to also double back the length of the rod so both leads of the coil are at the same end.
2. Wrap the tubing holding the amplifier with a thin copper sheet or foil and connect it to the amplifier ground. It's best to leave a small gap so the shield doesn't form a complete loop, which would act as a shorted turn around the rod. A small copper end cap can be later added for additional shielding.
3. The shield around the amplifier will affect the resonant frequency, so tuning needs to be done with the rod temporarily inserted into it's final position in the tube & shield assembly. The receiver's local oscillator should be adjusted per section 5.4 before performing this step. Power the unit up and select a tuning frequency of 300 kHz. A signal is applied by using a single turn of wire around the tube.
4. Set the signal source to the tuned frequency, and adjust the amplitude so the signal level at the antenna amp output is kept below 500 mV p-p. If using an external signal generator, find the resonant frequency by varying the generator frequency and watching for peak amplitude. Adjust the resonant frequency of the rod so it is 300 ± 10 kHz by adding or removing turns. If using the LO based signal source, adjust T4 to find the signal peak. Add or subtract turns so the tuning voltage is 2.4 ± 0.2V at resonance. Note that the PLL synthesizer will keep the LO frequency constant by changing the tuning capacitor voltage as T4 is varied
5. Wrap a layer of electrical tape around the rod to hold the windings in place, then finish assembling the antenna.
6. With the antenna fully assembled, one last tuning step is done. With everything hooked up and the receiver set for 303 kHz, apply the signal source using the single turn around the rod's tube as before, and observe the signal going into the receiver. If using an external signal generator, adjust the frequency for exactly 303 kHz (listening for tone using audio monitor may help). Adjust T4 for peak signal level. If using the LO based signal source, initially adjust T4 for peak signal amplitude, then adjust T4 again so the tuning diode voltage drops 20 mV. This last step compensates for the fact that the LO gets set 500 Hz above the tuned frequency. With either method, the final tuning voltage should be between 2 - 3 volts.

7. Whip Antenna

Tuning the whip antenna amp is quite simple. With a power source applied to the antenna (connecting it to the receiver works fine), connect a 303 (or 303.5) kHz, 25 - 50 mV p-p signal source to the input and adjust the transformer for peak amplitude at the amplifier output.