ICT-series WSPR balloon tracker capable of WSPR and JT9

Rev. 1, September 2019

Instructions

Original based on HABalloon by **Stephen KD2NDR**, Miami, Florida, October 25 2018

Improvements, advanced telemetry, new features, ground testing and flight testing by **Eduard YO3ICT**, Bucharest, Romania, April-September 2019

Credits also go to **Hans G0ULP** for developing the telemetry protocol and to **David VE3KCL**, **Mike SA6BSS** and **Ben PE2BZ** for all the help received during testing and flying.

You may use and modify the following code to suit your needs so long as it remains open source and it is for non-commercial use only.

The following software and hardware flew on ICT1, ICT2 and ICT3 balloons in 2019.

In the provided archive you will find the source code and the PCB layout files. This document is provided as a tutorial to get you up and running.

Fly at your own risk and follow your local aviation laws.

Contact: *yo9ict@gmail.com*

Firmware instructions

All of the following assume that you are using the usbasp AVR programmer.

Before going into the firmware itself, our little board's AVR chip runs at 4MHz. We need to set up some fuse bits using avrdude command lines.

We need to set the AVR to run on the external 4MHz resonator and the BOD level at 1.8V (Low fuse FD, High fuse DA, Extended fuse 06).

Avrdude commands:

avrdude -c usbasp -p m328p -v -U lfuse:w:0xFD:m

avrdude -c usbasp -p m328p -v -U hfuse:w:0xDA:m

avrdude -c usbasp -p m328p -v -U efuse:w:0x06:m

Install the latest Arduino IDE.

Then we **set up our little board with the correct initialization**.

Copy the code from the included boards.txt file to the end of your boards.txt file found under Program Files/arduino/hardware/arduino/avr and then choose this board in the Tools menu.

Next, we are using the delayMicroseconds function. **We need to get the Arduino IDE aware of our 4Mhz clock**. You'll need to replace the wiring.c file under Program Files/arduino/hardware/arduino/avr/cores/arduino. Replace the existing file with the one found in the archive.

Libraries required:

1. Time library : https://github.com/PaulStoffregen/Time
2. GPS library https://github.com/mikalhart/TinyGPSPlus
3. Si5351 library https://github.com/etherkit/Si5351Arduino
4. JT Encode library https://github.com/etherkit/JTEncode

Download all of them and install them in your libraries directory. You can also use Sketch – Include library menu from the Arduino IDE. Just point it to the zip file of each library and they will be installed quickly.

Edit the files to fit your conditions.

Important settings to do:

1. **Callsign** is set in the main .ino file on line 31. The provided source code comes with the fake callsign AA0AAA
2. Actual Si5351 **oscillator frequency** is set on line 242 of TelemFunctions.h. The provided source code comes with 27000000, meaning 27MHz
3. In ModeDef.h lines 11 and 12 we define the **actual on-air frequencies** for JT9 and WSPR
4. The **telemetry channel** is set in TelemFunctions.h on lines 80 and 81. Basically, we hard-code the first and the third characters of the telemetry callsign.

   Please read this: http://www.qrp-labs.com/ultimate3/ve3kcl-balloons/ve3kcl-s4.html#protocol to get a better understanding of the telemetry protocol and channels.

   Please read this: http://hojoham.blogspot.com/2016/10/known-flight-ids.html for known flight IDs. Ask **Mike KD2EAT** to get your channel assigned. Note: The list might change, as it contains some invalid channels (the ones starting with "1").

   The provided source code comes with an invalid telemetry channel to avoid interference while testing.

5. In TelemFunctions.h there are a lot of math functions (function loc_dbm_telem), including the **temperature** and **solar voltage** conversion formulas. Please calibrate them. Each AVR device may give different results. I provide a sample sketch (TEMP_VOLT_TEST). The PCB has a pad named TX. Hook up your UART to USB dongle to get the data out.

6. The source code provided has build-in three timing files for different timings of the WSPR and/or JT9 modes. The file can be selected within the main .ino file on line 61. You can include a different file. **The only flight proven timing file is timing3.h**. You can also ~~do~~make your own file. Just test. And test again. And test once more before flight.

The timing3.h file uses both JT9 and WSPR. The transmission schedule is based on a 6 minute transmission cycle:

Minute 2 - JT9 - Callsign + 6-digit locator
Minute 3 - JT9 - 7th and 8th of the extended 8-digit locator + Altitude + Ground speed
Minute 4 - WSPR - Standard WSPR message
Minute 6 - WSPR - WSPR telemetry

Minute 12 - WSPR - Standard WSPR message
Minute 14 - WSPR - WSPR telemetry
Minute 16 - WSPR - Standard WSPR message

Minute 22 - WSPR - Standard WSPR message
Minute 24 - WSPR - WSPR telemetry
Minute 26 - WSPR - Standard WSPR message

Minute 32 - JT9 - Callsign + 6-digit locator
Minute 33 - JT9 - 7th and 8th of the extended 8-digit locator + Altitude + Ground speed
Minute 34 - WSPR - Standard WSPR message
Minute 36 - WSPR - WSPR telemetry

Minute 42 - WSPR - Standard WSPR message
Minute 44 - WSPR - WSPR telemetry
Minute 46 - WSPR - Standard WSPR message

Minute 52 - WSPR - Standard WSPR message
Minute 54 - WSPR - WSPR telemetry
Minute 56 - WSPR - Standard WSPR message

Known bugs

Solar voltage is reported incorrectly. The hardware resistor divider R4 & R6 values should be changed to allow for greater voltage swing. The voltage formula must be recalculated as well.

Hardware instructions

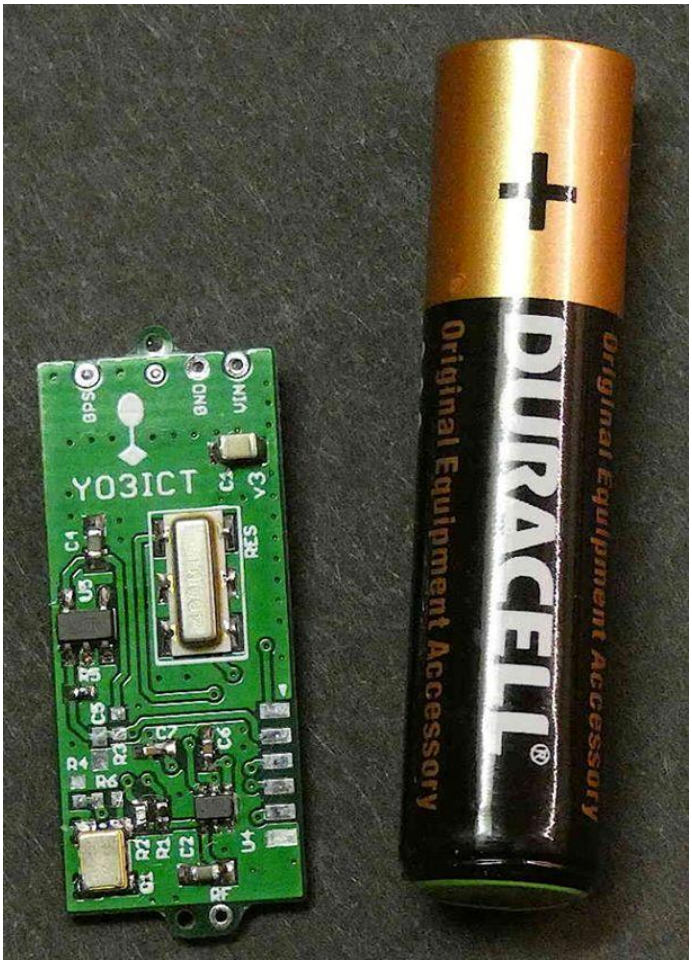
The PCB files provided are flight proven. Use a 50ohm resistor dummy load for testing. The PCB is 0.6mm thick.

Solder all the components. Note: The tracker won't start without the GPS module.

The GPS antenna is made of **4.5cm of guitar string wire**. It has a dedicated mounting hole.

The solar panels (6 pieces, the 39x19mm size) are soldered together in series using guitar string wire.

Pictures for reference:



Three panels on each side.

There are some holes on the PCB for power (which comes also via guitar string wire) and an **isolated tinned hole near the top, just below the top tether hole**.

That isolated tinned hole is for suspending the solar cells. The guitar string wire segment that connects the 3rd to the 4th solar cell is passing through that hole and is soldered. This provides stiffness as well as flexibility in the solar panel system**. This is essential to ensure trouble-free mounting, handling, launching and flying.**

The antenna is made of thin 0.1mm copper wire suspended by 0.08mm dynemaa fishing string. The string attaches to the two dummy holes at top and bottom of the PCB. The 'hot' part of the dipole attaches to the dedicated hole named RF at the bottom. The 'cold' part of the dipole gets attached to GND **AFTER** the solar panels have been attached. Try to provide some slack to the thin copper antenna wire before soldering. Failing to do so might result in broken solar cells or antenna wires.

Solar cells need to be soldered quickly and cleanly. Use flux, pre-solder the guitar string wire and use a temperature controller soldering iron (~330 degrees Celsius). Also, **solar panels should be as horizontal as possible**, otherwise the startup sun angle will be unpredictable.

The programming port pads are located on the side of the PCB and the white arrow points to the positive pad. The connector needed is a 1.27mm pitch row connector. **This is to be removed before flight to save weight**. Also clean the pads to get rid of excess solder. The programming layout is custom due to the PCB limitations.

In the end, the PCB is coated with some **lacquer** and then it is covered with **kapton tape**. This increases the thermal mass a bit, avoids moisture on the PCB and also helps with some basic thermal insulation.

The tracker and solar cells must came close to **4 grams weight** and the antenna (whole dipole for 14MHz) should weigh less than one gram.

What balloon to use?

SBS balloon or Chinese clear balloons, found on Aliexpress? As the SBS balloons are very expensive, we'll discuss the cheap ones.

Order as many as you can afford. Usually, the ones from the center of the packaging are damage-free.

The balloons need to be pressure tested and pre-stretched to allow for greater internal volume and higher altitude. Your best shot at circumnavigation is to fly above 11000m, at least.

Required:

1. Air mattress pump for rapid inflation/deflation
2. Aquarium pump for controlled presurization
3. Digital, differential manometer

Basically, the pre-stretch process is a matter of time, pressure and temperature.

To shed weight, cut the excess material around the balloon edge and also cut the top tether, unless you do a dual launch. **Do this BEFORE any attempt at balloon presurization.**

Target differential pressure is above 0.6 psi. **Go slowly above 0.4 psi**. This will also highlight defective balloons. Use the hair dryer on moderate position to heat the balloon as you increase the pressure.

The target should be a pressure of **around 0.6-0.65 psi, no balloon wrinkles on the edge and let it sit overnight**. You will want to experiment as different balloons and different pressures and temperatures means different results. Not all balloons are created equal. **David VE3KCL** and **Mike SA6BSS** have a lot of experience with this type of balloon.

After the overnight pressurization, it is time to put the balloon to storage, in preparation for launch. Use a clothes vacuum bag and some dessicant bags. **Avoid excess stress on the balloon!**

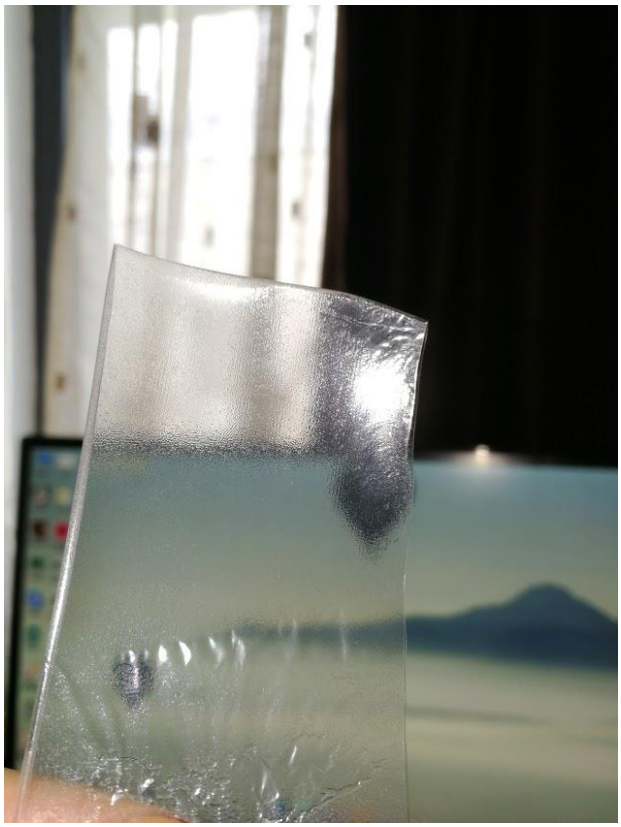
Launch

Use H2 for the best performance and highest altitude.

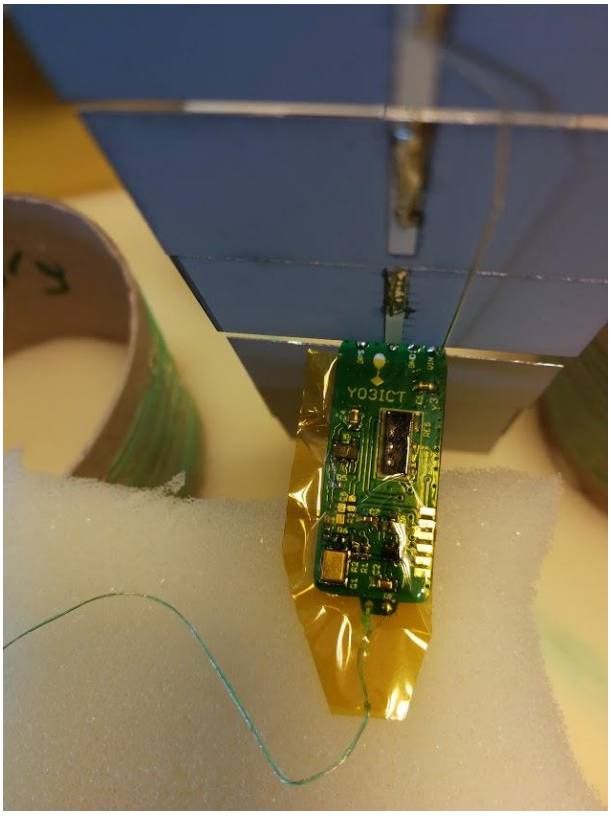
If using He, **use the purest available**, some retailers only offer 80% this will result in reduced performance and altitude.

1. Lay out a sheet to unfold the balloon on. **Handle the balloon with care**, try not to wrinkle the film any more than you have to. Avoid wearing clothes with zippers or buttons that may come in contact with the balloon.
2. **Filling and launching a super pressure balloon requires a very special skill set.** The most important is filling the balloon so it has the correct free lift. Please fill indoors and turn off heating and air conditioning, so the room is very still. Weigh everything that will be attached to the balloon, tracker, load line, tape, etc. Then add a maximum of 8 grams of free lift. I recommend you practice these procedures with a party balloon to refine your skills because if you over fill the balloon it will burst.
3. Once the fill is done, it's time to seal the neck.
4. Set the iron to around 140 degrees Celsius. You can experiment with different temperatures here.
5. You need a hard surface like wood to put a piece of a **mouse pad** on. Make sure there are no sharp edges. Lay the balloon neck down on the mouse pad.
6. **Use a piece of parchment paper**. Cut a piece of it to lay on top of the neck so the iron does not come in direct contact with the film.
7. Press the edge of the iron down **FIRMLY** on top of the parchment paper and hold iron in place for 3 to 5 seconds.
8. Iron the rest of the neck.
9. Attach payload to the neck of the balloon. You can trim the neck at this point.
10. Time to launch – good luck! Avoid launching in the winter. Low sun angle means that the daily run time of the tracker will be very low. Avoid launching in high winds. Avoid launching near airports.

Sealed neck pictures:



Tracker ready for flight, transported in a rigid metal box:



The antenna is rolled over the cardboard cylinders:

Example of my balloon filling hose:

Partially filled balloon, ready to be sealed:

No, I wasn't launching the TV remote.

ICT1 launch. You can clearly see the top and bottom antenna legs with the tracker in the middle:

Tracking

To get your balloon tracker on the **tracker.habhub.org** page please send email to **David SM3ULC**. You can also keep your own tracking map by programming a Phyton script or some VB code inside an Excel file. Contact me if you need help.

The WSPR network is big, but there's an area with very low coverage : East-Central Asia. You'll need to help your balloon by using some of the available KiwiSDRs (sdr.hu) from that area.

The best KiwiSDRs are Novosibirsk and Khabarovsk (Russia), Fukushima (Japan), Hawaii and KPH (California). Not all of them are always online. Do not rely on the build-in WSPR decoder. Feed the audio to a local instance of WSJT-X.

Good luck and clear skies!