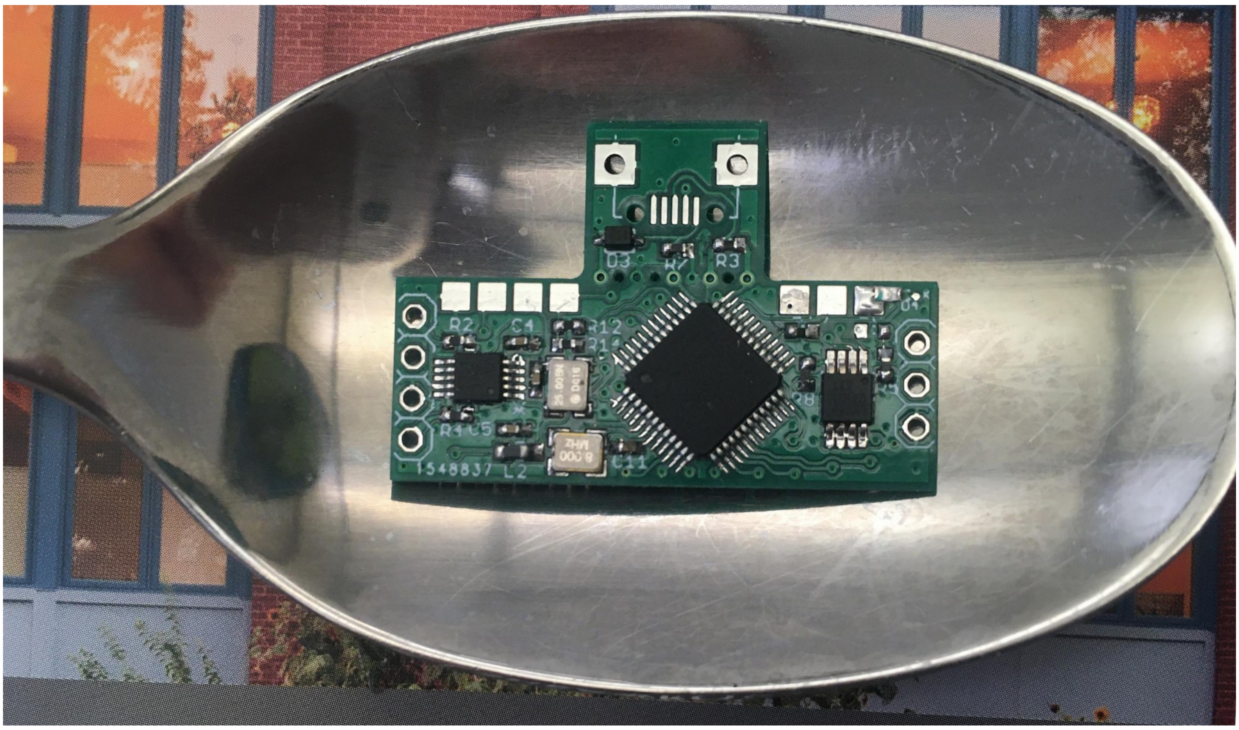
U4B

U4B – Ultimate4 Balloon tracker

Hardware manual



Please read this manual in conjunction with the operating manual and other documentation on the U4B product page
http://qrp-labs.com/qdx

Contents

1. Introduction

The U4B tracker was developed over a period of 7 years from 2015 to 2022, in collaboration with Dave VE3KCL who has launched 83 test flights from Toronto, Canada. With flight duration from 2 hours to 305 days (10 months, almost 17 laps around planet Earth), they all taught us something and were great fun.

U4B is designed to be an easy to use, lightweight, low-cost module that can be configured as simply as entering your callsign, yet for more advanced owners can be flexibly extended with more sensors and as much complexity as you like. Automated tracking maps and utilities are available on the QRP Labs website, both for simple tracking purposes and downloading your own telemetry. The U4B PCB contains:

- 33.0 x 12.7mm PCB (plus removable protrusion with micro-USB connector)
- Weight: 1.8g (with micro-USB protrusion removed)
- 32-bit ARM microcontroller running QDOS (**Q**RP Labs **D**isk **O**perating **S**ystem)
- 128K disk (implemented on EEPROM chip)
- 27mW (approximately) transmitter using Si5351A synthesizer
- TCXO referenced frequency stability
- Band coverage 2200m to 2m
- LM75 temperature sensor
- Status LED
- USB interface for configuration, programming and easy firmware update (just copy the new firmware file into the apparent USB Flash drive).

Simplest possible operation:

Just connect to U4B with a PC terminal emulator, and configure it with your callsign. Register the flight name, details and channel on the QRP Labs website. Fly!

More flexible and advanced features:

U4B contains a wealth of flexibility and hardware expansion options which you can use to customize your flight:

- 19 GPIO pins – of which 9 can be configured as analog inputs and 8 are easily accessible via PCB edge pads; all 19 can be used as digital input or output control pins
- I2C bus for connecting additional sensors e.g. pressure, humidity
- BASIC programming language with full-screen text editor, compiler and debugger
- 128K Disk storage for your programs and data; BASIC can read/write data files
- Command line utility
- Telemetry over WSPR for relaying your additional sensor data

The U4B radio transmitter can transmit the following modes:

- QRP Labs tracking and telemetry over WSPR
- WSPR (including extended mode and slow 15-minute WSPR)
- JT9 (1, 2, 5, 10, 30 minutes)
- JT65 (modes A, B, C)
- Hellshreiber (standard, DX, and slow multi-tone FSK)
- CW (standard speed, QRSS, FSKCW and DFCW)
- Customized “Glyph” patterns can produce a unique idenfier on QRSS

2. SAFETY FIRST

If you are anyone else gets seriously injured (or worse) that's seriously going to take the fun out of the whole thing. So pay massive amounts of attention to safety, PLEASE…

Launch in a wide flat area: First off, the best place to launch is a flat area, a WIDE flat area, with no obstacles for hundreds of meters in any direction; particularly obstacles involving power lines. A balloon can often travel along for a while almost horizontally in the slightest breeze you don't even realize exists, so don't assume anything is going straight up. Again, nowhere near or even in sight of power lines!

Determine wind direction: Ideal launch conditions are zero wind. But recognizing that rarely does one have such a luxury, it is necessary before everything, to determine the wind direction; then choose the launch site such that the balloon has the longest clear space to ascend into.

Launch from ground level: Don't be tempted to launch from a roof, or a balcony, even if it seems like a good idea (maybe you think it will get you higher than nearby obstacles). In the heat of the moment, your attention could be so focused on getting your precious dream airborne that you'll take unreasonable risks, balancing precariously near the edge just to dislodge it or stop that last bit of antenna catching on something… and before you know it, you'll fall off to your doom. Better to stay on the ground, do a bit of extra thinking to find a suitable launch site.

Mind hydrogen: remember, Helium is a non-explosive, non-flammable gas. Hydrogen has greater lift, is cheaper, a renewable resource, and leaks more slowly – but is explosive. So if you decide to use hydrogen, do some proper research about how to handle it properly, at the minimum following all safety instructions directed by whatever container of the stuff you've got hold of.

Aircraft: An oft-repeated objection to high altitude ballooning is that it's a danger to aircraft. Having spoken to numerous commercial and private pilots about this, I have yet to meet one who did other than laugh at the thought of something that tiny and delicate being any kind of danger to an aircraft. Modern aircraft simply have too many built-in redundant systems and safety features, over-engineering etc for such a small thing to be a hazard. Nevertheless, better not tempt fate, or risk any undue attention, by selecting a launch site anywhere near an airport. Stay even further away from any military facility.

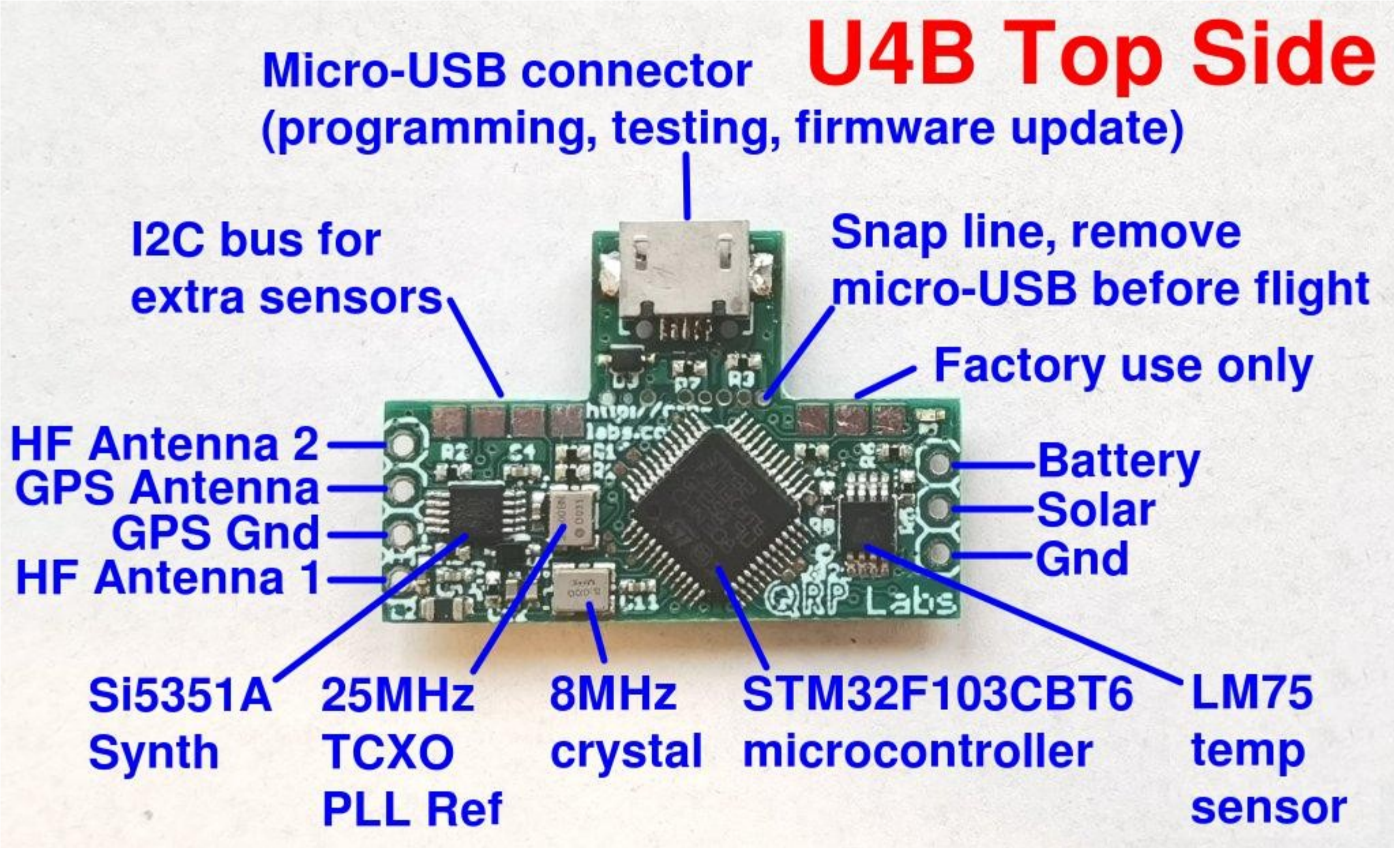
Rules, regulations: It's your responsibility to find out what laws, rules, regulations etc apply in your country. QRP Labs is not going to tell you, QRP Labs doesn't know. No idea at all. So make sure you undertake all necessary research and figure out what you can, and cannot do. Then make your own decisions accordingly.

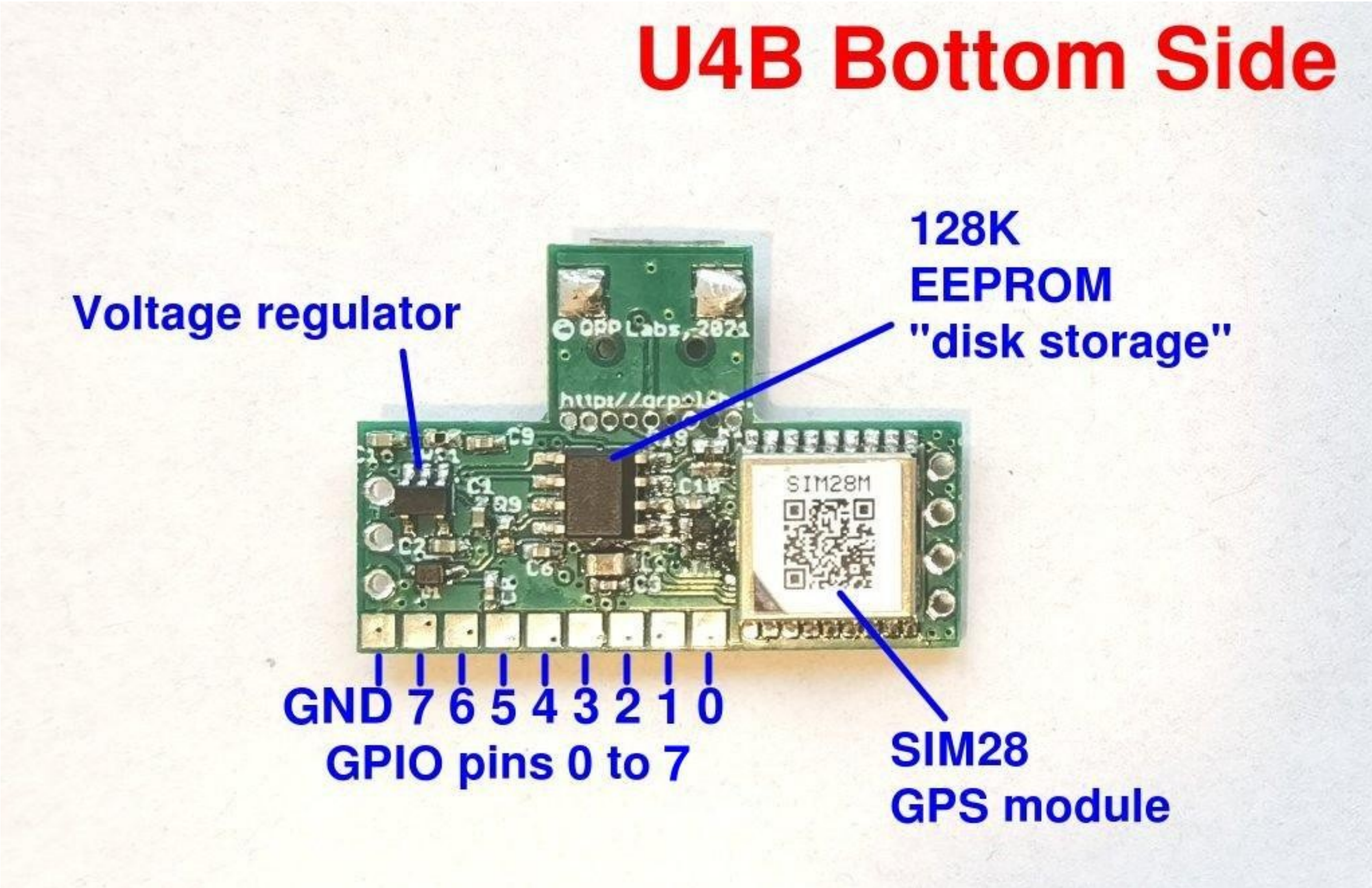
Test test test… OK this isn't really part of safety. Well maybe it is, if you consider preserving your sanity an important goal. TEST! Test, re-test, test every possible scenario you can think of. Solar power in the dark, solar power as the sun comes up, goes down, spinning around, clouds, blah blah. Whatever you can think of. If you're writing your own BASIC program try to think of all the possible routes the code can take and think of a way to check they all work properly. Test everything so thoroughly on the ground. There's already enough to go wrong with the wind, clouds, tangled antennas, leaks, miscalculation of gas volume, blah blah… at least get the U4B set up correctly! Once it's left your hands, you're very very unlikely to ever see it again. So you had better be sure it WORKS before you let go! This includes not breaking off the USB tab until the last moment – because testing and fixing something is a whole lot harder without that.

Common sense: This list is not exhaustive! Above all, use common sense! Best to delay a launch, and come back another day – there should be plenty – then risk injury or life.

3. Know your U4B

U4B is a 33.0 x 12.7mm PCB, using 0.6mm thick FR4 PCB for low weight. SMD components are mounted on both sides of the PCB.

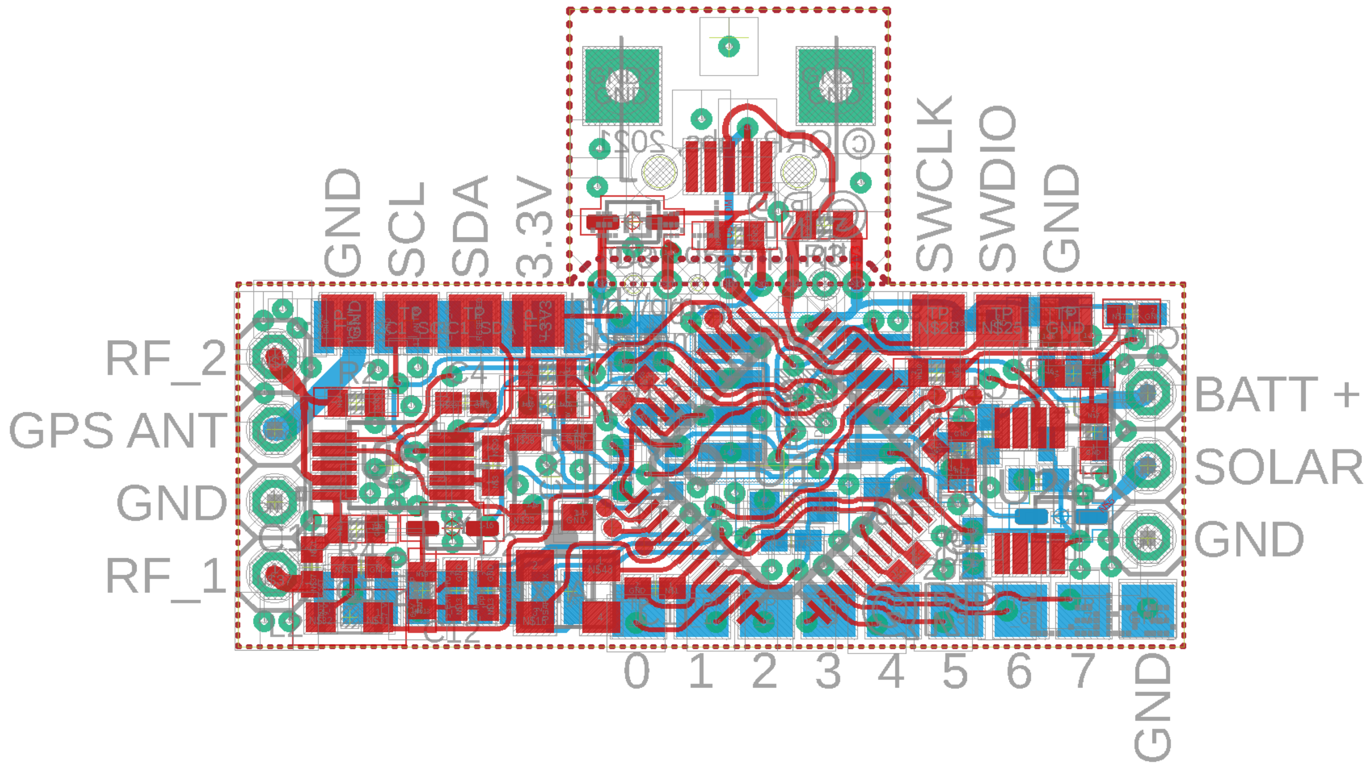




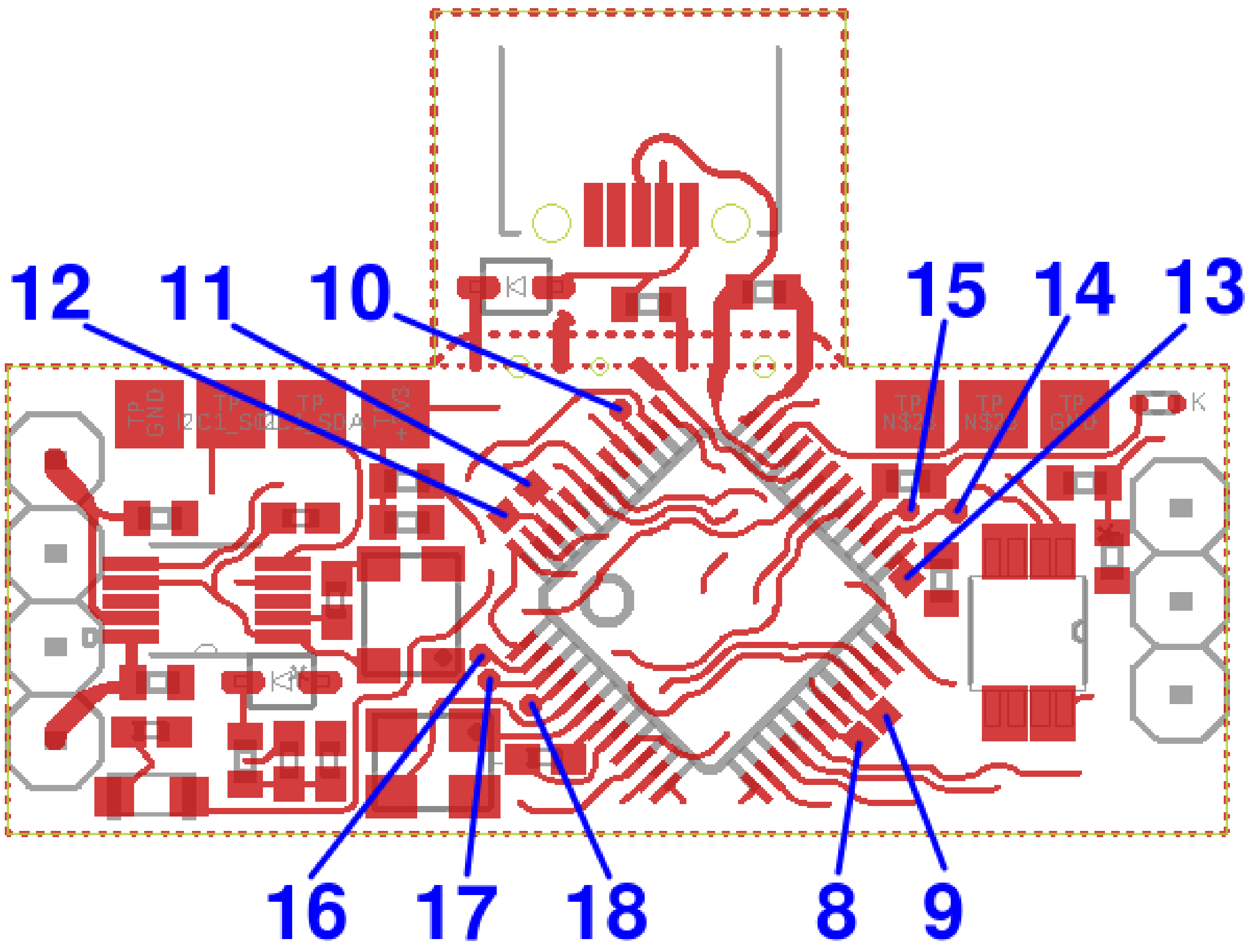
4. Parts list

Part	Value	Package	Description
C1	10uF	0402	Capacitor
C2	10uF	0402	Capacitor
C3	0.1uF	0402	Capacitor
C4	0.1uF	0402	Capacitor
C5	0.1uF	0402	Capacitor
C6	0.1uF	0402	Capacitor
C7	0.1uF	0402	Capacitor
C8	0.1uF	0402	Capacitor
C9	0.1uF	0402	Capacitor
C10	0.1uF	0402	Capacitor
C11	0.047uF	0402	Capacitor
C12	22uF	0402	Capacitor
C13	22uF	0402	Capacitor
C14	10uF	0402	Capacitor
C15	0.1uF	0402	Capacitor
D1	S4	SOD-323	Diodes
D2	S4	SOD-323	Diodes
D3	S4	SOD-323	Diodes
D4	Red LED	0402	LED
L1	2.2uH	2012	Inductor
L2	2.2uH	2012	Inductor
R1	1K	0402	Resistor
R2	22K	0402	Resistor
R3	1.5K	0402	Resistor
R4	22K	0402	Resistor
R5	100K	0402	Resistor
R6	280K	0402	Resistor
R7	22K	0402	Resistor
R8	22K	0402	Resistor
R9	22K	0402	Resistor
R10	22K	0402	Resistor
R11	1.5M	0402	Resistor
R12	100K	0402	Resistor
R14	100K	0402	Resistor
R15	5.6K	0402	Resistor
R19	1K	0402	Resistor
T1	SI1967DH-T1-E3CT-ND	SOT363	Dual MOSFET transistor
TCXO	25MHz	3225	TCXO
U$1	SIM28M	10x10mm	SIM28M GPS
U1	STM32F103CBT6	TQFP-48	STM32 chip
U2	LM75	SOIC-8	I2C Temperature sensor IC
U3	24M01	SOIC-8	128K I2C EEPROM IC
U4	RT9013-33	SOT23-5	3.3V LDO voltage regulator
U5	SI5351A	MSOP-10	Si5351A Synthesizer
USB	MICRO-USB	MICRO-USB	MicroUSB
XTAL	8MHz	3225	Crystal

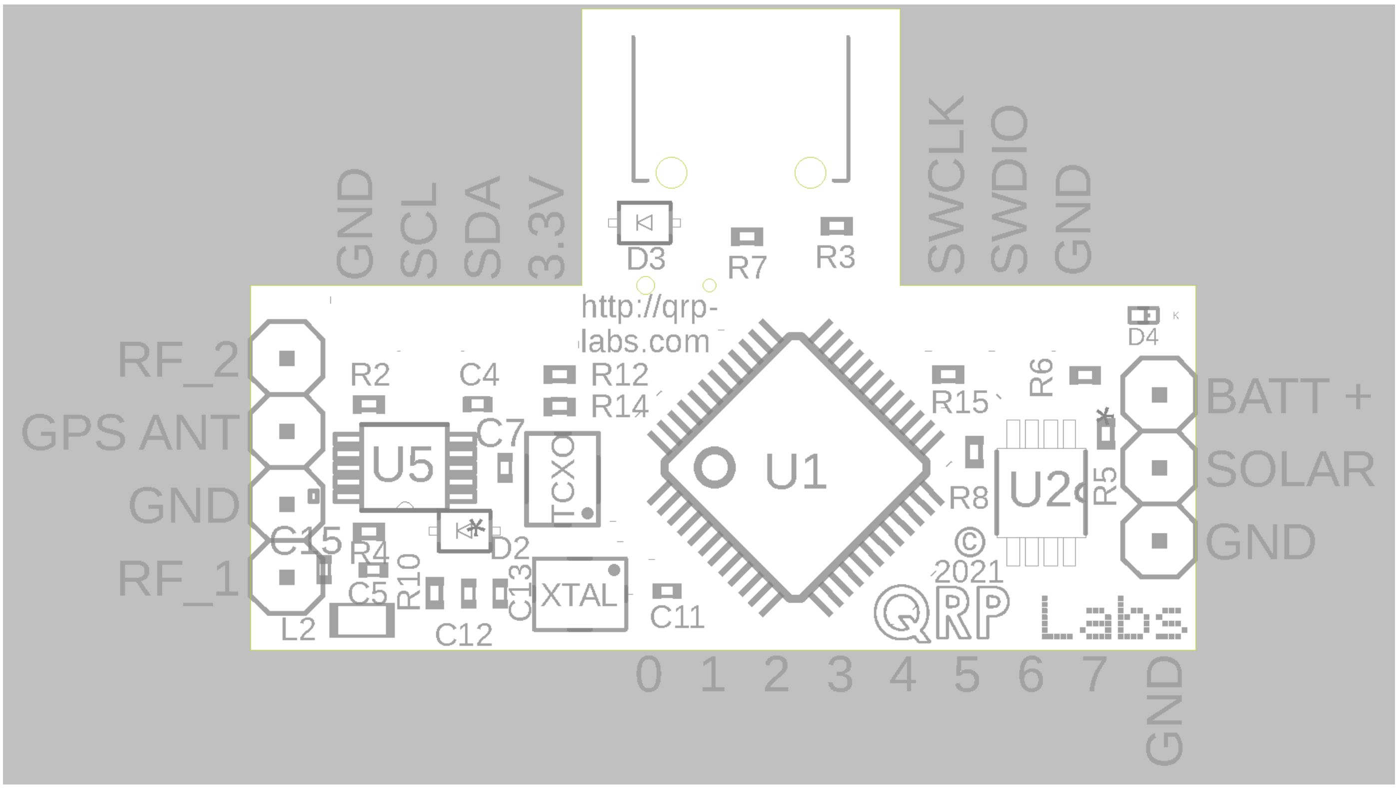
5. Track layout



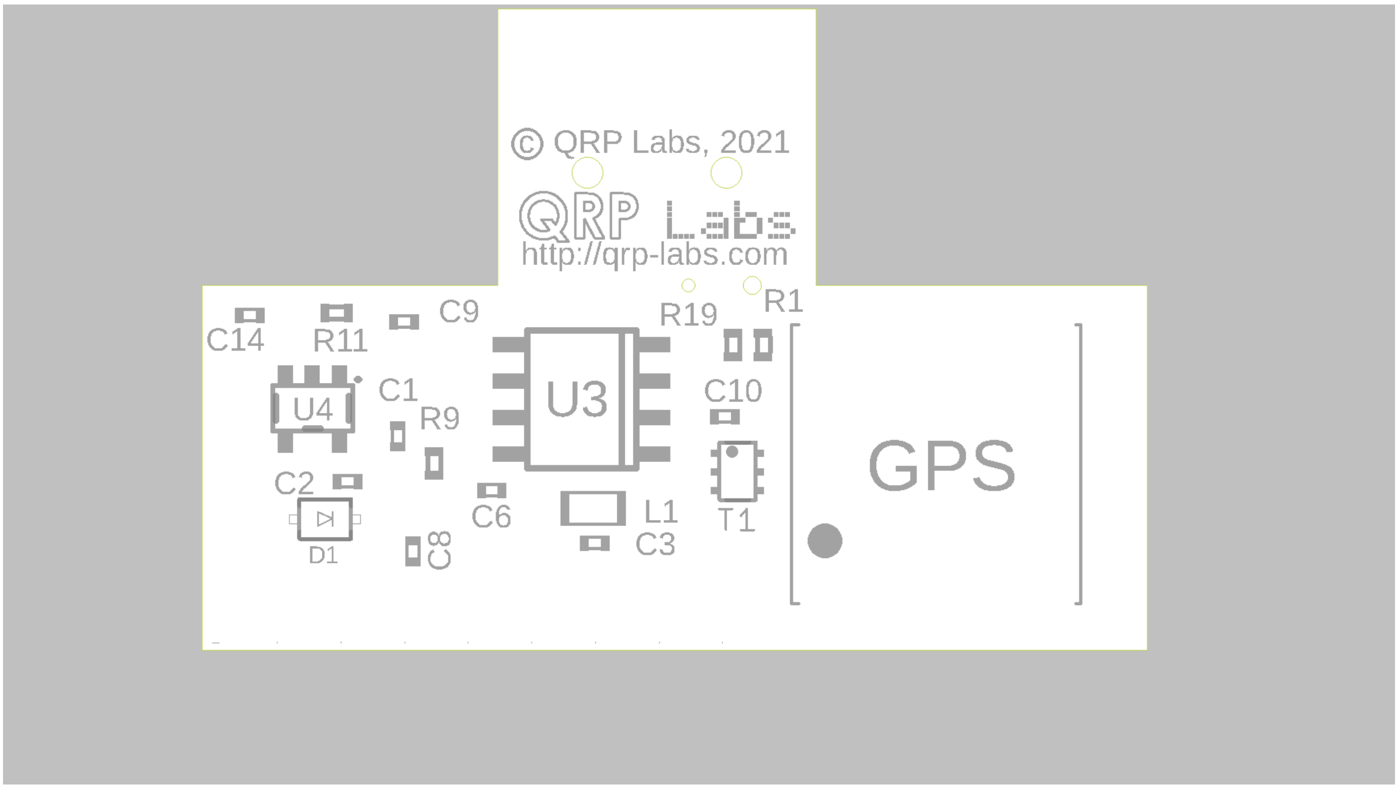
6. GPIO pins 8-18 pad locations



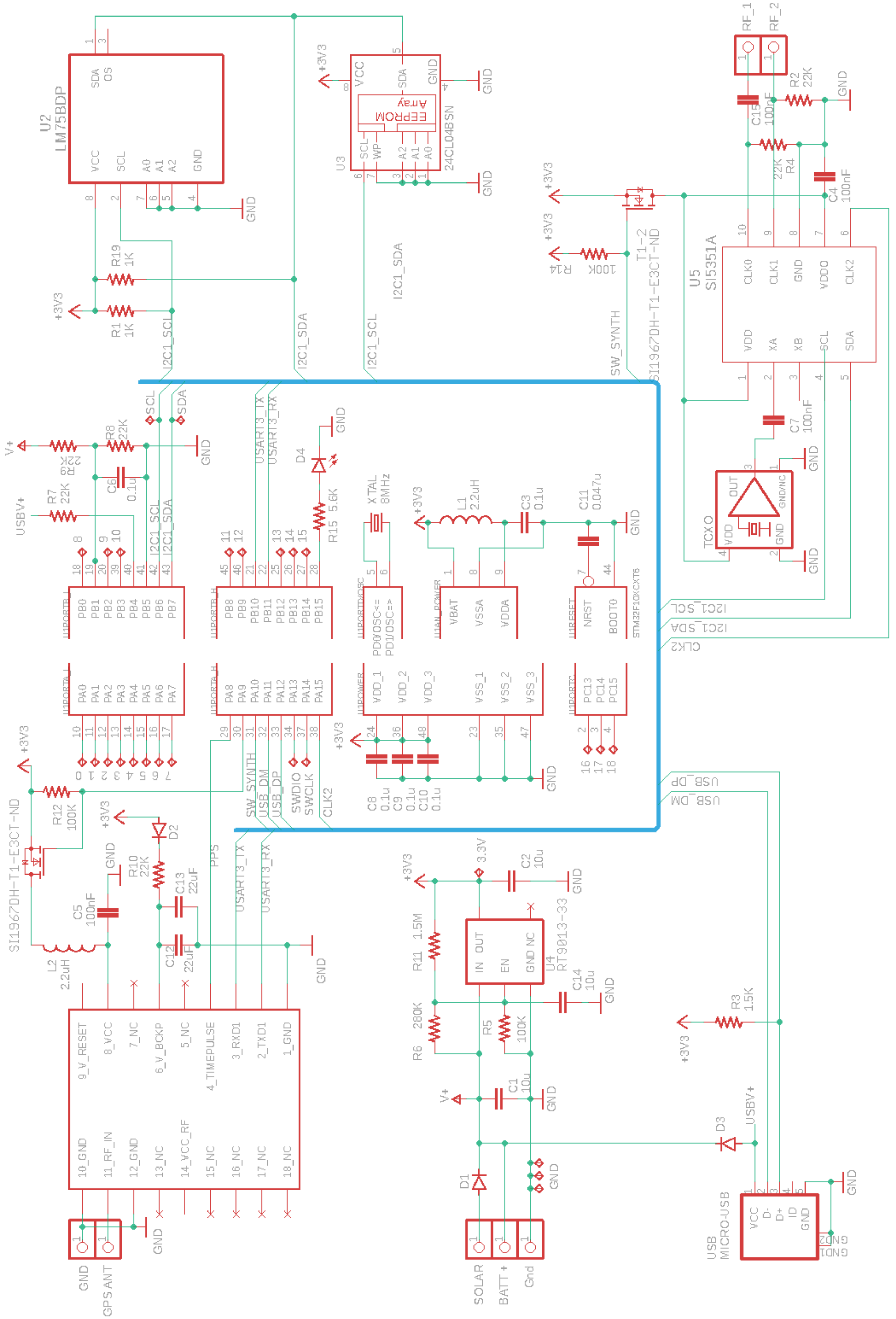
7. Parts layout, top side



8. Parts layout, bottom side



9. Schematic


U2
LM75BDP
R19 1K
R1 1K
U3
24CL04BSN
EEPROM Array
R14 100K
T1-2
SI1967DH-T1-E3CT-ND
U5
SI5351A
RF_1
RF_2
R2 22K
R4 22K
C15 100nF
C4 100nF
C7 100nF
TCXO
R8 22K
R9 22K
R7 22K
C6 0.1u
D4
R15 5.6K
XTAL 8MHz
L1 2.2uH
C3 0.1u
C11 0.047u
STM32F10XCXT6
I2C1_SCL
I2C1_SDA
CLK2
USB_DP
USB_DM
C8 0.1u
C9 0.1u
C10 0.1u
R12 100K
SI1967DH-T1-E3CT-ND
D2
R10 22K
C13 22uF
C5 100nF
C12 22uF
L2 2.2uH
C2 10u
R11 1.5M
U4
RT9013-33
C14 10u
R6 280K
R5 100K
C1 10u
D1
D3
R3 1.5K
USB MICRO-USB
GPS ANT
SOLAR
BATT+
Gnd
USBV+
V+
+3V3
GND

10. Circuit explanation

The U4B tracker has a rather simple design and does not require highly detailed explanation.

The brains of the device is an STM32F103CBT6 microcontroller. A 32-bit ARM Cortex M3 processor having 128K of program memory. In the U4B, 12K is used for the bootloader and 116K for the application firmware. Although the maximum speed of the microcontroller is 72MHz, it is run at a much lower speed in this leisurely application, to reduce current consumption. There is an 8MHz crystal as the system oscillator; internally this is used to generate a 4MHz CPU clock during flight, or 18MHz when a USB connection to a host PC is present.

The USB connector is a micro-USB type, located on a protrusion from the top edge of the nominally rectangular U4B PCB. This section of the PCB is a break-away tab, in other words a line of holes in-line with the top PCB edge can be snapped to remove this section for flight, thereby reducing the weight by several grams. The U4B may be powered from the USB host via a diode located on the breakaway tab. The other two components present on the breakaway tab are the necessary 1.5K Fullspeed USB pull-up resistor R3, and a 22K resistor R7 which the microcontroller uses to “sense” when a USB connection is present, and enable its USB peripheral accordingly.

The Si5351A Synthesizer IC is used as the “radio transmitter”, configured by the microcontroller over the I2C bus. It can be used in two ways, under firmware control.

1. Low power mode: Clk0 (connected to output pad RF_1 via a capacitor) is driven at the operating frequency, Clk1 (connected to output pad RF_2) is grounded. Power output into a 50-ohm load is found to be approximately 9mW.
2. High power mode: Clk0 and Clk1 are driven at the operating frequency in anti-phase (180-degree phase difference). The power output into a 50-ohm load across RF_1 and RF_2 is found to be approximately 27mW.

If Clk0 and Clk1 are connected to opposing legs of a dipole antenna, the power output can be conveniently controlled by BASIC commands, set to low or high power mode. There is no Low Pass Filter in the U4B, which has the advantage of allowing it to operate on any band; but the disadvantage that there is no harmonic attenuation; however given the very low power output this is not normally considered a problem. If it troubles you, you could add an external filter on a small PCB with appropriate SMD capacitors and inductors.

The 22K resistors R2 and R4 provide some protection against static build-up on the antenna during flight.

The synthesizer is powered via half of a dual P-channel MOSFET T1, under control of the microcontroller via the SW_SYNTH signal. Similarly, the SIM28M GPS is powered by the other half of the P-channel MOSFET under microcontroller control. In use, the microcontroller ensures that the GPS and Synthesizer are never both powered on at the same time; this limits the maximum current consumption of the device, easing the design of the power supply (normally, solar panels) particularly during early morning or late afternoon operation when the sun is likely to have a low angle of incidence on the solar panels if a horizontal panel arrangement is used.

The microcontroller receives serial data from the SIM28M GPS receiver module via a USART (serial) connection at the default 9600-baud data rate of the GPS module. Both transmit and receive serial data signals are implemented so that the microcontroller can write commands to the GPS; in particular this is necessary to be able put the GPS into “balloon mode” with the appropriate command.

Power to the GPS receiver is filtered by the 2.2uH inductor L2 to try to keep microcontroller digital noise out of the GPS receiver circuits. Power to the microcontroller Analog Supply pin is similarly filtered by L1. The battery backup connection to the GPS is always powered via diode D2, even when the GPS main power is switched off. This is essential to retain the GPS memory so that at next power-up a “warm start” is available, which has a very quick satellite acquisition time.

In addition to the Si5351A Synthesizer chip on the I2C bus, two other devices share are connected to the I2C bus: the LM75 temperature sensor IC U2, and the 24M01 128K Serial EEPROM IC U3. These latter two devices are kept powered on at all times.

7-bit I2C addresses used by devices in the U4B are:

- 0x48 U2, LM75 Temperature sensor IC
- 0x50 U3, 24M01 128K Serial EEPROM IC
- 0x60 U5, Si5351A Synthesizer IC

It is essential that if additional devices are connected to the I2C bus, you must ensure that they do not use these three I2C addresses. These devices may be read and written using BASIC commands.

There’s a 3.3V LDO voltage regulator IC, U4, RT9013-3.3 which has an enable input, controlled via a potential divider network R5, R6 and R11. This is set up to provide a hysteresis such that the “turn-on” voltage is somewhat higher than the “turn-off” voltage; it avoids rapid on/off oscillation of the power supply in low light conditions. The SOLAR input is connected to the BATT output and voltage regulator input, via a diode D1. This prevents reverse current into the solar panel in the dark when a connected battery still has charge.

The maximum rated input voltage of the RT9013-3.3 is 6.0V (absolute maximum rating) and recommended maximum operating voltage 5.5V. Care must therefore be taken not to use so many solar cells that 6.0 is exceeded. Remember that solar panels get BETTER as they get colder. In full sunshine at altitude, -55C temperatures can increase voltages and currents by up to 20%.

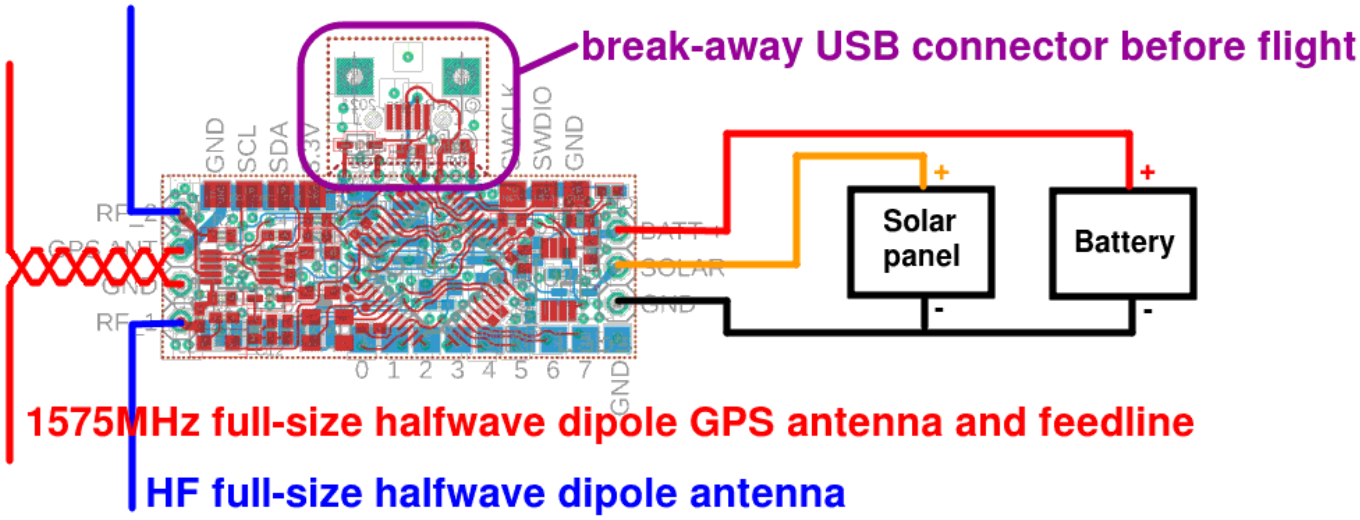
The U4B can be used with rechargeable batteries such as LiPo of various capacity; the higher the battery capacity, the longer operation after dark will be possible, but the higher capacity batteries are also heavier which will result in lower flight altitudes. There are many trade-offs to consider. Alternatively for very light-weight flights a battery can be eliminated altogether; an ultra-capacitor can be used or even nothing at all. However arguably some form of storage is useful to avoid drop-outs in the early morning and late afternoon, if the panel is rotating and tilted.

The microcontroller can read the available battery voltage V+ on its PB1 port, via potential divider R8/R9.

The U4B has 8 GPIO pins presented as pads along the lower edge of the PCB on the bottom side; these are known as pins 0 to 7 in the BASIC programming. They can be written and read as digital outputs or inputs (0V is “0”, +3.3V is “1”); or they can be read as 12-bit analog inputs where a value of 0 is Ground, and 4095 is +3.3V; these inputs can be used for reading analog sensors.

A further 11 GPIO pins are digital-only, and known as pins 8 to 18 in BASIC programs. Most applications will not need such a large number of GPIO pins but if you do, you will need to solder very fine wires to very tiny SMD pads on the top side of the board as identified in the diagram in section 5, above.

11. Basic flight connections

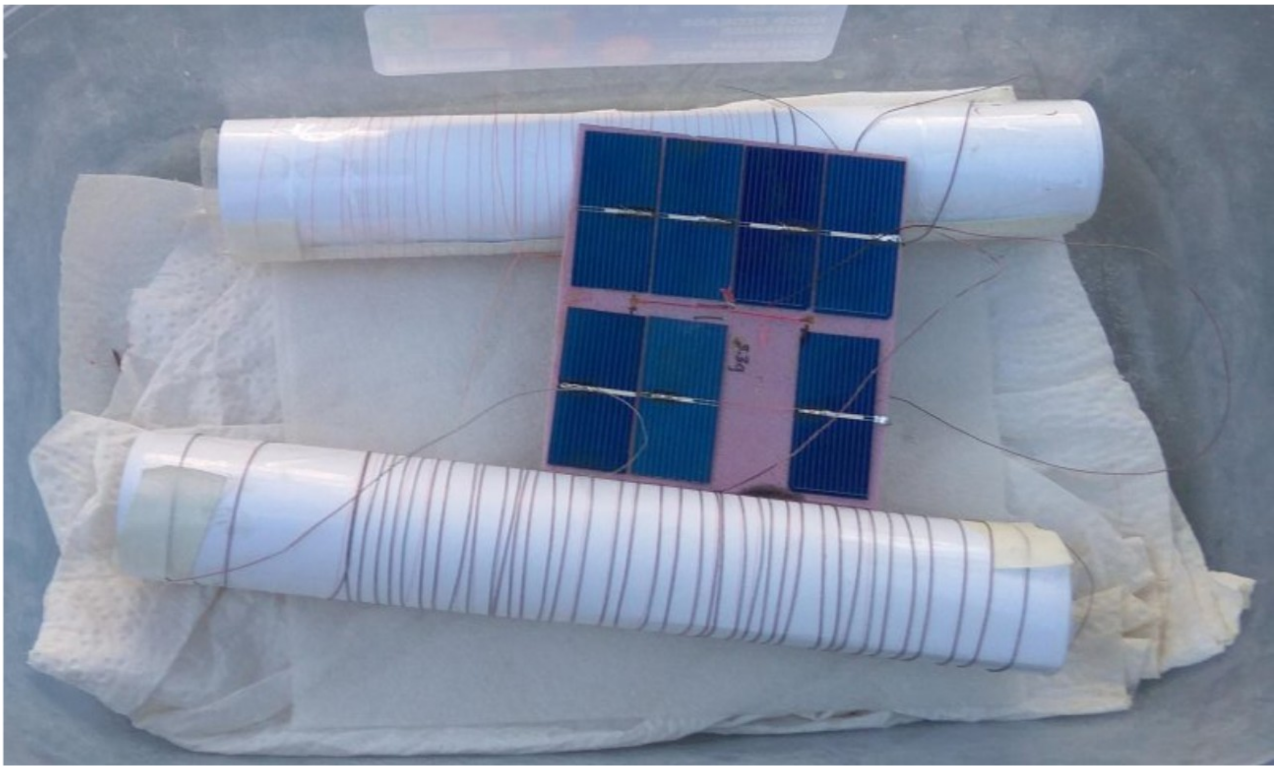


The HF antenna needs 1/4-wavelength on each leg (for example, each leg is 5m for 20m operation). A typical flight configuration has the top end of the top leg tied to the balloon, and the U4B payload suspended directly in the middle of the dipole.

The GPS antenna can be made of simple #28 (0.3mm) enameled wire; a 1/4-wave at 1575Mhz is about 45mm. The feedline consists of 1-inch of twisted wire, about 6 turns works well.

The above is just an example of a minimal flight tracking system. You can add your own sensors and complexity as you see fit!

There are a lot more practical tips about flight system preparation and launch, in the FDIM 2021 Conference proceedings article at http://qrp-labs.com/u4b



12. Resources

- Refer to the operating manual for details of the terminal applications (for configuration of U4B, text editing, writing BASIC programs, and testing etc.)
- Refer to other pdf publications on the U4B page on the QRP Labs website http://qrp-labs.com/qdx
- The operating manual also explains how to update the U4B firmware (using a USB connection to a PC), and how to set up tracking on the QRP Labs website.
- For updates and tips relating to this kit please visit the QRP Labs QDX kit page http://qrp-labs.com/u4b
- For any questions regarding the assembly and operation of this kit please join the QRP Labs group, see http://qrp-labs.com/group for details

13. Document Revision History

1.00	18-Apr-2021	First draft version version 1.00