Reach for the skies: extreme QRP at 35,000 feet

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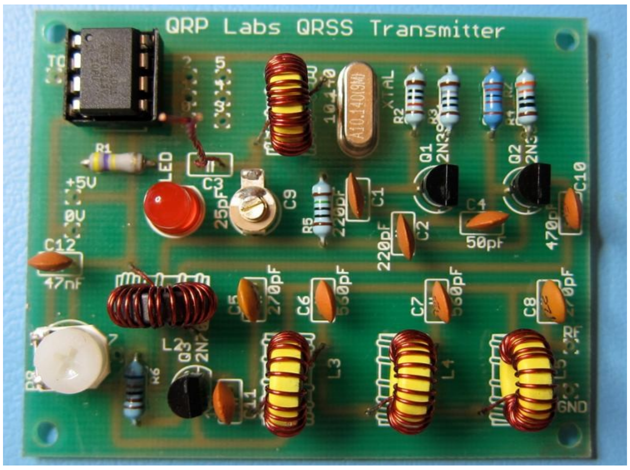
This article is about the invention of a system for sending telemetry over WSPR for use on tracking long distance balloon flights; variations of the concept have since been used by other balloonists in their own developments.

We'll look at how I came to take an interest in weak signal modes and what they are; how they are uniquely suited to the problem of very long distance communication with a tiny device weighing less than 10 grams; development of suitable hardware, firmware and communication protocols; and practical aspects of high altitude ballooning written by Dave VE3KCL.

Some history

I first started playing with QRSS in late 2003. Back then, there was no WSPR. There was only a very small gang known as QRSS Knights, gathered together on a mailing list, experimenting with various weak-signal mode variants of QRSS, plain slow on/off CW with typically ~5 second dit time.



I had a lot of fun designing and operating simple transmitting beacons, and more complex message encoding beacons; even a simple receiver. You can read about some of these on my website: http://hanssummers.com. In May 2010 that led to the first QRP Labs kit (pictured right), a simple low cost FSKCW callsign beacon with about 100mW power output. Steve G0XAR and I made 100 of these kits to accompany my presentation on week signal modes at FDIM 2010. It was the start of a thriving kit business, which since 2016 has become my full-time job, and filling my mind every waking (and sleeping) moment.

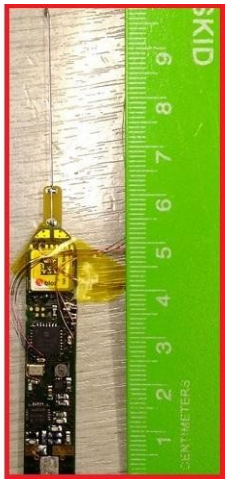
Roll along 2009 or 2010 or so, I had an idea to build an ocean-going buoy which would have some solar panels and a QRSS transmitter. It would have a bunch of sensors on board, and a GPS, and report back its location and the sensor values. Every day I used to walk to work along the river Thames in London and I'd be looking at the water and imagine my drain-pipe type of buoy bobbing along in the water (though really, practically speaking, you'd have to drop it off a boat miles off the coast, to avoid it getting stuck somewhere). I called the project "Voyager", after the two NASA space probes launched in the 70's which still send back signals from the far outer reaches of our solar system.

I had always been fascinated by spacecraft exploring the solar system. To me, a buoy floating around in the North Sea would be kind of like a poor-man's personal explorer. Some of the challenges are even similar, but on a much smaller, more hobbyist-solvable scale: sensors, long distance communications, low power. I actually built a transmitter and a 40m receiver to operate the project, but never got far with it. You can read more here http://hanssummers.com/voyager.

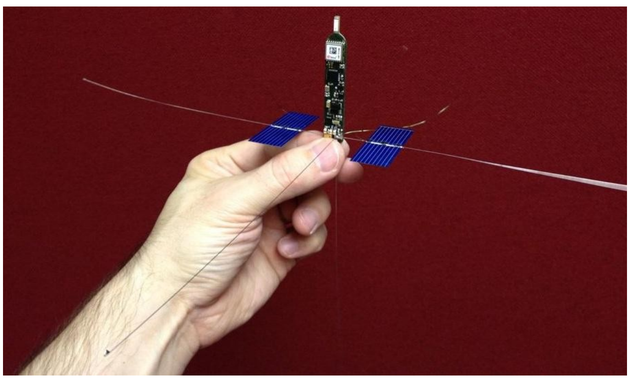
The next thing I found really interesting was the High Altitude Balloon (HAB) launches, which often seemed to be an engineering project in US universities (right). These use weather balloons filled with helium and ascend to up to around 30-35,000m altitude, where they burst, deploy a parachute and come back to Earth.

At that altitude, the sky looks black and the curvature of space is easily visible. So it’s popular to take along video cameras, as well as GPS and radio equipment for communicating the altitude and position, and batteries to run all that. Since these large balloons 2-5m in diameter can carry quite a significant payload, around 500 grams, they don’t have to try to miniaturize anything. The flights last a few hours, during which time they typically have line of sight radio communication with the balloon, so UHF telemetry is feasible e.g. on 70m bands. They often use integrated UHF telemetry modules for the communication. The chase is as much fun as the launch – teams enjoy driving sometimes a couple of hundred miles to hunt the balloon, to retrieve their equipment and precious photography and videos (see right).

Exciting though that all is – what REALLY made me sit up and pay attention, was when I came across the so-called floater or pico balloons in 2014. They’re a fraction of the size, a fraction of the weight, and a fraction of the cost (see right). Leo M0XER made the news in July 2014 with his first circumnavigation. It was the 64th flight in Leo’s balloon obsession that had started just over a year earlier. Leo had two more circumnavigation flights, B-63 and B66. He then appears to have retired from ballooning. Leo’s flights are all detailed here: http://leobodnar.com/balloons/



A weather balloon is made from latex (rubber), which stretches and stretches as it rises through the atmosphere and the air pressure decreases. Eventually it can stretch no more and BOOM! it bursts, and down it comes. Some latex balloon flights have succeeded in judging the amount of gas required at launch very precisely, and achieving an equilibrium altitude where the



Two party balloons were filled with hydrogen and tied together to give about 3 gms of boyancy to the payload (U3 and antenna)

pressures balance but the balloon envelope doesn't burst. Then they can travel quite long distances. The sun's strong ultraviolet radiation attacks the Latex though and as far as I know, they can't last more than a few days.

Floater balloons are different. They're made from a Mylar film (plastic) material. You've all seen the shiny foil balloons at parties, with helium inside. This is what is used for floater balloon flights. The Mylar doesn't stretch (much). The balloon is launched only partially gas-filled; as the altitude increases the gas expands, and eventually fills the entire available volume of the balloon. If you didn't over-fill it at the launch site, then an equilibrium altitude is reached, where the balloon can just float along in the wind. The Mylar film is inelastic and can withstand a certain pressure without bursting. It's a lot easier to target an equilibrium state than with a latex balloon, and the Mylar film is much more UV-resistant. The flights can last days or even months. Dave VE3KCL's record to date is 146 days aloft, using two cheap ($1.30) Chinese balloons from AliExpress.

The main risk to floater balloons is the weather. High altitude clouds deposit ice on the balloon envelope. It doesn't take many grams of ice to bring it down. We've seen many cases where as the balloon came down, weighed down by ice, the temperature warmed up, melting the ice; and in some cases even evaporating it before the balloon reached the ground, then we could observe a miraculous recovery and the flight continued. But really, if you want a long distance flight, with minimum or no risk of high altitude weather, you have to get above the clouds. 11,000m should be considered a minimum, preferably even more.

The difficulty is – to get to 11,000m you need a very light payload. Typical floater balloon payloads are around 10 grams. 10 grams isn't much, to carry a radio transmitter, power supply (solar panels), antenna, GPS receiver, and some computation capability to tie it all together. Yet, this thing is going to fly around the world. Over wide oceans and huge desolate landmasses devoid of many radio amateurs. We will want to know where it is, and ideally also something about its altitude, and perhaps other interesting parameters such as temperature and battery voltage.

Which brings us to the crux of the matter, and the reason we're all here: RADIO COMMUNICATION. The weather balloon crowd don't have so much of a problem because their balloons travel a couple of hundred miles at most, and the flights are all over in a few hours. Several watts of VHF or UHF will be easy to power with batteries, and they can carry ½ a kg or more; although it isn't trivial, neither is it particularly challenging. APRS is a popular tracking solution.

But for floater balloons the situation is entirely different. Not only do we need radio communications capable of spanning thousands of kilometers, but we can only carry a few grams. There's no possibility of carrying enough batteries for a flight lasting weeks, so solar cells are in order. And we certainly can't carry enough solar panels to generate several watts of RF. How can this be resolved?

Leo M0XER had used VHF modes mainly. The problem there is that as soon as your balloon flies over an ocean, or a sparsely inhabited part of the planet without lots of radio amateurs monitoring, everything goes quiet. You have no idea where the balloon is, until (if you're lucky), it files within a few hundred km of a radio amateur who happens to be monitoring whatever mode and frequency you're transmitting on. I came across various US flights using APRS http://www.aprs.org/ and they have exactly the same problem. With APRS, matters are complicated by the fact that different parts of the world use different APRS frequencies, so your balloon transmitter needs to be programmed to automatically adjust its transmission frequency depending on its location.

The solution to the communications problem must be weak signal modes on HF. Weak signal modes are particularly attractive because on a balloon we just don't have enough power capability, or enough payload carrying capability, for anything more than a few milliwatts of RF. We need HF to get beyond line-of-sight range and find suitable propagation for worldwide communication. I had recognized this back when I'd been thinking about the "Voyager" ocean buoy project, and had planned to use a telemetry system involving slanted dashes, whose presence would indicate a 1 and absence, a 0. The problem with that would have been painstakingly slow and tedious manual decoding.

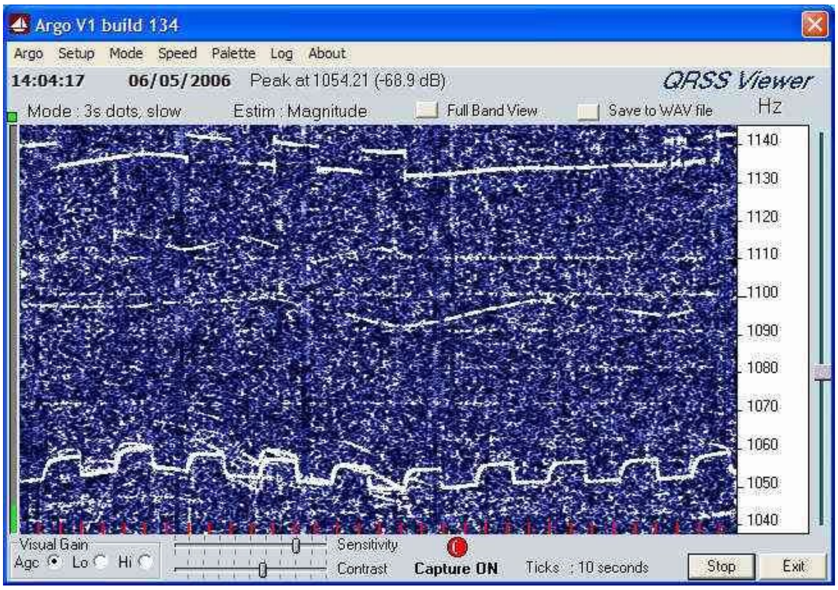
// / / / /// / /

which means:

110100101001110101

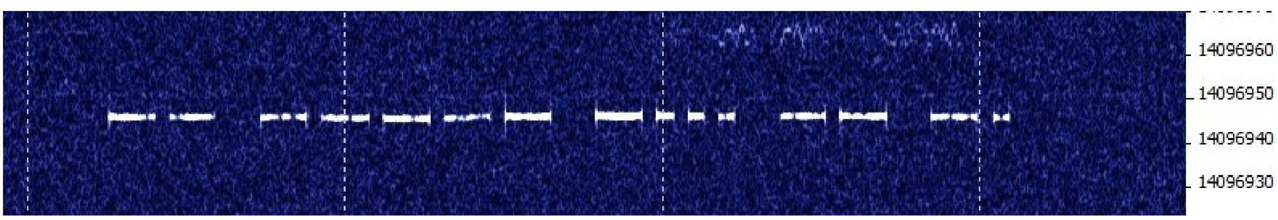
Weak Signal Modes

The most basic weak signal mode is QRSS, ordinary very very slow keyed Morse code. 12 wpm Morse has dits lasting 0.1 seconds. By comparison, QRSS is often used with dit duration of several seconds, or even longer in some circumstances. The result of this very slow transmission is that the bandwidth of the communication is sub-Hz. With suitable filtering, this results in a large signal-to-noise (SNR) advantage compared to other wider bandwidth transmission modes under otherwise like-for-like conditions (power level, antenna, band, distance etc).



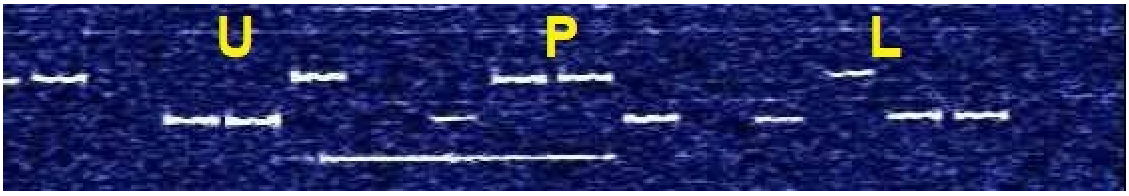
These signals are decoded with the aid of a modern computer, not by ear. Audio is fed from the radio receiver to the PC sound card, and then viewed on an audio spectrum analysis program. A very old but still functional and useful piece of software with easy set-up, is Argo (see right).

The display shows a small section of audio spectrum, typically only 100-200Hz, displaying the signal intensity in each frequency bucket by the brightness of the pixels.
The display scrolls across to the left, showing several minutes of reception. The display therefore builds up the received message; below shows an example M0BMN.

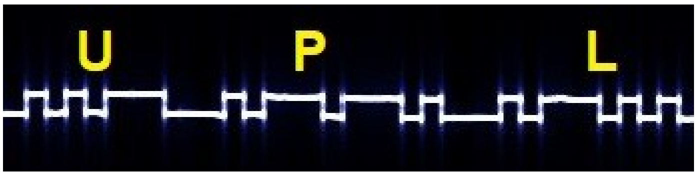


Other variations of the basic principle exist such as DFCW (where the dits and dahs are of the same duration but the dah is shifted up a few Hz compared to the dit) and FSKCW (continuous keying but the real “key-down” is shifted up a few Hz.

DFCW:



FSKCW:



Modern Digital modes

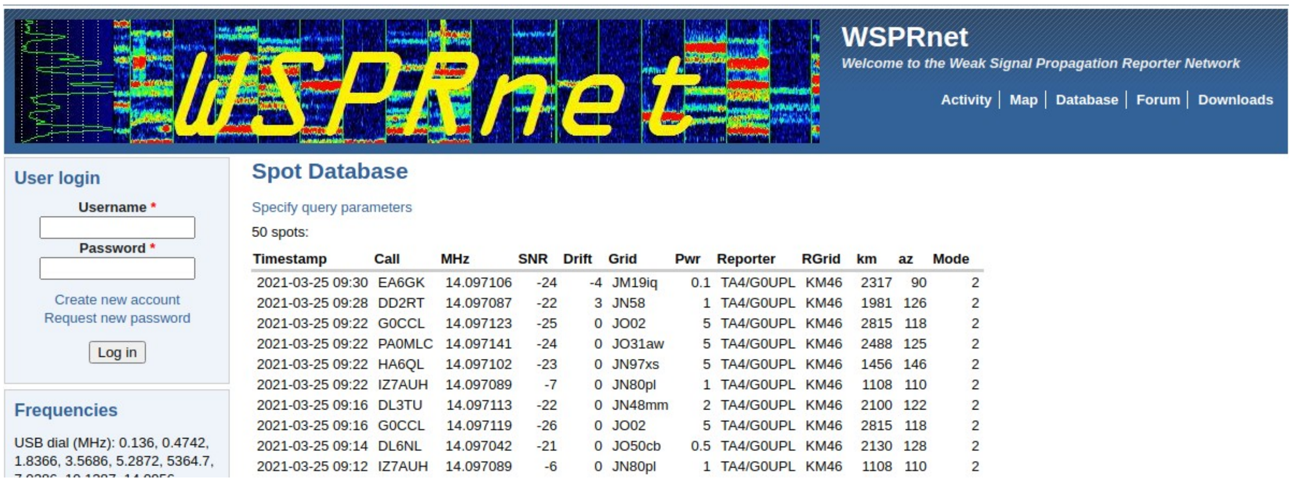
One of the oldest and most popular digital modes is WSPR (Weak Signal Propagation Reporter), that was created by Joe Taylor K1JT. Despite newer modes emerging, its worldwide popularity continues to increase. WSPR is a propagation reporting tool, not a QSO mode.

The transmission contains very limited information, simply the station’s callsign, 4-character Maidenhead grid square, and power level. That’s just 50 bits of data that is packed and encoded in a very clever way, providing forward error correction and extremely high SNR due to its narrowband nature. The 50 bits of information are encoded into a sequence of 162 tones, each tone is one of four audio frequencies that have a spacing of only 1.46Hz. The bandwidth of a WSPR transmission is therefore only 6Hz which is what gives it such an extraordinarily high SNR. The 162 tones are transmitted, commonly using an SSB transceiver, and take 112 seconds (almost two minutes) to send. On the Argo weak signal software, this is what a WSPR transmission looks like:

Several software packages exist for transmission and reception of WSPR, the most popular is the official WSJT-X software.

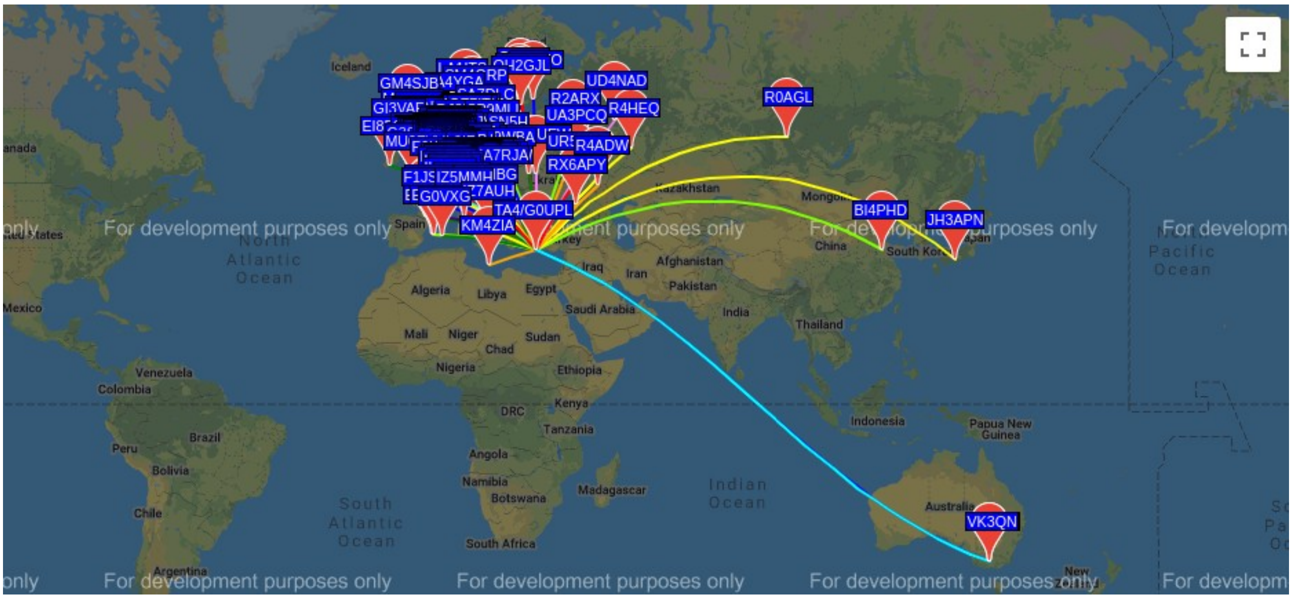
A transmitting station’s signal is picked up by monitoring stations and logged in an internet database. Stations (both transmitting and receiving stations) can view signal reports and plot maps at http://wsprnet.org .

Here’s an example of the WSPR website’s reception reporting:



Timestamp	Call	MHz	SNR	Drift	Grid	Pwr	Reporter	RGrid	km	az	Mode
2021-03-25 09:30	EA6GK	14.097106	-24	-4	JM19iq	0.1	TA4/G0UPL	KM46	2317	90	2
2021-03-25 09:28	DD2RT	14.097087	-22	3	JN58	1	TA4/G0UPL	KM46	1981	126	2
2021-03-25 09:22	G0CCL	14.097123	-25	0	JO02	5	TA4/G0UPL	KM46	2815	118	2
2021-03-25 09:22	PA0MLC	14.097141	-24	0	JO31aw	5	TA4/G0UPL	KM46	2488	125	2
2021-03-25 09:22	HA6QL	14.097102	-23	0	JN97xs	5	TA4/G0UPL	KM46	1456	146	2
2021-03-25 09:22	IZ7AUH	14.097089	-7	0	JN80pl	1	TA4/G0UPL	KM46	1108	110	2
2021-03-25 09:16	DL3TU	14.097113	-22	0	JN48mm	2	TA4/G0UPL	KM46	2100	122	2
2021-03-25 09:16	G0CCL	14.097119	-26	0	JO02	5	TA4/G0UPL	KM46	2815	118	2
2021-03-25 09:14	DL6NL	14.097042	-21	0	JO50cb	0.5	TA4/G0UPL	KM46	2130	128	2
2021-03-25 09:12	IZ7AUH	14.097089	-6	0	JN80pl	1	TA4/G0UPL	KM46	1108	110	2

And a map showing 20m WSPR reports by TA4/G0UPL during the last 24 hour period (all parameters are configurable):



Other digital modes have also been created by K1JT and a team of interested experimenters, including JT4, JT9, JT65, FT8 etc. Normally the number indicates the number of audio tones used, hence for example, JT9 uses 9 audio tones. These modes are each suited for different conditions, some are intended for specific uses such as EME.

It should start to become clear that these very low bandwidth digital modes, with their very high SNR allowing reception at great distance with extremely low power levels, might be an ideal candidate for tracking floater balloons.

Modern Digital modes for balloon tracking

The next great innovation in floater balloon tracking, as far as I was concerned, was by Andy VK3YT who launched a series of flights from Melbourne, Australia, documented on his website http://picospace.net/. Andy's "balloon phase" appears to have lasted from February 2014 to his 73rd flight which was in December 2019. Many of Andy's flights used JT9 mode and WSPR on 30m and 20m HF bands.

JT9 is a weak signal communications mode with powerful error correction. 13 characters of text are encoded into a series of 9-tones. These are transmitted typically in a 1-minute transmission (though the protocol also supports slower transmission rates for higher SNR).

Andy VK3YT developed a special telemetry protocol in which he encoded the various parameters such as location, altitude, battery voltage etc into a 13-character transmission for JT9. One important detail to mention, is that Andy didn't just take each character of the JT9 transmission and make it mean something, for example for altitude, A means 500m, B means 1000m, C means 1500m etc. Instead, he decided the resolution he wanted on each telemetry parameter, and encoded that into bits that were then reversed out into the 13 character transmission for JT9. This allowed him a lot more flexibility on data resolution.

Andy VK3YT actually needed TWO JT9 transmissions to transfer all the data he wanted. For decoding and collecting the data from tracking stations, he modified the WSJT-X software package, which is Open Source, to be able to decode his two JT9 telemetry packet styles, and upload the decoded data to his own server. Use of HF weak signal modes allowed Andy to reliably track his balloons even across the largest ocean of all, the Pacific ocean. He had several circumnavigation flights.

I followed all these flights avidly around 2014/2015. Around that time, I was also developing firmware improvements for the QRP Labs Ultimate3S http://qrp-labs.com/ultimate3/u3s which is a QRSS and WSPR and other weak-signal modes transmitter you probably know of, and is standalone with no PC required. I had had some requests to include JT9 in the list of supported modes and was working on that.

In late 2013 I had been discussing an ocean floater with tracker with a group of South African radio amateurs.

Then around Feb 2014 I had an email from Dave VE3KCL, which really was what kicked my balloon dreams into a whole new gear. Dave had taken an interest in high altitude "floater" balloons and thought it would be fun to launch an Ultimate3S on a balloon; he was excited to hear that I planned to implement Andy VK3YT's JT9 balloon telemetry messages.

It was the start of a long international friendship between Dave and I that has generated thousands of emails of correspondence, long IM chats, phone calls, meeting in person at Dayton hamvention when Dave (left) came to help me man the QRP Labs booth. Dave has tremendous energy and enthusiasm which is incredibly infectious. In April 2015 I officially included JT9 in the Ultimate3S firmware, and not long after, shared with Dave a series of beta versions that included things like Andy's JT9 telemetry for balloon tracking.

VE3KCL's first flight

So it was that in June 2015, Dave VE3KCL launched his first balloon, carrying an Ultimate3S, transmitting WSPR and JT9 telemetry, just as Andy VK3YT did on his balloon flights. It reached an altitude of 4,233m and flew for 2.5 hours, covering 68km. The second balloon flight the following month, had a very similar flight profile. These two flights are detailed at http://qrp-labs.com/flights/s1 and http://qrp-labs.com/flights/s2 . I recall a funny discussion from around this time, where Dave and I were discussing what to call the flights. After all, Leo M0XER used the prefix "B" as in B-1, B-2, B-3 etc., presumably the B was for either Balloon or Bodnar (Leo's surname), who knows. And Andy VK3YT used PS e.g. PS-1, PS-2 etc., clearly the PS for picospace after his website http://picospace.net. Dave suggested "S" for short, since 2½ hours was evidently as long as they could fly, and so S it was, starting with S-1, then S-2 etc.

By the third flight, Dave had uncovered the cause of the early demise – some heavy gas sitting in the bottom of his hydrogen tank meant that he was over-filling the balloons to get the calculated lift. Once properly emptied out and starting again with fresh, pure hydrogen, the flight duration increased dramatically.

Inventing a protocol for telemetry over WSPR

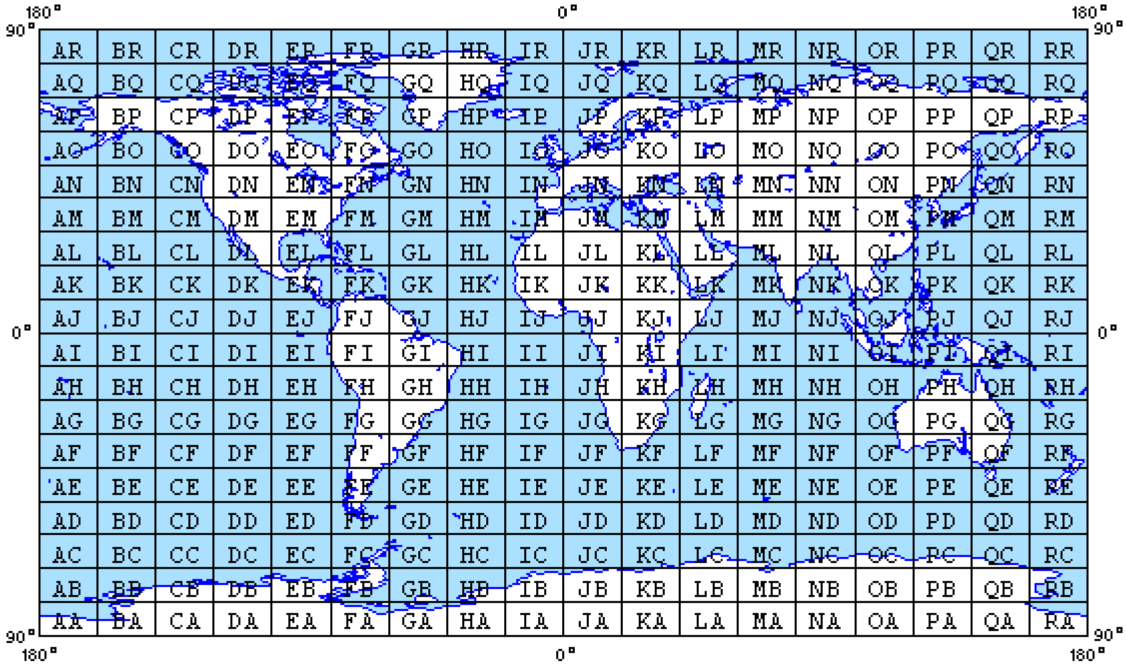
Meanwhile I continued observing the flights of Andy VK3YT and observed two sort-of problems with the tracking.

Firstly, by using JT9 for tracking, and a customized version of WSJT-X to decode it and upload the reports to his server, Andy had to recruit his own network of volunteer tracking stations to install the special WSJT-X version and listen for his balloon. This necessarily limited the number of stations globally that could receive the tiny signals from his flights, so there were at times, gaps in the tracking capability.

Secondly, Andy VK3YT was also using WSPR on his balloons. I observed that there were many occasions when no JT9 was decoded, but WSPR was – even by the same receiving stations – which eliminates any effect due to the much larger WSPR receiving network. This is as you would theoretically expect too, since the bandwidth of JT9, data payload (13 characters) and the bit-rate, are all higher – leading to lower Signal to Noise Ratio (SNR). In other words, more power would be necessary to achieve the same reception reports as WSPR. This is completely normal.

So it appeared, theoretically and practically, that WSPR would be a better solution for tracking balloons. However, a significant problem exists with using WSPR for tracking, too. This is due the fact that unlike the free-format 13-character text message carried by JT9 (and some other JT-modes), WSPR has a fixed-format:

- 6-character station callsign
- 4-character Maidenhead grid-square
- Power in dBm (19 different levels available)



The power level is one of 19 values from 0 to 60dBm, 0, 3, 7, 10, 13, 17, 20dBm etc. The problem is that a Maidenhead grid square measures 1° latitude by 2° longitude. According to ARRL at http://www.arrl.org/grid-squares, that is "approximately 70 × 100 miles in the continental US" (110 x 160km). Not only is the location precision very coarse, but we also lack that most crucial of parameters watched by any balloonist: the altitude!

I believe Andy VK3YT had started mapping altitude levels to the 19 power levels of the WSPR transmission, so that as a backup, if JT9 was unavailable – and if he had WSPR reports – then he could at least determine approximately where his balloon was and roughly at what altitude. But really, 19 levels is again a very coarse measure, and ideally we'd like more data from the balloon including battery level, temperature and speed. So WSPR in its intended state, isn't an ideal tracking tool.

The enormous advantage of WSPR is the worldwide tracking network! WSPR has been very popular, and is ever-growing in popularity, since it was first created in 2008. If it were possible to use WSPR for the tracking, then it would solve the first fundamental problem of Andy VK3YT's HF weak signal tracking, that of recruiting volunteers to install his special software for JT9 decoding. If the limitations of the protocol could be overcome, we would end up with the PERFECT tracking system for long distance "floater" balloons:

- Long range coverage by using HF
- Weak signal mode works fine with a few milliwatts
- Powerful error correction telemetry
- Worldwide existing network of monitoring stations
- Automatic tracking

Dave VE3KCL and I discussed all this frantically for several weeks and months, with various ideas on how to use the locator field of WSPR transmissions as well as the power level, to carry some of the data we wanted. We called it "WSPR abuse"!

A big breakthrough came when I noticed that NO official amateur radio callsigns ever exist with prefixes 0, 1 or Q, and had the idea that we could make use of this. The International Telecommunications Union (ITU) simply doesn't allocate any callsigns with these prefixes, according to their published policy. There have been some unofficial operations with callsign prefix, generally operations in states that have no official prefix of their own, or a number of troubled states (that I shall not provide examples of, for fear of somehow upsetting somebody somewhere) around the world whose existence, independence or sovereignty is disputed.

I started to design a telemetry packet, re-encoding our additional data into a second WSPR transmission, which was identified as telemetry, not a real amateur radio station, by using a callsign with 0 or Q as the first of the six characters. I also used the third callsign character, which is by the definition of the WSPR protocol, a numeric digit in the range 0-9. Each balloon telemetry would be identified by its callsign being of the format CxNxxx where:

- C is character '0' (zero) or 'Q'
- N is a number in the range 0-9
- x are characters re-purposed for our telemetry

Therefore 20 different "channels" were created, allowing 20 different balloon flights to use the telemetry system, without interference with each other. Later, inclusion of the '1' prefix increased the number of available channels to 30.

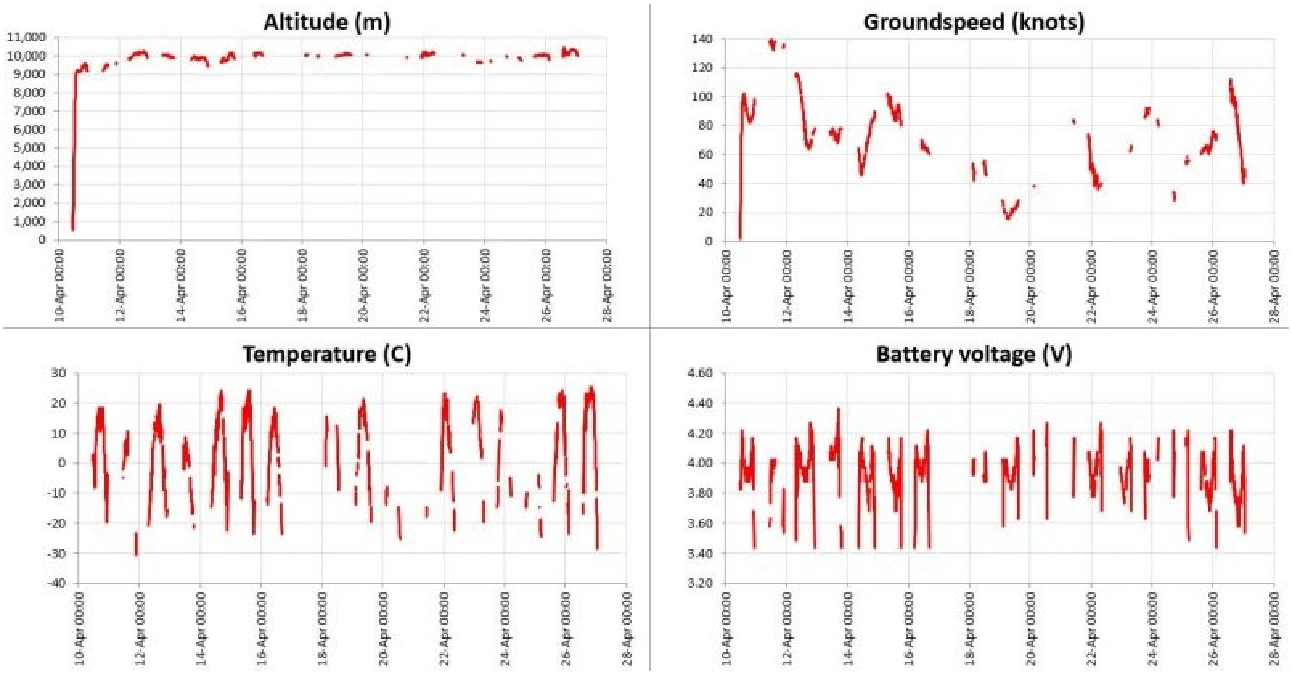
The four characters of the Maidenhead grid square, and the 19 levels of power, were also re-purposed to carry telemetry. A complete WSPR transmission consisting of station callsign, locator and power was therefore represented:

CxNxxx xxxx xx   (callsign, grid-square, power)

where x are the parts of the standard message whose bits are re-purposed to carry telemetry. A WSPR message contains only 50 bits to start with. After deducting the first callsign character (always 0, 1 or Q), the 3rd (always a number), and allowing for the fact that there are wasted un-used bits in the power field, which cannot be reclaimed – in the end we have only 39 binary bits of data to carry our desired telemetry. So careful thought is required as to the required resolution of data. What I designed for the WSPR telemetry protocol was:

- Maidenhead grid subsquare 5'th and 6'th characters, which are letters in the range 'A' to 'X'. In addition to the 4-character gridsquare sent in the main WSPR transmission, this gives us a location resolution of a few kilometers, which is adequate for tracking.
- Altitude: range 0 to 21,340m with a resolution of 20m. This altitude resolution of 20m is plenty fine enough!
- Temperature: -50C to +39C with a resolution of 1C (90 possible values)
- Battery voltage: 3.00 to 4.95V with a resolution of 0.05V (90 possible values)
- Ground speed in knots: 0 to 82 knots with a resolution of 2 knots
- GPS satellite status bit: 1 if we have a healthy good GPS lock
- GPS number of satellites: 1 if there are at least 8 tracked satellites

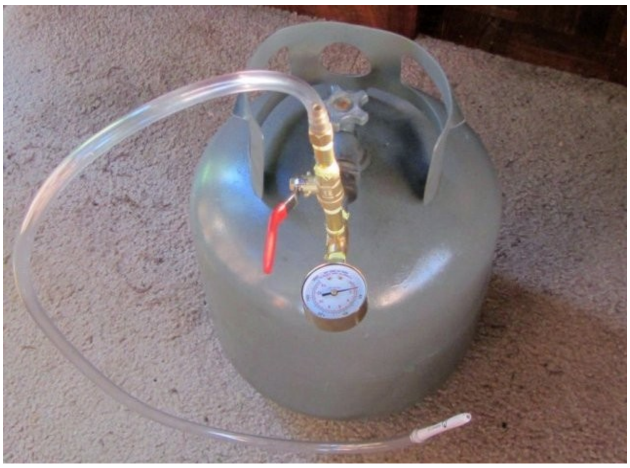
Altitude, temperature, battery voltage and ground speed "wrap" - by this I mean that for example, if the ground speed reported by the GPS is 86 knots, the telemetry will report it as 2 knots. 88 knots would be reported as 4 knots, and so on. This is important because when the balloons get in the powerful jet stream winds they can certainly exceed 84 knots and do so frequently. It is normally easy to know whether 84 needs to be added to the reported number, because of the difference in position which is easily calculated in kilometers, allowing an approximate speed to be determined, at least well enough to know whether it is above or below 84 knots.



This system is described in detail here http://qrp-labs.com/flights/s4#protocol with an example encoding/decoding spreadsheet. It has proven very reliable and robust. During many test flights with power level of about 10-20mW, communication has been possible across all the oceans and land masses of the world.

Probably the longest distance achieved was long-path reception in New Zealand, when one of the test balloon flights was in Europe, a distance of 22,000km! That’s well over a MILLION MILES PER WATT.

Dave VE3KCL S-series flight payloads

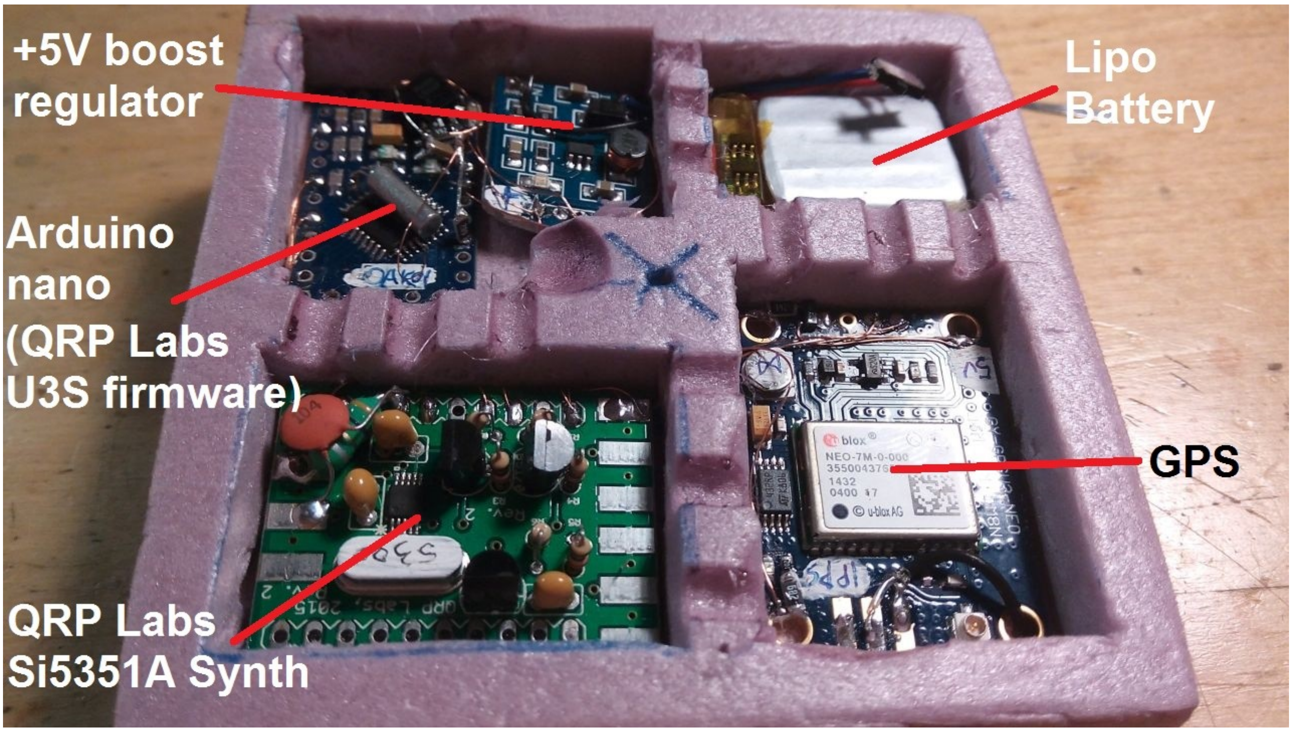


Some details are due, regarding Dave VE3KCL’s balloon hardware. The early flights used inexpensive Mylar “party balloons” printed with the message “Over The Hill” (see photograph, earlier) which is of course, about as far as they managed to fly. Hydrogen is a bit better at lifting than helium, has slower leakage rate due to the larger hydrogen molecule, and is also more environmentally friendly (since helium is a non-renewable resource). However hydrogen is also an explosive gas so some care in handling is required, with all due attention to necessary safety measures.

Dave VE3KCL’s early flights consisted of a collection of off-the-shelf hardware modules, packaged in a polystyrene enclosure. The parts of the system are:

- QRP Labs Si5351A Synth kit http://qrp-labs.com/synth
- Arduino Nano
- uBlox GPS board
- Voltage regulator module
- LiPo battery

The Arduino Nano was not used as an Arduino. It was only used because it contains the same ATmega328 processor as the Ultimate3S, but in a much smaller SMD package which saves weight. Dave flashed the 'nano's processor with the Ultimate3S firmware, the special version of the firmware that implements the WSPR telemetry system. Changing the Arduino nano's crystal to 20MHz to match the Ultimate3S was also needed. Eventually, Dave designed his own PCB to hold the necessary components, resulting in further weight savings.



Dave's S-series flights based on the Ultimate3S consisted of 26 flights in total. The 11th, in June 2016, was the first circumnavigation Dave achieved, about a year after his first 2.5-hour, 68km flight. What a scale of improvement in one year!

Tracking Spreadsheet

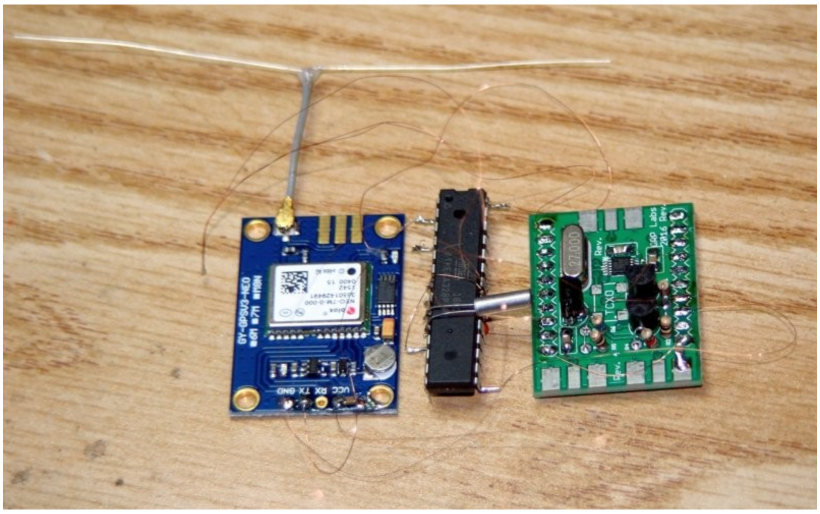
At the other end of the tracking system, was an Excel spreadsheet that I wrote. Every two minutes, the spreadsheet connected to WSPRnet and loaded the entire 5,000 last spots for 20m and 30m bands. The sheet then went through the list and parsed the spots to find any balloon telemetry spots, which were decoded and matched to the normal WSPR transmission reports in the preceding two-minute slots. The two pieces of information (4-character Maidenhead grid from the main WSPR transmission, and the 5th and 6th character grid subsquare information from the telemetry transmission) were pieced together and converted to latitude and longitude, which was written into an HTML file in Google Map format and FTPed to my website. The result was a live tracking map on the website that updated every 5 minutes, with the latest decoded information from the balloon (that was sent every 12 minutes or 10 minutes).

Balloon flights by Jim N2NXZ

Mention is due to other balloon celebrities who have also been involved with flying the special QRP Labs Ultimate3S code with the WSPR telemetry tracking system.

Prominent and indeed foremost among these is Jim N2NXZ who has his own particular style and enthusiasm. I particularly liked Jim’s low-tech way of implementing a low weight version of the Ultimate3S, which was simply using an existing set-up Ultimate3S ATmega328 chip, full-size DIP28 package, and soldering the wires of the GPS and Si5351A Synth kit directly to the chip! No PCB at all for the processor.

Jim had been experimenting with balloon flights for a number of years. But then started his own series of flights with prefix U3S since they were all based on the Ultimate3S kit, running the standard Ultimate3S firmware, not the special telemetry version. Somewhat later on, Jim did also run the special version with the WSPR telemetry. We even have a photograph of Jim launching his U3S-7 flight from the roof of his house!



Jim’s contribution is notable and commendable for his enthusiasm and non-traditional way of looking at things, which was always interesting to discuss, and we learned many things form these U3S-series flights too. In total Jim N2NXZ launched 33 balloons in his U3S-series, and they were always fun to watch and learn from.

Bob ZL1RS

Bob is notable not just for running several balloon flights, BB-01 to BB-05 using the special WSPR telemetry, the first time it was used in the southern hemisphere – but also for actually realizing in real life, my dream of an ocean buoy! You can read much more about this voyage here https://www.qsl.net/zl1rs/oceanfloater.html . Somewhat like my original "Voyager" plan, Bob used D-cell batteries in a drain pipe; but of course the JT9 and WSPR tracking was much more advanced than I had ever imagined back then. Bob's Ocean Floater project drifted around in the South Pacific Ocean for 407 days, reporting its position and condition continuously during that time.

Bob ZL1RS' 5th balloon launch BB-05, achieved circumnavigation with two laps around the world, finally coming down in the South Atlantic ocean half way around its third lap.

Daniel DL6OW

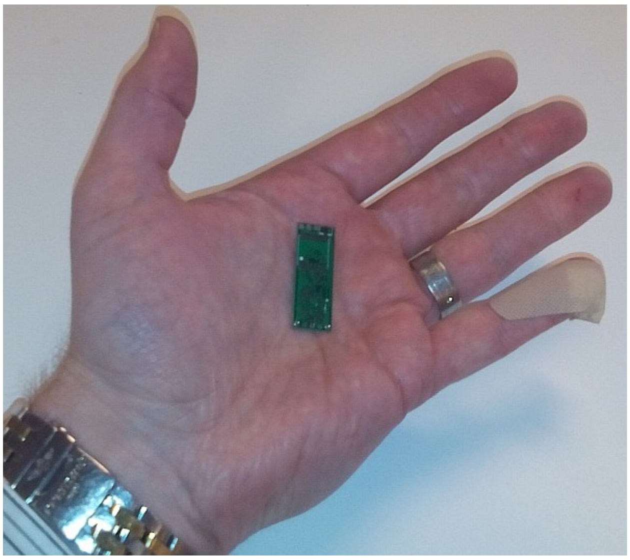
Then there is Daniel DL6OW and his friends flying the flag for Europe, with WSPR telemetry balloons called Stella-1, Stella-2 and so on up to Stella-22. Stella is the name of Daniel's daughter! Daniel's first flights, like Dave VE3KCL's, were on multiple connected off-the-shelf modules but subsequently he designed his own PCB to reduce the size and weight.

Others

Eventually the special Ultimate3S firmware found its way outside the small group noted above and several others have also flown it, or variations of it. Apologies for not listing in full all the names and details here, which would require a lot of research for which time is lacking. The WSPR telemetry protocol has since been used and modified by other balloon enthusiasts too, including Alan W7QO, Michael KD2EAT and Bill WB8ELK.

QRP Labs U3B tracker development

Right from the beginning in my conversations with Dave VE3KCL, I had been considering how nice it would be to produce and market a small tracker board. There are people who can design their own PCBs and assemble the SMD components, write the firmware and so on. But for every person like that, there must be 10 or 20 times more people who don't have the resources (experience, time) to do that. An assembled board would make it possible for many more people to participate in this interesting and crazy hobby of high altitude long distance ballooning!



I called my tracker “U3B”, since it was based on the Ultimate3S kit http://qrp-labs.com/ultimate3/u3s with the “B” suffix standing for Balloon. The size was 38.0 x 12.7mm, including transmitter, voltage regulator, GPS and ATmega328 processor. Components on both sides included 0402 size resistors and capacitors.

For fun and the extreme deliciously and un-neccessarily over-the-top-ness of it, the U3B did not use the standard or even a modified version of the Ultimate3S firmware. Instead I wrote a 32-bit virtual machine, that ran inside the 8-bit AVR processor (ATmega328), with a BASIC interpreter and compiler, storing the program in the 2K EEPROM of the processor. The idea behind this, was that the experimenter would be free of the constraints of the Ultimate3S system.

In the Ultimate3S, one configures a number of transmission slots, including specifying the mode and message to be transmitted. But in the U3B, the BASIC programming language statements included commands to transmit a message in CW, FSKCW, WSPR, or the Telemetry etc. Even JT9.

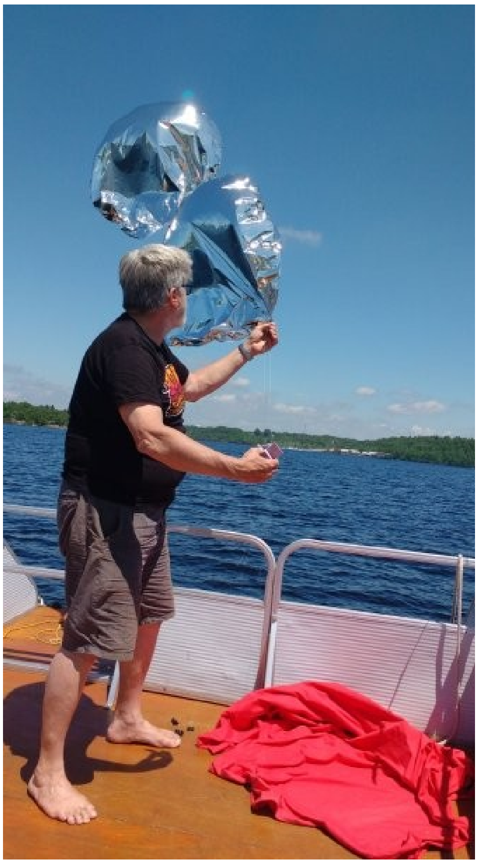
But the U3B system could be configured with a very very simple BASIC program for a really basic (pun not intended) flight. Or a more advanced user could write his program to customize the flight to his requirements. U3B had a number of I/O pins which could be read as analog or digital pins, or other sensors on the I2C bus could be read, and so on.

U3B was programmed via a 9600-baud serial port, using a USB-to-Serial converter and a terminal emulator program on a PC.

Dave VE3KCL assembled and flew the first prototype U3B on 16-Jun-2016 and so started the U3B-series of balloon flights, with U3B-1. The BASIC program listing of that first flight was:

```
 5 LET FR = 26999800
 6 GPS 300
 7 PRINT FS , FR
10 SLEEP 10 0
20 PRINT FS , FR
25 PRINT BT
30 TELE 2 10140260 10 "G0UPL"
35 PRINT BT
38 PRINT FS , FR
47 TELE 2 14097130 10 "G0UPL"
50 PRINT BT
70 PRINT FS , FR
75 JT9 1 10140400 "G0UPL #M6"
80 PRINT FS , FR
90 GPS 300
95 PRINT FS , FR
```

```
100 GOTO 10
```



Variables FS, FR and BT are system variables holding the system crystal frequency (20MHz), Si5351A reference frequency (27MHz) and Battery voltage respectively. You can see that there are commands for transmitting telemetry, JT9, and doing the GPS calibration.

In total there were 28 U3B test flights, each one experimenting with different aspects of the hardware, the firmware, or the software (BASIC flight program), and with varying degrees of success. The U3B prototypes turned out to be rather hard to modify, since everything was so incredibly small and closely packed; so we designed a PCB twice the size, with mostly all the components on the top side, and

<u>Dave VE3KCL and all the balloon technicalities</u>

Throughout nearly 6 years of collaboration on the balloon flights, Dave VE3KCL and I have worked closely together. I designed hardware, PCB layouts and wrote firmware and the tracking spreadsheet. Dave assembled the units to fly. Dave may be 2 decades my senior but he’s not afraid of hand-soldering 0402-size SMD components!

Dave has endless enthusiasm and has gone deep into many aspects of flying balloons, other than just the tracker hardware, firmware and software.

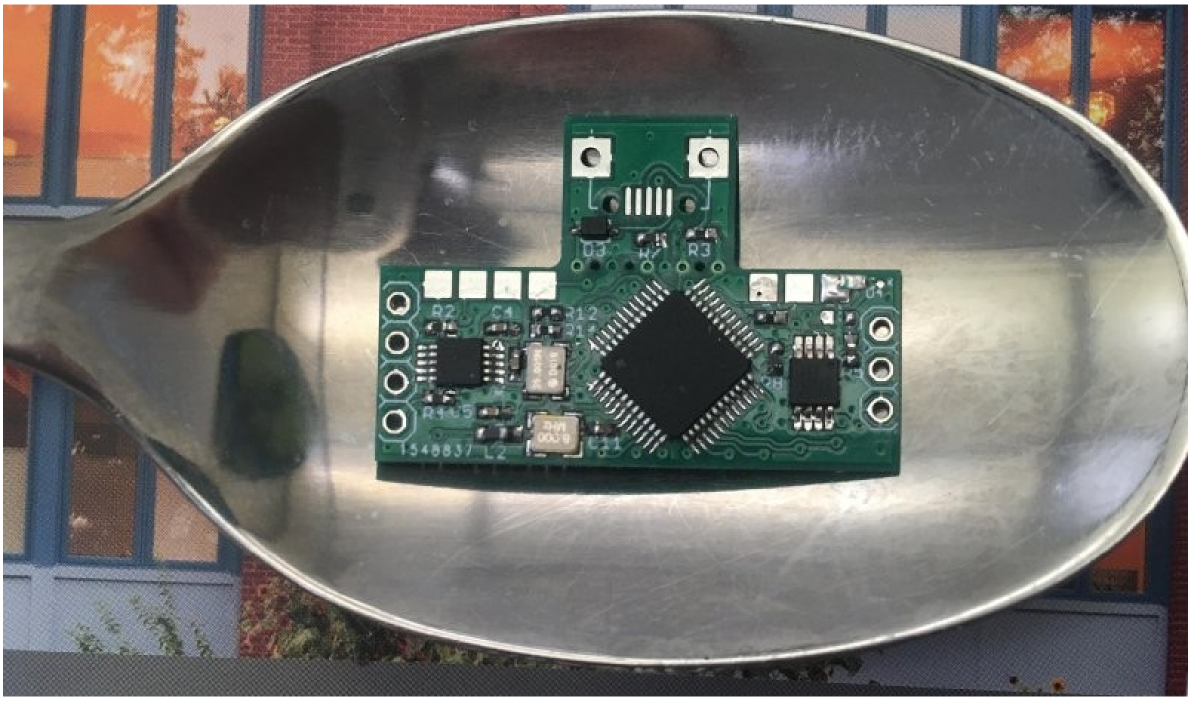
In the second part of this article, Dave explains many of the practical aspects of High Altitude “floater” balloon flights.

<u>U4B – at last…</u>

Then as my room-mate at the Dayton hamvention in May 2019, Dave VE3KCL and I got to discussing how to finally finish up the U3B project, Dave said if I allocate a whole week to it I could finish it (yeah-right!) and somehow during those discussions, it mutated into the U4B. “4” because now I have changed the processor to a 32-bit STM32 ARM processor. These have very much more raw power, peripherals and functions compared to an ATmega328 AVR processor, and yet have a very low price.

The U4B will be the final tracker, the one that that enters production. The first prototypes were on a double-sized board, with components on one side only, just like the U3B. There is a micro-USB connector on a protruding section of the PCB that is designed to snap off before flight, for weight-saving. Like the U3B, the U4B tracker weighs around 1.5 grams, it is a 33.0 x 12.7mm PCB with GPS, processor, Si5351A (synthesizer/transmitter), voltage regulator and 128K EEPROM chip.

The final board is pictured below.



The firmware contains a customized operating system called QDOS (QRP Labs Disk Operating System), which is a complete miniature computer system with:

- command prompt
- FAT12 file system on the 128K EEPROM
- file manager
- full-screen editor application
- BASIC compiler and integrated debugger
- 8 general purpose I/O pins that can be used as inputs or outputs, analog or digital, as well an an I2C bus for interfacing to digital sensors such as humidity etc

All of this is hosted on the device itself, there is no special software running on a PC downloading code into the U4B. The only thing needed is a terminal emulator, for example on Linux we use PuTTY. The U4B presents itself to the PC as a Virtual COM port serial device.

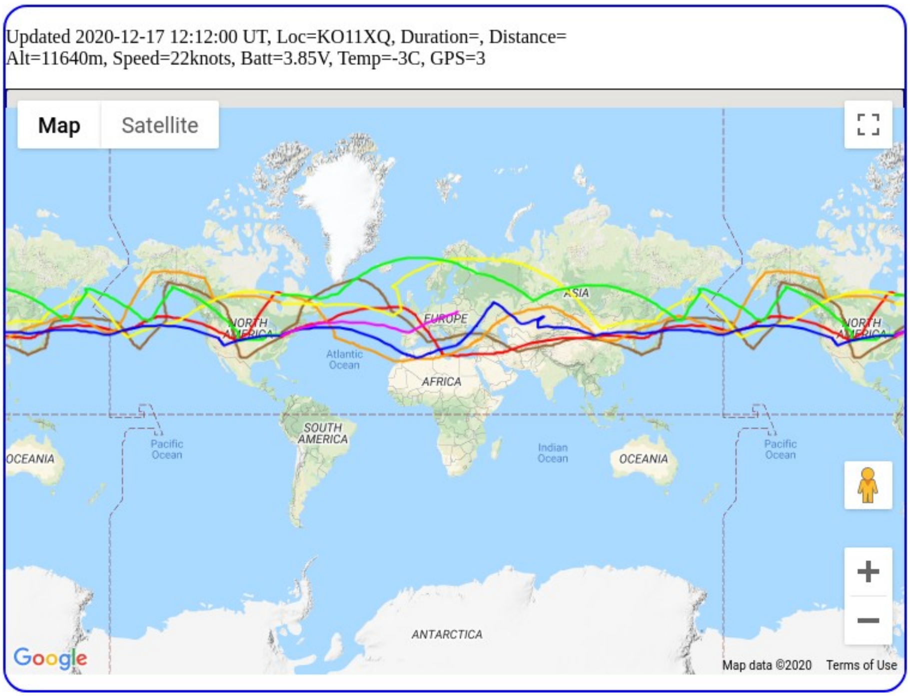
The BASIC programs have similar capabilities to the U3B. Which is to say, almost all the modes the Ultimate3S is capable of, as well as the WSPR telemetry type. The I/O pins, I2C bus communications, and radio transmitter can all be controlled by BASIC statements.

Modifications to the telemetry protocol allow up to 600 telemetry channels, and additional data fields for your own sensor data (8 general purpose analog/digital I/O pins, I2C bus sensors, and more).

At time of writing (21-Mar-2021) there have been 17 test flights of the U4B. From U4B-13 on, the flights use an actual real-size final PCB layout that will be used for the production batch.

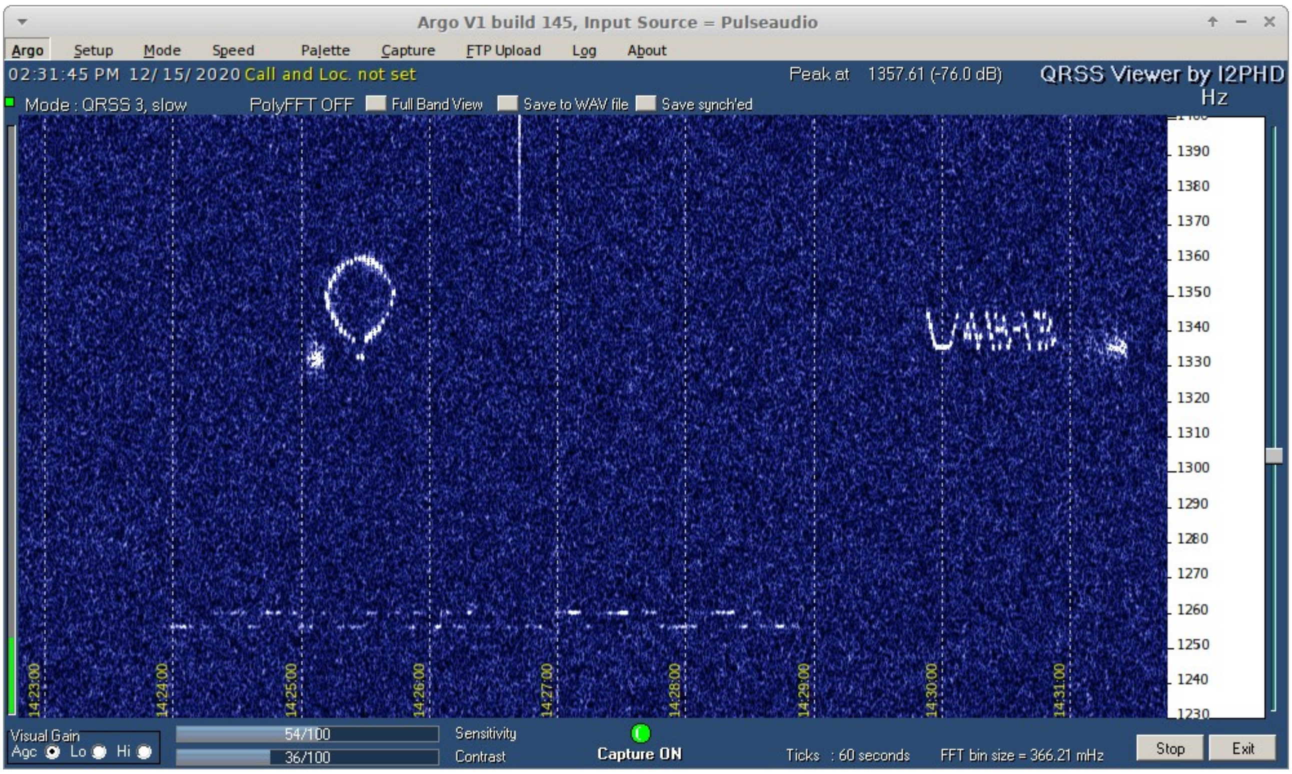
Flight U4B-17 has performed very well and is viewed as the final in the test flight series, now production may commence.

On the map (right), the colours indicate the lap of our planet, according to the standard resistor colour code. In its current position over Austria the line ending is purple, indicating the 7th lap.



To return to more traditional QRSS for a moment – many of the flights have included, as part of their transmission schedule, traditional QRSS modes such as FSKCW, and Slow-Helshreiber (shifted tones that produce character patterns). More recent flights include a charming balloon glyph.

The screenshot below was recorded by me (TA4/G0UPL) on 15-Dec-2020 from my QTH in South West Turkey while U4B-13 was crossing Northern Iraq. It shows the balloon glyph and the “U4B13” text. Note that this text is produced by a series of custom shifts; text can also be produced using slow-Helshreiber which uses the original font from the Hellshreiber machines developed by Rudolf Hell in the 1920’s.



One wonders what Rudolf Hellshreiber, or Samuel Morse, would have made of all this. 1.5 gram transmitters circling the globe, transmitting milliwatts? Talk about EXTREME QRP!

Practical aspects of High Altitude ballooning, by Dave VE3KCL

In the following sections, Dave VE3KCL shares his knowledge on some of the vital practicalities of flying high altitude “floater” balloons successfully.

Basic principles of floater balloons

A weather balloon is filled with a lifting gas like hydrogen or helium and as it rises the density and pressure of the air outside the balloon decreases and the balloon expands. Because the balloon is made of latex, and is elastic the external pressure becoming less as the balloon rises, the internal pressure becomes relatively higher than the external pressure. The balloon keeps expanding as the outside pressure decreases till a point when the balloon cannot expand anymore and it bursts.

A super pressure balloon is different from a latex balloon, used by the weather service, in that it’s walls are not that elastic and as the balloon rises and the external pressure decreases, because the walls of the balloon are much stronger, they will resist expanding any more as the altitude increases. At this point the density of the balloon and its payload becomes stable and the balloon stops rising. This is referred to as the float level. As the balloon volume is kept relatively constant the density of the balloon and its payload remains constant, and the balloon will float along at that level for long periods of time.

On a spreadsheet downloadable on Habhub one can enter many variables of flight, including the mass of the balloon and its payload, (the radio, antenna, solar panels,) and determine the differential pressure in the balloon at any flight level. (this pressure is the difference of pressure inside the balloon and outside the balloon that if exceeded could cause the balloon to burst).

Before a flight, as the balloon is being filled on the ground a weight is clipped on to the balloon that is the same as the payload + the weight of free lift. The balloon is filled with lifting gas till it is buoyant and neither goes up or down. An additional amount of gas is added to the balloon to make it rise. This additional amount of gas is referred to as the free lift and it is usually around 7 grams per with clear balloons. With 2 balloons lifting a payload the calculations are different.

So to fill the balloon we fabricate a weight that corresponds to the payload + the free lift.

For example, if the radio and antenna weighed 5 gram and we used 7 grams of free lift, We would attach a weight of 12 grams to the balloon and add gas till the balloon would be buoyant and not go up or down. The neck of the balloon is then sealed with a impulse or band sealer and the radio and balloon are taken to the launch site and let go.

At the launch the balloon and its payload is less dense than the surrounding air so the balloon rises, but at the float level the balloon cannot expand any further so the balloon and payload’s density becomes constant and equal to the density of the surround air. Recently with 2 clear balloons this equilibrium happens somewhere around 12 kilometers above the earth.

Other influences affect the float level of the balloon. If the balloon is flying over a high-pressure area on earth, the balloon will float at a higher altitude, as the density of the air around the balloon is higher and conversely if the balloon flies over a low-pressure area the balloon will float at a lower altitude. If the jet stream is very fast and the balloon is flying in the jet stream at over 100 knots per hour the balloon will often float lower than it would in a slow jet stream.

The jet stream is a high speed wind that exists around the world in a serpentine pattern. It usually blows from the west to the east in the northern hemisphere. NOAA, the National Oceanic and Atmospheric Administration in the USA studies the jet stream and makes online tools available for visitors to the NOAA website.

Hydrogen storage

Hydrogen gas is purchased from the welding supply as it has some welding applications. Hydrogen usually pure unlike Helium that can be diluted when used for party balloons. Sometimes Party balloon helium is mixed with air to make fill more balloons for less money. This type of party balloon Helium is not suitable for use in Super pressure or floater balloons as it will case the balloon to burst prematurely and instead pure Helium should be used. Hydrogen is flammable but has a few advantages over Helium. Hydrogen has more lift than helium, is a renewable resource and it does not leak through a balloon membrane as quickly as Helium.

The Hydrogen from the welding supply comes in high pressure cylinders containing greater than 2000 psi pressure. It is easy to use 20lb propane tanks to hold the Hydrogen at a lower pressure for filling balloons. The rated pressure of a propane tank is about 300 psi . These propane tanks are filled with about 150 psi of hydrogen reduced through a gas regulator from the high-pressure hydrogen cylinder. The propane tank is fitted with a ball valve to control the outflow of hydrogen into the balloon and a pressure gauge that indicates the remaining pressure in the propane tank. A three-foot clear plastic hose goes from the ball valve and is then reduced to a narrow tapered ¼” hose that will fit in the balloon neck, or fill port. The propane tank when filled to 150 psi. can properly inflate about four 36-inch balloons before it needs to be refilled again.

Launch day

It is advisable to check the weather forecast to find a good day for the balloon launch. The safest wind speed for a launch is no wind at all or dead calm. This calm condition is very rare but usually winds are lighter just before dawn. Dawn is the preferred time to let a balloon go. The weather forecast is checked a few hours before filling the balloons with attention to the wind speed and direction at the nearest airport. This information is usually available on the internet. It is not a good idea to launch a balloon, if the wind speed is any higher than 5 knots about 6 miles per hour.

The wind direction is important as sometimes the launch site has trees nearby that could interfere with the balloon's clear ascent path. Two different sites are used in Toronto, one that favours the prevailing wind, and one that is used when the wind is coming from the opposite direction. Often a day with low wind, has the wind changing direction on that day, but usually the weather forecast will indicate which way the wind direction should be changing over time. If the launch space is big enough, one does not have to worry about the wind direction. One location nearby has about 150 meters or almost 500 feet clear with low trees at either end and the other, at the edge of a lake, is wide open for miles in the direction of the prevailing winds. Unfortunately, the lake site has dogs and dog walkers and runners and a number of moving hazards that could cause a problem with the very fine antenna wire.

-17 U4B

RADIO	5.02
ANT	.7
MISC	.1
	5.82
½ PAYLOAD	2.91
FL	7.5
BALANCE	10.41gm

About an hour before a launch, if the weather looks good the balloons are filled with hydrogen and balanced to have the required amount of free lift, then sealed with an impulse sealer.

It is a good idea to handle the balloons as little as possible, as every crease in the envelope could possibly leak the lifting gas a little faster. Using two balloons per flight is preferred, and after sealing, they are weighed down with clips and weights. The lower balloon with the short line is held at floor level with a weight while the upper balloon is fastened to the top of lower balloon with Tyvek construction tape. This product holds building wrap on buildings through the winter and is very robust, and good for the small job of holding balloons together. The upper balloon has a longer line (long enough as not to rub on the lower balloon when it is fully inflated). These lines, the long and the short, are tied together near the bottom of the lower balloon. A folded bed sheet is laid on a table, the balloons are stacked on the sheet and then the rest of the sheet if folded over the balloons to make a bag. The edges of the sheet are fastened with clips allowing the two lines to exit the opening in the front of the sheet so the lines can be tied to the balloon antenna without releasing the balloons.

A telltale is made, a wind indicator constructed from a very thin plastic bag that is cut into a long 3/8" wide strip about 2 feet long, and tape one end to a stiff wire. This is taken to the launch site and held up to determine the direction of the wind locally. It will respond to very light wind.

The radio is kept in shoe box with foam and paper padding and contains both the upper and lower antenna elements on rolls loose at one end and soldered to the radio at the other. Since the wire is so thin a tight coil is wound to absorb shocks. About 10 turns of about 1/8" or less diameter is formed on the end of the antenna wire. This is coil is made on a small Phillips screw driver before soldering the end of the coil to the antenna stubs that come out of the radio. Prior to leaving the house one makes sure the tracking program and WSPR radio is running so the first spots will be recorded.

Three important things go to the launch: the bag of balloons, the shoe box with the radio and the telltale.

At the launch site one first determines the local wind direction, and then moves up wind in the launch space so the maximum clear distance is in the downwind direction.

The balloon bag is laid on the ground with the lines facing downwind and the shoe box is placed about 10 feet further downwind from the balloons. If the radio has a battery, the switch is now turned on so the GPS can acquire a position fix. The radio is kept in the shoe box and the upper dipole element is carefully unwound making sure there is lots of slack and the radio does not get jerked in the process. It is smoother unrolling the wire from the roll, if there is a wooden dowel rod in the middle of the roll. The upper dipole element is tied to the lines protruding from the balloon bag and knotted about 3 times. The lower dipole element is then unrolled carefully and laid in a loose zig zag pattern in the downwind direction from the shoe box.

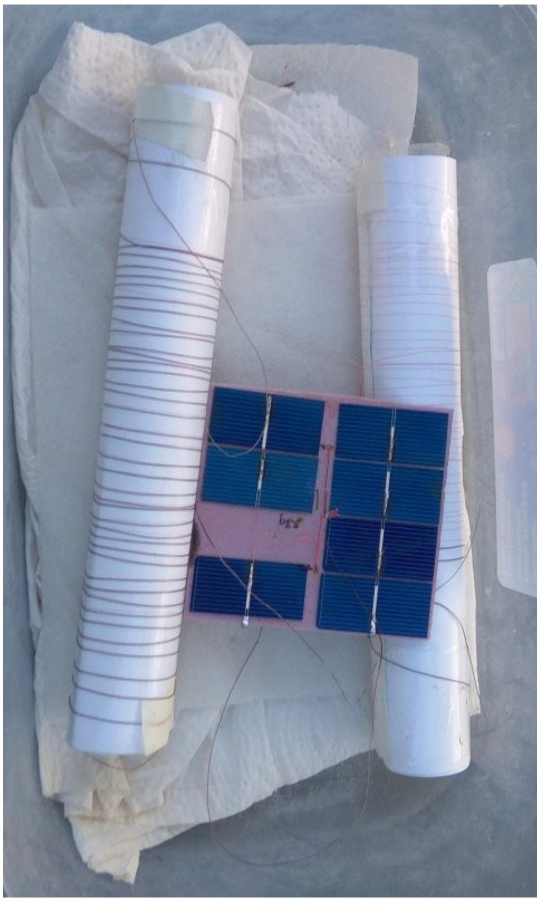
The radio is carefully taken out of the shoe box and the empty shoe box is moved 4 or 5 feet away from the antenna line. An assistant removes the clips and takes the balloons out of the balloon sheet holding the balloons by the attachment point where the lines are fixed to the lower balloon. At this point usually the balloons a blowing sideways in any light wind, so one waits for the balloons to be pointing straight upwards or the wind is having a lull before the assistant lets go of the balloons.

The radio is held in one hand and the other hand holds the upper antenna wire above the radio to make sure it does not get tangled when the balloons pull the radio upwards. Usually the balloons blow downwind toward the radio and lift the radio out of one's hand as the balloons are overhead. Sometimes it does not work that nicely in a strong breeze, and the person holding the radio has to run to keep under the balloons till the balloons are finally are high enough to lift away. The person holding the radio has to use caution to stay away from the lower antenna element on the ground and attempt to keep the balloons directly overhead so that they lift off vertically. If the wind is too strong, and the balloons are not overhead, the balloons can pull the radio out of one's hand and downwind. The radio might then swing down and hit the ground, being dragged along, or get the antenna tangled, so it is best to try and keep the balloons overhead before releasing the radio.

Antennas

The radio uses a vertical dipole cut for 20 m and is located between the upper and lower dipole elements. The wire used in the U4B series is 42-gauge magnet wire and this is very weak but light. To make the antenna more robust, the wire dipole element is glued to Dyneema (Kevlar) fishing line that is very strong and lightweight. The construction of the antenna is made in the hallway with a few screws in the woodwork at a distance of ¼ wave resonance at 20m or about 5 meters apart. Green masking tape is used in the construction process to hold the wires or fishing line. First the Dyneema is strung between the two screws and the ends fastened with tape and then the magnet wire is installed on top of the fishing line making sure it is tensioned so the lines are touching and parallel. Then one uses green contact cement (the type that can glue foam) and take a dab of cement between finger and thumb and wipe it for about 2 feet either end of the dipole so it is glued solidly for that area.

The remaining section of the antenna is glued between the end parts at about 1-foot intervals by putting cement between thumb and finger and then touching the antenna wire and fishing line at intervals. The lower element is done differently to save weight. Since the lower element just hangs, and is not in tension holding up the radio, like the upper element. Magnet wire first taped between the two screws, and then a leader of about 2 feet of Dyneema line is cemented to the magnet wire from the radio end of the antenna. The magnet wire and the short fishing line is glued together in that area only for strength, and the rest of the magnet wire on the lower element hangs freely. Antenna rolls are constructed from printer paper and are rolled so they are about 8.5 inches long and taped them with wide clear tape at either ends. The clear tape makes attaching and removing the antenna wire simpler, as the green masking tape, used to secure the antenna wire ends does not damage the surface when being removed. One end of the roll is marked Radio. When the antenna is rolled up, it is fastened with green masking tape and it is started from the end opposite to the Radio end. It is hand wound trying to keep the lines separate till the Radio end is reached and then the wire is fastened with tape. The radio ends of the upper and lower dipoles are attached and soldered to the radio antenna stubs and because the way it was rolled up it will unroll smoothly at the launch site. The radio and antenna rolls are placed in the shoe box and if it is sunny the radio is put out in the sun to confirm it works.



Pre-stretching Balloons

Not all varieties of balloons are suited to pre-stretching. The Clear 36-inch balloons from AliExpress used in the last flights, can be stretched before flight. The burst pressure on these balloons varies but is in the range of .65psi. As too much handling is bad for the balloon envelope. These balloons are stored flat between 2 pieces of 3/16" plywood with black plastic sheet next to the wood.

As soon as the package arrives in the mail, the date of arrival is written on the neck of the balloons, and then they are transferred to this wooden sandwich. The edges of the plywood are fastened with spring clips. On occasion the perimeter seals of the balloon are sub optimal, and an impulse sealer is used to go over any sections of perimeter seal that does not look good.

A modified fish tank air pump for about 12$ can provide air pressure to stretch balloons or even some vacuum to evacuate them. To make it work for vacuum one seals the inlet holes for the intake manifold in the bottom of the air pump and a new hole is drilled into the intake manifold. Into this hole, a plastic pipe made from a from an aquarium hose joiner is glued in with crazy glue.

To inflate and control the pressure while stretching the balloons one uses an air dryer to pre dry the air first, a pressure regulator to limit the pressure and a manometer to measure the line pressure or inflation pressure in the balloon. The air drier is made with a preserving jar filled with crystal cat litter or silica gel that dries the air from the air pump. From the air pump the dry air from the drier is joined by a few T joiners for aquarium tubing to connect an adjustable pressure regulator and also to a manometer. A manometer is a $30 device that measures pressure quite accurately used by gas fitters. To save time, 5 balloons are joined together and are stretched at the same time. One may explode in the process.

The air pressure is gradually raised using by adjusting the regulator and the humidity should be high to facilitate the balloon stretching. Stretching begins to occur at about .4 psi and the pressure is slowly raised to about 5.5 psi while the physical dimensions of one of the balloons are checked. It is assumed that since all the balloons are receiving the same pressure at the same time they will stretch to similar dimensions. Previously, a check of all 5 balloons was done at the same time and were all about the same dimensions, so only one balloon is now monitored for dimensional change.

When the target dimensions are obtained and the predetermined volume of about .17 cubic meters is reached, the pressure is lowered and maintained at about .35 psi for a few hours to keep the balloon from contracting too quickly. The balloon weighs about 35 grams and has a specific volume when it comes fresh out of the package. By stretching and increasing the volume of the balloon, it's inflated density is decreased, because the stretched volume is larger than the original volume, but the weight is the same. The lower the density of the balloon and its payload, the higher float level the balloon will achieve.

The difference between an unstretched balloon and a stretched one, can be from 10500 meters to 12500 meters lifting the same payload.

High clouds

Clouds are the enemy of super pressure or floater balloons. In the winter, high clouds are not a serious problem for balloons in the northern hemisphere. The safest months for balloon flights are months that have an "R" in their name. In these cool months, high clouds do not form and the highest clouds are mostly below the float level or below 10000 meters.

In the summer however with a lot of heat generated by increased solar energy, the clouds develop to very high altitudes. Although the ambient temperature at 11km is often below -30c, if a balloon floats though a cloud it can pick up ice crystals or super cooled water that can attach to the surface, weigh the balloon down. Once the balloon's free lift of (usually between 4 and 15 grams) is exceeded by the weight of ice crystals or water, the balloon starts descending. Here the excess lift from the lifting gas has been exceeded by the increased weight of water or ice. This condition is often referred to as icing.

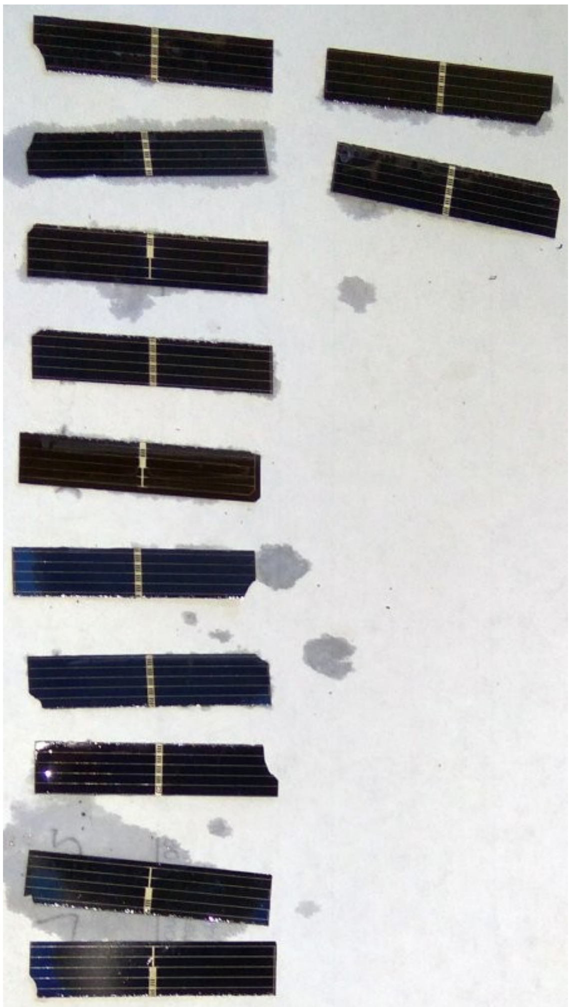
When the balloon is experiencing icing, it descends pretty rapidly until an altitude where the air temperature is above freezing. In warm air, the ice can melt off, and the balloon can become lighter and can rise again. If this warm up altitude happens to be during a rain storm, sometimes the weight of the rain can still exceed the free lift and the balloon will keep descending to the ground. On rare occasions when this situation has occurred, the balloon was able to eventually dry enough to lift off the ground and fly away.

Usually hitting the ground is very treacherous, the antenna can get snagged in a tree or the fragile solar panels could be bumped then crack and fail. Sometimes at night, when the payload was carrying a battery and the temperature was too cold for the LiPo battery to function, because the battery chemistry had frozen, the balloon iced and started descending. There was no solar or battery power to run the radio till below the freezing level at which time, the LiPo battery thawed out and started powering the transmitter. On the receiving side, one saw by the sudden appearance of the balloon telemetry, in the dark, indicating that the balloon was at a lower altitude and descending. Sometimes, the balloon would slow stop and then continue to rise again as the ice melted away and it became lighter. And also, it would not rise again but land in the sea, a very difficult place to make a recovery from.

Nothing creates a sinking feeling in a balloonist's heart faster than seeing an unexpected telemetry in the middle of the night indicating that the lovely balloon previously safely crossing the Atlantic at 12km has lost 9000 meters of altitude and is heading for a certain death.

Battery life

There is a lot of variability in the type of LiPo battery available from AliExpress. Since the characteristics of a LiPo battery are often related to volume and weight or density, one can construct a spreadsheet to estimate the capacity from the published battery dimensions. Armed with a spreadsheet, one could usually determine, by the dimensions of the battery, the expected mAh capacity. This can weed out battery products with exaggerated capacity claims.



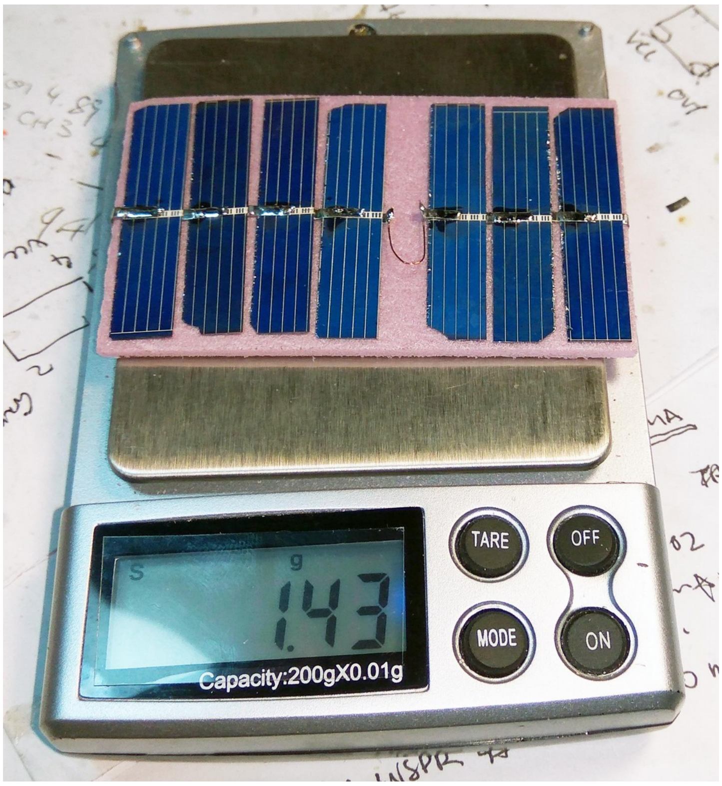
In early flights, attempts to have the transmitter turn on at night and transmit it's position were not successful. The battery sometimes was able to transmit for as long as 4 hours after normal solar powered transmission would have ceased, and at temperatures as low as -30c. It was noticed that physical characteristics like fat or thick LiPos did much better in capacity in the cold when compared to long thin shaped LiPo batteries. At this point, it may be possible to utilize some of the battery power to heat an insulated box containing the battery and radio if the battery is big enough and the insulation light and effective enough to keep the battery warm enough to function in very cold conditions.

Experiments of transmitting on a longer spaced schedule so less power was used, did not work. This process consumed less power and made less heat so the temperature dropped at a faster rate and the battery failed from the cold earlier than using more frequent transmissions. As the battery gets colder the internal resistance gets larger and the voltage decreases under load to a point when there is not enough voltage to run the radio.

Solar cells

Solar cells are about .2mm thick and are quite fragile. Soldering wires to the solar cells is difficult and overheating can crack the cell or burn up the solderable metal surface on the bottom of the cell. Recently 36g magnet wire is used to join the cells together and green contact cement to attach the cells to a foam backing. The solar cell foam panel will also serve as the top of the radio box. The gluing of the connected cells to the foam is rather difficult. The technique now used is to take the soldered cells and place them upside down on a piece of foam that is the exact same size of the foam section they are to be glued to. Green contact cement to the high sections of the underside of the cells (the cells never lay flat do to the connection wires) as the high sections of solar cells s will be the parts that touch the foam where it attaches.

After the glue, the foam base is put on the top of the solar cells and the two pieces of foam with cells in between is inverted. The panels are now loosely glued to the foam base and just a slight movement with a toothpick or similar device can arrange the solar cells perfectly on the foam base. This should be dry in 10-15 minutes.



After drying the solar panel is tested in the sun for full short circuit current. It is tested again with a suitable load resistor to draw about 60 ma., in the sun (transmitter consumption in high power mode) and checked by rotation to see at what angle the solar panel does not produce a working voltage. The solar cells should work down to about a solar elevation of about 12 to 16 degrees.

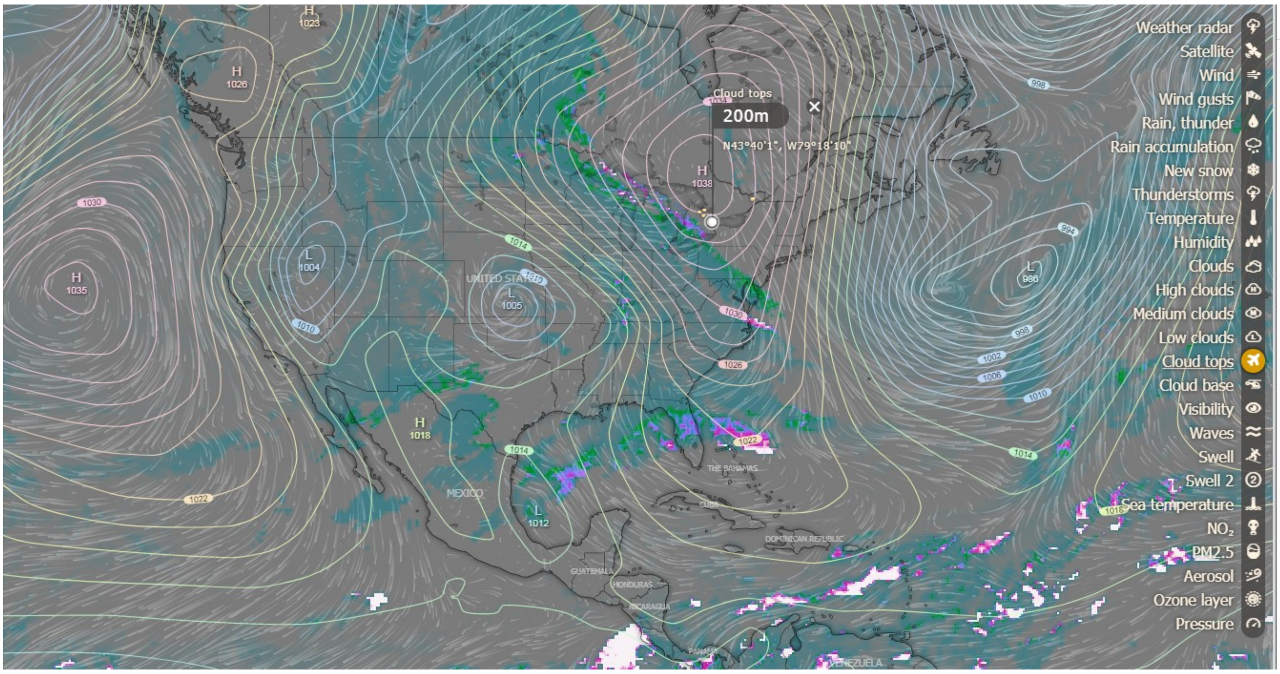
Bob Sutton in New Zealand was the first to use 3 sets of solar panels placed 120 degrees apart and was able to transmit from sunrise to sunset which could extend the transmission day from 2 to 3 hours.

Other techniques have been tried by Mikael Dagman in Sweden using a magnet to orient one side of the solar panel to North and sloping the other side of the panel to the south. This method has been reported to work well in the winter when the sun is always rising between the south east and south west directions and extends the transmission day by operating much closer to the horizon at sunrise and sunset.

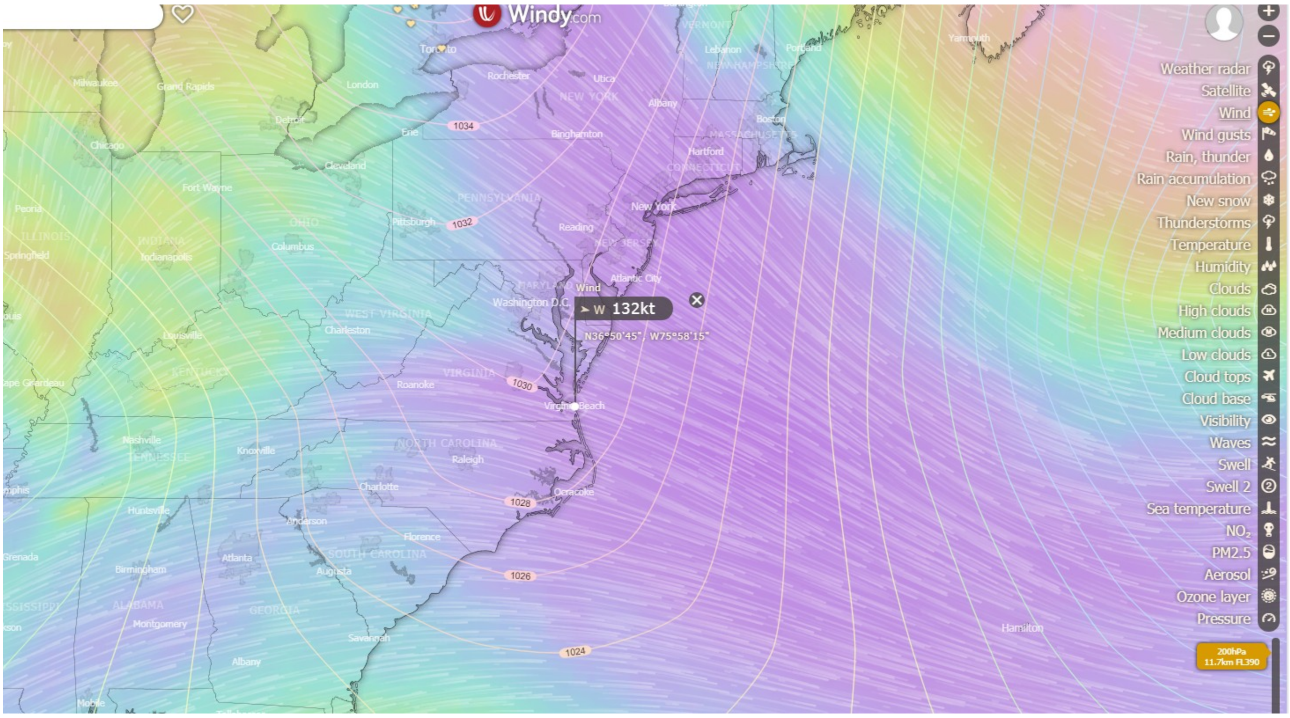
Windy.com

Windy.com is weather application that is a very valuable resource for setting up and watching flight. It is web based customizable weather map that can show one the location of high clouds tops, the wind currents at altitude, and forecast for the day of the launch. Windy allows one to change the colours of the watched parameters to make problems stand out. Clouds are a hazard with floater balloons and Windy expands to show maps of a number of cloud statistics in almost real time.

Of particular interest is Cloud tops that show high clouds, a hazard in the balloon’s path. One can change the colours of the display of cloud tops to display differently with altitude. It is an advantage for ease of use, to make clouds below 10000 meters invisible and display clouds in red at 11000 meters and white at 12000 meters and above.



One can see at a glance in the above image, that there is clear sailing across the USA except for a few spots off the coast of Florida and a little bit of high clouds off the coast of Virginia.

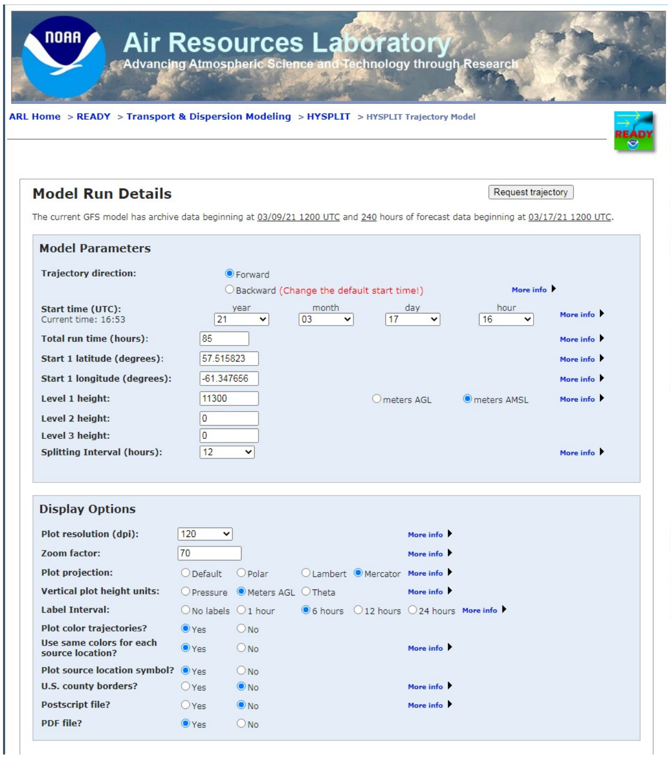


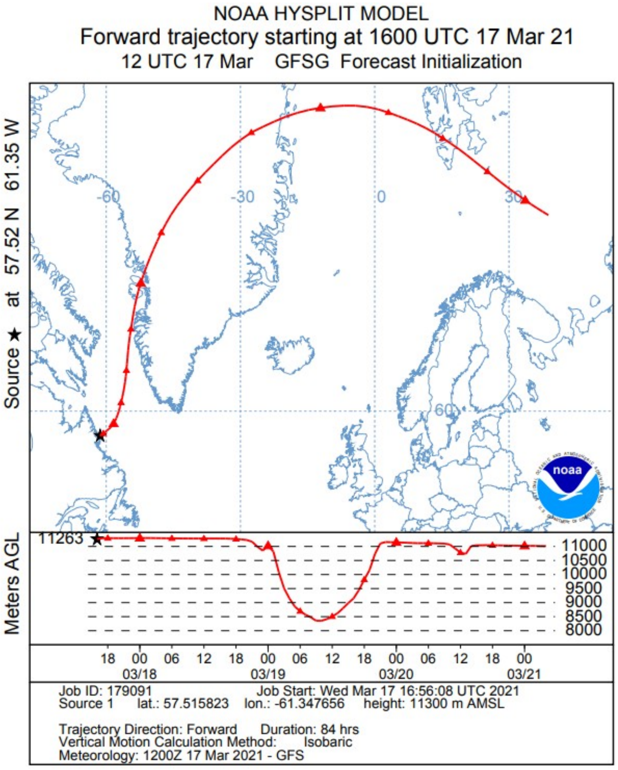
On that same map pressure isobars are shown. The balloon floats higher over high pressure and floats at a lower altitude over low pressure. Wind speed at various altitudes can be shown in a customizable colour scheme. There is a draggable indicator that one can put in the balloon’s path to get a good idea of the wind speed. In the image at 11700 meters above sea level. The draggable position flag shows the wind at this moment is 132 knots from the west.

Windy is a huge free resource with the additional benefit that one can move the time on the forecast bar at the bottom of the page and see how the clouds and wind should change in an approximate future forecast.

Forecasting the balloons path using NOAA

NOAA (The National Oceanic and Atmospheric Administration) and it's Air Resources Laboratory has an online forecasting tool called Hysplit that allows one to enter the balloon's latitude, longitude, altitude over sea level and time. It will generate a map of the balloons projected path over the next 3 or 4 days. Hysplit is quite accurate, quite often predicting the upper atmospheric winds and when a balloon may return if it has disappeared over the north pole in the dark and is not transmitting its location. When the balloon is absent in the dark, one can do a forecast at the end of a previous forecast, and it has known to work predicting a balloon's return. If the balloon radio consistently starts transmitting at about 16 degrees of sun above the horizon in the morning, by looking at solar elevation websites and the NOAA Hysplit map, one can predict approximately where and when the balloon will start transmitting on the next sunrise.



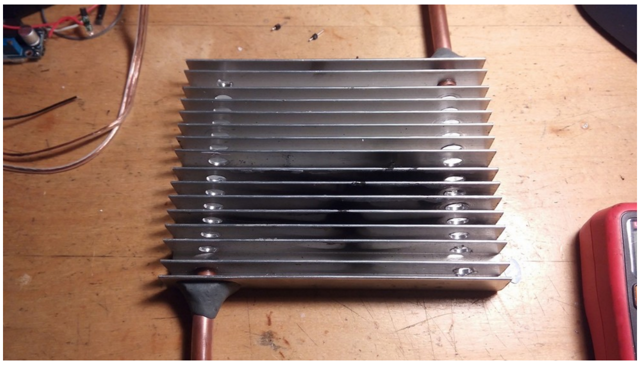


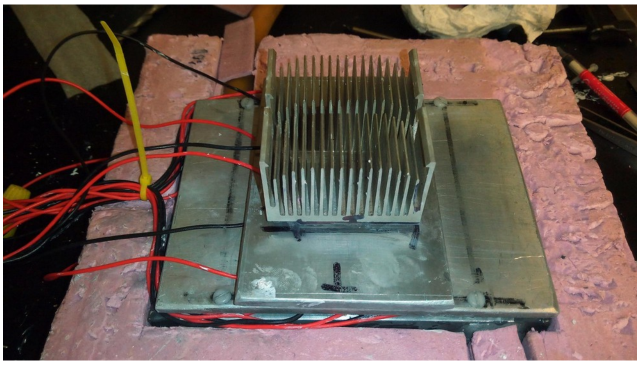
Testing equipment for cold and a Peltier cooler

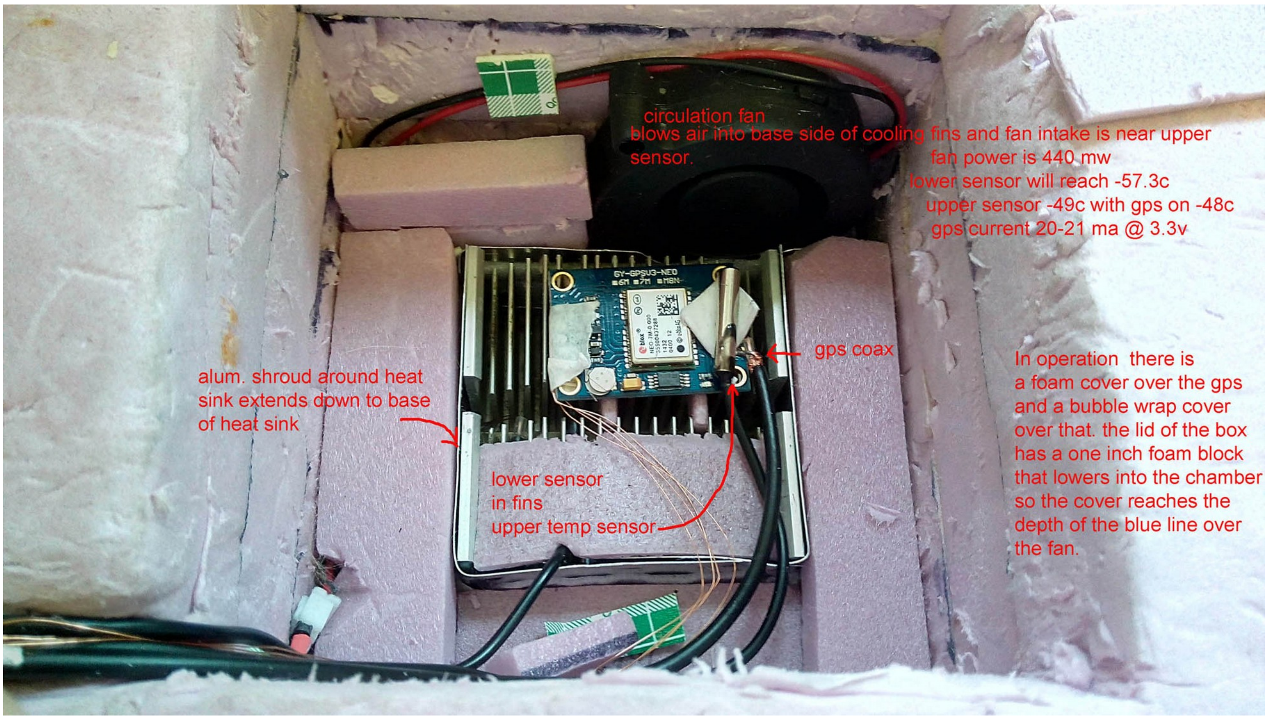
The house fridge/freezer will go down to -12c or so which is warm compared to the -40c to -50c temperature at balloon’s floating altitude. It became necessary to test some of the components in the cold to see if they would work in those difficult conditions.

Starting with dry ice that went to -90c or so, it was difficult to create a sustained even cold temperature, but dry ice gave some indications that the devices would fail in the cold but it was almost impossible to measure the temperature right next to the device under test.

It seemed possible however, to build a cooler that could duplicate flying temperatures using cheap Peltier modules from China. Under DC power one side of the Peltier device becomes cold and the other side becomes hot. These devices are not very efficient at cooling, so there is a lot of heat to remove in 3 stages to make a small space at the top of the device that is quite cold. It appeared that water cooling would be the best way to remove a large quantity of heat, so a big aluminum heat sink was found and drilled out for entry and exit tubes.



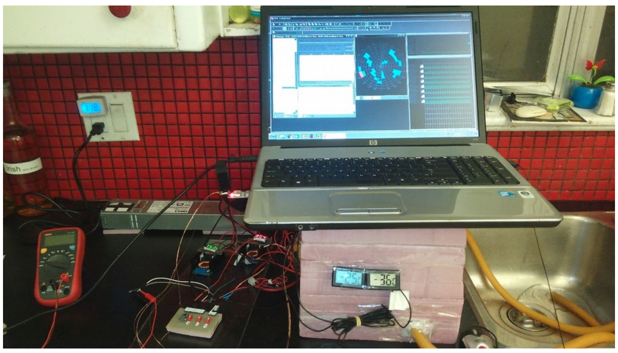


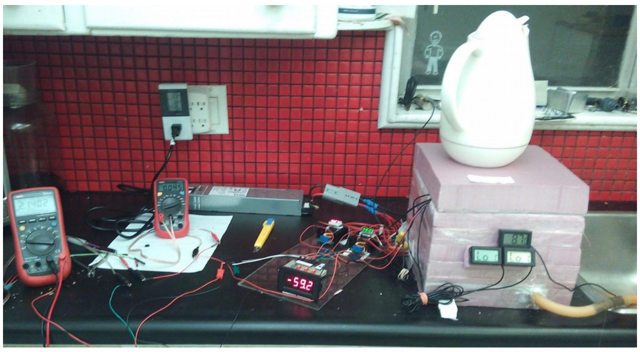


Aluminum flashing was used to seal the open side of the heat exchanger that would be the base of the cooling device. Gaps, pipes and joining surfaces were sealed with epoxy and the finished heat exchanger was pressure tested at low pressure.

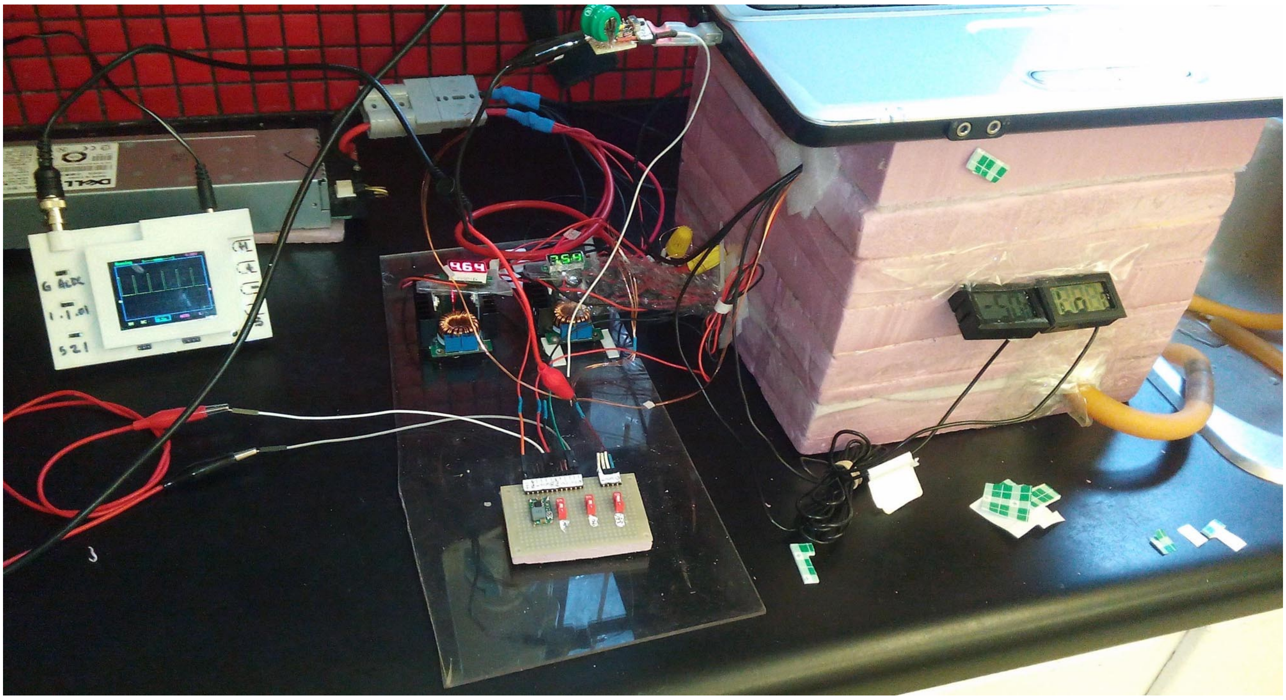
The device had to remove about 300 watts of heat from the box and air would not be as efficient as water cooling. The box was constructed out of 2-inch-high density foam that had blown down from the top of a building and arrived on the street below just as the project was started. The base cooling layer was fitted with 6 Peltier modules attached with heat sink compound and nylon screws to the water heat exchanger. Aluminum plates were used between the stages to create the contact pressure on the Peltier modules and transfer the heat between each stage of cooling.

The second level had two Peltier modules and top level had one module and was topped with an old computer heat sink. The walls and top of the device were sealed for leaks. LM335 temperature sensors were fitted to each cooling stage to monitor temperature, so the power to each sage could be balanced.

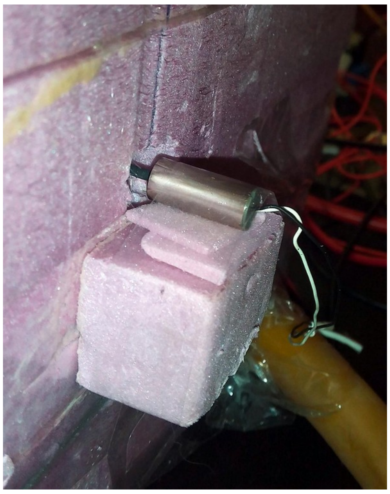




To get the coldest temperature on the top level of the cooler there is a delicate balance of power to each of upper cooling stages. The DC power control to the Peltier stages was handled by buck converters on the second and third stage, while the base stage was run full out at 12v from the power supplied by a Dell server power supply.



Two cooling stages and the exit water temperature were monitored by simple battery digital thermometers that bottomed out at -50C and then displayed “low”. The top or coldest stage was monitored by an analog LM335 chip and a digital calibrated digital sensor.



Early versions used a circulation fan in the cold third stage to help distribute the cold around the parts under test, but it soon became evident that these small motors would not turn at -40c. Eventually a solution was found by putting a small helicopter propeller in the box with the helicopter motor on the outside of the box where it was warmer. The propeller was linked through the foam wall with a small shaft to the external motor which allowed the propeller to spin and circulate the air in the cold third stage.

Cold testing was done on the balloon radio, various GPS modules and LiPo batteries. One of the GPS modules failed and never recovered after a cold session under power. Internal resistance of LiPo batteries was mapped and for various cells showing that the fatter cells were more robust at low temperatures than the long thing cells.

Conclusions by Hans G0UPL

Flying high altitude “floater” balloons is a fascinating hobby and extreme HF QRP radio weak signal communication techniques are ideal for tracking the flights.

As has been seen, it is truly a multi-disciplinary hobby bringing together many facets of science, meteorology, electronic engineering hardware, software, radio communications, modern digital encoding protocols and more.

It has been a great pleasure and inspiration working with Dave VE3KCL on the developments and test flights described in this article. I hope that the information herein has been useful and my inspire you too, to reach for the skies with extreme QRP.

73 and happy flying
Hans G0UPL
http://qrp-labs.com
http://hanssummers.com