Multi-Mode Transmitter

for high-altitude balloon telemetry

- Bill Brown WB8ELK, High Altitude Research Corporation

Long duration high altitude balloon missions will often travel beyond the range of a ground station's line-of-sight VHF/UHF communications range. This is particularly problematic when flying in remote areas or over the ocean. One solution is to fly a satellite modem but these can be quite costly particularly for missions that may have no chance of recovery. Described in this paper is a low-cost low-power HF telemetry transmitter that can relay a balloon's position along with system telemetry over thousands of miles. A modified open-source decoding program is used to decode the data, check for error-free reception and then post the report directly to a server. Each valid report is automatically displayed on a Google Map-enabled website with features dedicated to high altitude ballooning. Anyone with an HF radio and computer connected to the Internet can then act as a remote reception site to enable a large world-wide distributed network of ground stations.

I've been flying amateur radio high-altitude balloons (ARHAB) for the past 24 years. These balloons often achieve altitudes in excess of 100,000 feet and have a radio horizon over 400 miles. As those who operate on the VHF and UHF bands know, antenna height is everything, so just imagine the possibilities of a 20-mile high antenna.

The typical GPS tracking system for a high altitude balloon consists of an APRS transmitter operating on 144.39 MHz or another nearby simplex FM frequency. The telemetry sent via this method is somewhat limited and does require a decent signal to hit digipeaters and ground stations operating as Internet Gateway stations. Quite often I'd lose signal as my APRS payloads would parachute back to Earth if it landed in rugged terrain and out of range of a digipeater. Trying to pull out a weak APRS signal buried under strong local APRS stations proved to be quite a challenge.

As an alternative to APRS, I decided to come up with a tracking transmitter that could be heard on SSB mode as a way to determine the landing site using weak signal operating practices. I try to stay under a watt output power to prolong battery life and keep the weight down for these experiments, particularly since helium prices have been shooting up and often fly two meter and 70cm transmitters that put out only 25 milliwatts with good results.

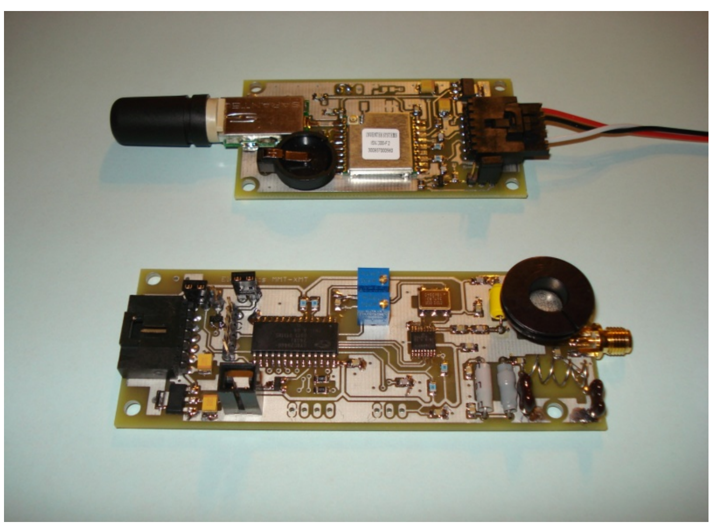
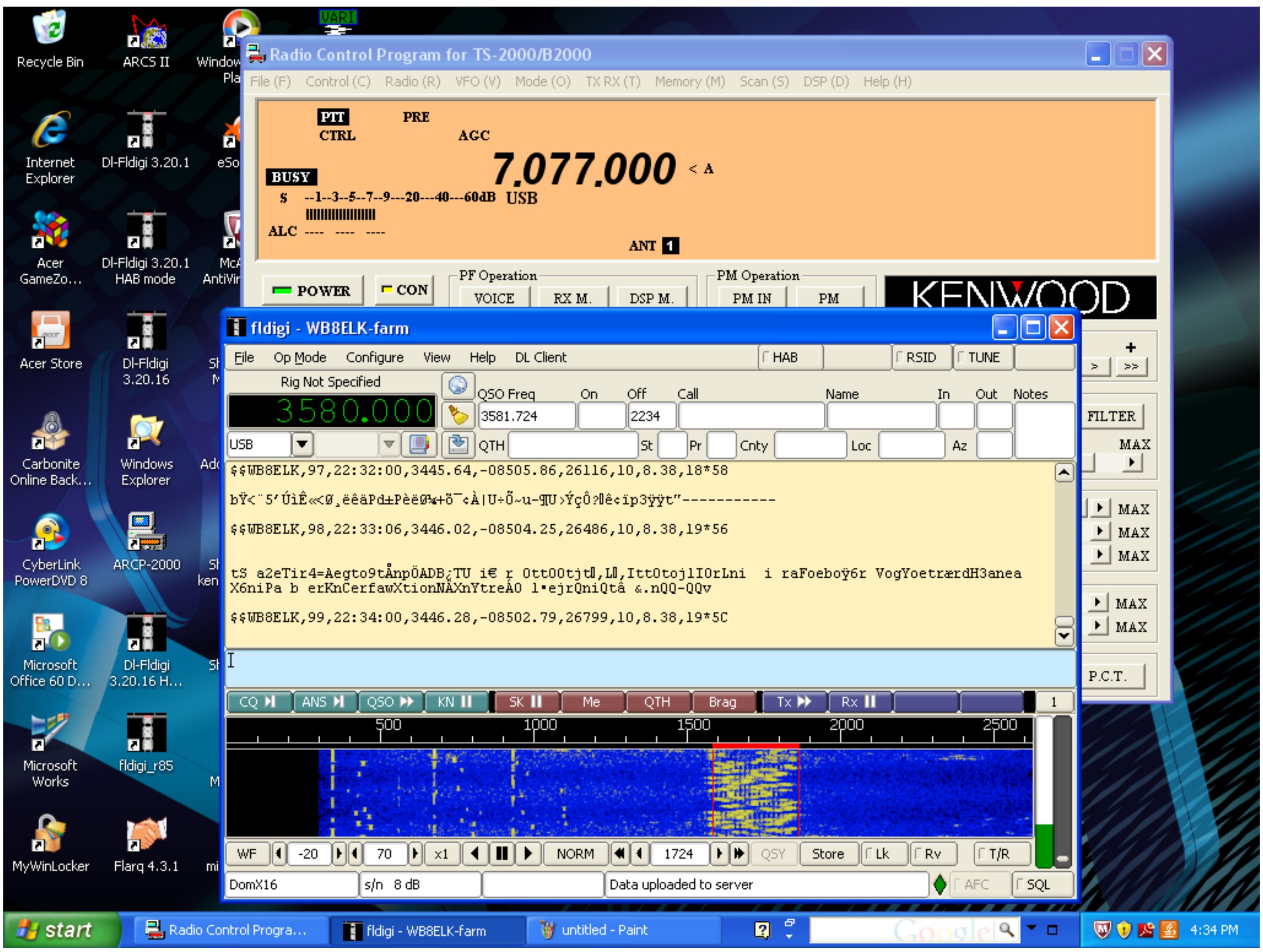


Photo of the Multi-Mode Transmitter along with its companion GPS receiver.

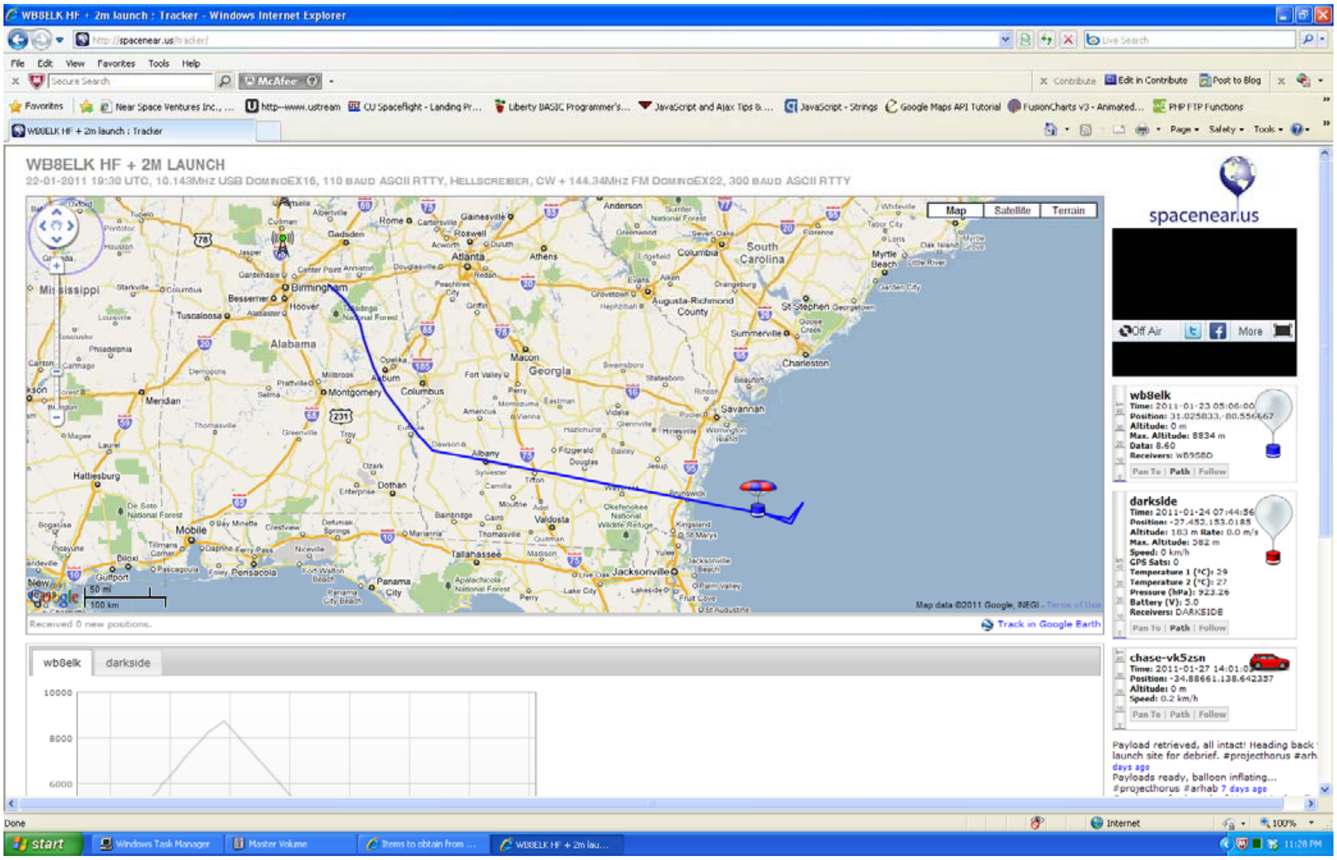
MMT Digital Modes

I had to find digital modes that were relatively easy to encode and would fit easily into an 8-bit microcontroller. It turned out that CW, RTTY and Hellscreiber turned out to be reasonable to implement. I wanted another mode that was very weak signal and had better performance than even CW and Hellscreiber. Many weak signal digital modes had promise but needed convoluted encoding methods that chewed up my micro's small memory and required massive floating point math operations. Fortunately I found a mode that was easy to implement that also had remarkable weak signal capabilities. DominoEX turned out to be the answer. DominoEX is an 18-tone MFSK mode that seemed to be made for my project. During a flight that can see internal temperatures varying from 44 deg C to -45 deg C on its way to the stratosphere and back, my little transmitter does see some temperature drift. It turns out that DominoEX works with a feature called Offset Incremental Frequency Keying (IFK+) developed by Murray Greenman ZL1BPU. The data is dependent on the spacing between tones rather than the absolute tone frequency. As a result, it can tolerate 200 Hz/minute of frequency drift. Comparing the weak-signal performance against CW, RTTY, Hellscreiber and PSK31, DominoEX wins hands-down. I can copy a perfect telemetry frame with DominoEX when CW is only a guess and only garbage is decoded with the other modes. In addition to the exceptional weak signal performance, DominoEX uses an extensive Varicode alphabet and also displays a secondary text banner capability. I typically fly the DominoEX16 mode at an equivalent of about 100 WPM for SSB modes and when running my MMT as an FM transmitter (direct-FM on the VCXO), I run DominoEX22 which equates to about 140 WPM. When the signal is strong, I also run 300 baud ASCII RTTY on my FM version that can be decoded through selection of the Custom RTTY pulldown menu on FLdigi.



DominoEX16 telemetry data from a balloon flight as decoded by dl-FLdigi.

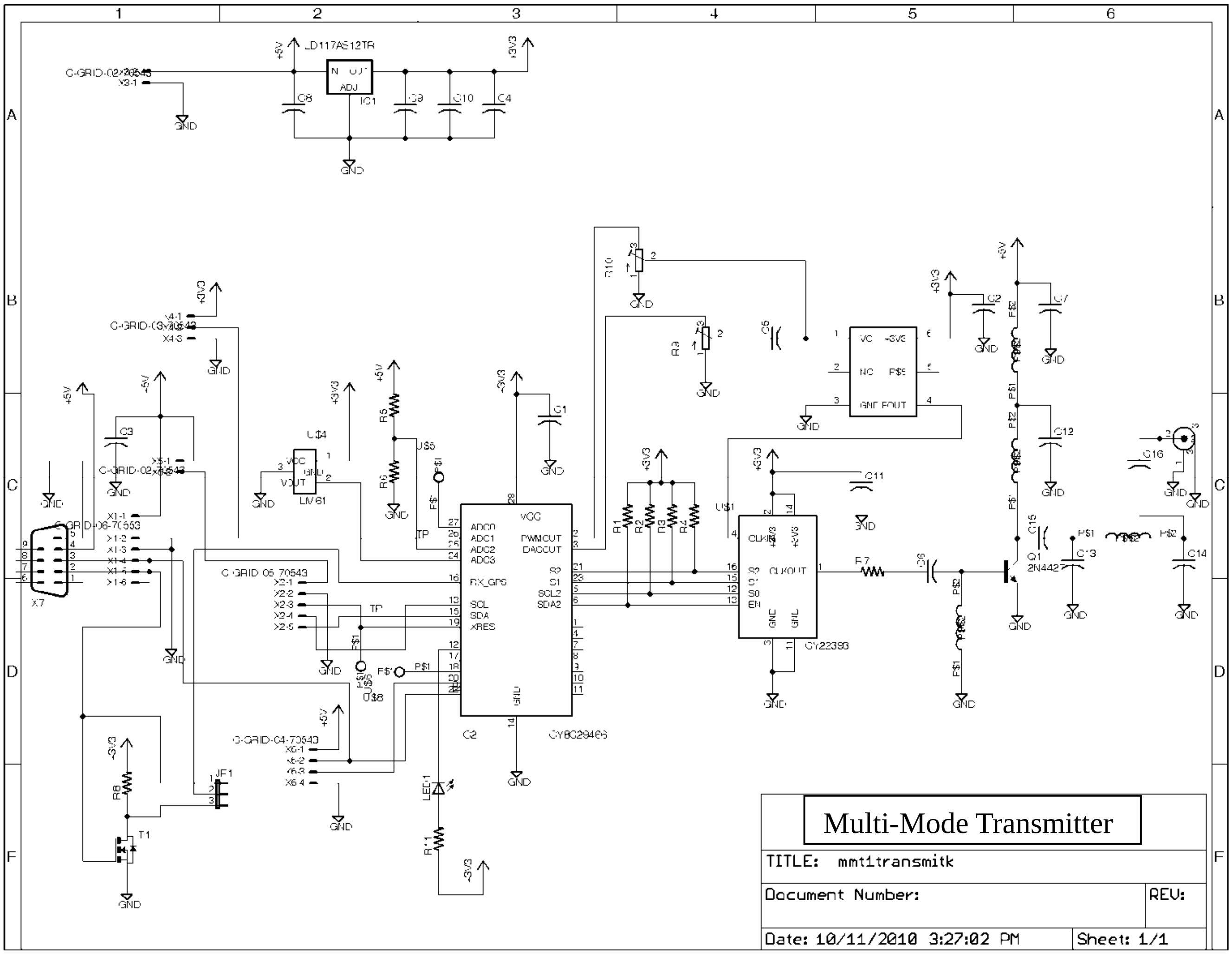
There are many free soundcard programs that can be used to decode the telemetry. My favorites are FLdigi, MultiPSK and DM780, IZ8BLY's Hellscreiber program and DominoEXFEC written by ZL2AFP. For those who'd like to track high altitude balloons, I recommend a modified version of FLdigi called dl-FLdigi that includes a script that automatically uploads any checksum-verified telemetry frames that you receive and posts them to a server that plots the position on a Google Map at http://spacenear.us/tracker .



Position data uploaded from dl-FLdigi is plotted onto a Google at SpaceNear.us/tracker

The MMT Transmitter

The design goals of the transmitter was for 200 milliwatts output power, low-cost components and to be as lightweight as possible. I chose the Cypress PSoC CY8C29466 microcontroller since it has a variety of integrated analog modules. This allowed me to use analog filters, op-amps and DACs with just one chip. The development system is a free download from Cypress and is a powerful IDE that allows you to graphically place modules and assign input and output pins in a schematic capture style interface. Once you place the modules and select your pins, you can then program your code with C. You can embed assembly routines in the C code or for the more adventurous and die-hard bit-pushers, you can use assembly for the entire coding.



Schematic diagram of the Multi-Mode Transmitter

This digital and analog microcontroller allows me to generate sine waves for my DominoEX and RTTY tones simply by filtering a PWM square wave output (when modulating tones via FM mode). For SSB digital modes, I use the DAC output to directly frequency shift a VCXO (voltage-controlled crystal oscillator) reference via its frequency adjust control pin. Modes such as RTTY or DominoEX are created by adjusting the voltage from the DAC to the VCXO's adjust pin. Hellscreiber and CW are implemented by turning the synthesizer outputs on and off with a single control pin from the microcontroller. If operating the MMT in FM mode, the VCXO is directly modulated with the audio tones.

I could have used the very capable synthesizer ICs made by Analog Devices, but keeping the costs low and the complexity low required me to go a different route. I found a low-cost Cypress clock synthesizer (the CY22393) that combined with a VCXO reference on 16.384 MHz allows me to select frequencies across the two-meter band. One added feature is that this circuit can be programmed to operate on any HF or VHF frequency band from 80 meters all the way to 2 meters. The only difference is in the final amplifier stage and output filter. The exciter portion is the same no matter which band you choose.

The power output from the CY22393 clock synthesizer is a very respectable 25 milliwatts. I've flown this transmitter many times with no final amplifier stage on 2 meters and have heard it well enough to copy the DominoEX telemetry from 508 miles away at my mountaintop QTH south of Huntsville, AL while it was riding on the DePauw W9YJ balloon 92,000 feet high just east of Kansas City, MO.

However, to boost the power a bit, I usually fly an amplifier circuit to generate about 200 milliwatts on 2 meters resulting in excellent signals during a flight. I have operated one of these transmitters on 6 lithium AA batteries for upwards of 24 hours.

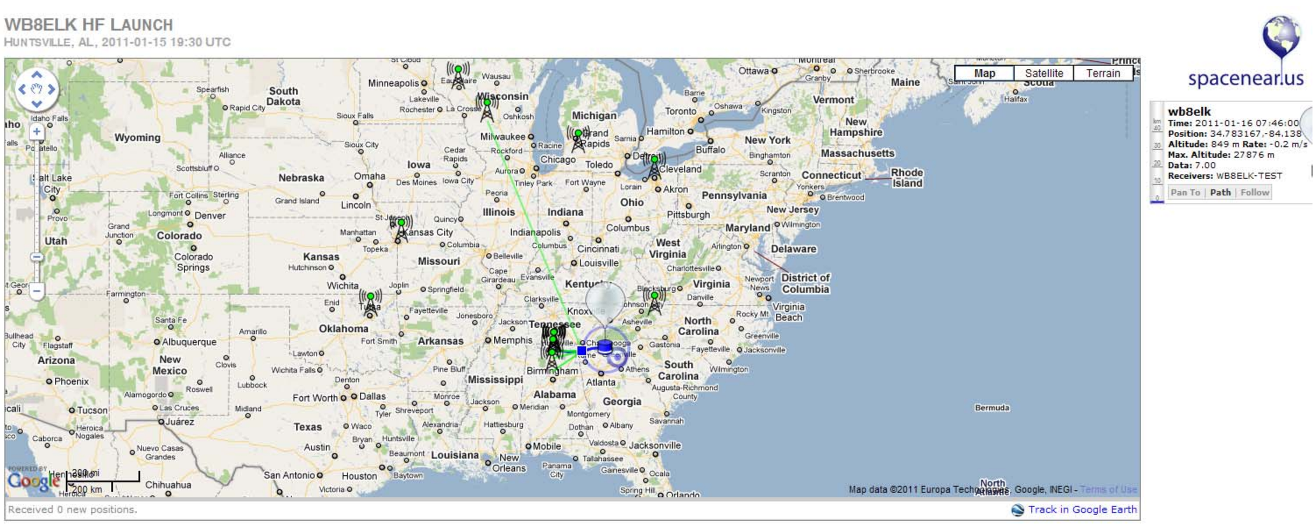
Over the horizon tracking on HF frequencies

Since many of my recent balloon flights have been long duration in nature, I designed a version of the MMT transmitter for flight tests on several common HF bands. A one-watt output was achieved using an efficient class-E design using a 2N7000 FET as the final amplifier. The antenna consisted of a vertical half-wave dipole constructed out of 22 gauge wire with the feed point at the HF tracking transmitter payload. I've found that the most reliable modes and data speeds for HF operation are DominoEX16, Hellscreiber, Morse Code and 110 baud ASCII RTTY. The RTTY mode requires a strong signal for best results, but the DominoEX mode can be copied down to -10 dB below the noise level. I can barely tell there is a signal on my radio and can still copy perfect telemetry via the DominoEX mode.

Many flight tests were conducted over the past several years on the 40, 30, 20, 15, 10, 6 and 2 meter amateur radio bands. Using the dl-FLdigi program running on a computer attached to the audio output of an HF receiver at amateur radio stations scattered across the US and the world, a distributed network of ground stations can decode the balloon telemetry from thousands of miles away. When a number of stations are listening for a flight, at least a couple of stations will be able to receive the telemetry and gateway it to the SpaceNear Google map depending on HF propagation.

Daytime propagation favors the use of 20 or 30 meters for optimum path distances. One recent flight operating on 14.102 MHz (20 meters) landed in a remote area of north Georgia. We were able to copy the position reports down to about 15,000 feet from direct reception in Alabama, but lost the signal when it went below our line-of-sight horizon. However, amateur radio station KA6MAL in northern California was able to receive and decode the telemetry from nearly 2100 miles distance precisely locating the balloon's landing spot in a tree behind a farm. He was able to decode it for an hour or more after it had landed.

Night flights are best conducted on the 40 meter or 30 meters bands. I prefer 40 meters for night operations, as 30 meter propagation sometimes closes down at night. Frequencies from 20 meters and higher are generally closed at night, particularly during the winter months. Ralph Wallio W0RPK in Iowa has been able to receive telemetry from several of my recent flights on both the 30 meter and 40 meter bands from 700 to 800 miles distance. I was able to receive position reports from over 1500 miles away during a night flight last January on 40 meters using an Internet HF radio in Colorado (www.globaltuners.com) to receive and decode the flight telemetry while it was over Georgia. Joe Mayenschein WB9SBD in Wisconsin was able to copy the position of a flight done in January on 30 meters that splashed down 100 miles east of Jacksonville, Florida. He was able to actually hear the transmission end abruptly as it hit the ocean.



Valid position report reception paths are also indicated on the SpaceNear website. This screenshot shows telemetry reception on 7.102 MHz by WB9SBD in Wisconsin as well as the local direct paths to Alabama ground stations while the payload was over north Georgia. Each antenna symbol indicates a ground station listening for the HF balloon signal.

Conclusion

This low-power HF transmitter can reliably send position reports and telemetry over many thousands of miles, well beyond the typical 400-mile range of VHF/UHF tracking systems. If there are a number of widely scattered HF receive stations hooked to the Internet via the open-source dl-FLdigi program, the chances of receiving position reports and telemetry are excellent. This is particular useful when a balloon mission is flying over very remote areas such as trans-Altantic paths that are well beyond the range of land-based VHF/UHF line-of-sight digipeater or telemetry ground stations.

Resource Links:

My website with links to high altitude ballooning: www.wb8elk.com

Information about the Multi-Mode Transmitter: www.elktronics.com

High Altitude Research Corporation: www.harcspace.com

Worldwide Launch Schedule of Amateur Radio High Altitude Balloons: www.arhab.org

Google Map tracking of RTTY and DominoEX balloons: http://spacenear.us/tracker

Balloon modified dl-FLdigi: https://github.com/jamescoxon/dl-fldigi/downloads

FLdigi: www.w1hkj.com

MMT microcontroller and synthesizer: www.cypress.com

Internet HF radios: www.globaltuners.com

DominoEX information: http://www.qsl.net/zl1bpu/MFSK/DEX.htm

Dedicated Hellscreiber program: http://xoomer.virgilio.it/aporcino/Hell/index.htm

My contact email: wb8elk@gmail.com