70 cm Multi-mode Beacon for KH6HME

This beacon project started as an idea at N6GN. It seemed to me an interesting thought to augment one or more of the existing CW beacons operating at KH6HME by turning it into a WSPR source. Doing this should offer the possibility of discovering propagation across the Hawaii-Mainland path much sooner than simple CW allowed. Since WSPR-2 can detect down to almost -30 dB S/N in an SSB bandwidth, it potentially has 20 dB or more advantage over what the human ear can detect. Experienced CW operators generally can copy down to around -10 dB S/N in the same bandwidth. Additionally, the Internet based database provided by WSPRnet.org offered the potential of having many stations on the mainland monitor and report round-the-clock. This seemed an improvement over the present arrangement of a few operators listening only as they were able and reporting via the forum on QSL.net.

I wondered how much of the time there might be “almost a duct” that we were missing with the current arrangement. What might we learn by being able to see more deeply into the ducting process? Automating the process with a more sensitive system might add a lot of information in this regard.

I originally contacted Fred, K6IJ/KH7Y, around 2014 and suggested the possibility of providing a beacon. When Fred responded positively in early 2016 to the idea of a WSPR beacon, I dialogued via email with him and a few others about the idea, trying to see how it might be arranged, whether the task might be broken up into pieces owned by several different people and what band(s) would be preferred. Fred suggested that in his opinion, as caretaker of the current beacons, 70 cm was the best choice. After getting a better idea of the space available, power budget and general climate of the beacons and after contacting Chip Angle, N6CA, who has built equipment for the site to see if he had any suggestions or cautions I began to settle on an approach for an initial candidate design.

While there were offers of help and support from several California hams, since Fred indicated he planned to reuse the existing 70cm antenna, actual beacon construction was by John, K6PZB, and myself. John put together the copper filter following my suggestions and built the base and support for the whole works. He definitely performed some of the drudgery and I want to acknowledge and thank him for this!

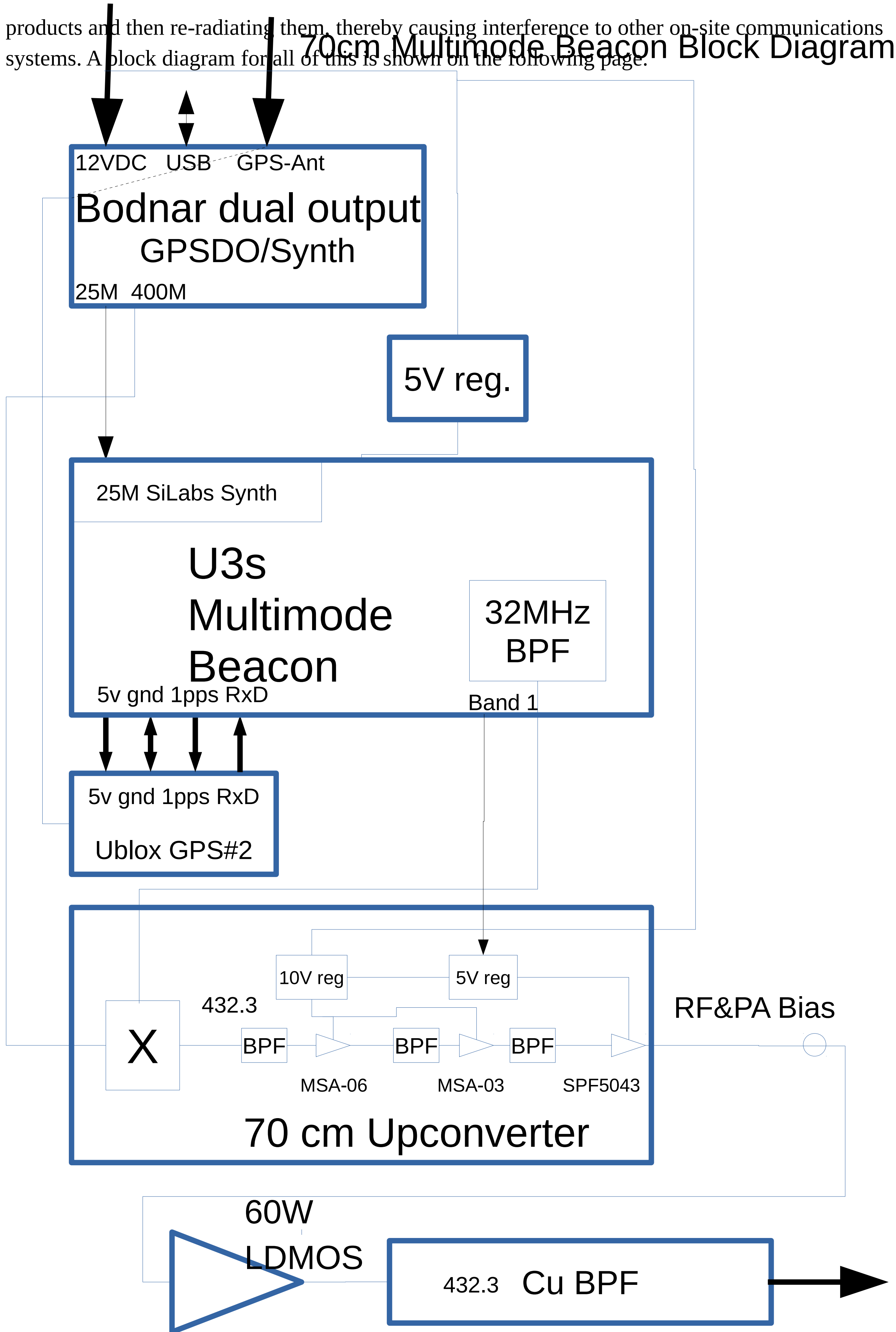
The design I was considering was to base the system on a simple QRPLabs U3s multi-mode beacon. The standard beacon can produce quite a number of modes from LF through the amateur VHF allocations, although it generally has been used only for HF operation. But WSPR’s stability requirements have made commercial radios and even the U3s inadequate for VHF use. Drift of less than a couple of Hertz over the 2 minute WSPR interval is necessary and drift ten times better than that is desirable. Additionally, from our experiences at VHF and UHF on the West Coast, we have found great advantage in having good frequency accuracy as well as stability. The group of WSPRers on 2m and 70cm on the Mainland have generally found it worthwhile to reference their radios to either GPS or rubidium standards. With the recent availability of the Bodnar GPSDO it has become easy to reference the U3s. This has shown itself to be a reasonable way to generate a quality WSPR signal all the way to 2m. However, the upper frequency limit of the Silicon Labs synthesizer in the U3s is roughly 200 MHz so this approach offered no direct solution for 70 cm WSPR operation.

To solve this problem, I decided to use one of the Bodnar GPSDO's two outputs as an LO for upconversion from a lower HF frequency, where the U3s works pretty well. By also referencing the U3s synthesizer, a 27 MHz crystal on stock units, with the 2nd output of the Bodnar, there seemed to be everything necessary to create a stable and accurate 70cm beacon at low cost. My idea was to generate a clean HF signal and also a clean UHF LO and then up-convert and amplify to at least the 20 watt level of the current KH6HME 70 cm CW beacon on 432.310 MHz. This functionality would replace the present 22W CW-only beacon in use at KH6HME as well as adding WSPR capability.

After creating a list of potentially interested parties, I asked for opinions and recommendations, particularly from those at the HI end as well as N6CA who constructed several of the existing beacons for KH6HME. With these inputs I arrived at a sort of project definition for a multi-mode replacement.

The beacon is to operate at an unattended site that is shared and at which KH6HME activities are as a guest. It's vital that a good relationship continue with the landlords who are the operators of the NPR radio link for which the site was originally constructed. There is also a 144.82 MHz repeater at the same site. The beacon needs to be both reliable and squeaky clean. It's presence should require both minimum maintenance and have exactly zero detrimental effect on any of the other site operations. DC power to operate the beacons is donated and must be considered in any design. Fred suggested that 12VDC at as much as 15A was available.

The QRPlabs U3s multi-mode beacon uses a popular but fairly simple Atmel controller combined with a Silicon Labs synthesizer IC capable of producing quite a variety of beacon signals. However, although the synthesizer is capable of generating signals past 2m, as mentioned above, the quality of the stock timebase prevents WSPR operation at VHF. To solve the timebase problem, I replaced the 27 MHz TCXO clock that comes with the U3s with a synthesized 25.000000 MHz signal from one output of the Bodnar. The second output provides a 400.000000 MHz LO for the up-conversion. The upconversion is done in a Mini-Circuits double-balanced mixer which is followed by IC gain/filter stages. The output of the third stage is amplified by a 'brick' LDMOS power amplifier (PA). Although the result is very clean since the PA has built-in filtering, the high power output is still followed by a high Q, low loss, narrow filter made from copper water pipe. The reason for this filter is not so much to achieve better spurious rejection but rather to eliminate the possibility of strong out-of-band signals entering the PA via the antenna, mixing within PA non-linearities, generating unwanted spurious products and then re-radiating them, thereby causing interference to other on-site communications systems. A block diagram for all of this is shown on the following page.



As seen in the block diagram, the entire system is to run from 12-14 VDC with a goal of requiring no more than 15 amperes from the donated power at the site.

The original beacon could be adjust to produce more than 70 watts key-down from the PA when run from 13.8V at about 10A. Average power is less than that because CW is run part of the time and because the digital modes do not entirely fill minute-long perioude. Average power depends upon the programming schedule since duty cycle varies with mode.

Besides DC power the only connections are an external GPS antenna and the 432 transmit antenna.

Both the U3s and the innards of a Bodnar GPSDO are mounted inside of a ‘standard’ QRPlabs enclosure. This still leaves enough room left over to house the transmitting up-converter and a second GPS receiver. This second receiver was necessary only because I had no source code for the Bodnar and was unable to get its GPS to produce the necessary NMEA ASCII strings along with a 1 PPS timing mark required by the U3s. A single external active GPS antenna is biased from the Bodnar and a crude splitter supplies some of that same signal to the second GPS.

The first PA was specified to have full 60W output with only 50mW of drive. a SPF5043 MMIC capable of almost 150 mW was used to drive it. This can over-drive the PA. Were any of the beacon modes of varying amplitude, e.g. SSB or complex modulation types, overdrive might produce unacceptable distortion. But since the modes of interest are only CW and JT modes, WSPR, JT9, JT65 and perhaps a few others that do not have an amplitude component, a limiting PA even a Class C amplifier could have sufficed.

The stages of the transmitting converter use a lot of bandpass filtering. All of these filters are Toko helicals, that I happened to have or could modify to work on 70cm. The output of the U3s has a 32.3 MHz bandpass filter in place of the lowpass one that comes supplied. All of this filtering is done to minimize unwanted spectral components in the output, especially any that would be out-of-band for amateur 70cm operation.

As it turns out, the U3s is <u>not</u> perfectly clean spectrally. The synthesizer, as programmed by the stock software, does generate some nearby spurious signals but they are not large. As programmed using Bodnar’s algorithm and the programming provided by Hans Summers code in the U3s and operating the U3s at 32.3 MHz, there is a family of ~5 kHz sidebands either side of the main signal. The strongest of these is a little less than -40 dBC. This is larger than I would have liked but seems tolerable given the application.

Any signals beyond the aggregate filter bandwidths including the final transmit filter, are suppressed a great deal. The U3s also has hard keying on CW. This produces noticeable key clicks if signals are strong. However, they extend only a little ways either side of center and these also seem acceptable. It isn’t likely that except during very strong openings or adjacent locals on 70cm that they will be noticed.

I’ve not provided a detailed schematic of the transmit converter since the block diagram above should suffice for anyone sufficiently skilled to service it and since no schematic is available for the Bodnar GPSDO either. But here are a few comments.

The “Band 1” line from the U3s is used as a PTT. When it is asserted, circuitry in the upconverter enables the PA Bias, 3.75-5 VDC from an LDO regulator sourced from a 10V regulator that is always on. This bias only turns on stages in the upconverter stage but also simultaneously passes the bias via the interconnecting RF coax to the PA. In the PA, that bias is applied to the bias control input of the PA. This level can be adjusted with a pot on the upconverter board and is accessible externally. This bias affects the operating point of the PA and varies the gain so that this pot is an effective means to set power level and total current and power to the beacon. I thought it might be important to be able to control total power because of thermal concerns.

If it is desired to reduce drive or output power, this may be done two ways. As shown in the figure below, the U3s has had Vcc removed from the output FET(s). This leaves it operating as a crude variable attenuator, in series with the input drive, that is adjustable with the original FET bias pot. The 32.3 MHz drive to the upconverter can be controlled this way. If additional output control is desired, the ~5V bias coming into the PA can be adjusted with the potentiometer at the LDO. My initial rough target was 30 watts out of the beacon/PA assembly when operated from 13.8 VDC, while maintaining acceptable temperature rise so as to not compromise MTBF for the beacon. The copper filter, cables and connectors have about 1.1 dB insertion loss so the final result can be at least 3 dB more power output than the existing 70cm beacon. There is around a little variation over temperature and for a 1 V input supply voltage change.

After building and burn-in testing the beacon for four months a problem was noticed. The power suddenly dropped about 10 dB to 4 watts. In the process of diagnosing that and after watching the heat sink temperature hover near maximum acceptable limits of 55C, I decided to replace the 60W PA with a 30W one. Previously at 40 watts out of the filter, 52 out of the PA, there was about 30 degree Centigrade rise in heat sink temperature with typical transmitter duty cycle (described in another document). This assumed only convection cooling. Even a very small amount of air flow over the fins of the heat sink drop decreased this to below 10 degrees C rise but I didn’t really want to have to rely on a fan at a remote location.

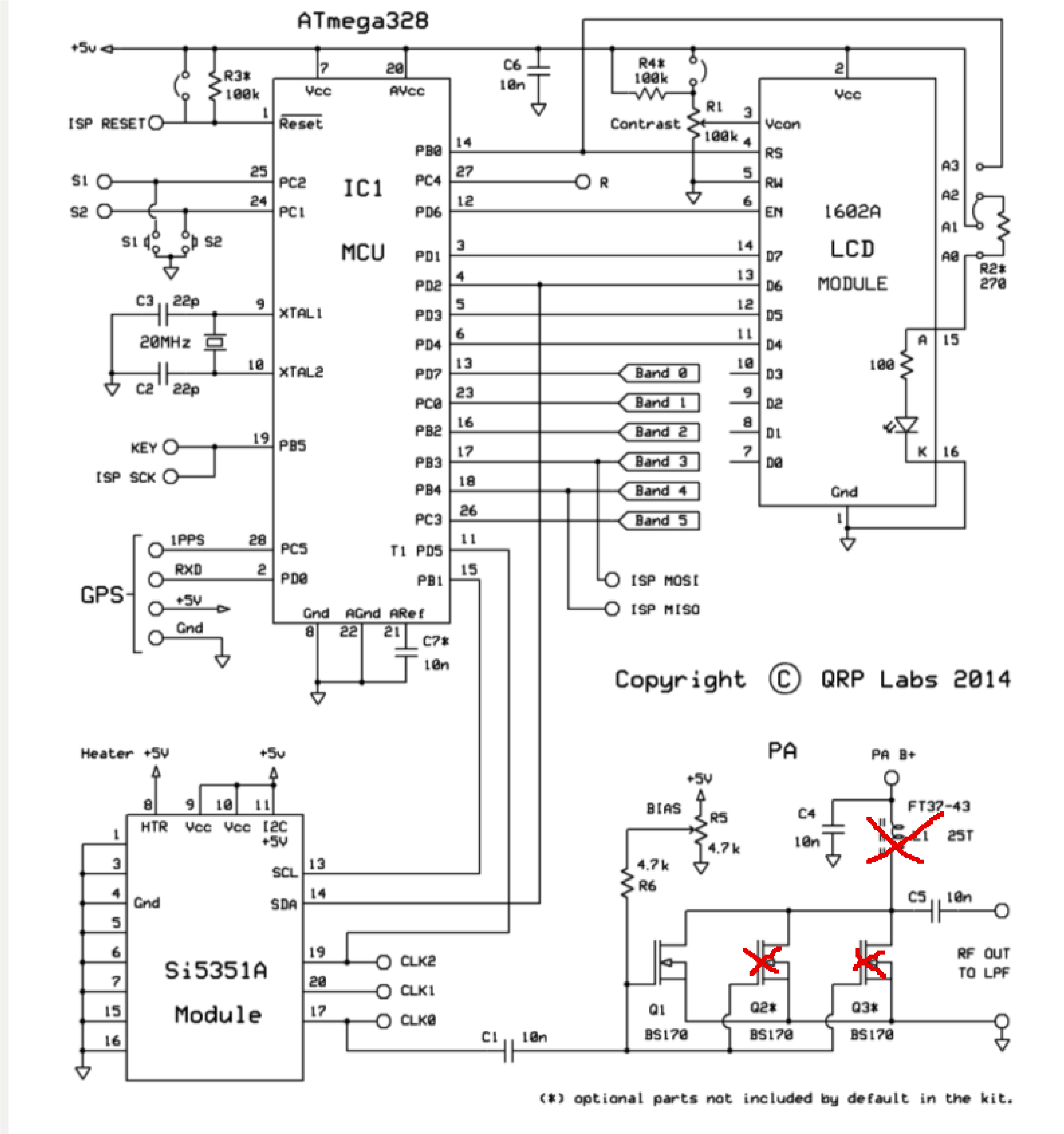
By replacing the 60W brick which pulled about 10A at 50W out of the filter with a 30W one that pulls 7A for 30W out of the filter, overall temperature rise was reduced quite a lot. That 2.2 dB sacrifice of output power seemed worth the greatly reduced temperature rise and probably increased MTBF. This change also let me remove the external fan from the beacon.

The beacon, except for the PA, power switch and connectors is housed entirely inside one of the QRPLabs enclosure. Two controls have been added, the toggle switch in the upper left enables programming. ***It should be left down to avoid unintended programming*** that can take hours to repair! It is shown here in the “UP” position in which the Menu and Edit buttons are active. Watch out, it might take several hours to reprogram this thing from a cold start even with all the documentation. This is in part due to the minimalist User Interface of the U3s. There are only the two buttons and the two line LCD display available for all programming. As described in the QRPLabs Documentation, the Menu button advances to the next item while the Edit button selects whatever is showing. This sounds easy but there is some nesting of Menus for Mode setting and Message entry and it is easy to make a typo. Because the Menu only selects the next, not the previous thing, this can make a typo correction painful.

Besides this Program-only-when-up switch, I’ve added a green LED seen between the Edit button and the Power switch on the right in the picture above. This is the Output1 LED from the Bodnar. It blinks when the Bodnar is searching for satellites, at which time there is no U3s clock or upconverter LO, Once GPS satellites have been found it turns solid green, indicating that the synthesizer is providing the desired signals. Generally this light should go to solid green within a minute, or at most a few minutes after a cold start when the GPS has moved and has no idea in the world where it is. This front panel power switch does NOT turn off the Bodnar, which is powered on any time the entire beacon box has its Main Power switch on the back turned on and 12VDC is present. Put another way, the Power switch seen on the front panel only turns the U3s on and off, it doesn’t affect the Bodnar nor the PA. To really turn everything off, use the Main Power switch on the back of the assembly or else remove the 12 VDC source.

The Bodnar’s USB connector is accessible if the bottom screws holding the U3s base ‘tray’ are removed. Since this has been pre-set to provide 25 and 400 MHz and since any other settings would require verification, this should not have to be used.

The second GPS receiver is set for cold start and can take much longer to achieve a 3D fix and know where it is and what time it is. As a result, the beacon can transmit badly timed frames with bogus grid square information during a warm up period that might be 20-30 minutes long after a big geographic relocation.


ATmega328
IC1
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