The DX Beacons

by Kevin

Anyone chasing DX for more than a year knows and has listened to the beacons. The premise is simple – set the VFO of your radio to the beacon frequency of the band of interest (14.100MHz for 20m) and listen. Over the next three minutes, copy the callsigns of beacons you hear, and that will be an indicator of propagation conditions.

Part I of this article covers how the beacons operate, how to use them, monitoring software, and the modernization program currently under way. Part II covers the deployment of the beacons to the various sites. Come along with us.

What are the beacons?

There are 18 beacons deployed around the earth in locations to cover as many points and continents as practical (see map below), to aid checking current propagation. Each beacon is operated, managed, and maintained by a local volunteer operator. The equipment consists of a vertical antenna, an HF transmitter, a GPS receiver, and a controller. The program is sponsored by NCDXF and the IARU, known as the International Beacon Program. The primary web page: <http://www.ncdxf.org/pages/beacons.html>.

Each beacon sends a callsign followed by a series of four one second long dashes. The callsign and 1st long dash is sent at a power output of 100 Watts (50dBm). The 2nd at 40 dBm, then 30 dBm, and finally 100 mW (20dBm). The quick decade decay of RF power will help the listener determine how good other signals on that band might be heard. If you're close to a radio right now, pause for three minutes, tune the radio to 14.100 and listen. Hearing the beacons thru a few cycles will enhance your understanding of how they work.

Each beacon will transmit on each of the five bands, once every three minutes. The frequencies are 14.100 (20m), 18.110, 21.150, 24.950, 28.200. Any one beacon will start its cycle on 20m, then progress to each of the higher bands. Beaconing on an individual band occupies a slot duration of 10 seconds. Any one beacon will be active for 10 seconds * 5 bands or 50 seconds.

Table 1

Slot Start time	Callsign	DX Entity	Location
0	4U1UN	United Nations	New York City
10	VE8AT	Canada	Eureka, Nunavut
20	W6WX	United States	Mt Ununhum
30	KH6RS	Hawaii	Maui
40	ZL6B	New Zealand	Masterton
50	VK6RBP	Australia	Rolystone
60	JA2IGY	Japan	Mt Asama
70	RR9O	Russia	Novosibirsk
80	VR2B	Hong Kong	Hong Kong
90	4S7B	Sri Lanka	Colombo
100	ZS6DN	South Africa	Pretoria
110	5Z4B	Kenya	Kariobangi
120	4X6TU	Israel	Tel Aviv
130	OH2B	Finland	Lohja
140	CS3B	Madera	Santo da Serra
150	LU4AA	Argentina	Buenos Aires
160	OA4B	Peru	Lima
170	YV5B	Venezuela	Caracas

You might be wondering, or if you listened to the beacons, how they stay in concert, and don't overlap, or "step" on each other. The magic is in using a GPS receiver to match timing. Each beacon is assigned one of 18 slots. The controller uses the GPS receiver to get a precise time, down to a few milliseconds.

With an accurate time of today, and an assigned slot, each beacon can start it's cycle staying in convert with the other beacons. See figure 3 showing how the beacons progress around a three-minute timing wheel.

How to use the beacons

As described earlier, you can just tune to a band of interest and listen. This gives an immediate indication of propagation. There are three other ways to use the beacons – spots via the RBN, software to guide listening (DX monitor), and software to decode the beacons and give a long-term graph of beacon reception (FAROS).
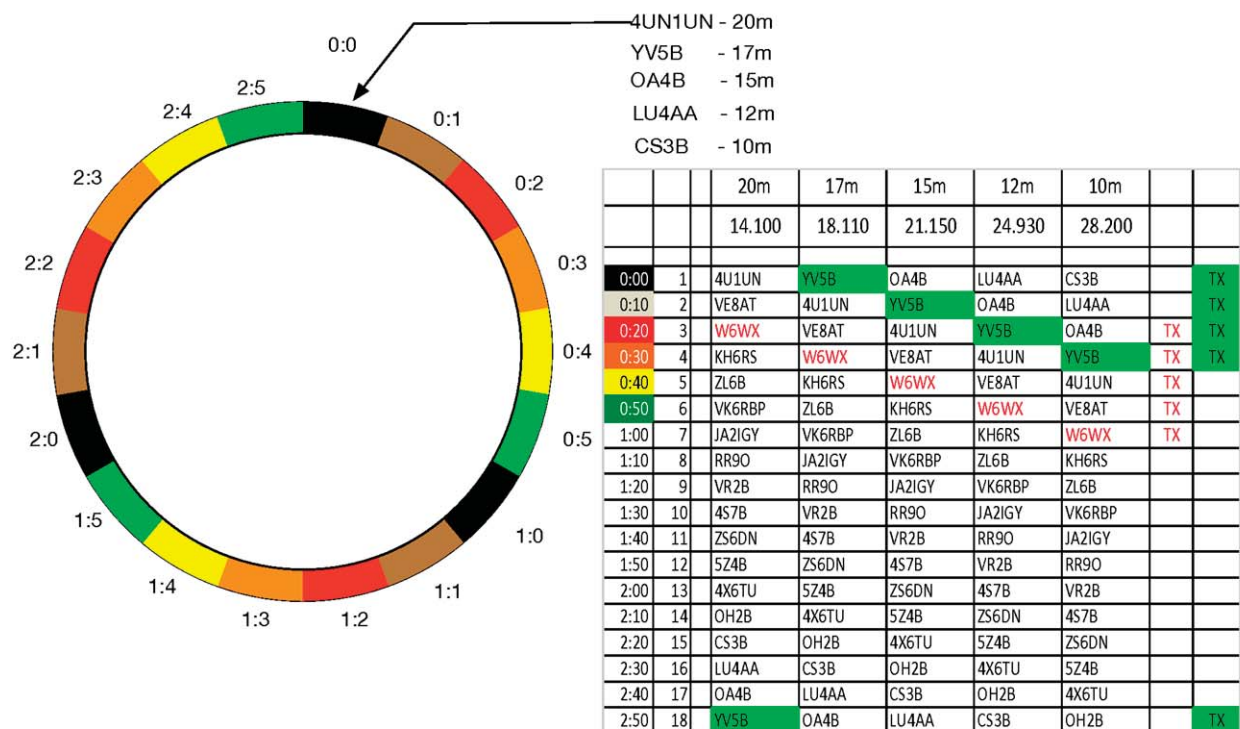
4UN1UN - 20m
YV5B   - 17m
OA4B   - 15m
LU4AA - 12m
CS3B   - 10m

		20m	17m	15m	12m	10m		
		14.100	18.110	21.150	24.930	28.200		
0:00	1	4U1UN	YV5B	OA4B	LU4AA	CS3B		TX
0:10	2	VE8AT	4U1UN	YV5B	OA4B	LU4AA		TX
0:20	3	W6WX	VE8AT	4U1UN	YV5B	OA4B	TX	TX
0:30	4	KH6RS	W6WX	VE8AT	4U1UN	YV5B	TX	TX
0:40	5	ZL6B	KH6RS	W6WX	VE8AT	4U1UN	TX	
0:50	6	VK6RBP	ZL6B	KH6RS	W6WX	VE8AT	TX	
1:00	7	JA2IGY	VK6RBP	ZL6B	KH6RS	W6WX	TX	
1:10	8	RR9O	JA2IGY	VK6RBP	ZL6B	KH6RS		
1:20	9	VR2B	RR9O	JA2IGY	VK6RBP	ZL6B		
1:30	10	4S7B	VR2B	RR9O	JA2IGY	VK6RBP		
1:40	11	ZS6DN	4S7B	VR2B	RR9O	JA2IGY		
1:50	12	5Z4B	ZS6DN	4S7B	VR2B	RR9O		
2:00	13	4X6TU	5Z4B	ZS6DN	4S7B	VR2B		
2:10	14	OH2B	4X6TU	5Z4B	ZS6DN	4S7B		
2:20	15	CS3B	OH2B	4X6TU	5Z4B	ZS6DN		
2:30	16	LU4AA	CS3B	OH2B	4X6TU	5Z4B		
2:40	17	OA4B	LU4AA	CS3B	OH2B	4X6TU		
2:50	18	YV5B	OA4B	LU4AA	CS3B	OH2B		TX

Figure 3

RBN, or reverse beacon network, is organized by Pete, N4ZR using VE3NEA's CW Skimmer software. The purpose of the RBN is to produce spots automatically; similar to listen and spot DX Spider networks. The RBN software will also spot the beacons and report thru the DX Cluster network. Thru reviewing the beacons heard, from various locations, some information can be learned about propagation.

To use RBN, go to URL http://reversebeacon.net/ Select dx spots from the menu along the top, then select beacons, then select ncdxf beacons, and press enter.

Several software packages, and wall clocks are available which can be used as an aid to which beacon is currently active. This software can also drive your radio thru a CAT (or other) radio interface to set the VFO for a given beacon. DX Monitor can track a beacon in time, or track a beacon across bands. When tracking in time, DX Monitor will display what beacon you should be hearing; when tracking a beacon, it will tune the radio to the correct band, at the correct time for a selected beacon. DX Monitor won't decode the CW signal, nor plot when a beacon is heard. You still have to be present, and use your ears. Once installed, select the maps button, on the main toolbar for DX Monitor. From the maps display select plot. From this menu there are various options to monitor the beacons. An example is figure 4.

FAROS is a unique software package. It will tune your radio, decode the signals, display a spectrograph of beacon signals, and build a nice tile map of beacon reception status over time. You can configure FAROS then look at the collected data, perhaps days later to get an idea of propagation. This can be interesting and revealing.

FAROS also collects and stores a very insightful set of data points for each beacon it hears – time of day (UTC), signal strength, QSB, delay, and "Evidence". FAROS will graph these data points for beacon. Examining this can reveal interesting effects and propagation openings.

One interesting aspect of FAROS operation – it will report if the beacon is heard via short path, or long path.

Figure 5 and 6 show the history FAROS can provide. W6WX beacon is close to the author's QTH. That is reflected in the capture history. Notice the missing signals reports in figure 5 on 17m. This was caused by the antenna falling down.

Figure 7 displays the spectroscope capture window of FAROS. Notice the parameters when W6WX is detected. Figure 8 displays daily detail for OA4B on 20m. Note the red dashed line for short path and long path.

FAROS determines LP versus SP by noting the delay time from start of transmission, till CW dits begin arriving at the location – Time of flight (TOF). This is why FAROS must have an accurate time of day, accurate position of the listener, and an up to date database
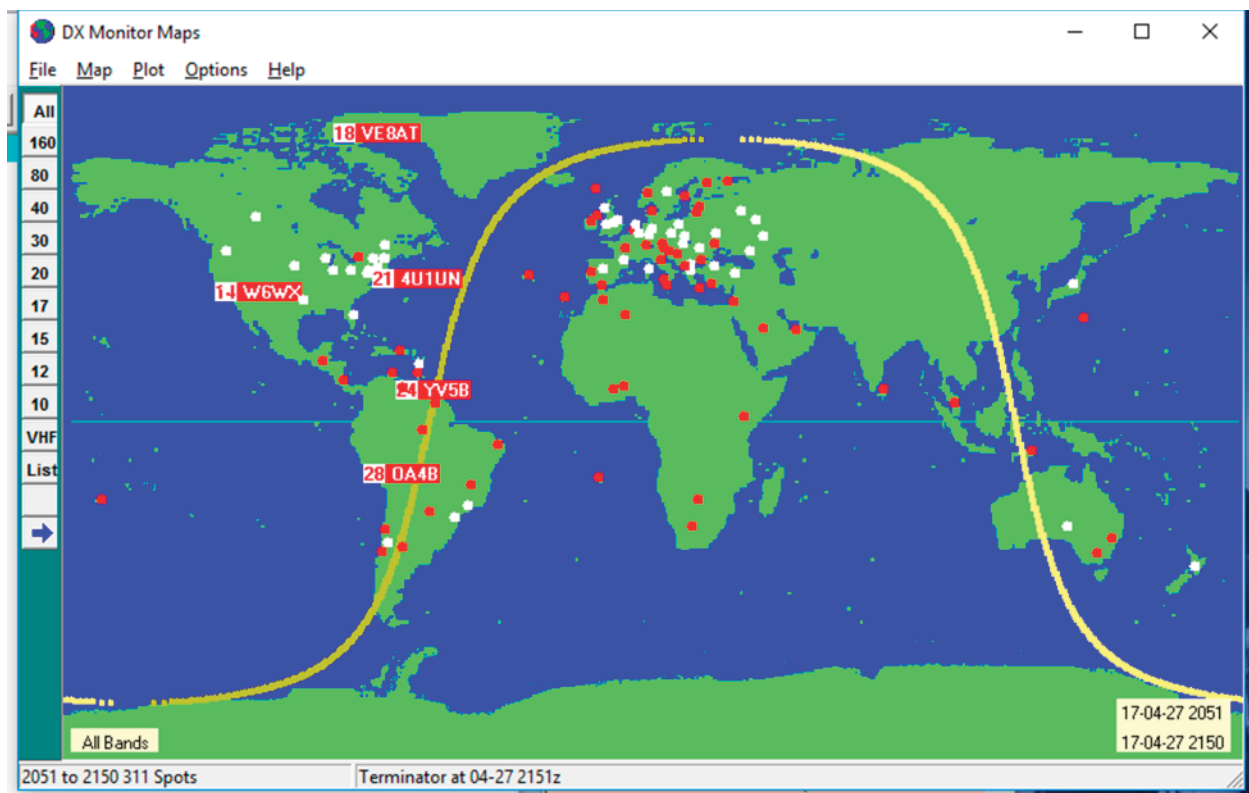
Figure 4

of the beacon locations. FAROS also depends upon the beacons knowing the correct time of day – we will see how the beacon controller achieves that.

Modernization Program (or V2 upgrade)
Decisions to be made!

The version 1 beacon hardware has been on the air since 1996. Much of the equipment has reached end of life. In the last few years, there hasn't been a time when all the beacons we're all functioning.

The V2 program was started with a goal of modernization. Consideration was given to a new format; new techniques; Internet access; and how to improve the life, while reducing the maintenance effort.

An initial question we asked – are the beacons even needed anymore, given the RBN. The answer is yes. The beacons are a known signal (frequency, accurate time, and location). They are always on. This answers the question – are the bands dead, or is anyone calling CQ. The authors used the beacons on the TX3X DXPedition to learn the depth of the solar storm that hit. We also got a round about answer about who beside Hams use the beacons – more about that later.

Once that question was complete, we thought about using WSPRnet and having each beacon listen to the other beacons to provide propagation information.

We also casually asked what our fellow hams liked and disliked about the beacons. Everyone wants a lot more "service" – mostly an RBN facility at each of the beacons. They also wanted to be able to tap into reception reports via the web. The dislike was easy – beacons not being on the air. The coverage, and locations was viewed as good, possibly great. A number of people volunteered to add beacons, or take on a beacon.

For many of the requested items, we'd need either cell service, or Internet service at the beacon site. As it turns out, that wasn't practical for most of the sites. Getting a beacon on the air is easy – site the two antennas, small shelf for the equipment, and AC power. All done when the Internet was still the forming DARPAnet, and mobile phones were only mobile if you had a car to put them in.

WSPRnet is an interesting beaconing technology. It can't be monitored by ear. A full PC and lots of software is needed. There is a central collection management group. NCDXF didn't want to take on that activity for the beacon program.

In the end, we decided to stay with the existing set off 18 beacons, same format, and just upgrade the equipment.

On with the program

The original beacon equipment configuration was a Kenwood TS-50 radio, a Cushcraft (now MFJ) MA5V antenna, Trimble smart GPS anten-
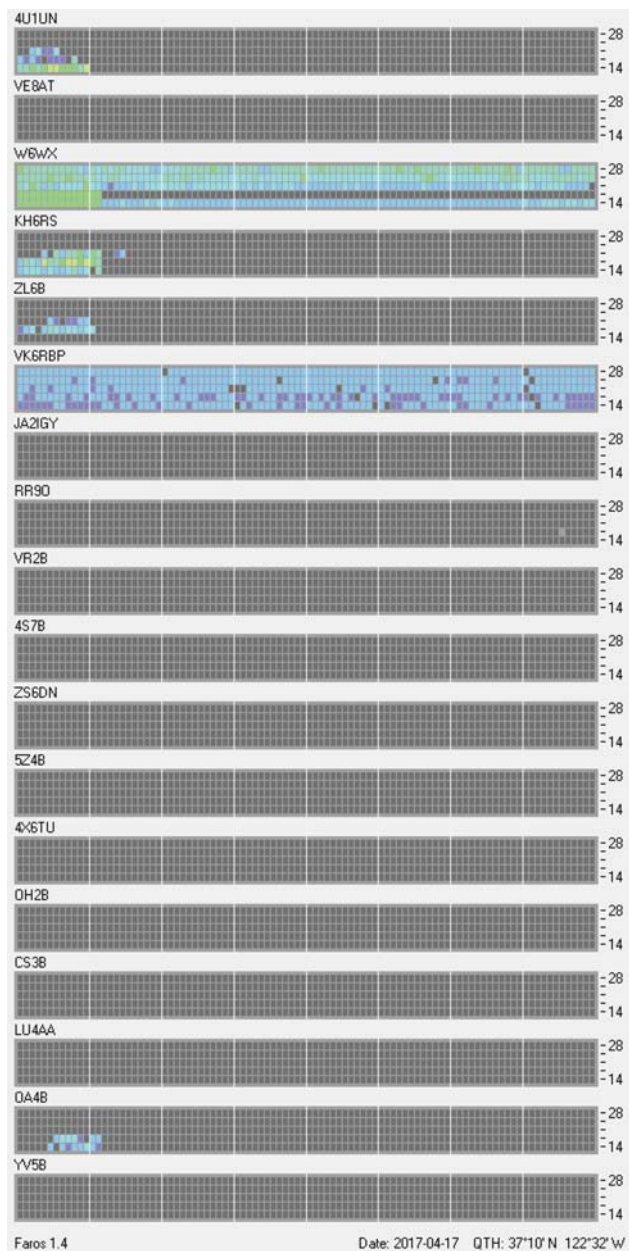
Figure 5

Figure 6

na, and custom controller. The version two controllers would follow a similar set of equipment.

N6XG surveyed the existing group of 18 beacons site operators, and found all of them had problems with the MA5V antennas, and many of them had been repairing other portions of the equipment as needed. Walt decided to provide a complete new set of everything to get on the air. This would enhance the lifetime of the V2 beacon deployment, get all sites to deploy and get on the air quickly, reduce logistics, and make maintenance easier with common equipment.

The V2 equipment consisted of an ICOM IC-7200 radio, new GPS antenna, SAMULEX power supply, MA5V antennas, all the cables, and coax-

es needed, and of course, a new custom controller.
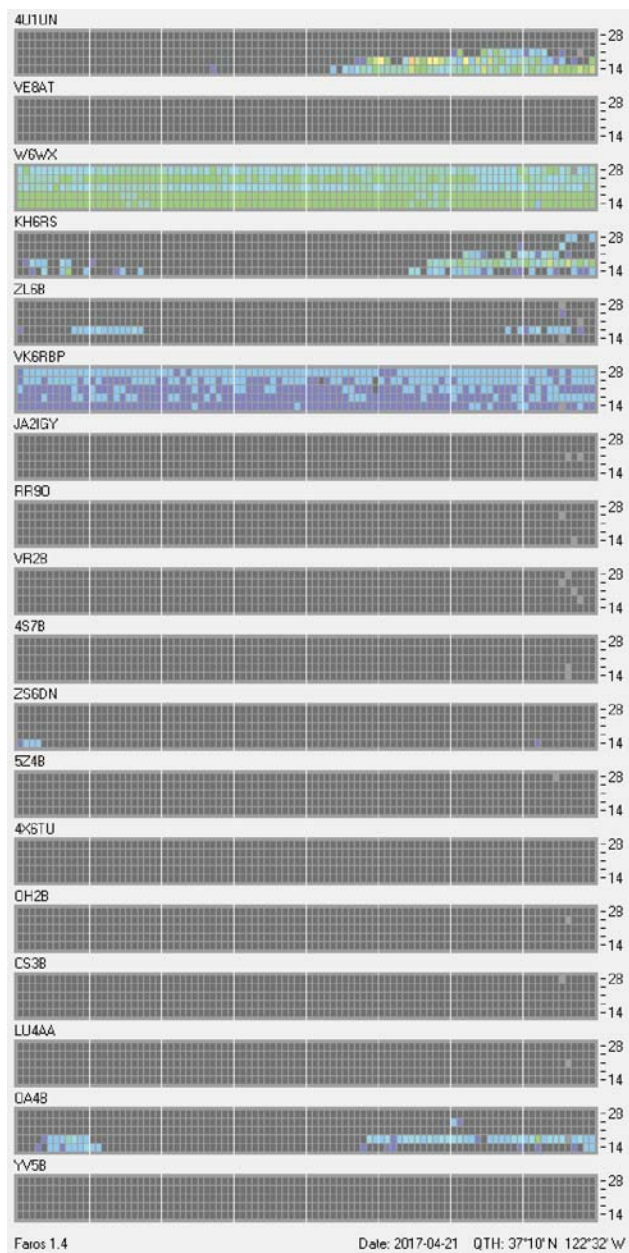
The new controller uses an Arduino Leonardo SBC and a custom shield. The shield contains a CI-V interface to the radio, PTT and CW signaling, and a GPS receiver. Power for the controller came from the '7200 where it was fused, and converted to the voltages needed. This all made for a nice interface to the controller package – a 7 pin DIN connector, and a SMA RF connector to the GPS antenna. N6XG designed and manufactured a custom cable for interconnect the controller with the IC-7200 radio. The block diagram is figure 9.

Software in the Arduino controls the '7200 via the CI-V interface, turns on the transmitter via the PTT line, and sends CW station identification via
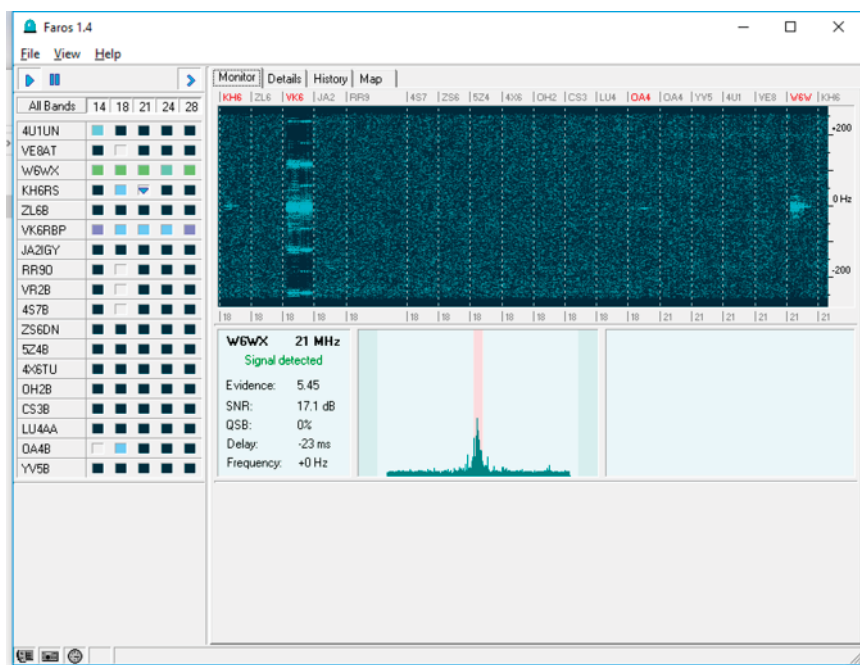
Figure 7

the CW line. The GPS receiver provides accurate timing and begins the ID cycle at the precise time.

In the original beacon, the GPS receiver was completely contained in the external antenna. Interface to the antenna was an RS-422 signaling and 1PPS, coming into the controller via a multi--conductor cable. This scheme was satisfactory. The GPS timing industry didn't develop further along this path. Rather, excellent GPS chips were developed, with excellent performance, at an inexpensive price, all using external simple helix receive antennas and a built in LNA.

For the V2 controller, we choose to use a GTOP PA6H receiver (built with an MT3339 chipset), along with a PCTEL GPS Timing antenna (GPS-TMG-26N). The GPS receiver was designed as part of the Arduino shield. The external GPS antenna contains an LNA, receiving power over the coax. We designed a current limited and sensing power supply with a DC block on the shield to power the LNA in the antenna. The GPS receiver chip connects to the Arduino via a TTL serial TX and RX signals, and a 1PPS signal.

The remainder of the controller consisted of a 2 x 16 RGB backlit LCD display, a menu button, and a reset button. Custom front and rear panels were fabricated using front panel express. Building a custom

shield made for a very compact, integrated, and reliable package.

WA5ZNU, Leigh Klotz implemented the software control loop. The software validated and verified connection of the radio, GPS receiver, and LCD display. GPS timing was then established.

The GPS receiver was monitored until it reported that it had established location and timing, by locating at least four Satellites. Once the GPS receiver was locked, NMEA sentences were use to learn the time of day, and set the internal three minute loop timer. The GPS sentence provides the time of day. Arrival of the packet or sentence isn't precise enough to establish clock synchronization. The packet takes time to transmit along a serial with from the GPS receiver into the software. This timing has a lot of jitter in it. Further issues are – is the time correct at the start of the packet, then end of the packet? This is where the 1PPS signal is used. The 1PPS signal is connected to an interrupt input pin. The interrupt routine can increment a counter to advance the clock, and signal the main loop at a 1 second boundary has been reached.

The GPS 1PPS signals the start of a one second boundary. The NEMA sentence tells you what time it was when the 1PPS arrived. For the GTOP PA6H re-
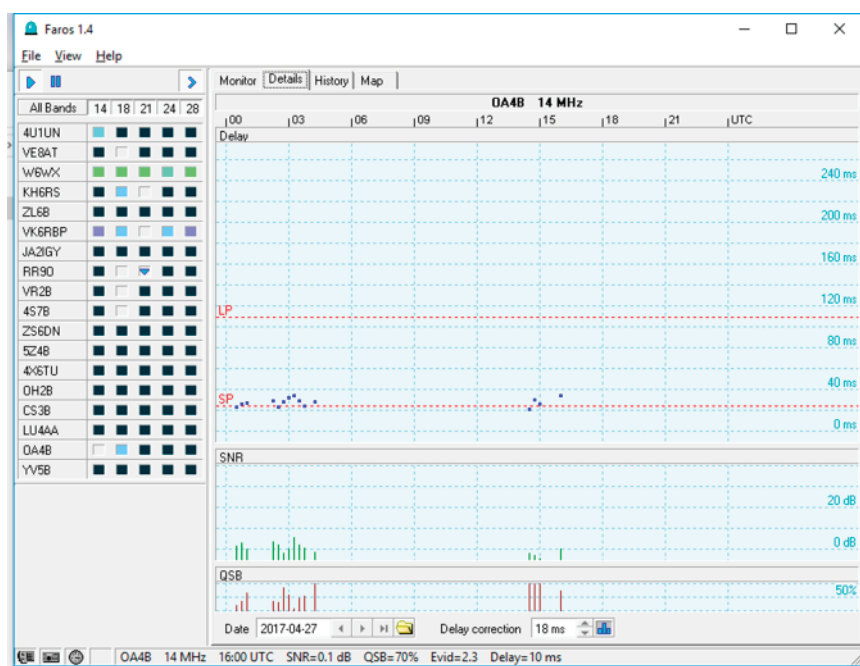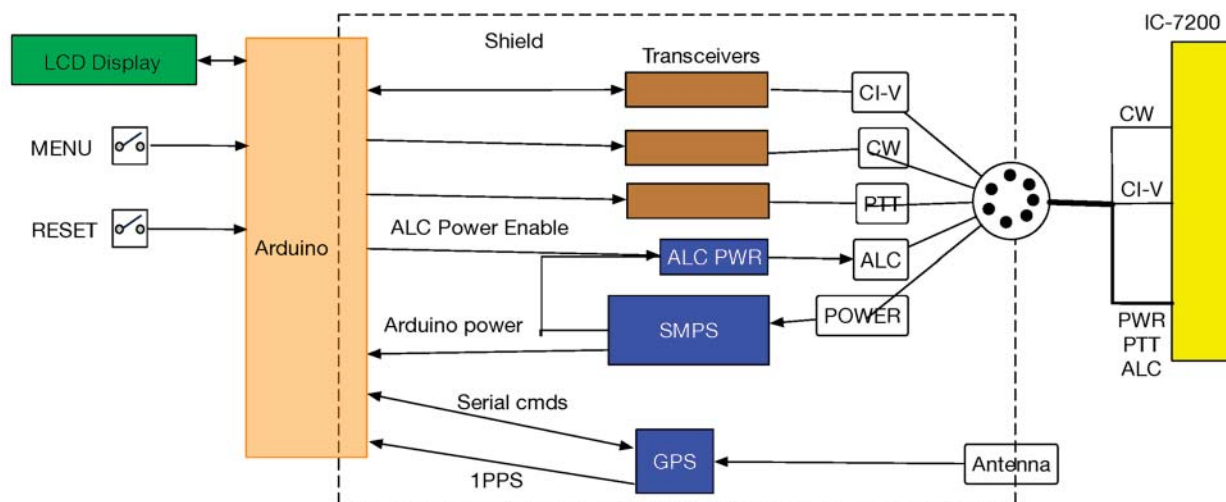

Figure 8

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Figure 9

ceiver, the NEMA sentence transmission starts 50mS after the rising edge of the 1PPS. The software uses this combination to set the internal three-minute beacon loop counter. The internal counter could loose count of seconds, due to masked interrupts, and other delays. Once during each three-minute cycle, the software loop compares the expected time of day, with that reported by the GPS, and a correction is applied. This is known as using the GPS timing to "discipline" the local oscillator.

The other external item needed is the call sign of the beacon and what time slot to send the beacon sequence in (slots are 0 to 170 seconds). The callsign and time slots are kept in a database in the software code. Selection is done via a menu command, and is programmed by N6XG before he ships a new unit to a beacon operator.

The processing loop operates primarily as a switch using the number of seconds since zero of the three-minute loop. At the correct time, the loop will start the beacon transmission consisting of a CW id (the station callsign) at 22.5 WPM, then four one second long dashes, in decade declining power levels. The sequence starts on the 20m band, then at the next 10 second mark, the software advances to the next band, repeating the beacon sequence thru 17m, 15m, 12m, and 10m.

The V1 controller adjusted transmitter RF power delivered to the antenna via ALC input to the radio. For V2, we expected to use the power control command available with the IC-7200 via CI-V. This worked for power levels of 50, 40, and 30dBm. The RF power was measured carefully with both a Wavenode and LP-700, and values programmed into the software. We couldn't set the command level low enough to achieve a 20dBm

(100mW). The solution was to build an ALC power control on the shield. When 20dBm power level was needed, the power level was programmed as low as it would go (zero), and the ALC voltage turned on, via digital output pin. This worked well.

We now had working hardware, a full kit to ship, and software. We were "80%" done.

Prototype and bringup.

Initial bringup, testing, and validation of the V2 beacon controller was done at the home QTH of K6TD, and then moved to the W6WX location.

W6WX is located on Mt Umunhum, located in San Jose, CA. It's the sight of the very first beacon as it's close to the home QTH of W6NL, and is maintained by K6GSJ, Lance Ginner.

Initial validation was done via "ear", and all listeners, especially N6TV indicated the new unit had correct timing, beacon format, and acceptable signals.

However, we began to get reports from "non-Ham" users and FAROS observers that the timing was not correct. We were very surprised to get reports from gov't agencies. This lead us to discover the beacons are widely used, as they are always on, very accurate, and "available when everything else fails".

We began testing with FAROS and confirmed reports the new beacon wasn't detected. It was clear that FAROS was hearing the beacon well, it our test location, and decoding CW correctly. We finally concluded the issue had to be the timing. Specifically, the time from the start of a one second epoch to the start of the CW ID. Email communication with VE3NEA didn't reveal what might be wrong. Alex did provide some details of the detection technique.

To resolve this issue, we setup a listening station in the newly remodeled shack of ND2T in Palo Alto, CA, where we could compare the timing of existing beacons with the new beacon.

Tom and the authors were anxious and intent on getting the timing fixed. We planned a listening and adjustment session one morning in Tom's shack. After much observation, tweaking, conjecture, real time emails with VE3NEA, without any luck, Tom grabbed a magnifying glass, looked at the FAROS spectrograph and noted, the test beacon looked to be "three pixels to early".

What is the time duration of a pixel? We arbitrarily declared a pixel on the display be 100ms, and then proceeded in real time, remotely from ND2T's shack, update the software with an additional delay of 300ms before the start of the CW ID. In three minutes, FAROS reported a successful decode! Success! We had a new beacon controller. The kicker was getting an email from VE3NEA in about ten minutes, observing that we "figured it out".

Actually, the first unit was a hacked together unit with various evaluation and demo boards. By no means would it withstand the test of time. Nonetheless, the unit was put in service at W6WX and continued to operate for over a year w/o any issues. The beacon operator in KH6 heard about the new version and asked we provide them one. We quickly put together another test unit, travelled to Hawaii, and put it on the air. It's still on the air, working well.

Over the next year , we finished the final hardware, debugged the software and readied the units for deployment. The DX Beacons are on the way to returning as one more tool for the DX Chaser. Let us know how you've used the DX Beacons to aid the chase.

How GPS Can Provide Precise Timing

Let's cover how a GPS receiver, designed for navigation, can be used to learn an accurate time of day, within even microseconds. The GPS "system" consists of a constellation of thirty-one satellites orbiting the earth. Each satellite sends a coded signal out with, among other elements, the time it began transmitting the signal. Each GPS contains an extremely precise clock reference in it – usually an atomic clock, that is constantly measured and tune for accuracy by the GPS system operator – the USAF.

At any one time, a GPS receiver would be receiving a time stamped signal from between four and twelve satellites. Thru published tables, the receiver knows the orbit parameters for every satellite. With the time stamp in the received signal (TOA – time of arrival) and the calculated orbital position, the receiver calculates the distance to the satellite. With enough satellites, and some geometry, the receiver can now calculate its position. This is how a GPS receiver can be used for navigation, as part of a tracking or charting system, such as the Google Maps app on your smartphone, or the NAV function in your car.

To compute position, a GPS receiver measures the time needed for the signal to travel from the satellite. With the time taken for the signal to travel, and the position of the satellite, the receiver can compute the distance to the satellite. Using a distance to four satellites, the receiver can compute the 3D location.

Measuring time of flight requires an accurate clock in the receiver. The clock must also be synchronized to the time of day in the satellite. A GPS receiver starts with an accurate clock oscillator. Thru reception of signals from the satellite, primarily the PN sequence decoding, the local oscillator is synched to the GPS satellite clock. It's this disciplined local oscillator clock that provides precise 1PPS (one pulse per second) timing. Under proper conditions, the 1PPSsignal can achieve 10ns accuracy.

A GPS receiver suitable for timing usage will provide a data packet with the current time of day, and more interestingly, a very precise, one pulse per second (1PPS), signal- usually as a signal pin. With the 1PPS pin driven into a controller and the TOD message, a beacon controller will become synchronized to a precise time of day. There is a bit of magic in determining what the correct time of day is. The 1PPS signal will tell you the second. The receiver will send to the controller, via a UART style bus, a message with the time of day in it. This message can take several 10s of milliseconds to arrive, and it can't be synchronized to a time event. The answer is – the time of day in the message is what it "was" when the 1PPS pulse was emitted. This allows a controller to set its time of day clock.

Contributions and Acknowledgements

The originator and guiding light for the beacons is Dave Leeson, W6NL (ex-W6QHS). He invented the basic concept of the timing loop, for frequency and time sharing, using GPS to maintain the time, and kept the program going.

Peter Jennings, VE3SUN, Charlie Mason, W4NJK have been the primary managers of the beacons, maintaining the web site, communicating with the beacon operators, and liaison with NCDXF and IARU.

Tom Berson, ND2T, President of NCDXF. Tom provided guidance for the V2 program, provided much technical insight, and debugging; Leigh Klotz, WA-

5ZNU, wrote the basic software timing loop; Stu Phillips, K6TU, a strong technical partner, and pointing out the not so obvious solutions to various problems.

Ray Novak, N9JA, and ICOM USA for their support of the project. Never could have gotten the project deployed without Ray's support.

Lastly, my design and deployment partner, Walt Wilson, N6XG. He has become the face of the beacons to the operators, working closely to get V2 packages deployed.

Many others contributed to the V2 beacon program. Thanks to all!