Ever wonder how much of the noise you hear on the HF bands is actually comprised of signals too weak to be copied? W6DTW takes us exploring with a weak-signal mode that can pull great DX out from under the noise!

Communicating Under the Noise JT65A on HF – Part I

BY DAVID T. WITKOWSKI,* W6DTW, with TOMAS HOOD,† NW7US

Being the geek that I am, I often envision what the invisible world around us might look like if we could see beyond the visible light spectrum; cosmic rays and neutrinos streaking through the sky like a meteor storm, electric and magnetic fields surrounding antennas and power lines, uninsulated walls and windows leaking heat via infrared. Likewise, it's fascinating to think that at any given moment, thousands if not millions of distinct radio, TV, and cellular phone signals surround us, unseen and unfelt, their existence revealed by the familiar magic of a radio receiver's ability to convert microvolts of RF energy into audible sounds. Yet this leads me to wonder: How many signals are there that we *can't* hear, and how might we detect them? When we hear a rush of static from our rig's speaker, is there something underneath the noise unheard and undetected? What if there was a way to receive those messages, to add greater sensitivity to your HF station, using the equipment you likely already have? As it turns out there is, and it's called JT65A.

The JT65A communications protocol was conceived and first implemented by Joe Taylor, K1JT. Joe, a Professor Emeritus of physics at Princeton University, shares a Nobel Prize with Russell Alan Hulse (ex-WB2LAV) for the discovery of the first pulsar in a binary system as well as the first confirmation of the existence of gravitational radiation in the amount and with the properties first predicted by Albert Einstein. Joe has contributed to the amateur radio community in much the same way, changing the playing field for weak-signal operation.

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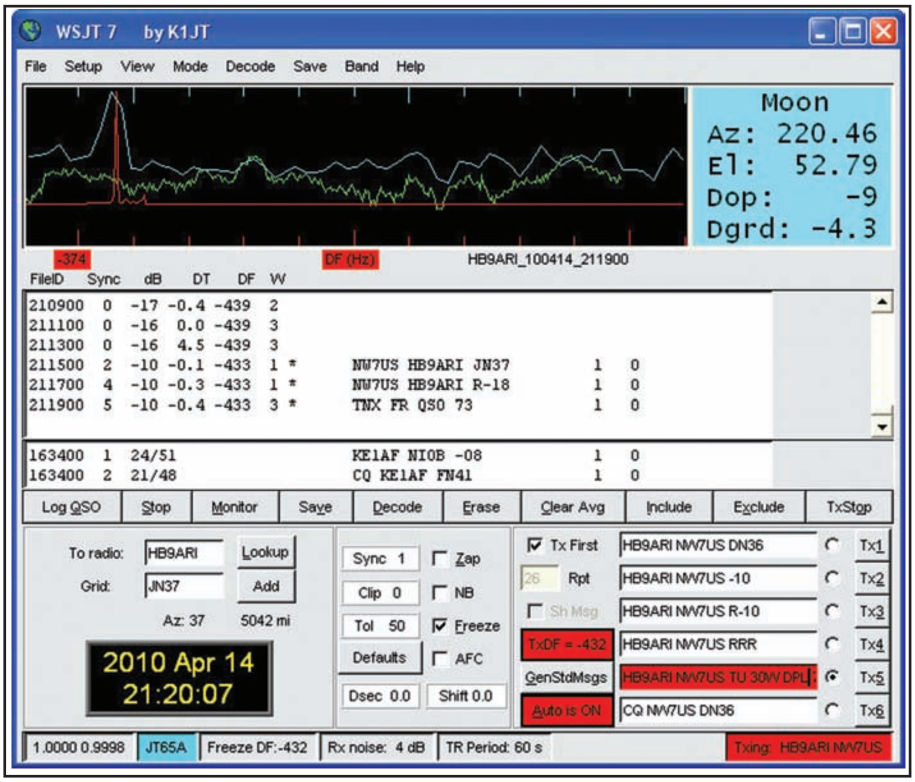

Fig. 1– A screen capture showing the WSJT software by Joe Taylor, K1JT, in the JT65A digital communications protocol mode on the 20-meter JT65A frequency, 14.076 USB. NW7US just made a successful two-way digital exchange with HB9ARI. (Source: NW7US, using WSJT)

Joe was first licensed as an amateur radio operator while he was still a teenager. His ham radio interest led him into astronomy *(see* CQ *interview, October 2009 issue—ed.).* When he applied his mind to the idea of developing a communications protocol that would work well under very low signal-to-noise ratio conditions on a communications signal path between, say, the moon and Earth-bound amateur radio stations, he formulated a number of protocols that have revolutionized the world of amateur radio weak-signal DXing.

In 2001, Joe wrote the WSJT (for "Weak Signal/Joe Taylor) software (http://physics.princeton.edu/pulsar/K1JT/wsjt.html) that implemented these new weak-signal communications protocols. WSJT offers several modes (including FSK441, the JT65 family, and JT6M) intended to support meteor-scatter, troposcatter, and Earth-Moon-Earth (EME, or "moonbounce") communications. JT65A is a specific protocol designed for weak-signal conditions on the shortwave (HF) frequencies (see figs. 1 and 2), taking into account the specific ways in which an HF radio signal propagates via the ionosphere and "suffers" under changing conditions.

JT65A is actually a "sub-mode" of

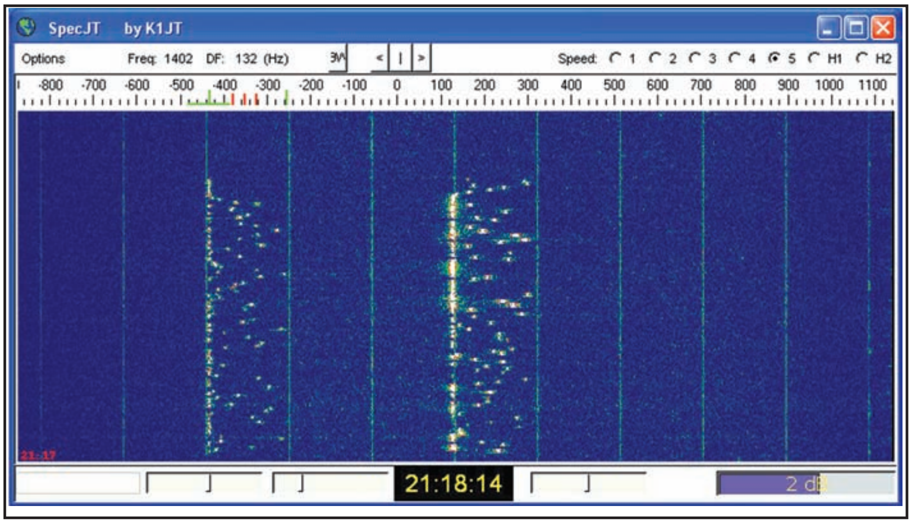

Fig. 2– The "waterfall" display, a feature of the WSJT software, showing several JT65A digital signals. One of these, the "trace" on the left, is the signal from HB9ARI as received at NW7US. (Source: NW7US, using WSJT)

Joe's original JT65 protocol, which he designed to optimize EME contacts on the HF and VHF bands. JT65 includes error-correcting features that make it very robust, even with signals much too weak to be heard. It was later realized that this protocol, with some adaptation, would also be very usable for terrestrial HF communications.

A Bit of Background

Before we can talk about the benefits of a mode such as JT65A, we need to delve into a bit of background on communications and information theory. In the earliest days of wireless, the conversion mechanism between received signals and language was via the human ear, the difference between background static and the static of a spark-gap transmitter interpreted as Morse code and written down by an operator at the receiving end. Technology advancements would later give rise to continuous-amplitude wave (CW) and voice (phone) transmitters, the difference between the two being a tradeoff between better detection of weak signals for CW and faster throughput for phone. Figs. 3 and 4 illustrate this concept by revealing the "footprint" of a "usable" CW and voice (using single sideband), respectively. These figures reveal that, using the same antenna and power level, the useful range of the CW signal is much greater than that of an SSB signal. This is why CW has been noted as a great mode for weaker-signal operation, and why low-power (QRP) operation is typically a CW-mode endeavor.

Speaking strictly in terms of detectable signal-to-noise ratios (SNR), a CW signal that is "encoded" at twelve words per minute (12 wpm) is generally held to be copyable at an SNR of –15 dB, whereas a phone transmission that sends information at 250 wpm requires an SNR of +6 dB. (These ratios are typically calculated based on a 2.5-kHz channel bandwidth.) If we normalize these to a 1 character-per-second (cps) rate—e.g., 12 wpm CW versus speaking one letter per second phonetically in phone—the detectable SNR for phone becomes –8 dB. Therefore, on a truly level playing field, CW yields an improvement of 7 dB over phone.

The adoption of machine-to-machine communication (for instance, RTTY, Hellschreiber, etc.) in the early to mid-20th century provided faster throughput and a marginal increase in SNR performance, but at the expense of channel bandwidth. The normalized SNR of these early machine-to-machine modes works out to be only about 2 dB, hardly an improvement worth getting excited about. (Although to be fair, the value of RTTY was not so much from SNR improvements, but rather that it printed directly to paper, freeing the radio operator to do other tasks.)

Even the development of PSK31 in the late 1990s by Peter Martinez, G3PLX, did not yield an improvement in normalized SNR, although it did reduce the bandwidth requirements through the use of Varicode, a form of data compression.

If the application of data compression can reduce bandwidth requirements, are there other techniques that can be applied to improving SNR performance? And how much room for additional improvement might there be? In the 1940s, Claude Shannon and Ralph Hartley, both of whom were researchers at Bell Labs, developed the Shannon-Hartley Theorem. This theorem provides an equation (proved by Shannon in 1948) for calculating the maximum amount of digital information that can be

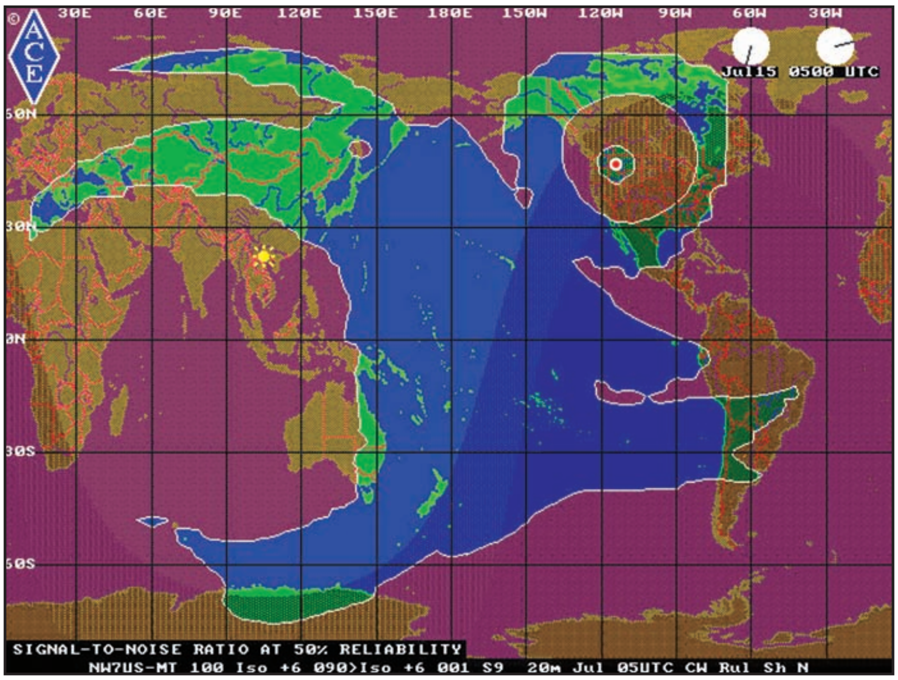

Fig. 3–- The "footprint" of a 100-watt CW signal at 0500 on the 20-meter band. Compare this with the footprint of a 100-watt SSB signal at the same time, as seen in fig. 4. (Source: ACE-HF Pro [http://hfradio.org/ace-hf], as used by NW7US)

reliably decoded over a communications channel with a specified bandwidth in the presence of noise (see Equation 1). Shannon-Hartley doesn't tell us how to reach the theoretical limit, it just tells us what that limit is.

As it turns out, for real-time data streams we can't get to the theoretical limit. Each modulation technique (for example, RTTY uses "frequency-shift keying," CW and Hellschreiber use "on-off keying," and PSK31 uses "phase-shift keying") has an inherent limitation in the ability of the receiver system, whether machine-human or pure machine, to discriminate between states. Improving SNR beyond a certain point becomes impossible.

However, all is not lost. An alternate technique for improving SNR is to implement redundancy in the data. We use redundancy all the time in amateur radio—repeating callsigns, signal reports, locator grids, etc. Of course, this effectively reduces the channel capacity, or *throughput*, which appears in Shannon-Hartley as bits/second—i.e., a function of time. If PSK31 has a throughput of 30 wpm, and we repeat our callsign six times to overcome a weak path, then clearly our throughput is less than 30 wpm. What we've effectively done by using redundancy is to reduce the SNR required for detection of our callsign. Of course, in this example, we still rely on the operator to look at the decoded text and, using the human mind's awesome ability to do pattern recognition, extract the callsign from the garbled text.

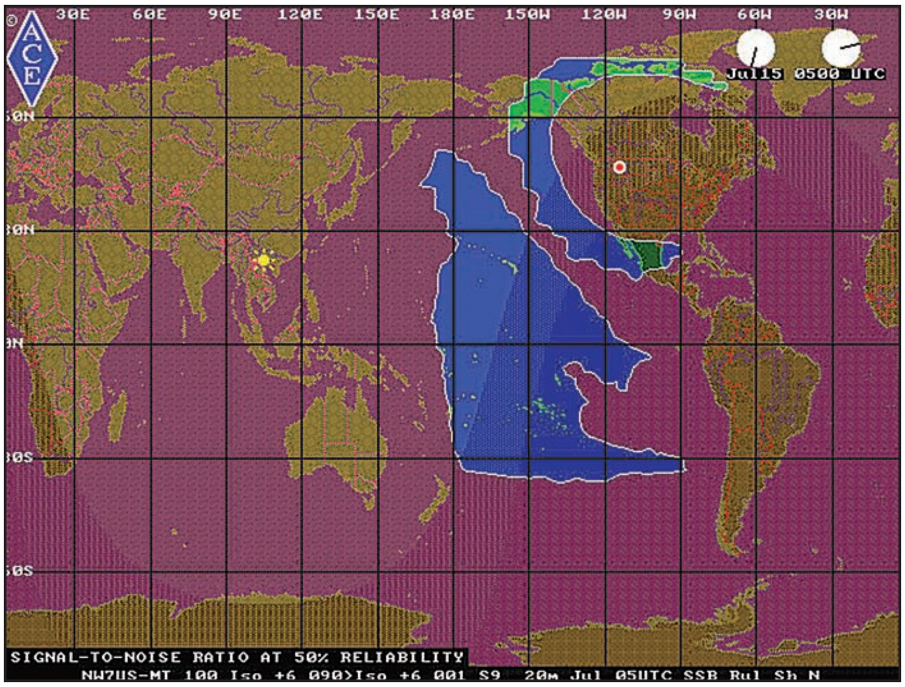

Fig. 4- The "footprint" of a 100-watt SSB signal at 0500 on the 20-meter band. Note tha using the same power level and antenna, the footprint of a "usable" CW signal is greater than that of a SSB signal. (Source: ACE-HF Pro [http://hfradio.org/ace-hf], as used by NW7US)

Thus, if we're willing to accept lower throughput and use redundancy, we can improve SNR for a given modulation method. Further improvement can be achieved by using an error-correcting code, leveraging the power of a computer to encode the data in a process known as Forward Error Correction (FEC). We can then use a computer on the receiver to invert the FEC encoding and correlate the redundant data blocks into a single error-free block of data. Combining redundant sending and error-correcting codes allows us to reach a throughput close to the limit predicted by Shannon-Hartley. JT65A's performance tracks well with theory and has been shown to yield an additional 7 dB of detectable SNR (nearly approaching the theoretical limit), which equates to a 5× improvement in system performance. This mean that reliable decoding of a signal at –24 dB SNR is now possible, and effectively turns your 20-watt portable station into a 100-watt boomer!

Equation 1– Considering all possible multi-level and multi-phase encoding techniques, the Shannon-Hartley theorem states that the channel capacity C, meaning the theoretical tightest upper bound[1] on the information rate (excluding error correcting codes) of clean (or arbitrarily low bit error rate) data that can be sent with a given average signal power S through an analog communication channel subject to additive white Gaussian noise of power N, is:

$$C = B \log_2 (1 + S/N)$$

where:
C is the channel capacity in bits per second;
B is the bandwidth of the channel in Hertz (passband bandwidth in case of a modulated signal);
S is the total received signal power over the bandwidth (in case of a modulated signal, often denoted C—i.e., modulated carrier), measured in watts or $volts^2$;
N is the total noise or interference power over the bandwidth, measured in watts or $volts^2$; and
S/N is the signal-to-noise ratio (SNR) or the carrier-to-noise ratio (CNR) of the communication signal to the Gaussian noise interference, expressed as a linear power ratio (not as logarithmic decibels).

Note:
1. For an explanation of this terminology, see <http://oakroadsystems.com/math/polysol.htm#Bounds>

JT65A

In late 2006 Victor, UAØLGY, and Tetsu, JE5FLM, completed the first JT65 QSO on HF. Interest grew quickly in 2007 as several members of the "digitalradio" Yahoo Group began experimenting with applying JT65A to weak-signal DX. People such as Andy, K3UK, created helpful guides for new operators looking to get involved. Dial frequencies range from 80m (3.576 MHz) to 10m (28.076 MHz), but 90% of the activity happens at 14.076 MHz. (All are USB; more on this in Part II.)

Benefits of JT65A

JT65A on HF offers several benefits. It requires minimal transmit power, mak-

ing it suitable for highly portable stations, DXpeditions, and situations where running QRO (high power) might create interference and draw the unwanted attention and ire of neighbors or, worse yet, spouses. The vast majority of JT65A QSOs on HF are completed using less than 50 watts ERP.

Perhaps best of all, JT65A allows people whose living situations require the use of stealthy antennas to work some real DX! My first-ever confirmed contact with South Africa was made using JT65A from my home in northern California using 50 watts into a jury-rigged doublet made from TV twin-lead and 16AWG speaker wire, and hung out a second-story window. An apartment-dwelling friend of mine got started on JT65A by attaching an auto-tuner to a rain gutter on his building, a setup that allowed him to work a VK4 station from what normally would be a much-compromised location.

JT65A also allows operation in high-noise and high-QSB environments, because the redundancy provided by the forward-error correction allows nearly 80% of the transmission to be lost and still be decoded.

Hardware

Hardware requirements for JT65A are straightforward and no different from most other digimodes. JT65A uses an AFSK interface between your PC and rig. If you're already set up to run PSK31 via Ham Radio Deluxe's DM780 package, MixW, MultiPSK, etc., then you're good to go with one exception; you'll need a method for accurately syncing your PC's clock. PTT can be accomplished through either serial-port triggering or VOX. The only twist is that the accuracy of your PC clock will have a direct effect on your ability to decode and be decoded, and if you're more than a second or so off-sync, nobody will decode you and you won't decode anyone else. More about this in Part II.

Software

Operators wishing to try out the JT65A mode have several different software packages to choose from. The original WSJT package, originally coded by K1JT, is now an open-source project (under GPL license) that is maintained and enhanced by a small group of developers. To use JT65A you will want to obtain WSJT7, because as of June 2010, WSJT8 contains some new experimental modes such as JT64A and JT8 but does *not* contain JT65A. WSJT7 is available as a binary download for Windows® and a package for Debian-based Linux distros. If you're comfortable with compiling your own source code, it is fairly straightforward to get WSJT7 running on FreeBSD, Macintosh OS/X, and most other UNIX-like operating systems.

In 2008 Joe Large, W6CQZ (now W4CQZ), branched off from the main WSJT codebase and developed the JT65-HF software package (fig. 5). JT65-HF (information on downloading and operation can be found at <http://tinyurl.com/JT65-HF>) is intended, as the name implies, to be used on HF and as such only offers JT65A (it does not offer wider-bandwidth submodes JT65B for VHF or JT65C for UHF; FSK441 for Meteor, WSPR, and so on, the modes that are part of WSJT7). However, JT65-HF offers several enhancements such as simultaneous decode of all signals in a full 2-kHz passband, a real-time client that reports the decoded "captures" from the waterfall to a DX cluster and/or a reception logging system, automatic soundcard rate calibration, and the ability to query your rig's dial frequency via Ham Radio Deluxe, OmniRig, or DX Commander.

Patrick, F6CTE's MultiPSK application also offers JT65A. However, MultiPSK is commercial (versus WSJT and JT65-HF, which are free) and as such I have no experience with it. You are encouraged to experiment with the various software packages and determine which is best suited for your operating style.

Regarding the requirement to keep your PC clock synchronized: If your station is at home, and you have internet access, then you should use a time sync client such as Dimension4 or Symmtime. Both are free and readily available online. The reason you want this is that the built-in time-sync feature in Windows XP/Vista/7 is *not* accurate enough to allow proper JT65A operation; you should disable it and use a dedicated sync client. If you don't have internet access at home, or are working rover/portable, then you might consider using a GPS dongle together with a software package that locks the PC's clock with the time signals received via GPS. (Many GPS vendors provide a small software utility with the GPS which will do just that, but I've also used the UI-View32 APRS software package which can link up with many GPS dongles and adjust your PC's clock.) If you're in a pinch, on a tight budget, and still want to work JT65A, you can try syncing to the WWV tones from NIST in Boulder, CO or other shortwave sources. F6CTE's MultiPSK package comes with a WWV clock receiver application (clock.exe), but bear in mind that PC clocks tend to drift a lot even during a short period of time, so you'll have to tune back to WWV and readjust your clock about every 30 minutes. For best

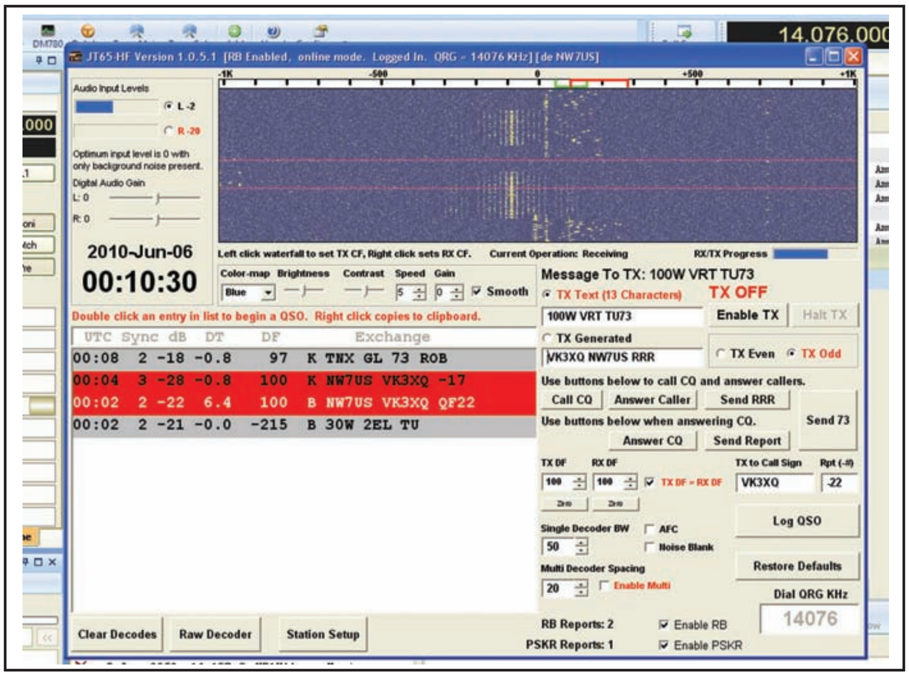

Fig. 5– The window of the JT65-HF software showing the waterfall capture of the JT65A digital signal of VK3XQ and the "captures" of the QSO between VK3XQ and NW7US. (Source: NW7US, using the JT65-HF software)

performance you'll want a GPS dongle; these can be purchased online for about US$30.

Reverse Beacons and Propagation Maps

One of the enhancements offered by JT65-HF is the reporting in real-time of decoded messages to both a DX cluster and a reception reporting system, often referred to in the JT65 community as a "reverse beacon." Those familiar with the automated DX cluster reporting in Alex, VE3NEA's CW Skimmer, or the ability of DM780 (part of Ham Radio Deluxe) to upload PSK31 decodes to Phil, N1DQ's excellent *PSKReporter*, will quickly grasp the value of this feature; every person running JT65-HF can effortlessly become part of a worldwide network of monitoring stations that report their decoded messages to a web-based server for use by the amateur community (fig. 6). The PSKReporter website is at <http://pskreporter.info>.

The data provided by automatic collection/aggregation of reverse beacons from JT65A users around the world, combined with the ability of JT65A to decode signals approaching the Shannon-Hartley limit, has been very valuable in showing that propagation often exists where common sense says it shouldn't—such as 40-meter and even 80-meter openings that occurred nightly for almost a week last winter around 0700Z between South Africa and the western USA. It also provides a method for visualizing worldwide propagation of JT65A messages via maps such as those provided by PSKReporter. Call CQ and within a minute or two you can check the map to see just how far away you were heard! In addition to monitoring my propagation, I've used the worldwide reverse beacon network to do things such as compare the relative performance of antennas.

If you're looking for less visual and more detailed propagation data in a DX cluster style interface, then JT65A reception reports are also available via Laurie VK3AMA's HamSpots system, and via W4CQZ's website. W4CQZ's website also hosts a JT65A "chat-room" which features a live-updating list of reception reports displayed right on the page.

Using JT65A is not only interesting from the perspective of studying propagation on HF, but is useful for communication with DX stations around the globe which might not be possible using other protocols and modes. Often, JT65A users can work DX on bands where no other mode, including CW, is working at that time.

Coming Up in Part II

Next month, we'll dive into how to use JT65A in real-world communications. We will use the JT65-HF software as our example because of its features and because of the ongoing improvements being made by its author. Until next month, if you are adventurous and jump into this exciting area of weak-signal DXing, enjoy all that JT65A offers.

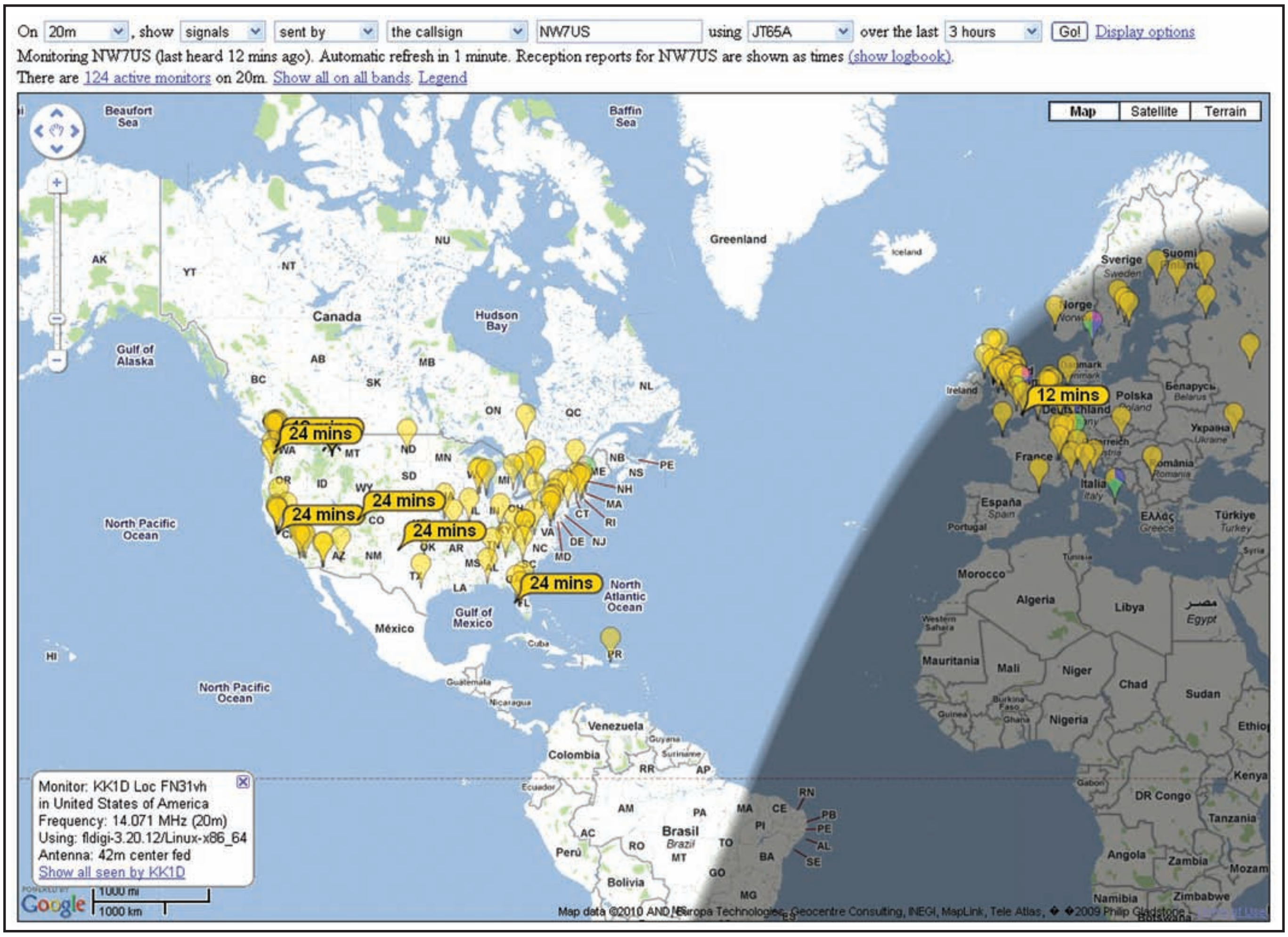

Fig. 6– The PSKReporter map showing the reception of the JT65A signal as sent by NW7US. The stations "hearing" NW7US (as a "capture" by the remote JT65A software) are shown with the time since NW7US was last heard. (Source: PSKReporter at <http://pskreporter.info>)