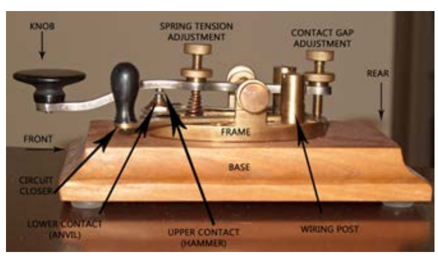
Data Collection from WWV, WWVH, and WWVB: A Histoanatomy (microscopic description) of NIST's Radio Beacon Transmissions

David Kazdan

Case Western Reserve University Department of Electrical Engineering
Case Amateur Radio Club W8EDU



PRESENTED AT:

ABSTRACT: THE NIST BEACON STATIONS AS "SIGNALS OF OPPORTUNITY" FOR IONOSPHERIC STUDIES

WWV's birthday cake for the official NIST centennial ceremony, 1 October 2019.

Dial (303) 499-7111 (Colorado) or (808) 335-4363 (Hawaii)! Listen to WWV or WWVH live!

The United States Department of Commerce's National Institute of Standards and Technology (NIST) maintains time- and frequency-standard radio transmitters in Colorado and Hawaii. All are at power levels and of adequate antenna efficiency for international reception. They transmit frequency and time-of-day information on internationally allocated frequencies and are directly connected to NIST atomic clocks. Frequency and time accuracy at the transmitters is on the order of one part in 10^{14}.

The design use of the system is different from its research uses, which are considered here: The shortwave signals of WWV and WWVH are sent in full-carrier, double-sideband amplitude modulation format. They are easily receivable by inexpensive shortwave radios using simple whip antennas. Such a receiver is adequate for providing time of day and laboratory-quality audio-frequency tones. An example is receiving accurate clock setting information for celestial navigation at sea. More sophisticated receivers can transduce the carrier frequency itself, providing part-in-10^7 accuracy without modification.

Similarly, the longwave signals of WWVB are sent in a combination of digital and phase-shift modulation with an encoding of time-of-day, day-of month, year, daylight savings time, and other information. Nearly all consumer "atomic clocks" self-set from these signals.

In research, the signals' distortion at point of reception is of interest. This poster describes various sub-parts of the signals--the overall "histoanatomy" of the transmissions--that might be used for making inferences about the atmospheric and ionospheric path from the transmitter to the receiver. Because their frequency and phase accuracy is so high at the transmitter point and because accurate time and frequency are distributed to receiving points by another method, the transmissions of the NIST stations may be used as reliable “signals of opportunity” for geophysical explorations. These uses of the signals are outside of their intended use and design, but are supported and encouraged by NIST.

Information may be found here about the modulation systems and structures of WWV, WWVH, and WWVB. We offer suggested uses of various signal components in a geophysical research setting. Examples will be cited of current use in ionosphere “sounding” through distant reception of the beacon signals. Signals available from the stations include their carriers, the AM binary time of day IRIG-H code (all three stations), second ticks, hour and day markers, and tone modulations (WWV and WWVH), plus the phase-shift time of day encoding unique to WWVB. (https://www.nist.gov/system/files/documents/2017/05/09/NIST-Enhanced-WWVB-Broadcast-Format-1_01-2013-11-06.pdf) (link is to a .pdf to be read on your device)

Please do correspond with us and with NIST about your uses of these signals.

Logo of amateur station WW0WWV for the WWV centennial event, on-site at the station 1 October 2019. Nerdstock! It was great fun.

AMPLITUDE MODULATION IS ANTIQUE. CAN IT REALLY BE USED FOR SCIENCE? AND WHAT'S THAT PHASE MODULATION DOING ON WWVB?

WWV and WWVH run AM! It's excellent for communications and measurement, despite FM being touted as "radio's second chance" in 1946 (https://worldradiohistory.com/BOOKSHELF-ARH/Business/Radio's-Second-Chance-Siepmann-1946.pdf) (scientific measurement wasn't Siepmann's topic, and broadcast AM's *content* was a mess). True, amplitude modulation dates back to the earliest days of radio communication. Even Morse code radiotelegraphy is AM--the signal is amplitude modulated on and off digitally by the telegraph key. For analog modulation, AM turns out to be among the modulation methods of choice for beacon monitoring (precise, wideband frequency-swept signals would be another good choice, but they are another story for other transmitters and another poster).

WWV and WWVH are classified as full-carrier, double-sideband AM, with FCC and International Telecommunications Union designation A3EG (The "G" designator means monophonic, broadcast-quality sound). This is the same as AM broadcast and international shortwave broadcast. Extensive technical information about the stations, their transmitters, and their modulations may be found in the station library. (https://www.nist.gov/pml/time-and-frequency-division/radio-stations/wwv/wwvwwvh-station-library)

(Note that the main amateur radio voice mode is J3E, single-sideband, suppressed carrier. It is more power-efficient than A3EG but has no transmitted frequency reference and is not suitable for WWV's purposes. It also would not work for the sort of data collection described here. The Canadian standards station CHU, operated by the Institute for National Measurement Standards of the National Research Council, uses H3E, single-sideband modulation with full carrier. It provides a useful data-collection signal across the north American continent from WWV Information on CHU may be found here: NRC shortwave station broadcasts (https://nrc.canada.ca/en/certifications-evaluations-standards/canadas-official-time/nrc-shortwave-station-broadcasts-chu) and Wikipedia on CHU (https://en.wikipedia.org/wiki/CHU_(radio_station)))

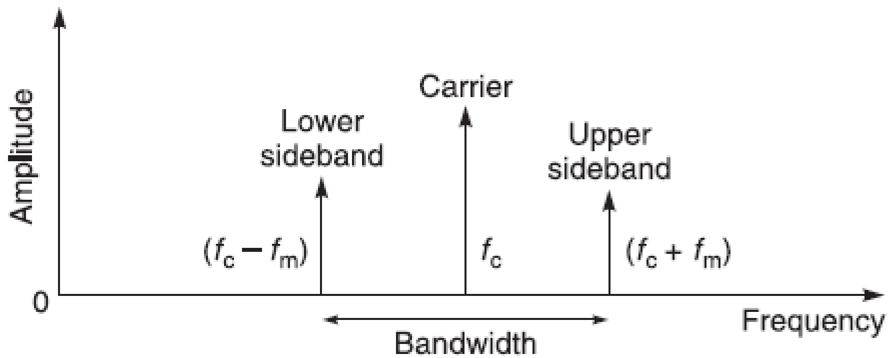
The distinguishing feature of an AM signal is its carrier. That's the "dial frequency" of an AM station. When your local broadcast station identifies itself as "1260 on your AM dial," the announcer means 1260 kilohertz for the carrier (by FCC regulation, plus-or-minus 20 Hz [200 Hz for broadcast FM, which is anounced in megahertz]). By the physics of A3E, the carrier will always contain at least 2/3 of the transmitter's total ouput power. For that reason, in broadcast audio it is considered inefficient--none of the music or speech is contained in the carrier, it's just going along for the ride and providing a frequency reference to the receiver for demodulating the transmitted information. It also provides an amplitude reference for the modulating content, facilitating automatic gain control and constant-volume output from a broadcast receiver. For research data collection, the constant power content of the carrier provides an advantage over more modern modulation methods:

The first advantage of A3E over other possible modulations is that the carrier has constant transmitted power and thus its signal strength is therefore a direct indicator of propagation. Noise distorts that measurement but it's the best available and is usually quite good. Additionally, if the transmitter is properly adjusted, the carrier is unchanging in frequency as well as amplitude. Such a transmitter is frequency stable and without phase noise; while perfection is hard to attain, real AM transmitters perform these functions well and NISTS, *very* well.

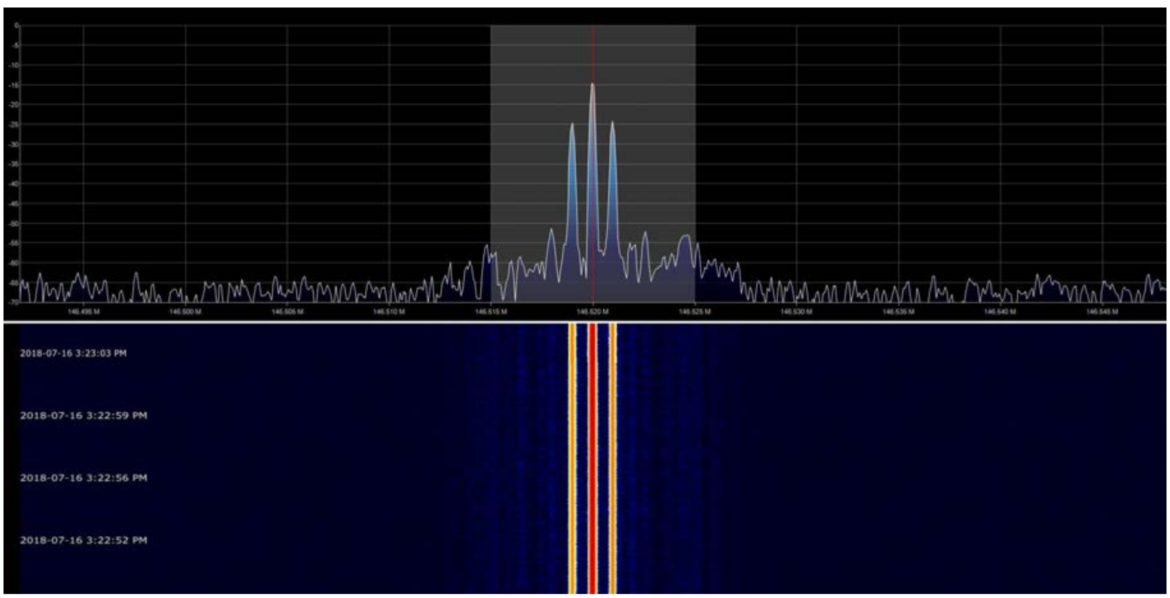
The modulations of AM multiply the carrier and produce a time-domain (oscilloscope display) waveform that looks like this:

The carrier is "squiggling" too fast in the envelope to be seen as anything but a haze, but the modulating tone is the symmetric sinusoid of the envelope's outside. The signal depicted in the stamp would be demodulated and sent to the radio's speaker to sound like a single, constant pitch.

In frequency domain, the spectrum of a carrier modulated by a sine wave looks like this:



Here is a "waterfall" image of such an AM signal, modulated by a 1000 Hz tone:



The spectral display above shows signal amplitude by frequency, with the two sidebands symmetric about the higher amplitude carrier; the time-frequency analysis below shows the unchanging nature of the signal as time unfolds from the top down, with amplitude color encoded.

The carrier isn't affected by the modulation. Transmitted audio silence sends the carrier by itself; the sidebands are set up by the modulation. The modulation sidebands add to the total power of the signal and are symmetric about the carrier (note that in the lower sideband, *higher* modulating frequencies map to *lower* sideband frequencies). The sidebands' form and symmetry around the carrier is what informs the receiver of what pitch, phase, and amplitude of audio signal to send to the loudspeaker.

WWV/H carriers may be received and scrutinized for data, *and so may the sidebands.* The lowest-frequency modulation is the 100 Hz binary time code, far enough from the carrier (in frequency) to permit isolated examination of the two.

Other panels in this poster describe the various modulating signals and the utility of each in ionospheric sounding.

WWVB at 60 kHz (in the low frequency band)has two layered encodings. The amplitude modulation duplicates WWV/H's time codes, sent as one frame of one bit per second data per minute. Superimposed on that is a phase-shift code, also for clock setting. The phase shifts make 60 kHz phase detection difficult although not impossible; that code does not affect field-strength (received amplitude) monitoring of the signal.

THE HEARTBEAT OF THE ELECTROMAGNETIC SPECTRUM: EXTRACTING DATA FROM THE SECOND "TICKS" AND THE AM BINARY TIME CODES (WWV, WWVH, AND WWVB)

A replica ship's radio room clock, showing the manditory silent times for radiotelegraph (green) and radiotelephone (red). Call SOS on 500 kHz Morse or 2182 kHz SSB at those times, should the need arise. (https://en.wikipedia.org/wiki/Radio_silence) This "atomic" clock is located at Case Amateur Radio Club station W8EDU.

This video gives a feel for WWV and WWVH live, as it might be delivered to your shortwave radio straight from the Heaviside layer:

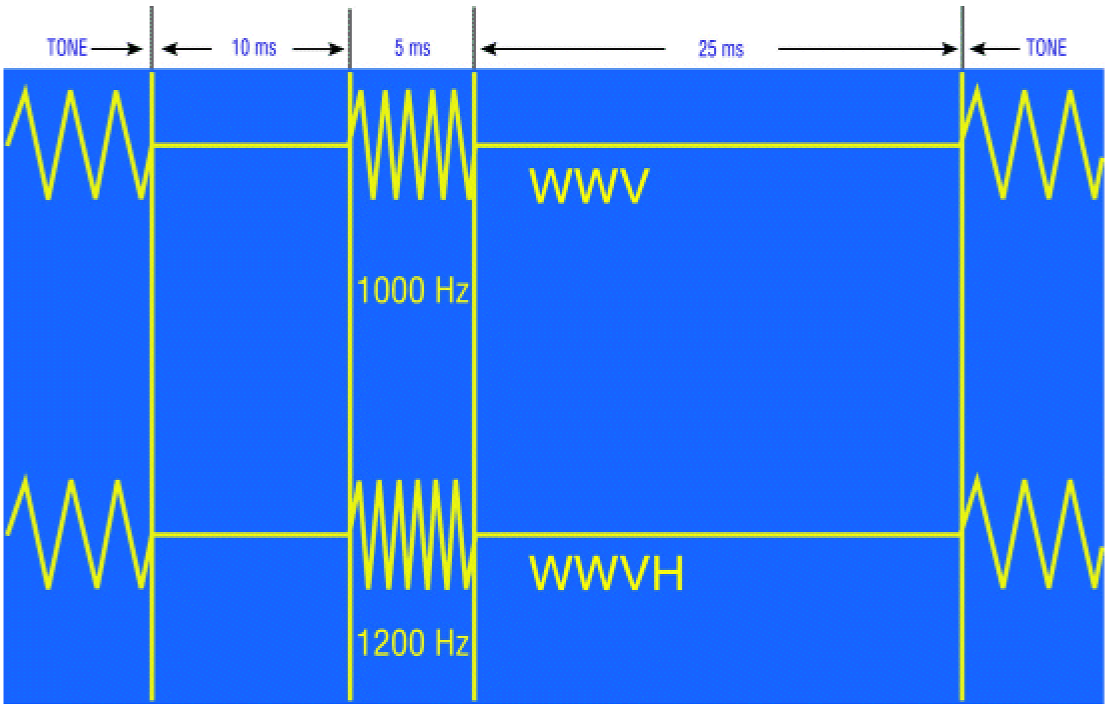
[VIDEO] https://player.vimeo.com/video/301546007?byline=0&badge=0&portrait=0&title=0

The second ticks are clearly heard, as are some modulating tones. The 29th second's tick is omitted. Listen closely for the female voice announcement from WWVH, then the louder male one from WWV. In this example, WWV is coming in much more strongly than WWVH but WWVH is audible. The second ticks from the two are separated by 200 Hz (here, 20% or a minor third); aurally, they are difficult to separate but they are easy to distinguish with instrumentation.

The second ticks from WWV and WWVH are an interesting target signal for ionospheric studies. From both stations, they are sent 100% modulated with silent guard times around them. They therefore have as much power as an AM signals's modulation can have: Each of the two identical sidebands is sent with 1/6 the power of the carrier, or about 8 dB down. They may be examined in a narrow bandwidth with minimum noise. Information about multipath propagation and about single-path delay may be extracted from examination of this portion of the beacon modulation.

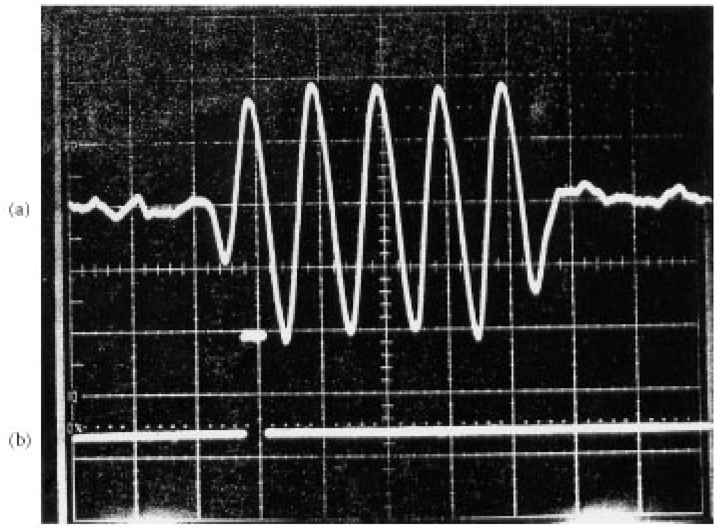
The second ticks from WWV and WWVH are separated in frequency and may be examined separately even if both stations are being received at the same time with equal strength. This contrasts with the carrier, which is the same frequency for WWV and WWVH; the received frequency is a linear combination of the received frequency of each considered separately, weighted by their relative received power.

The second ticks are, like everything else for the beacons' signals, carefully specified. WWV sends five cycles of 1000 Hz modulation to form the "click," while WWVH sends six cycles of 1200 Hz:



The guard silence of 10 milliseconds before and 25 ms after each click improves both aural and instrumented reception. The silence does disrupt reception of the audio tones, described in another pane.

Here is a demodulated second tick signal as recorded by Matthys 2004 (https://oxford.universitypressscholarship.com/view/10.1093/acprof:oso/9780198529712.001.0001/acprof-9780198529712-chapter-35). The top oscilloscope trace is from radio receiver's audio output. Notice that the first deviation from baseline may suggest a multipath reception: it is down instead of up, and that the last half-cycle is of dimished amplitude. The bottom trace is a locally synthesized top-of-minute pulse, derived from the received signal's first positive-going zero crossing.

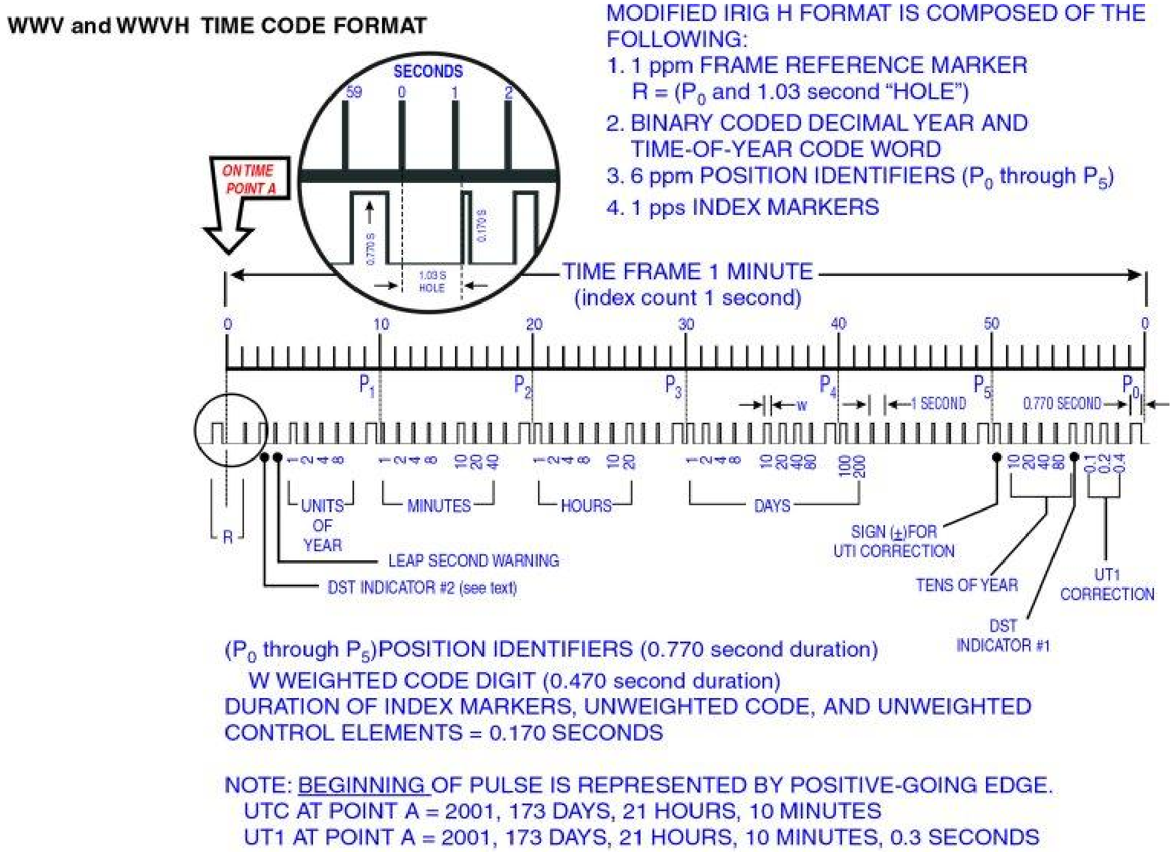


This trace's differences from the transmitted version suggest some imperfection in the communications channel. Those imperfections are in fact the object of the propagation studies.

Approaches to studying the second ticks include:

1. Counting zero-crossings. Normally 5 zero-crossings per tick are expected for WWV, and 6 for WWVH. More may be identified, which suggests multipath addition of signals with varying delays.
2. Signal beginning times, usually identified with a bandpass filter followed by a time-domain matched filter. When compared with a local GPSDO, the varying time delay from transmission in Colorado to the reception time will suggest the total "skip" path length. Compare this with the Doppler method, which identifies the rate of change of path length.
3. Combination of zero-crossing and (absolute) signal beginning times, which permit identification of delays and apparent Doppler shift due to multipath reception.

The time code subcarrier: Yet another data collection modality involves the binary time code, which is sent on a 100 Hz subcarrier on WWV and WWVH, and which directly amplitude-modulates WWVB (a different code phase-shifts WWVB). The code is a modification of the Inter-Range Instrumentation Group code (https://www.wsmr.army.mil/RCCsite/Documents/200-16_IRIG_Serial_Time_Code_Formats/200-16_IRIG_Serial_Time_Code_Formats.pdf) and is depicted here:



Its intended use is for self-setting clocks, such as the consumer-grade "atomic" clocks widely available at the $20-30US level. Those almost all use WWVB; a few clocks have been sold using WWV/H, most notably the Heathkit "Most Accurate Clock" which included an elaborate scheme for choosing the best-received WWV frequency and locking to it (it was the subject of one of the few patents Heathkit ever took out). It is described here (http://schaffrath.net/mac.html#:~:text=The%20Heathkit%20Most%20Accurate%20Clock%20II,%20Model%20GCW-1001,,by%20the%20National%20Institute%20of%20Standards%20and%20Technology.), and a quite extraordinary, multi-decade data collection system using it is due to John Gibbons N8OBJ, here (http://www.n8obj.com/Heathkit.html).

For data collection, the IRIG time code is quite an opportunity *via* matched filtering. The code may be taken to be a one-minute long, high-entropy pseudorandom code that should give exceptional precision for time alignment measurement when used with a matched filter. The measuring computer can recompute the matched filter ever minute, since the changing content of the code can be predicted from the computer's clock at the beginning of each frame. A disadvantage over monitoring the second ticks is that longer times would be involved, likely either 10 or 60 seconds. We do not have results yet to report on this but, well, check at the next HamSCI.

By the way, the IRIG code at 100 Hz is below the low-frequency audio cutoff of a "well-designed" communications receiver. They're not all well-designed, however, and the code is audible in the speaker output of many of them. Since the code's leading edge perfectly matches that of the seconds tick, the 100 Hz and 1000 Hz combination is a bit reminiscent of cardiac valve sounds in a stethoscope--and thus, together, form "the heartbeat of the electromagnetic spectrum."

The WWVB amplitude time code could be used similarly. The WWVB phase code, superimposed on the amplitude code, has possibilities, but these have not been explored, at least by us. The phase code is decoded partially by a purpose-built integrated circuit (http://everset-tech.com/receivers/) and implemented in some commercial clocks. (http://leapsecond.com/pages/ultratomic/) Carrier recovery could be performed with a Costas loop (https://en.wikipedia.org/wiki/Costas_loop) at 60 kHz or a squaring amplifier at 120 kHz; current work at W8EDU centers on the latter. A Tayloe detector (https://www.norcalqrp.org/files/Tayloe_mixer_x3a.pdf) is another possibility for creating a signal at soundcard frequencies which could be investigated in software.

THE AUDIO TONES: 500 AND 600 HZ, AND EVEN A-440 (WWV AND WWVH)

In its function as a calibrator for laboratory instruments all the way down to tuning forks, WWV transmits a schedule of three sustained audio tones over each hour. Each tone is sent for 45 seconds except the pauses for the second ticks. The schedule of 500 and 600 hertz tones is on the diagrams below. The tones are meant for verification of various oscillators in a physics laboratory,; they may even be used for the tuning of musical instruments. International Standards Organization standard number 16 places A on the treble staff (A above piano middle C, or A_4) at 440 Hz plus or minus 0.5 Hz, and WWV is the international source of that audio.

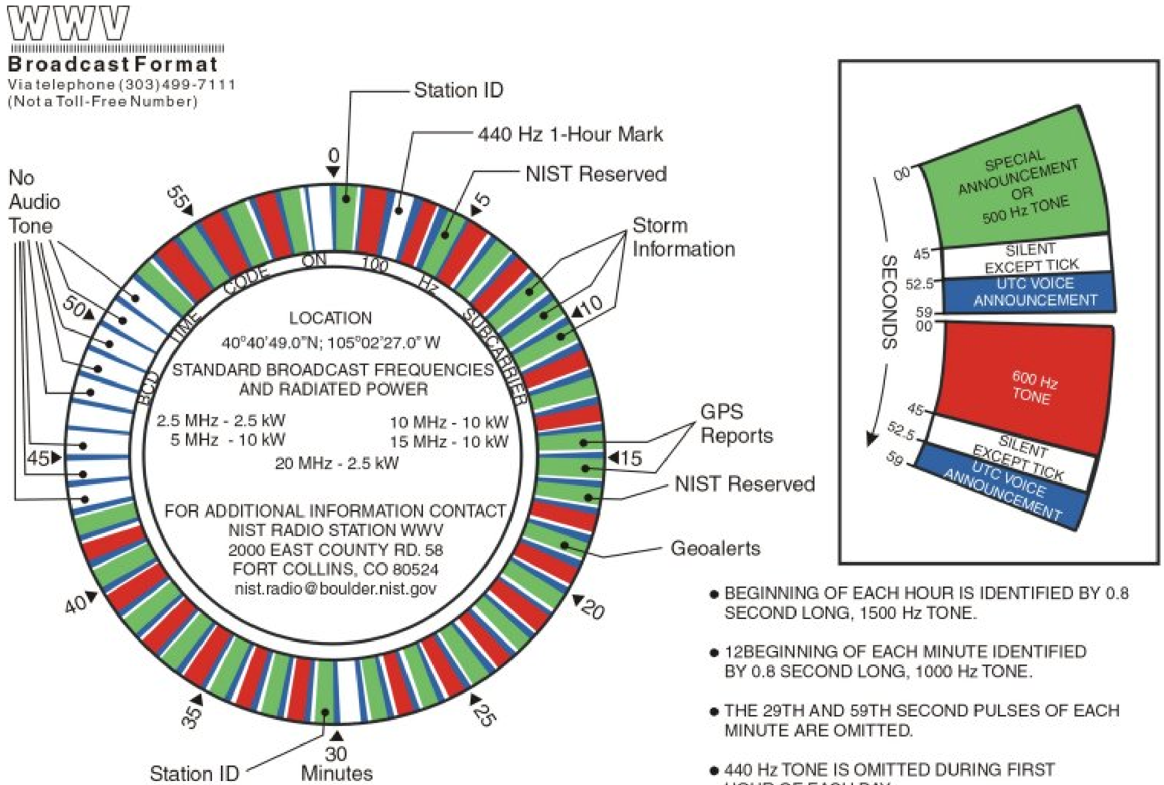
(On the stations' schedules, the 440 Hz tone is labeled as the "1-hour mark" (there is a separate 1500 Hz tone from both stations at the actual beginning of the hour) Musical A-440 is an ISO standard rather than SI and is so not an official, government function in the United States Note that the tone is omitted at the top of each UTC day, an inconvenience for orchestra rehearsals beginning at 7:00 PM EST. Radio amateurs who are also musicians forget this *once*. Their ensembles' oboists never forget)

These audio tones are carried as any other tones would be from an AM broadcast station. Turn on the radio, tune to WWV, and these tones come out of the speaker with atomic clock accuracy. Because the signal is sent full-carrier AM, the accuracy is "perfect" even if the receiver is not precise and the ionosphere is batting the signal about. That's advantage of old-iron AM for these purposes.

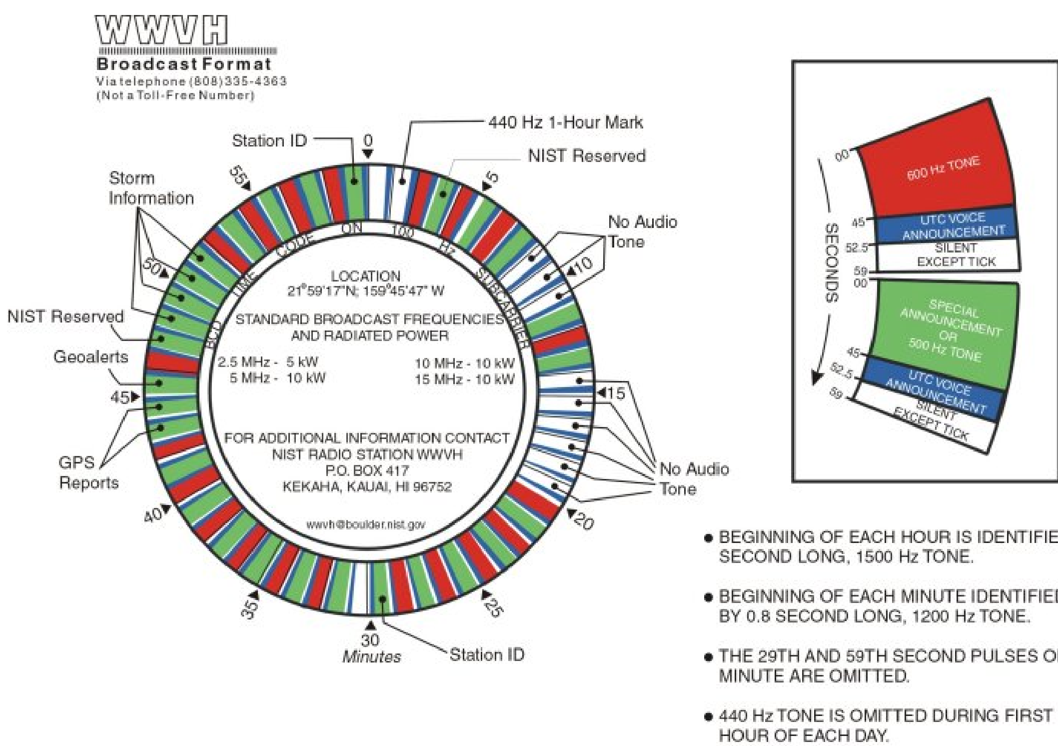
The carrier is the strongest part of the AM signal and never changes. It is very useful for examing signal path changes through frequency shift, BUT: WWV and WWVH use the same carrier frequencies (except for WWV's unique ones on 20 and 25 MHz). If one station is too weak at a given location to be received, the shifts from the other one may be measured, but that's not always the case. Even though WWVH's antennas are pointed west from Hawaii, its signal is sometimes comparable to WWV's even in the eastern US. Such is the ionosphere! Those cats in the Heaviside layer can be quite influential and quite fickle. Accurate carrier data collection is dependent on one station being stronger at the receive point than the other, so that the frequency shift of the dominant station may be examined in isolation.

When the two stations are of comparable strength, carrier examination is less useful. The two stations have a schedule of modulated tones, however, which show up as sidebands a frequency distance away from the carrier. They are separated in frequency from the carrier more than enough to be examined separately.

They are also separated one station's tones from another.



- BEGINNING OF EACH HOUR IS IDENTIFIED BY 0.8 SECOND LONG, 1500 Hz TONE.
- 12BEGINNING OF EACH MINUTE IDENTIFIED BY 0.8 SECOND LONG, 1000 Hz TONE.
- THE 29TH AND 59TH SECOND PULSES OF EACH MINUTE ARE OMITTED.
- 440 Hz TONE IS OMITTED DURING FIRST HOUR OF EACH DAY.



- BEGINNING OF EACH HOUR IS IDENTIFIED BY 0.8 SECOND LONG, 1500 Hz TONE.
- BEGINNING OF EACH MINUTE IDENTIFIED BY 0.8 SECOND LONG, 1200 Hz TONE.
- THE 29TH AND 59TH SECOND PULSES OF EACH MINUTE ARE OMITTED.
- 440 Hz TONE IS OMITTED DURING FIRST HOUR OF EACH DAY.

The tones are on a strict schedule, minute-by-minute over each hour. Not all minutes have any tone at all; some minutes are silent except for the second ticks, and some have voice announcements instead of the tones. But most do, and these graphics gives the schedules for WWV and WWVH. Note that the tones never overlap; none of the three tone slots of 440, 500 or 600 Hz is ever occupied by both stations at the same time. During the minutes that have 500 Hz from one, 600 Hz is transmitted by the other.

The nature of these modulation sidebands in AM is that the sidebands exist as independent radio signals spaced a precise frequency below and above the carrier's frequency. That frequency is the audio tone. They are of lower amplitude than the carrier and therefore will have lower signal-to-noise ratio, but their ionospheric distorition characteristics and short-term received amplitude changes may be followed just as the carriers' are. Summarizing the advantages and disadvantages of tone detection *vs.* over examinations of the carrier:

The carrier is of higher power and is sometines the only part of the signal that may be received.

The nonoverlapping 500/600 Hz tone schedule permits differentiatable between the two stations, and further permits distinguishing the relative strengths and frequency shifts/splitting of the two stations.

The tones are interrupted briefly each second for the ticks' guard interval. This removes 40 ms total from each second. Our measurements indicate that the frequency may be estimated fairly well with fldigi anyway, but the silence in each second does add to the noise.

Differential fading may be examined across the signal bandwidth by looking at the two carriers simultaneously. We haven't done any computations on this, the level of channel inhomogeneity is often apparent looking at the evolving spectrum on fldigi.

That carrier could be more apparent with a signal processing equivalent of an astronomer's averted vision (https://en.wikipedia.org/wiki/Averted_vision): differential examination of WWV and WWVH's carriers' frequency shifts with the variant phase-locked loop called the Costas loop (https://en.wikipedia.org/wiki/Costas_loop). The Costas loop locks a local oscillator on the arithmetic mean of two signals and was intended for carrier recovery in double-sideband suppressed carrier transmission. The circuit is now widely used in demodulating phase-shifted digital signals (it is one approach to demodulating WWVB's phase-shift code, for example). With a notch filter on the station's nominal frquency to (counterintuitively) *remove* the carrier, the loop oscillator would be able to lock on the two sidebands for the 500 and 600 Hz tones of WWV and WWVH differentially (each would require a bandpass filter). The loop's filter acts as a memory element in such a system, so the estimated carrier would be expected to carry well over the second ticks' guard times. If implemented in software, the hardware notch filtering might not be needed at all.

And speaking of audio: The voice announcements are identical in each transmission and are as phase-coherent as everything else in the sidebands. Matched filters to the two announcers' voices are in principle possible. Let us know when you get that working.

THE CARRIERS: WWV AND WWVH. WWVB, SORT OF BUT IT'S HARDER. AND A LAGNIAPPE*

For most research purposes, the AM signal's carrier is "where the action is." It is a stable sinusoid, of constant power and frequency independent of modulation (*pace* small nonlinearities in the modulation chain. The WWV engineering crew tends to those transmitters quite well). When the audio is silent, the carrier contains all of the transmitted power emitted from the station; when the microphone is on and at maximum (100%) modulation, the carrier still contains 2/3 of the transmitted power. Pure-tone modulations, however, occupy their own spectral territory. When they are playing, there's power in that part of the spectrum; when there not, there isn't. The relative contribution of WWV and WWVH *carriers* to their common spectral space may be inferred by examining the received power of the *separate modulation tones*. When conditions are poor enough that the carrier is detectable but the tones are not, it's usually a safe assumption that the nearer station is dominant. Information may then be recorded from the signal's received strength and in its instaneous received frequency.

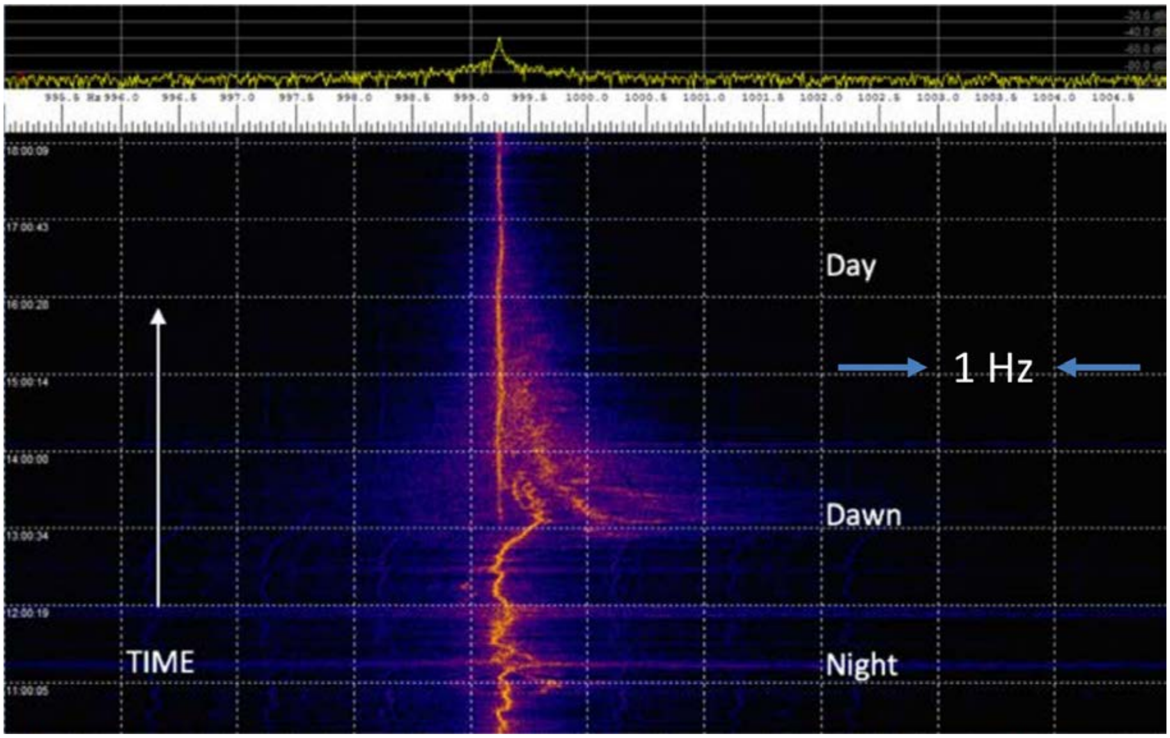
The core of carrier frequency measurements is having an accurate, stable local reference. In modern era, that is provided through the GPS constellation, with 10^{12} accuracy available in the $200US range. The launched WWV/H signal's accuracy is known good to 10^{14}, and the receiver's discrimination is nearly as good, so the frequency change enroute may be computed to suitable accuracy given the HF noise energy.

The mathematics of frequency estimation in noise is beyond the scope of this poster, but the most common approaches are

1. examining the phase slip of the signal as compared with the reference over a specified time and integrating the phase change to frequency change from nominal, and
2. collecting a sampled epoch of data, performing a discrete Fourier transform, and examining the maximum likelihood estimator of signal frequency by any of several methods. For signals expected to be a single frequency in noise, the Tsui and Reisenfeld algorithm (https://opus.lib.uts.edu.au/bitstream/10453/5785/1/2006005592.pdf) is in fldigi, robust, and well-verified (pdf linked, download to your computer).
3. For signals that are not anticipated to be single-frequency, the MUSIC algorithm can be made to work. Statistical tests of multimodality generally have not worked well; automated checking for multipath, multi-Doppler distortion has been difficult.

The software package fldigi by W1HJK and collaborators is most commonly used but several other excellent packages exist. In fldigi, the "analylsis" mode uses the time-domain method, and the "FMT" mode uses the Tsui and Reisenfeld algorithm.

Examination of the signals' finer frequency structure, such as multipath, multi-Doppler splitting during earliest morning illumination of the upper ionosphere, is mostly a manual task. Using variable-scale discrete Fourier techniques, Steve Cerwin (see Cerwin 2018 (https://hamsci.com/sites/default/files/publications/2018_QEX_Cerwin_Eclipse) for extensive looks at the signal during the 2017 solar eclipse). has found such splitting using SpectrumLab (https://www.qsl.net/dl4yhf/spectra1.html):

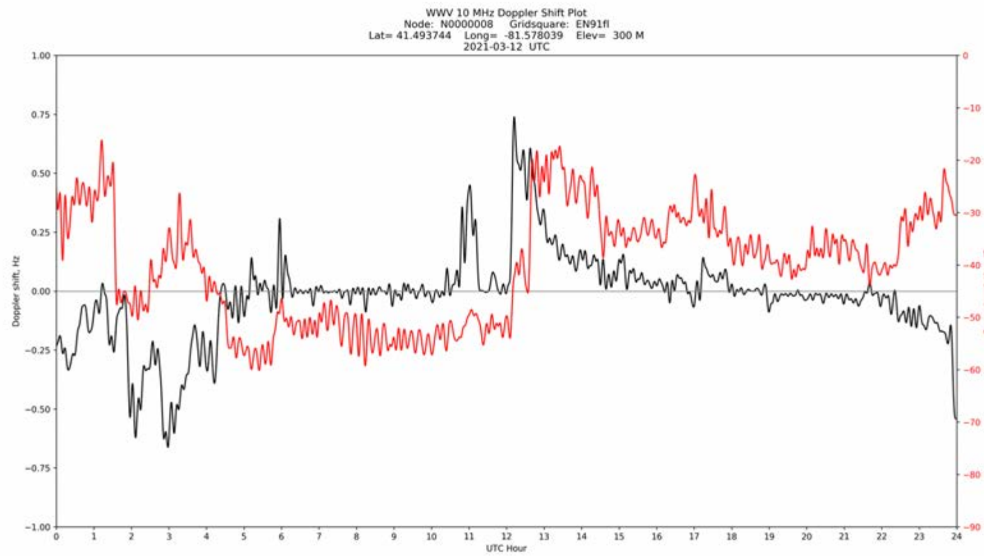


Sunrise transitions WWV's 5 Mhz carrier from turbulent (bottom) to split, to stable (top), as received one morning in eastern Texas. Data epochs of 10 to 1000 seconds provide frequency resolution of 0.1 to 0.001 Hz for these studies.

The WWVB carrier is harder to use for frequency monitoring than its MF and HF brethren, and distinctly harder than it was prior to 2012. That year, a phase modulation signal was layered on top of its amplitude modulation.
WWVB sources a signal of customary NIST excellence at 60 kHz, amplitude modulated with a one bit-per-second time code similar to the modified IRIG-H used on WWV and WWVH. The modulation is not 100%, so even during the >500 ms intervals between codes, there is enough carrier for lock and measurement. The problem is: There is a newer second time code, which uses phase modulation instead of AM. The phase system provides considerable enhancement to so-equipped clocks without altering the function of older, simpler clocks that use the AM code, but that phase-shifting makes tracking the 60 kHz carrier impossible with simple phase detecting receivers. Passing the signal through a squaring amplifier and reading the resulting 120 kHz signal solves the problem, but at the expense of greater receiver complexity. The code system is described here (https://www.nist.gov/system/files/documents/2017/05/09/NIST-Enhanced-WWVB-Broadcast-Format-1_01-2013-11-06.pdf) (.pdf); a well-designed receiver due to John A. Magliacane, KD2BD is here (http://www.arrl.org/files/file/QEX_Next_Issue/2015/Nov-Dec_2015/Magliacane.pdf) (.pdf). W8EDU is working on a simpler receiver that discards amplitude information; watch this space for results.

The fldigi software package remains the standard-bearer of citizen-science frequency estimation. Its "FMT" algorithm is named for its use in the American Radio Relay League biennial Frequency, Measuring Test, a contest of competitive metrology much beloved by the shortwave community. You may enter the fray: The potential for nerd glory is well worth an attempt at measuring a stable but unknown signal far off in the distance, distorted by the overhead electron ocean of the ionosphere. Current winners generally report measurements of 3.5, 7, 10, or 14 MHz amateur-band signals within 0.1 Hz and sometimes with 0.01. All entries are welcome, however, with about 150 professional and amateur metrologists entering each round. The next FMT (https://fmt.arrl.org/) will be Thursday evening 8 April (9 April 2021UTC). General information about the contest may be found here (http://www.k5cm.com/), thanks to Connie K5CM. If you're interested in transmitting the unknown and "being the Connie," let us know, we'll put you in touch with event organizers.

A feature of the T&R algorithm is that it reports signal relative amplitude without additional processing. Here is a sample graph from station AD8Y showing one UTC day of WWV 10 MHz as received in northeast Ohio:



The red graph is received signal strength, the black is frequency shift from nominal. Measurements are on 1 second epochs and no attempt is made to discern multiple frequency components within the narrow estimation band. The mid-UTC-day positive doppler shift and strength increase is around the time of local sunrise, when the ultraviolet-supported layers of the ionosphere are forming. Local sunset in this graph is around 0100 UTC.

For WWVB, most efforts center around received signal strength measurement. The phase-shift modulation has made 60 kHz phase monitoring impossible, and few amateurs have taken on the task of 120 kHz signal recovery for the purpose. A description of the Eclipse Mob project for monitoring WWVB signal strength during the 2017 total solar eclipse may be found here (https://www.nist.gov/blogs/taking-measure/weird-signals-listening-eclipse). A new effort is planned for the 2024 eclipse.

It's also worth noting that older WWVB literature may be misleading. There were phase measurement systems that used the 60 kHz carrier before the phase shift modulation was installed. Tracor made some of the more heroic ones (https://www.glkinst.com/test-equipment/manuals/Tracor900A.pdf), which included chart recorders so that the crystal local oscillator's phase could be compared with WWVB's, LORAN's, or other standards stations. Spectracom made similar units. (https://www.orolia.com/sites/default/files/document-files/8163_manual.pdf) These do not work any more. They especially do not record the "station ID" of WWVB, a 45 degree phase shift sent for five inutes each hour. This was added for east coast US users to distinguish the stations signals from those of MSF in Rugy, England. The station is now identified by the modulation itself; the previous system was referred to as "a bear marking its territory" for those accustomed to a Morse ID. It provided a chart recorder notch once each hour. Again, it is not longer transmitted and will not be received. Those receivers are fairly cheap on Ebay. From an ad there: "Note, these are no longer compatible with the current WWVB protocol so will require modification to work. I'll leave that to you." On the other hand, where there's a will, there's a way. (http://maxmcarter.com/rubidium/2012_mod/)

[VIDEO] https://www.youtube.com/embed/sdCLNtXDJb8?rel=0&start=225&fs=1&modestbranding=1&rel=0&showinfo=0
This video shows off the time-frequency analysis of the carrier, the IRIB time code 100 Hz symmetric about the carrier, and the time ticks. The special centennial voice announcement is also in this clip. The recording was made on-site at the transmitters and is so nearly noise-free.

Older voice announcements and the old high-seas severe weather reports. WWV continues to have a secondary official function as a civil defence broadcaster. (https://www.kunc.org/news/2019-10-01/how-a-little-known-radio-station-in-fort-collins-might-one-day-save-the-world)Note that i 1972, UTC hadn't been defined yet; the times here are in GMT, the older system of standardized time.

[VIDEO] https://www.youtube.com/embed/tP42qAiEY5I?rel=0&fs=1&modestbranding=1&rel=0&showinfo=0

and of course, the lagniappe. Thanks for spending time reviewing the poster.

[VIDEO] https://www.youtube.com/embed/ijdK6LorE7I?rel=0&fs=1&modestbranding=1&rel=0&showinfo=0

Enjoy HamSCI! DE AD8Y

* Lagniappe: A New Orleans local word for an "extra." (https://en.wikipedia.org/wiki/Lagniappe) Aren't you glad you scrolled down here? From Mark Twain's *Life on the Mississippi*:

We picked up one excellent word—a word worth travelling to New Orleans to get; a nice limber, expressive, handy word—"lagniappe." They pronounce it lanny-yap. It is Spanish—so they said. We discovered it at the head of a column of odds and ends in the Picayune, the first day; heard twenty people use it the second; inquired what it meant the third; adopted it and got facility in swinging it the fourth. It has a restricted meaning, but I think the people spread it out a little when they choose. It is the equivalent of the thirteenth roll in a "baker's dozen." It is something thrown in, gratis, for good measure. The custom originated in the Spanish quarter of the city. When a child or a servant buys something in a shop—or even the mayor or the governor, for aught I know—he finishes the operation by saying—"Give me something for lagniappe."

The shopman always responds; gives the child a bit of licorice-root, gives the servant a cheap cigar or a spool of thread, gives the governor—I don't know what he gives the governor; support, likely.

When you are invited to drink, and this does occur now and then in New Orleans—and you say, "What, again?—no, I've had enough;" the other party says, "But just this one time more—this is for lagniappe." When the beau perceives that he is stacking his compliments a trifle too high, and sees by the young lady's countenance that the edifice would have been better with the top compliment left off, he puts his "I beg pardon—no harm intended," into the briefer form of "Oh, that's for lagniappe."

AUTHOR INFORMATION

David Kazdan, MD, PhD

Amateur radio AD8Y

Radiotelegraph Operator certificate T000000003

Assistant Professor (retired), anesthesiology

Adjunct Assistant Professor, electrical engineering

Faculty advisor, Case Amateur Radio Club W8EDU

Commercial pilot certificate ASEL, instrument-rated

Case Western Reserve University

Cleveland, Ohio, USA

ABSTRACT

The United States Department of Commerce's National Institute of Standards and Technology (NIST) maintains a system of time and frequency radio transmitters in Colorado and Hawaii. All are at power levels and of adequate antenna efficiency for international reception. They are responsible for transmitting frequency and time-of-day information on internationally allocated frequencies and are directly connected to NIST atomic clocks. Frequency and time accuracy at the transmitters is on the order of one part in 1014.

The signals are sent in full-carrier, double-sideband amplitude modulation format. The intended uses center on reception of the signals using shortwave radios of varying levels of sophistication. An example is receiving accurate clock setting information for celestial navigation at sea, for which a simple shortwave radio and short wire antenna is sufficient.

This poster will explore research uses of the signals. Because their frequency and phase accuracy is so high at the transmitter point, they may be used as reliable "signals of opportunity" for geophysical explorations. These uses of the signals are outside of their intended use and design, but are supported and encouraged by NIST.

This poster will provide information about the modulation system and structures of WWV, WWVH, and WWVB, and offer suggested directions for use of various signal components in a geophysical research setting. Examples will be cited of current use in ionosphere "sounding" through distant reception of the beacon signals. Signals available from the stations include their carriers, the binary time code (all three stations), second ticks, hour and day markers, and tone modulations (WWV and WWVH), and phase-shift encoding (WWVB).

REFERENCES

Adaptive… (nist.gov), on the phase-shift time of day code used by WWVB uniquely.