IonTV: Using WWV Timing Reference Signals to Observe Ionospheric Variation

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Central question in this presentation:

[Bill Liles]:
“Can reception of WWV time ticks be used as a low cost distributed ionospheric / space weather sensor?”

First:
• What is WWV?
• What do its time signals look like?
• Are they useful for remote sensing?
• How hard is it to process them?

[Samson et al., 1990]
NIST radio station WWV broadcasts time and frequency information 24 hours per day, 7 days per week to millions of listeners worldwide. WWV is located near Fort Collins, Colorado, about 100 kilometers north of Denver. The broadcast information includes time announcements, standard time intervals, standard frequencies, UT1 time corrections, a BCD time code, geophysical alerts and marine storm warnings.

2.5, 5*, 10*, 15*, 20, [25] MHz

* = 10 kW power

Synchronized to NIST time standards

NB: also WWVH from Hawaii, WWVB at VLF frequencies
What does WWV sound like?

Then
(Hallicrafters SX-110)

Now
(e.g. KiwiSDR)

Very familiar to hams, SWLs
WWV Time and Information on HF Frequencies

LOCATION
40°40'49.0"N, 105°02'27.0"W

STANDARD BROADCAST FREQUENCIES AND RADIATED POWER
2.5 MHz - 2.5 kW
5 MHz - 10 kW
10 MHz - 10 kW
15 MHz - 10 kW
20 MHz - 2.5 kW

FOR ADDITIONAL INFORMATION CONTACT
NIST RADIO STATION WWV
2000 EAST COUNTY RD. 58
FORT COLLINS, CO 80524
nist.radio@boulder.nist.gov

Station ID
440 Hz 1-Hour Mark
NIST Reserved
GPS Reports
NIST Reserved
Geoalerts

BEGINNING OF EACH HOUR IS IDENTIFIED BY 0.8 SECOND LONG, 1500 Hz TONE.

BEGINNING 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.
WWV Time and Information on HF Frequencies:
100 Hz subcarrier (Binary coded decimal)
Pulses always there, once per second

WWV and WWVH TIME CODE FORMAT

MODIFIED TRIG H FORMAT IS COMPOSED OF THE FOLLOWING:
1. 1 ppm FRAME REFERENCE MARKER
   \( R = (P_0 \text{ and } 1.03 \text{ second "HOLE"}) \)
2. BINARY CODED DECIMAL YEAR AND TIME-OF-YEAR CODE WORD
3. 6 ppm POSITION IDENTIFIERS (\( P_0 \text{ through } P_6 \))
4. 1 pps INDEX MARKERS

(P_0 \text{ through } P_5) \text{ POSITION IDENTIFIERS (0.770 second duration)}
W WEIGHTED CODE DIGIT (0.470 second duration)
DURATION OF INDEX MARKERS, UNWEIGHTED CODE, AND UNWEIGHTED CONTROL ELEMENTS = 0.170 SECONDS

NOTE: BEGINNING OF PULSE IS REPRESENTED BY POSITIVE-GOING EDGE.
UTC AT POINT A = 2001, 173 DAYS, 21 HOURS, 10 MINUTES
UT1 AT POINT A = 2001, 173 DAYS, 21 HOURS, 10 MINUTES, 0.3 SECONDS
Simulated WWV signal with 100 Hz subcarrier

(NB: carrier at 0 Hz is the subject of other talks)

Simulated 20 dB fade every 6 seconds
(you’ll see why later)
The real world

Fan dipole in W1PJE backyard
Time tick detection algorithm

WWV recording → Heterodyne -100 Hz → LP filter 10 Hz → Threshold detect → Matched filter → Edge location

Remove carrier offset using locked PLL (Dusenbury, Kerby-Patel) cf. 2019 URSI talk

BP filter center=100 Hz

Locate first few 100 Hz zero crossings after edge location

HDF5 file

WWV 10 MHz 2005-02-25 17:15:00.000000 UTC

https://github.com/MITHaystack/digital_rf
Time tick detection algorithm

- **Threshold detect**
  - (after -100 Hz mix, 10 Hz LP filter)

- **Matched filter**

- **Coincidence detector**
  - (reject spurious matched filter hits)
Pulse detect example
Statistical Results:
Simulated WWV
Matched filter detect
1 second edge variations
Fading effects on edge location
Statistical Results: Simulated WWV

2nd zero crossing after matched filter edge detect

1 second variations

Better.. Better..
Obtain some ground wave WWV transmissions

E. Miller, G. Bust [JHU/APL] field campaign near Ft. Collins, CO during January 2019 URSI meeting

“Liles errand”
Ettus N210 software defined radio, ARR preamp

Laptop recording (Linux, of course)

Power conditioning (mobile op)

WWV transmitting towers
WWV Ground Wave: Clean signal at TX

Note strong harmonics
(more cut off by plotting scale)
WWV Ground Wave Signal Statistics

(only envelope edge detections shown; remember they are ‘blurry’ if any fades occur)
Remember W1PJE’s back yard?

(Note: not the same time as WWV local collect)
Ionospheric effects on time tick variance?

NB: not the same collect time…

Typical ground wave (Colorado)  Ionospheric path (Massachusetts)

Ionosphere is having some kind of impact.
Now all we have to do is figure out what it means!
Summary

- WWV has potential as a simple ionospheric remote sensor
- Interesting signal detection problem
- But what do the results mean?
- Much more work needed…

Thanks for listening.
NOTE: This is a collective effort.

John Cameron Swayze says..