GPS in Ham Radio

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Hazel Park Amateur Radio Club
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GPS is Everywhere
Topics

- How GPS Works
- Amateur Radio Applications
- Experimenting With GPS
What GPS Tells You

- Latitude
- Longitude
- Altitude
- Speed
- Heading
- Time

... once per second
History

- 1978 – Navstar 1 satellite launched
- 1983 – Following KAL 007 incident, Pres. Reagan allows civilian use
- 1995 – GPS fully operational
- 1998 – Garmin Street Pilot introduced
- 2007 – FAA announces most ground-based navaids to shut down by 2025
- 2008 – iPhone 3S includes GPS
Topics

- How GPS Works
- Amateur Radio Applications
- Experimenting With GPS
HOW GPS WORKS
GPS System Segments

1- Satellite/Space Segment
2- Control Segment
3- User Segment

Master Station
Monitor Stations
Ground Antennas
GPS Process

1. The USAF tells each satellite its precise orbital parameters.
2. Each satellite sends precise timing signals and orbital information.
3. A GPS receiver decodes location and distance of 4+ satellites to find its latitude, longitude plus UTC time.
Satellites

- 31 satellites in 6 orbital planes at 12,550 mile altitude
- Circular 12-hour orbits
- Minimum 4 satellites visible anywhere on earth
- Usually 6 to 10 satellites visible
- Transmit on 1.575 GHz, 475 W EIRP
- Oldest launched 1997, newest 2016
Satellites in View
Block IIF Satellite

- About 8 x 7 x 7 ft
- Solar panels
  70 x 12 ft, 2 KW
- Weight 3750 lb
- Launched 2010-16
- 4 atomic clocks
- Additional civilian and military signals
Atomic Clocks

- Each satellite carries 4 atomic clocks
- Compensated for special relativity (speeded up)
- Compensated for general relativity (slowed down)
- Accurate received on earth
- Usually UTC ± 7 ns
Spread Spectrum Transmission

- 1575.42 carrier
- BPSK modulated
- 1023-bit pseudo-random sequence
- Repeats every 1 ms
- XORed with 50 BPS data stream
- Bandwidth ≈ 2 MHz
Spread Spectrum Reception

- IF signal S/N -20 dB
- Correlate with local replica PRN bit stream
- Recovered 1 KHz S/N +20 dB
- Also Doppler shift!
- Recover 50 BPS data
What the Satellite Sends

Every 6 seconds, each satellite sends a 300-bit message:

- Time stamp every 30 seconds
- Ephemeris every 30 seconds
- Almanac every 12.5 minutes
- Other data every 12.5 minutes
Satellite Orbit
Calculating Satellite Position

- Just solve these equations!

\[
\begin{align*}
\frac{da}{dt} &= 2 \frac{\partial R}{na \partial \lambda} \\
\frac{di}{dt} &= \frac{1}{na^2 \sqrt{1-e^2} \sin i} \left[ \cos i \left( \frac{\partial R}{\partial \xi} - \frac{\partial R}{\partial \eta} \frac{\partial \eta}{\partial \xi} + \frac{\partial R}{\partial \lambda} \right) - \frac{\partial R}{\partial \Omega} \right] \\
\frac{d\Omega}{dt} &= \frac{1}{na^2 \sqrt{1-e^2} \sin i} \frac{\partial R}{\partial i} \\
\frac{d\xi}{dt} &= \frac{\sqrt{1-e^2}}{na^2} \frac{\partial R}{\partial \eta} - \frac{\cos i}{na^2 \sqrt{1-e^2} \sin i} \frac{\partial R}{\partial \xi} + \frac{\xi^2 e^2 - \sqrt{1-e^2}}{na^2 e^2} \frac{\partial R}{\partial \lambda} \\
\frac{d\eta}{dt} &= -\frac{\sqrt{1-e^2}}{na^2} \frac{\partial R}{\partial \xi} + \frac{\cos i}{na^2 \sqrt{1-e^2} \sin i} \frac{\partial R}{\partial \eta} + \frac{1-e^2 - \sqrt{1-e^2}}{na^2 e^2} \frac{\partial R}{\partial \lambda} \\
\frac{d\lambda}{dt} &= n - \frac{2}{na \partial a} \frac{\cos i - \xi \frac{\partial R}{\partial \xi} + \eta \frac{\partial R}{\partial \eta}}{na^2 \sqrt{1-e^2} \sin i} \frac{\partial R}{\partial a} - \frac{1-e^2 - \sqrt{1-e^2}}{na^2 e^2} \left( \xi \frac{\partial R}{\partial \xi} + \eta \frac{\partial R}{\partial \eta} \right)
\end{align*}
\]
Trilateration

The distances from you to three satellites intersect at a point, giving your location on earth.
Distance to a Satellite

Let your coordinates be \( \{x, y, z\} \)

And \( \Delta x_s = x_s - x \)

e tc.

Then

\[
d_s = \sqrt{(\Delta x_s)^2 + (\Delta y_s)^2 + (\Delta z_s)^2} = c \Delta t_s
\]
Finding Your Exact Location

Solve these equations:

\[ d_1 = c(t_{t,1} - t_{r,1} + t_c) = \sqrt{(x_1 - x)^2 + (y_1 - y)^2 + (z_1 - z)^2} \]
\[ d_2 = c(t_{t,2} - t_{r,2} + t_c) = \sqrt{(x_2 - x)^2 + (y_2 - y)^2 + (z_2 - z)^2} \]
\[ d_3 = c(t_{t,3} - t_{r,3} + t_c) = \sqrt{(x_3 - x)^2 + (y_3 - y)^2 + (z_3 - z)^2} \]
\[ d_4 = c(t_{t,4} - t_{r,4} + t_c) = \sqrt{(x_4 - x)^2 + (y_4 - y)^2 + (z_4 - z)^2} \]

unknowns: x, y, z (location), t (time)
Shape of the Earth

- Planet Earth is slightly flattened
- A line through the equator is 25.6 miles longer than a line from pole to pole
- GPS accounts for this with WGS84 geoid model
- Used to convert 3-D coordinates to latitude – longitude – altitude
Location Accuracy

95% of the time - 50 ft.

Typical - 15 ft.
Location Accuracy

- Basic GPS (95%) – 50 ft.
- Basic GPS (typical) – 15 feet
- Non-consumer equipment ($$$$)
- Differential GPS – 10 feet
- Surveyor’s equipment – inches
Topics

- How GPS Works
- **Amateur Radio Applications**
- Experimenting With GPS
AMATEUR RADIO APPLICATIONS

- Location
- Time
- Frequency
APRS
APRS
Balloon and Rocket Tracking
Drone Autopilot
Finding Grid Squares

LocatorDroid Android phone app
Repeater Finder

- RFinder app
- $9.99/yr
Rigs with Repeater Locator

Icom ID-4100A, ID-5100A VHF xcvrs

- Have D-STAR repeater directory + GPS
- Can add FM repeaters + locations
GPS Clock
GPS Time for FT8 Operation

- FT8 needs time sync ± 1 sec
- PC with 20 PPM oscillator can drift by 2 seconds per day
- Windows synchronizes time only once per week!
- Most FT8 ops use NTP time sync
- What if there’s no internet while portable? (Field Day, wilderness)
What’s Good Enough?
GPS Time Server

- Use GPS + Raspberry Pi - < $100
- Configure NTP server software
- Connect to router
## Frequency Standards

<table>
<thead>
<tr>
<th>Signal/Device</th>
<th>Frequency Tolerance</th>
</tr>
</thead>
<tbody>
<tr>
<td>10 MHz WWV as received</td>
<td>2 PPM</td>
</tr>
<tr>
<td>Zero beat to 10 MHz WWV</td>
<td>20-30 PPM</td>
</tr>
<tr>
<td>Typical HF transceiver</td>
<td>20-50 PPM</td>
</tr>
<tr>
<td>Elecraft KTCX03-1</td>
<td>1 PPM</td>
</tr>
<tr>
<td>Received GPS clock</td>
<td>.1 PPB or better</td>
</tr>
<tr>
<td>GPS disciplined oscillator</td>
<td>.1 PPB or better</td>
</tr>
</tbody>
</table>
GPS Disciplined Oscillator

- Use GPS receiver pulse output as reference frequency

- Approaches:
  - KHz or MHz GPS output drives PLL
  - 1 PPS pulse gates programmable XO pulse count; software adjusts settings
  - 1 PPS pulse gates VCO pulse count; software drives VCO control voltage
WB0OEW GPS-Stabilized VFO
Topics

- How GPS Works
- Amateur Radio Applications
- Experimenting With GPS
EXPERIMENTING WITH GPS

- General Approach
- GPS Hardware
- Buying from China
- Arduino
- Books
- Starter Projects
Module Level Homebrew

Times have changed since Heathkits and Bud chassis...

<table>
<thead>
<tr>
<th>Traditional</th>
<th>Module Level</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discrete components, ICs</td>
<td>Boards and modules</td>
</tr>
<tr>
<td>Soldering</td>
<td>Wires and cables</td>
</tr>
<tr>
<td>Knobs</td>
<td>Buttons</td>
</tr>
<tr>
<td>Variable capacitors, potentiometers</td>
<td>Software</td>
</tr>
<tr>
<td>Indicators and meters</td>
<td>Displays</td>
</tr>
<tr>
<td>Junkbox</td>
<td>Mail order</td>
</tr>
</tbody>
</table>
GPS Modules

Get modules with

- uBlox-6, -7 or -8 series chip – or –
- SiRF chipsets
  (support for others may be spotty)

- PPS output
- NVM or battery backup RAM
- Option for external powered antenna
- Description for RC, UAV, drone, autopilot
GPS Module Connections

- Serial UART out/in – right side
- Hardware pulse 1/second (PPS)
- +3.3/5 v, Gnd
- Ext. antenna (IPX, lower left)
- USB – some units
Module Sources

- **Domestic**
  - Amazon (check which vendor)
  - Adafruit
  - Sparkfun

- **From Hong Kong/China via eBay**
  - Lower prices but 3 to 8 week delivery
  - Look at seller reputation
  - Beware low prices with high shipping
Typical China Prices (2017)

VK16E GPS module - $6.26, $8.36
GY-NEO6MV2 module + ant. - $4.93
Active GPS antenna, 3m cable - $3.02
SMA female to IPX female cable - $3.39
USB to serial TTL cable - $2.49
Arduino UNO clone - $6.09
16x2 character LCD w/backlight - $1.92
SPI serial adapter for LCD - $0.80
Amazon Prices (2019)

Geekstory GN-180 GPS module - $15.98
NEO6MV2 module + ant. - $11.95
Active GPS antenna, 3m cable - $10.95
SMA female to IPX female cable – $3.00
USB to serial TTL cable – $3.33
Arduino UNO clone – $11.86
16x2 character LCD w/backlight - $5.99
SPI serial adapter for LCD - $6.36
Typical GPS Output

Once per second:

RMC – Minimum nav data
VTG – Course
GGA – Fix data
GSA – Sats used & precision
GSV – Satellites in view
GLL – Geographic position
GRS – Range residuals
GST – Error statistics
ZDA – Time and date
GBS – Satellite faults
NMEA Sentence Example

$GPRMC,123519,A,4807.038,N,01131.000,E,022.4,084.4,230317,003.1,W*6A

Where:

RMC                    Recommended Minimum sentence C
123519                 Fix taken at 12:35:19 UTC
A                      Message status A=OK or V Void.
4807.038,N             Latitude 48 deg 07.038' N
01131.000,E            Longitude 11 deg 31.000' E
022.4                  Speed over the ground in knots
084.4                  Track angle in degrees True
230317                 Date - 23rd of March 2017
003.1,W                Magnetic Variation
*6A                    Checksum data, always begins with *
GPS Evaluation Software
Arduino
Project – ADS-B Receiver
Project – GPS Clock
Books

GPS For Dummies, by Joel McNamara
Pinpoint, by Greg Milner
GSM and GPS Projects With Arduino, by Marco Schwartz
Arduino Applied, by Neil Cameron
101 Spy Gadgets for the Evil Genius, by Brad Graham and Kathy McGowan
Arduino Workshop, by John Boxall
Web Sites

- www.n2yo.com/whats-up/
  - live tracking, choose GPS Operational
- www.rtl-sdr.com - look for ADS-B
- clearskyinstitute.com/ham/gps/
  - WB0OEW GPS disciplined VFO
- https://time.is - how accurate is your PC clock? (no www.)
Software

- Manufacturer Demo Software
  - uBlox – u-center
  - SiRF – SiRF Demo
  - Others – ???

- ADS-B reception
  - Dump1090 (Win, Linux), Cocoa1090 (Mac)
  - Virtual Radar Server
  -.adsbScope
  - PlanePlotter (about $30)
SUMMARY

- Over decades, GPS has gone from military navigation system to general navigation to everyday utility
- Ham radio can make good use of GPS location, time, and frequency
- Experimenting with GPS is easy and cheap
GPS in Ham Radio

Questions?