Global Positioning System (GPS)
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GPS Haiku

- In ultimate cold through solar wind you orbit, to warmth you guide me
- Wife says pull over, no clear view of satellites, ask for directions
- Batteries are toast, map compass reading not learned, I await searchers

Basic GPS Design

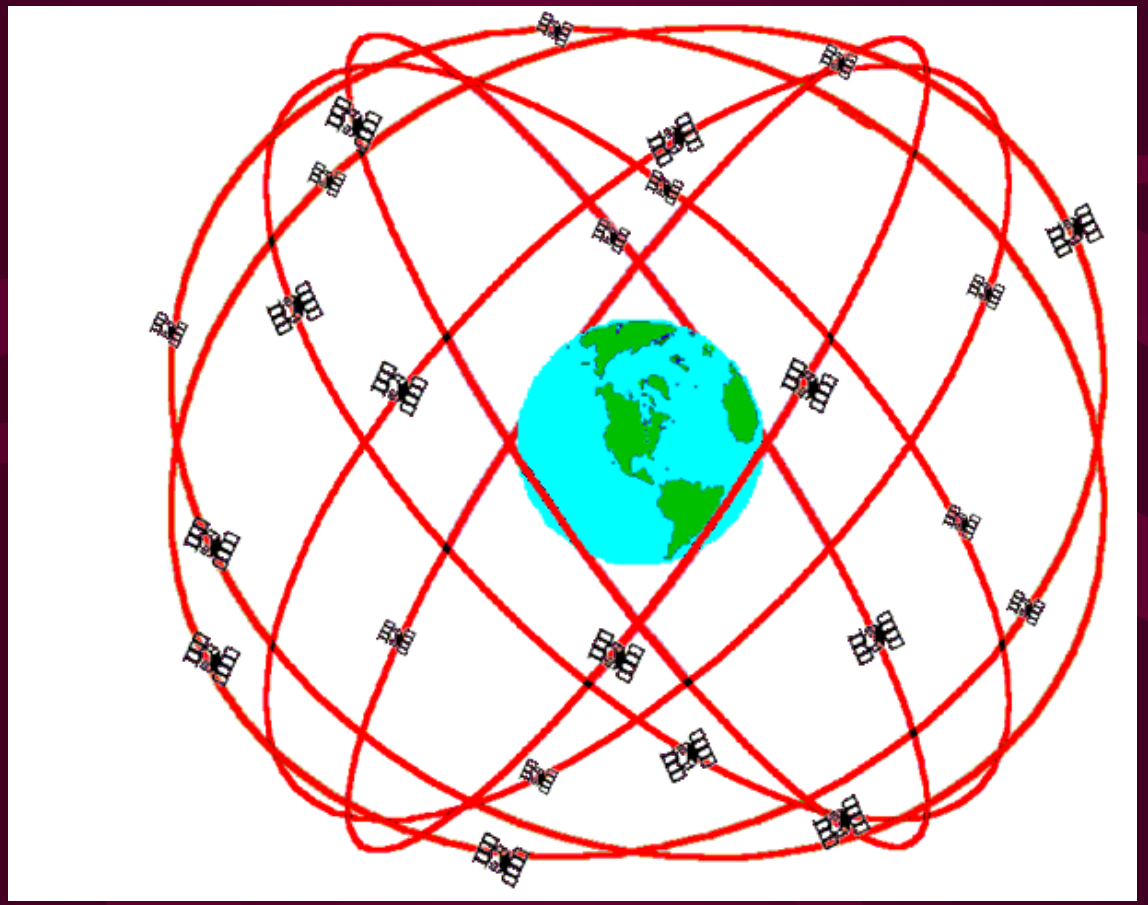
- GPS (DoD) with 24 active satellites, Glonass (Russian Federation) with only 11 active satellites, European Galileo (planning stage)
- GPS: Three segments - Space, Control, and User

  Space Segment: 24 satellites + 4 spares in 12 hour, 20,100 km, 55° orbits, four satellites in each of the six orbital planes

  Control Segment: Ground stations adjust satellite clocks, provide orbital parameters (almanac, ephemeris) for each satellite

  User Segment: GPS receivers provide navigational and time information to users. Strength of the received signal is only 1 billionth of a TV signal

GPS Satellite Orbits



Operating Modes

- Precise Positioning System (PPS) - US and allied military, authorized government agencies - 22 m horizontal, 27.7 m vertical, 100 ns accuracy (95% of time). Resistant to jamming (L1/L2)
- Standard Positioning System (SPS) - civilian use - 100 m horizontal, 156 m vertical, 340 ns accuracy with S/A, improved to nearly PPS values after May 1 2000 (L1 only)

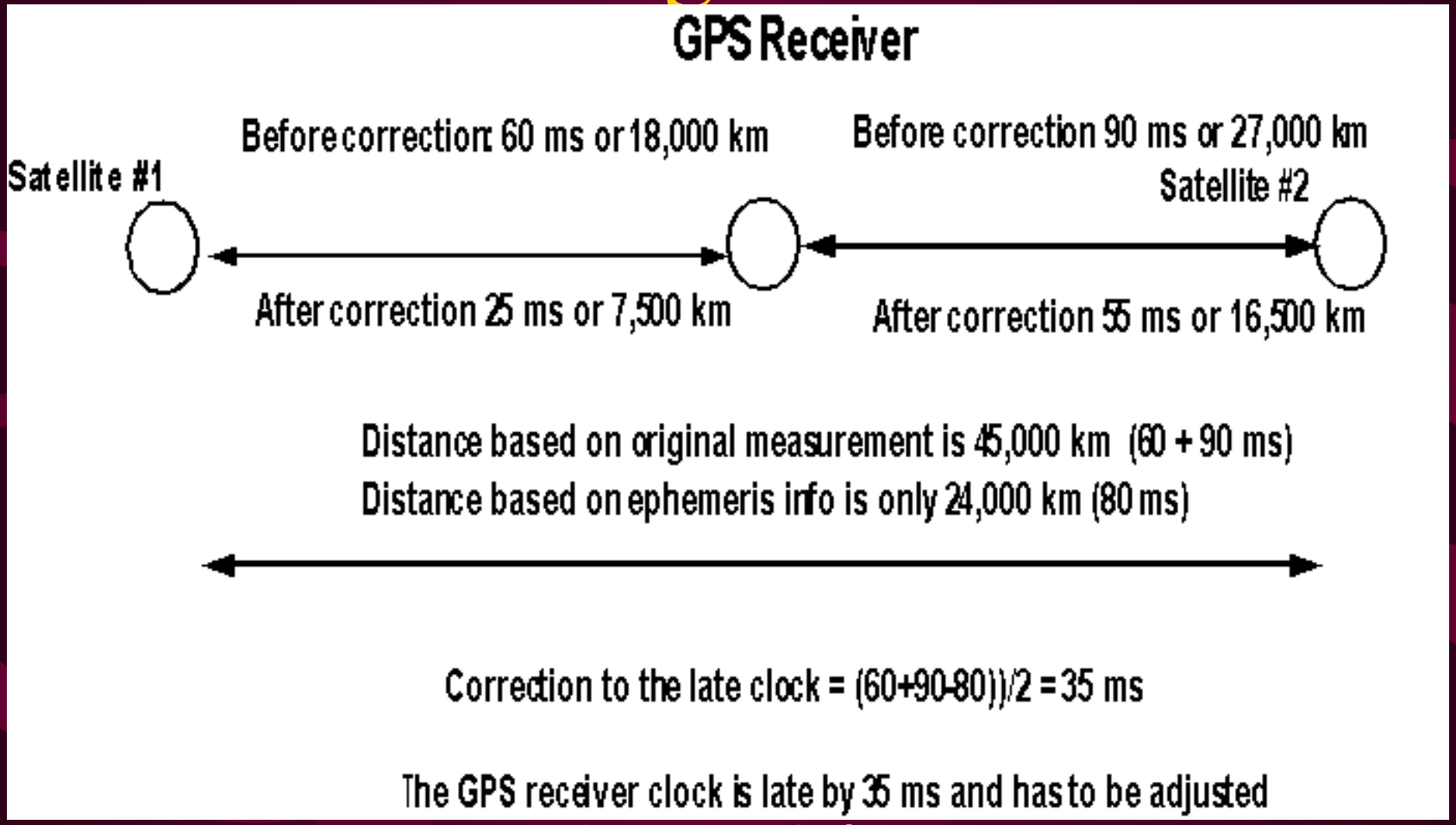
Operating Modes (cont.)

- Differential Carrier Phase for surveying with postprocessing - at least two receivers - sub cm accuracy
- Differential GPS (DGPS) - ground signal required - 1 to 5 m horizontal accuracy
- Wide Area Augmentation System (WAAS) - as of February 2004 implemented only in US with 25 ground stations and 2 geosynchronous satellites. Accuracy - 7 m vertical/horizontal

Determining Position on the Globe

- Almanac (status and clock information), ephemeris (orbital information) are broadcast to GPS receivers at same frequencies for each satellite (1.2 and 1.5 GHz, 20 - 25 cm)
- . Different ID codes used by each satellite - Timing information is based on satellite clocks
- Cesium/rubidium clocks - 1 sec in 300 years
- Triangulation by adjusting receiver clock: 1 μs = 300 meters.

Simplified Example of Linear "Triangulation"



Simplified Example of Linear "Triangulation"

- Example: Distance between 2 satellites (from ephemeris information): 24,000 km or 80 ms (c = 300,000 km/sec)
- Time difference: GPS to Satellite #1 (from almanac information) - 60 ms
- Time difference: GPS to Satellite #2 - 90 ms
- Conclusion:l clock in the GPS receiver is late by (90+60-80)/2= 35 ms
- Corrected time to Satellite #1: 60-35 = 25 ms or 7,500 km
- Corrected time to Satellite #2: 90-35 = 55 ms or 16,500 km
- 4 satellites required for 3D triangulation

Sources of Error

- Code noise, receiver noise, satellite clock - 1 m each
- Ephemeris data error, troposphere delay - 1 m each
- Unmodeled ionosphere delay - 10 m , multipath - 1 m
- Satellite constellation geometry - 10 m
- S/A (RIP) reduced horizontal accuracy from 22 to 100 m (95% of time). S/A was introduced in 1980 and discontinued at midnight on May 1, 2000 by order of president Bill Clinton
- Human and software errors can make GPS useless

GPS and Relativity Theory

- Special Relativity (SR): Clocks affected by satellite speed relative to earth frame of reference
- General Relativity (GR): Clocks affected by differences in gravitational field between satellites and receivers
- SR effects compensated by adjusting satellite clock divider ratios - different ratio for rubidium/cesium clocks on satellites and on earth
- A 48 page paper describing effects of relativity: http://arxiv.org/PS_cache/gr-qc/pdf/0306/0306076.pdf

Derived Navigational Information

- Lat/Lon in degrees, UTM, and in other units
- Local time, UTC, elapsed time, ETA, ETE, altitude
- Speed, heading, bearing (true or magnetic) all in land or marine terms (SPD/SOG, HDG/COG, VMG, Landmarks/Waypoints, etc.)
- Distance to destination, distance traveled
- “Bread crumb” trail

Types and Cost of GPS Receivers

- Hand-held, “watch”, car and boat mounted, PDA attachments ($100 - $1,000)
- Built into cars (OEM) with voice guidance, maps, street and address software with road lock, inertial navigation and DGPS ($1,000 - $3,000)
- For land surveys with Carrier Phase Comparison and post processing ($5,000 - $20,000)
- Military with PPS and S/A decryption ($???)

Portable GPS Receivers ($100 - $500)

Car Mounted GPS Receivers ($700 - $1,500)

- Magellan 700
- Door to Door guidance
- Voice output

Portable GPS Receivers ($100 - $300)

Etrex Summit, with electronic digital compass, barometer and altimeter, but as reported by many users has poor sensitivity

Integrated Pocket PC/GPS

Mitac Mio 168

Full featured Pocket PC

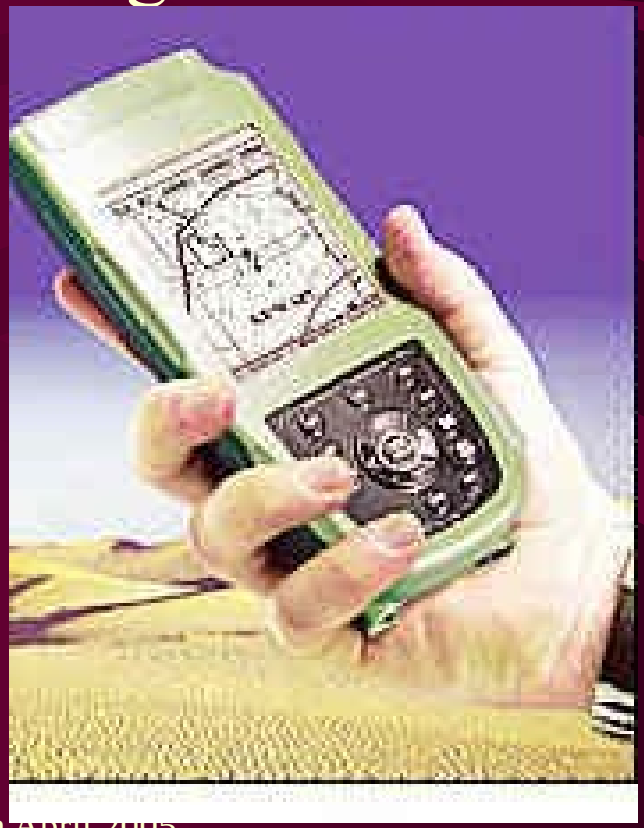
With integrated GPS

Main problem: after 4 hours

Of operation needs recharging

Military Units

- Plugger and 2 competing designs



Features in $100 - $1,000 Price Range

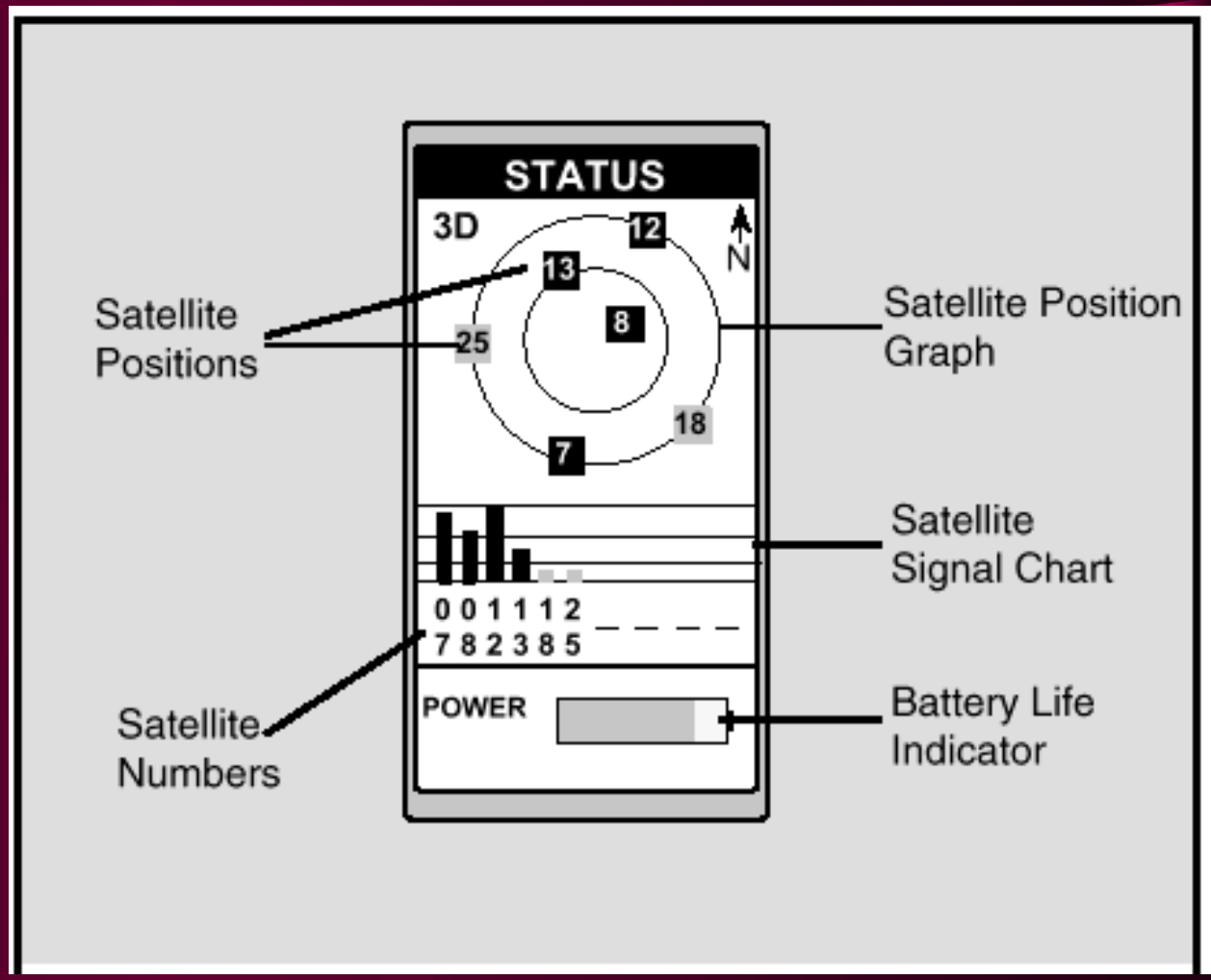
- Small manufacturers - Garmin, Magellan, Lawrence
- Marketing decides on feature sets and models
- Not much advertising - little awareness, except by boat owners and hikers
- Storing of waypoints, routes and tracks
- 8 - 15 display screens with context sensitive menus
- Color display, back light
- Depending on price range - user waypoints, city waypoints, fixed maps, maps on cartridges, maps downloadable from CDs, door-to-door voice directions

Additional Features in $100 - $1,000 Price Range

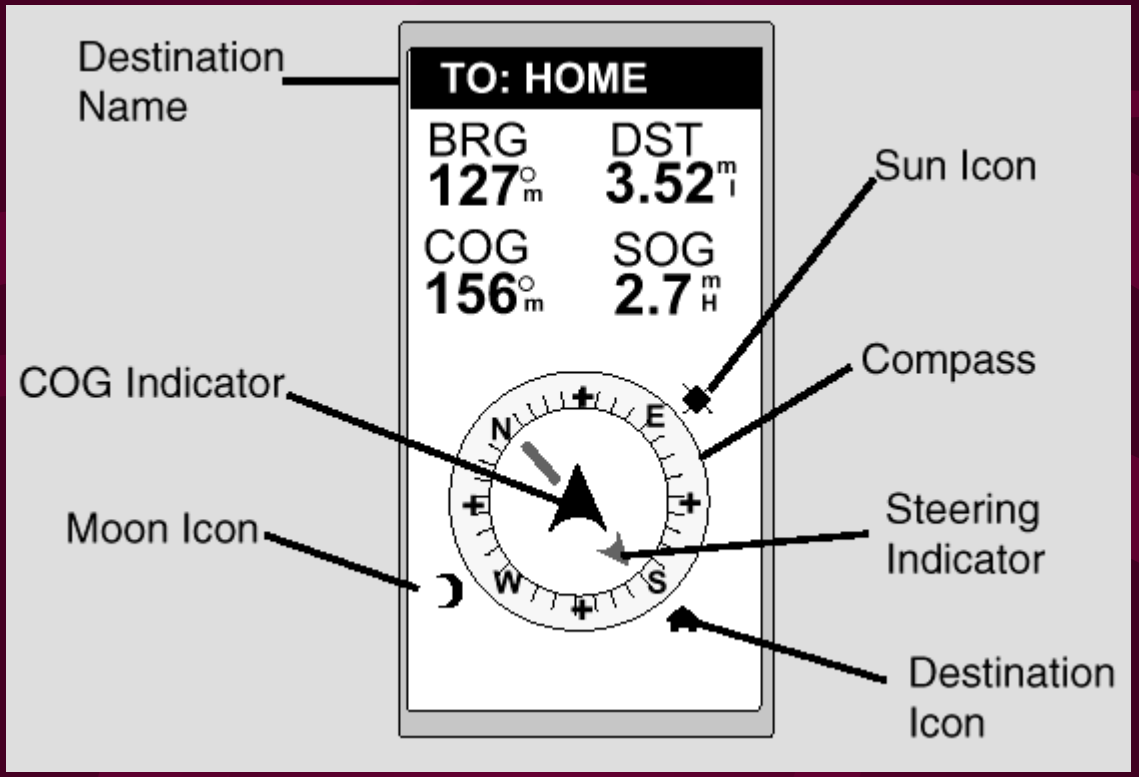
- Parallel input for up to 18 satellites vs. multiplexed input
- Selection of map datums, coordinate systems
- Simulation mode
- 100 - 1000 waypoints
- 10 - 50 routes with back tracking, MOB
- Sun/Moon rise and set, moon phase, dynamic display
- Wide range of scales on map display (0.1 - 1,000 mi)
- Proximity and other alarms

Satellite Status

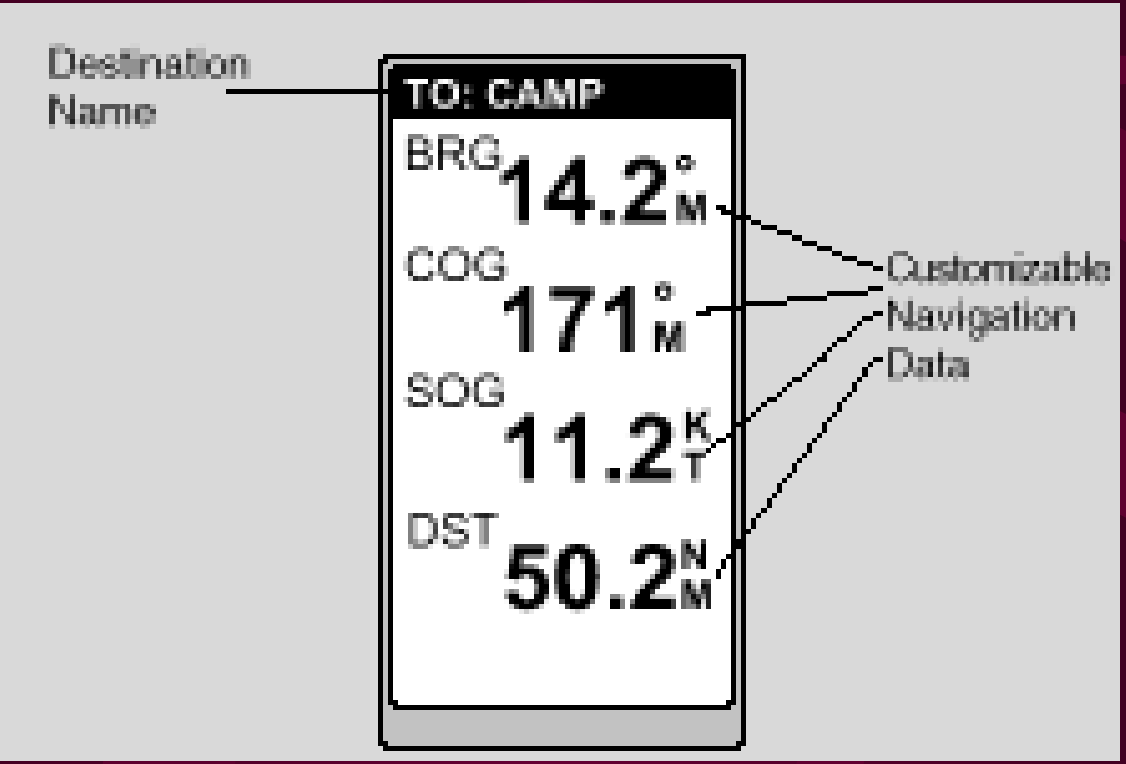
- 5,300 mi. horizon



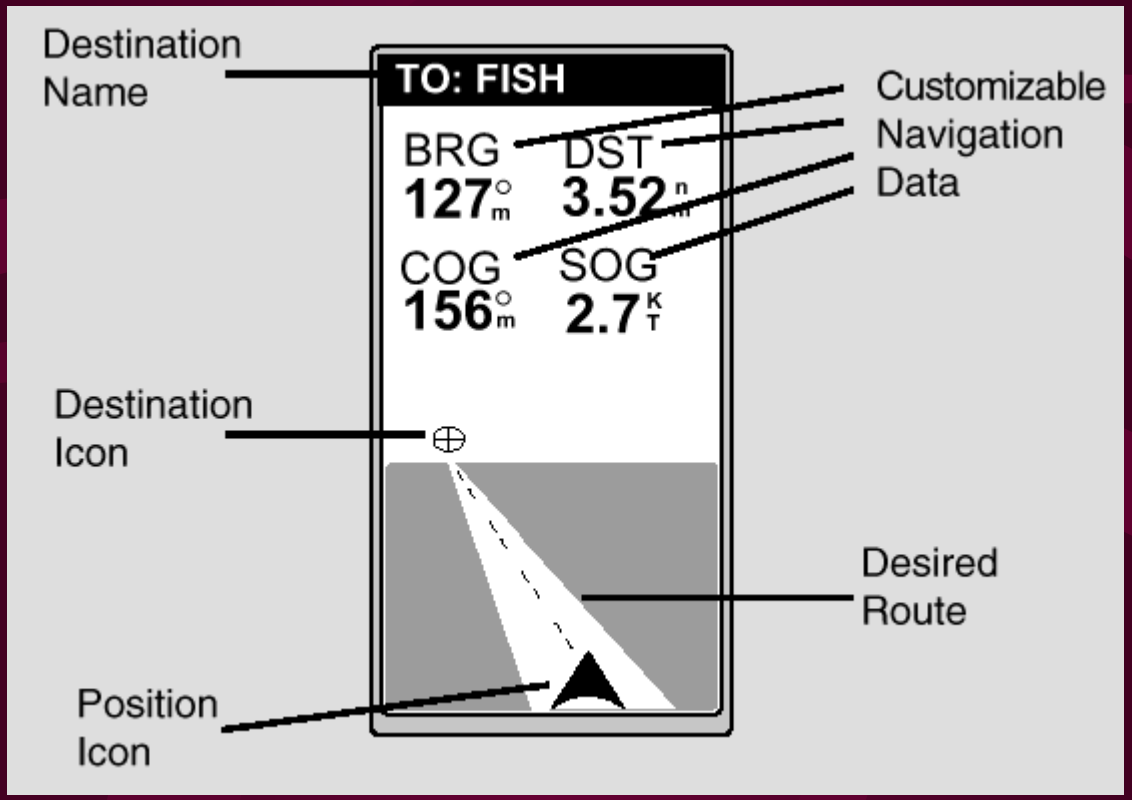
Compass Rose



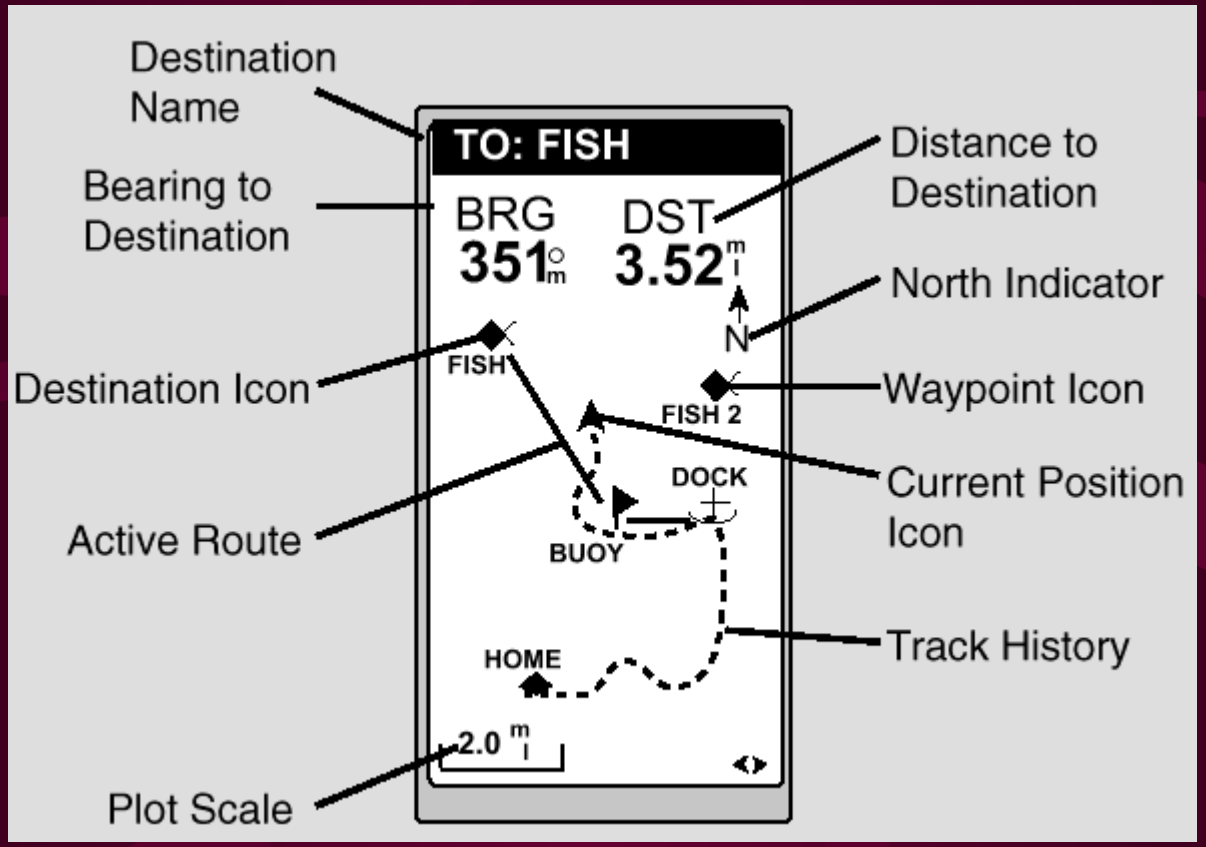
GoTo Large Screen



Alternate GoTo Screen

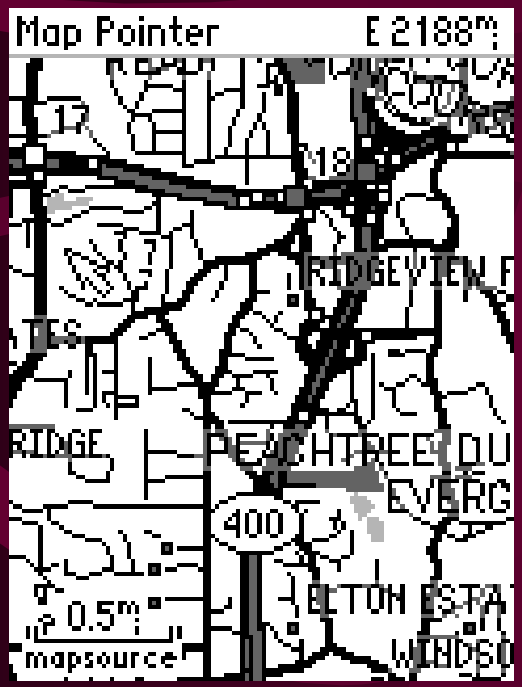


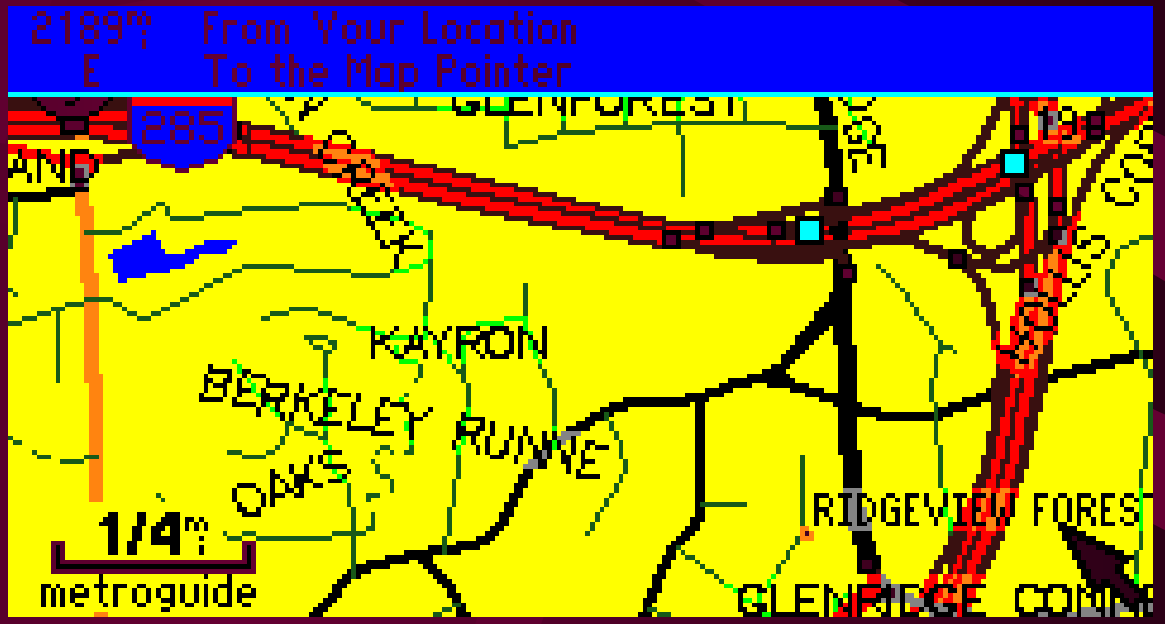
Graphical Position Display (Without Map Capability)



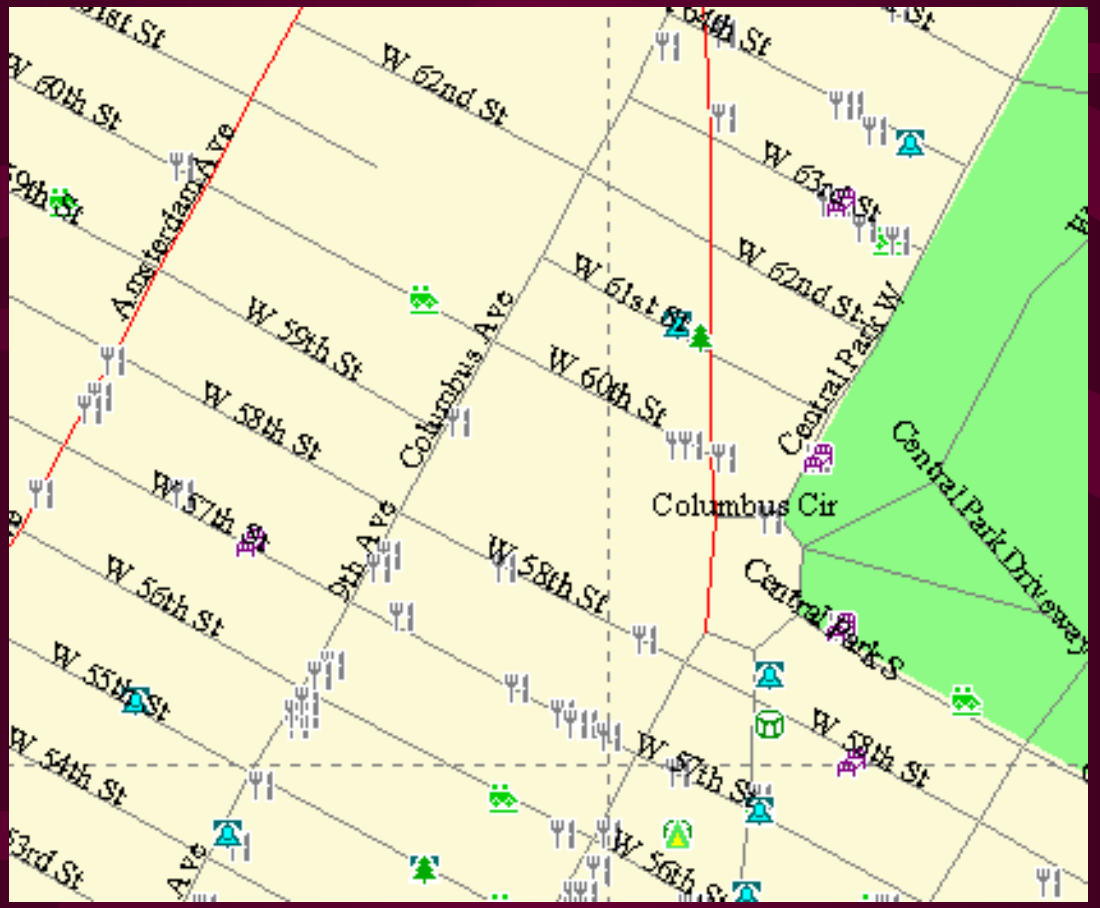
Graphical Position Display (With Map Capability)

- B/W and Color Map Displays

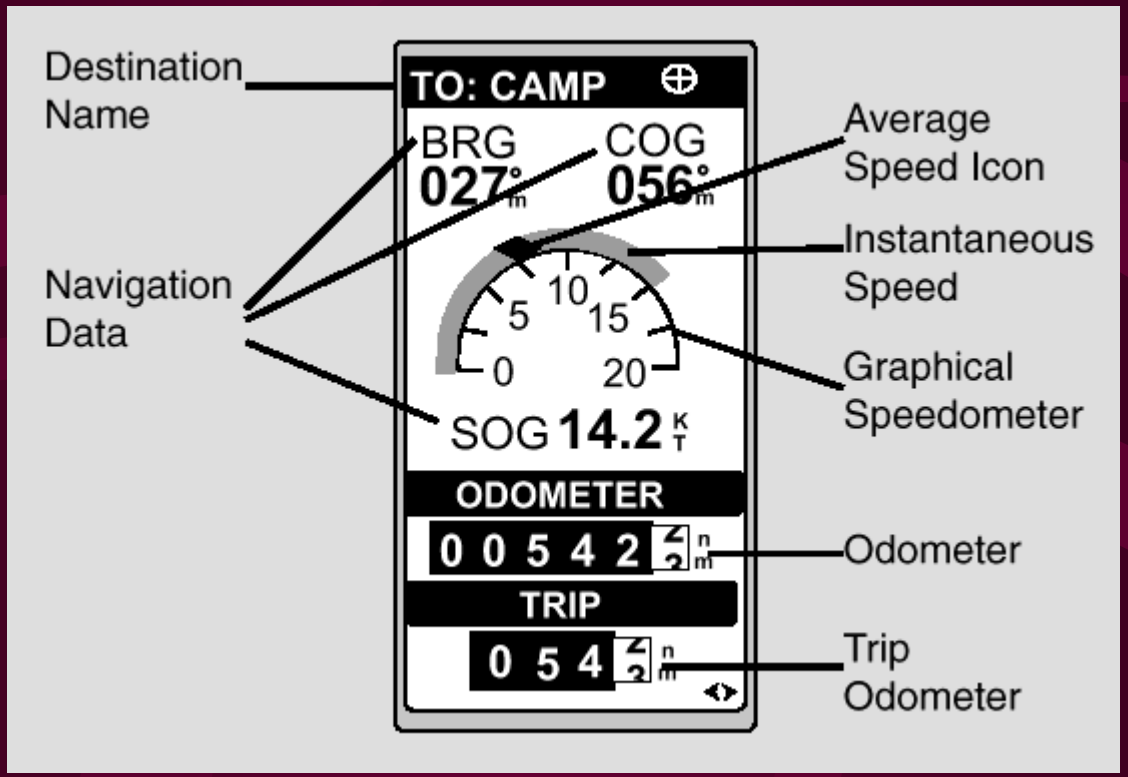




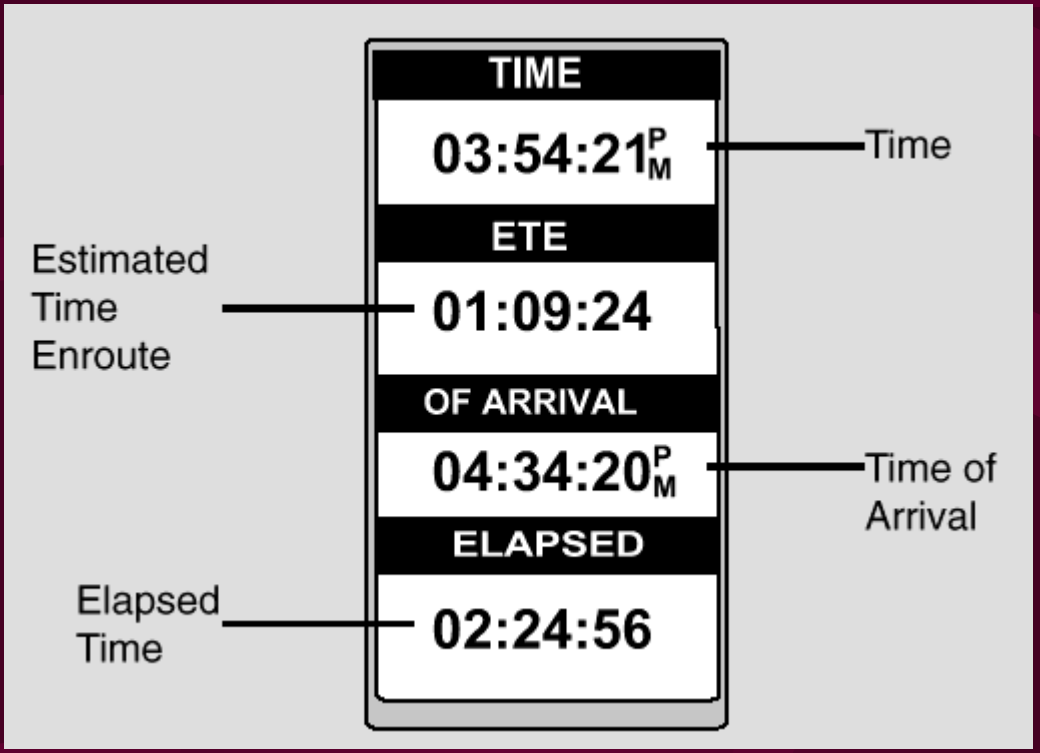
Graphical Position Display With Map Capability New York City (Central Park)



Tachometer/Odometer Screen



Time Screen



Flash Memory Usage

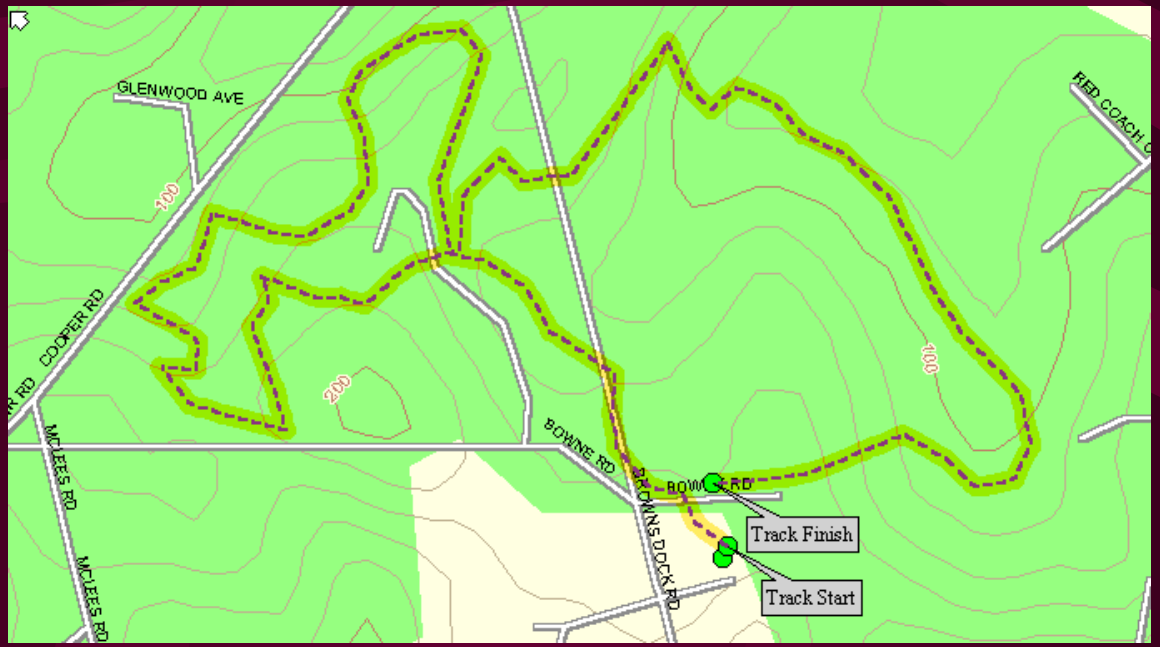
- Example - Magellan SporTrak Pro - 32 Mbytes reserved for base and detailed maps, waypoints, routes and tracks
- Installation of detailed maps only possible with proprietary protocols and specific (and expensive) manufacturer's software, though there are some "hacks"
- Basemaps are factory installed but there are ways for uploading and downloading them on some units
- Access to user data (waypoints, routes, tracks, current position) available with most commercial software

Hiking and Driving with a GPS

- Heading - direction of travel, Bearing - direction to a waypoint
- Using a compass, compass rose on GPS (>5 mi/h speed required for accurate heading indication), dynamic Sun/Moon display
- Making turns when Bearing and Heading differ by, e.g., 90 deg or TURN = 90 deg
- Marking trail head and trail crossings
- Horizontal accuracy - 100 ft or better (after 05/01/00).

Transferring a Hike to a Topo Map

- Uploading tracks to a mapping program, e.g., to TOPO USA on the PC (Huber Woods, NJ)



GPS On A Commercial Flight

- Hold against window - a great sensitivity test
- Know where you are, also speed, altitude
- Flight attendant: “Please put it away”
- Captain: “You can use it, provided you tell us if we are going off-course.”
- Check if allowed by airline (subject to pilot discretion): http://gpsinformation.net/airgps/airgps.htm

GPS/PC/PDA Connection

- RS-232 serial port 1,200 - 115,200 bps, also USB
- NMEA and proprietary protocols
- Software for the moving map display, waypoint, track and route saving, locating streets, addresses
- Operating system upgrades distributed via Internet
- Commercial software (Street Atlas, Solus, Topo USA), shareware (Ozi Explorer) and free (MagWay, EasyGPS, TrackMaker)
- Topo, street maps on CDs and on cartridges

GPS on the Web

- General links - http://gpsinformation.net
- DoD specs: http://www.navcen.uscg.gov/gps/geninfo/2001SPSPerformanceStandardFINAL.pdf
- Usenet - sci.geo.satellite-nav
- Yahoo news groups for specific models
- US address search - http://www.mapsonus.com (don't forget to convert to your current format, e.g., ddd.dddd to ddd.mm.ss or vice versa!). Also programs such as MS Streets &Trips or DeLorme Street Atlas
- Manufacturer and vendor web pages

Power Sources

- 2 - 6 mostly AA batteries, 100 - 200 mA drain
- Primary - Alkaline (2,000 mAh), Lithium (2,500 mAh)
- Rechargeable - NiCad (450 - 800 mAh), NiMH (1,000 - 2,200 mAh). Manufacturer specs not reliable
- Factors for selection - battery capacity, charging memory, temperature dependence, weight and price
- Cigarette lighter cable with voltage regulator (10-14V converted to a specific GPS voltage)

Where Do We Go From Here

- New generation Block 3 satellites. Higher power (2,000W instead of current 500W) with additional frequencies L3 through L5 will replace current Block 2 satellites - 18 out of 24 are past their design limits
- Use in civil aviation
- Expanded use by emergency services in conjunction with cellular networks (911, OnStar)
- Privacy concerns (1984)
- Expanded military use (cruise missiles, precision munitions, drones)

Brookdale Computer User Group (BCUG)

- Group of 300+ volunteers interested in computers
- BCUG is is an independent non-profit organization not associated with Brookdale Community College
- Monthly general meetings at Brookdale Community College campus in Lincroft, NJ, monthly newsletter
- Currently 18 special interest groups meet monthly at various locations
- Dues are $25/year, $20 for non-working retirees
- For more information: www.bcug.com