GPS Secrets

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Talk Outline

- System Description and Operating Modes
- Finding Your Position on the Globe
- Types and Features of GPS Receivers
- Communicating With Your GPS
- Hiking and Geocaching
- Privacy Issues
- Looking into the Future

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 21 active satellites, European Galileo (planning stage)

- GPS: 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. Strength of the received signal is only 1 billionth of a TV signal

GPS Satellite Orbits
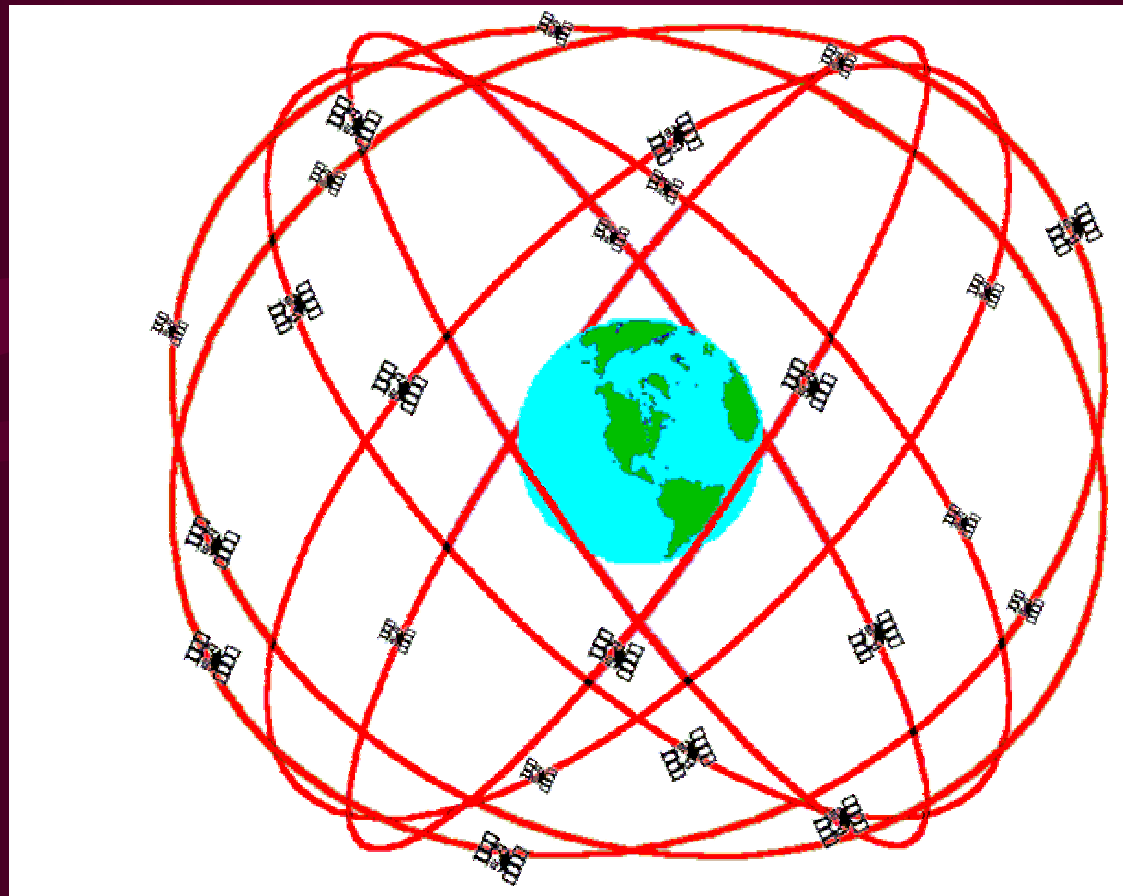
Artist's Rendering

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, but with no resistance to jamming

Operating Modes (cont.)

- Differential Carrier Phase for surveying with post processing - at least two receivers - sub cm accuracy
- Differential GPS (DGPS) - ground signal required - 1 to 5 m hor izontal 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
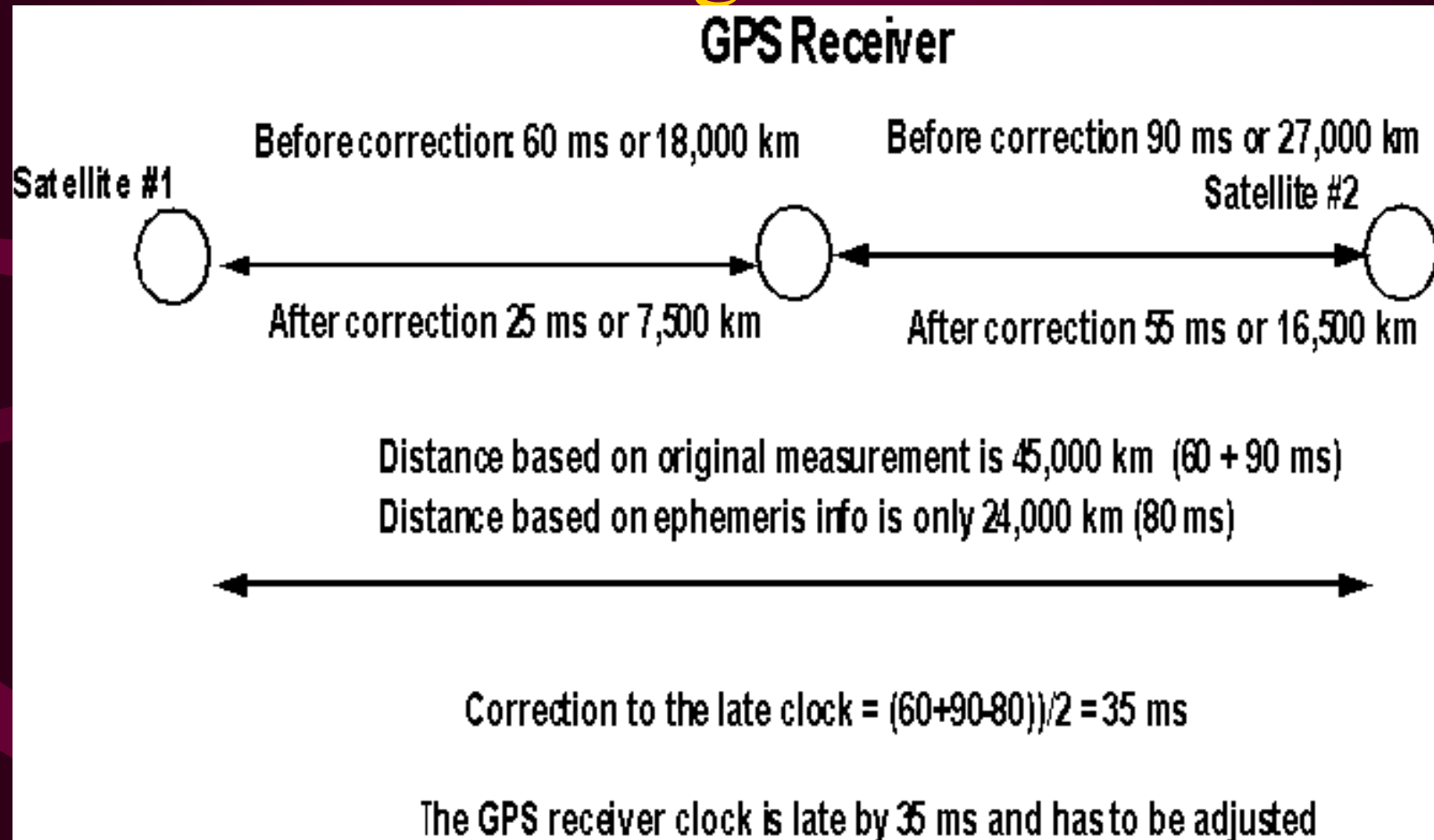
Determining Position on the Globe

- 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"

- 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: 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

Simplified Example of Linear "Triangulation"

GPS Receiver

Before correction: 60 ms or 18,000 km

Before correction 90 ms or 27,000 km

Satellite #1

Satellite #2

After correction 25 ms or 7,500 km

After correction 55 ms or 16,500 km

Distance based on original measurement is 45,000 km (60 + 90 ms)

Distance based on ephemeris info is only 24,000 km (80 ms)

Correction to the late clock = (60+90-80))/2 = 35 ms

The GPS receiver clock is late by 35 ms and has to be adjusted

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 useles

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", integrated into cell phones, PDA attachments ($100 - $500)

- Built into cars (OEM) or add-ons with voice guidance, maps, street and address software with road lock, and inertial navigation ($150- $2,000)

- For land surveys with Carrier Phase Comparison and post processing ($5,000 - $20,000)

- Military with PPS and S/A decryption ($???)

Features in GPS Receivers

- 8 - 15 display screens with context-sensitive menus

- 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
GPS Receivers

- 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

Door to Door Navigation

- Proprietary programs under Linux, Windows CE
- Shortest path algorithms
- Text to Speech with keywords
- Rotating map and birds eye view
- Voice selection
- Integration with real time traffic information

Modifying GPS Vocabulary

- Editors available from Garmin and other sources

- http://turboccc.wikispaces.com/TTSVoiceEditor

- http://www.garmin.com/garmin/cms/site/us/ontheroad/voicestudio

Portable GPS Receivers
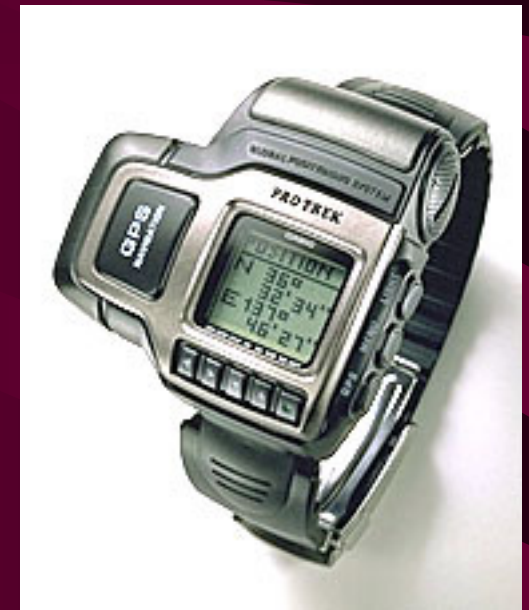
Specialized GPS For Geocaching

Garmin Oregon

Car Mounted GPS Receivers

- Magellan 2200T

- Touch Screen

- Door-to-Door guidance
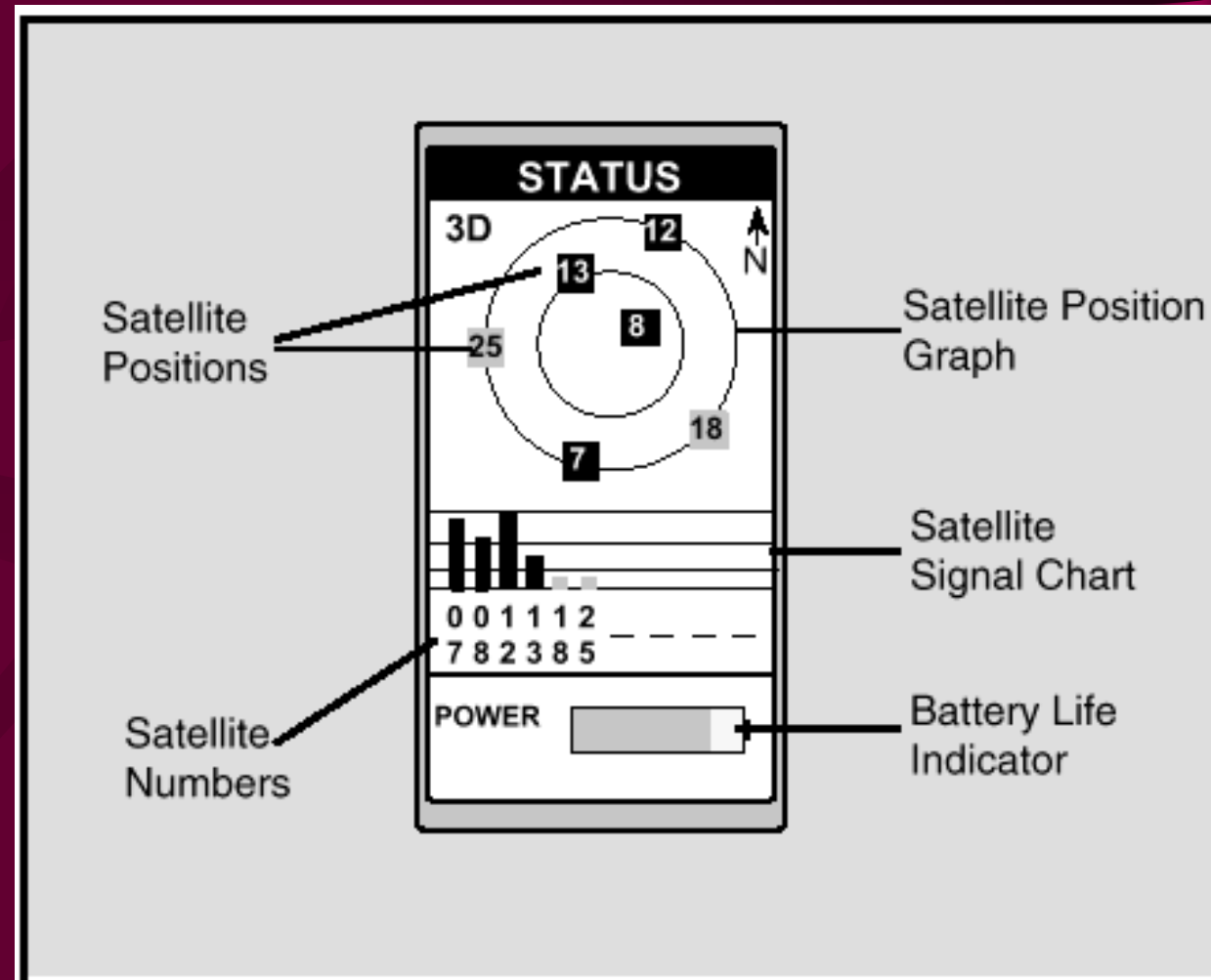
- Voice output

GPS in Smart p hones

Military GPS
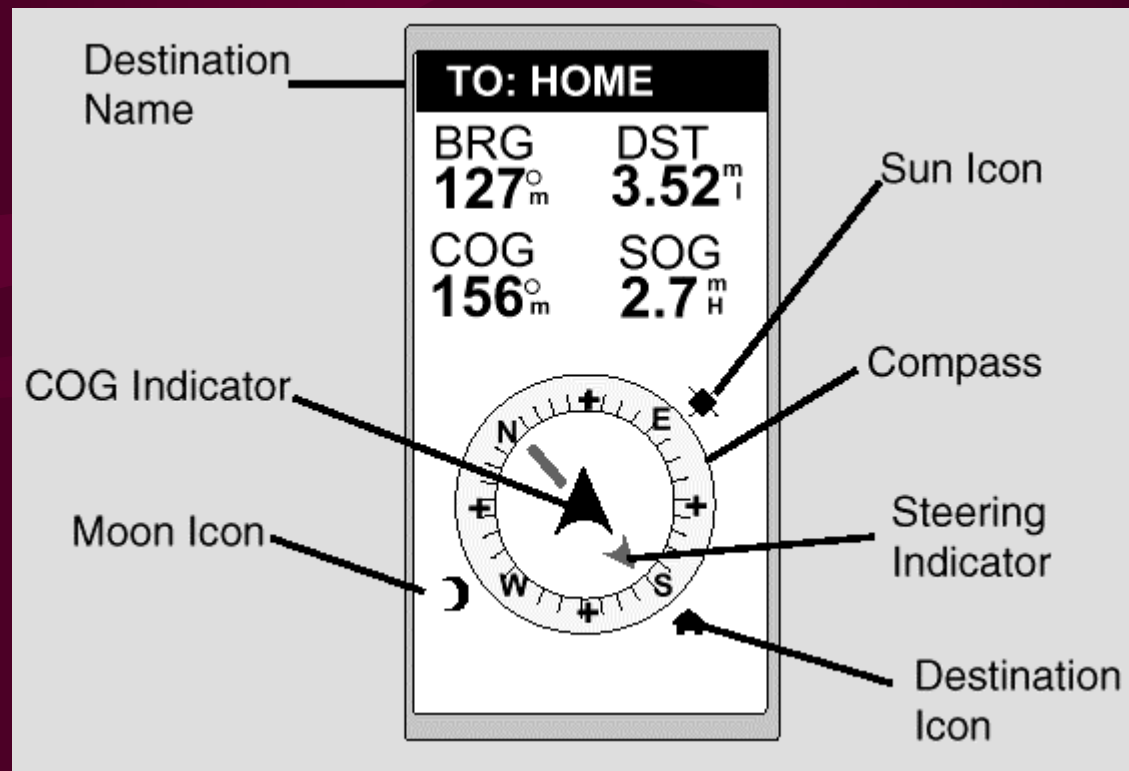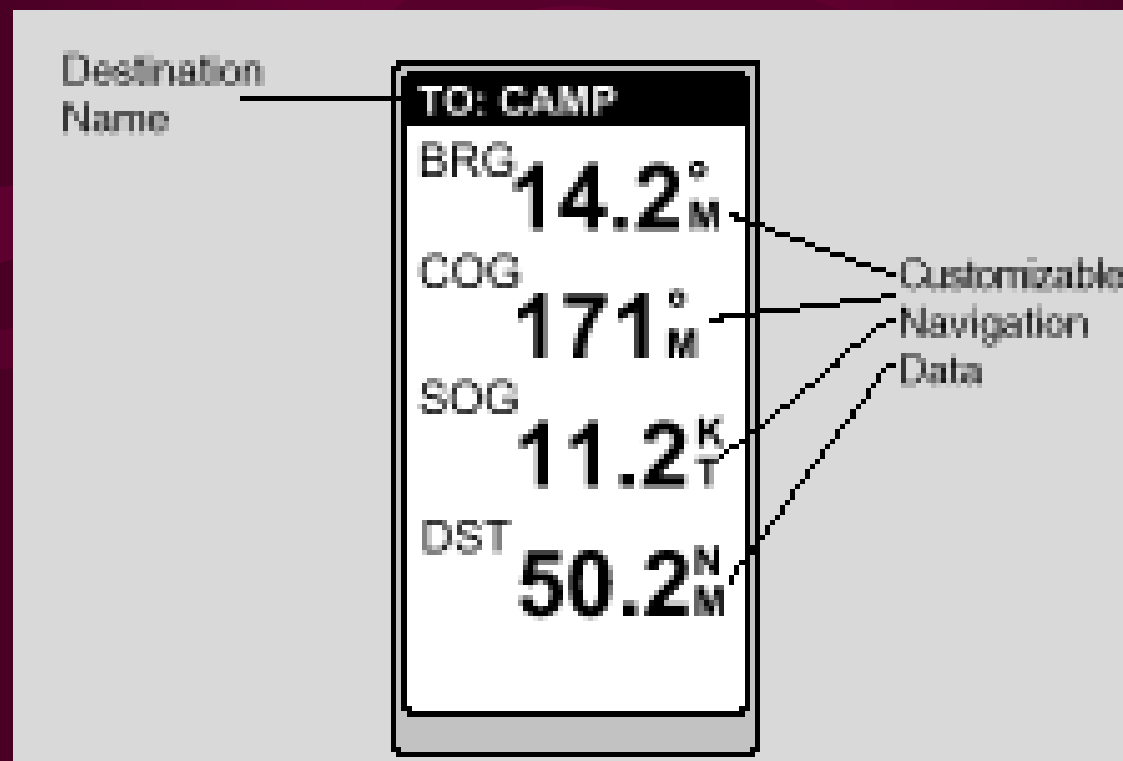
- Plugger and 2 competing designs
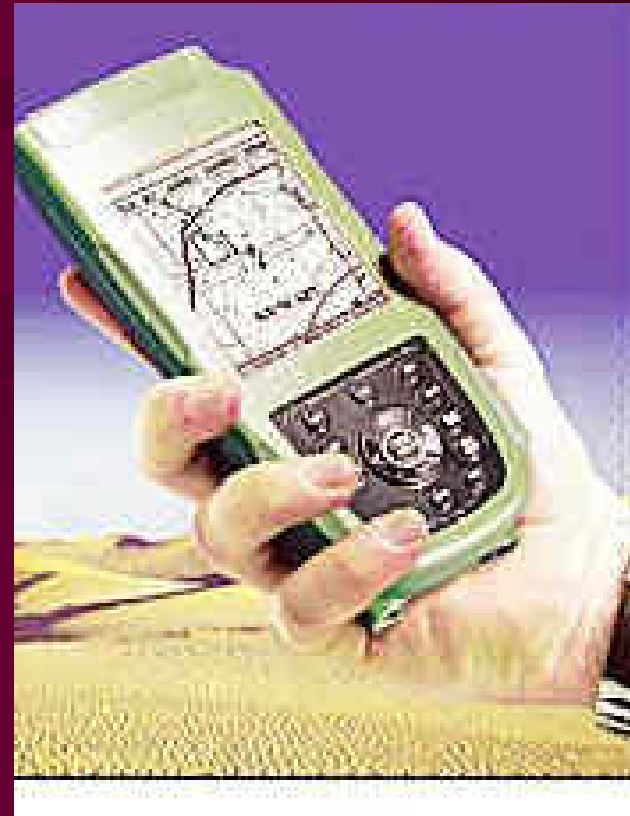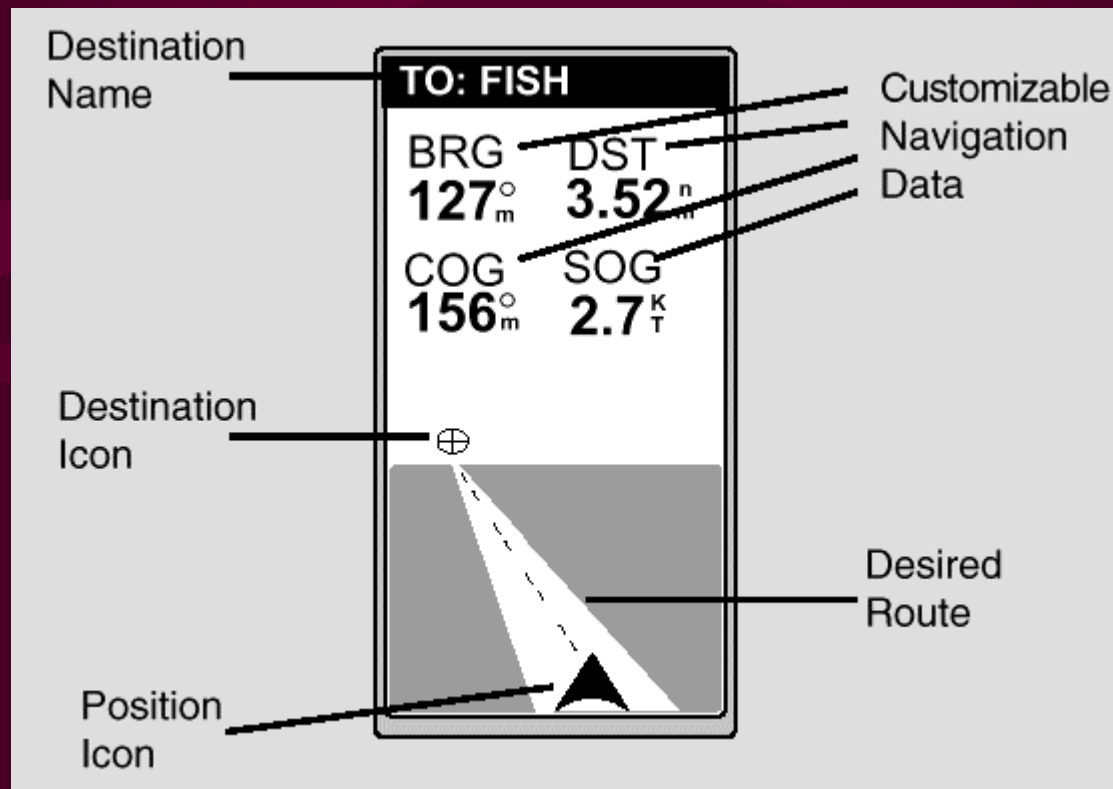
Satellite Status

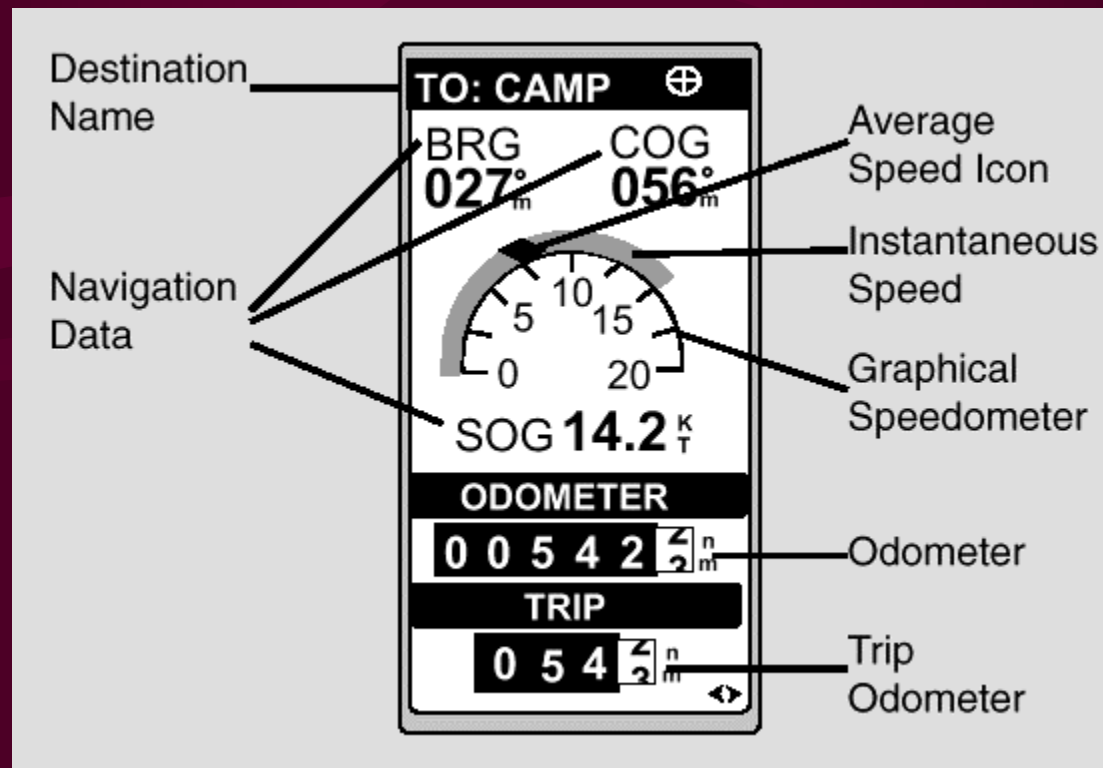- 5,300 mi. horizon

Compass Rose
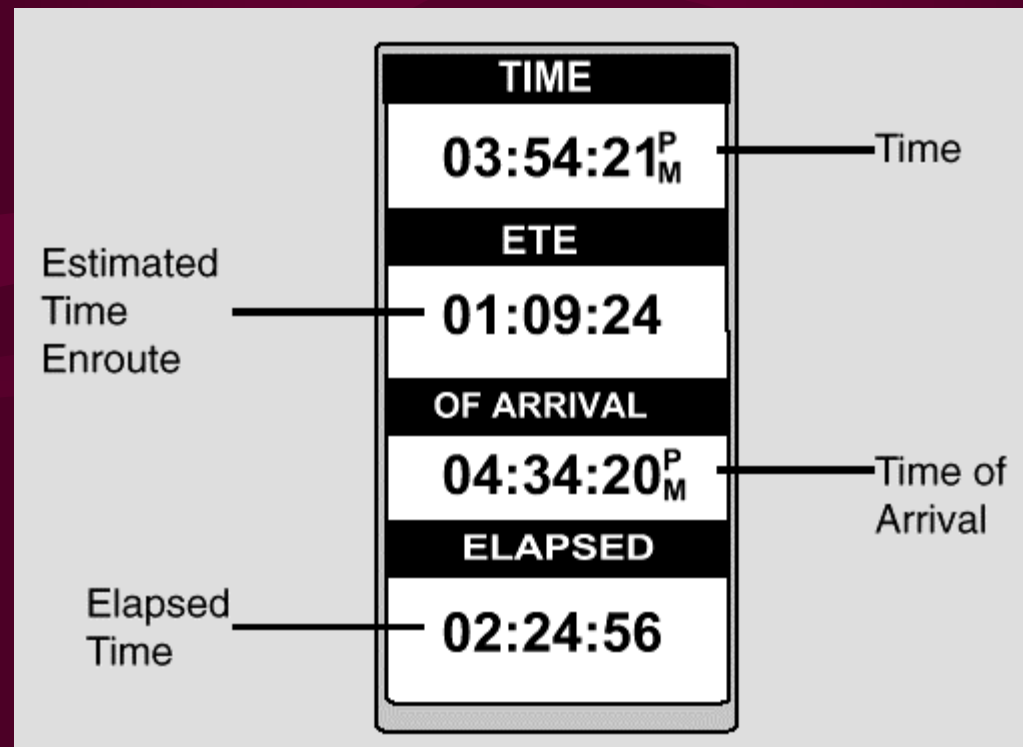
GoTo Large Screen

Alternate GoTo Screen

Tachometer/Odometer Screen

Time Screen

GPS/PC/PDA Connection

- USB in newer, serial interface in older units
- NMEA 0183 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 Talking to a PC

- Format of an NMEA 0183 phrase:

  $(descriptor),data,*checksum (hl)<CR><LF>

- Checksum required to validate a command

Program to Compute CHECKSUM

- 10 PRINT "Program to compute checksum by Cass Lewart "
- 20 PRINT "Enter string to compute checksum, "
- 25 LINE INPUT "e.g., $PMGNCMD,VERSION* : ",A$
- 30 L1=LEN(A$)

CHECKSUM Program (cont)

- 50 C=0
- 60 FOR I=2 TO L1-1
- 70 C=C XOR ASC(MID$(A$,I,1))
- 80 NEXT
- 90 B$=HEX$(C)
- 95 IF LEN(B$)=1 THEN LET B$="0"+B$
- 100 PRINT "CHECKSUM OF ";A$;" IS - ", B$

NMEA 0183 Example: Request for Model and Software Version

- Sent To GPS:

- $PMGNCMD,VERSION*28

- Response from GPS:

- $PMGNVER,PID,SID,c---c,,ssssssssssss*hl

Installing Basemaps

- Main source of income for GPS manufacturers
- Price differences in various regions
- Procedure depends on GPS model
- Find secret keystrokes

Secret Keystrokes

- Software trap doors

- Manufacturer and model-specific

- Apply caution!

- Example (Magellan Sportrak): Press and hold NAV key while pressing the PWR key. A small rectangle should appear on the GPS screen with "00".

Hiking with a GPS

- Heading - direction of travel, Bearing - direction to a waypoint (in degrees)
- 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 - 50 ft or better

Transferring a Hike to a Topo Map

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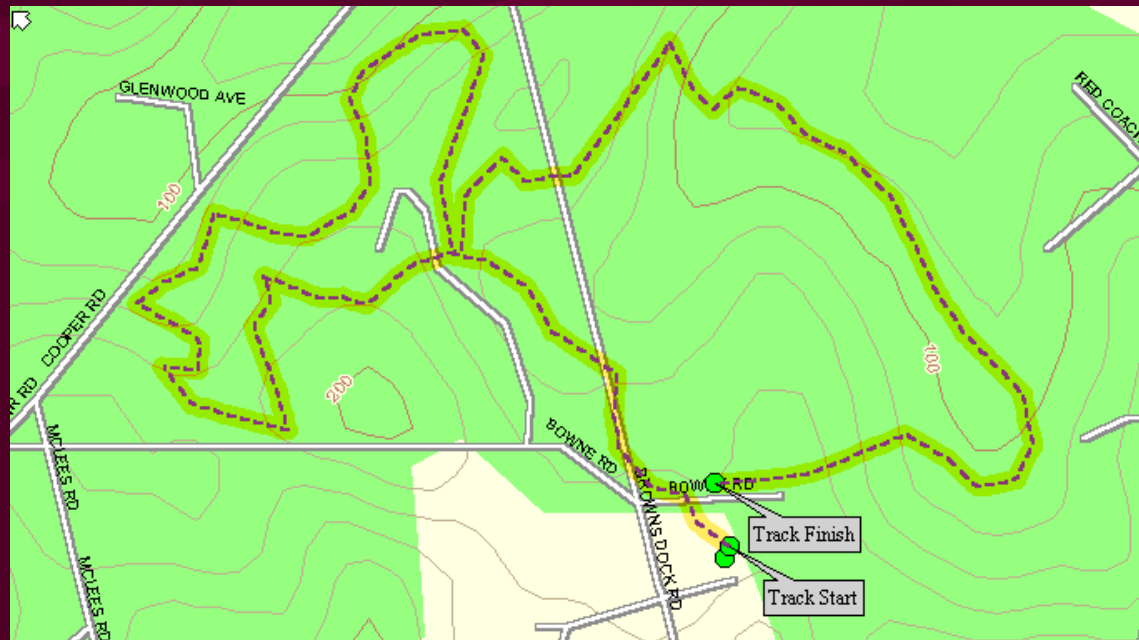
Compass Use when Hiking

- Set Compass to "Bearing"
- K&R Meridian PRO
- Prismatic vs. Lensatic Compass
- Precision within 1-2 degrees
- Protection from Eddy Currents

Geocaching

- A new world-wide sport requires a GPS and a compass
- Coordinates with a short description
- Hints – such as "Think of Marx Brothers Movies"
- One cache may lead to another one
- http://www.geocaching.com/

Geocachers

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 on the Web

- General links - http://gpsinformation.net/

- 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 (Portable Units)

- 2 - 6 mostly AA batteries, 100 - 200 mA drain

- Primary - Alkaline (2,000 mAh), Lithium (2,500 mAh)

- Rechargeable - NiMH (1,500 - 2,200 mAh). Manufacturer specs not reliable

- Trend toward built-in rechargeables (built-in obsolescence)

Privacy Issues

- Plain GPS is a passive device
- When integrated with a cell phone it may transmit user location
- TLC investigation
- Privacy is dead (1984)

Current Trends

- Paid subscription to map updates and traffic info
- $200/year Mercedes update charge
- Emphasis on more expensive car units for door-to-door navigation
- Converting a one-time sale to a steady revenue stream

Where Do We Go From Here

- New generation Block 3 satellites. Higher power (2,000W instead of current 50W) 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, Sprint Family Locator)

- Expanded military use (cruise missiles, precision munitions, drones)