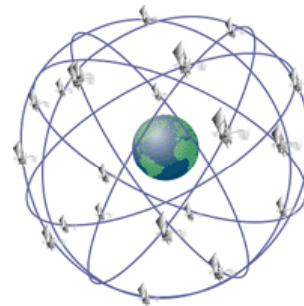
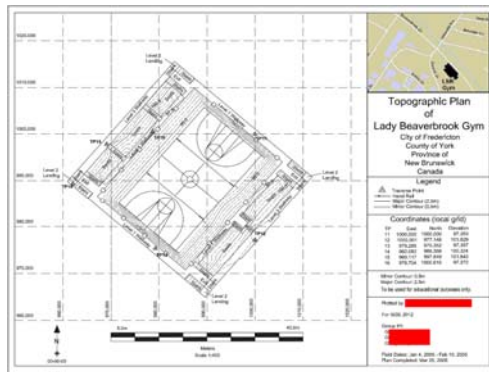


Principles of GNSS Positioning & Different Methodology

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GNSS Positioning

◆ Contents

- Geometry Concept of 2D GNSS positioning
- Geometry Concept of 3D GNSS positioning
- **Mathematical Concept**
- DOP concept
- **Error Budget**
- **Positioning Methodology**
- **Application**

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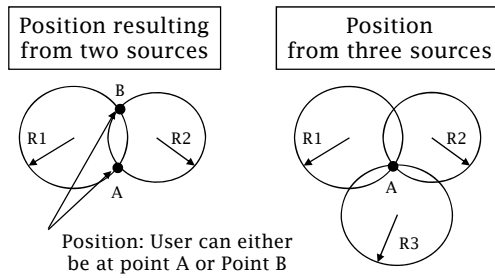
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GNSS Positioning

◆ Concept of GNSS Positioning (1/3): 2D

- Two-dimensional Position Determination

- Positioning determination from measurements to three sources



- Consider a clock offset by user ϵ (next)

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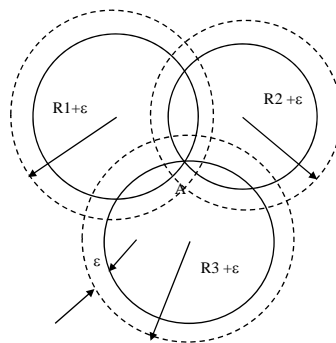
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GNSS Positioning

◆ Concept of GNSS Positioning (2/3): 2D

- Two-dimensional Position Determination

- Consider a clock offset by user ϵ (next)



- User clock offset is common, it can be compensated (using relative positioning technique)

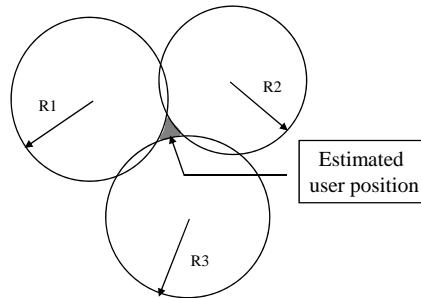
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GNSS Positioning

◆ Concept of GNSS Positioning (3/3): 2D

- Now, consider the independent measurement errors
- Atmospheric effects & Emitter clock offset
- Interferences like as noise, etc.
- Not common to all measurements, it can not be compensated



- User location is somewhere within the triangular error space

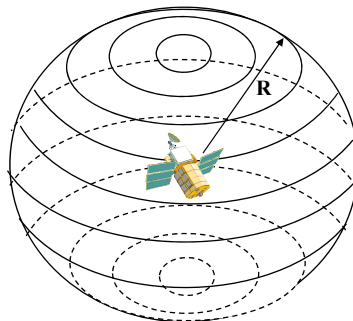
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GNSS Positioning

◆ Concept of GNSS Positioning (1/3): 3D

- **Three-dimensional Position Determination**
 - The user would be located somewhere on the surface of a sphere (range R) centered about the satellite



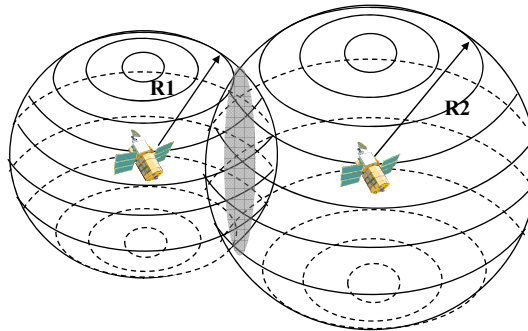
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GNSS Positioning

◆ Concept of GNSS Positioning (2/3): 3D

- **Three-dimensional Position Determination**
 - The user would be somewhere on the surface of both spheres when the simultaneous measurements by 2 sources



- Located either on the perimeter of the shaded circle

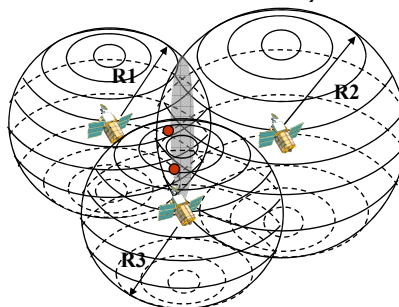
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GNSS Positioning

◆ Concept of GNSS Positioning (3/3): 3D

- **Three-dimensional Position Determination**
 - The user would be at points which is intersected the shaded circle perimeter by third sphere when the simultaneous measurements by 3 sources



- The candidate locations are mirror images of one another w.r.t. the plane of the satellites.

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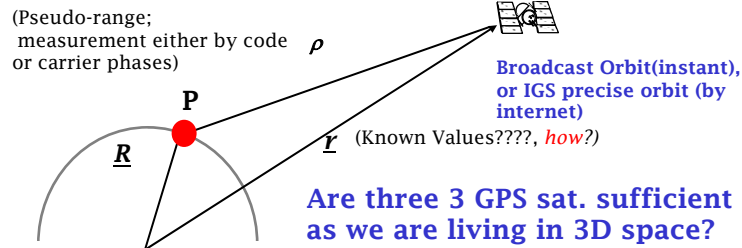
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GNSS Positioning

◆ Math. Concept of GNSS Positioning

$$\rho = \underline{r} - \underline{R} \quad \longrightarrow \quad \text{NEED THE 3 SVs (minimum why?)}$$

$$= \sqrt{(r_x - R_x)^2 + (r_y - R_y)^2 + (r_z - R_z)^2}$$



$$\rho = \underline{r} - \underline{R} + \text{Clock Bias} \quad \longrightarrow \quad \text{NEED THE 4 SVs}$$

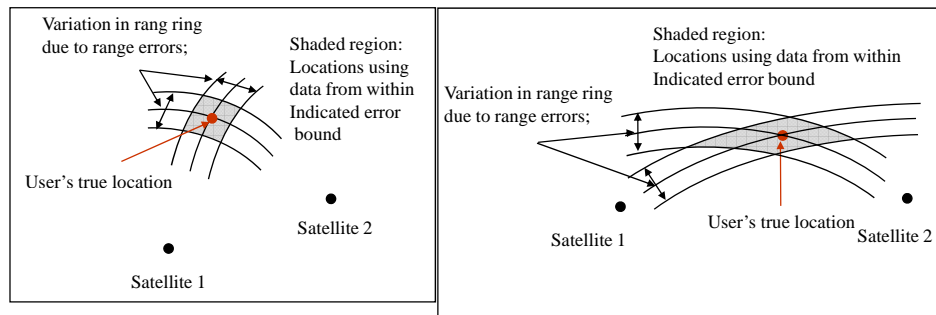
$$= \sqrt{(r_x - R_x)^2 + (r_y - R_y)^2 + (r_z - R_z)^2} + C_b$$

after linearization $\longrightarrow \quad A\vec{x} = \vec{l} \quad \vec{x} = (A^T A)^{-1} \vec{l}$

GNSS Positioning

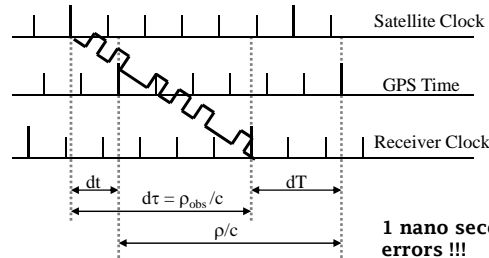
◆ D.O.P Concept (geometric interpretation)

- Concept: The position error that results from measurement errors depends on the user/satellites relative geometry



GNSS Positioning

◆ Pseudorange Measurement



Pseudorange : C/A (Coarse Acquisition) or Carrier Phases.
Basic concepts are same, but signal.
- Carrier phases are 100 precise than C/A

1 nano seconds error = ??? range errors !!!

- **Pseudorange Observation Equation (in metre)**

$$\rho_{\text{obs}} = \rho + d\rho + c \cdot (dt - dT) + d_{\text{ion}} + d_{\text{trop}} + \varepsilon$$

Where,

ρ : Geometric Range, $d\rho$: Orbital Errors
 dt : Satellite Clock Error, dT : Receiver Clock Error
 d_{ion} : Ionospheric Delay, d_{trop} : Tropospheric Delay
 ε : Noise

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GNSS Positioning

◆ Error Budget for GPS (1σ) **In general case, but also depends on Rx used**

- Satellite Clock Error ~ 2.1 m
- SV Ephemeris Error 0.05 (precise) - 2 m (nav.)
- Ionospheric Refraction ~ 4 m (res. slant)
- Tropospheric Refraction ~ 0.7 m (res. slant)
- Selective Availability (N/A) ~ 70 m (not anymore)
- Receiver Noise ~ 0.5 m
- Multipath ~ 1.4 m (maximum; different for a correlator tech.; code and phase are diff.; e.g. phase=1/4 wavelength = 5 cm on L1 for a narrow correlator)
- Dilution Of Precision : Above * 1 ~ 6 (lower the better)



Total Error without SA : ~ 30m (without major error correction, e.g. troposphere, but no multipath)

Total Error without SA, error mitigation: 3~10m (code point positioning)

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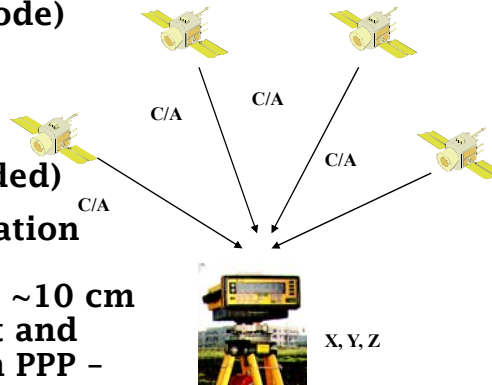
GNSS Positioning

◆ Positioning Methods

- Point Positioning (C/A code)
- 1 Receiver
- Standalone Positioning
- Accuracy: 3~10m (No aided)
- Land, Marine, Air Navigation

(by using carrier phases: ~10 cm depends on environment and methodology, e.g. NRCAN PPP – *post-processed*)

- please find the web for NRCAN PPP or **our GGE's online GAPS PPP**



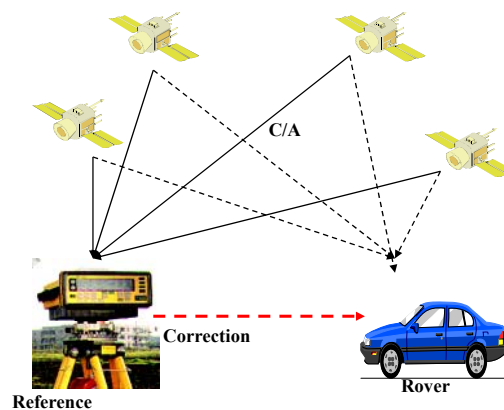
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GNSS Positioning

◆ Positioning Methods

- DGPS (C/A code)
- Reference + Rover + **Communication Link**
- Relative Positioning
- Positioning accuracy: around 1~2m
- High-precision Applications



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GNSS Positioning

◆ Positioning Methods

- DGPS (Code+Phase, for Kinematics or Post-Processed)

- Receivers + Reference + Computer + S/W

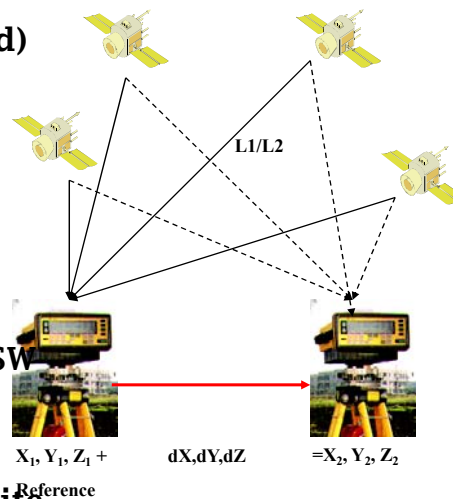
- Relative Positioning

- Accuracy: 2cm over 80 km (*real-time*)

- Accuracy: 5mm +/- 1ppm * baseline distance (geodetic SW level - *post processed*)

- Geodesy, ERP, GIS, etc.

- Careful for the reference site



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GNSS Positioning

◆ Differential GPS (DGPS)

- Also Called "*Relative Positioning*"

- At least 2 Receivers Required

- One Over A Known Position "Base" or "Reference"

- Other Receiver Over Unknown Position "Rover"

- Base and Rover Receive Same SV Range Data

- Base Receiver Measures Vector Difference Between Received Position Data And Known Position

- Base Correction Value Applied To Rover Positioning

- Real-Time (RTCM format) & Post-Processing

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GNSS Positioning

◆ DGPS and Link Methods

- **Real-Time DGPS**
 - **LADGPS** (Local Area DGPS)
 - Scalar correction to the code measurement for each sat.
 - **WADGPS** (Wide Area DGPS) → WAAS
 - vector correction (clock, sat. position, etc.) for each sat. using communication sat. like EGNOS
 - **CDGPS** (Carrier-Phase DGPS)
 - Relative to the carrier phase at a reference site
 - Dynamic CDGPS(RTK)
 - **IDGPS** (Inverted DGPS)
 - position determination at the control center

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GNSS Positioning

◆ DGPS and Link Methods

- **Communication Link Methods**
 - **Groundwave System**
 - Marine Radiobeacons
 - 2 MHz Groundwave Systems
 -
 - **VHF and UHF Networks**
 - Special Mobile Radio System
 - Cellular Radio
 - FM Subcarrier (RTCM Proposed)
 -
 - **Mobile Satellite Communications**
 - Inmarsat, etc.

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GNSS Positioning

◆ DGPS Techniques

	LADGPS	CDGPS	WADGPS
Method	Code-base	Code/Carrier-base	Code/Carrier-base
Accuracy	meter	Centimeter	meter
Coverage	~200Km	~100 Km	~1000Km
Reference Data	RTCM 1/9	RTCM 18-21 RTCM 3 Raw Data	Error correction vector
Techniques	DGPS IDGPS	Kinematic (RTK/Semi), Static	WAAS
Applications	Navigation	Survey	Aviation
Reference Type	Single Reference		Multi-References

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GNSS Positioning

◆ New RTK Techniques (real-time kinematic)

- ◆ Long Baseline Kinematic GPS
 - ◆ Univ. of New Brunswick, Canada
- ◆ Multi-Reference Station DGPS
 - ◆ Univ. of Calgary, Canada
 - ◆ Decrease inter-ref. Station distance by 2 to 3 & number of ref. Receivers by 3 to 5
- ◆ Virtual Reference System(VRS)
 - ◆ Trimble/Spectra Precision
 - ◆ Generate of data/RTK correction for the user location
 - ◆ raw data handling(QC/Data conversion/Error Estimation)
 - ◆ Internet Web Server
 - ◆ few decimeter for 100-300Km separation & Cm for 50-70Km

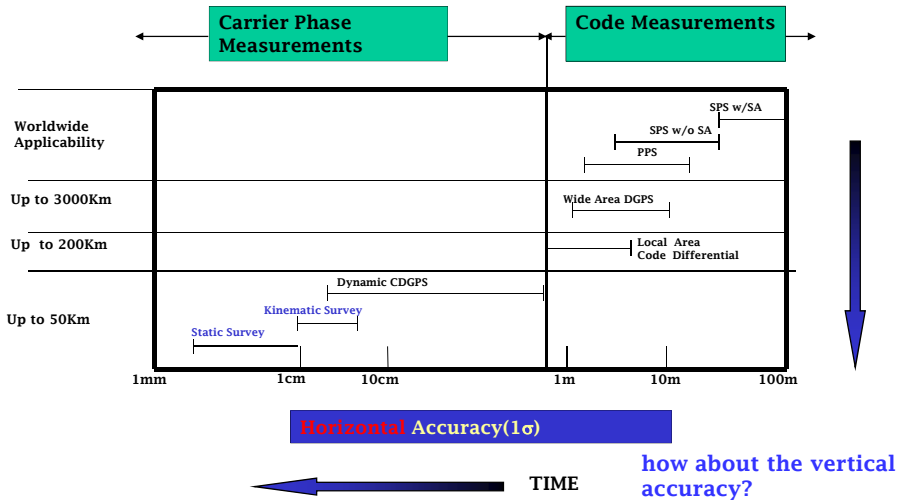


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GNSS Positioning

◆ Methods vs. Accuracy



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GNSS Positioning

◆ Application (details)

Accuracy	LAND	General User / U.S. Soldier Navigation(Car, Truck, Bus, Taxi, ...) Leisure(Climbing, Tracking, ...) Military Timing
≥ 10 M		
Methods	MARINE	Navigation(Ship, Boat, ...) Leisure(Fishing, Diving, ...)
SPS PPS	AIR	Navigation(Aircraft, Balloon, ...)
	SPACE	On-Board Orbit Determination



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GNSS Positioning

◆ Application (details)

Accuracy	LAND	Navigation(ITS/IVS/IVHS/...) Mapping/GIS Military(Map, ...) Emergency & Rescue
M Level		
Methods		
LADGPS WADGPS IDGPS	MARINE	Navigation(Approaching, ...) Mapping/GIS
	AIR	Navigation(Aircraft, ...) Air Traffic Control Military(Missile, Combat aircraft,...)



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GNSS Positioning

◆ Application (details)

Accuracy	LAND	GIS/LIS Geodesy (Geoid Determination, ...) Environment Monitoring Survey Deformation Monitoring
~ Cm		
Methods		
CDGPS Kinematic Survey	AIR	Approaching Automatic Landing(Category III) Military(Guided Missile, ..)
	SPACE	Orbit & Attitude Determinations



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GNSS Positioning

◆ Application (details)

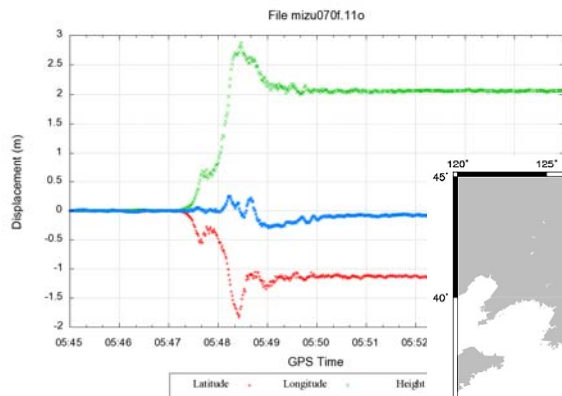
Accuracy	LAND	ITRF/ERP Geodesy Environment Monitoring Plate Motion Crustal Deformation Seismology(Earthquake Prediction, ..) Tectonics
mm		
Methods		
Static Survey		



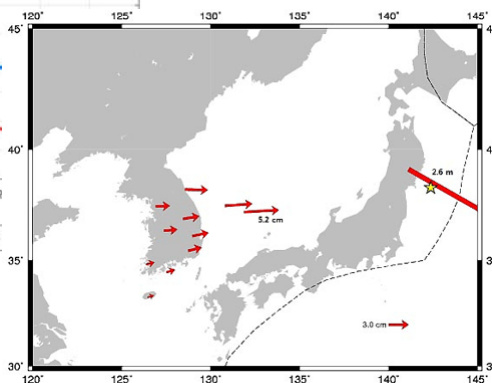
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e.g. Sendai 9.0 Earthquake



Courtesy: Simon Banville



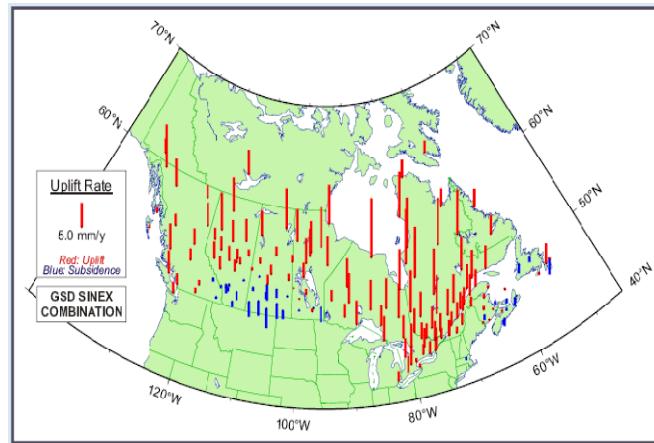
Courtesy: Korean Astronomy and Space Institute (KASI)

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GNSS Positioning

◆ Application (Crustal Deformation - Uplift)



Crustal Deformation Velocities From Episodic Regional Measurements at Canadian Base Network Sites

J.A. Henton, M.R. Craymer, M. Piraszewski, E. Lapelle
(http://www.geod.nrcan.gc.ca/cbn/fm04_minil.pdf), Based on Bernese Software v4.x

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GNSS Positioning

◆ Application (details)

- GPS Modernization & Applications
 - New Frequency for Civil Users
 - GPS + GLONASS + Galileo + etc. (GNSS)
 - Nationwide DGPS
 - Spaceborne GPS
 - PNS (PDA/Mobile Phone)
 - Wrist Watch (Casio, Swatch)
- Wireless Location System
 - Cell-Aided Positioning
 - SnapTrack
 - Qualcomm (MSM3300)
 - IMT2000 (WCDMA)
 - Indoor Applications



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GNSS Positioning

◆ GPS Receiver Category

RECREATIONAL RECEIVER

- Low-end Single-frequency receiver (\$200-\$600)
- Handheld (antenna, receiver and controller integrated)
 - Meant to record tracks, waypoints and routes
 - Navigation features and multiple screens
 - Many can display proprietary maps (roads, points of interest)
- One COM port
 - To output position information (in NMEA format) for Navigation/Mapping software on laptop/ Pocket PC
 - or to input RTCM corrections (from beacon or CDGPS radio)
- Most are WAAS enabled

MAPPING-GRADE RECEIVER

- Higher-end Single-frequency Receiver (\$2,000 to \$10,000)
- Receiver/Antenna/Controller
 - Handheld (all-in-one) or separate
 - Can log position data into GIS software
 - Within the receiver
 - or running on laptop/Pocket PC
 - Can record raw GPS data (Code and Phase) for post-processing
- Usually one COM Port
 - To output position information (in NMEA format)
 - or to input RTCM corrections (from beacon or CDGPS radio)
- Many new receivers also have a Bluetooth wireless serial port

reference system



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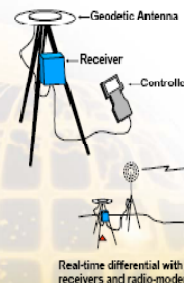
GNSS Positioning

◆ GPS Receiver Category

GEODETIC-GRADE RECEIVER

- Dual-frequency Receiver (>\$10,000 each)
- Receiver/Antenna/Controller
 - Usually as separate components
 - Geodetic Antenna (\$2,000-\$10,000)
- Meant for centimetric accuracy surveys
 - Can output raw GPS data (dual-freq Code and Phase) for post-processing
 - Capable of Real-time Code Differential (RTCM)
 - Most have RTK (Real-time Phase Differential) option
- Multiple COM Ports
 - To input RTCM or RTK
 - To output position information (in NMEA format)
 - To output raw GPS data to data recorder

Canadian spatial reference system



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