GNSS-INS Sensors

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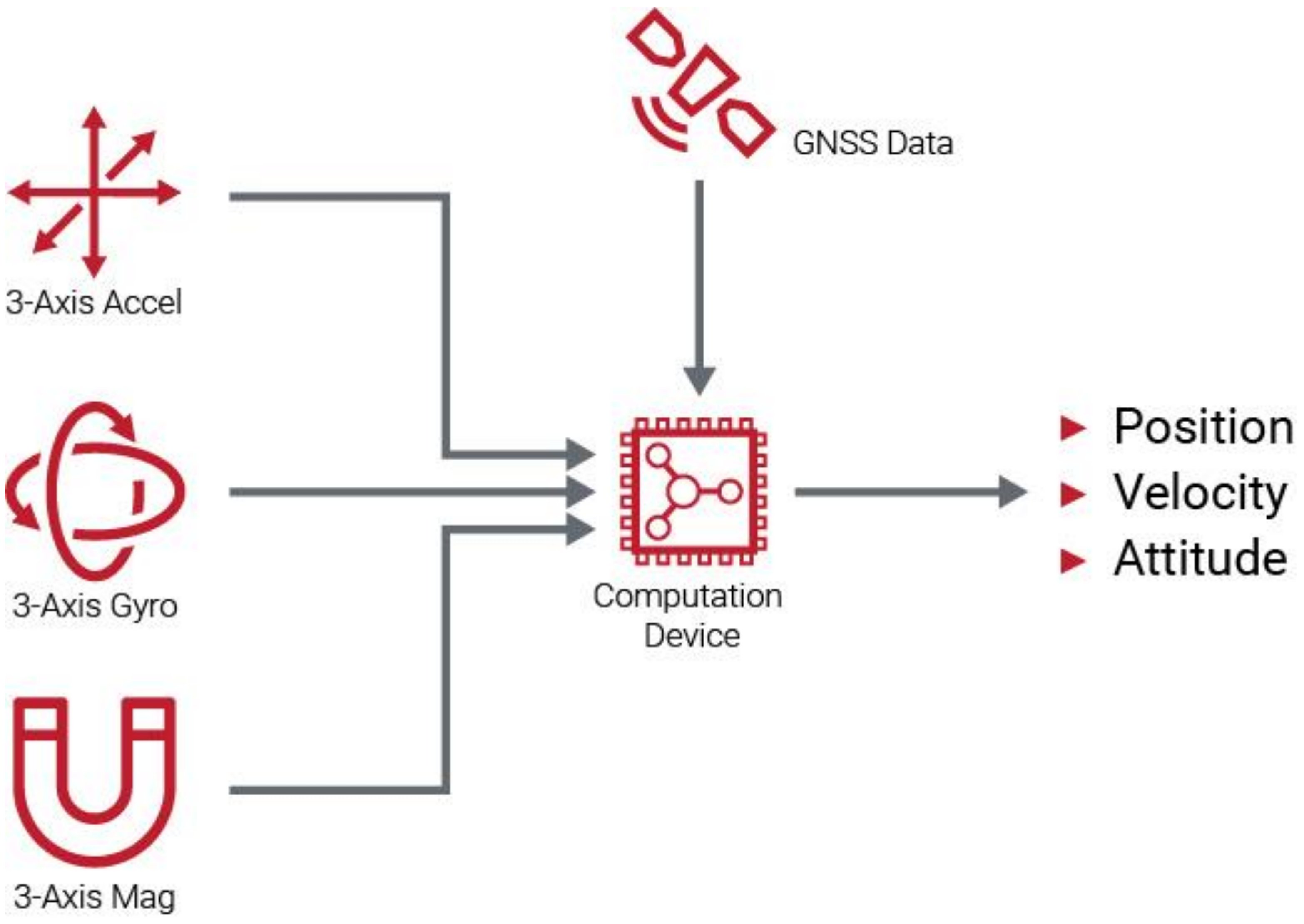
Content overview

What is GNSS-INS?

GNSS-INS

- Global Navigation Satellite Systems (GNSS)
  - Constellations
    - GPS
    - Galileo
    - GLONASS
    - BeiDou
  - Absolute positioning with a few Hz
- Inertial Navigation System (INS)
  - Combination of sensors
    - Gyroscopes
    - Accelerometers
    - Magnetometer
    - Barometric altimeter
  - Relative positioning with high rate

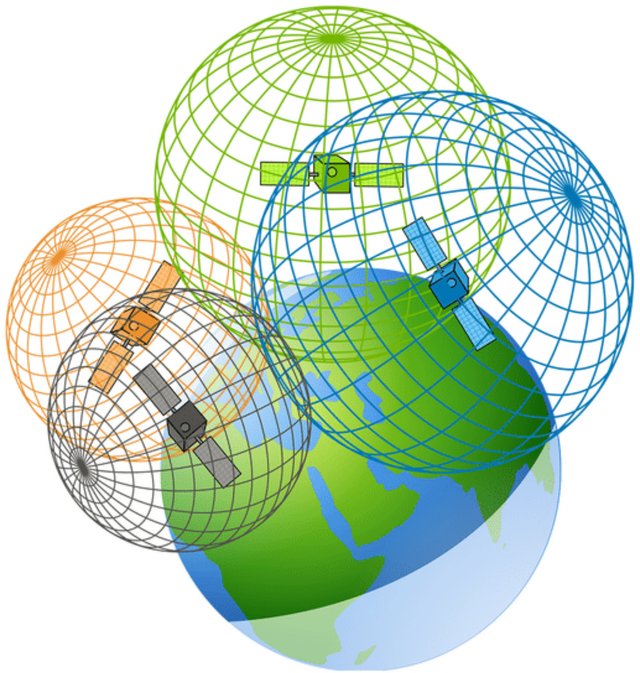
Dead reckoning

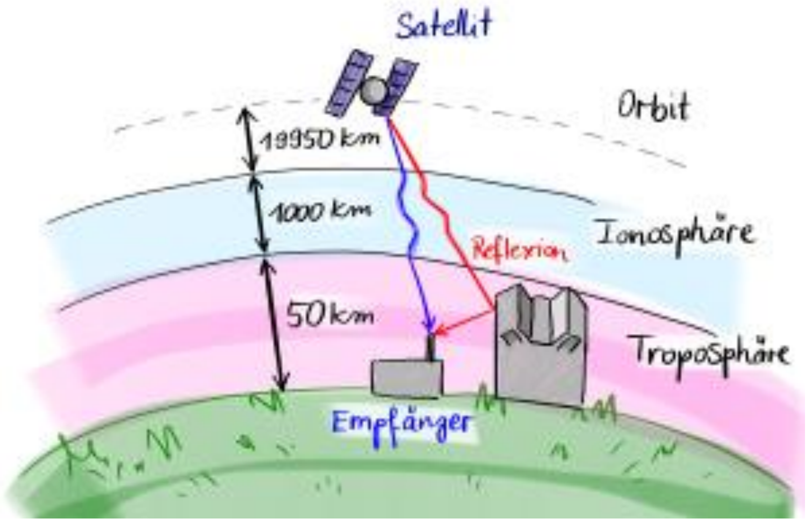


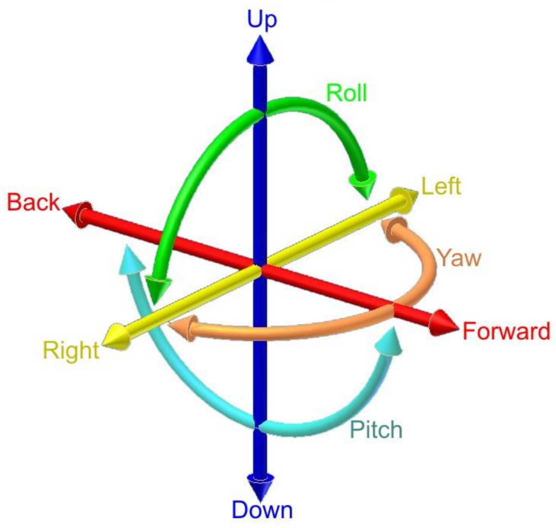
Physical principles

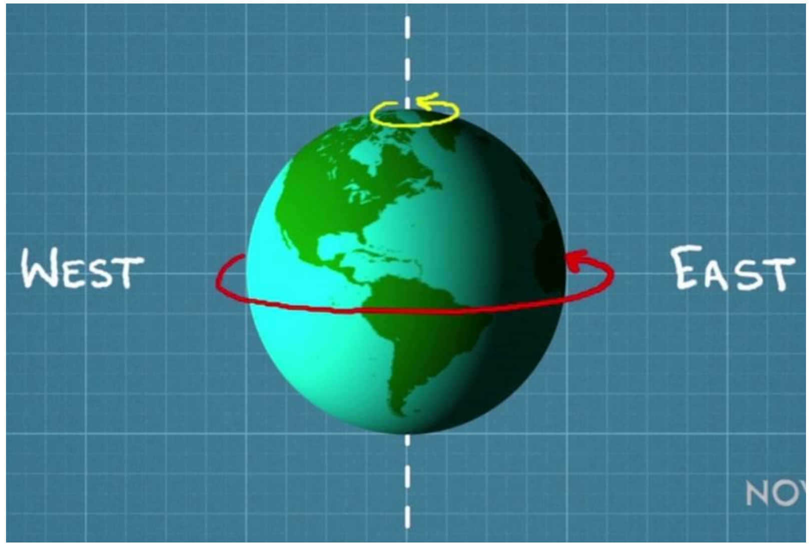
- Global Navigation Satellite Systems (GNSS)
  - Trilateration
  - Orbital mechanisms
  - Signal propagation
  - Relativity theory
- Inertial Navigation System (INS)
  - Classical mechanics
  - Theory of electromagnetics
- Coordinate systems
  - Relative and absolute
  - Transformations

≠ Triangulation









Internal

GNSS-INS systems

Applications

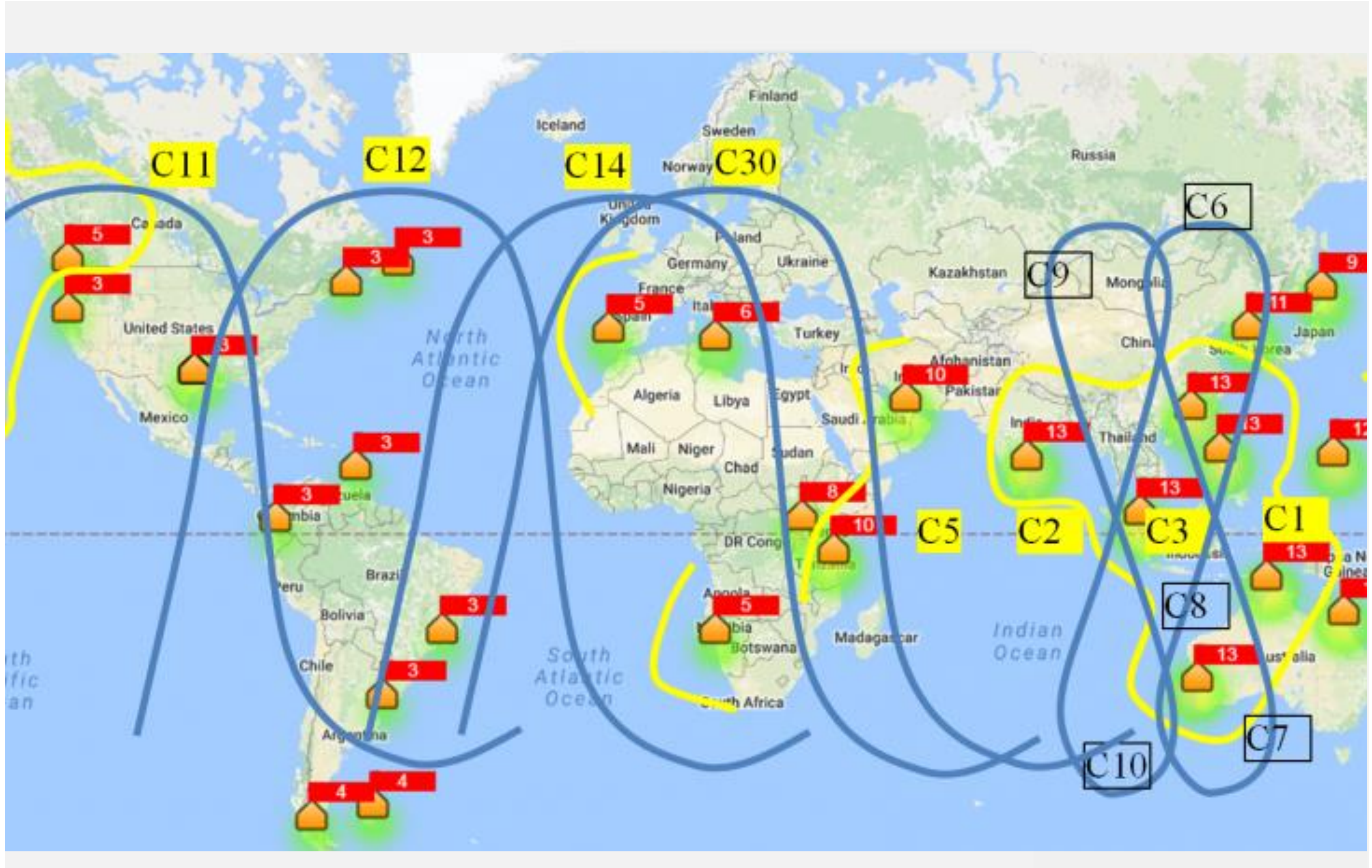
- Aerospace and aviation
- Augmented- and virtual reality
- Autonomous vehicles and robotics *
- Maritime and underwater applications
- Geospatial mapping and surveying
- Military and defense
- Railway and transportation systems
- Personal navigation, sport, and entertainment
- Precision agriculture
- Space exploration
- Wildlife tracking

… and much more

How does GNSS work?

GNSS constellations

- 4 + 2 different GNSS constellations
  - Global providers
    - GPS (USA) – 24 satellites
      Global Positioning System
    - Galileo (EU) – 25 satellites
      Galileo Satellite Navigation System
    - BeiDou (CN) – 30 satellites
      BeiDou Navigation Satelite System
    - GLONASS (RU) – 24 satellites
      Globalnaya Navigazionnaya Sputnikovaya Sistema
  - Regional providers
    - QZSS (JP) – 4 satellites
      Quasi-Zenith Satellite System
    - IRNSS (IN) – 5 satellites
      Indian Regional Navigation Satellite System



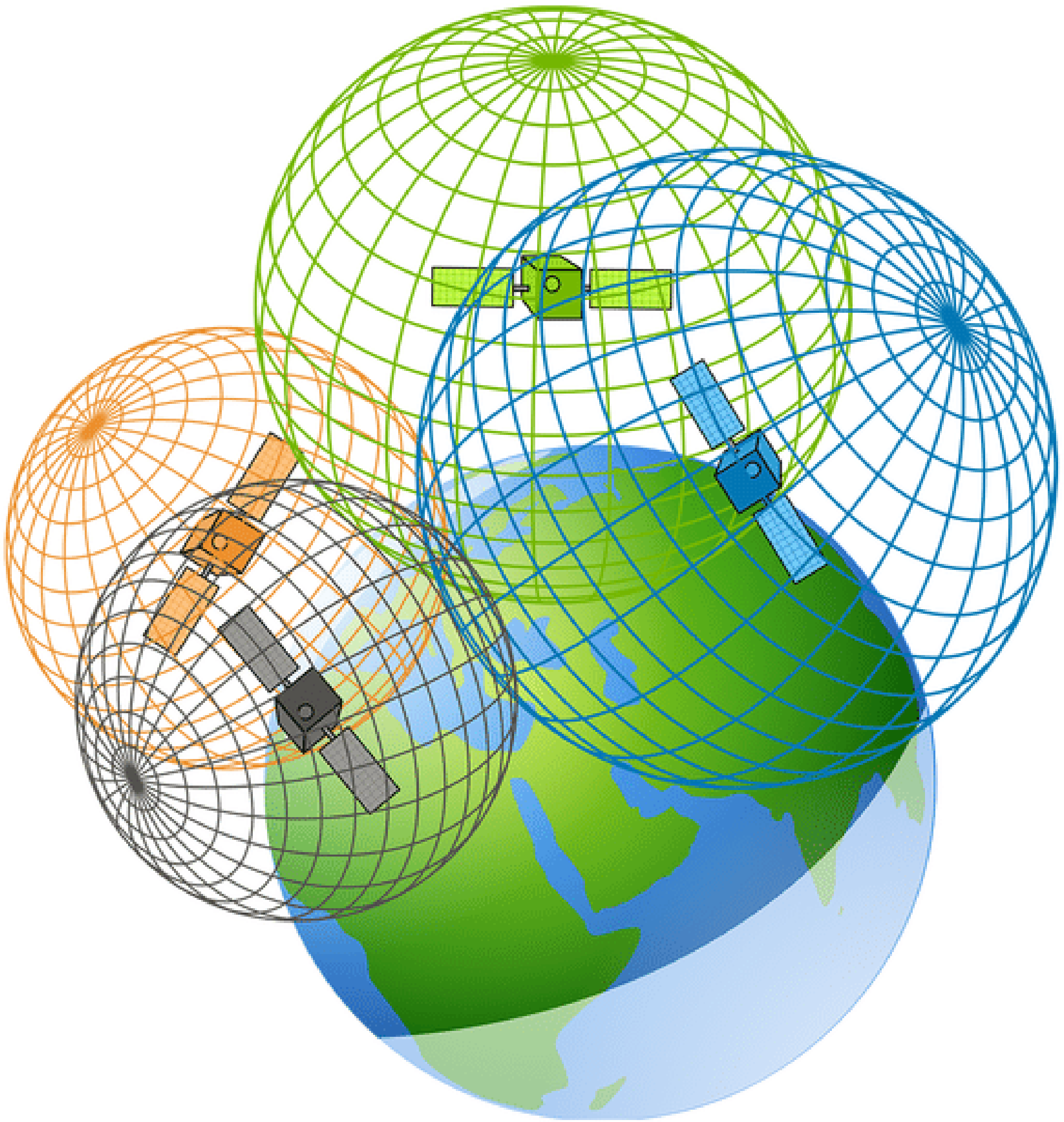
* # of operational satelites

Internal

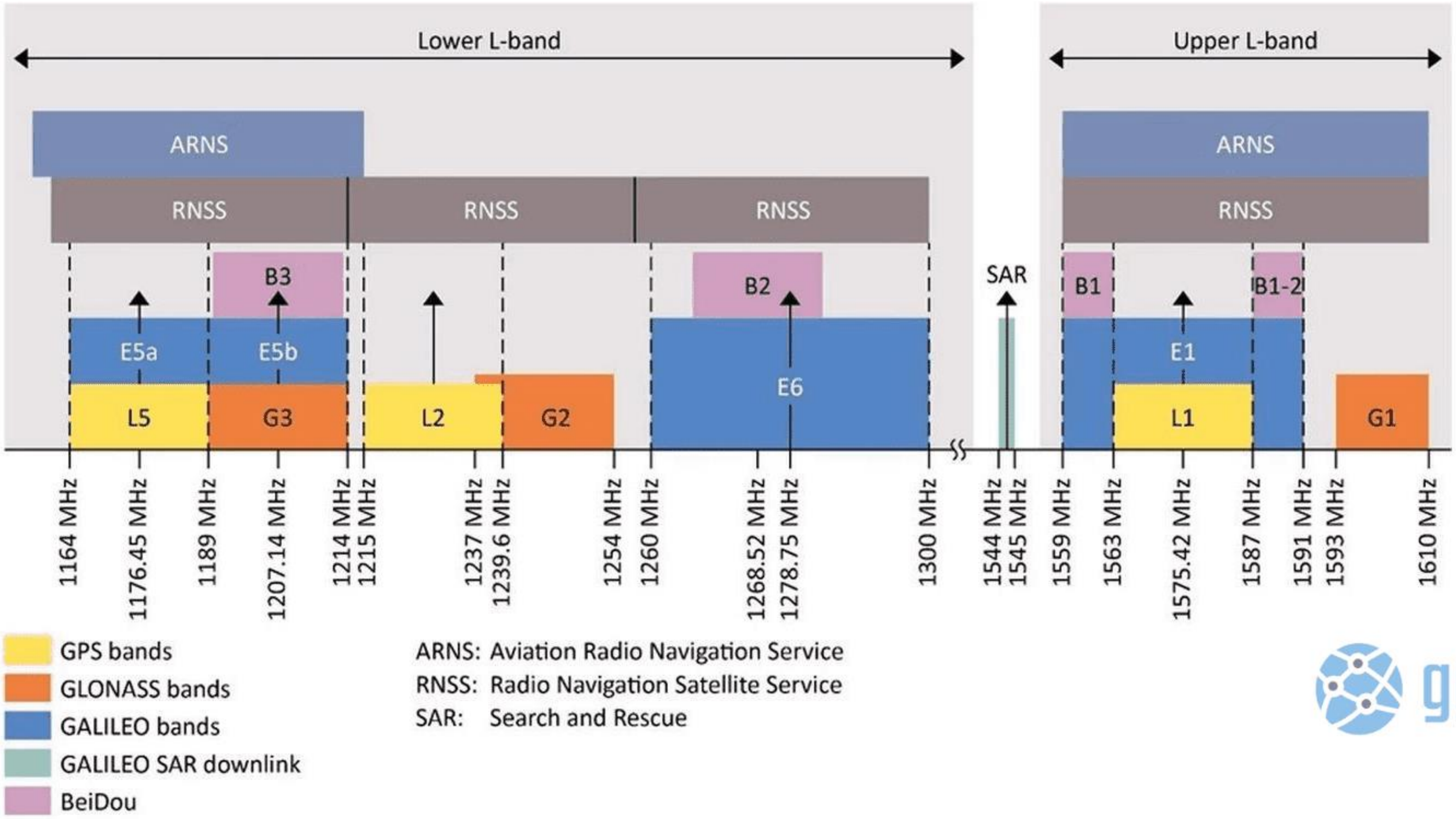
GNSS signal

- GNSS provides (at least) the following information
  - Unique identifier
    - Pseudorandom Noise (PRN) code
  - Timing information
  - Orbital information (ephemeris, almanac)
  - Health status

- Calculating position, velocity, and time (PVT)
  - Coded message
  - Trilateration
  - Doppler shift



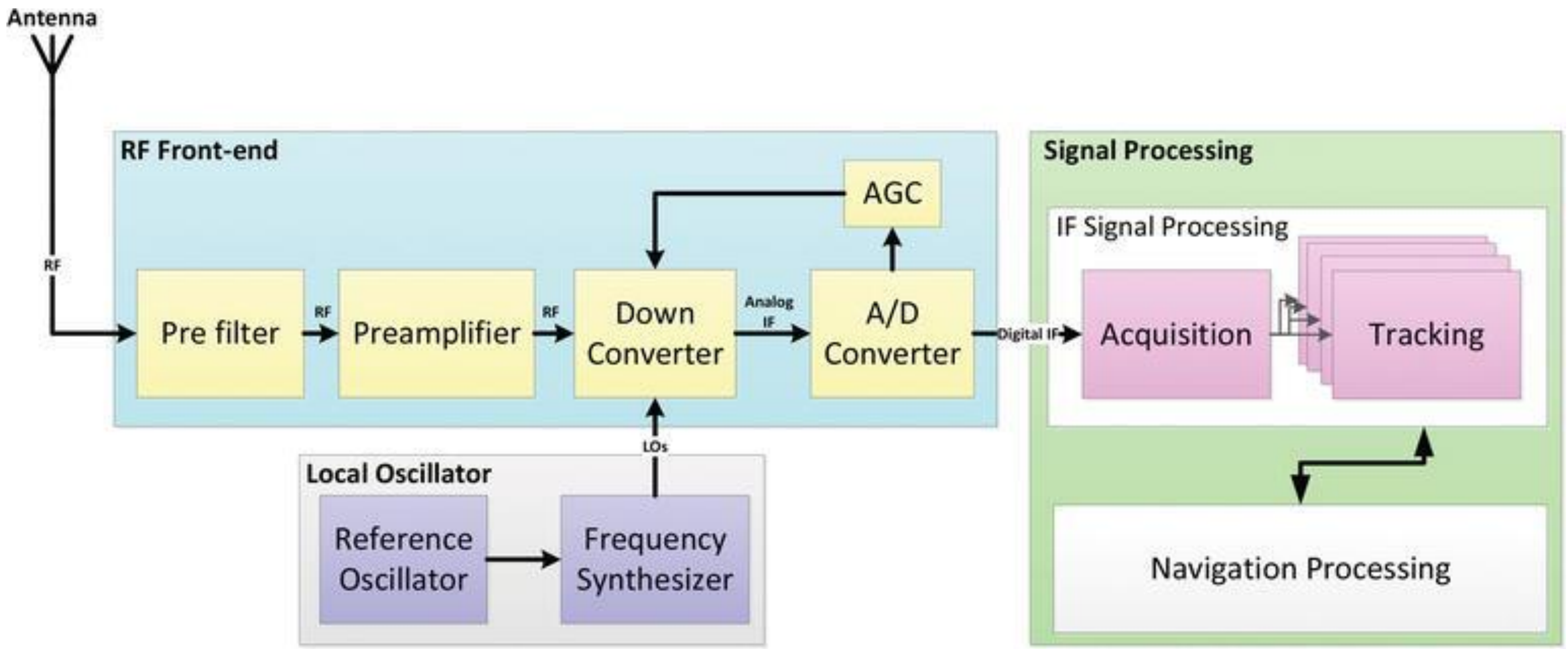
GNSS bands



Lower L-band
Upper L-band
ARNS
RNSS
RNSS
RNSS
ARNS
RNSS
B3
B2
SAR
B1
B1-2
E5a
E5b
E1
E6
L5
G3
L2
G2
L1
G1
1164 MHz
1176.45 MHz
1189 MHz
1207.14 MHz
1214 MHz
1215 MHz
1237 MHz
1239.6 MHz
1254 MHz
1260 MHz
1268.52 MHz
1278.75 MHz
1300 MHz
1544 MHz
1545 MHz
1559 MHz
1563 MHz
1575.42 MHz
1587 MHz
1591 MHz
1593 MHz
1610 MHz
GPS bands
GLONASS bands
GALILEO bands
GALILEO SAR downlink
BeiDou
ARNS: Aviation Radio Navigation Service
RNSS: Radio Navigation Satellite Service
SAR: Search and Rescue

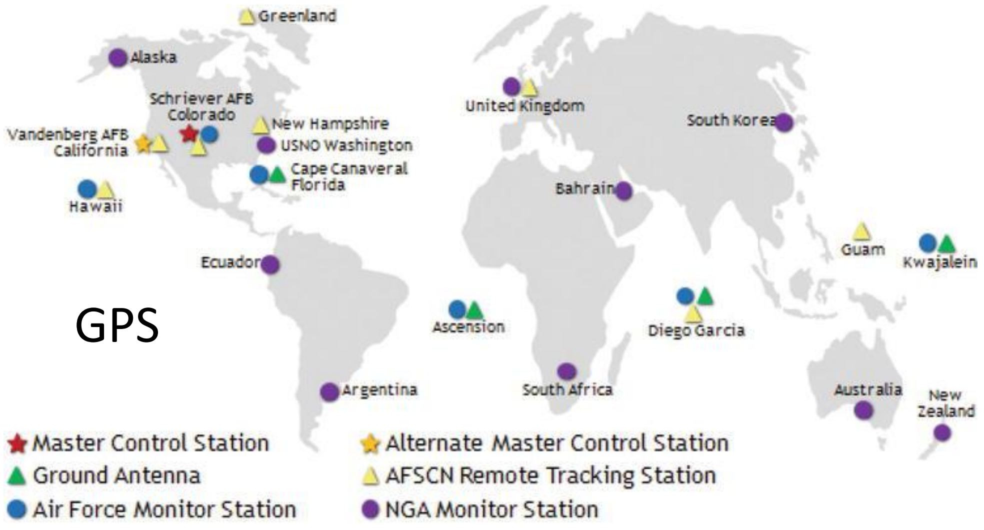
GNSS receiver

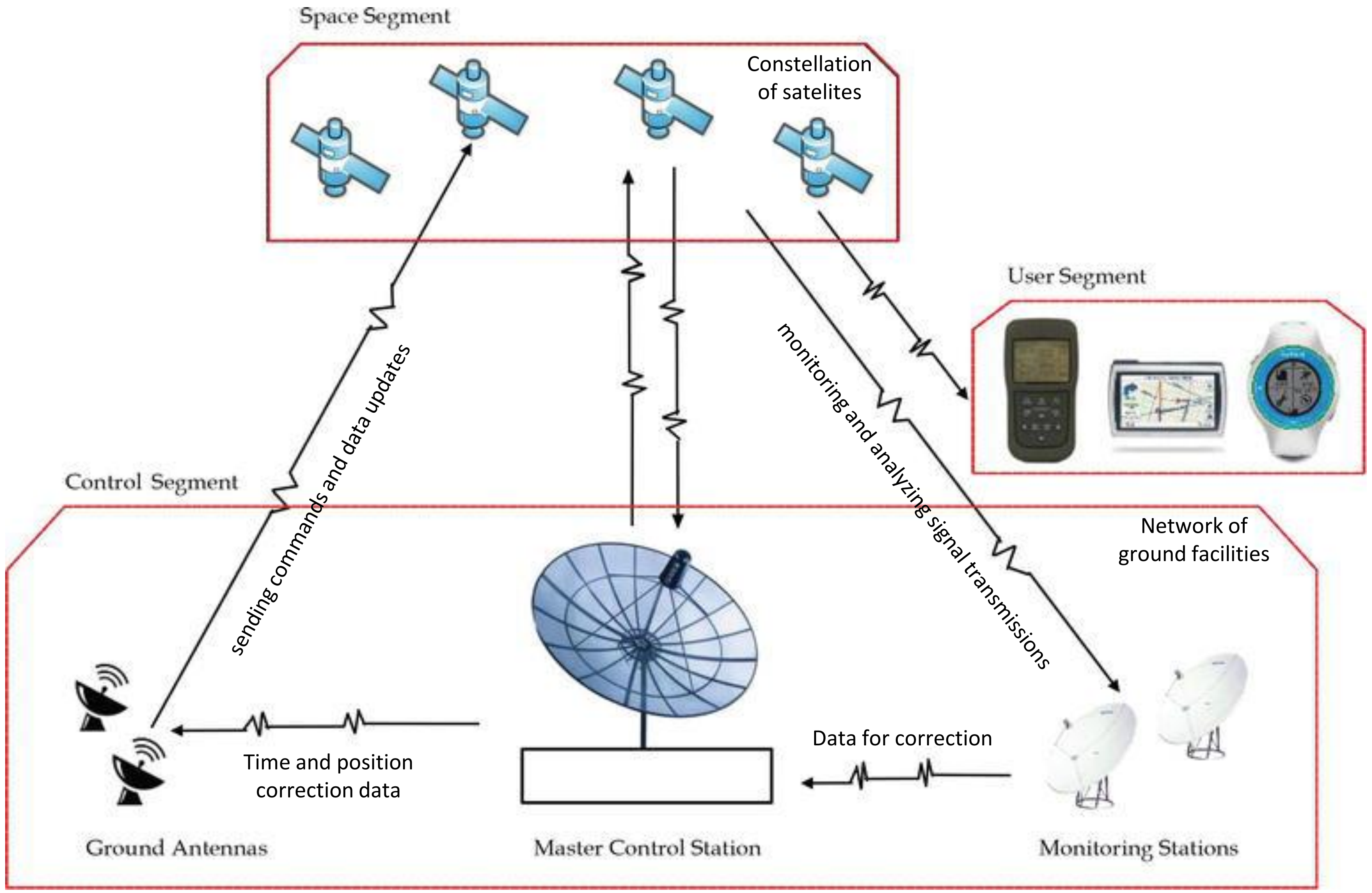
- GNSS receiver components
  - Antenna
  - RF Front-End
  - Signal processing unit
  - Oscillator / clock
  - Memory
  - Power supply
  - Communication interface



GNSS ecosystem

- Global network of ground facilities
  - Master control station
  - Ground antennas
  - Monitoring stations

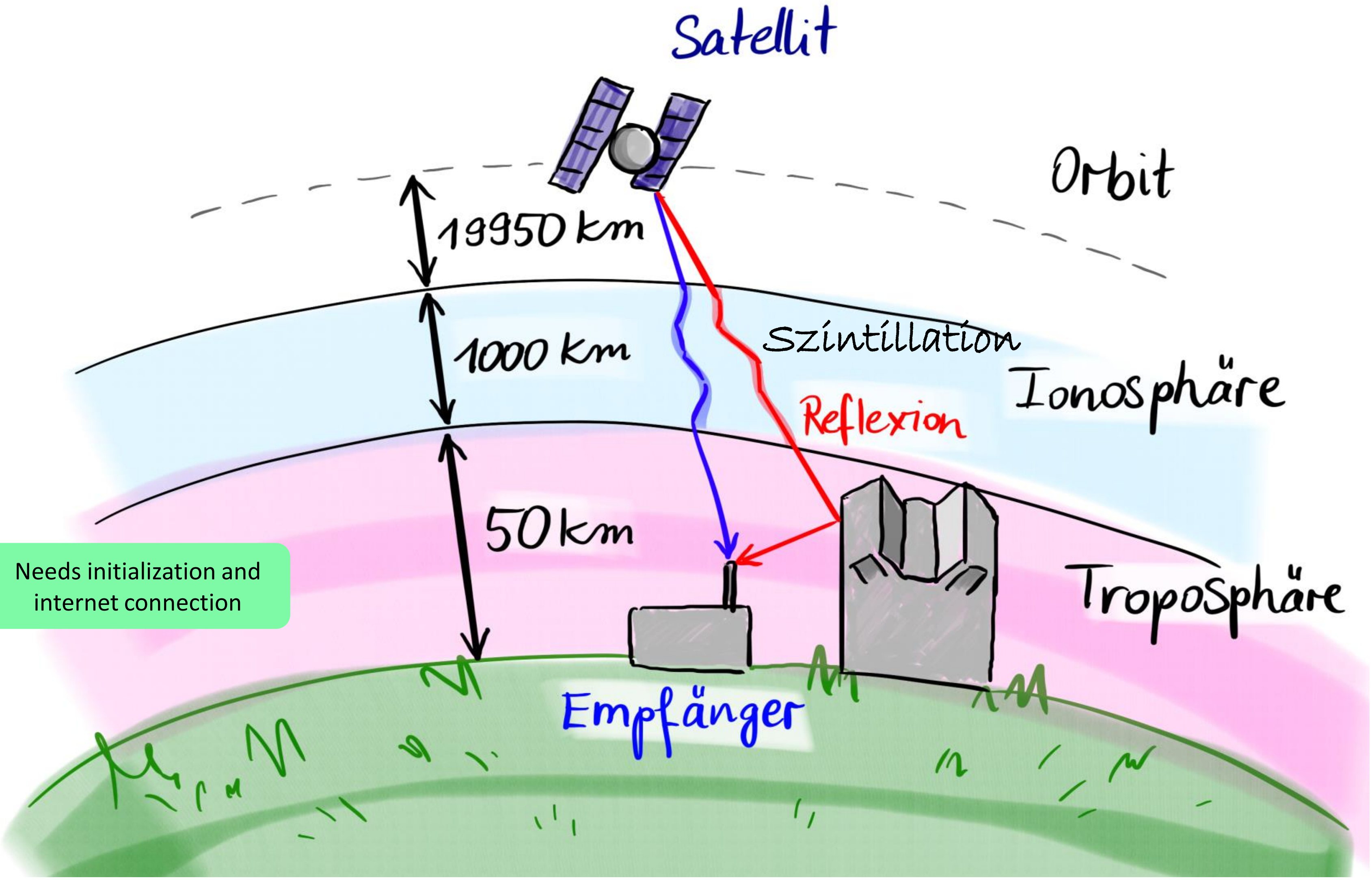




GNSS accuracy

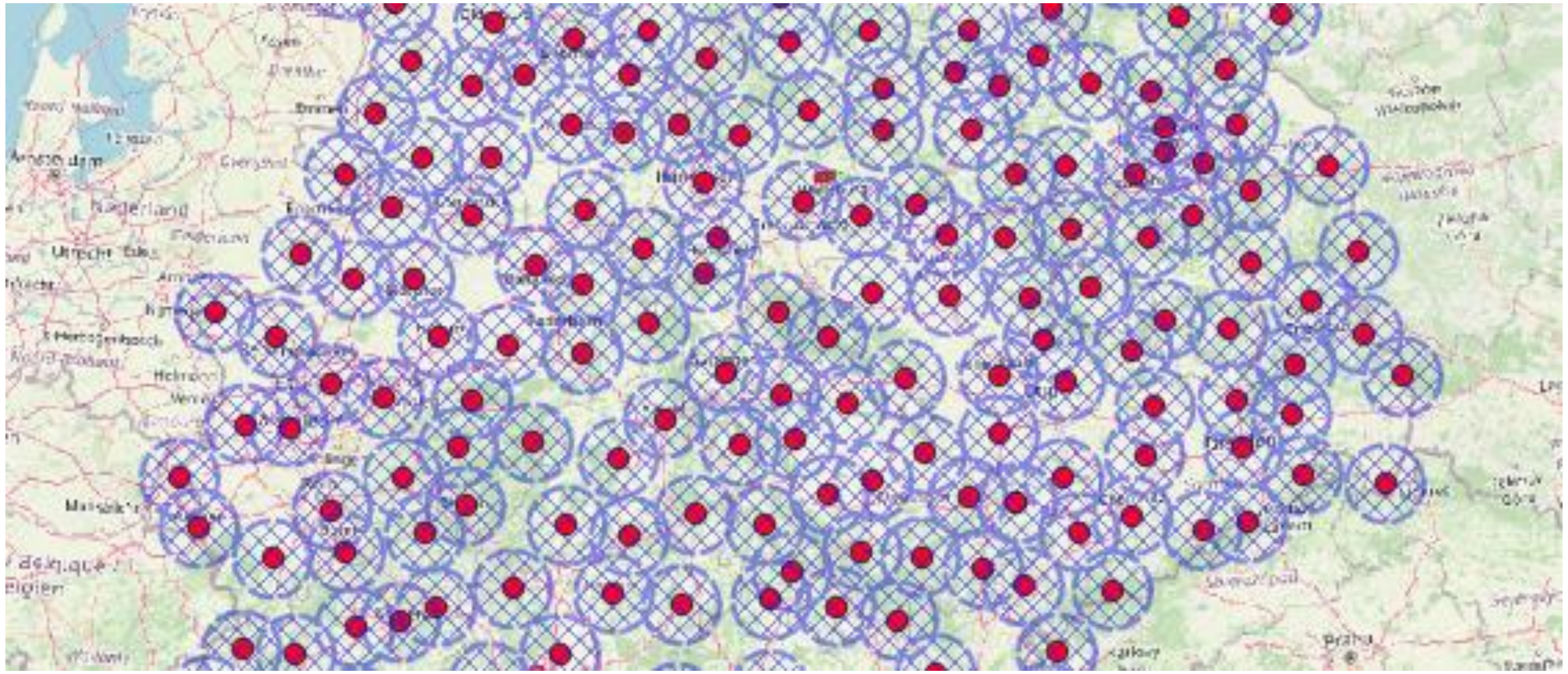
- Real world effects, e.g.:
  - Scintillations
  - Reflections (multi-path)
  - Old ephemerides
  - Outages
- Accuracy of conventional GNSS methods
  - Ideal case: ~ 2 meters
- Accuracy of Precise Point Positioning (PPP)
  - Typically: ~ 0.2 meters by
    - carrier phase of the GNSS signal
    - differential delay of bands
    - up-to-date ephemerides

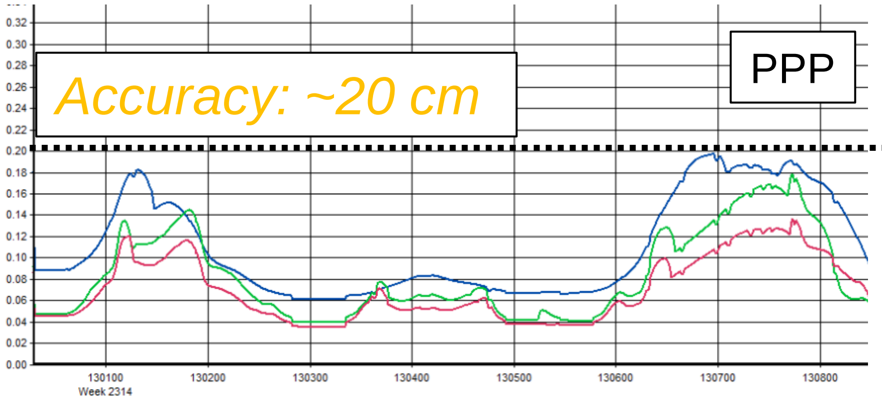
Needs initialization and internet connection

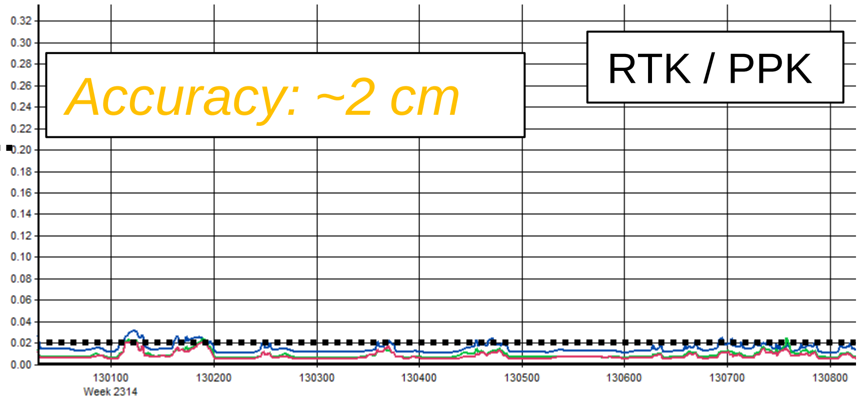


Base stations

- Further correction for higher accuracy
  - Real Time Kinematic (RTK)
  - Post-Processing Kinematic (PPK)
- Implementation
  - Base station network
- Correction:
  - NTRIP
    - Correction signal via GSM network
  - RINEX
    - Correction signal from database







Coordinate systems

- Some typical coordinate systems
  - World Geodetic System 1984 (WGS84)
    - Global geodetic coordinate system
    - Latitude [°], longitude [°], and altitude [m] above WGS84 ellipsoid
  - Earth Centered, Earth Fixed (ECEF)
    - Global cartesian coordinate system
    - X, Y, Z [m] from Earth's center
  - East-North-Up (ENU)
    - Local cartesian coordinate system
    - E, N, U [m] to a reference point
- Coordinate System transformations
  - for further applications e.g. GNSS-INS

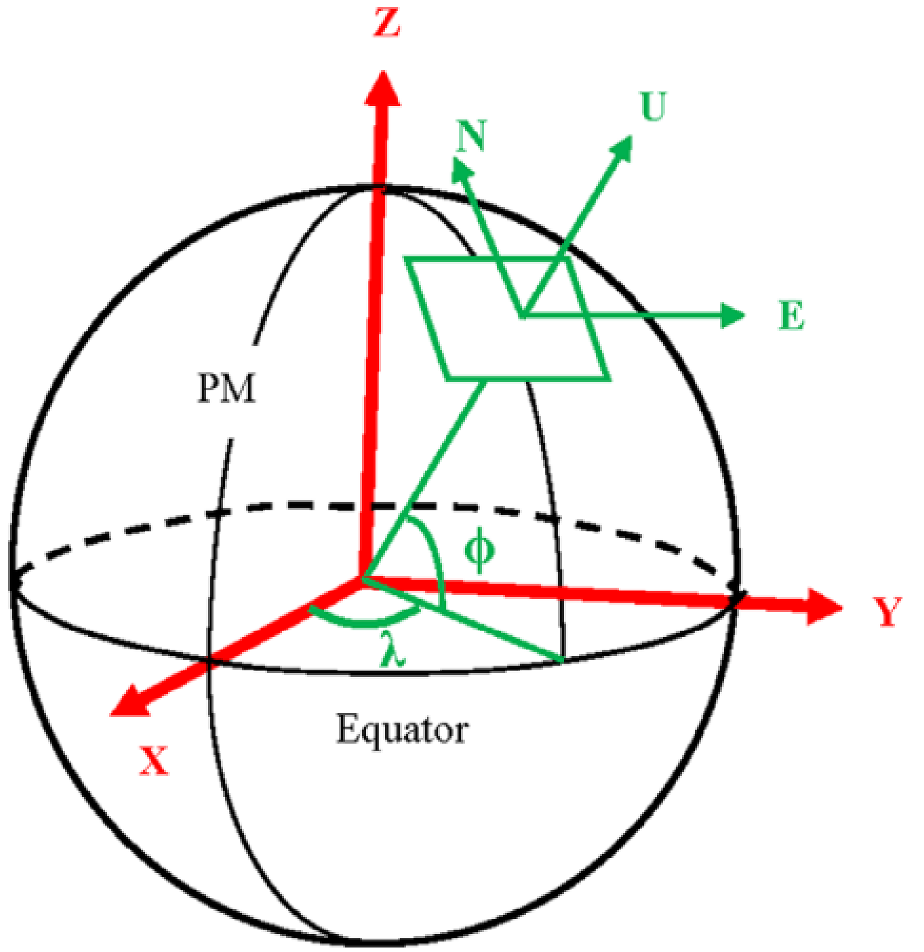
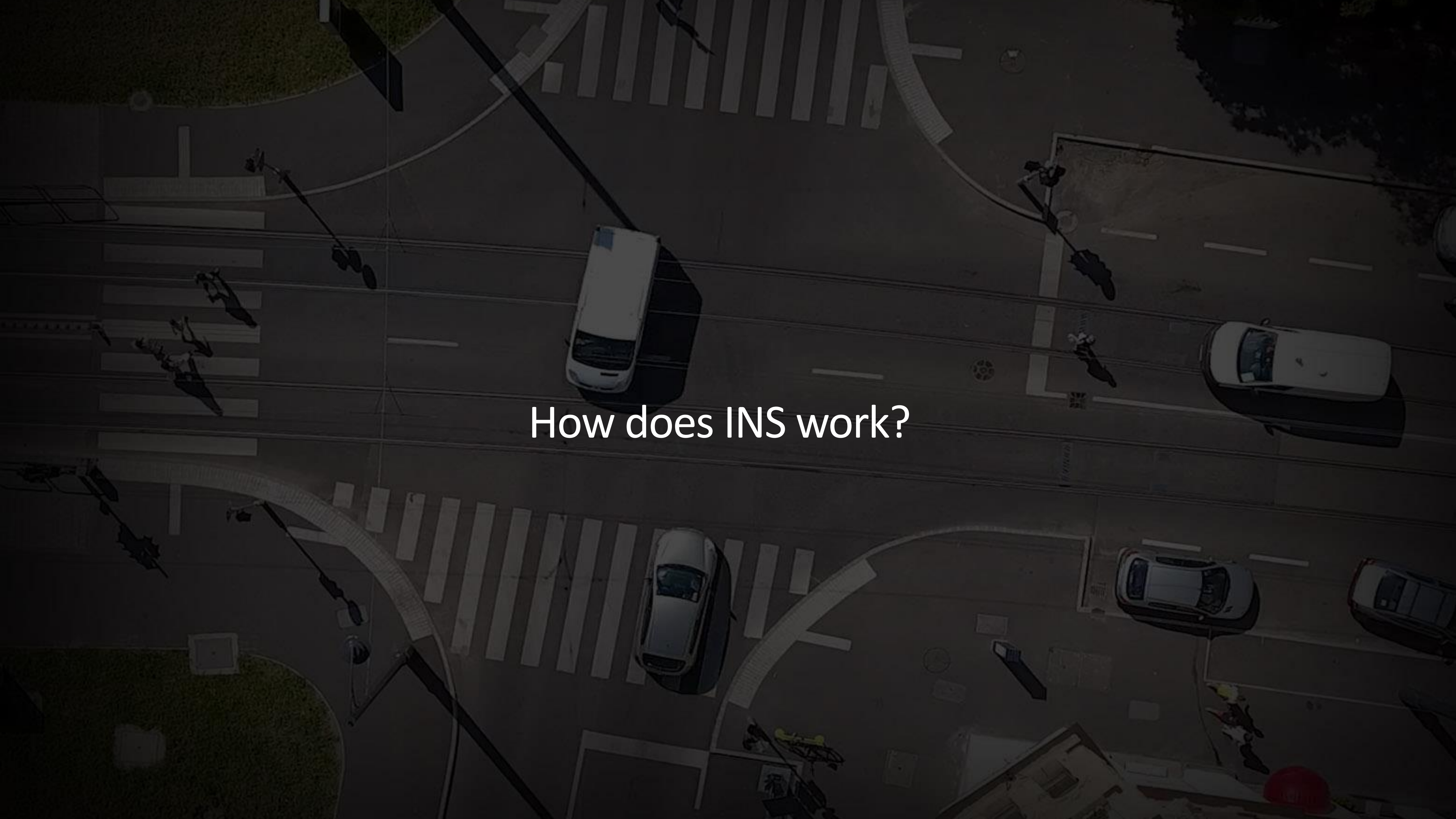


Fig. 3. A schematic diagram for the WGS84, ECEF, and ENU coordinate systems for the Earth and their transformation relationships (PM line is the Prime Meridian; ϕ and λ are latitude and longitude in WGS84; X,Y,Z for ECEF; and E,N,U for ENU).

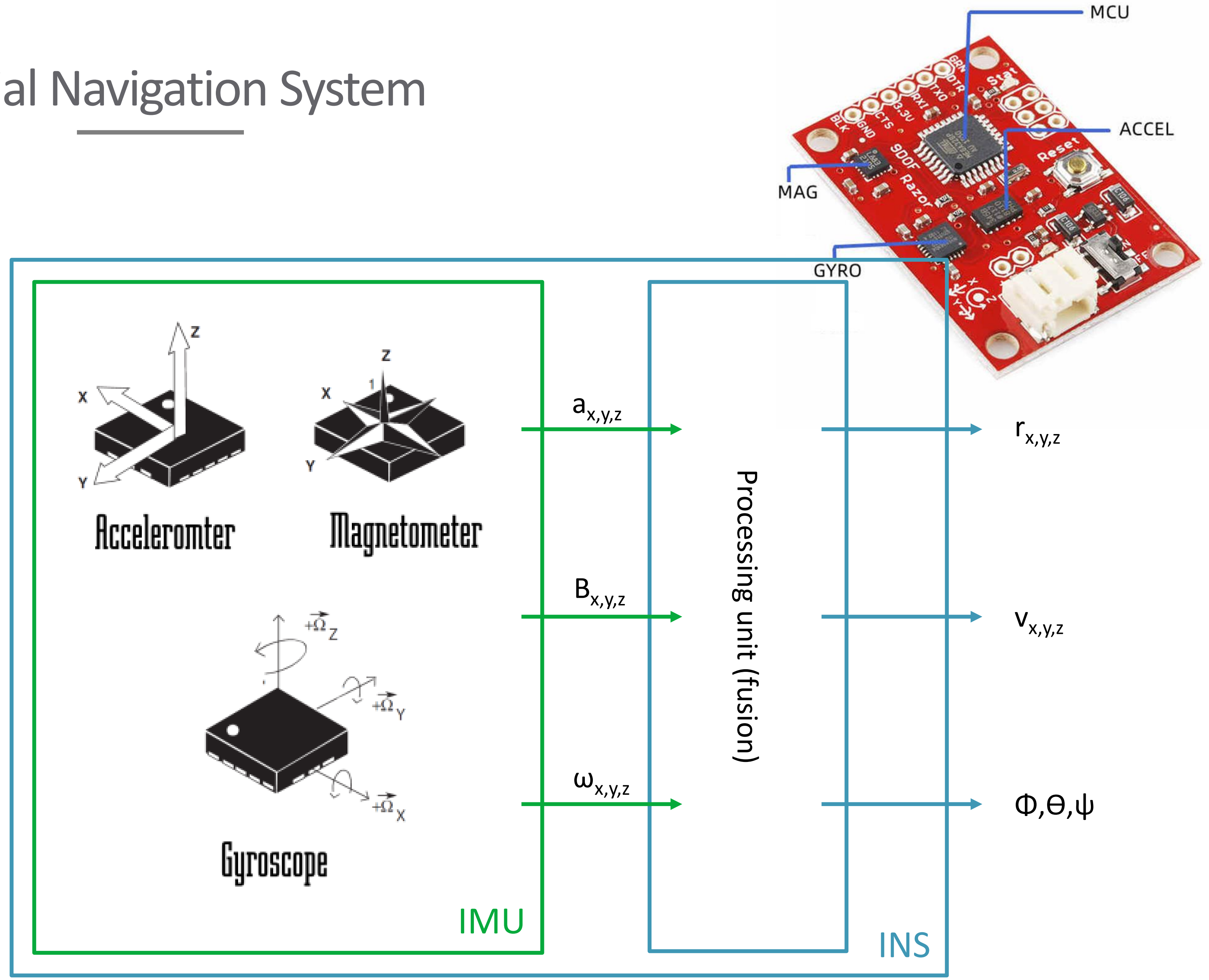


How does INS work?

Inertial Navigation System

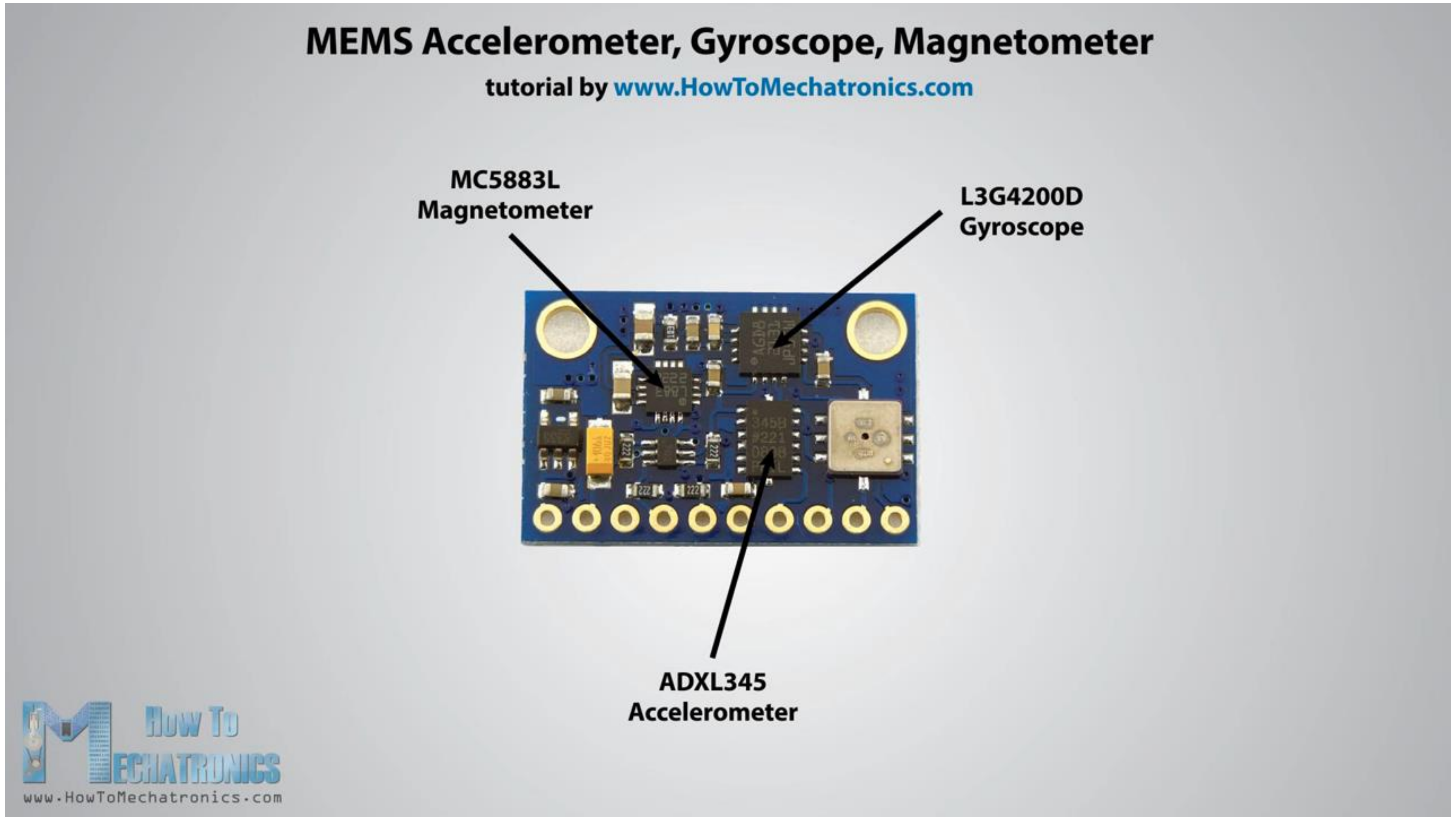
- Inertial Navigation System (INS)
  - Inertial Measurement Unit (IMU)
    - Gyroscopes
    - Accelerometers
    - Magnetometer (optional)
    - Barometric altimeter (optional)
  - Processing unit for calculation of
    - Relative position
    - Relative velocity
    - Orientation

    (dead reckoning)
- Reference:
  - Gravitational force
  - Magnetic field of North-Pole



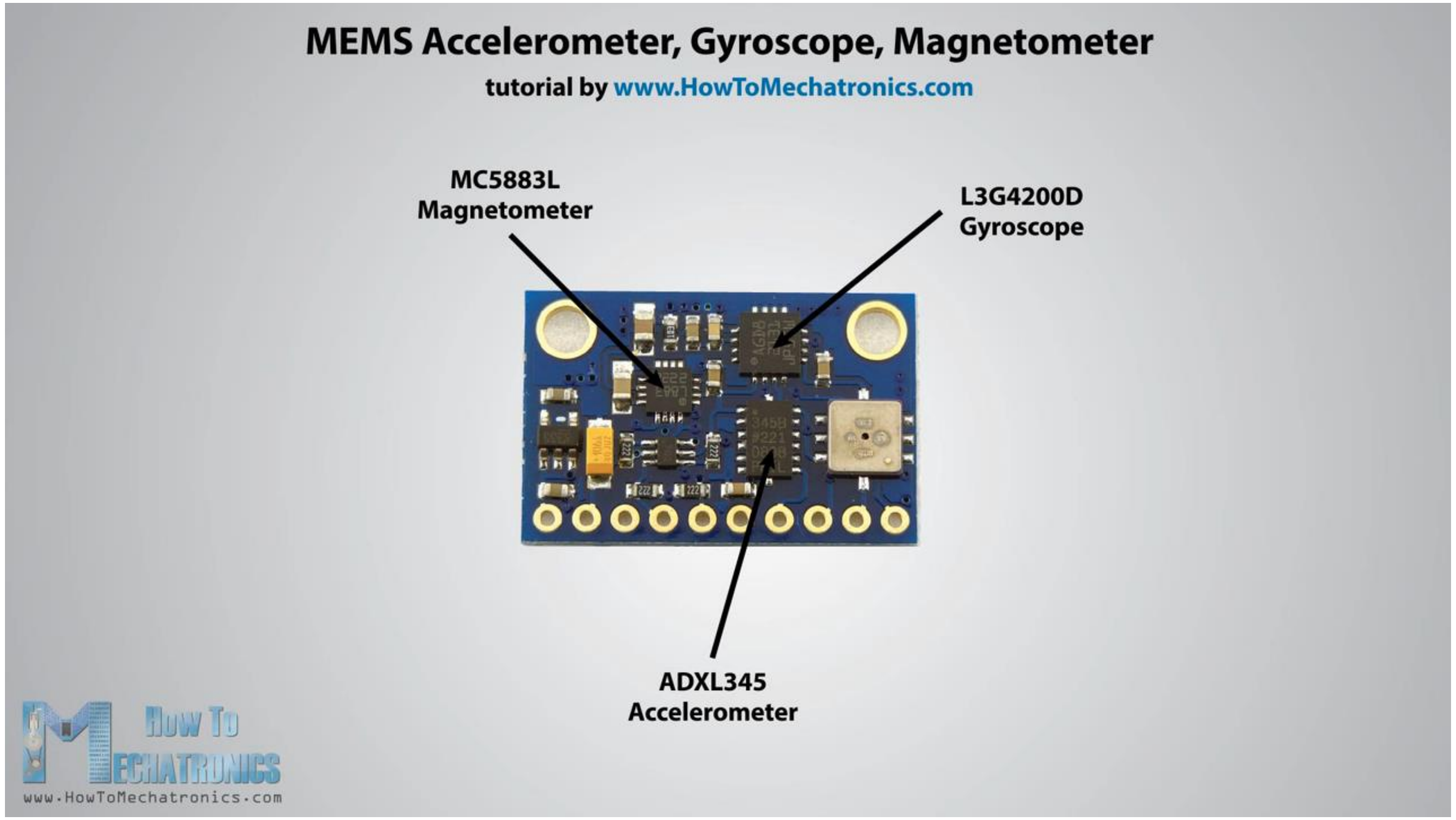
MEMS accelerometer

- Design:
  - Micromachined structure on Si wafer
    - Polysilicon springs
    - Suspended mass
    - Moving and fixed capacitor plates
- Measurement:
  - Hooke's and Newton's 2nd law
  - Deflection alters the capacitance between the moving and fixed capacitor plates
  - Variation in capacitance is proportional to the acceleration along the axis
    - Static acceleration: due to gravity
    - Dynamic acceleration: due to movement



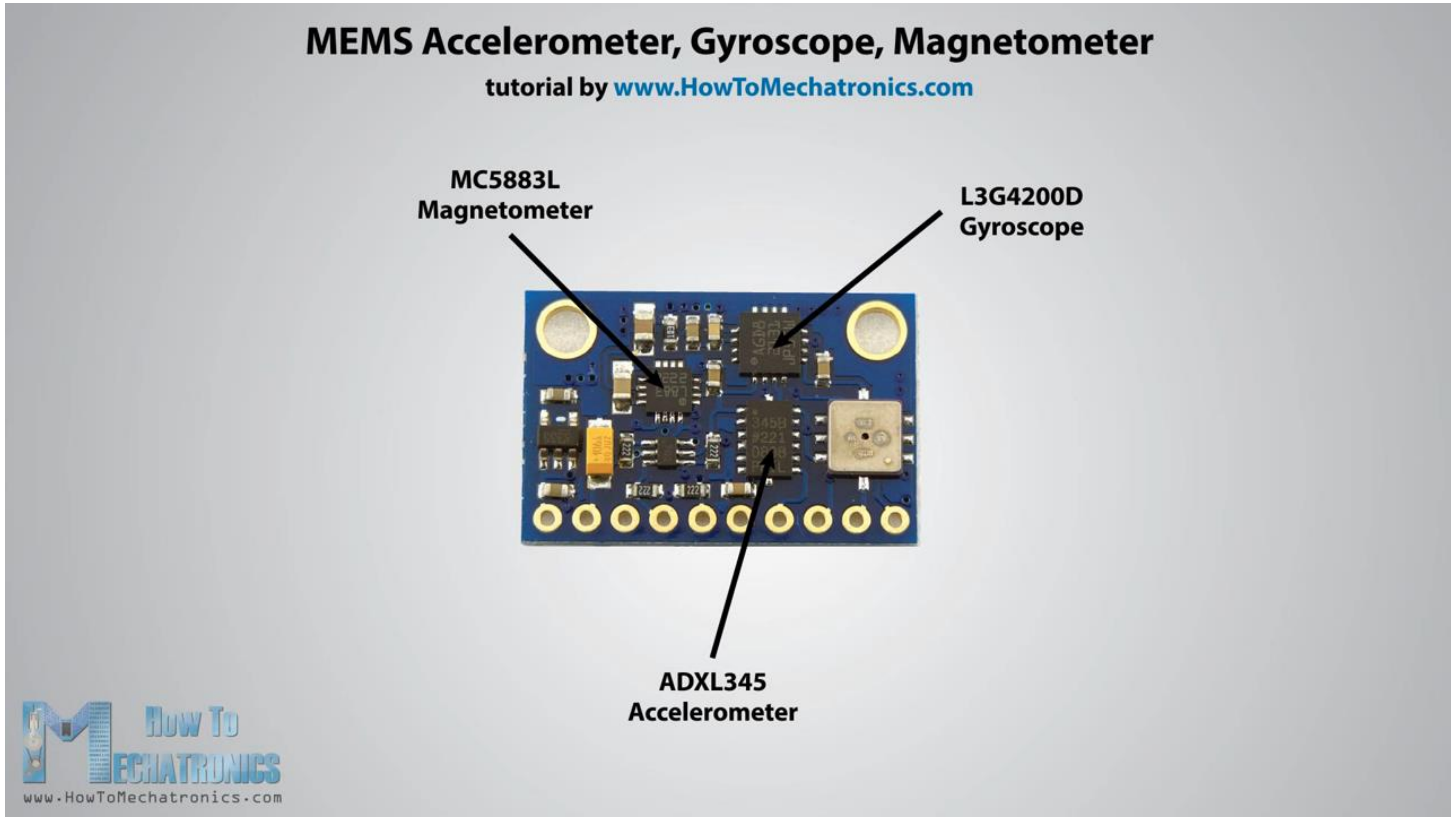
MEMS gyroscope

- Design:
  - Micromachined structure on Si wafer
    - Polysilicon springs
    - Resonating mass
    - Tuning fork design
- Measurement:
  - Coriolis effect
  - Deflection alters the capacitance between the vibrating and fixed capacitor plates
  - Variation in capacitance is proportional to the angular velocity around the axis

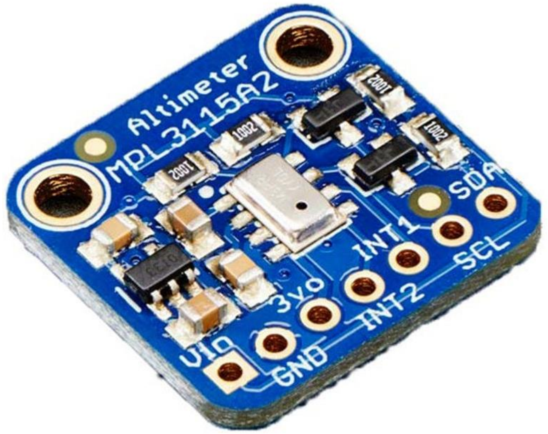


MEMS magnetometer

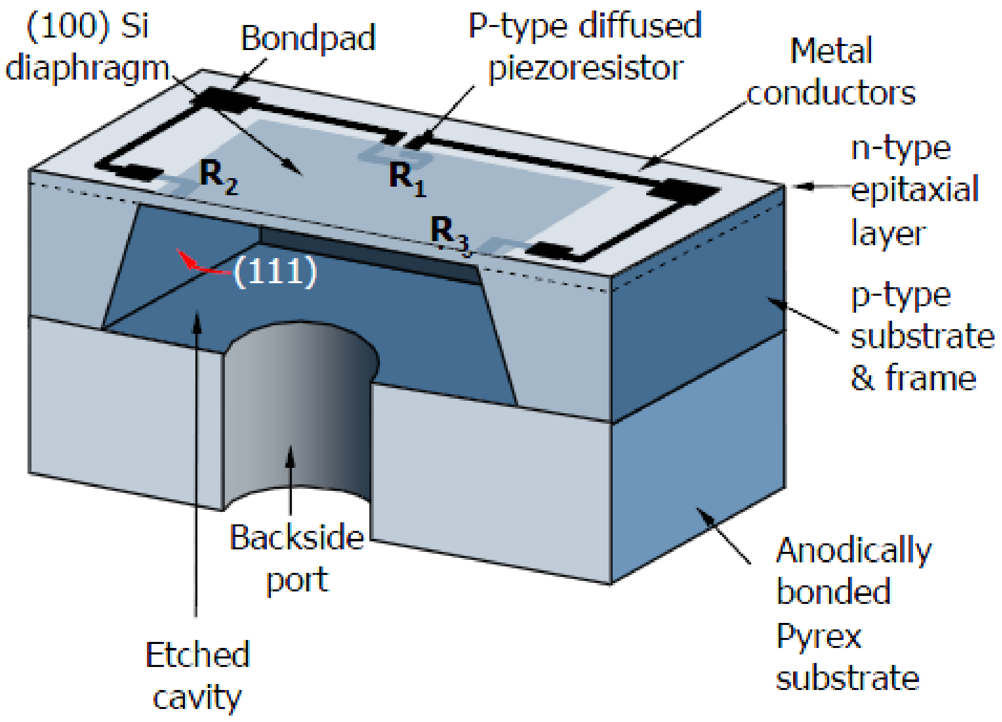
- Design:
  - Micromachined structure on Si wafer
    - Hall effect sensor
    - Magneto-resistive sensor
      - Thin film deposition
- Measurement:
  - Hall Effect Sensors: Generate a voltage that is proportional to the magnetic field when current flows through the sensor.
  - Magneto-resistive Sensors: Change in electrical resistance due to the alignment of magnetic domains in response to external magnetic fields.
  - The output of the sensor is proportional to the strength and direction of the magnetic field along the axis



MEMS altimeters

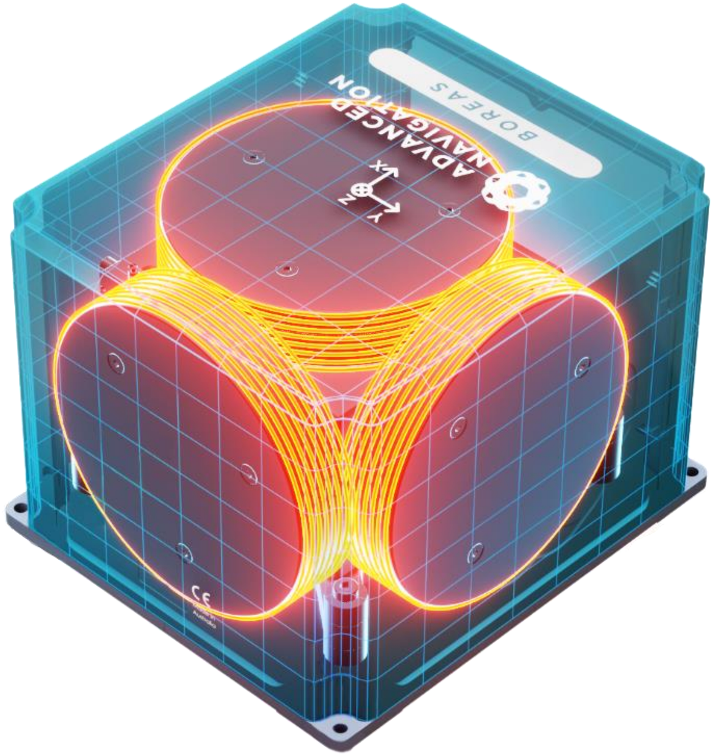


- Design:
  - Micromachined structure on Si wafer
    - Diaphragm
    - Capacitive elements or
    - Piezoresistive elements
- Measurement:
  - Changes in pressure causes deformation in a diaphragm
    - Capacitive sensors: Changes in the distance between capacitor plates result in variation of capacitance.
    - Piezoresistive Sensors: Changes in resistance due to the stress on the sensor elements.



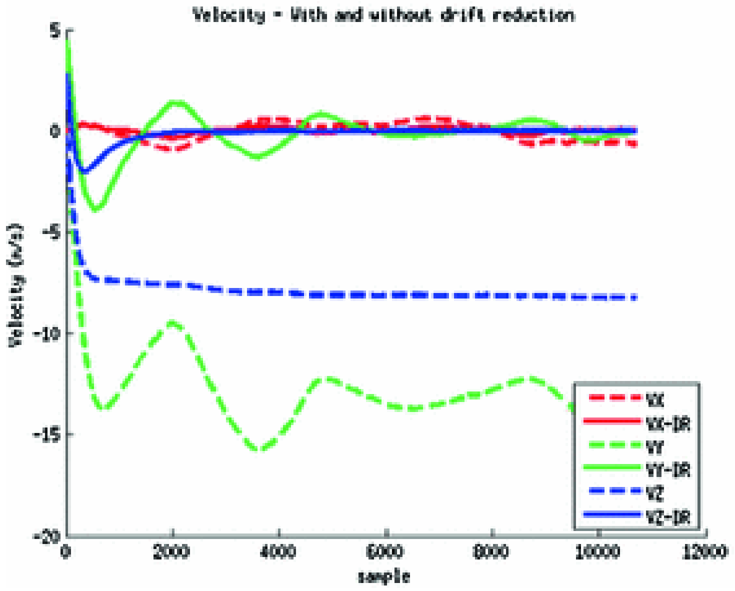
Fiber optic gyroscopes

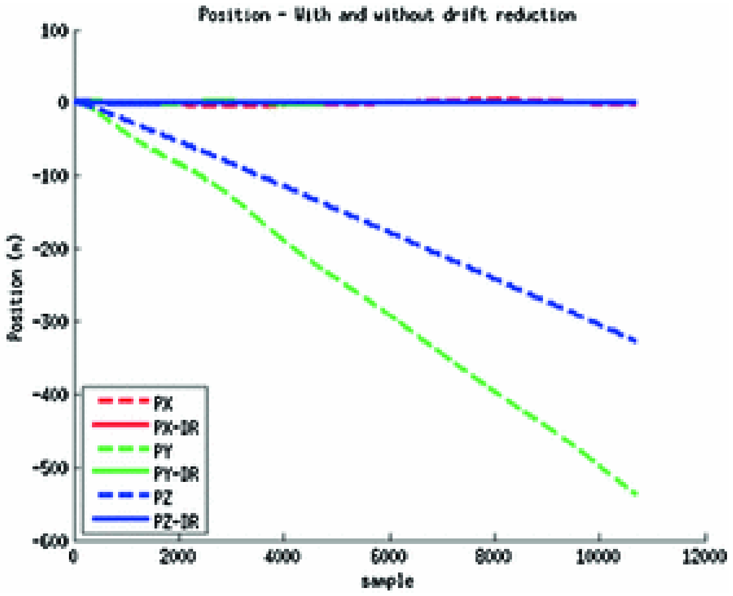
- Design:
  - Coil of optical fiber
    - Coil of several kilometer
    - Coherent light source (laser)
    - Interferometer
- Measurement:
  - Sagnac effect: phase shift between two counter-propagating light beams in a rotating frame
  - The phase difference measured by an interferometer is directly proportional to the rate of rotation, i.e. angular velocity.



Challenges

- Sources of inaccuracy
  - Imperfect calibration
  - Measurement errors
    - Imperfect measurement
    - Measurement noise
    - Numerical inaccuracies
  - Imperfect algorithms
- Impact: inaccurate dead reckoning (drift)
- Solution: GNSS-INS fusion
  - Suppressing errors from inaccuracies
- GNSS signal outage or low quality
  - Disrupts the correction process





GNSS-INS performance

Performance metrics

- Some relevant performance metrics
  - Signal tracking
  - Position, velocity, orientation accuracy
  - Position, velocity, orientation drift
  - Measurement limits (dynamic range)
  - Initialization time
  - Data rate

  - Power consumption
  - Ingress protection rating (wiki)
  - Mechanical resistance
  - Operating temperature
  - Communication interface
  - Compliance

  - Example 1
  - Example 2

Performance[1]

Signal tracking

GPS	L1 C/A, L1C, L2C, L2P, L5
GLONASS[2]	L1 C/A, L2 C/A, L2P, L3, L5
Galileo[3]	E1, E5 AltBOC, E5a, E5b, E6
BeiDou	B1I, B1C, B2I, B2a, B2b, B3I
QZSS	L1 C/A, L1C, L1S, L2C, L5, L6
NavIC (IRNSS)	L5
SBAS	L1, L5
L-Band	up to 5 channels

Horizontal position accuracy (RMS)

Single point L1/L2	1.2 m
SBAS[4]	60 cm
TerraStar-L[5]	40 cm
TerraStar-C PRO[5]	2.5 cm
TerraStar-X[5]	2 cm
RTK	1 cm + 1 ppm

Maximum data rate

GNSS measurements	up to 20 Hz
GNSS position	up to 20 Hz
INS solution	up to 200 Hz
IMU raw data rate	200 Hz

Time to first fix[6]

Cold start	< 34 s (typ)
Hot start	< 20 s (typ)

Time accuracy[7] < 5 ns RMS

Velocity limit[8] 600 m/s

IMU performance[9]

Gyroscope performance

Technology	MEMS
Dynamic range	450 °/s
Bias instability[10]	0.8 °/hr
Angular random walk[10]	0.06 °/√hr

Accelerometer performance

Technology	MEMS
Dynamic range	10 g
Bias instability[10]	0.012 mg
Velocity random walk[10]	0.025 m/s/√hr

Environmental

Temperature

Operating	-40°C to +75°C
Storage	-40°C to +85°C

Humidity 95% non-condensing

Ingress protection rating IP67

Vibration (operating)

Random MIL-STD 810H, Method 514.8

Profiles:
- Rail CAT 11 – 0.5 g RMS
- Composite wheeled vehicle CAT 4 – 2.24 g RMS
- Aircraft propeller CAT 13 – 4.5 g RMS

Acceleration (operating) MIL-STD-810H, Method 513.8, Procedure II (16 g)

Bump (operating) IEC 60068-2-27 (25 g)

Shock (operating) MIL-STD-810H, Method 516.8, Procedure 1, 40 g 11 ms terminal sawtooth

Compliance

FCC, ISED, CE and Global Type Approvals

Physical and electrical

Dimensions	147 x 125 x 55 mm
Weight	560 g

Power

Input voltage	+9 to +36 VDC
Power consumption[11]	3.4 W

Antenna LNA power output

Output voltage	5 VDC ±5%
Maximum current	200 mA

Connectors

Antenna	TNC
USB device	Micro A/B
USB host	Micro A/B
Serial, CAN, Event I/O	DSUB HD26
Ethernet	RJ45
Power	SAL M12, 5 pin, male

Communication ports

1 RS-232	up to 460,800 bps
2 RS-232/RS-422 selectable	up to 460,800 bps
1 USB 2.0 (device)	HS
1 USB 2.0 (host)	HS
1 Ethernet	10/100 Mbps
1 CAN Bus	1 Mbps
1 Wi-Fi	
3 Event inputs	
3 Event outputs	
1 Pulse Per Second (PPS) output	
1 Quadrature wheel sensor input	

Status LEDs

Power, GNSS, INS, Data logging, USB

Included accessories

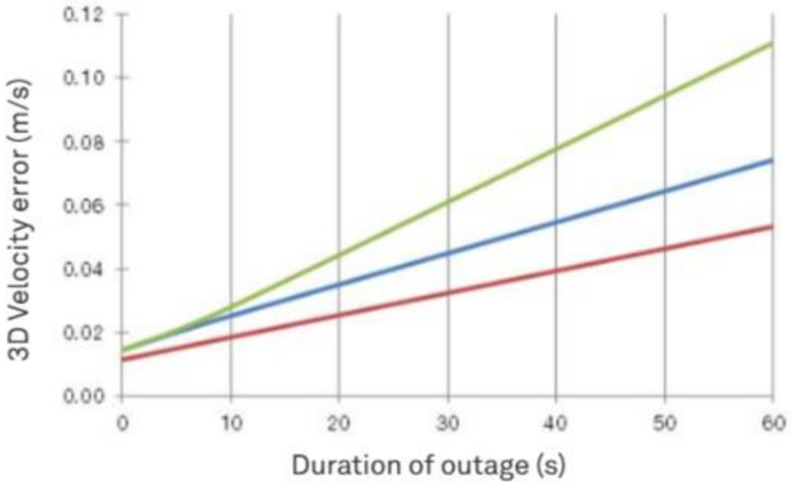
- Power cable
- USB cable
- DSUB HD26 to DB9 RS-232 cable

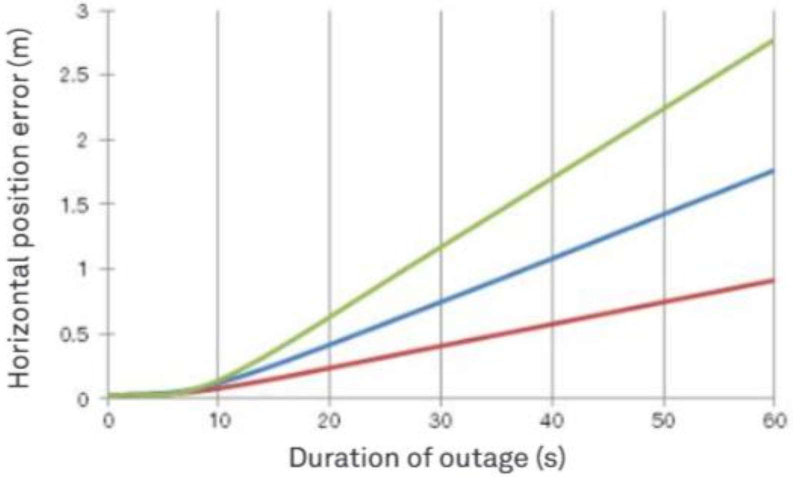
Optional accessories

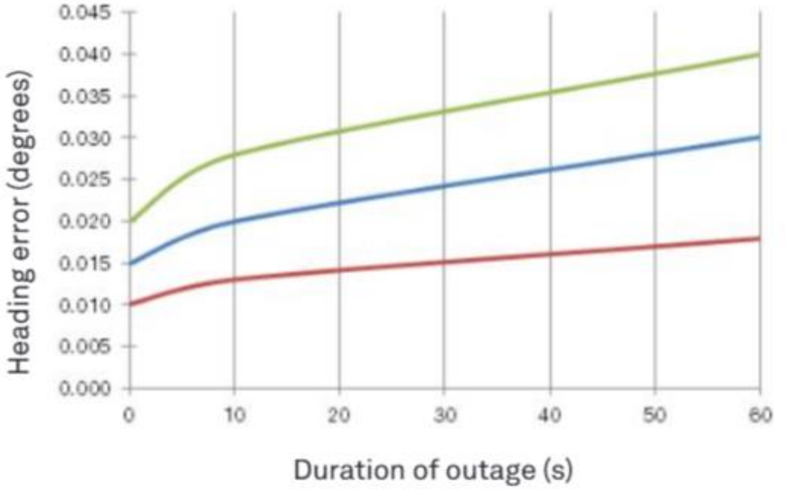
- Full breakout cable for DSUB HD26
- DSUB HD26 to M12 IMU cable

Performance tests

- Test procedures and performance criteria
  - ISO 17123-8
  - ISO 25082-1
- Comparisons
  - Example 1
  - Example 2
- Evaluation reports of manufacturers / users
  - Example 3

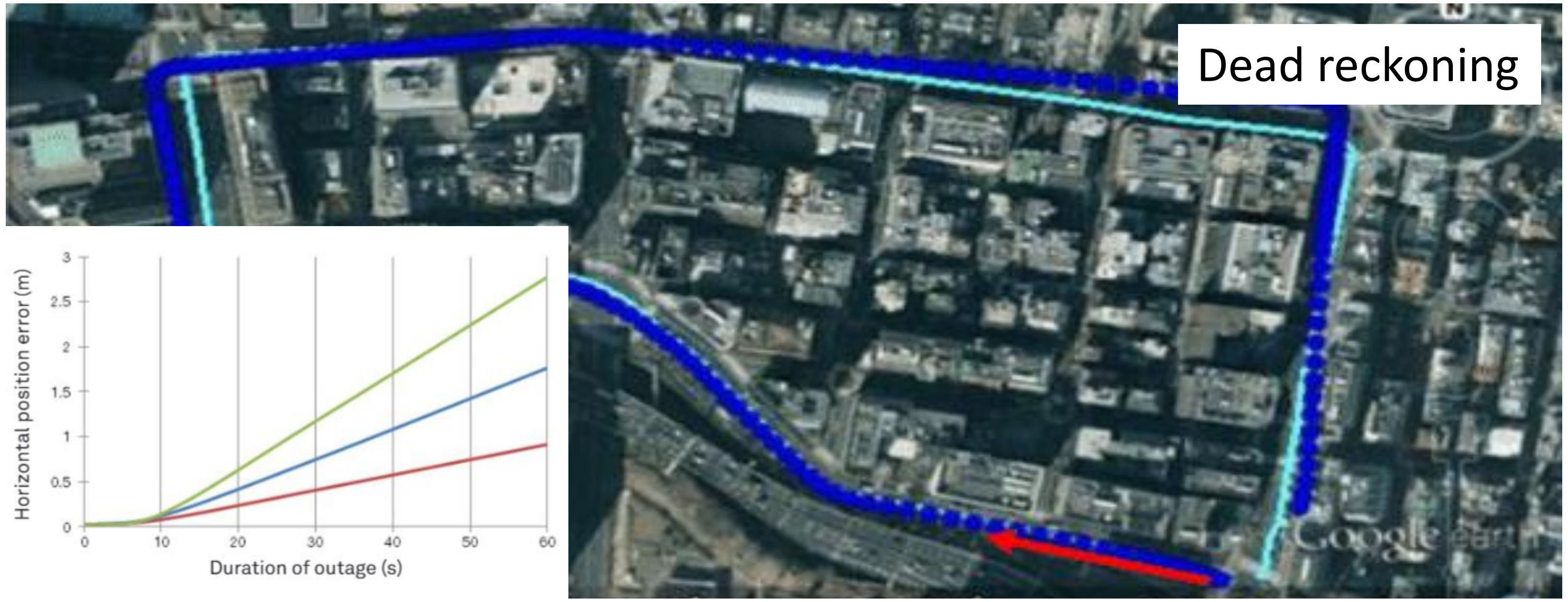


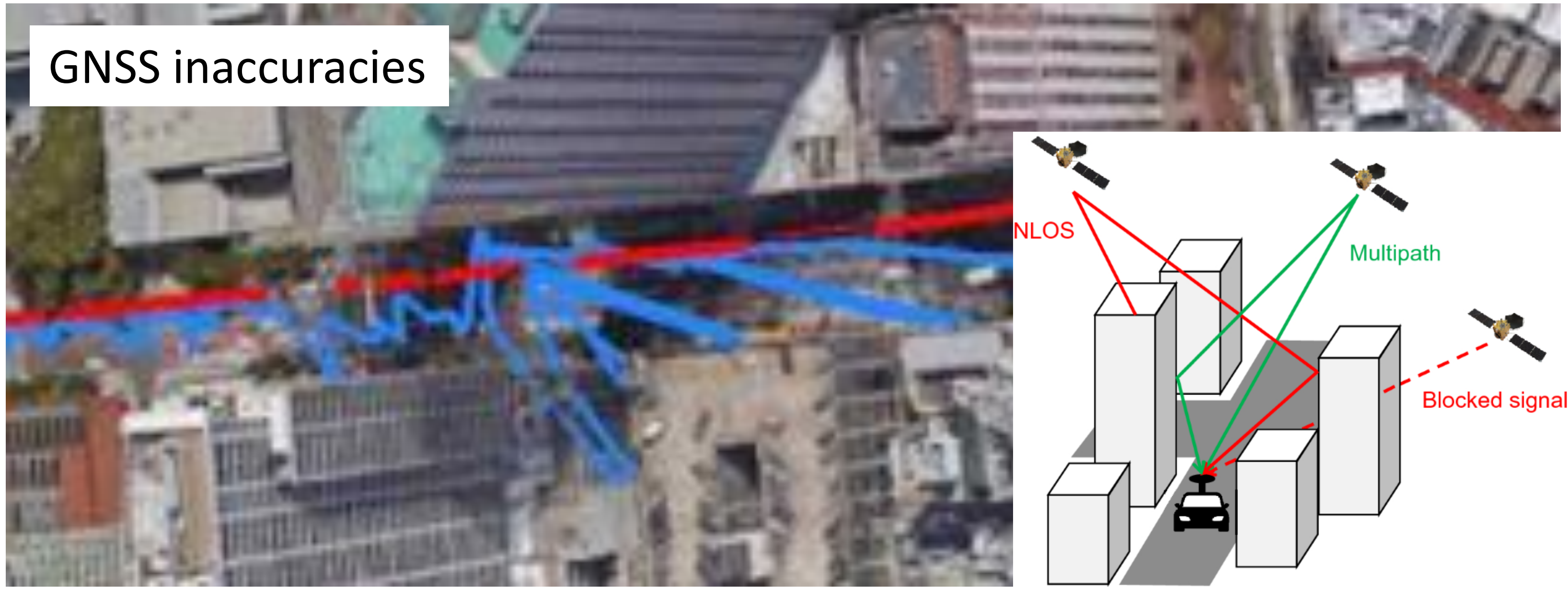




Performance limitations

- GNSS
  - Ephemeris inaccuracies
  - Correction data inaccuracies
  - Ionospheric and tropospheric disturbances
  - Multipath effects
  - Antenna quality, receiver sensitivity
  - Signal outage, GNSS jamming or spoofing
- INS
  - Accuracy limitations (noise)
  - Sensor drift
  - Temperature sensitivity
  - Vibration and mechanical shock
- GNSS-INS
  - Calibration inaccuracies
  - Data latency
  - Data fusion inaccuracies



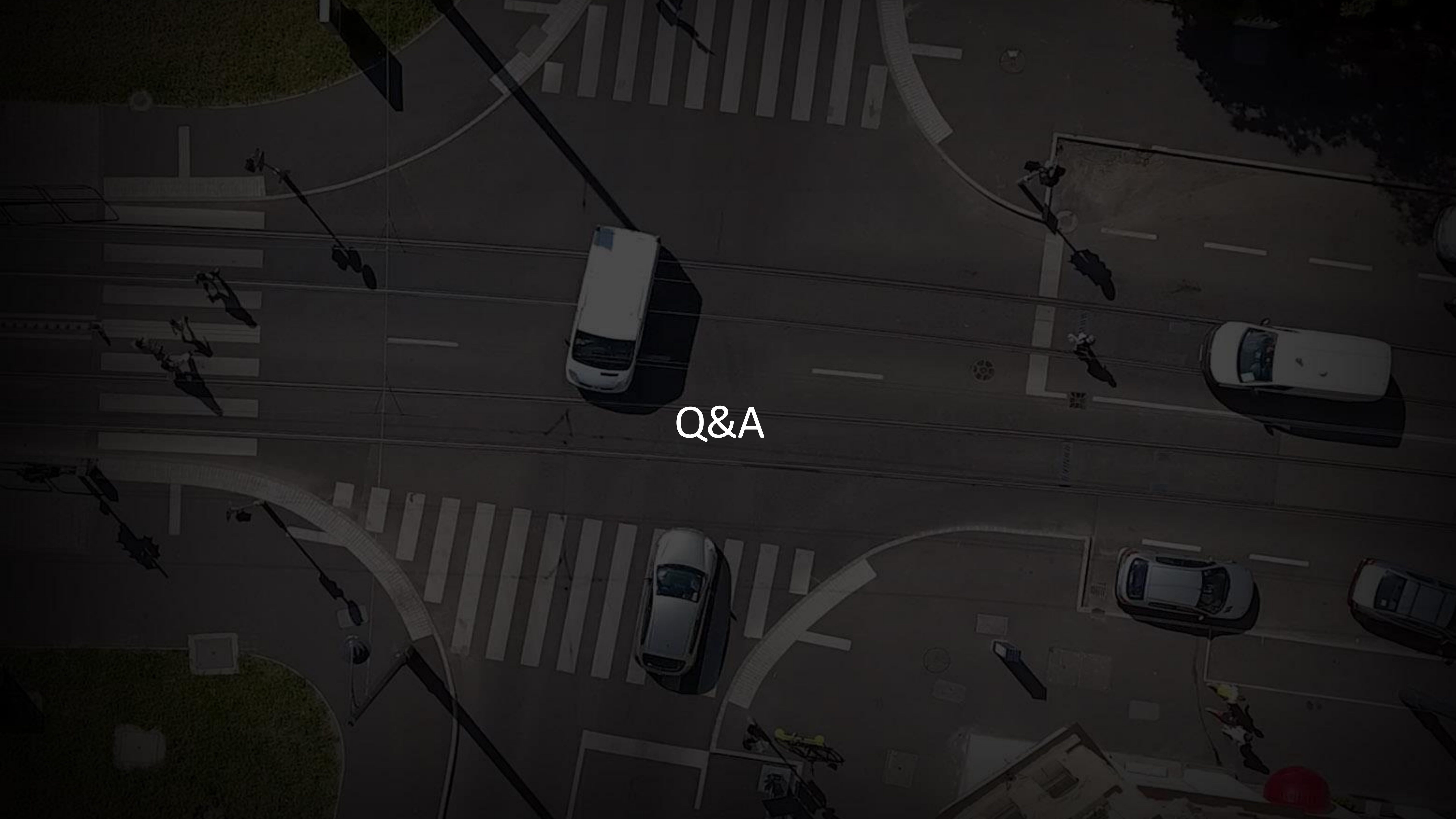


Automotive GNSS-INSs

Relevant manufacturers

Some relevant automotive GNSS-INS manufacturers

- Advanced Navigation
- Applanix (Trimble subsidiary)
- CHCNAV
- Honeywell
- KVH Industries
- iMAR Navigation
- Inertial Labs
- NovAtel (Hexagon)
- OxTS (Oxford Technical Solutions)
- SBG Systems
- Septentrio
- Trimble
- Ublox
- Unicore
- VectorNav Technologies
- Xsens



Q&A