Fundamentals of Satellite Navigation

Halmat Atta Ali

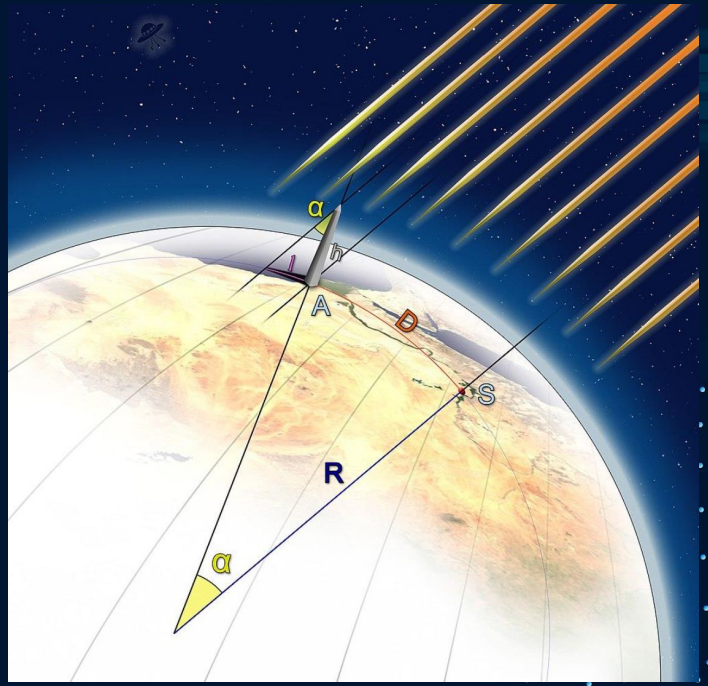
BRGTC

We Live on a Ball

Eratosthenes

Born: 276 BPE

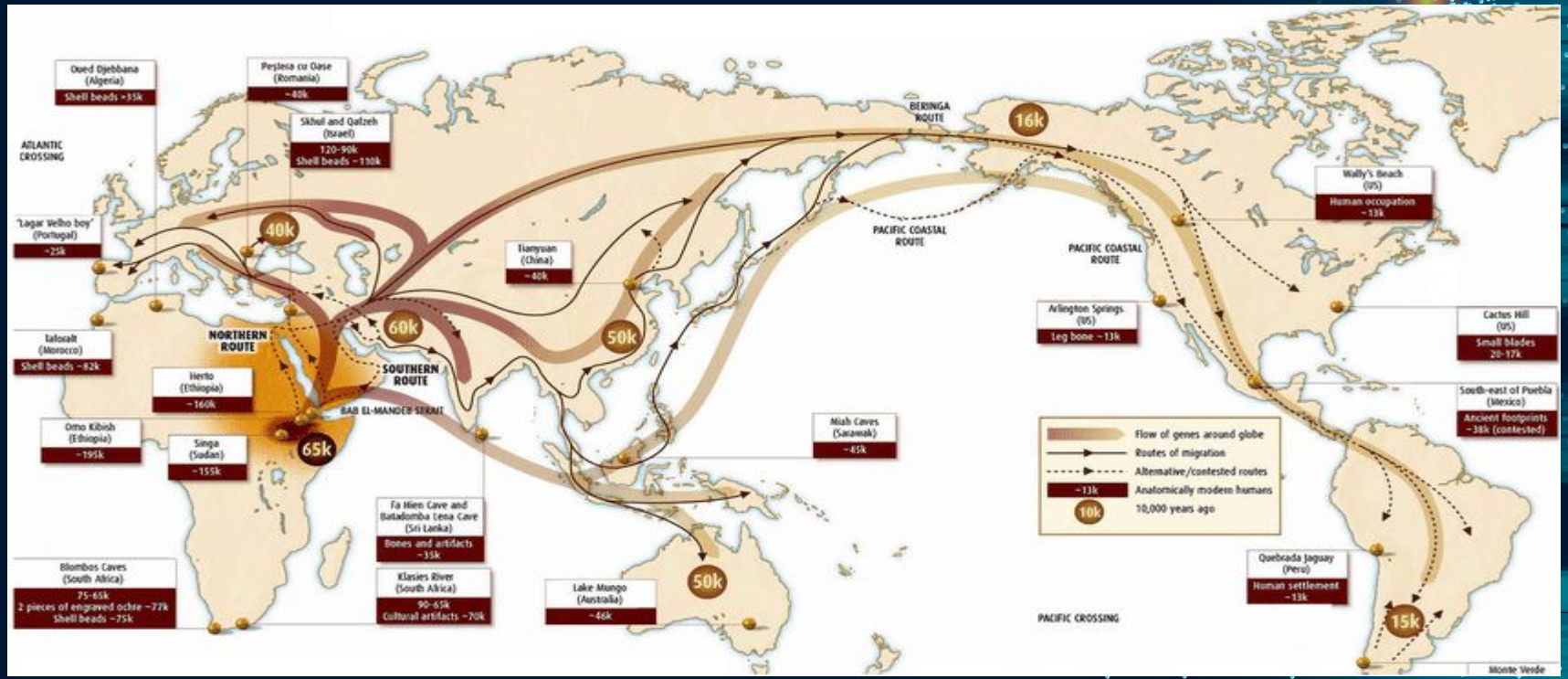
Cyrene (in modern Libya)



"Oh that's just a myth. It wasn't one extra straw that did this. It was a Steinway."

Early Evidence of Man’s Understanding of Animal Navigation

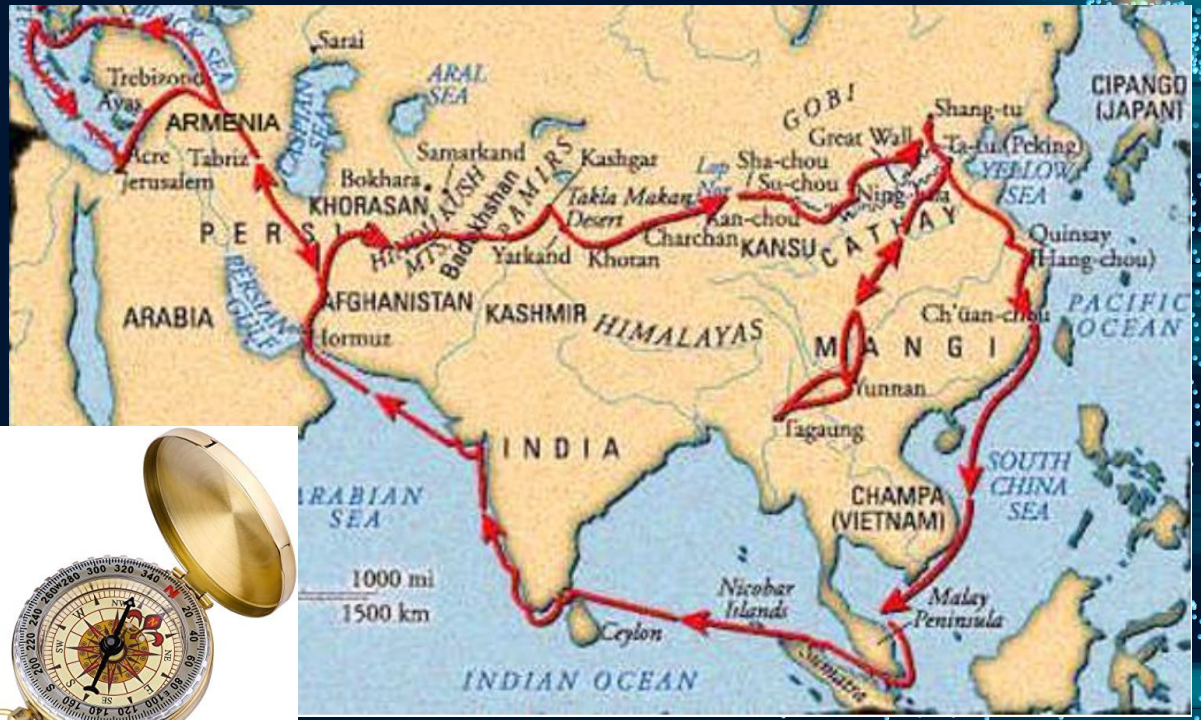
The Migration of Anatomically Modern Humans



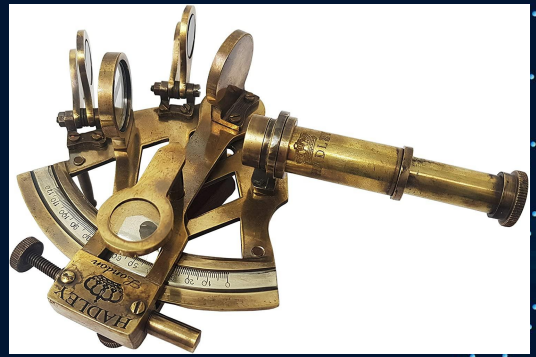
Medieval Navigation

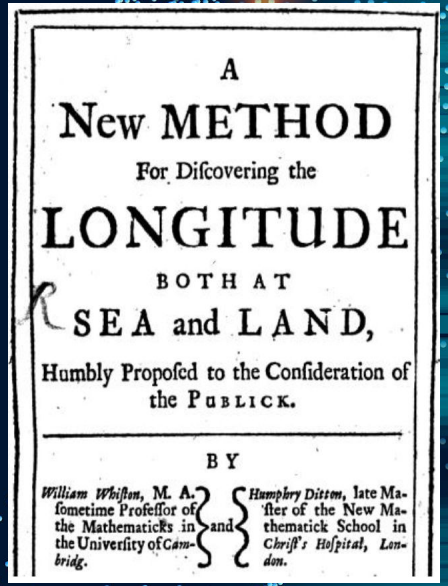
Medieval Navigation

Marco Polo
(September 15, 1254
– January 8, 1324)



The Longitude Problem





A
New METHOD
For Discovering the
LONGITUDE
BOTH AT
SEA and LAND,
Humbly Proposed to the Consideration of the PUBLICK.

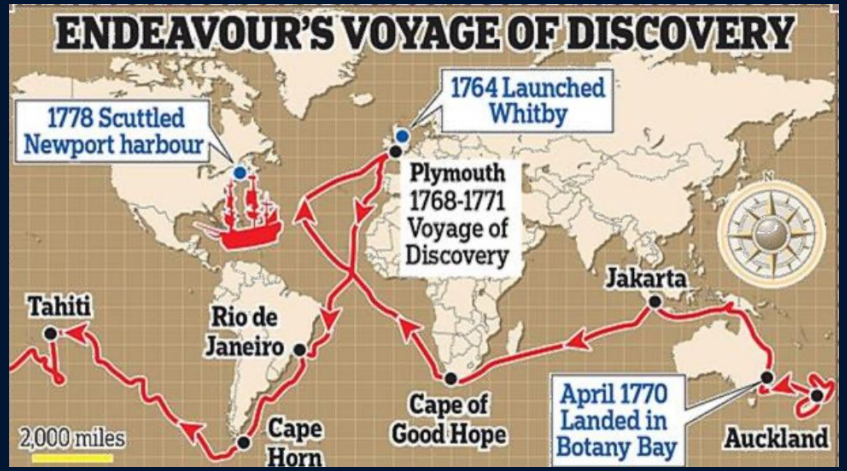
BY

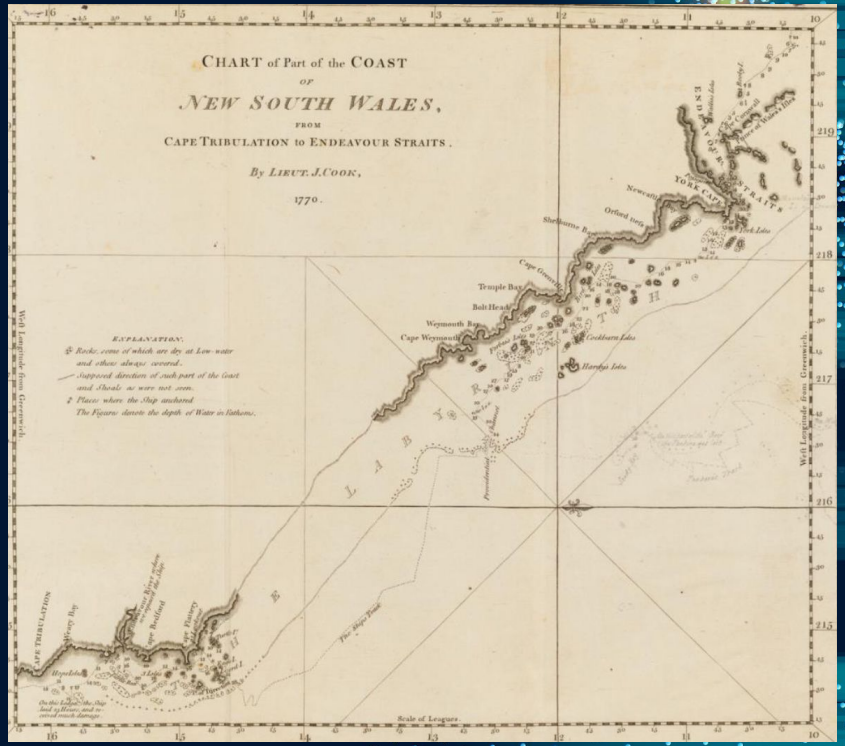
William Whiston, M. A. sometime Professor of the Mathematicks in the University of *Cambridg.* and *Humphry Ditton*, late Master of the New Mathematick School in *Christ's Hospital, London.*

Clock Sextant compass

https://www.youtube.com/watch?v=3mHC-Pf8-dU&t=411s

The Age of Maps





james cook Venus

https://www.youtube.com/watch?v=UM0Zk6-s3UY

The Origins of Radio Navigation

1907

Radio: Direction Finding Stations

Ettore Bellini and Alessandro Tosi in Italy developed the first practical direction finding system. Direction finding was used operationally in World War I. By the early 1920s, a series of stations in Europe and North America were providing guidance to ships and aircraft.

Ettore Bellini and Alessandro Tosi in Italy developed the first practical direction finding system.
Credit: National Archives and Records Administration.

https://www.youtube.com/watch?v=N8rZIAHxAH4

The Origins of Radio Navigation

1913

Radio: NAA (Broadcast time by radio)

The U.S. Navy established a radio station NAA in Arlington, Virginia and broadcasted time signals. Longitude between the U.S. Naval Observatory and the Paris Observatory was established through the repeated exchange of radio siganls from the NAA towers in Arlington and the Eiffel Tower in Paris in 1913-14.

Towers for U.S. Navy radio station NAA, Arlington, Virginia.
Credit: D.C. Public Library

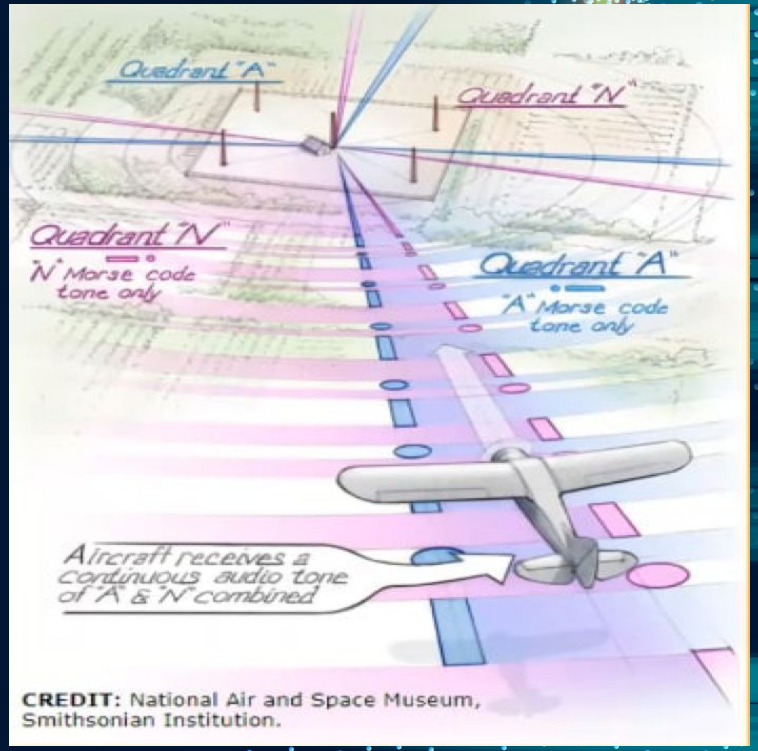
https://www.annapoliscreative.com/naval-communications-history-in-annapolis-an-anniversary/

The Origins of Radio Navigation

1926

Radio Range

The U.S. National Bureau of Standards undertook the creation of a nationwide system of directional radio beams called the Radio Range to provide guidance for commercial aircraft. This system remained in use in the United States until the early 1970s.



CREDIT: National Air and Space Museum, Smithsonian Institution.

The Origins of Radio Navigation

1942

Gee

Gee was a radio navigation system used by the Royal Air Force during World War I. It measured the time delay between two radio signals to produce a fix, with accuracy on the order of a few hundred metres at ranges up to about 350 miles (560 km). It was the first hyperbolic navigation system to be used operationally, entering service with RAF Bomber Command in 1942.

https://www.youtube.com/watch?v=ycE3U8sGpW0

The Origins of Radionavigation

1944

LORAN

The LORAN system of electronic navigation became operational, providing positioning over much of the Pacific and Atlantic Oceans with an accuracy similar to celestial navigation. The United States shut down its last LORAN transmitters in 2010.

LORAN Day and Night Coverage, 1945 By the end of World War II, the LORAN system could be used over 30 percent of the globe.

Credit: National Air and Space Museum, Smithsonian Institution.

https://www.youtube.com/watch?v=PDtHulWGMGg

The Origins of Radio Navigation

1949

Atomic Clock

The National Bureau of Standards (now National Institute of Standards and Technology) announced the construction of the world's first atomic clock in 1949. The project was an outgrowth of the Bureau's studies for measuring electrical quantities at microwave frequencies. Based on the vibrations of the ammonia molecule, the clock controlled a quartz oscillator to drive a clock dial.

First atomic clock
Credit: National Institute for Standards and Technology

The Space Age

The Washington Post
Times Herald

Missiles on the Moon

This month's Air Force magazine quotes Brig. Gen. Homer A. Boushey, an American expert on aerial research, as advocating the value of the moon for strategical uses. It says:

"The moon's high ground could, General Boushey suggests, serve as a launching point toward Earth for retaliatory missiles with only about 20 per cent of the thrust needed on Earth. These missiles could—thanks to the lack of resistant atmosphere—be launched from shafts sunk into the moon's surface, perhaps even catapulted, with no internal propellant. Once a missile was launched Earthward, the moon-based crew could track and guide it."

Such concepts are fantastic but no longer fanciful. And their potential military implication is immense. Manned platforms in outer space or missile ramps upon the moon would give the controlling nation a seemingly overwhelming advantage from which to dictate.

Expert Sees Moon As Rocket Base

International News Service

The Air Force's top space expert predicted yesterday the moon will be a military rocket base for either Russia or the U. S. within 10 years.

Brig. Gen. Homer A. Boushey, deputy director of Air Force research and development, said the moon will provide a "retaliation base of unequaled advantage" for raining "sure and massive destruction" on earth.

He urged an all-out effort to reach the moon first because Russia has made such a project the "first aim" of its national policy.

The General told the Aero Club of Washington that he fully supports the view that "He who controls the moon, controls the earth."

The Huntsville Times

Man Enters Space

'So Close, Yet So Far,' Sighs Cape
U.S. Had Hoped For Own Launch

Soviet Officer Orbits Globe In 5-Ton Ship
Maximum Height Reached Reported As 188 Miles

Hobbs Admits 1944 Slaying

Praise Is Heaped On Major Gagarin

Worker Stands By Story

Reds Deny Spacemen Have Died

To Keep Up, U.S.A. Must Run Like Hell

Reds Win Running Lead In Race To Control Space

First to the Moon

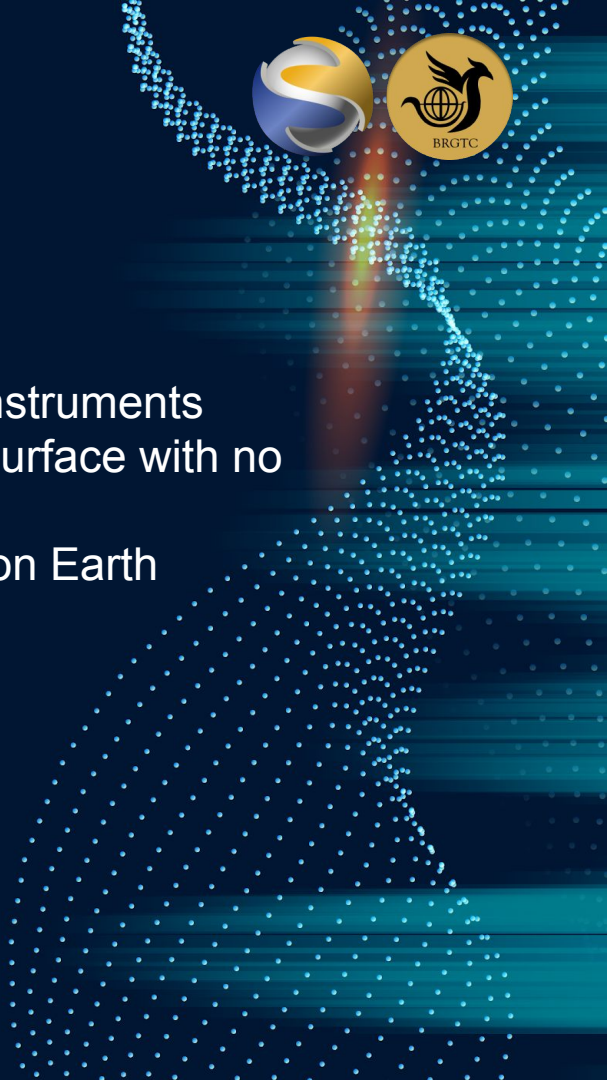
“During the early part of the flight I could not see anything through the scanning telescope that I could recognize, for instance - a constellation. I could see several stars, but I couldn't pinpoint them because I didn't know the surrounding stars”.

“Several times the scanning telescope eyepiece unscrewed itself in zero g and was found floating in the cabin”.

“It is very loose and should be tightened up”.

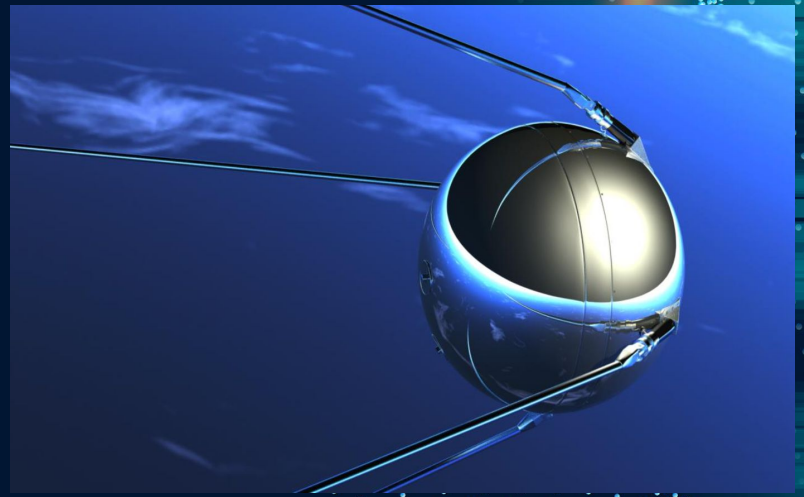
Space – A New Perspective on the Earth

- Allow large areas of Earth to be viewed at once
- Zoom in for increased coverage
- Access data on places that are hard to get to
- Collect more data & more quickly than ground-based instruments
- See into space better than with telescopes on Earth's surface with no atmospheric obscuration
- Allow us to position ourselves and navigate anywhere on Earth



- Sputnik 1 launched on 4 October 1957
- 83 kg and 58 cm wide
- 96 minutes to circle the earth
- Regular beeps told the world it was there
- 142-588-mile elliptical orbit height (LEO)
- Orbited the earth for 92 days

https://www.youtube.com/watch?v=5M-QinwmdKc



Johns Hopkins's Applied Physics Laboratory (APL – Baltimore, Maryland) monitored Sputnik's radio transmissions

Within hours they could pinpoint where the satellite was along its orbit

"All the News That's Fit to Print"

The New York Times.

LATE CITY EDITION

VOL. CIX... No. 36,631. NEW YORK, SATURDAY, OCTOBER 5, 1957. FIVE CENTS

SOVIET FIRES EARTH SATELLITE INTO SPACE; IT IS CIRCLING THE GLOBE AT 18,000 M. P. H.; SPHERE TRACKED IN 4 CROSSINGS OVER U. S.

HOFFA IS ELECTED TEAMSTERS' HEAD; WARNS OF BATTLE

Defeats Tom Fork 3 to 1 —Says Union Will Fight 'With Every Guns'

ON TOWER OF VICTORY: Dave Beck, retiring head of the Teamsters, with wife, and Harry A. Hoffa upon his election as union's president. He slight in Mrs. Hoffa.

COURSE RECORDED

Navy Picks Up Radio Signals—4 Report Sighting Device

560 MILES HIGH

Visible With Simple Binoculars, Moscow Statement Says

Device Is 8 Times Heavier Than One Planned by U.S.

FAUBUS COMPARES HIS STAND TO LEE'S

Says He Will Remain Loyal to People of Arkansas—All Is Quiet at School

Fla Widens in City; 10% Rate Predicted, 200,000 Pupils Out

ARGENTINA TAKES EMERGENCY STEPS

State of Siege Proclaimed in Buenos Aires Region—Arrests Reported

SATELLITE SIGNAL BROADCAST HERE

Inquiry Carried on Radio and TV—First Reported by Long Island Station

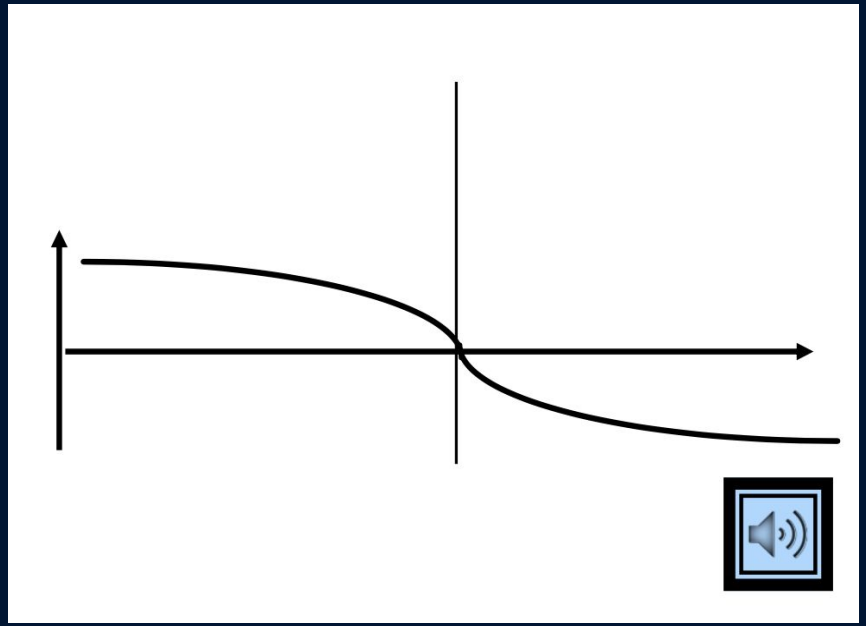
Ex-Premier Mollet Accepts Bid To Form a New French Cabinet

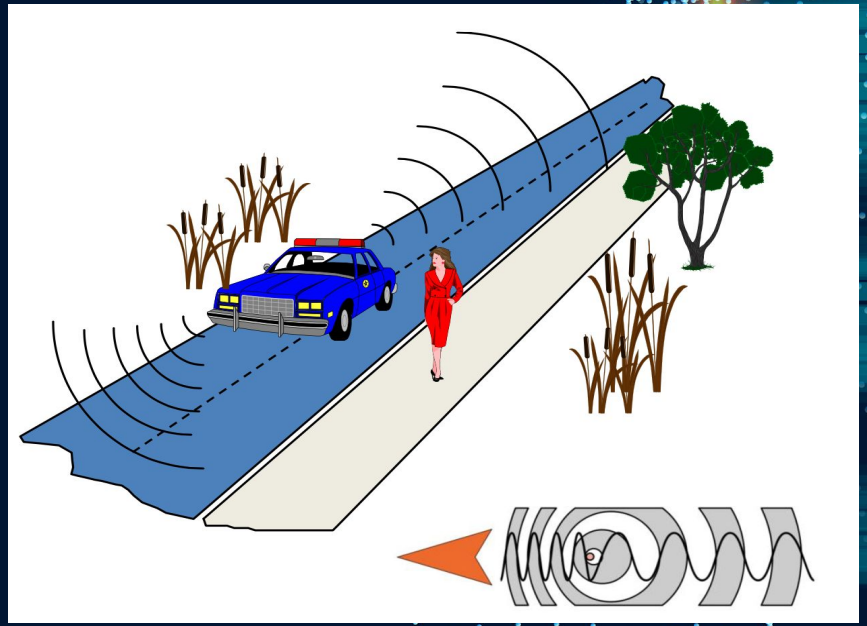
Socialist Leader Agrees With Reluctance and Without Giving Much Hope

City Sifts Charge That Schapiro, Brooklyn Councilman, Sold a Job

Warsaw Crushes New Protest; Clubs, Tear Gas Rout Students

Frequency





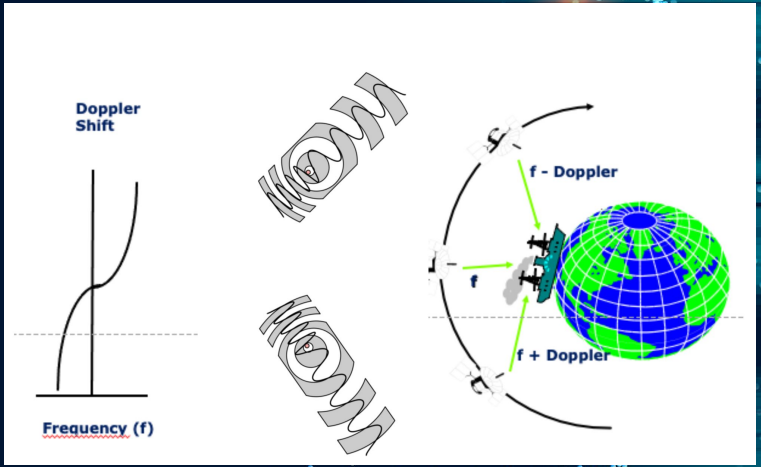
- Within one year John Hopkins APL started exploring the INVERSE effect
- Pinpointing the user's location given that of the satellite

TRANSIT Satellite

TRANSIT was the first operational satellite positioning system. Six satellites gave worldwide coverage every 90 minutes and provided positions that were accurate to within 200 meters (660 feet). Positions were obtained by measuring the Doppler shift of the satellite signal. TRANSIT was effective, but it was limited by low accuracy and lack of 24-hour availability. The TRANSIT system operated until 1996

Transit

- 1959: Development started
- 1964: Operational for military use
- 1967: Released for civil use
- 1996: Phased out
- Orbital height: 1075 km (LEO)
- Orbital period: 107 min
- Polar orbits i ≈ 90°
- Two carrier frequencies: f2 = 400, f1 = 150 MHz
- 2-d navigation system only
- Time interval between position fixes: 35 to 100 min
- Accuracy (1 σ): 200 m ... 400 m



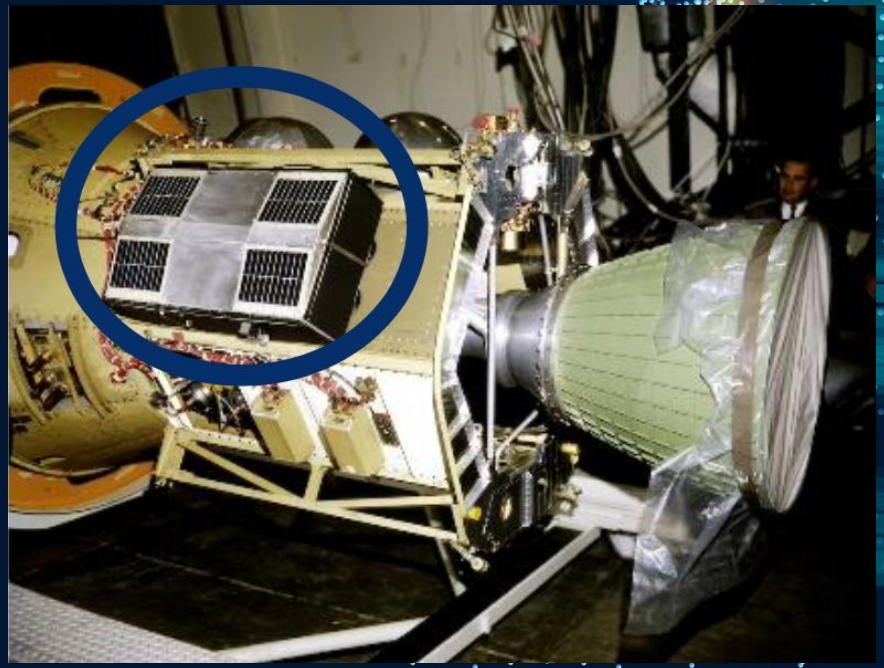
The Navy Navigation Satellite System 1967
https://www.youtube.com/watch?v=FfJlLjNak0U

The Omega Navigation System (1969)
https://www.youtube.com/watch?v=7mFAemn1pSw

Timation – Highly accurate Satellite based time keeping system Developed by the US Navy

Pioneering the development of atomic clocks

Around the same time the US Airforce was funding the System **621b project** That aimed to provide a 3D satellite based navigation system utilising something called **Pseudo Random Noise**

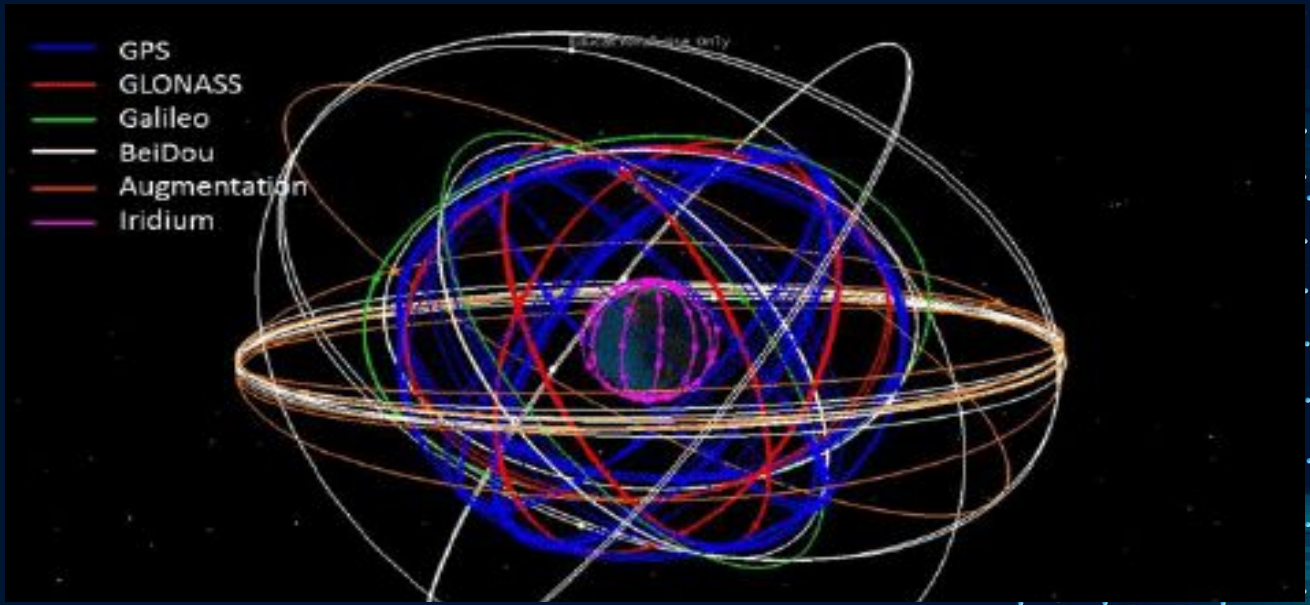


NAVigation Satellite Timing And Ranging
Global Positioning System

Operated by the United States Space Force (USSF)
Schriever Air Force Base
Colorado Springs, Colorado

US government developed and operated (>>$32b landed investment)
GPS receiver and signal specifications made available in 1983 - for the public good!
1st SV launched in 1989, 24th in 1994
Selective Availability switched off in May 2000 (GPS III will not include SA)

- Provide world-wide coverage, 24 or more MEO satellites
- Rely on timing synchronisation; and ranging
- Should be interoperable
- Main systems are GPS, GLONASS, BEIDOU & GALILEO
- Consist of MEO, GEO, GSO & IGSO

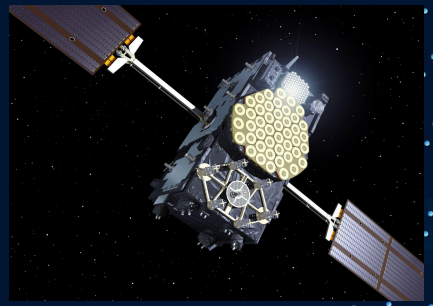


- Global Navigation Satellite Systems
- Horizontal positioning accuracy up to 5m, anywhere in the world in open sky conditions
- Nano-second timing
- Sovereign capability
- Multiple use
- Free to use signals
- Driver for economic activity
- Critical Infrastructure

GPS III

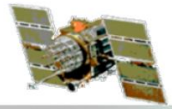
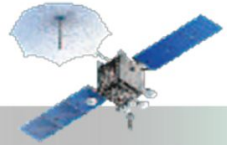
BEIDOU

GALILEO

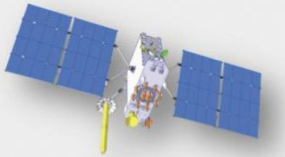
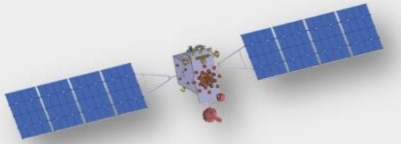


GLONASS

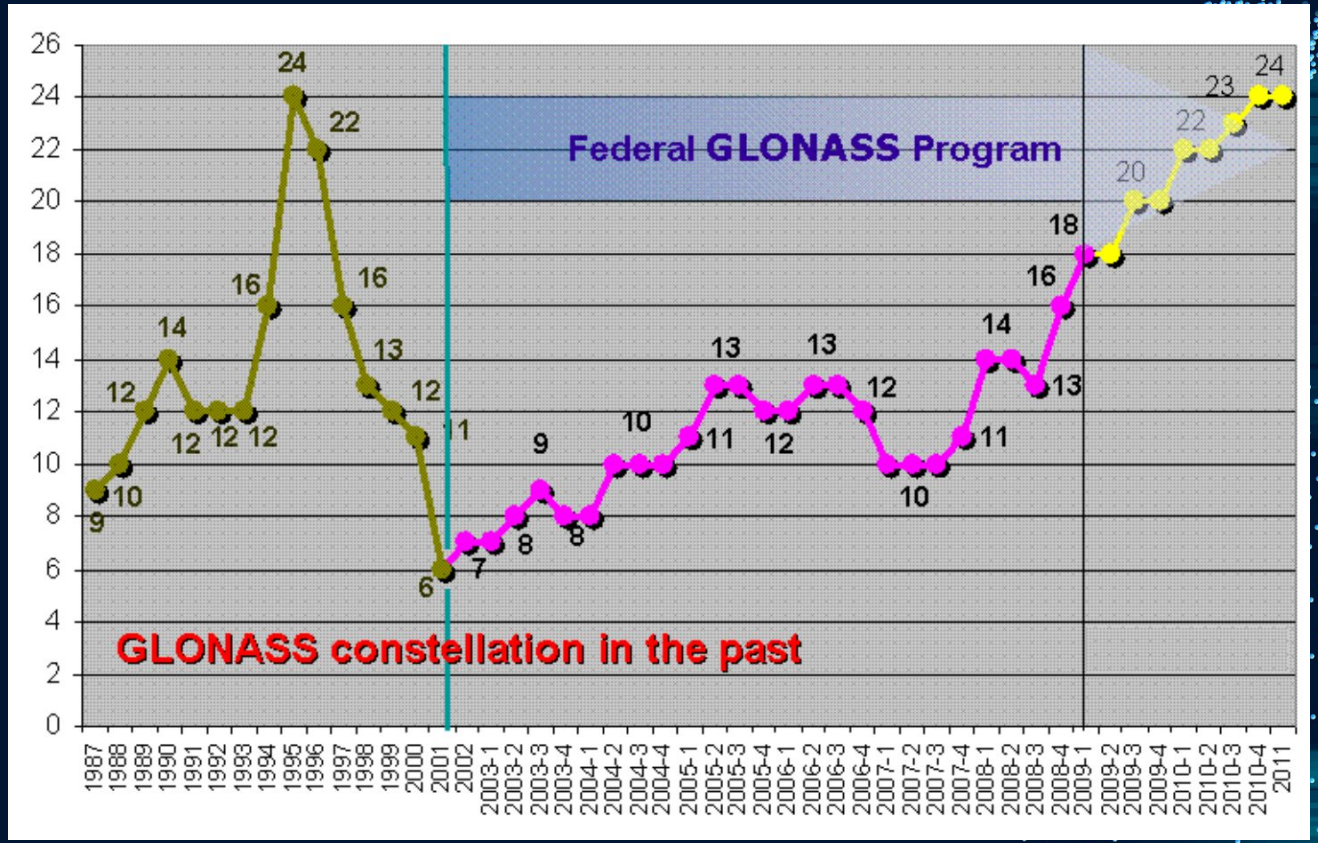
GPS Satellite History

1995	2005-2016	2010-2018	2014 - 2021
GPS IIA	**GPS II R / IIR-M**	**GPS IIF**	**GPS III**
			
• Standard Service • Single frequency (L1) • Coarse acquisition code navigation • Precise Service • Y-Code (L1Y & L2Y)	• IIA/IIR capabilities plus • 2nd civil signal (L2C) • M-Code (L1M & L2M)	• IIR-M capability plus • 3rd civil signal (L5) • 12 year design life	• Backward compatible • 4th civil signal (L1C) • Increased accuracy • Increased integrity
Legacy Control System	Architecture Evolution Plan (AEP)		Next Generation Control Segment (OCX)

GLONASS Satellite History

1982	2009	2010	2013
Glonass	**Glonass-M**	**Glonass-K1**	**Glonass-K2**
			
• 3 year design life • Clock stability - $5*10^{-13}$ • Signals : L1SF, L2SF, L1OF, (FDMA) • Totally launched 81 satellites ▪ Real operational life time 4.5 years	• 7 year design life • Clock stability 1*10-13; • Signals : L1SF, L2SF, L1OF, L2OF (FDMA) • Totally launched 28 satellites and going to launch about 11 satellite until to end 2012	• 10 year design life; • Clock stability 5*10-14; • Signals L1SF, L2SF, L1OF, L2OF (FDMA) • L3OC (CDMA) - test :	• 10 year design life; • Clock stability 1*10-14; • Signals L1SF, L2SF, L1OF, L2OF (FDMA) • L1OC, L3OC, L1SC, L2SC (CDMA) :

GLONASS Collection History

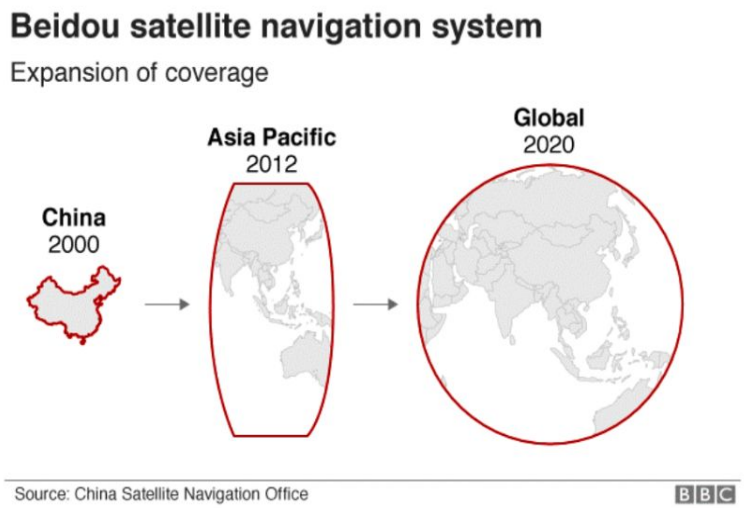


GNSS Constellations - Beidou

System Features

- 49 currently operational, including legacy satellites. Eventual constellation of 27 MEO + 5 GEO + 3 IGSO
- 3 orbits with inclination of 55°
- Orbit height 21,500km, time of orbit 12h 53m

CHARACTERISTICS	GEO AND IGSO SATELLITES	MEO SATELLITES
Prime	Chinese Academy of Space Technology (CAST)	Chinese Academy of Space Technology (CAST)
Satellite Platform	DFH - 3/3B	DFH - 3B
Lifetime	~ 15 years	~ 12 years
Weight	828 kg	1615 kg
Signals	B1 (open and authorised access) B2 (open access) B3 (authorized access)	B1 (open and authorised access) B2 (open access) B3 (authorized access)
Additional capabilities	Laser reflectors Cosmic ray registration	Laser reflectors Cosmic ray registration



GNSS Constellations - Galileo

System Features

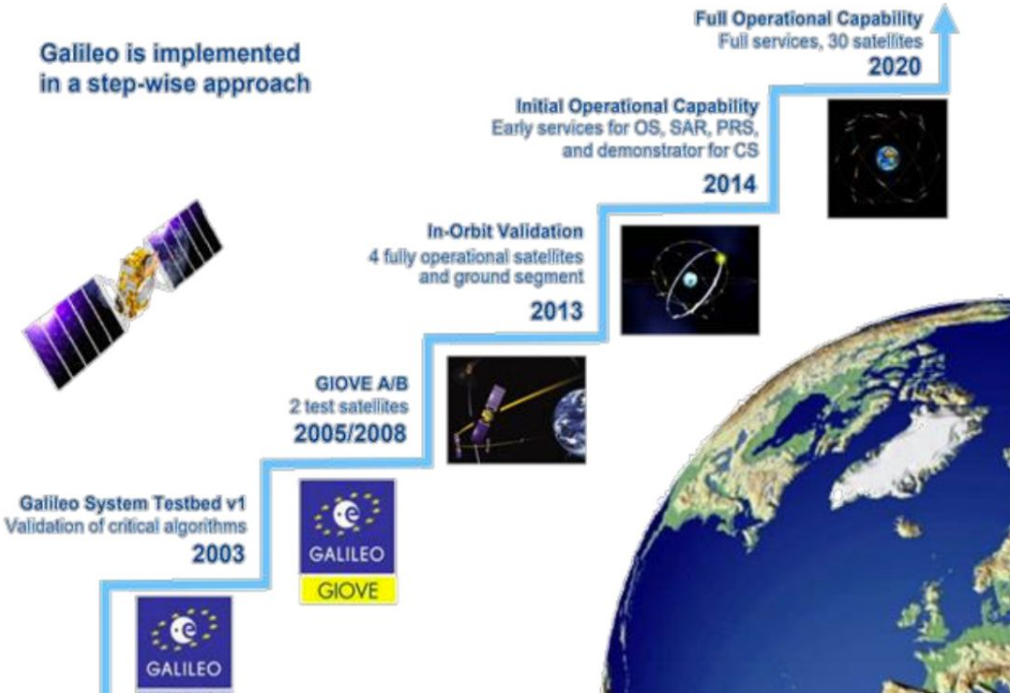
- 30 satellites (planned) 24 operational + 2 spares
- 3 orbits with 9 satellites per orbit with inclination of 56° ascending nodes separated by 120° longitude
- Orbit height 23,222km, time of orbit ~14h
- Life Expectancy >12 years
- Satellite mass 675kg
- Power supply minimum 1.5kW

Services

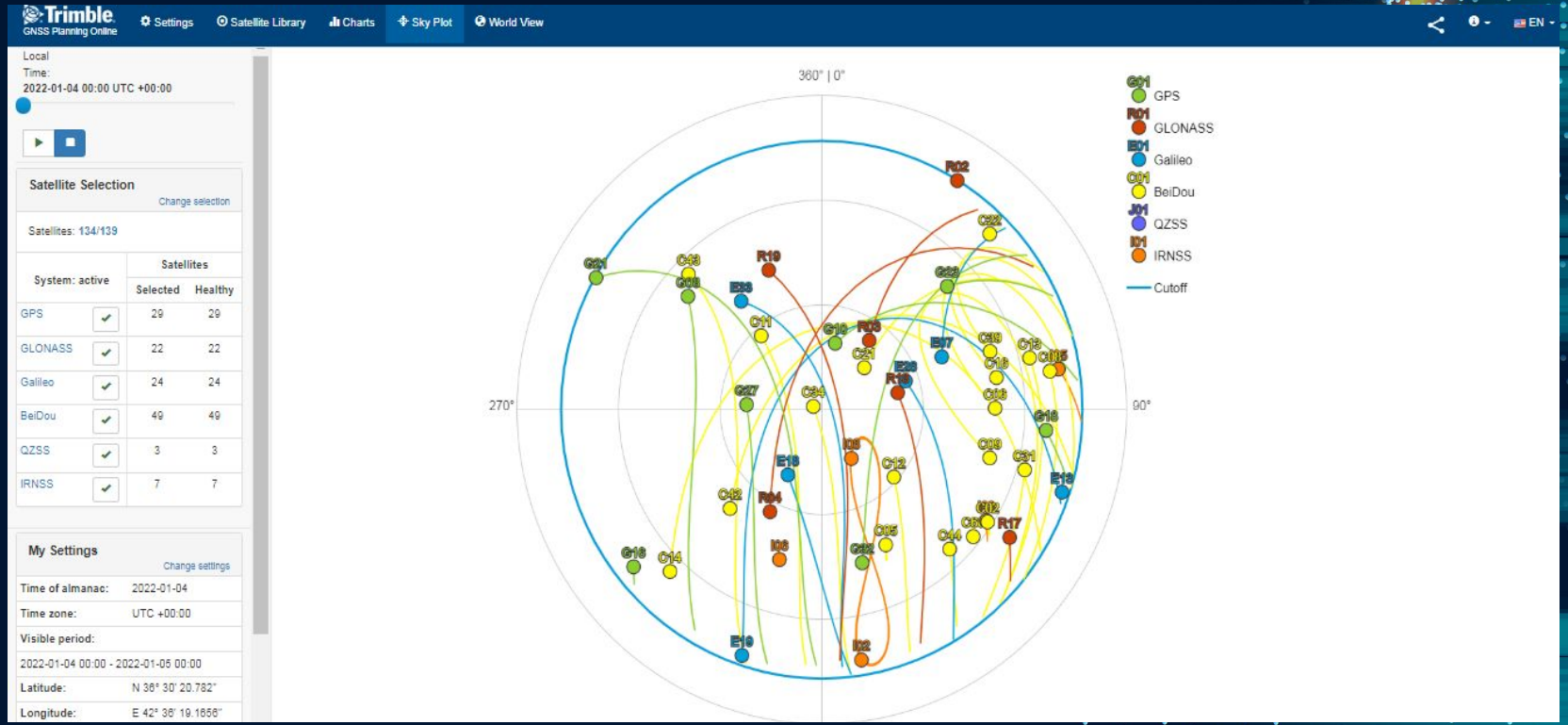
- Galileo satellite-only services
  - Open service
  - Safety of Life
  - Commercial
  - Public Regulated Service***
  - Search and Rescue
- Galileo locally assisted services
- EGNOS service
- Galileo combined service

System Features

Four Galileo signals. E5a, E5b, E6 and E2-L1-E1. E5a and E2-L1-E1 overlap the existing L1 and L5 GPS signals. The minimum power received from the Galileo signals is -152dBW, more than double the power of the C/A code from GPS.



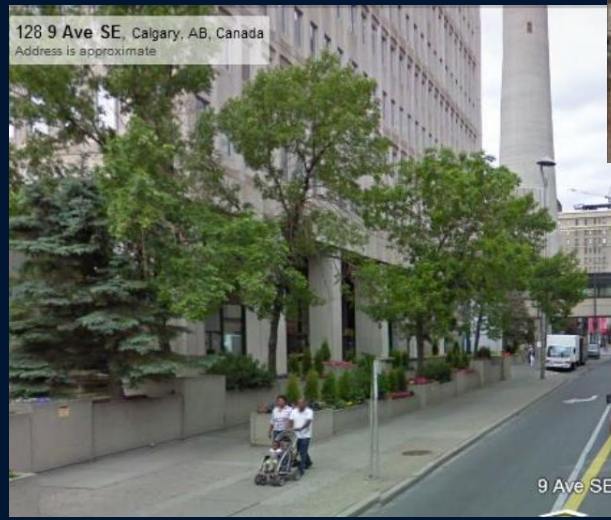
www.gnssplanningonline.com



Some common GNSS Applications include:

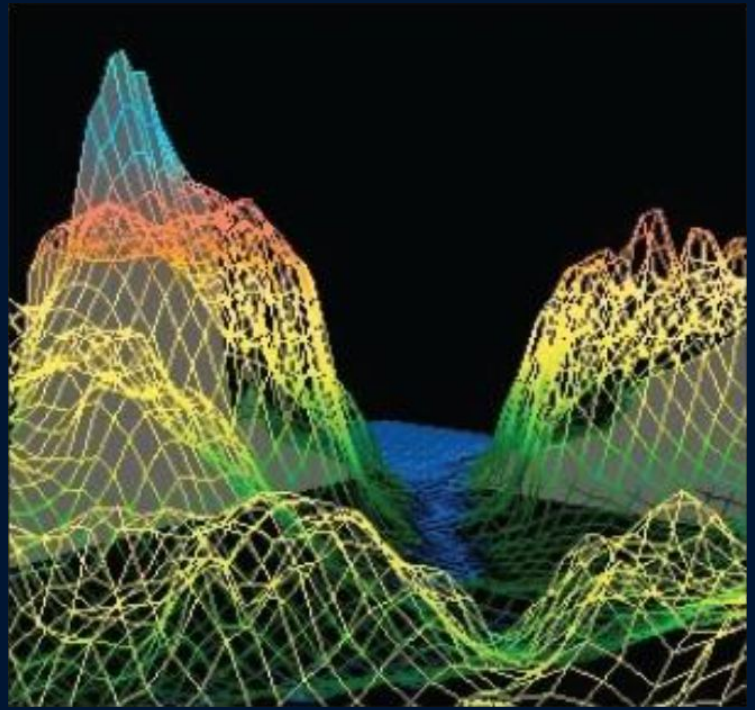
- Transportation
- Timing
- Machine Control
- Marine
- Surveying
- Defence
- Port Automation
- Portable navigation devices
- Air, marine, and ground based vehicle navigation

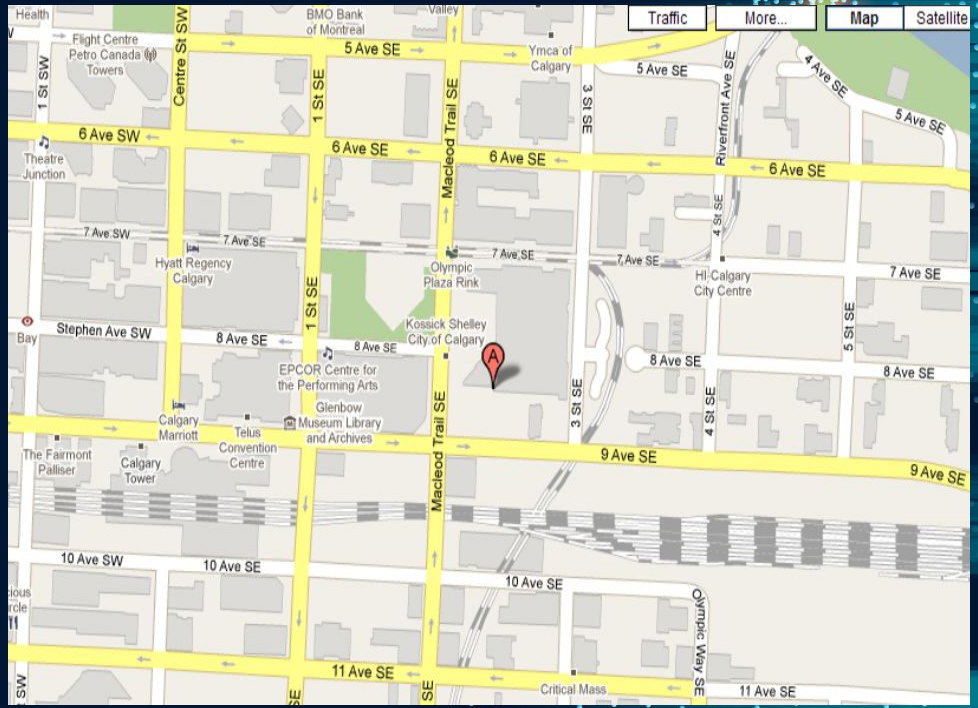
Surveying


128 9 Ave SE, Calgary, AB, Canada
Address is approximate
Telus Conv
Centre
9 Ave SE


Google

GIS



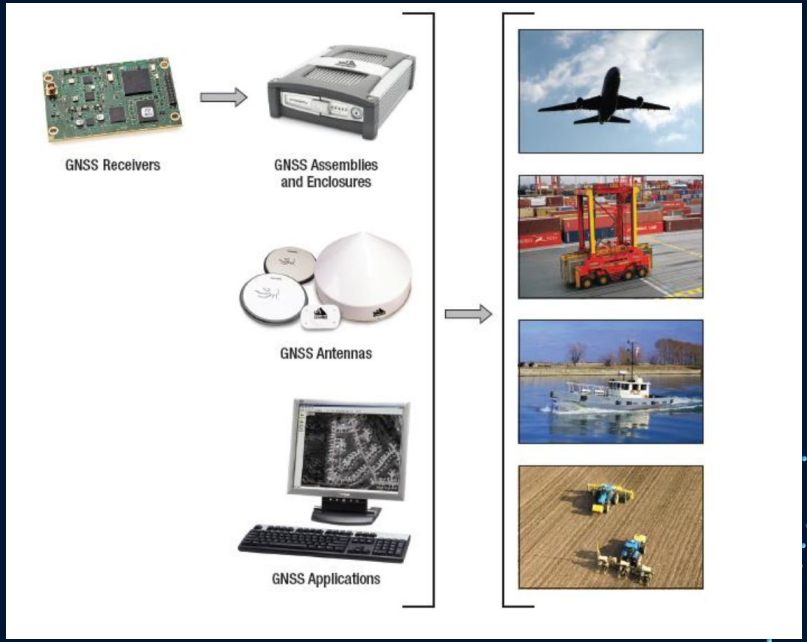

Traffic
More...
Map
Satellite
Health
Flight Centre
Petro Canada Towers
BMO Bank of Montreal
Ymca of Calgary
5 Ave SE
6 Ave SW
6 Ave SE
Theatre Junction
Centre St SW
1 St SW
1 St SE
Macleod Trail SE
3 St SE
Riverfront Ave SE
4 Ave SE
4 St SE
7 Ave SW
7 Ave SE
Hyatt Regency Calgary
Olympic Plaza Rink
Hl Calgary City Centre
5 St SE
Stephen Ave SW
8 Ave SE
Kossick Shelley City of Calgary
EPCOR Centre for the Performing Arts
Glenbow Museum Library and Archives
Calgary Marriott
Telus Convention Centre
The Fairmont Palliser
Calgary Tower
9 Ave SE
10 Ave SW
10 Ave SE
11 Ave SE
Critical Mass
Olympic Way SE

Port Automation

Defence

Equipment

There are different types of GNSS equipment available depending on the application and project requirements



Positioning:

Determination of position and attitude (orientation) in three dimensions and their changes in time

GNSS! Guidance:

Providing direction to get from A to B

Navigation:

Positioning and guidance from an initial position to a destination

Navigation = Positioning + Guidance

Other systems

- VLBI
- (LLR – not since ITRF2000)
- SLR
- GNSS
- DORIS

Thank you for Your Participation

Halmat Atta Ali

https://www.esurveyiq.com/

BRGTC