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Doppler shift satellite navigation

NAVSAT-TRANSIT and adherents

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Abstract— **Short article dissertates about Satellite navigation systems based on Doppler shift. Discussed are advantages and disadvantages of such systems especially in connection with aviation. In last part are mentioned nowadays satellite navigation systems based on Doppler shift effect.**

Keywords - component; TRANSIT, NAVSAT, DORIS, Doppler shift, satellite navigation

I. TRANSIT

GPS NAVSTAR is today most used navigation system, but it wasn´t the first satellite based navigation, this navigation system is derived from satellite based navigation system called TRANSIT. Transit was developed for support of American nuclear submarine fleet, and started to operate in 1964. Space segment was made from about 10 satellites which transmitted on 150 and 400 MHz. The biggest difference was the main principle on which is the position determined. The position information was computed from Doppler shift.

The Doppler shift was different for every position of satellites, which was moving 17 000 mph and receiver on Earth. The signal received from Transit satellite in a ground station will appear higher in frequency as the satellite approaches the observer and lower as the satellite recedes from the observer. When we know exact position of several satellites, we may compute position of receiver on ground of finding intersection point. Similar, only reversal principle is used in newer Doris Doppler satellite navigation, which will be mentioned further. When the satellite moves closer to the emitting beacons, the frequency of the signal received by Doris instruments onboard the satellite is higher than one of the emitted signal, and lower when it moves away.

For transit the difference was usually smaller than 10 kHz. When there was more than one Transit satellite over horizon, it was possible to find the actual position of transmitting beacon more precisely. Problem was that moving of receiver on Earth caused mismatch because it changed the Doppler shift. For slowly moving ships this fault was not so important but usage of this system for aviation would have been problematic because computing of right position was difficult even without receiver moving. The shortest time to obtain actual position was 2 minutes, what was time of one cycle of satellite message send by Transit.

Later the system was improved by adding another signal, which improves the navigation information by using more precise ephemerides of satellite. This second precision signal was encrypted. Not unlike GPS signal L2 nowadays.

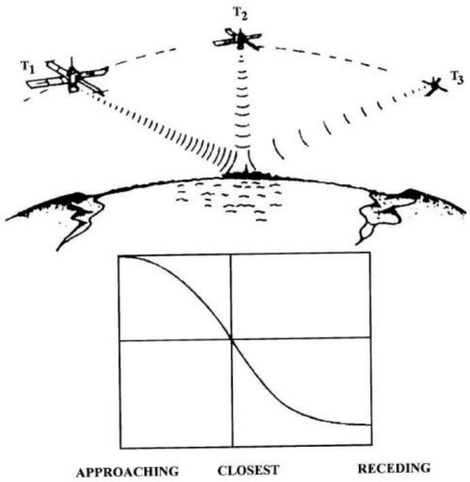

Figure 1. Doppler navigation principle

Another issue of Transit was big error of satellite position. In 1960´s the information about ionosphere and Earth´s magnetic a gravitation field was quite insufficient so the estimates of satellite positions were imprecise and they have to be often corrected. Satellite position was measured from Earth and uploaded to every single satellite twice a day, what made ground operations quite costly. Higher costs in ground segment were highly compensated by extremely cheap operation of satellites. Satellites were originally designed to operate only 14 months and then being replaced by new series. But in operation it appears that the real lifetime of satellite was more than 20 years. The system was upgraded only by 2 enhanced satellites, and was operational till 1996. Even in 2013 some of the satellites are still in orbit and working in US NAVY research program of ionosphere. TRANSIT satellites were one of longest serving satellites.

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II. TRANSIT IN AVIATION

In 1974 was developed first aviation satellite navigation. A hybrid aircraft navigation system has been developed using Loran-C signals for continuous position information, with periodic position updates from the Navy Navigation Satellite System (NAVSAT) to improve the accuracy of the system. Laboratory tests and flight tests have demonstrated the performance of the NAVSAT/Loran-C hybrid system and have established high confidence levels in its ability to provide accurate position information, and to obtain in-flight local Loran-C grid calibration. This automatic system uses a Loran-C receiver, a NAVSAT receiver, a small computer, and associated display units to provide real-time readout of latitude and longitude. Similar hybrid system was developed for cooperation NAVSAT/DECCA. In early 90´s there were navigation receivers usable for aviation which was made by connection of GPS and NAVSAT in one device. In this time because of small number of GPS satellites in operation was TRANSIT more precise in more than 60% of situations.

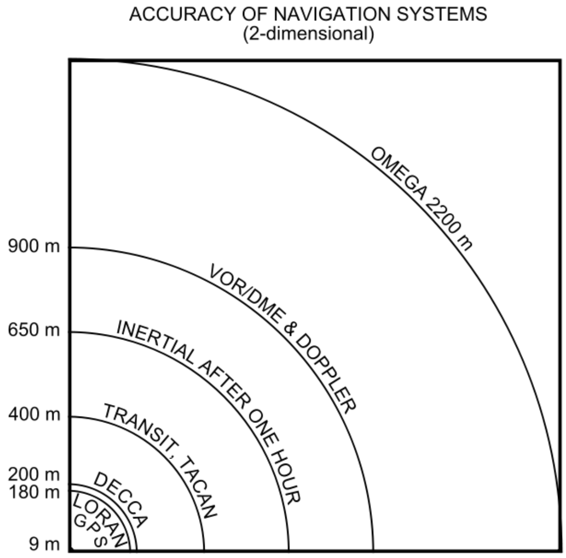

Figure 1. Accuracy of navigation systems [6]

The precision of position estimate was highly dependent on how precise was operator in aircraft able to determine its speed and altitude. Error in altitude or speed of aircraft lowers the precision of position estimate. This error is the most important aspect why Doppler navigation is not used for primary position estimate today. These errors are compensate able but depends on another systems and makes the whole system more complicated and less precise, and that was main reason why decision was made in favor of developing of GPS NAVSTAR against TRANSIT Navstar. But despite these errors the results of Transit was so great that, according Flight International from March 1966 [1] NASA concludes: "Based on its own evaluations, studies conducted by NASA, various subsystems and components already tested in orbit,… the Satellite Navigation Corporation system will materially reduce the risks and costs of marine and air travel, at a cost to the user that would be lower than any other system now in operation or contemplated." In other words, since 1965 was NASA convinced that satellite navigation is the best way how to navigate.

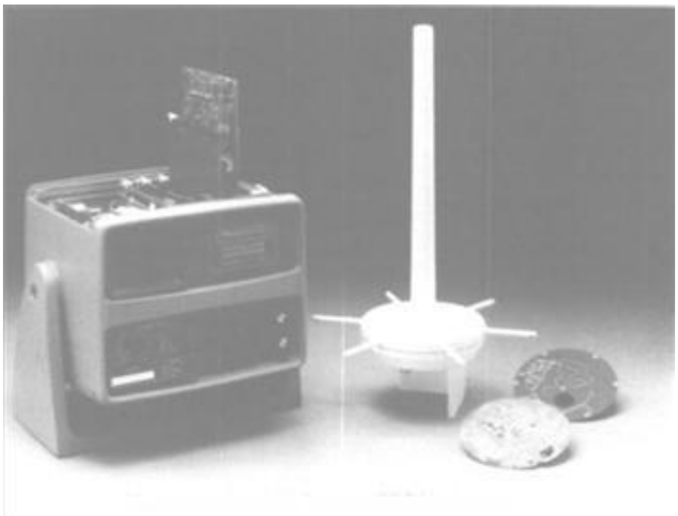
Figure 2 Magnavox MX 1100-GPS – Navsat /GPS combined device [2]

In early 1980 there were made several attempts for development of TRANSIT based “black box”. An autonomous system to track aircraft position during time independently on other aircraft navigation and aerometric devices. This system is possibly still equipped in some US NAVY aircrafts [3], although today is not operational. But before releasing this system to public use precedence was given to similar system using GPS.

Before TRANSIT was successfully used for government and commercial usage, there were large scientific project for Earth gravitation model prediction. The model is essential for prediction of satellite position and despite some modern improvements; it is still the same model which was developed for usage of TRANSIT. Earth segment of TRANSIT was not as large as GPS but many surface station used for TRANSIT are used for GPS now. The key position was in Laguna Peak, Point Mugu in California. Transit broadcasted on two frequencies 150 and 400 MHz, because it was estimated that using two different frequencies will help suppress the ionospheric error. Again this is the same principle used by GPS.

III. MODERN DOPPLER NAVIGATION SYSTEMS

Despite the problems of Doppler system mentioned above, TRANSIT was not last satellite navigation system based on Doppler shift. Evolution of this system was developed in France. Doppler Orbitography and Radiopositioning Integrated by Satellite (DORIS). This system was designed primarily as a means of determining a satellite’s orbit, but has been used for a wider range of applications such as precise positioning and measuring the flow of glaciers. Doris uses its Doppler navigation system to precisely position the satellites in orbit. This precision is essential for applications in geodesy and the precision is better than 2cm. What makes it the most precise tool for applications like altimetric mission for oceanography. For aviation is important that DORIS information are used to enhance ionosphere model of Earth which is used by other Satellite navigations. When the satellite position is precisely determined on its orbit, the Doris system can be used to locate a Doris ground beacon which is outside the reference network, at a point requiring temporary monitoring (volcanoes, geological faults, glaciers ...). This system is suitable for objects fixed or moving very slowly and is useful in the geophysics and geodesy fields. There is possible usage for DORIS in emergency situation and SAR in places where there is bad signal form GPS, Especially high earth latitude because of near polar orbit of DORIS satellites is its coverage there much better. DORIS system is not intended for use in aviation, it´s main purpose is for precise determination of satellite position for position estimation.

Figure 3. Argos receiver on sea mammal [5]

The Doppler satellite navigation is used also in ARGOS program for surveillance and data collection system dedicated to studying and protecting our planet's environment. The space segment of this system consists of in-situ data collection platforms equipped with sensors and transmitters and the Argos instrument aboard NOAA and EUMETSAT polar-orbiting satellites [4]. Advantage of these transmitters against GPS is its lower weight, power consumption and shorter time before first usage because this system doesn't need long time to download almanach. Transmitters were miniaturized to possible implementation on animals, or small objects. These miniaturized transmitters are now usable for UAVs as backup system for finding place of landing. Despite this initiative is quite new, Argos is used as a tracking system for maritime transport, adventurers and yachts for longer time. Main advantages of this system are automatic signals, robustness and availability in every place even in high latitudes.

Location accuracy varies with the geometrical conditions of the satellite passes, the stability of the transmitter oscillator, the number of messages collected and their distribution in the pass. This means in particular that a given transmitter can have locations distributed over several classes during its lifetime. Classes for which accuracy is estimated and related values:

Class 3: better than 250 m radius

Class 2: better than 500 m radius

Class 1: better than 1500 m radius

Class 0: over 1500 m radius

The error is assumed to be isotropic and hence characterized by a single number called the radius of error. It corresponds to one standard deviation (sigma) of the estimated location error. The location class is attributed based on the radius of error. The location class and associated error are sufficient for many applications. On first sight it is clear that error is significantly higher than GPS error. Today is prepared fourth generation of ARGOS system which should be much more precise and what would make it comparable alternative for standard satellite based navigation systems such as GPS or GLONASS.

IV. COSPAS SARSAT

According to statement of Cospas-Sarsat program, the mission is to provide accurate, timely and reliable distress alert and location data to help Search and Rescue (SAR) authorities assist persons in distress. The objective of the Cospas-Sarsat System is to reduce, as far as possible, delays in the provision of distress alerts to SAR services, and the time required to locate a person in distress at sea or on land and provide assistance to that person, all of which have a direct impact on the probability of survival. To achieve this objective, Cospas-Sarsat Participants implement, maintain, co-ordinate and operate a satellite system capable of detecting distress alert transmissions from radio beacons that comply with Cospas-Sarsat specifications and performance standards, and of determining their position anywhere on the globe. The distress alert and location data is provided by Cospas-Sarsat participants to the responsible SAR services. [7] There are today 43 countries participating in the program, Czech Republic is not a participant.

Cospas-Sarsat is created by combination of two different approaches to beacon position finding. First, geostationary or geosynchronous orbiting satellites, called GEOSAR are only transmitting signal from becon to control centers and are unable to find positions of beacons. Parts of GEOSAR are also different satellites from NOAA and other providers. Second part of the system is so called LEOSARs which are low near polar orbiting satellites. LEOSAR consists of 6 satellites. Five of them, NOAA 15-19 are belonging to US The National Oceanic and Atmospheric Administration (NOAA) a one METOP-A belongs to European Organization for the Exploitation of Meteorological Satellites (EUMETSAT). These meteorological satellites are equipped with receiver of distress signal transmitted on frequency 406 MHz. The LEOSAR system calculates the location of distress events using Doppler processing techniques. Only one satellite is enough to estimate position of transmitting beacon. The disadvantage is fact that system has not consequential coverage of whole Earth. With 4 satellites typically in process it can take more than 30 minutes before at least one satellite came to position to detect transmission of distress beacon. Position of transmitting beacon is in real time send to local ground control center which manages SAR. When there is no ground control center in reach of satellite the information about position of distress beacon is stored in internal memory and send to ground when the connection with control center is established. It is important to note that LEOSAR is only one part of Cospas-Sarsat system, in combination with GEOSAR is system reliability very high and ELT distress beacons are mandatory equipment onboard of commercial aircrafts all over the world.

REFERENCES

[1] Flight international, March 1966; accesible on http://www.flightglobal.com/pdfarchive/

[2] http://www.digitalwavepublishing.com/pubs/NWM/maritimereporter/198512/?pgno=54.

[3] G.Swan; Colloquium on Marine Electronic Navigation Systems, Applications and Design.;London, Engl;Code8707

[4] Argos User's manual - PDF format accesible via http://www.argos-system.org/web/en/76-user-s-manual.php

[5] http://www.argo.ucsd.edu/

[6]http://en.wikipedia.org/wiki/Transit_(satellite)

[7]http://www.cospas-sarsat.org/en/about-cospas-sarsat/about-the-programme-g/international-cospas-sarsat-programme