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DESIGN OF A SATELLITE NAVIGATION SYSTEM – GPS

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GPS (Global Positioning System) was created by the USA Department of defense in the 60s of the twentieth century. Navigation systems using satellites transmit signals, their coordinates in outer space, to the receiver with a time delay of a fraction of a second. Based on this data, knowing the laws of physics, you can use calculations to determine your location. The WGS84 three-dimensional coordinate system is used to determine the coordinates of an object. It determines the coordinates of an object relative to the center of mass of the Earth with an error of less than 2 cm.

The system in question consists of three interconnected segments: space, control, and user. Each of them has its own characteristics. Special attention should be paid to the space segment, which is currently undergoing modernization. All 32 satellites of the orbital group are planned to be replaced with new-generation satellites that surpass the old ones in all their characteristics. The manufacturer of the new generation of satellites is the American military-industrial Corporation Lockheed Martin.

The system in question is currently more accurate than its counterparts and is the most popular in the world, with over 4 billion users. According to the USA Department of defense, the updated orbital group of satellites will be fully operational in 2023.

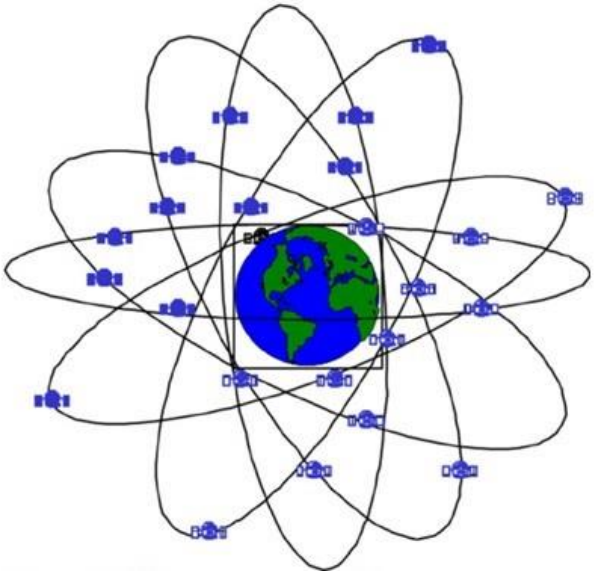
The Soviet satellite PS-1, which was launched into space in October 1957, laid the foundation for the emergence of satellite systems. Then, in October 1957, employees of the John Hopkins company of the University of Baltimore (USA), based on the analysis of the radio signal received from the PS-1, proved that determining the orbit of satellites by their own signals is quite possible.

The first such system in the world is considered Transit, it was also called NAVSAT. Its development began in 1958 at the Johns Hopkins University Applied Physics Laboratory with the support of the US Navy. At that time, the main user of Transit was the US Navy. With its help, the us military determined the exact location of its strategic submarines.

Transit consisted of six simple spacecraft that orbited the Earth at an altitude of 1,100 km and operated at frequencies of 400 and 150 MHz. The main disadvantages of this system were not complete coverage of the Earth's surface and limited time spent in the field of view[1].

The Doppler effect was used to determine the object's coordinates. The essence of this effect is as follows: the frequency of the received signal depends on the distance to the Earth's surface, it increases when the device approaches and decreases when it is removed. This means that if you know your location on Earth, it becomes possible to determine the location coordinates and the speed of the satellite, and vice versa, knowing the position of the vehicle in space, it is possible to calculate your speed and your location.The devices moved along a known trajectory and broadcast on a known frequency. The receiver received a signal of a slightly different frequency. By shifting the frequency of signals from several satellites, the location was calculated. Satellites allowed to determine the location of an object at every point of the globe every hour and a half with an accuracy of 200 meters. Transit lasted until 1996.

The year of birth of the global positioning system, better known as GPS, can be considered 1973, when the US Department of defense initiated the process of unification of navigation systems, as different departments were working on different systems that were incompatible with each other.



Picture 1. Orbital group of GPS satellites

In the beginning, it was intended only for the military. But soon the situation changed, with the development of microelectronics, GPS receivers became more accessible. The GPS system became more popular, then the number of civilian consumers significantly exceeded the number of military.

The civil-purpose system provided a fairly high accuracy of determining coordinates, just a few meters for slow-moving and stationary objects. By the end of 1975, there were 6 navigation spacecraft in circular earth orbits.

Structure of the GPS satellite positioning system. Currently, the us Department of defense is implementing a project to modernize the orbital grouping of GPS navigation satellite systems. In December 2018, Elon Musk's private space company, Space X, launched a Falcon 9 launch vehicle with the first third-generation positioning satellite as a payload. This device was named Vespucci, after the Florentine Navigator Amerigo Vespucci, after whom the American continent was named[8].

The Falcon 9 launch vehicle was launched from the SLC-40 launch pad at the United States air force base at Cape Canaveral in Florida.

The orbital group of the first generation of GPS positioning system satellites will consist of thirty-two vehicles-they are intended to replace the vehicles that now provide GPS signal to the world. The first ten of them in the Space Vehicle version (Block IIIA) will run until 2023, and the remaining 22 — in the Follow On configuration (Block IIIF) — will start running from 2025 to 2034.

The new satellites will provide unprecedented power of the transmitted signal, navigation accuracy will be 3 times higher than the current one, and protection from noise reduction will increase by 8 times.

The Creator of the new satellites is the American firm LockheedMartin. And according to the manufacturer's representatives, the service life of the device has been increased to 15 years.

"How accurate will the positioning be? We can't disclose this information, but spread your hands: our accuracy will be within these limits, " Lockheed Martin noted in 2018.

Vespucci is located in the middle earth orbit (soo) at an altitude of approximately 20,000 km above sea level, where, in addition to GPS devices, the Galileo (European Union) and GLONASS (Russian Federation) probes are also located.

Picture 2. Vespucci before installing under the head fairing

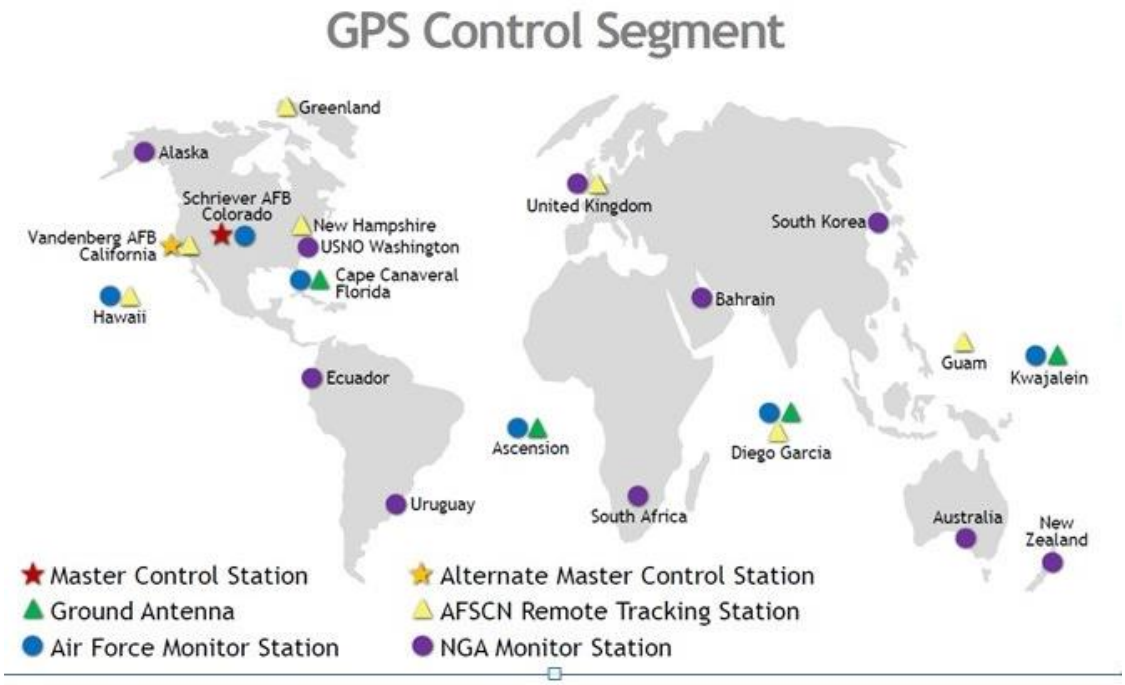
Vespucci is the first GPS translator of the new civilian L1C signal, which is also used by other systems like the European Galileo [3].

The updated group of satellites will not be fully operational until 2022: there are some problems with the parallel program for upgrading ground-based satellite control systems.

The structurally modernized system will consist of three parts:

Space segment-consists of thirty-two satellites moving around the Earth in six orbits. Each of them has 4-6 navigation satellites that travel at an average speed of 14,000 km / h.

The Control Segment is the main control station located in Falcon Air-a military base in the us state of Colorado, and five unmanned monitoring stations (MS) located at strategic points around the world. This also includes ground antennas and monitoring stations. The locations of the five unmanned monitoring stations are marked with blue circles on the map below[1].



Picture 3. The map of GPS Control Segment

The User Segment consists of receivers managed by government institutions and hundreds of millions of receiving devices owned by ordinary users. All users are divided into two main groups: military users who can use the two L_1 and L_2 frequencies, and civilian users who can only use the L1 frequency. GPS is passive, meaning that the signal is transmitted only in one way, from the satellite to the receiver [4].

GPS signal: there are at least four satellites in the visible area of the receiver anywhere on the planet. Each device continuously transmits signals on two l-band frequencies, designated as L_1 and L_2 (the letter L means "link", "link"). The L-band covers frequencies from 1 to 2 GHz.

Frequency centers:

• L_1 = 1,57542 GHz;

• L_1 = 1,22760 GHz.

The GPS positioning system uses three types of signal modulation:

C/A is a rough reception code, P-code is a protected code, and Y, which is used together with the P-code, and it is called - P (Y).

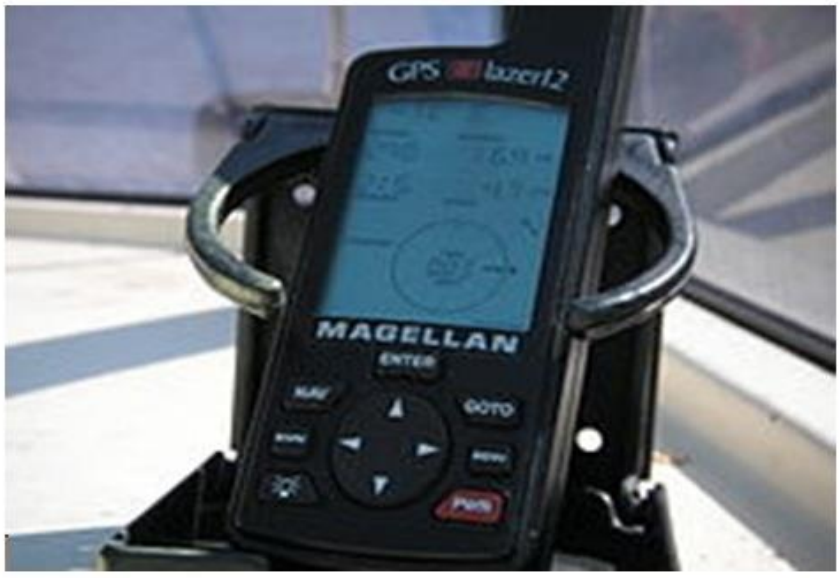
Frequency L_1 (wavelength L_1=19 cm) is formed by multiplying the reference clock frequency by 154 and modulated by C/A and P-codes, the frequency L_2 (wavelength L_2=24 cm), it is formed by multiplying the frequency of the oscillator 120 and modulated by the R-code. In addition, both of these frequencies are further modulated by the navigation message. The presence of P-codes at two frequencies allows you to confidently assess the ionosphere correction and improve accuracy.

The position of the receiver is fixed by solving a system of equations:

$$(x_1 - x)^2 + (y_1 - y)^2 + (z_1 - z)^2 = [c(\Delta t_{c1} - \Delta t_z)]^2$$
$$(x_2 - x)^2 + (y_2 - y)^2 + (z_2 - z)^2 = [c(\Delta t_{c2} - \Delta t_z)]^2$$
$$(x_3 - x)^2 + (y_3 - y)^2 + (z_3 - z)^2 = [c(\Delta t_{c3} - \Delta t_z)]^2$$
$$(x_4 - x)^2 + (y_4 - y)^2 + (z_4 - z)^2 = [c(\Delta t_{c4} - \Delta t_z)]^2$$

In this equation, three coordinates (X, Y, Z) and the same synchronization error Δtz for all satellites are unknown.

Using GPS technology: In every store that specializes in selling electronics, you can buy equipment with integrated GPS technology. GPS receivers are equipped with almost all electronics that a person uses in everyday life, from mobile phones to vehicles.



Picture 4. GPS receiver of MagellanNavigation company

The modern high-tech world is impossible to imagine without gadgets. Literally every person has a mobile phone, smart watch, fitness bracelets. And the cars are equipped with trackers that track their movement.

A person can find the place they need on an electronic map in their phone with an accuracy of up to several meters. And all this is thanks to GPS technology. GPS technologies fall under the scope of application:

- cartography;
- transport and communication;
- geodesy;
- aviation;
- seamanship;
- recreation and entertainment and much more.

And it will expand every year.

The global GPS satellite system of the second generation is based on the principles of rangefinding and is designed for high-precision determination of three coordinates of a place that make up the speed and time vectors of various moving objects. The system was developed by order and is under the control of the DOD (air force) of the United States. The United States provides the system as standard for civil, commercial, and scientific use without charging a special fee. It is determined that the US Department of transportation is responsible for the use of the system by civilian consumers. Location detection and navigation using the global positioning system (GPS) have become deeply embedded in our daily lives. The GPS navigation satellite system, being the first of its kind, is still the most widespread and popular. This is mainly due to the high accuracy of determining coordinates. After all, the new satellites are equipped with the latest technical means and electronics.

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