Japan's Quasi-Zenith Communication and Position Satellite System

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Abstract: *Japan decided to set up their satellite communication and positioning system, called "Quasi-Zenith Satellite System" (abbreviated QZSS) or in Japanese "Jun-Ten-Cho". In order to get QZSS satellite on the horizon above the elevation angle of 70° for ten hours, apparent orbits of 24-hour satellites in circular and elliptical trajectories have been tested. Thereby three QZSS satellites have been scheduled for alternate substitution during zenith in Japan. Position determining by GPS and QZSS satellites will be enhanced in the cities where the horizons are screened by high buildings. Besides, QZSS satellites will help mobile communications and broad casting without repeaters on the Earth surface or other electronic devices.*

Keywords: *position, communication, quasi-zenith satellite system, geostationary satellite, 24-hour satellite, Japan*

1 Introduction

In the year 2003, Japan as a technologically advanced country, started a project called "Quasi – Zenith Satellite System" (abbreviated QZSS) or in Japanese "Jun–Ten–Cho". According to finished pilot – projects, the QZSS satellite system will enhance determining of position of the fixed points and transport vehicles (Petrovski et al. 2003). However, this satellite system will be also used as a mobile communication system, as well as a radio system.

For the mobile communications in Japan, it would be optimal to have a satellite which would approximately stand in zenith in Japan. But there is no such a satellite nor there can be one, so there was a need to find a solution with some kind of high satellites.

Geostationary satellites in their orbiting around the Earth have equal angle speed as the angle speed of the Earth rotation around its axis. In order for these two speeds to be equal ($\omega_{Earth} = \omega_{geostat.s}$) and in order for the satellite to be geostationary, a satellite has to fulfil three conditions:

1) The satellite has to be on the height H = 35786 km above the Earth surface.
2) Its orbit has to lie in the equatorial plane, i.e. that the angle of inclination between the equatorial plane and the plane in which the satellite is orbiting is i = 0°
3) Its orbit has to be circular, not elliptical.

If these three conditions are fulfilled, the satellite will be seen from a certain point on the Earth as if it "apparently rests" and stands on the same spot above the horizon regardless of the daily rotation of the Earth. Even if only the first two conditions had been fulfilled, the satellite would not have been geostationary, that is, it would not "stand still" in the same place above the horizon of the spectator on the Earth. Namely, in this case the satellite would apparently move for the stationary spectator on the Earth, swinging in the equatorial plane around a certain balanced position.

Japanski kvazizenitni komunikacijski i pozicijski satelitski sustav

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Sažetak: *U Japanu su odlučili postaviti svoj satelitski komunikacijski i pozicijski sustav, koji su nazvali "Quasi-Zenith Satellite System" (skraćeno QZSS) ili japanski "Jun-Ten-Cho". Kako bi dobili QZSS-satelit po 10 sati na horizontu iznad elevacijskoga kuta od 70°, ispitane su prividne putanje 24-satnih satelita u kružnim i eliptičnim putanjama. Pritom su predviđena tri QZSS-satelita tako da se naizmjenično smjenjuju pri zenitu u Japanu. Položajna određivanja s pomoću GPS-a i QZSS-satelita bit će poboljšana u gradovima gdje su horizonti zaklonjeni visokim zgradama. Osim toga u Japanu će QZSS-sateliti pomoći mobilnim komunikacijama i emitiranju radioprograma bez repetitora na površini Zemlje i drugih elektroničkih uređaja.*

Ključne riječi: *položaj, komunikacija, kvazizenitni satelitski sustav, geostacionarni satelit, 24-satni satelit, Japan.*

1. Uvod

Japan je, kao tehnološki napredna zemlja, započeo u 2003. godini projekt nazvan *Quasi-Zenith Satellite System* (skraćeno nazvan QZSS) ili japanski *Jun-Ten-Cho*. Prema učinjenim pilot projektima QZSS-satelitski sustav poboljšat će određivanje položaja nepomičnih točaka i transportnih vozila (Petrovski i dr. 2003). Međutim, taj satelitski sustav koristit će se isto tako kao *mobilni komunikacijski sustav*, ali i *radiosustav*.

Upravo za mobilnu komunikaciju u Japanu bilo bi najpovoljnije da ima neki satelit koji bi približno stajao u zenitu u Japanu. Međutim, takvog satelita nema i ne možemo imati, pa je trebalo potražiti rješenje s nekom vrstom visokih satelita.

Geostacionarni sateliti u svojem gibanju oko Zemlje imaju kutnu brzinu jednaku kutnoj brzini rotacije Zemlje oko svoje osi. Da bi te dvije kutne brzine bile jednake ($\omega_{\text{Zemlje}} = \omega_{\text{geostac.s.}}$) i da bi satelit bio geostacionaran, moraju biti ispunjena tri uvjeta:

1) da je satelit na visini H = 35 786 km iznad površine Zemlje
2) da mu putanja leži u ekvatorskoj ravnini, tj. da je kut nagiba između ekvatorske ravnine i ravnine u kojoj kruži satelit i = 0°
3) da mu je putanja kružna, a ne eliptična.

Ako su ispunjena ta tri uvjeta, satelit će se vidjeti s nekog mjesta na Zemlji kao da „prividno miruje“ i stoji na istome mjestu na horizontu bez obzira na dnevnu rotaciju Zemlje. Čak da su ispunjena samo prva dva uvjeta takav satelit ne bi bio geostacionaran, tj. ne bi „mirno stajao“ na istome mjestu iznad horizonta opažača na Zemlji. Naime, u tom slučaju satelit bi se prividno gibao za „mirnog“ promatrača na Zemlji njišući se u ekvatorskoj ravnini oko nekog ravnotežnog položaja.

Jednostavnim računom dolazi se do toga da bi se geostacionarni satelit, smješten u ekvatorskoj ravnini na

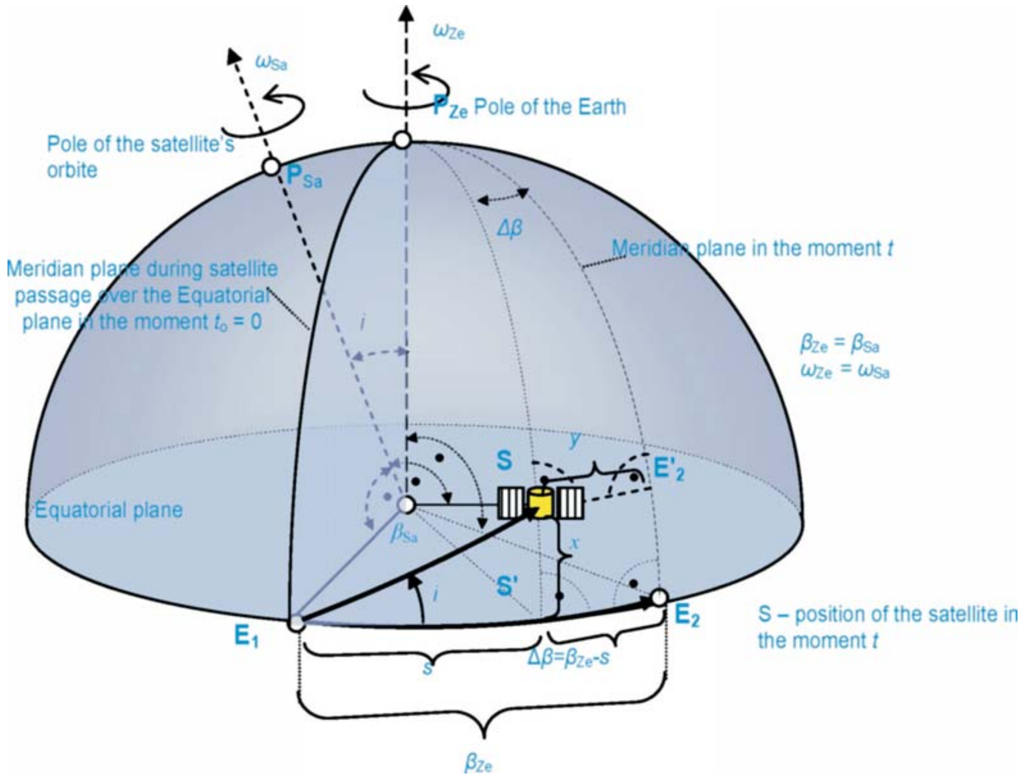


Fig. 1. Graphic illustration of why the spectator on the Earth sees relative motion of 24-hour satellites in circular orbit in relation to "still" Earth

By simple calculations, one comes to the conclusion that a geostationary satellite, situated in the equatorial plane on the geographical longitude of Tokyo, would be "visible" in Tokyo (Japan) above the horizon, under the elevation angle of 47°. Thereby geostationary satellites situated in the equatorial plane in the neighbouring geographical longitudes would be "visible" in Tokyo in the state of relative resting, under even smaller elevation angles above the horizon.

That kind of geostationary satellite would not be suited for mobile communication in Japan, nor for the positioning, especially in narrow city streets with high buildings.

Namely, there has been a request for the Japan's satellite (satellites) for the communication and positioning to be as long as possible on the elevation angles higher than 70° above the horizon, i.e. to be at most 20° away from the zenith.

This is why the Japanese were not able to produce their satellite system for communication and positioning by designing and launching geostationary satellite in the orbit around the Earth, but they needed to seek the solution with some kind of high satellites. That positioning QZSS could work also independently, but with limited accuracy.

It should be mentioned that the Japanese had no desire to create their own, independent positioning satellite system, but their desire was to enhance position determination in highly populated cities by adding one, two or three QZSS satellites near the zenith, together with GPS. This solution would be much more cost-effective.

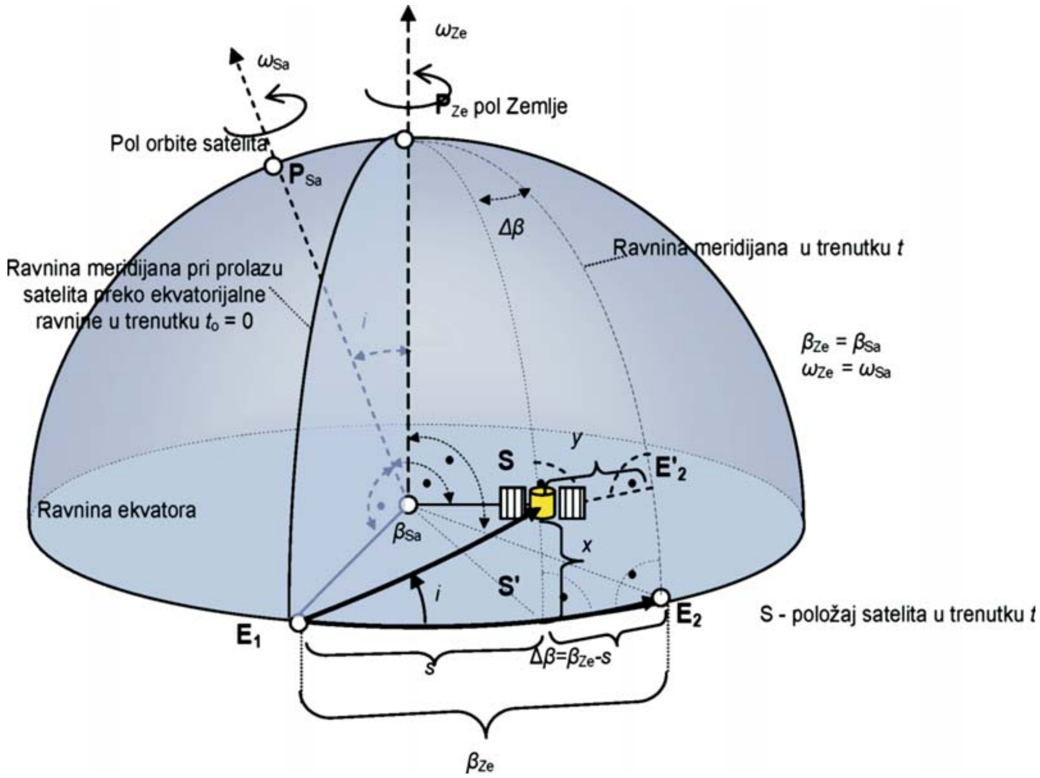
Several Japanese state organizations, and also those from private sector, cooperate on the development of the QZSS satellite system. Four ministries:

- Ministry of Public Management, Home Affairs, Posts and Telecommunications,
- Ministry of Education, Culture, Sports, Science and Technology,
- Ministry of Economy, Trade and Industry and
- Ministry of Land, Infrastructure and Transport

are conducting research and development on improvement of satellite technology, and on the selection of orbital elements of satellite system for the creation of enhanced communication and positioning system. In this, the Japan Aerospace Exploration Agency (JAXA) serves for the coordination of cooperation in joined researches with relevant research institutes on the experimental positioning system of high accuracy.

The private sector has set up a special company "Advanced Satellite Business Corporation" (ASBC) that will develop communication and radio-transmitting system.

Creation of basic design and production of engineering models of the equipment on the satellite has been started in 2004. It is planned that the first QZSS satellite will be launched in 2008. The second and third QZSS satellites will be launched in 2009. The QZSS will be made available for civil use in 2011 after three years of experimenting.



Slika 1. Grafički prikaz koji pojašnjava zbog čega opažač na Zemlji vidi relativno pomicanje 24-satnih satelita u kružnoj orbiti u odnosu na „mirnu“ Zemlju

geografskoj dužini Tokija, „vidio“ u Tokiju (Japanu) iznad horizonta pod elevacijskim kutom od 47°. Pritom bi se geostacionarni sateliti smješteni u ekvatorsku ravninu u susjednim geografskim dužinama „vidjeli“ u Tokiju u stanju relativnog mirovanja na još manjim elevacijskim kutovima iznad horizonta.

Takav geostacionarni satelit ne bi odgovarao u Japanu za mobilnu komunikaciju, pa ni za položajna određivanja, posebice u uskim gradskim ulicama s visokim zgradama.

Naime, postavljen je zahtjev da japanski satelit (sateliti) za komunikacije i položajna određivanja bude što duže vrijeme, po mogućnosti, na elevacijskim kutovima većim od 70° iznad horizonta, tj. da su sateliti udaljeni od zenita najviše 20°. Zato Japanci nisu mogli riješiti svoj satelitski sustav za komunikacije i pozicijska određivanja izradom i lansiranjem u orbitu oko Zemlje geostacionarnog satelita, već se moralo tražiti rješenje s nekom vrstom visokih satelita. Taj pozicijski QZSS mogao bi raditi i samostalno, ali s ograničenom točnosti.

Valja napomenuti da Japanci nisu željeli izraditi svoj samostalni satelitski sustav za položajna određivanja, već je njihova želja bila da dodavanjem jednog, dvaju ili triju QZSS-satelita u blizini zenita zajedno s GPS-sustavom poboljšaju određivanje položaja u gusto nastanjenim gradovima. To bi bilo mnogo ekonomičnije rješenje sa znatno manjim financijskim opterećenjem.

Nekoliko japanskih državnih organizacija, ali i iz privatnog sektora, surađuje na razvoju QZSS-satelitskog sustava. Tako četiri ministarstva:

- Ministarstvo narodnog upravljanja, domaće radinosti, pošta i telekomunikacija,
- Ministarstvo obrazovanja, kulture, sporta, znanosti i tehnologije,
- Ministarstvo ekonomije, trgovine i transporta
- Ministarstvo zemljišta, infrastrukture i transporta

vode istraživanje i razvoj na unapređenju satelitske tehnologije i odabiru orbitalnih elemenata satelitskog sustava za stvaranje poboljšanoga komunikacijskog i pozicijskog sustava. Pritom agencija Japan Aerospace Exploration Agency (JAXA) služi za koordinaciju suradnje u pridruženim istraživanjima s relevantnim istraživačkim institutima na eksperimentalnom pozicijskom sustavu visoke točnosti.

Privatni sektor je uspostavio posebnu kompaniju *Advanced Satellite Business Corporation* (ASBC), koja će razviti komunikacijski i radioodašiljački sustav.

Izrada osnovnog dizajna i proizvodnja inženjerskih modela opreme na satelitu započete su 2004. godine. Planira se da će prvi QZSS-satelit biti lansiran 2008. godine. Drugi i treći QZSS-satelit bit će lansirani u 2009. godini. Nakon tri godine eksperimentiranja QZSS bit će pušten u rad za civilnu uporabu, a to znači 2011. godine.

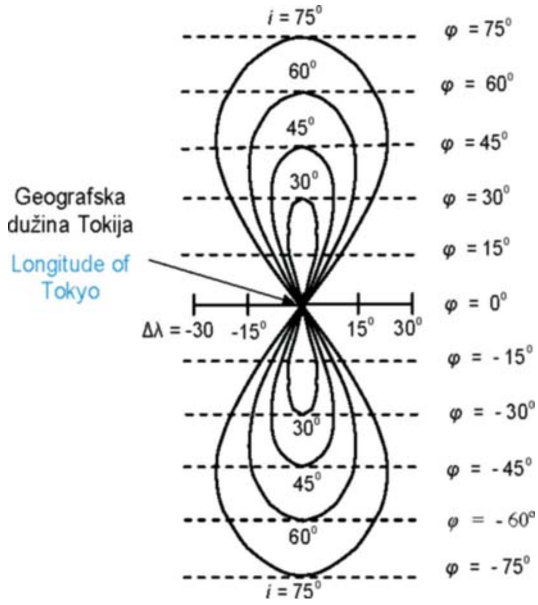


Fig. 2. Apparent orbits of relative motion of 24-hour satellites on their circular orbit (eccentricity e = 0) for different inclinations of orbits of the satellites during their motion around the Earth (i = 30°, 45°, 60° and 75°), as a spectator on the Earth sees them

Slika 2. Grafički prikaz prividnih putanja relativnoga gibanja 24-satnih satelita po njihovoj kružnoj putanji (ekscentricitet e = 0) za različite nagibe orbita satelita u njihovu gibanju oko Zemlje (i = 30°, 45°, 60° i 75°), kako ih vidi opažač na Zemlji

2 Apparent motion of 24-hour satellites around the Earth in the sky

24-Hour satellites rotate around the Earth with the same angle speed as the Earth rotates around its axis, that is, they go around the Earth in 24 hours, so this is how they got their name. This is why one can think at first that they must stand in the sky in the same way geostationary satellites do. But there is a difference between geostationary satellites and 24-hour satellites.

Geostationary satellites orbit around the Earth in the equator plane at the same angle speed as the Earth's. This is why they apparently "stand still" on the sky for a spectator on the Earth. However, this is not the case with 24-hour satellites, because they orbit around the Earth on the orbits that close an inclination angle *i* with the equator plane. This is why they will not appear to "stand still" at the same place on the celestial sphere, but they will move slowly and apparently in the sky above the spectator on the Earth. This will happen regardless of the fact that they have the same angle speed like the Earth around its rotating axis.

24-hour satellites travel around the Earth once a day, and they are situated on the same height, *H* = 35786 km above the Earth's surface, as well as the geostationary satellite, but their orbits are not in the equator plane, but their orbiting planes have certain inclination angle with the equatorial plane *i*. However, their orbits can be circular or elliptic.

Analyses of the use of 24-hour satellites for selection of satellites for the QZSS was done by (Petrovski et al. 2003) in the article "Japan's New Integrated Communication and Position – Service for Mobile Users".

2a Motion of 24-hour satellites on the circular orbits around the Earth and their apparent motion in the sky

24-hour satellites in the circular orbits and under certain inclination angles *i* in relation to equatorial plane can be described as a *number eight* on the sky for the "standing spectator" on the Earth. This apparent motion of 24-hour satellites is caused by combining rotation of the Earth around its axis and rotation of the satellite around the Earth on the axis inclined under the angle *i* in relation to the equatorial plane.

This occurrence can be best explained by Fig. 1. In the initial moment *t* = 0 let the 24-hour satellite be in the equatorial plane. After the time *t*, the Earth will turn around its rotation axis for the angle β_{Earth}. At the same time *t* 24-hour satellites will rotate around their orbit for the equal angle β_{Sa}. Namely, angle speed of the Earth ω_{Earth} and angle speed of 24-hour satellite ω_{Sa} are equal, so the banking angles of longitude plane and of 24-hour satellite in its plane will be equal, that is $\beta_{Earth} = \beta_{Sa}$.

However, these inclination angles β_{Earth} and β_{Sa} do not lie in the same plane, but their planes close between themselves an inclination angle *i* of the 24-hour satellite orbit. This is why the projection of banking angle of the satellite in the plane of the satellite's orbit β_{Sa} will be projected in the equatorial plan in the S' spot, e.g. it will be shorter from β_{Earth}. This means that a spectator on the Earth will at first see 24-hour satellite lapses on the west side. It will remain this way until the plane of the Earth's longitude does not turn for 90°, when the 24-hour satellite appears in that displaced longitude's plane.

In order to mathematically determine this apparent motion of 24-hour satellites, one can observe the spherical triangle E_1SS' and calculate the size of the projection of the spherical side angle β_{Sa} in the equatorial plane, which has been marked with letter *s* on the Fig. 1. This way we get:

$$s = \arctan[\tan(\beta_{Sa}) \cdot \cos(i)] \tag{1}$$

So the lagging angle of the 24-hour satellite in the equatorial plane is:

$$\Delta\beta = \beta_{Earth} - s \tag{2}$$

Now it can be calculated, from the very same spherical triangle E_1SS' the value of angle distance *x* from the equatorial plane and the plane the satellite passes through. In this way, we get:

$$x = \arctan[\sin(s) \cdot \tan(i)]. \tag{3}$$

2. Prividno gibanje 24-satnih satelita oko Zemlje na nebeskom svodu

24-satni sateliti rotiraju oko Zemlje istom kutnom brzinom kojom Zemlja rotira oko svoje osi, tj. oni obiđu oko Zemlje za 24 sata, pa su po tome i dobili ime. Zato se u prvi trenutak može pomisliti da oni moraju stajati na nebeskom svodu isto tako kao što stoje geostacionarni sateliti. Međutim, postoji razlika između geostacionarnih i 24-satnih satelita.

Naime, geostacionarni sateliti kruže oko Zemlje u ravnini ekvatora istom kutnom brzinom kao Zemlja. Zato oni prividno „mirno" stoje na nebeskom svodu za promatrača na Zemlji. Međutim, to nije tako s 24-satnim satelitima, jer oni kruže oko Zemlje po putanjama u ravninama koje zatvaraju neki kut nagiba *i* s ravninom ekvatora. Zbog toga oni neće prividno *mirno* stajati na istome mjestu na nebeskom svodu, već će doći do njihova sporog prividnoga gibanja na nebeskom svodu iznad promatrača na Zemlji. To će se dogoditi unatoč tome što oni imaju istu kutnu brzinu kao i Zemlja pri rotaciji oko svoje osi.

24-satni sateliti obiđu oko Zemlje jedanput u danu, a oni se nalaze na istoj visini *H* = 35 786 km iznad površine Zemlje kao i geostacionarni sateliti, samo što se njihove putanje ne nalaze u ekvatorskoj ravnini, već njihove ravnine putanja zauzimaju neki kut nagiba s ekvatorskom ravninom *i*. Pritom njihove putanje mogu biti kružne ili eliptične.

Analizu primjene 24-satnih satelita za izbor orbita satelita QZSS-a učinili su (Petrovski i dr. 2003) u članku *Japan's New Integrated Communication and Position – Service for Mobile Users*.

2a. Gibanje 24-satnih satelita po kružnim putanjama oko Zemlje i njihovo prividno gibanje na nebeskom svodu

Gibanjem po u kružnim putanjama i pod nekim od kutova nagiba *i* u odnosu na ravninu ekvatora 24-satni sateliti opisat će *osmicu* na nebeskom svodu za „mirnog promatrača" na Zemlji. To prividno gibanje 24-satnih satelita izazvano je kombiniranom rotacijom Zemlje oko svoje osi i rotacijom satelita oko Zemlje po putanji nagnutoj pod kutom *i* u odnosu na ravninu ekvatora.

Ta pojava može se najbolje pojasniti prema sl. 1. Neka je u početnom trenutku *t* = 0 24-satni satelit u ravnini ekvatora. Nakon vremena *t* Zemlja će se zakrenuti oko svoje rotacijske osi za kut β_{Ze}. Za to isto vrijeme *t* 24-satni satelit će rotirati po svojoj putanji za isto toliki kut β_{Sa}. Naime, kutna brzina Zemlje ω_{Ze} i kutna brzina 24-satnog satelita ω_{Sa} su jednake, pa će i kutovi zakreta ravnine meridijana i zakreta 24-satnog satelita u njegovoj ravnini biti jednaki, tj. bit će $\beta_{Ze} = \beta_{Sa}$.

Međutim, ti kutovi zakreta β_{Ze} i β_{Sa} ne leže u jednoj ravnini nego njihove ravnine zatvaraju između sebe kut nagiba *i* putanje 24-satnog satelita. Zato će se projekcija kuta zakreta satelita u ravnini putanje satelita β_{Sa} projicirati u ravninu ekvatora u točku S', tj. ona će biti kraća od β_{Ze}. To znači da će opažač na Zemlji na početku vidjeti da 24-satni satelit zaostaje na zapadnoj strani. Tako će biti sve dok se ravnina Zemljina meridijana ne zakrene za 90°, kada će se i 24-satni satelit pojaviti u toj pomaknutoj ravnini meridijana.

Da bi se matematički odredilo to prividno pomicanje 24-satnih satelita, može se promotriti sferni trokut E_1S S' te izračunati veličina projekcije kuta sferne stranice β_{Sa} u ravnini ekvatora, koja je na sl. 1 označena slovom *s*. Tako se dobije da je:

$$s = \arctan\left[\tan(\beta_{Sa}) \cdot \cos(i)\right] \qquad (1)$$

pa tako kut zaostajanja 24-satnog satelita u ravnini ekvatora iznosi:

$$\Delta\beta = \beta_{Earth} - s \qquad (2)$$

Sada se može izračunati, iz istoga toga sfernog trokuta E_1SS', na kojoj kutnoj udaljenosti *x* od ravnine ekvatora prolazi 24-satni satelit. Tako se dobije da je:

$$x = \arctan\left[\sin(s) \cdot \tan(i)\right]. \qquad (3)$$

Iz sfernog trokuta $P_{Ze}SE'_2$ može se izračunati i koordinata *y* izražena u stupnjevima, pa je:

$$y = \arctan\left[\cos(x) \cdot \tan(\Delta\beta)\right]. \qquad (4)$$

Za različite nagibe *i* putanje satelita izračunane su s pomoću jednadžbi (1), (2), (3) i (4) kutne vrijednosti *x* i *y* za iscrtavanje grafičkog prikaza putanja prividnoga (relativnoga) gibanja 24-satnih satelita, kako se to vidi na Zemlji (sl. 2).

Iz grafikona na sl. 2 vidi se da 24-satni sateliti u svom prividnom relativnom gibanju dosežu do geografskih širina koje su jednake njihovim nagibima putanja. Osim toga te *simetrične osmice* postaju sve veće kad je nagib satelitske putanje *i* veći.

Predviđa se da bi se 3 takva 24-satna QZSS-satelita smjenjivali svakih 8 sati u zenitu iznad Japana. Na taj bi način jedan satelit uvijek bio približno u zenitu, a drugi bi bio na nešto većoj zenitnoj udaljenosti. Treći QZSS-satelit bio bi tada negdje na jugu, pa možda i kraće vrijeme ispod horizonta u Tokiju. To bi se moglo ostvariti tako da svaki QZSS-satelit ima svoju ravninu putanje i da su im uzlazni čvorovi u ravnini ekvatora pomaknuti po longitudi za 120° (sl. 4). Upravo zato što će jedan od QZSS-satelita uvijek biti blizu zenita, Japanci su taj satelitski sustav nazvali kvazizenitnim.

2b. Gibanje 24-satnih satelita po eliptičnim putanjama oko Zemlje i njihovo prividno gibanje na nebeskom svodu

Johan Kepler (1571 – 1630) postavio je na temelju astronomskih opažanja gibanja planeta Marsa tri zakona o gibanju planeta koji su po njemu dobili ime. Na osnovi tih zakona može se pojasniti i gibanje umjetnih Zemljinih satelita.

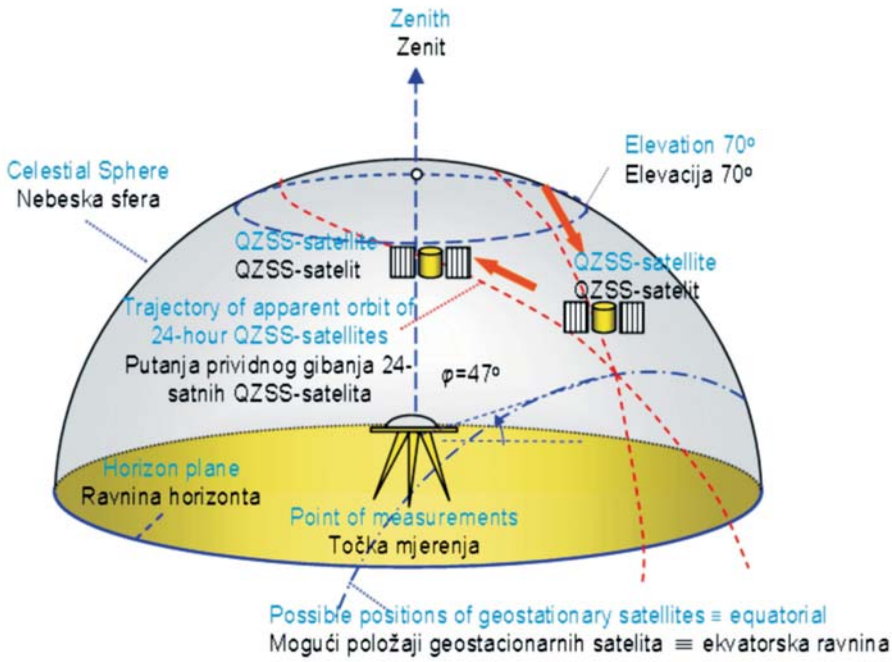


Fig. 3. View of celestial sphere in Japan with apparent, relative orbits of QZSS – satellites, as the standing spectator on the Earth sees them in Japan and neighbouring areas. Possible positions of geostationary satellites have been represented as well. (Third QZSS satellite is on the south and spends less time under the horizon.)

Slika 3. Pogled na nebesku sferu u Japanu s prividnim relativnim putanjama QZSS-satelita, kako ih vidi mirni opažač na Zemlji u Japanu i susjednim područjima. Osim toga prikazani su i mogući položaji geostacionarnih satelita. (Treći QZSS-satelit je na jugu i kraće vrijeme pod horizontom.)

The coordinate y expressed in degrees can be calculated from the spherical triangle $P_{Earth}SE'_2$. We get:

$$y = \arctan[\cos(x) \cdot \tan(\Delta\beta)]. \qquad (4)$$

For different inclinations i of the satellite's orbit, with the help of equations (1), (2), (3) and (4), angle values of x and y were calculated for drawing of graphical display of orbits of apparent (relative) motion of 24-hour satellites, as it is seen on the Earth, which is shown in Fig. 2.

From the chart in the Fig. 2, it is obvious that 24-hour satellite in its apparent relative motion reaches latitudes that are equal to their orbital inclinations. Besides, these *symmetrical eights* become greater when the inclination of the satellite's orbit i is greater.

It is being anticipated that 3 of these 24-hour QZSS satellites would be substituting every 8 hours on the zenith above Japan. In this way, there will always be one satellite approximately in zenith, and another QZSS satellite would be on somewhat greater zenith distance. The third QZSS satellite would then be somewhere on the south, so it can be shorter the time under the horizon in Tokyo. This could be done in the way that every QZSS satellite has its own orbital plane and that their ascending nodes in the equatorial plane are moved on the longitude for 120° (Fig. 4). The Japanese called this satellite system quasi-zenith because there will always be one QZSS satellite near the zenith.

2b. Motion of 24-hour satellites on the elliptical orbits around the Earth and their apparent motion in the sky

Johan Kepler (1571–1630) set 3 laws of planet motion, which were named after him, based on astronomical observations of motion of the planet Mars. Motion of artificial Earth's satellites can also be explained based on these laws.

From the 3rd Kepler's law follows that this equation must be satisfied:

$$\frac{T^2_{geost.s.}}{T^2_{24\text{-hour.s.}}} = \frac{\alpha^3_{geost.s.}}{\alpha^3_{24\text{-hour.s.}}}, \qquad (5)$$

where:

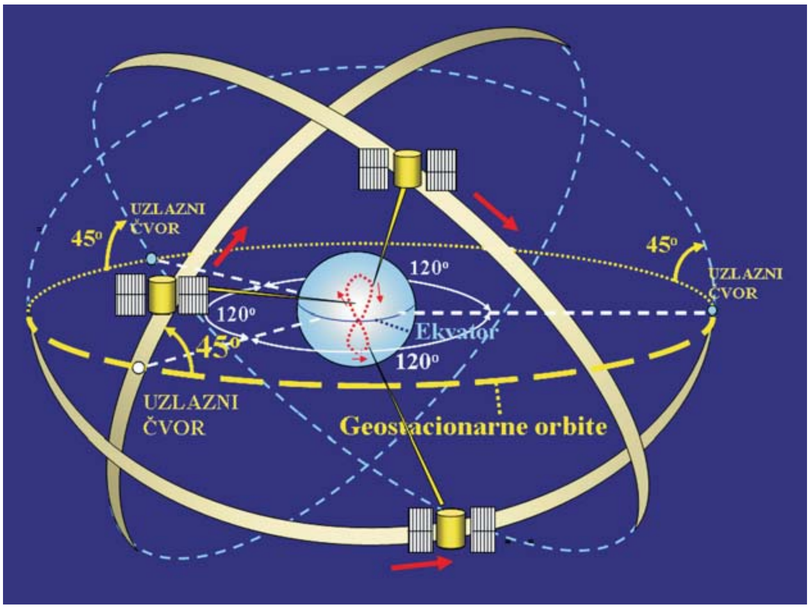
$T_{geost.}$ – orbital time of geostationary satellite

$T_{24\text{-hour.s.}}$ – orbital time of 24-hour satellite

$a_{geost.s.}$ – large semiaxis of geostationary satellites' elliptical orbit (35768 km+6370 km = 42156 km)

$a_{24\text{-hour.s}}$ – large semiaxis of 24-hour satellites' ellipti cal orbit

Since the orbiting times of geostationary satellite and 24-hour satellite are equal ($T_{geost.s} = T_{24\text{-hour.s.}}$), according to equation (5) big half axis of elliptical orbits have to be equal ($\alpha_{geost.s} = \alpha_{24\text{-hour.s}}$).



Ulazni čvor = Ascending node
Ekvator = Equator
Geostacionarne orbite = Geostationary orbits

Fig. 4. Representation of arrangement of QZSS satellites in three different satellite orbital planes under the inclination angle i = 45° in relation to the equatorial plane. Orbits of these satellites are circular, and QZSS satellites are represented at the same moment.

Slika 4. Zorni prikaz rasporeda QZSS-satelita u tri različite satelitske orbitalne ravnine pod kutom nagiba i = 45° u odnosu na ravninu ekvatora. Putanje tih satelita su kružne, a položaji QZSS-satelita prikazani su u istom trenutku.

Iz III. Keplerova zakona proizlazi da mora biti zadovoljena jednadžba:

$$\frac{T^2_{geost.s.}}{T^2_{24\text{-hour.s.}}} = \frac{\alpha^3_{geost.s.}}{\alpha^3_{24\text{-hour.s.}}}, \qquad (5)$$

gdje su:

$T_{geost.s.}$ – ophodno vrijeme geostacionarnog satelita,

$T_{24\text{-sat.s.}}$ – ophodno vrijeme 24-satnog satelita,

$\alpha_{geost.s.}$ – velika poluos eliptične putanje geostacionarnog satelita (35 786 km+6370 km= 42156 km),

$\alpha_{24\text{-sat.s}}$ – velika poluos eliptične putanje 24-satnog satelita.

Budući da su ophodna vremena geostacionarnog satelita i 24-satnog satelita jednaka ($T_{geost.s.}=T_{24\text{-sat.s.}}$), prema jednadžbi (5) velike poluosi eliptičnih putanja moraju biti jednake ($\alpha_{geost.s} =\alpha_{24\text{-sat.s.}}$).

Po II. Keplerovu zakonu radijus-vektor položaja satelita u odnosu na središte Zemlje prekriva u jednakim vremenskim intervalima jednake površine, tj. kaže se da su plošne brzine konstantne.

Iz sl. 5 vidi se da je u apogeju brzina satelita najmanja, a u perigeju najveća, dok se brzina satelita u bilo kojoj drugoj točki eliptične putanje nalazi između tih vrijednosti, tj. bit će:

$$v_{perigee} > v > v_{apogee}.$$

Zato je najpovoljnije za Japan da se ravnina eliptične putanje QZSS-satelita postavi tako da se točka njihova apogeja nalazi iznad Japana, jer će se u tom položaju QZSS-satelit duže zadržavati iznad Japana.

Postavljanjem triju QZSS-satelita u tri ravnine pod kutovima nagiba *i* međusobno udaljenih po 120° između njihovih uzlaznih čvorova može se postići da se tijekom dana oni naizmjenično nalaze blizu zenita u Japanu i relativno dugo zadržavaju nad Japanom.

Da bi se numerički odredila prividna putanja QZSS-satelita u eliptičkoj putanji, kako ju vidi „mirni“ promatrač na Zemlji, trebalo bi:

- projicirati položaj QZSS-satelita s eliptične putanje na sferu,
- iz tih koordinata sa sfere, po jednadžbama (1) – (4), odrediti koordinate *x* i *y* položaja QZSS-satelita izražene u stupnjevima i
- grafički prikazati uzastopne položaje prividne putanje QZSS-satelita.

U članku (Petrovski i dr. 2003) provedena su istraživanja mogućnosti korištenja putanja 24-satnih satelita s različitim ekscentricitetima *e* i za razne nagibe ravnina putanja *i*.

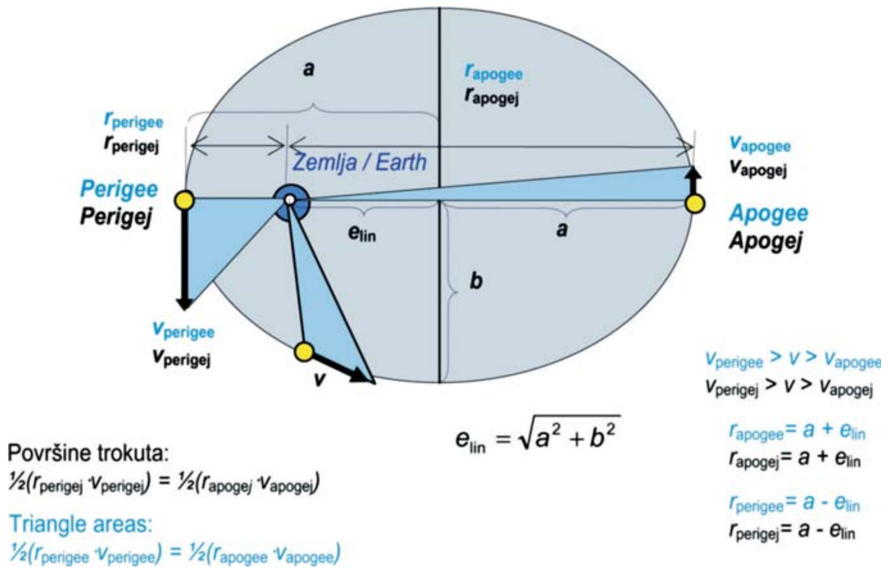


Fig. 5. Elliptical orbit of the satellite, perigee (as the nearest point of the Earth), apogee (as the most distant point), speed in perigee, speed in apogee, as planes' speed in perigee and apogee, which are equal according to the 2nd Kepler's law

Slika 5. Eliptična putanja satelita, perigej (kao najbliža točka Zemlje), apogej (kao najudaljenija točka), brzina u perigeju, brzina u apogeju, kao plošne brzine u perigeju i apogeju koje su jednake po II. Keplerovu zakonu

According to 2nd Kepler's law, radius of vector's position of the satellite in relation to Earth's centre covers equal surfaces at equal time intervals, i.e. it is said that planes' velocities are constant.

It can be seen from Fig. 5 that satellite's velocity is lowest in the apogee, greatest in the perigee, while the velocity of the satellite in any other point of elliptical orbit is between these values, that is:

$$\nu_{perigee} > \nu > \nu_{apogee}.$$

This is why it is best for Japan to set the plane of elliptical orbit of QZSS satellite in the way that points of their apogee are above Japan, because in this position the QZSS satellite will remain over Japan longer.

By setting three QZSS satellites in 3 planes under the inclination angles *i*, 120° between their ascending nodes, it can be achieved that during a day they alternately stay near the zenith in Japan and remain over Japan for a relatively long time.

In order to numerically determine apparent orbit of QZSS satellites in elliptical orbit, as a "standing" spectator sees it on the Earth, one should:

- ❑ project position of QZSS satellite from the elliptical orbit to sphere,
- ❑ out of these coordinates from the sphere, according to equations (1) – (4), determine coordinates *x* and *y* of the QZSS satellite's position, expressed in degrees
- ❑ graphically demonstrate sequential positions of QZSS satellites' apparent orbit

In the article (Petrovski et al. 2003), experiments for possible usage of 24-hour satellites' orbits with different eccentricities *e* and for different inclinations of orbits' planes *i*, have been conducted.

Orbit of 24-hour satellite will have different form for different values of eccentricities of apparent motion:

a) For the inclination of orbital plane *i* = 45° and eccentricity *e* = 0.099 apparent orbit of 24-hour satellite will have the shape of *asymmetrical eight* (Fig. 6), while they are symmetrical with the circular orbits of 24-hour satellites.

b) For the grater eccentricity of elliptical orbit, apparent orbit of 24-hour satellite motion will no longer have shape of an asymmetrical eight, but it will assume the shape of *rain drops*. It can be seen in Fig. 7 for the eccentricity of elliptical orbits of 24-hour satellites *e* = 0.21 and orbital inclination *i* = 45°. Apparent motion orbit of QZSS satellite will expand even more for somewhat greater eccentricity *e*. This kind of orbit of a QZSS satellite would be appropriate for an area wider than Japan, so, for this case, possibilities with 3 and 4 QZSS satellites have been tested.

Clear spatial image could also be constructed for this case, when QZSS has three QZSS satellites in elliptical orbits, as it is demonstrated in Fig. 4, for circular orbits of QZSS satellite.

Fig. 6. Apparent orbits of three 24-hour satellites with the inclination of orbital plane in relation to equatorial plane i = 45° and eccentricity e = 0.099

Slika 6. Prividne putanje triju 24-satnih satelita s nagibom ravnine putanje u odnosu na ravninu ekvatora i = 45° ekscentricitetom e = 0,099

Fig. 7. Apparent orbits of three 24-hour satellites with orbital plane inclination in relation to equatorial plane i = 42.5° and eccentricity e = 0.021

Slika 7. Prividne putanje triju 24-satnih satelita s nagibom ravnine putanje u odnosu na ravninu ekvatora i = 42,5° i ekscentricitetom e = 0,21

Za različite vrijednosti ekscentriciteta prividna putanja gibanja 24-satnog satelita bit će različita oblika:

a) Za nagib ravnine putanje *i* = 45° i ekscentricitet *e* = 0,099 dobije se da je prividna putanja gibanja 24-satnog satelita u obliku *nesimetrične osmice* (sl. 6), a kod kružnih putanja 24-satnih satelita one su simetrične.

b) Za veći ekscentricitet eliptične putanje prividna putanja gibanja 24-satnog satelita više neće biti u obliku nesimetrične osmice, već će se ona pretvoriti u oblik *kapi kiše*. To se vidi i na sl. 7 za ekscentricitet eliptičnih putanja 24-satnih satelita *e* = 0,21 i nagib orbite *i* = 42,5°. Za još nešto veći ekscentricitet *e* prividna putanja gibanja QZSS-satelita još će se više proširiti. Takva putanja QZSS-satelita odgovarala bi za neko šire područje od Japana, pa su za taj slučaj ispitane mogućnosti s 3 i 4 QZSS-satelita.

Mogla bi se konstruirati i prostorna zorna slika za slučaj kada QZSS ima tri QZSS-satelita u eliptičnim putanjama, kao što je to pokazano na sl. 4 za kružne putanje QZSS-satelita.

3. Točnost položajnog određivanja

U radovima (URL 2) i (Petrovski i dr. 2003) provedena je analiza mogućnosti uporabe QZSS-pozicijskog sustava. Tako je na primjeru gusto nastanjenog Shinjukija (donjega grada Tokija) pokazano da bi se ondje mogli odrediti položaji točaka:

- samo uporabom GPS-a na 24% ukupne površine i
- uz istodobnu uporabu GPS-a i QZSS-satelita na 70%.

To je svakako znatno poboljšanje položajnog određivanja s pomoću zajedničkog mjerenja GPS-om i QZSS-satelitima.

U radu (URL 4) iscrtane su dvije karte svijeta na kojima su označeni GDOP-ovi (Geometrical Dilution of Precision – mjera s kojom je izražena ovisnost preciznosti položajnih određivanja o konstelaciji, tj. o geometriji rasporeda GPS-satelita iznad određivane točke). S pomoću GDOP-ova opisana je moguća točnost određivanja koordinata položaja, koja ovisi o konstelaciji satelita. Na jednoj karti ucrtani su GDOP-ovi kada se upotrebljava samo GPS, a na drugoj su karti ucrtani GDOP-ovi kad se upotrebljavaju GPS-sateliti i QZSS-sateliti.

4. Tehničke karakteristike kvazizenitnoga satelitskog sustava

Satelitski pozicijski sustav QZSS planiran je tako da je kompatibilan i interoperabilan s civilnom specifikacijom moderniziranoga GPS-a, te će tako biti dopuna GPS-u u Japanu. QZSS-sateliti odašiljat će signale L1, L2 i L5 . Signali L2 i L5 imat će istu strukturu i karakteristike kao i GPS-ovi signali L2C i L5, dok će se struktura signala L1 još istraživati, jer ima više mogućnosti. Također je planiran i dodatni eksperimentalni signal Lx s globalnim snopom.

3 Accuracy of position determination

In the papers (URL 2) and (Petrovski et al. 2003), analyses of possibilities of the QZSS position system was made. In this way, on the example of densely populated Shinjuku (lower city of Tokyo), it was demonstrated that there could be determined positions of the points:

- only by using GPS on 24 % of overall surface and
- by simultaneously using GPS and QZSS satellite on 70%

This is certainly great enhancement of position determination with the help of combined measuring with GPS and QZSS satellites.

In the paper (URL 4) two world maps have been drawn, on which GDOPs (Geometrical Dilution of Precision) have been marked. With the help of GDOPs, possible accuracy of determining of position coordinates has been described, which depends of satellite's constellation. On one map, GDOPS were drawn when only GPS is used, and on the other, GDOPs were drawn when the GPS satellites and QZSS satellites are in use.

4 Technical characteristics of quasi-zenith satellite system

QZSS satellite position system is planned in a way to be compatible and interoperable with civil specification of modernized GPS, so it will be a complement in Japan. The QZSS satellite will emit signals L1, L2 and L5. Signals L2 and L5 will have same structure and characteristics as GPS's signals L2C and L5, while the structure of L1 signal will be researched further, since it has more possibilities. Additional experimental signal Lx with global beam has been planned.

QZSS time will be maintained in relation to UTC (CRL) (Universal time coordinated and determined by Communications Research Laboratory from Japan) and will be compared with UTC (USNO) (Universal time coordinated and determined by United States Navy Observatory from USA). Coefficients af0, af1 and af2 will be emitted by QZS satellites so that the users can receive corresponding GPS time. Aimed accuracy of emitting GPS – QZSS time is to be less than 3 nanoseconds over the 24-hour period.

In QZSS, usage of coordination system ITRS (International Terrestrial Referent System) is planned, which is almost equivalent to global geodetic system WGS'84, only more accurate. There is a possibility that Japanese geodetic datum (JGD – 2000), which is connected with ITRS will be used in the system (Petrovski et al. 2003, pp 28). The Japanese geodetic datum JGD-2000 is also called the Japan satellite navigation Geodetic System JGS (URL 5). The discrepancy between the QZSS coordinate system from GPS and Galileo will be less than 0.02 m.

Devices on QZSS satellites for positioning are made in Japan Aerospace Exploration Agency (JAXA) and Communications Research Laboratory (CRL). In order to secure high accuracy of frequency and accuracy of signal emitting, each QZSS satellite will carry ruby and caesium atomic standard of frequency. First satellite will carry active hydrogen massager, which will be made by CRL to demonstrate technology of H – maser.

CRL also develops bilateral data exchange between QZSS satellites and terrestrial controlling system with a precision of under a nanosecond.

Terrestrial segment, which will monitor motion of QZSS satellites, will consist of control station and several motion monitoring stations for QZSS satellites, situated in Japan and abroad. They will be developed by JAXA, CLR and other institutes. Three or four laser stations for measuring distance to the satellite will be used for the test and initial calibration of QZSS'.

Besides mentioned devices important for the operation of position system, there will be many devices for mobile communications and radio broad casting on QZSS satellites. On QZSS satellites L–, S– and Ku – range of radio broad casting wave will be used. S– (Shortwave) for radio emissions and communications at lower speeds, Ku– range for high speed communication and TT&C.

Next planned step is adjustment of QZSS so it can be used together with Russian navigational system GLONASS, and also with planned European GALILEO.

5 Conclusion

We will not be able to use Japan's QZSS satellite communication and positioning system in Croatia. It should be emphasized that the situation concerning positioning is different today. Namely, navigation system GLONASS has been partially constructed, and first European navigation satellite GIOVE "A" of Galileo system was launched in orbit around the Earth in 2005. So, we have not requirement for the establishemnt of a Croatian satellite navigation system today.

These QZSS satellites could help cartographic – geodetic measurement in cities with high buildings and narrow streets, and drivers in cars who use satellite navigation.

However, satellites like QZSS could certainly help mobile communications in Croatia, since in that manner number of repeaters and other necessary electronic devices for the communication would be considerably diminished.

The Japanese have registered five types of constellations of the QZSS with International Telecommunications Union in October 2002.

QZSS-vrijeme održavat će se u odnosu na svjetsko koordinirano vrijeme UTC(CRL) (svjetsko vrijeme UTC koje je dano prema Communications Research Laboratory iz Japana)i bit će komparirano s UTC(USNO) (svjetsko vrijeme koje je dano prema United States Navy Observatory iz SAD-a). Koeficijente af0, af1 i af2 odašiljat će QZSS-sateliti tako da korisnici mogu dobiti odgovarajuće GPS-vrijeme. Ciljana je točnost odašiljanja GPS-QZSS vremena da bude manja od 3 nanosekunde preko 24-satnog perioda.

U QZSS-u planira se upotreba koordinatnog sustava ITRS (International Terrestrial Referent System), koji je gotovo ekvivalentan svjetskom geodetskom sustavu WGS'84, samo je još točniji. Postoji mogućnost da se u QZSS-u koristi i Japanski geodetski datum (JGD-2000), koji je povezan s ITRS-om (Petrovski i dr. 2003, str. 28). Japanski geodetski datum JGD-2000, nazvan je i the Japan satellite navigation Geodetic System – JGS (URL 5).Odstupanje QZSS koordinatnog sustava od GPS i Galileja bit će manje od 0,02 m.

Uređaji na QZSS-satelitima za pozicioniranje izrađuju se u Japan Aerospace Exploration Agency (JAXA) i Communications Research Laboratory (CRL). Za osiguranje visoke točnosti frekvencije i točnosti odašiljanja signala svaki QZSS-satelit nosit će rubinov i cezijev atomski standard frekvencije. Prvi satelit nosit će i aktivni hidrogenski maser, koji će izraditi CRL, da demonstrira tehnologiju H-masera.

CRL također razvija dvosmjernu vezu razmjene podataka između QZSS-satelita i zemaljskog upravljačkog sustava s preciznosti ispod nanosekunde.

Zemaljski segment koji će pratiti gibanje QZSS-satelita sastojat će se od glavne kontrolne stanice i nekoliko stanica za praćenje gibanja QZSS-satelita smještenih u Japanu i inozemstvu. Njih će razviti JAXA, CRL i drugi instituti. Tri ili četiri laserske stanice za mjerenje udaljenosti do satelita bit će uporabljene za test i početnu kalibraciju QZSS-a.

Osim spomenutih uređaja bitnih za ispravan rad pozicijskog sustava, na QZSS-satelitima nalazit će se i mnogobrojni uređaji za mobilnu komunikaciju i radio-odašiljanje. Na QZSS-satelitima koristit će se L-, S- i Ku-područje emitiranja radiovalova: S-područje (kratkovalno) za odašiljanje radioemisija i komunikaciju s nižom brzinom, Ku-područje za komunikaciju s velikom brzinom i TT&C.

Sljedeći planirani korak je da se QZSS prilagodi tako da se može zajednički koristiti i s ruskim navigacijskim sustavom GLONASS-om, kao i planiranim europskim GALILEOM.

5. Zaključak

Japanski QZSS-satelitski komunikacijski i pozicijski sustav ne ćemo moći koristiti u Hrvatskoj. Valja naglasiti da je danas situacija što se tiče pozicijskih određivanja drugačija. Naime, djelomično je izgrađen navigacijski sustav GLONASS, a 2005. godine izbačen je u orbitu oko Zemlje prvi europski navigacijski satelit GIOVE ''A'' Galilejeva sustava. Tako danas više nema izričite potrebe za stvaranjem nekog posebnoga hrvatskog satelitskog navigacijskog sustava.

Takvi QZSS-sateliti mogli bi pomoći kartografsko-geodetskoj izmjeri u gradovima s visokim zgradama i uskim ulicama, kao i vozačima u automobilima koji koriste satelitsku navigaciju.

Međutim, što se tiče komunikacija sateliti slični QZSS-satelitima sigurno bi mogli znatno pomoći mobilnim komunikacijama u Hrvatskoj, jer bi na taj način bio znatno smanjen broj repetitora i drugih potrebnih elektroničkih uređaja za komunikaciju.

Pet tipova konstelacije QZSS-a Japanci su registrirali kod International Telecommunications Union u listopadu 2002. godine.

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