Basic GNSS

It may be a bit unexpected but many of the plans that will change GPS as a practical utility will be implemented entirely outside of the GPS system itself.

The GPS system is one component of the worldwide effort now known as the Global Navigation Satellite System *GNSS*, another is the GLONASS system of the Russian Federation, a third is the GALILEO system administered by the EU, a fourth is the Beidou/Compass system being built in China and a fifth may be the Japanese Quasi-Zenith Satellite System. The concept is nothing less than this; these networks of satellites will begin to work together augmented in some cases by both ground-based *GBAS* and space-based *SBAS* systems to provide positioning, navigation and timing solutions to users around the world. One goal of this cooperation is interoperability. Interoperability is the idea that properly equipped receivers will be able to obtain useful signals from all available the satellites in all the constellations and have their solutions improved rather than impeded by the various configurations of different satellite signals.

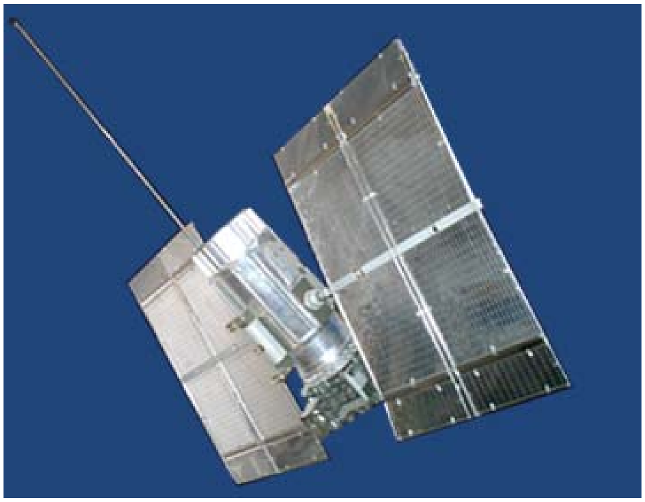
One example of the scope of this increased horizon in global positioning is illustrated by the name change of the International GPS Service to the International GNSS service *IGS*. It is, "a voluntary federation of more than 200 worldwide agencies that pool resources and permanent GPS & GLONASS station data to generate precise GPS & GLONASS products."[1]

One immediate effect of GNSS is the substantial growth of the available constellation of satellites and their signals. As long as they do not interfere with one another, the more signals that are available for positioning and navigation the better. The two systems that are currently online and available are GPS and GLONASS. We have discussed GPS, now GLONASS.

GLONASS

Russia's Globalnaya Navigationnaya Sputnikovaya Sistema - Global Orbiting Navigation Satellite System, known as GLONASS, did not reach full operational status before the collapse of the Soviet Union. Its first satellites reached orbit in October of 1982 a bit more than 4 years after the GPS constellation was begun. A nearly full constellation of 24 or so GLONASS satellites was achieved in 1996 but by 2001 only about 7 healthy satellites remained on orbit about 1000 km lower than the orbit of GPS satellites. And the remaining 7 were only expected to have a design life of three years. The situation was not helped by the independence of Kazakhstan, subsequent difficulties over the Baikonur Cosmodrome launch facility and lack of funds. The system was in poor health.

Signs of Renewal. Today there are signs of renewal. Since a decision in August of 2001 that outlined a program to rebuild and modernize GLONASS. For example, there are improvements in the satellites themselves.



GLONASS Uragan
Figure 1.1

The original GLONASS satellite was the Uragan. It was first launched in 1982 and had an intended life-span of 4 years.

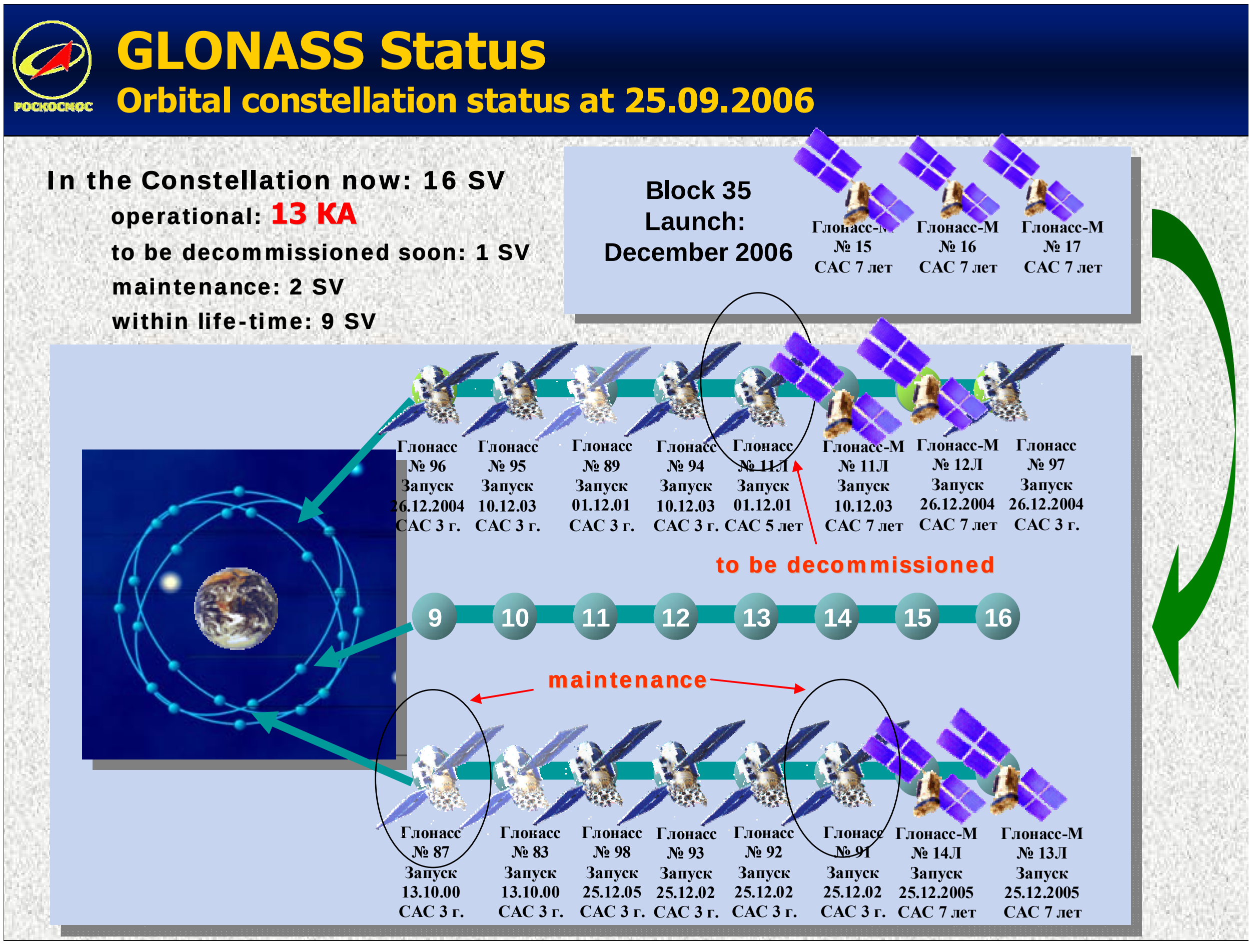
GLONASS Uragan M
Figure 1.2[2]

The M version of the GLONASS Uragan has improved antennas over the earlier spacecraft. They are also expected to have extended lifetimes of 7 years and carry separate transmission frequencies which are dedicated to civilian users. The first of these were launched in 2003

GLONASS Uragan K
Figure 1.3[3]

The K version of the GLONASS Uragan has a third L-band transmitter for civilian users, an extended service life of 12-15 years and costs less to produce. The first launch of these satellites is expected in 2009.

There has also been a recent approval of plans to substantially increase the funding and accelerated the restoration of a complete constellation including upgrading its ground sector. It appears it will be possible to remove the legal barriers to civil use of the GNSS receivers and develop a civilian mass market in GNSS in Russia including digital mapping and equipment.



GLONASS Status

Orbital constellation status at 25.09.2006

In the Constellation now: 16 SV

operational: 13 KA

to be decommissioned soon: 1 SV

maintenance: 2 SV

within life-time: 9 SV

Block 35
Launch:
December 2006

Глонасс-М
№ 15
САС 7 лет

Глонасс-М
№ 16
САС 7 лет

Глонасс-М
№ 17
САС 7 лет

Глонасс
№ 96
Запуск
26.12.2004
САС 3 г.

Глонасс
№ 95
Запуск
10.12.03
САС 3 г.

Глонасс
№ 89
Запуск
01.12.01
САС 3 г.

Глонасс
№ 94
Запуск
10.12.03
САС 3 г.

Глонасс
№ 11Л
Запуск
01.12.01
САС 5 лет

Глонасс-М
№ 11Л
Запуск
10.12.03
САС 7 лет

Глонасс-М
№ 12Л
Запуск
26.12.2004
САС 7 лет

Глонасс
№ 97
Запуск
26.12.2004
САС 3 г.

to be decommissioned

9 10 11 12 13 14 15 16

maintenance

Глонасс
№ 87
Запуск
13.10.00
САС 3 г.

Глонасс
№ 83
Запуск
13.10.00
САС 3 г.

Глонасс
№ 98
Запуск
25.12.05
САС 3 г.

Глонасс
№ 93
Запуск
25.12.02
САС 3 г.

Глонасс
№ 92
Запуск
25.12.02
САС 3 г.

Глонасс
№ 91
Запуск
25.12.02
САС 3 г.

Глонасс-М
№ 14Л
Запуск
25.12.2005
САС 7 лет

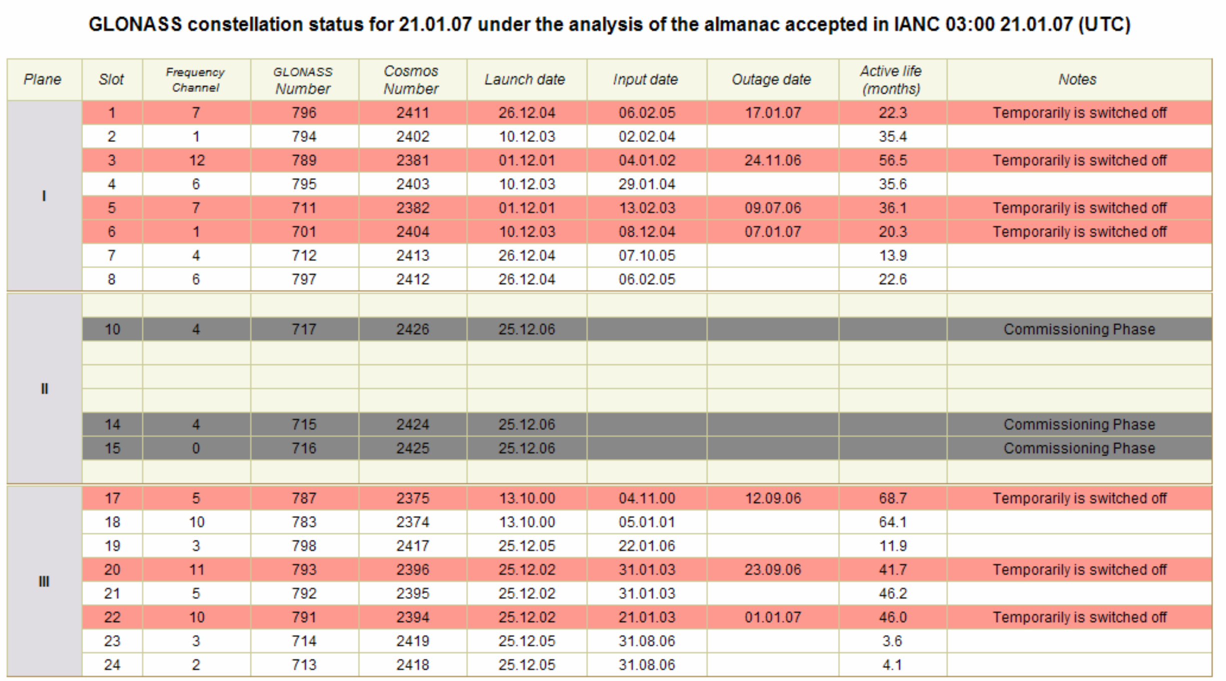
Глонасс-М
№ 13Л
Запуск
25.12.2005
САС 7 лет

GLONASS Constellation Status Sept. 25, 2006
Figure 1.4[4]

The constellation has increased. A complete GLONASS system would contain 21 active and three spare satellites spread over three orbital planes at the altitude of 19,100 km inclined 64.8 degrees toward the Equator.

Please note that the addition of a 7 to the satellite numbers in Figure 1.4 converts them to their GLONASS numbers, i.e. No. 98 – GLONASS Number 798.

The day after Christmas in 2004 three GLONASS satellites were launched. The mission included two Uragan, *796 and 797* and a follow-on Uragan-M satellite, *712*. The next year, on Christmas day three more GLONASS satellites a regular Uragan spacecraft *798* and a pair of upgraded Uragan-M satellites, *713 and 714*, achieved orbit.   While this brought the number of active satellites to 17 these two Uragan-M spacecraft did not enter service until August 2006.   While the GPS system has six orbital planes, as mentioned GLONASS has three. In September of 2006, 3 out of the 8 satellites in the 3rd plane were deactivated, apparently in anticipation of the re-configuration of the constellation for the launch on Christmas Day in 2006. On that day again three GLONASS satellites, *715, 716 and 717,* all Uragan M satellites were launched. These achieved orbit but, as shown in Figure1.5, are in the commissioning phase and still need to use their own propulsion systems to reach their final operational orbits.



GLONASS constellation status for 21.01.07 under the analysis of the almanac accepted in IANC 03:00 21.01.07 (UTC)

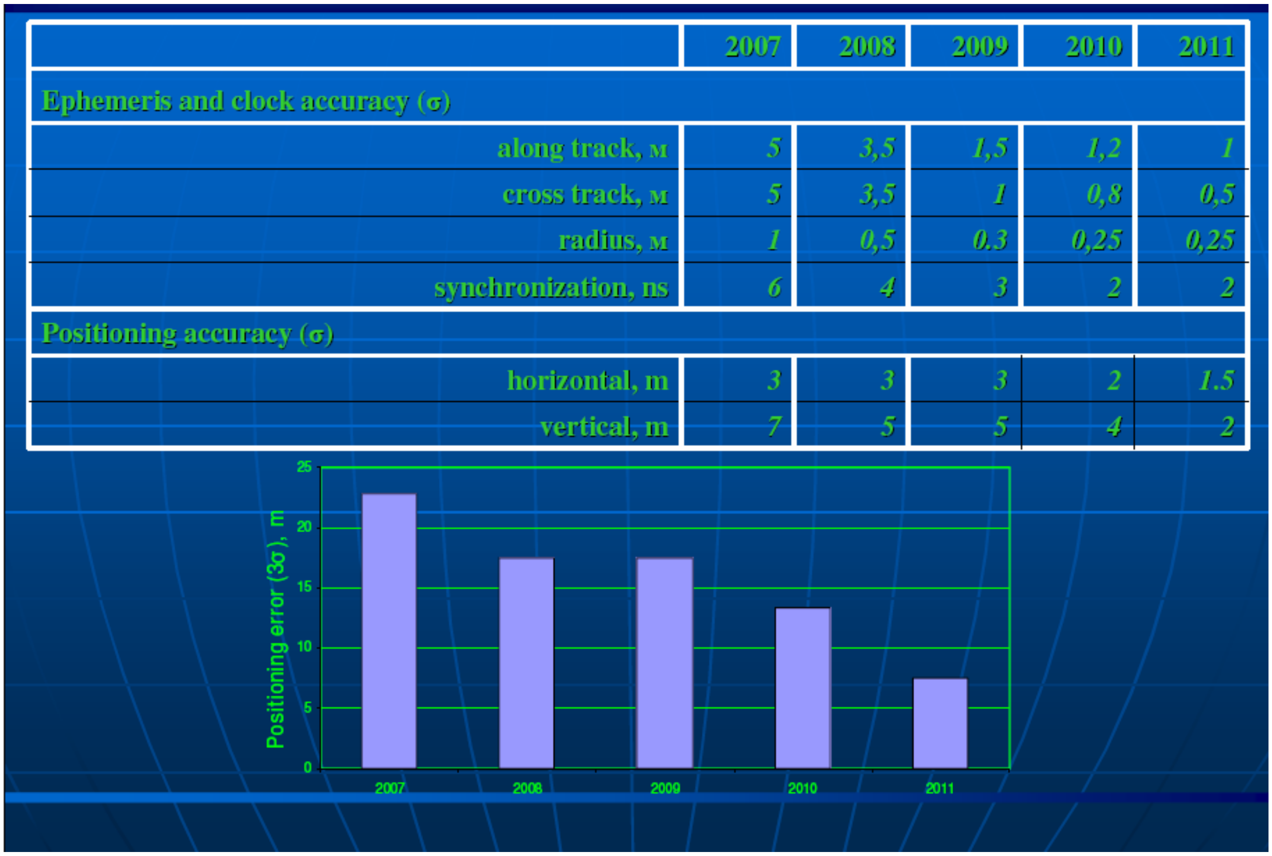
Plane	Slot	Frequency Channel	GLONASS Number	Cosmos Number	Launch date	Input date	Outage date	Active life (months)	Notes
I	1	7	796	2411	26.12.04	06.02.05	17.01.07	22.3	Temporarily is switched off
	2	1	794	2402	10.12.03	02.02.04		35.4	
	3	12	789	2381	01.12.01	04.01.02	24.11.06	56.5	Temporarily is switched off
	4	6	795	2403	10.12.03	29.01.04		35.6	
	5	7	711	2382	01.12.01	13.02.03	09.07.06	36.1	Temporarily is switched off
	6	1	701	2404	10.12.03	08.12.04	07.01.07	20.3	Temporarily is switched off
	7	4	712	2413	26.12.04	07.10.05		13.9	
	8	6	797	2412	26.12.04	06.02.05		22.6	
II									
	10	4	717	2426	25.12.06				Commissioning Phase
	14	4	715	2424	25.12.06				Commissioning Phase
	15	0	716	2425	25.12.06				Commissioning Phase
III	17	5	787	2375	13.10.00	04.11.00	12.09.06	68.7	Temporarily is switched off
	18	10	783	2374	13.10.00	05.01.01		64.1	
	19	3	798	2417	25.12.05	22.01.06		11.9	
	20	11	793	2396	25.12.02	31.01.03	23.09.06	41.7	Temporarily is switched off
	21	5	792	2395	25.12.02	31.01.03		46.2	
	22	10	791	2394	25.12.02	21.01.03	01.01.07	46.0	Temporarily is switched off
	23	3	714	2419	25.12.05	31.08.06		3.6	
	24	2	713	2418	25.12.05	31.08.06		4.1	

GLONASS Constellation Status Jan. 21, 2007
Figure 1.5[5]

The launch goal is to have 18 satellites available by the end of 2007. Figure 1.4 shows the status of the GLONASS constellation as of September 25, 2006 with 16 satellites and Figure 1.5 shows its status on January 21, 2007. Activation of 713 and 714 had been delayed because of frozen fuel lines but they were made available on August 31, 2006 and then increased the number of satellites on orbit to 16. Four were temporarily switched off in September and one has been off-line since July 9. Today, according to the Russian Space Agency website, 9 of the 16 satellites currently available are temporarily switched off and the 3 Uragan M launched most recently are in the commissioning phase. Full worldwide 24 hour coverage is expected by 2011. In that year, or before there are expected to be 21 Uragan-M satellites in 3 orbital planes, with 3 on-orbit spares in place.

GLONASS Signals. Regarding the signals broadcast by these satellites the original objective was similar to the plan embraced by GPS a system that would provide 100 meters accuracy with a deliberately degraded standard C/A signal and a 10-20 meter accuracy with its P signals available exclusively to the military. However, that changed at the end of 2004, the *Federal Space Agency*, *FKA*, announced a plan to provide access to the high-precision navigation data to all users. This is, of course, based on the code solution. The standard code chip lengths on the GLONASS L1 are 0.511MHz – 3135.03 L1 cycles/chip standard and 5.11 MHz precise – 313.503 L1 cycles/chip. On L2 they are 0.511MHz – 2438.36 L2 cycles/chip standard and 5.11 MHz precise – 243.836 L2 cycles/chip. Please see Figure 1.9.

It is encouraging that in 2005-2006 the GLONASS signal in space range error, the *UERE*, has decreased about a 30%. It is not up to the standard of GPS, but is improving.



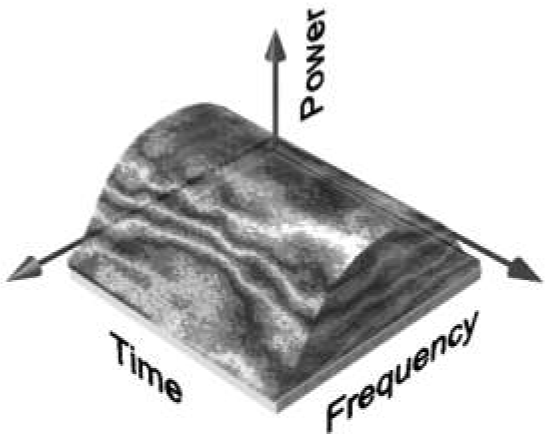
	2007	2008	2009	2010	2011
Ephemeris and clock accuracy (σ)					
along track, м	*5*	*3,5*	*1,5*	*1,2*	*1*
cross track, м	*5*	*3,5*	*1*	*0,8*	*0,5*
radius, м	*1*	*0,5*	*0.3*	*0,25*	*0,25*
synchronization, ns	*6*	*4*	*3*	*2*	*2*
Positioning accuracy (σ)					
horizontal, m	*3*	*3*	*3*	*2*	*1.5*
vertical, m	*7*	*5*	*5*	*4*	*2*

Evolution of GLONASS Navigation Accuracy
Figure 1.6[6]

As shown in Figure 1.6 ephemeris and clock accuracy are expected to improve steadily over the next few years. If the new approaches bear fruit the positioning accuracy will also improve markedly.

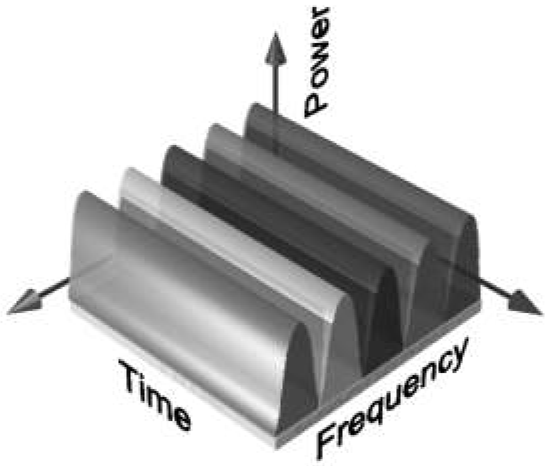
CDMA and FDMA. As you know a receiver collecting signals from GPS or GALILEO for that matter gets a different code from each satellite but each code it receives has exactly the same frequency. This approach is known as CDMA (Code Division Multiple

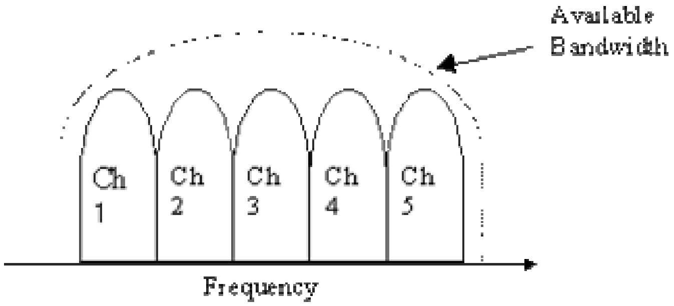
Access). CDMA technology was originally developed by the military during World War II.[7] Researchers were looking for ways of communicating that would be secure in the presence of jamming. CDMA does not use frequency channels or time slots. As in GPS CDMA usually involves a narrow band message multiplied by a large bandwidth PRN, pseudo-random noise, signal. As you have read these PRN codes are attached to the GPS carrier by changes in phase. Then all the users can receive the same frequency bands. And again, just as in GPS with CDMA the transmitted message is recovered by correlating the received signal with the PRN code available at the receiver.



Code Division Multiple Access CDMA
Figure 1.7[8]

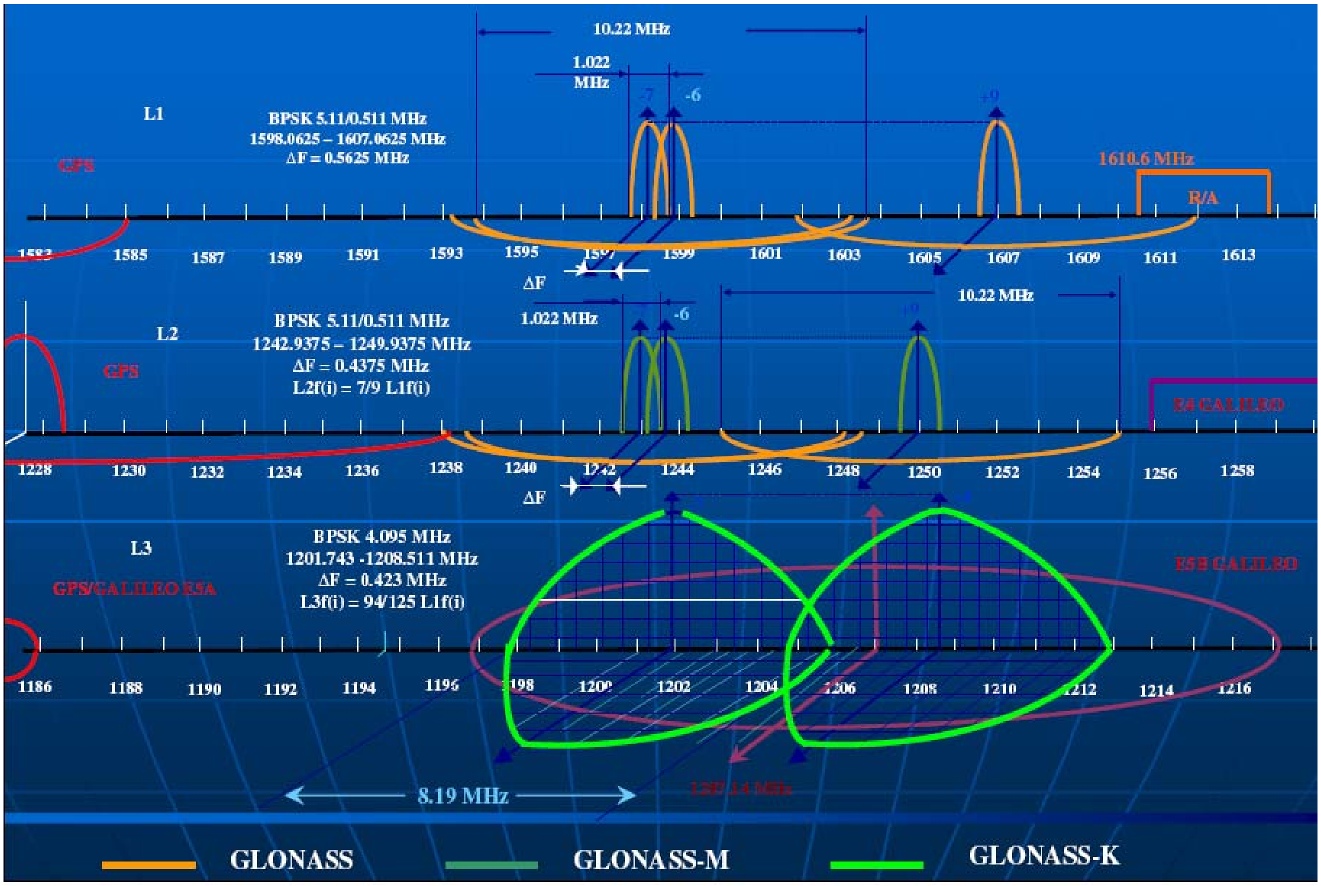
GLONASS uses a different strategy. The satellites transmit L-Band signals at a bit different frequencies than GPS, and instead of two distinct codes each code a GLONASS receiver collects from GLONASS satellites is exactly the same, but each satellite broadcasts it at a different frequency. This is known as FDMA (Frequency Division Multiple Access).





Frequency Division Multiple Access FDMA
Figure 1.8[9]

As shown in Figure 1.9, there are two L bands and they have ranges of frequencies, in the future there may be an L3.



GLONASS Signals
Figure 1.9[10]

L1 is centered on 1602 MHz with a range between ~1598.0625 to ~1607.0625 MHz and L2 is centered on 1246 MHz with a range between ~1242.9375 to ~1249.9375 MHz. However, within those ranges there can be up to 25 channels of L-band signals; currently there are 16 channels on each to accommodate the available satellites. Please note in the figure the -7 on the left and the +9 on the right for a total range from the center of 16. Each channel is separated from the others by a ΔF which is 0.5625 MHz on L1 and 0.4375MHz on L2. In other words each GLONASS satellite broadcasts the same code, but each satellite gets its own frequencies.

Also shown on Figure 1.9 is a civil reference signal on the L2 frequency. It is shown here in the dark green to indicate that it will be carried on the M satellites. It will substantially increase the accuracy of navigation relaying on civil signals in a similar fashion as L2C will add capability on the GPS L2 signal. Also notice that GLONASS signals do not overlap GPS frequencies, but the third civil reference signal on L3 that will be available on the K satellites will be within a new frequency band that includes 1201.743-1208.511 MHz and will overlap GALILEO's E5B signal. This could be good news.

Along that line with the revitalization of GLONASS underway interoperability between it and other systems is enticing. While there are some differences in the signals available from GPS, the EU's GALILEO system and GLONASS they are surmountable. And Russia has discussed development and use of GLONASS in parallel with the American GPS and European GALILEO systems.

Changes to FDMA. There may be some changes to the FDMA approach in the future. Recently Russia agreed to alter the architecture a bit. In order to use only half as many bands GLONASS will now assign the same frequency to satellites that are in the same orbital plane but are always on opposite sides of the Earth.

This will not only reduce the amount of the radio spectrum used by GLONASS it may actually improve its broadcast ephemeris information. Utilizing so many frequencies makes it difficult to accommodate the wide variety of propagation rates and keep the ephemeris information sent to the receivers within good limits. There are a number of receiver manufacturers that have GPS/GLONASS receivers available but the differences between FDMA and CDMA signals increases the technical difficulty and costs of such equipment. In the last few months of 2006 it was mentioned that GLONASS probably will be able to implement CDMA signals on the third frequency and at L1. This could make it easier for GPS and GALILEO to be interoperable with GLONASS.

In fact, there are many efforts underway to improve the GLONASS accuracy. The stability of the satellites on-board clocks has improved from $5x10^{-13}$ to $1x10^{-13}$ over 24 hours with precision thermal stabilization. The GLONASS Navigation Message will include the difference between GPS time and GLONASS time, which is significant.

GLONASS Time. As you know there are no leap seconds introduced to GPS Time in synch with UTC. However things are different in GLONASS. Leap seconds are incorporated into the time standard of the system. Therefore, there is no integer-second difference between GLONASS Time and UTC as there is with GPS. Still that is not the whole story. The epoch and rate of Russian time, relative to UTC (BIH) is monitored and corrected periodically by the Main Metrological Center of Russian Time and Frequency Service (VNIIFTRI) at Mendeleevo, Moscow. They establish the regional version of UTC which is known as UTC(CIS). There is a constant offset of three hours between GLONASS Time and UTC (CIS). However, with these differences available in the Navigation Message from GLONASS they can be accommodated. There are also efforts to increase the number of available tracking facilities in the GLONASS Ground Segment from 9 to 12, tie the GLONASS coordinate system to the International Terrestrial Reference System (ITRS), and launch the improved Uragan K spacecraft which may add a third L3 frequency band including differential ephemeris and time corrections that would allow sub-meter real-time positioning accuracy.

Considering interoperability, given the fact that the first GALILEO satellite reached orbit atop a Soyuz-Fregat rocket there is every reason to believe that the GALILEO/GLONASS agreement concerning the signal compatibility and interoperability at the GLONASS L3 and Galileo E5b or E6b bands will be successful.

GALILEO

Just over a dozen years after the idea was first proposed the work on GALILEO culminated in the launch of GIOVE-A (Galileo In Orbit Validation Experiment – A) December 28, 2005. The name GIOVE, Italian for Jupiter, is also a tribute to Galileo Galilei discoverer of Jupiter’s moons. In any case, it is intended to be the first of 30 satellites of the constellation. These satellites will orbit in 3 planes, 10 in each plane at approximately 3600 km higher than the GPS constellation. Like the GPS system GALILEO will utilize CDMA (Code Division Multiple Access). The full constellation of GALILEO satellites and full operational capability is expected to be in place by about 2008-2010. It took the combined efforts of 27 countries and public-private partnerships to get it done.

Actually, the Galileo Joint Undertaking *GJU*, is the body set up by the European Commission and the European Space Agency *ESA* to oversee Galileo's development phase, This phase will be financed in public-private partnerships, *PPP*. And it is the responsibility of the GJU to help mobilize the public and private sector funds required to complete the various phases of the program. In other words, GALILEO’s will be controlled by a civilian agency with a more of a business-operating model than is the case of GPS. The European Commission owns the physical system, the ground stations, satellites and so on. They are a public asset. Nevertheless the day-to-day operations will be the responsibility of a concessionaire.

But the EU’s GALILEO is on its way. It is emphatically a civil system and is clearly designed to reduce Europe’s dependence on the US military controlled GPS.

GIOVE A and GIOVE B. In fact one of the motivations to launching Giove-A was to allow European government authorities to register its Galileo frequencies with international regulators. Registration is necessary to prevent the frequency registration from expiring. It has done its job and continues to work well in orbit and now Europe has about two years to build a replacement satellite without facing a confiscation of its frequency reservations. This is fortunate because GIOVE-B the follow on to GIOVE-A has had its launch delayed because of a short circuit discovered during testing. It will probably go up in 2007.

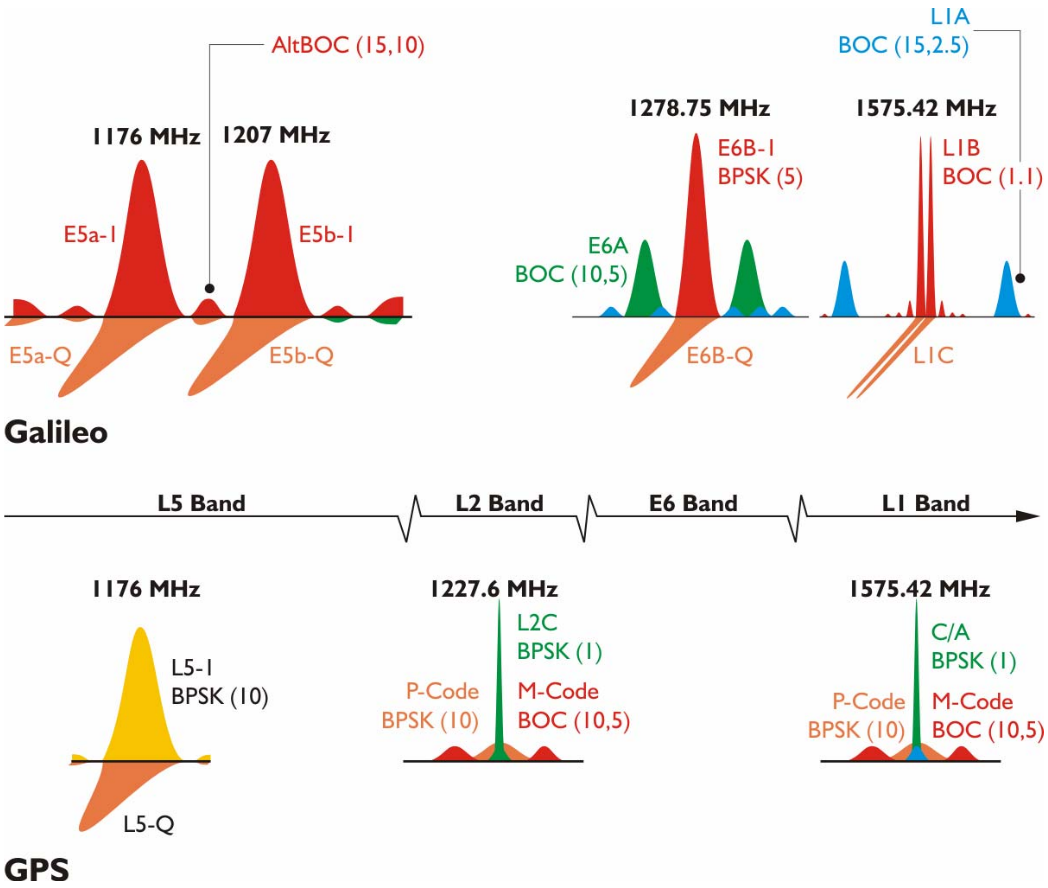
GIOVE-B is more like the satellites that will comprise the GALILEO constellation than is GIOVE-A. And as an illustration of the partnerships necessary for the success of GALILEO it is instructive to know that Galileo Industries, the consortium that is building Giove-B is also building the first four operational Galileo satellites. But GIOVE-B is scheduled for launch aboard a Russian Soyuz rocket.

GALILEO Signals and Services. The GALILEO signals are known as L1, E5a and E5b. It is worth noting that these signals will be compatible with the existing L1 GPS signal and the coming L5 signal. Please see Figure 1.10, more about that later. The system will also broadcast a third frequency band - E6.

GALILEO has defined five levels of service that will be provided by the system. They include - the Open Service which uses the basic signals and is quite similar to GPS and GLONASS. The Safety of Life Service is along the same line but provides increased guarantees including integrity monitoring. Users are warned if there are signal problems. The Public Regulated Service is encrypted and is meant to assist public security and civil authorities. It provides users with protection against jamming. The Search and Rescue Service is intended to enhance space-based services and improve response time to distress beacons and alert messages. Encrypted custom solutions for unique applications are provided in the Commercial Service. The business model is still under development, but the GALILEO concessionaire while delivering agreed service for the other four will probably find that the Commercial Service will generate the most profits.

Interoperability. Any discussion of interoperability between GPS and GALILEO must consider the overlapping signals. It is a prerequisite that the signals center on the same frequency if they are to be used in a combined fashion. For example, please recall that the third GLONASS civil reference signal on L3 that will be available on the K satellites will be within a new frequency band that includes 1201.743-1208.511 MHz and will overlap GALILEO's E5B signal

In Figure 1.10 the GALILEO signals are shown on the top and the GPS signals on the bottom. The GALILEO satellites broadcast signal in several frequency ranges including1176-1207 MHz, near GPS L5.



Interoperability GALILEO and GPS
Figure 1.10[11]

Please note in Figure 1.10 that GALILEO's E5a signal is centered exactly at 1176 as is L5. The other overlapping signals can be seen at 1575.42 MHz where both GALILEO's L1 and the GPS Ll frequency are both centered. Also, notice that in both cases the GPS signal is based on the binary phase shift key (BPSK) and the GALILEO signal is accomplished with the binary offset carrier (BOC) method. The compatibility of these methods can be seen graphically in Figure 1.10. An important characteristic of BOC modulation is that the codes greatest power density is at the edges that is at the *nulls* which, as it did with the M code on GPS mitigates interference with the existing codes. In this case, not only will there not be interference between the codes on GALILEO and GPS where they overlap they can actually be used together. GALILEO also has a signal

E6b at 1278.75 MHz. As you can see this band does not overlap any GPS frequency, however it does happen to coincide with the band that Russia is considering for L3 on GLONASS.

These fortuitous coincidences of frequencies did not happen without discussion.

As negotiations proceeded between the US and the EU one of the most contentious issues arose just as the European Union was moving to get GALILEO off the ground. They announced their intention to overlay GALILEO’s Public Regulated Service (PRS) code on the U.S. military’s M-code. The possibility that this would make it difficult for the DoD to jam the GALILEO signal in wartime without also jamming the U.S. signal was considered. It became known as the M-code overlay issue. In June of 2004 the US and the EU reached an agreement that ensured the Galileo's signals would not harm the navigation warfare capabilities of the United States and NATO.

So it looks as if some of the hurdles to interoperability between GALILEO and GPS are falling away. If the two systems can be compatible, when GALILEO is fully operational later this decade, they will provide more than twice the signal-in-space resource available to Global Navigation Satellite System (GNSS) users today.

As mentioned above it looks as if interoperability between its L1 and E5A frequencies and the GPS L1 and L5 frequencies respectively can be accomplished. Therefore, for 1- to 10-meter accuracy the frequencies are already matched at L1 and L5, and the code rates are synchronized around the multiples of 1.023 MHz. However, submeter users may have some issues with time drift between the systems. The problem may require a broadcast correction.

Chinese Beidou System

Beidou 1 Satellite
Figure 1.11

Perhaps it is appropriate to say a word or two about the Chinese System. The fourth GNSS system, joining those undertaken by the United States – *GPS*, Russia – *GLONASS* and Europe – *GALILEO*, will be the Chinese Beidou or *North Dipper* aka *Compass.* The system is already operational but is expected to expand substantially. The Chinese government had launched three Beidou GEO, geostationary Compass Navigation Satellite System *CNSS* satellites, by May of 2003. The Beidou-1 and 1B, launched in 2000 at 140º and 80º E. longitude respectively were followed by 1C in 2003 over 110.5º

E. longitude. Since the system only requires two satellites to function 1C is actually an in-orbit spare.

In an announcement made through the government news agency, Xinhua, the People's Republic of China National Space Administration said that two more GEO will be launched in 2007 on the way to an enhanced system of up to 35 satellites will cover all of China and neighboring nations by 2008. It is expected to include five GEO and 30 MEO or medium Earth orbit satellites in six orbital planes, the latter operating near the GPS and GALILEO altitude of 20,000 kilometers.

There will be two levels of service. One will be a 10m Open Service and the other will be an Authorized Service. The Open Service will offer an accuracy of 10m, 0.2 mps velocity accuracy and timing accuracy within 50 nanoseconds. The Authorized Service will be available to subscribers and will provide more reliable positioning and system integrity information. This bifurcation will probably resemble GALILEO’s publicly regulated service, *PRS*, or the encrypted *P-code* and *M* GPS military signals. However, details are difficult to come by.

This is all actually a bit of a surprise since there had been some expectation that China would pre-empt the expansion of its system in favor of participation in the GALILEO project.

Third Beidou Satellite Launched 2003
Figure 1.12

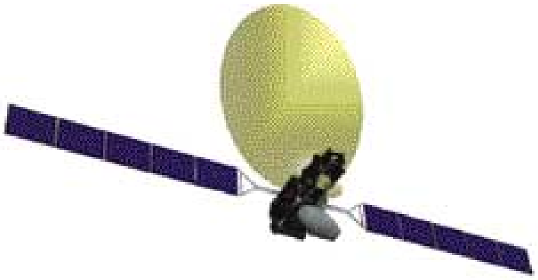
Frequencies. Frequency requests have been made by China for bands for the Beidou signals that may interfere with the Galileo Public Regulated Service (PRS) and the GPS M-code on Ll and L2. The requests are under consideration by the International Telecommuncations Union (ITU), a United Nations affiliate responsible for achieving handling the use of radio spectrum worldwide. The issue will probably be discussed at the World Radiocommunication Conference 2007 set for Geneva, Switzerland, next October/November.

China has said that it is willing to cooperate with other countries in arranging the Beidou so that it will operate with other global satellite positioning systems. However, the proposal to overlay the M-code would prevent the U.S. military from jamming Beidou transmissions without jamming its own signals. This would raise an alarm in the Department of Defense as did the original GALILEO Public Regulated Service design.

The issue is also a concern to the European Union (EU), which has wanted to engage China's support in GALILEO.

In fact, the GJU signed an agreement in October 2003 that included a €200 million Chinese contribution to the Galileo program. However, that participation apparently will not allow the full membership that China wants and GALILEO officials for their part are concerned that expansion of Beidou functionality will undermine the Galileo business case. Even though Beidou has long been planned European industry and governments had expected on it being only used a military system. But recent announcements that Beidou would provide an open level of service in 2008 with 10-meter accuracy, in addition to its encrypted military service has shown their expectations are not correct. The open service will be free to Chinese citizens and other countries depending on the arrangements they make with China. In any case, European plans to sell receivers and signal subscriptions in China are in jeopardy.

The Quasi-Zenith Satellite System from Japan



QZSS Satellite
Figure 1.13

The Japanese Quasi-Zenith Satellite System *QZSS* was originally proposed by a private sector consortium, but now the Japanese government plans to launch three geo-synchronous satellites broadcasting GPS-like signals. The configuration is intended to provide satellites at high elevation angles over Japan. This is the origin of the term *quasi-zenith*. It is actually a multi-satellite augmentation system designed to benefit modified GPS receivers operating in areas with significant signal obstructions such as urban canyons. The first demonstration QZSS satellite will be launched in 2008 and the satellites will also pass over parts of the Asia-Pacific region and will effectively increase the number of satellites available to suitably equipped GPS users in that region.

THE FUTURE

The goal of a single receiver that can track all the old and new satellite signals with a significant performance improvement and without a significant cost increase looks possible. But after all, the main attraction of interoperability between these systems is the greatly increased number of satellites and signals, better satellite availability, better dilution of precision, immediate ambiguity resolution on long baselines with three-frequency data, better accuracy in urban settings, and fewer multipath worries. And it is beginning to look like at least some of those things are achievable.

So what is coming? Ten years from now there may be as many as 80 satellites from GPS, GLONASS, Galileo and QZSS. The systems will provide users with a variety of signals and codes. The availability of many more satellites will enable new applications in areas where the current lack of satellites has been a hindrance to market growth.

For civil users, new signals which will provide more protection from interference, ability to compensation for ionospheric delays with pseudoranges and wide-laning or even tri-laning capability. For military users there will be greater anti-jam capability and security. For everybody improvement in accuracy, availability, integrity, and reliability

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