Architecture and Signal Structure of GLONASS

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Abstract: Global Navigation Satellite System has emerged as a pioneering way of determining ones position, in recent years, with accuracy up to less than one meter. The Russian counterpart of GPS is called GLONASS. GLONASS is a radio-based satellite navigation system, developed by the former Soviet Union and now operated by Russian Space Forces. The satellite navigation system GLONASS was conceived in the late 1960s, Development of the GLONASS system started in the mid-1970s, parallel to the American GPS. The government of Soviet Union made a decision to develop the system in 1976. The first launch took place in 1982. Until its dismissal in 1991, the Soviet Union launched 43 GLONASS-related satellites. Work on the system was continued by the Russian Federation which brought it its full operational capability in 1995. In the following years, the system fell into disrepair due to the economic crisis in the country and reduced space funding. Starting from 2000, the government under President Vladimir Putin made the restoration of GLONASS a top priority, its funding was doubled and after a rest of several years, launches were restarted again. In 2003, a new satellite design, GLONASS-M, was introduced. By early 2011, GLONASS had 22 operational satellites, two short of the required constellation of 24 to provide global coverage. The latest and significantly improved satellite type, GLONASS-K, was launched in February 2011.

Keywords: GLONASS, GPS, architecture, signal structure.

1 Introduction to Global Navigation satellite System (GNSS)

Satellite navigation system is a system of satellites that provide autonomous geo-spatial positioning with global coverage. It allows small electronic receivers to determine their location (longitude, latitude, and altitude) to within a few meters using time signals transmitted along a line-of-sight by radio from satellites. Receivers calculate the precise time as well as position, which can be used as a reference for scientific experiments. A satellite navigation system with global coverage may be termed a global navigation satellite system or GNSS.

As of September 2013, only the United States NAVSTAR Global Positioning System (GPS) and the Russian GLONASS are global operational GNSSs. China is in the process of expanding its regional navigation system into the global Compass navigation system by 2020. The European Union's Galileo positioning system is a GNSS in initial deployment phase, scheduled to be fully operational by 2020 at the earliest. France, India and Japan are in the process of developing regional navigation systems.

1.1 GPS (Global Positioning System)

Global Positioning System [1] is a space based satellite based Navigation system developed by US Department of Defense in 1970s and maintained by the US government, which provides location and time information in all weather conditions, anywhere on or near the Earth where there is an unobstructed line of sight to four or more GPS satellites. GPS was originally found for military use, later it served even for civilian applications such as surveying and navigation. The United States Global Positioning System (GPS) consists of up to 32 medium Earth orbit satellites in six different orbital planes, with the exact number of satellites varying as older satellites are retired and replaced. Operational since 1978 and globally available since 1994, GPS is currently the world's most utilized satellite navigation system; it is freely accessible to anyone with a GPS receiver [2].

1.2 COMPASS

China has indicated they intend to expand their regional navigation system called Beidou or Big Dipper, into a global navigation system by 2020 a program that has been called Compass in China's official news agency Xinhua. The Compass system is proposed to utilize 30 medium Earth orbit satellites and five geostationary satellites. A 12-satellite regional version is expected to be completed by 2012.

1.3 GALILEO

The European Union and European Space Agency agreed in March 2002 to introduce own alternative to GPS, called the Galileo positioning system [3]. At an estimated cost of EUR 3.0 billion, the system of 30 MEO satellites was originally scheduled to be operational in 2010. The estimated year to become operational is 2014. The first experimental satellite was launched on 28 December 2005. Galileo is expected to be compatible with the modernized GPS system. The receivers will be able to combine the signals from both Galileo and GPS satellites to greatly increase the accuracy. Galileo is now not expected to be in full service until 2020 at the earliest and at a substantially higher cost.

1.4 IRNSS

The **Indian Regional Navigational Satellite System** (**IRNSS**) is an autonomous regional satellite navigation system being developed by Indian Space Research Organization (ISRO) which would be under the total control of government of India [4]. The government approved the project in May 2006, with the intention of the system to be completed and implemented by 2014. It will consist of a constellation of 7 navigational satellites. All the 7 satellites will be placed in the Geostationary orbit (GEO) to have a larger signal footprint and lower number of satellites to map the region. It is intended to provide an all-weather absolute position accuracy of better than 7.6 meters throughout India and within a region extending approximately 1,500 km around it. A goal of complete Indian control has been stated, with the space segment, ground segment and user receivers all being built in India.

2. GLONASS System

GLONASS (GLObal Navigation Satellite System) is a radio-based satellite navigation system operated for the Russian government by the Russian Space Forces. It is an alternative and complementary to the United States Global Positioning System (GPS), the Chinese COMPASS navigation system or the planned GALILEO positioning system of the

European Union (EU) [5]. GLONASS has emerged as a pioneering way of determining ones position, in recent years, with accuracy up to less than one meter. This provides reliable positioning, navigation, and timing services to users on a continuous worldwide basis freely available to all, although both GPS and GLONASS are primarily intended for military users. A completely deployed GLONASS constellation is composed of 24 satellites in three orbital planes. Eight satellites are equally spaced in each plane. The satellites operate in circular 19,100km orbits at an inclination of 64.8°, and each satellite completes the orbit in approximately 11 hours and 15 minutes (GLONASS ICD 2002). GLONASS receivers compute their position in the GLONASS Reference System using satellite technology and based on triangulation principles. It is especially suited for usage in high latitude and where getting GPS signal is problematic, the latest version GLONASS is GLONASS-K.

In GPS or GLONASS the satellites need to be synchronized and can only perform as a constellation of at least four visible satellites for every possible user location without forgetting the GDOP requirement.

The main difference between GPS and GLONASS is that in GLONASS each satellite has its own frequencies but the same code whereas in GPS also satellites use the same frequencies but have different codes. GLONASS uses what is called a frequency division multiple access method (FDMA) whereas GPS and Galileo uses a code division multiple access technique (CDMA).

3 Architecture of GLONASS

The architecture of GLONASS system consists of three segments:

- The Space segment
- The Control Segment
- The User segment

The structure of GLONASS system is shown in figure 1. All these segments operate together to provide accurate three-dimensional positioning, timing and velocity data to users worldwide.

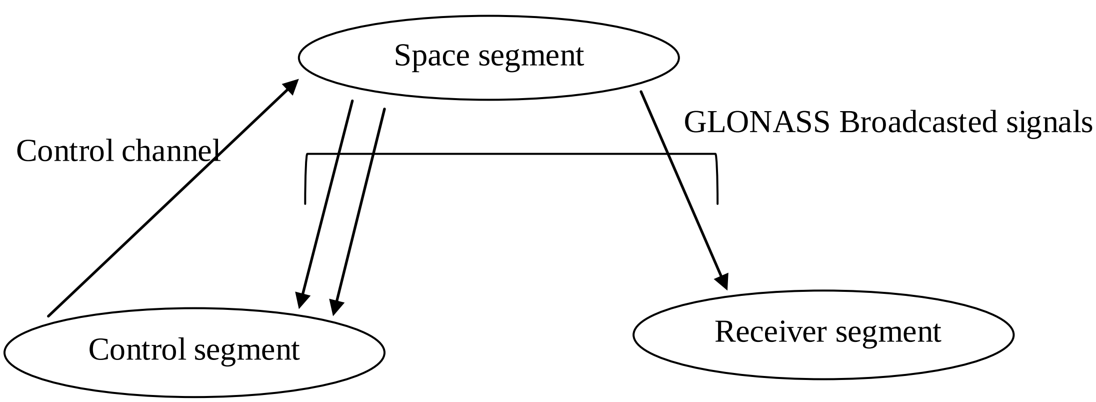

Figure 1 Structure of GLONASS system

3.1 Space Segment

The Space Segment of the GLONASS system was designed for nominal constellation of 24 satellites distributed over three orbital planes with an inclination of 64.8° (angle between equator and satellite orbit is called inclination angle) and each orbit has eight satellites. The longitude of ascending node differs by 120° from plane to plane. The altitude of near-circular orbits is around 19,100km, leading to an orbital period of11h 15 min 44s. These GLONASS satellites continuously broadcast ephemeris data which provides satellite ranging and timing information, and also to store and retransmit the navigation message sent by the control segment. These transmissions are controlled by highly stable atomic clocks on board the satellites [10].

GLONASS Satellite Constellation: The GLONASS system 24 satellites are arranged in a set of 8 satellites in 3 orbital planes as shown in figure 2.

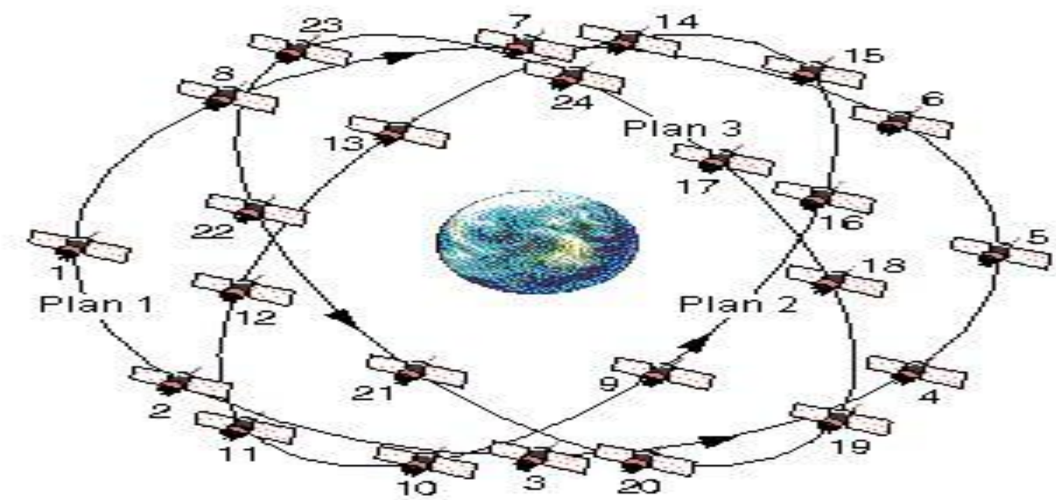

Figure 2 GLONASS Satellite Constellation

Each satellite is identified by its slot number, which defines the orbital plane and its location within the plane. These satellites kept at such heights provide at least four visible satellites to user at any location and at any time on the earth. A minimum of four satellites in view allows a GLONASS receiver to compute its position in three dimensions [14]. GLONASS satellites transmit two types of signal: Standard Precision Service (SPS) and High Precision Service (HPS) signal.

3.2 Control Segment

The GLONASS Control Segment (also referred to as Ground Segment or Operational Control System) is responsible for the proper operation of the system. It includes data upload stations, System Control Centre and the network of the Telemetry, Tracking and Control (TT&C) Stations that are located throughout the territory of Russia to ensure maximum satellite coverage and ground antennas.

The Control Segment consists of the system control centre and a network of command tracking stations across Russia. The GLONASS control segment, similar to GPS, must monitor the status of satellites, determine the ephemerides and satellite clock offsets with respect to GLONASS time and UTC (Coordinated Universal Time), and twice a day upload the navigation data to the satellites.

The ground stations make pseudo range measurements by passively tracking the satellites. This data is used by the master control station to update the navigation message with ephemeris data, corrections and almanac data. This updated information is called TT&C (Telemetry, Tracking and Command) data. This information for each satellite is uploaded by a ground uplink antenna when that particular satellite is in view of the antenna [14].

3.3 User Segment (Receiving Segment)

The GLONASS User Segment consists of L-band radio receiver/processors and antennas which receive GLONASS navigation signals and utilizes these signals to find out the user's location on surface of the earth using triangulation principles.

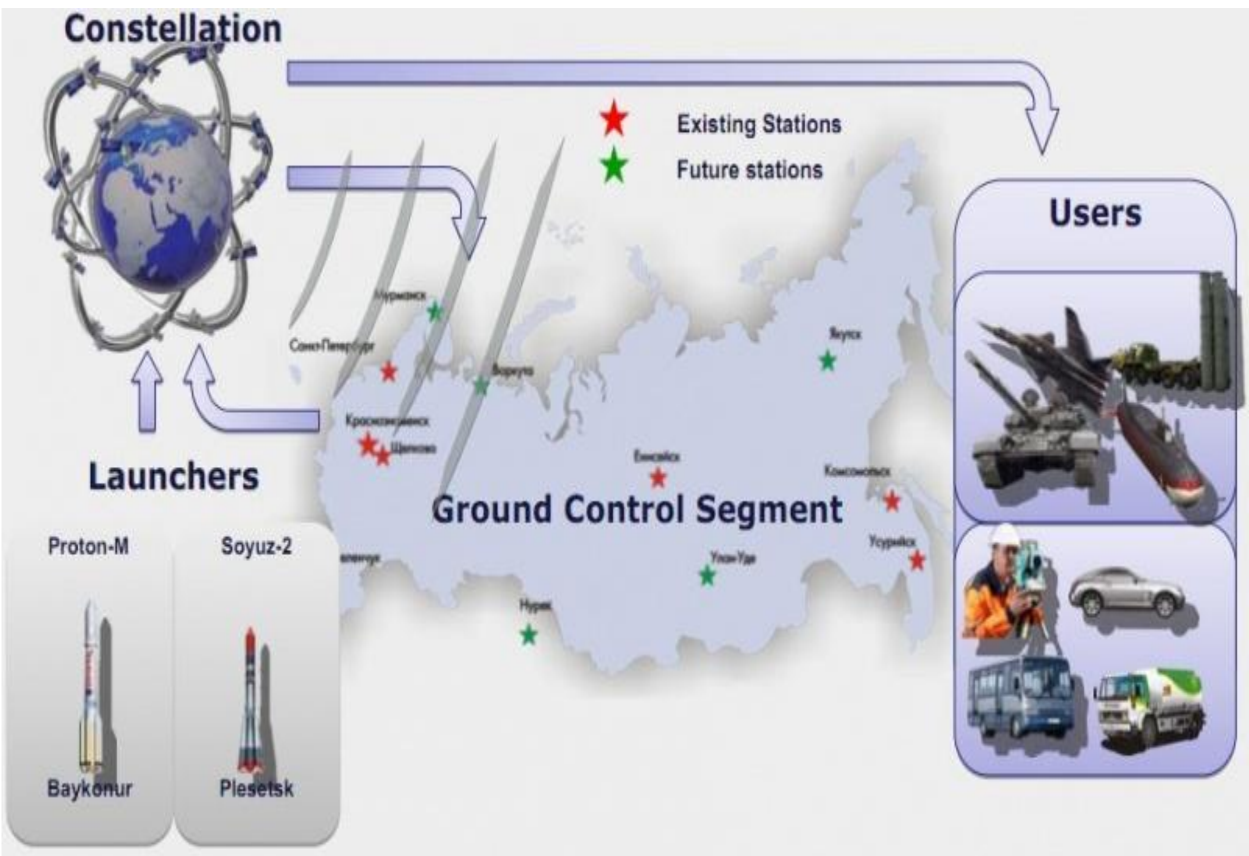

Figure 3 GLONASS Architecture

The GLONASS receivers employ the hemispherical coverage which has a Right Hand Circular Polarization (RHCP). The polarization ensures the differentiation between the multipath and direct path signals. The GLONASS receiver determines pseudo ranges and solves the navigation equations in order to obtain their coordinates and provide a very accurate time. It does this by calculating the code and carrier phases and demodulating the navigation message data.

4 GLONASS Signal Structure

The GLONASS signals are transmitted on two different frequencies, L1 and L2 carrier sub-bands. These satellite generated carrier frequency of L1 and L2 sub bands are modulated by the modulo-2 addition of pseudo random noise code, navigation data using Binary Phase Shift Keying (BPSK) modulation technique. GLONASS satellite broadcasted signals include ranging signals, used to measure the distance to the satellite, and navigation messages. However, in GLONASS each satellite transmits the same ranging code signal on different carrier frequencies using Frequency Division Multiple Access (FDMA) technique.

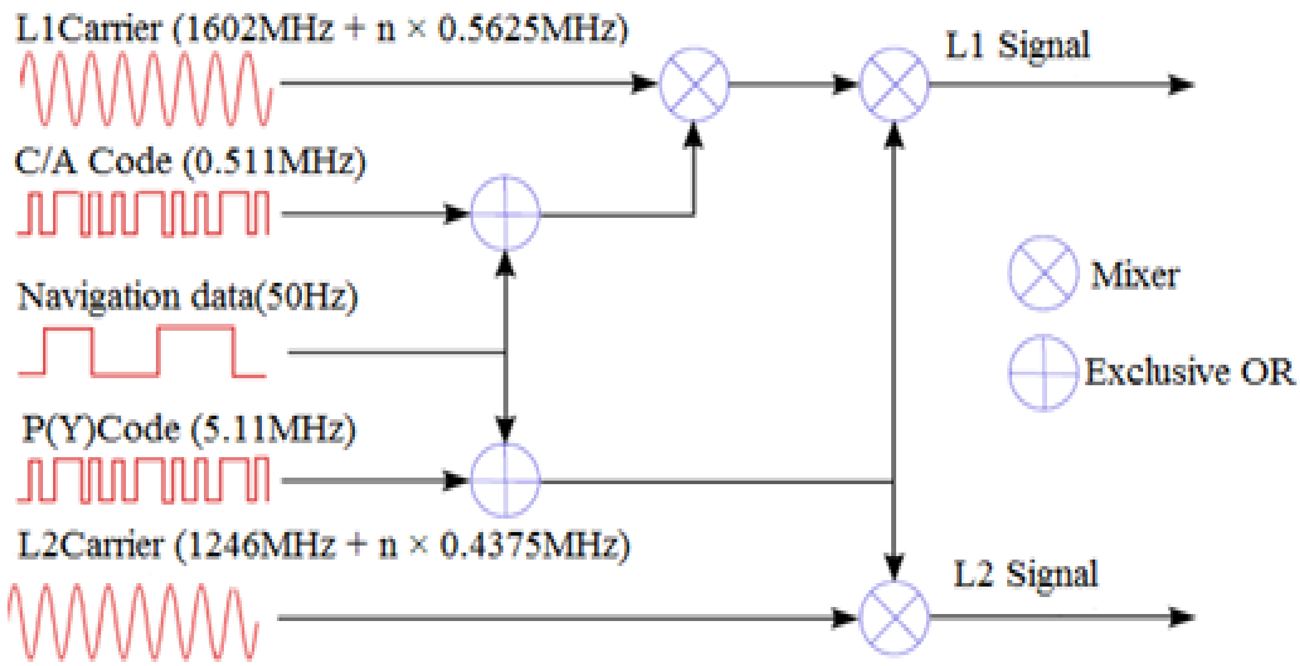

Figure 4 GLONASS Transmitted Signal

The mathematical equation of GLONASS satellites transmitted civilian signal (C/A code) on L1 band has the following structure

$$S_n(t) = \sqrt{2P}PRN(t)D_n(t)\cos(2(F_c + n \times 0.5625 \times 10^6 Hz)t + \emptyset) \quad \text{................Eq. 1}$$

Where: S_n = GLONASS Broadcast on n^{th} frequency channel
n = Indicates the frequency channel number
P = Signal Power
PRN = PRN code (511kcps)
D_n = Navigation Data for the n^{th} frequency channel
F_c = 1602.0MHz (GLONASS Nominal Frequency (zero channel))
Ø = Phase offset

Any GLONASS satellite broadcasted signal consists of three basic components

- Ranging code
- Carrier
- Navigation data

4.1 Ranging code:

It also called Pseudo random Noise code. It is a random binary sequence having special properties. There are basically two types of standard ranging signals generated by GLONASS satellites. They are:

- Precision Code (P-code) /High accuracy signal.
- Coarse (or Clear) Acquisition code (C/A-code) /Standard accuracy signal.

4.1.1 Precision Code (P - code)

The Precision code with clock rate of 5.11 MHz is encrypted by special code. This P code at 5.11MHz is bi-phase (BPSK) modulated on L2 carrier frequency, therefore the main lobe of the spectrum is 10.22 MHz wide from null to null. The chip length is about 0.195µs (1/5.11MHz).

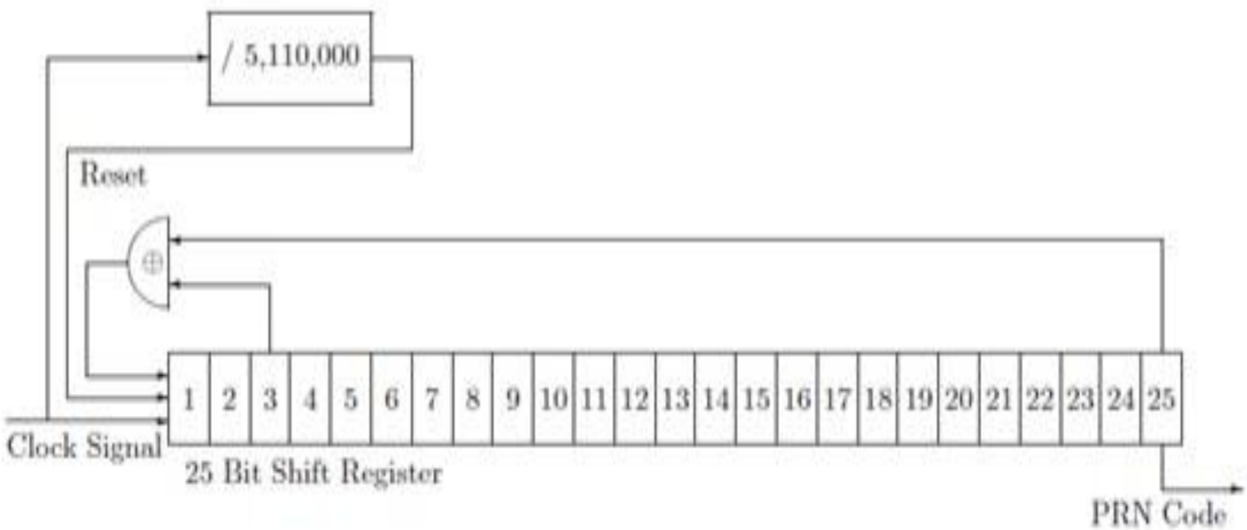

Figure 5 P – code generator

The Precision code is not directly transmitted by satellite; it is encrypted by Y-code so it is often referred as P(Y) code. The P(Y) code is not available to civilian users and is primarily used by military. The P(Y) code has similar properties as that of P-code. It can also be called as High precision service (HPS) code (or) High accuracy signal [2]. A functional block diagram of GLONASS P- code generator is shown in figure 5. Satellite generated P – code comprises of 25 bit shift register with a tap feedback that would produce a 33554431 – bit maximum length sequence, except for the fact that, it is short cycled to 5, 11,000 bits. It is clocked at a rate of 5.11MHz so that it repeats once per second. The initial state is defined such that each bit contains the value '1'. All satellites generate a same P-code and this code is modulated on L2 sub bands.

The P – code can be described by the polynomial mentioned below

$1 + x^3 + x^{25}$...Eq. 2

All satellites broadcast civilian signals on both L1 and L2 carrier signals. The L1 band carrier signal is modulated by the C/A code; the L2 carrier signal is modulated by P-code and C/A code. Now our focus is on the L1band modulated C/A code of GLONASS satellite system described in next section.

4.1.2 Coarse Acquisition Code (C/A code)

In GNSS the C/A (Coarse or Clear acquisition) codes are primarily used for broadcasting civilian signals on L1 band radio frequency with a clock rate 0.511 MHz, therefore the main lobe of the spectrum is 1.022MHz and is shown in figure 6. It can be freely available to civilian users worldwide for positioning receiver on the earth [2].

The GLONASS C/A code belongs to the family of pseudorandom noise (PRN) codes known as the M-codes. C/A code can also called as ranging code and it is used for standard positioning service, so it can also be called as standard accuracy ranging code. All GLONASS satellites use the same C/A-code. The pseudorandom noise (PRN) codes transmitted by the GLONASS satellites are deterministic sequences having a special noise like properties. Each C/A code is generated using a tapped 9 bit linear feedback shift register (LFSR). It generates a maximal length sequence of length $L = 2^n – 1$. The C/A code generator of GLONASS satellite system is shown in Figure 6.

The C/A – code can be described by the polynomial mentioned below

$1 + x^5 + x^9$.. E q. 3

The nominal values of L1 sub band carrier frequencies are defined by following expressions

$F_{L1} = F_c + n \times 0.5625 \times 10^6 Hz$…………………E q. 4

Where ‘n’ (-7 to 6) is the frequency channel of signals transmitted by GLONASS satellites in the L1 and L2 sub band.

F_c = 1602 MHz for L1 sub band
F_{L1} = GLONASS satellite broadcasted carrier signal on L1 sub band.
n = frequency slot number or PRN number.

The C/A code as employed by the GLONASS satellite system is a Pseudo Random Noise sequence of binary digits or chips derived from the seventh bit of nine bit shift register. Let us assume a 9 bit shift register containing all ‘1’s (Let us Assume ‘0’ as ‘1’ and ‘1’ as ‘-1’). The C/A code signal is generated from the 7th bit of nine bit shift register. The feedback values are taken from 5th and 9th bits of shift register; these two bits are XOR operated (when it is ‘0’ and ‘1’), but here multiplied (as it is ‘1’ and ‘-1’). The produced output is fed back to 1st bit of shift register

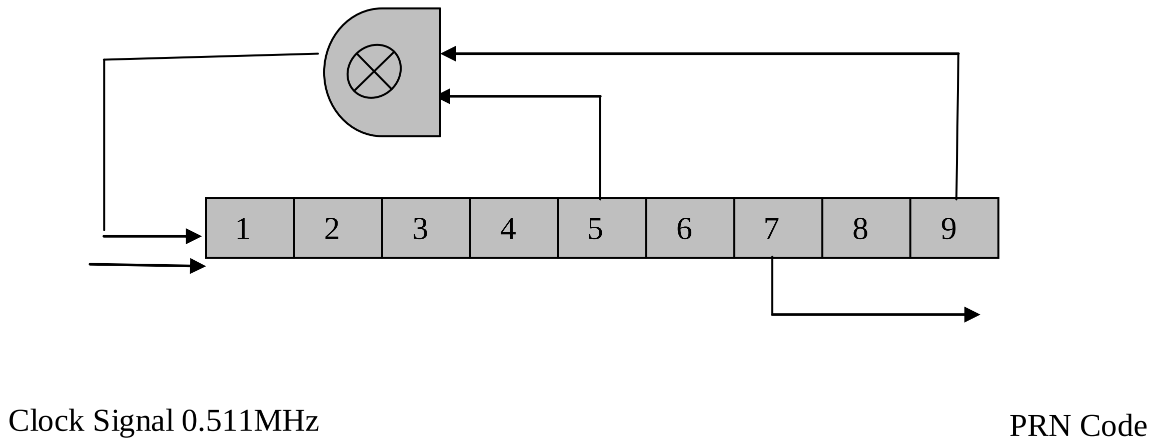

Figure 6 GLONASS C/A code generator

Thus a maximum length sequence generator can be made from shift register with proper feedback. The resultant signal and data signal perform modulo-2 addition technique and spread the data signal. The speeded signal is modulated on particular frequency channel of L1 sub band using BPSK modulation. The operating rule of the modulo-2 adder and Multiplication is shown in below.

Table 1: Exclusive operation and Multiplication

Input1	Input2	Output
0	0	0
0	1	1
1	0	1
1	1	1

Input1	Input2	Output
-1	-1	1
-1	-1	-1
1	-1	-1
1	1	1

The C/A code signal bandwidth for GLONASS is approximately half in comparison to GPS signal. Because in GPS each C/A code signal has 2.044MHz bandwidth from null to null but in GLONASS, the ranging code signal has 1.022MHz bandwidth from null to null.

4.2 Carrier

Each GLONASS satellite transmits navigation signals in two sub-bands of L-band (L1 1.6 GHz and L2 1.2 GHz) frequencies. In some situation two GLONASS satellites may transmit same carrier frequency if they are located in antipodal slots of a single orbital plane.

GLONASS system uses FDMA technique it means each satellite generates its own carrier frequency with a small amount of step size in the L1 and L2 band of frequencies. However each satellite is assigned one of the 24 frequencies with a step size of 0.5625MHz using 15 channel frequency divisions multiple access (FDMA) speeded over the 14 MHz band at intervals of 562.5 kHz, so bandwidth of GLONASS satellite system in L1band frequency is approximately 13MHz. The carrier signal with frequency F_{L1} or F_{L2} is modulated by the Modulo-2 addition of Pseudorandom (Ranging) code and digital data of navigation message.

Frequency plan: The frequencies of L-band is divided in to two bands that are: The L1 sub-band ranges from “1598.0 MHz to 1605.5MHz” in steps of “0.5625MHz” while L2 sub- band ranges from “1242.9375MHz to 1248.625MHz” in steps of “0.4375MHz”. The frequency spectrum of GLONASS system is shown in below figure 7. The nominal values of L1 and L2 carrier frequency are defined by the following expressions:

$F_{L1} = F_{c1} + n \times 0.5625 \times 10^6 Hz$……………………………………Eq. 5 $F_{L2} = F_{c2} + n \times 0.4375 \times 10^6 Hz$……………………………………Eq. 6

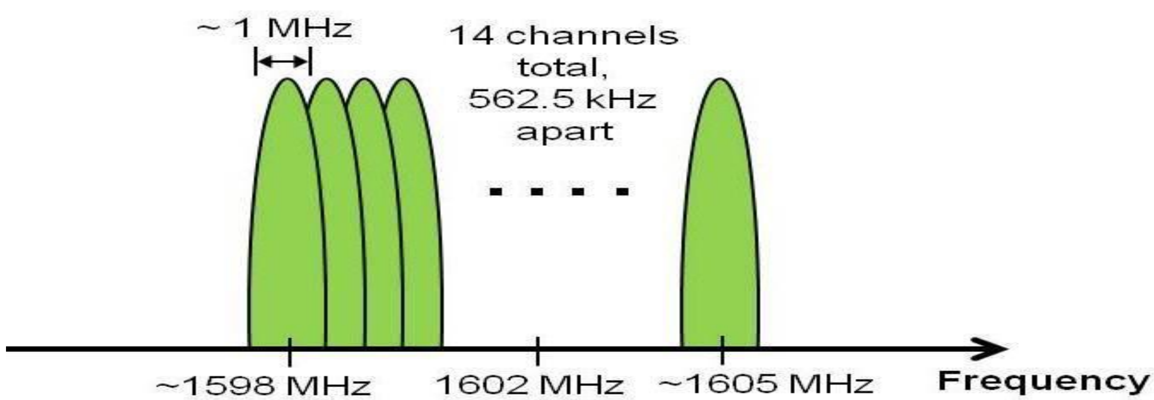

Figure 7 GLONASS L1 signal spectrum

Where ‘n’ is the frequency channel of signals transmitted by GLONASS satellites in the L1 and L2 sub band.

F_{c1} = 1602MHz for L1 sub band and F_{c2} = 1246MHz for L2 sub band.

F_{L1}=nominal frequency of zero frequency channel 1602 MHz of L1 sub band

F_{L2} = nominal frequency of zero frequency channel 1246 MHz of L2 sub band

The channel number ‘n’ of any particular GLONASS satellite is provided in the almanac of navigation data. It is a unique integer for each satellite and varies from -7 to 6. Satellites on opposite side of earth have same frequency. So that frequency can be reused.

4.3 Navigation data

The GLONASS navigation message is generated as continuously repeating super-frames. A super-frame consists of frames and a frame consists of strings.

Table 2.2: GLONASS carrier frequencies in L1 and L2 sub-bands

No. of Channel	Nominal value of frequency in L1 sub-band, MHz	No. of channel	Nominal value of frequency in L2 sub-band, MHz
06	1605.375	06	1248.625
05	1604.8125	05	1248.1875
04	1604.25	04	1247.75
03	1603.6875	03	1247.3125
02	1603.125	02	1246.875
01	1602.5625	01	1246.4375
0	1602.0	0	1246.0
-01	1601.4375	-01	1245.5625
-02	1600.8750	-02	1245.1250
-03	1600.3125	-03	1244.6875
-04	1599.7500	-04	1244.2500
-05	1599.1875	-05	1243.8125
-06	1598.6250	-06	1243.3750
07	1598.0625	-07	1242.9378

The navigation data contains information regarding satellite orbits, clock information. This information is uploaded to all satellites from the ground stations in the GLONASS Control Segment. The navigation data have a bit rate of 50 bps.

5 Correlation Properties of C/A Code

The most important characteristics of the C/A codes are their correlation properties. The auto correlation of sequence is correlation of a sequence with itself. The auto correlation of a sequence x (n) is defined by

$$R_{xx}(m) = \sum_{n=0}^{L} \mathrm{x(n)x(n+m)} \text{..} \text{ Eq. 7}$$

If the time shift m=0 the we have

$$R_{xx}(0) = \sum_{n=0}^{L} x(n)^2 \text{..} \text{Eq. 8}$$

Cross correlation can be defined as correlation of two different signals, but in GLONASS cross correlation is not applicable because here all satellites uses same C/A code or PRN code so only auto correlation is applicable. But in GPS the cross correlation properties are required because it uses different PRN codes for all satellites so here the cross correlation gives the low cross correlation peak as two different signals cannot match so that the resulting power is very low. If the codes are orthogonal the cross correlation result is zero but the GPS C/A codes are GOLD codes, these are not orthogonal code but near orthogonal codes.

The auto correlation function of C/A code is

$$R_{xx}(t) = \sum_{n=0}^{L} \mathrm{x(n)x(n+t)} \quad \text{.......................................Eq. 9}$$

If the time shift t=0

$$R_{xx}(0) = \sum_{n=0}^{L} x(n)^2 \quad \text{..Eq. 10}$$

Where: x (n) is the satellite generated C/A code.

x (n + t) is locally generated C/A code with time shift.

The correlation peak repeats every code period. The high correlation peak property of the Autocorrelation function is used to synchronize the receiver locally generated code with the code of the received signal.

High autocorrelation peak and low cross-correlation peaks can provide a wide dynamic range for signal acquisition. In order to detect a weak signal in the presence of strong signals, the autocorrelation peak of the weak signal must be stronger than the cross-correlation peaks from the strong signals.

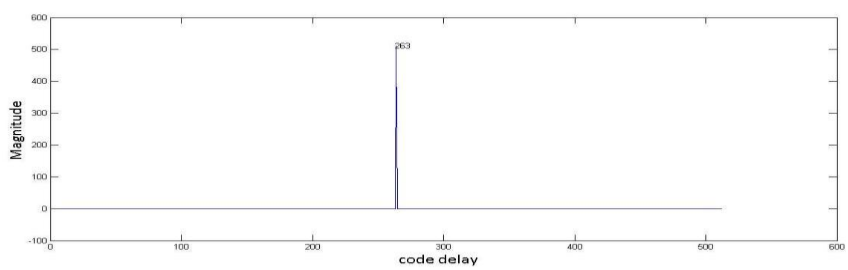

Figure 8 Autocorrelation of 0.511MHz

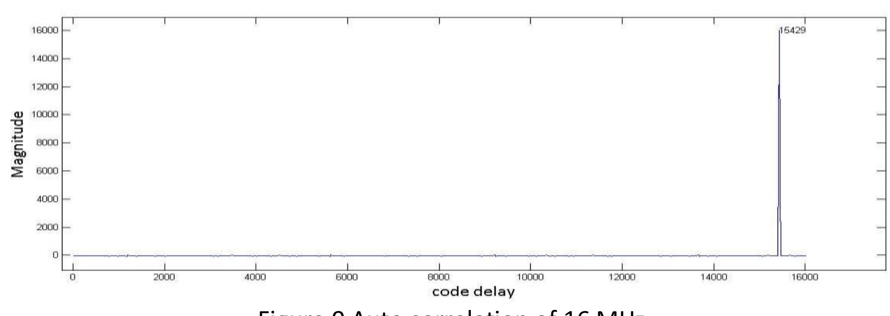

Figure 9 Auto correlation of 16 MHz

To remove the ranging code from the incoming signal correlation is required. Locally we generate the same ranging code but delayed; when both codes match then correlation will give the peak value as the delay between incoming signal and locally generated ranging code is zero.

GLONASS satellite system uses the M-codes, these codes are very easy to generate and have excellent auto correlation properties but have poor cross correlation properties.
Thus we can generate different signals with different delay values of same C/A code signal for the periodic autocorrelation results. The results are changing for different delayed signals of same C/A code signal, and then the auto correlation of those different delayed signals will produce different peak values.

The above Figure 9 shows the correlation between 16MHz sampled C/A code and locally generated delayed version of C/A code. Therefore it gives maximum value or peak value when both codes are well aligned. However, the graph explains that the orginal signal is well algined after 15429 bits long with the delayed version of same signal. Thus it will produce some amount of bits lag of original signal due to the time delay between two signals. Thus the auto correlation can be performed.

6. Conclusion

This paper explains about the introduction of GLONASS architecture and discusses about GLONASS satellite signal structure, frequency allocation of channels in L band frequencies, correlation properties of C/A code. These are very useful to understand base band processing of GLONASS software receiver.

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