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Navigation Software Development for application on LEO Satellites

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# Abstract

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Thales Alenia Space - Italia (Vimodrone) has been active for many years in the development of GPS navigation receivers for precise onboard operations, such as Precise Orbit Determination (POD), Radio Occultation with GPS signals and Attitude Determination. One of its core navigation products is the space receiver LAGRANGE. This receiver has been designed for applications in low orbits (LEO). The original development began during the early '90s and today it represents a leading product in Europe despite needing some design upgrades in order to compete with the standards and requirements of international space agencies (ESA). Particular objectives are the reduction of power consumption and the update for Modern GPS and GALILEO signals. For this reason TAS-I started a research and development activity with the purpose of designing a new single board space receiver (instead of the old multi board system)

# 1. Introduction

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*Navigation* is defined as the science of getting a craft or person from one place to another. Each of us conducts some form of navigation in our daily lives. Driving to work or walking to a store requires that we employ fundamental navigation skills. For most of us, these skills require utilizing our eyes, common sense, and landmarks. However, in some cases where a more accurate knowledge of our position, intended course, or transit time to a desired destination is required, navigation aids other than landmarks are used. These may be in the form of a simple clock to determine the velocity over a known distance or the odometer in our car to keep track of the distance traveled. Some other navigation aids transmit electronic signals and therefore are more complex. These are referred to as *radionavigation aids*.

Signals from one or more radionavigation aids enable a person (herein referred to as the *user*) to compute their position. (Some radionavigation aids provide the capability for velocity determination and time dissemination as well.) It is important to note that it is the user's radionavigation receiver that processes these signals and computes the position fix. The receiver performs the necessary computations (e.g., range, bearing, and estimated time of arrival) for the user to navigate to a desired location. In some applications, the receiver may only partially process the received signals, with the navigation computations performed at another location.

## 1.1 GPS Overview

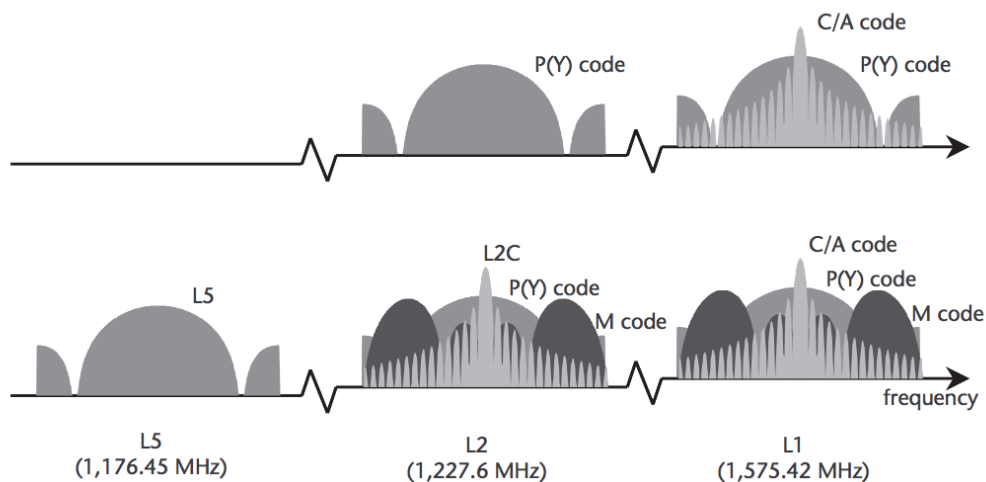
Presently, GPS is fully operational and meets the criteria established in the 1960s for an optimum positioning system. The system provides accurate, continuous, worldwide, three-dimensional position and velocity information to users with the appropriate receiving equipment. GPS also disseminates a form of Coordinated Universal Time (UTC). The satellite constellation nominally consists of 24 satellites arranged in 6 orbital planes with 4 satellites per plane. A worldwide ground control/monitoring network monitors the health and status of the satellites. This network also uploads navigation and other data to the satellites. GPS can provide service to an unlimited number of users since the user receivers operate passively (i.e., receive only). The system utilizes the concept of one-way time of arrival (TOA) ranging. Satellite transmissions are referenced to highly accurate atomic frequency standards onboard the satellites, which are in synchronism with a GPS time base. The satellites broadcast ranging codes and navigation data on two frequencies using a technique called code division multiple access (CDMA); that is, there are only two legacy frequencies in use by the system, called L1 (1,575.42 MHz) and L2 (1,227.6 MHz). Each satellite transmits on these frequencies, but with different ranging codes than those employed by other satellites. These codes were selected because they have low cross-correlation properties with respect to one another. Each satellite generates a short code referred to as the coarse/acquisition or C/A code and a long code denoted as the precision or P(Y) code. (Additional signals are forthcoming). The navigation data provides the means for the receiver to determine the location of the satellite at the time of signal transmission, whereas the ranging code enables the user's receiver to determine the transit (i.e., propagation) time of the signal and thereby determine the satellite-to-user range. This technique requires that the user receiver also contains a clock. Utilizing this technique to measure the receiver's three-dimensional location requires that TOA ranging measurements be made to four satellites. If the receiver clock were synchronized with the satellite clocks, only three range measurements would be required. However, a crystal clock is usually employed in navigation receivers to minimize the cost, complexity, and size of the receiver. Thus, four measurements are required to determine user latitude, longitude, height, and receiver clock offset from internal system time. If either system time or height is accurately known, less than four satellites are required.

GPS is a dual-use system. That is, it provides separate services for civil and military users. These are called the Standard Positioning Service (SPS) and the Precise Positioning Service (PPS). The SPS is designated for the civil community, whereas the PPS is intended for U.S. authorized military and select government agency users. Access to the GPS PPS is controlled through cryptography. Initial operating capability (IOC) for GPS was attained in December 1993, when a combination of 24 proto-type and production satellites was available and position determination/timing services complied with the associated specified predictable accuracies. GPS reached full operational capability (FOC) in early 1995, when the entire 24 production satellite constellation was in place and extensive testing of the ground control segment and its interactions with the constellation was completed.

### PPS

The PPS is specified to provide a predictable accuracy of at least 22m (2 drms, 95%) in the horizontal plane and 27.7m (95%) in the vertical plane. The distance root mean square (drms) is a common measure used in navigation. Twice the drms value, or 2 drms, is the radius of a circle that contains at least 95% of all possible fixes that can be obtained with a system (in this case, the PPS) at any one place. The PPS provides a UTC time transfer accuracy within 200 ns (95%) referenced to the time kept at the U.S. Naval Observatory (USNO) and is denoted as UTC (USNO). Velocity measurement accuracy is specified as 0.2 m/s (95%).

As stated earlier, the PPS is primarily intended for military and select government agency users. Civilian use is permitted, but only with special U.S. DOD approval. Access to the aforementioned PPS position accuracies is controlled through two cryptographic features denoted as antispoofing (AS) and selective availability (SA). AS is a mechanism intended to defeat deception jamming through encryption of the military signals. Deception jamming is a technique in which an adversary would replicate one or more of the satellite ranging codes, navigation data signal(s), and carrier frequency Doppler effects with the intent of deceiving a victim receiver. SA had intentionally degraded SPS user accuracy by *dithering* the satellite's clock, thereby corrupting TOA measurement accuracy. Furthermore, SA could have introduced errors into the broadcast navigation data parameters. SA was discontinued on May 1, 2000, and per current U.S. government policy is to remain off. When it was activated, PPS users removed SA effects through cryptography.



**Figure 1 - GPS Signal evolution**

### SPS

The SPS is available to all users worldwide free of direct charges. There are no restrictions on SPS usage. This service is specified to provide accuracies of better than 13m (95%) in the horizontal plane and 22m (95%) in the vertical plane (global average; signal-in-space errors only). UTC



(USNO) time dissemination accuracy is specified to be better than 40 ns (95%). SPS measured performance is typically much better than specification.



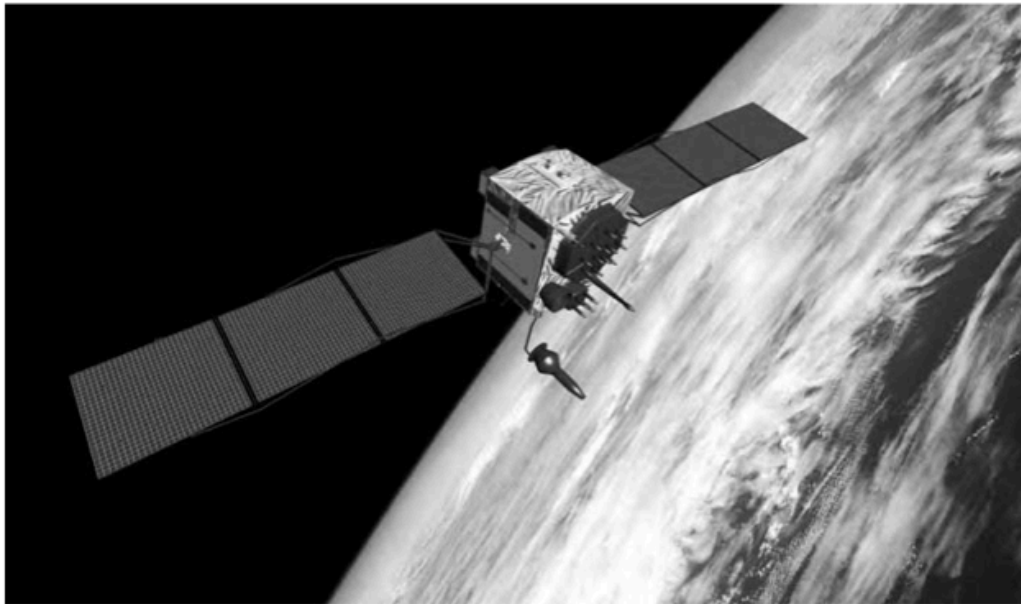
**Figure 2 - Block IIR-M Satellite**

## **1.2 GPS Modernization Program**

In January 1999, the U.S. government announced a new GPS modernization initiative that called for the addition of two civil signals to be added to new GPS satellites. These signals are denoted as L2C and L5. The L2C signal will be available for nonsafety of life applications at the L2 frequency; the L5 signal resides in an aeronautical radionavigation service (ARNS) band at 1,176.45 MHz. L5 is intended for safety-of-life use applications. These additional signals will provide SPS users the ability to correct for ionospheric delays by making dual frequency measurements, thereby significantly increasing civil user accuracy. By using the carrier phase of all three signals (L1 C/A, L2C, and L5) and differential processing techniques, very high user accuracy (on the order of millimeters) can be rapidly obtained. The additional signals also increase the receiver's robustness to interference. If one signal experiences high interference, then the receiver can switch to another signal. It is the intent of the U.S. government that these new signals will aid civil, commercial, and scientific users worldwide. One example is that the combined use of L1 (which also resides in an ARNS band) and L5 will greatly enhance civil aviation.

During the mid to late 1990s, a new military signal called M code was developed for the PPS. This signal will be transmitted on both L1 and L2 and is spectrally separated from the GPS civil signals in those bands. The spectral separation permits the use of noninterfering higher power M code modes that increase resistance to interference. Furthermore, M code will provide robust acquisition, increased accuracy, and increased security over the legacy P(Y) code.

The GPS III program was underway. This program was conceived in 2000 to reassess the entire GPS architecture and determine the necessary architecture to meet civil and military user needs through 2030. It is envisioned that GPS III will provide submeter position accuracy, greater timing accuracy, a system integrity solution, a high data capacity intersatellite crosslink capability, and higher signal power to meet military antijam requirements.



**Figure 3 - Block IIF Satellite**

### **1.3 GALILEO Satellite System**

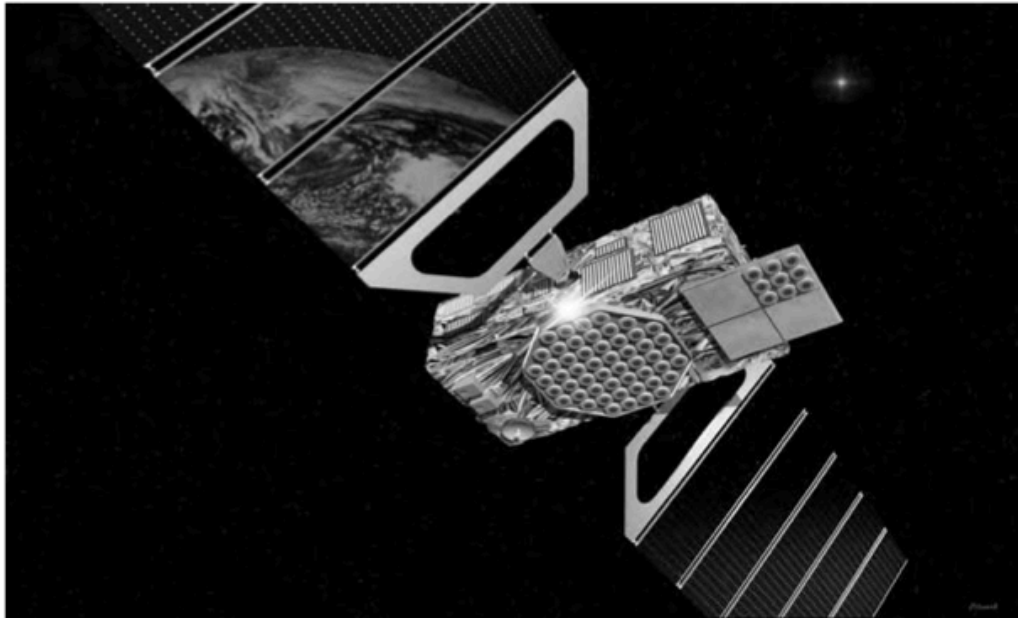
In 1998, the European Union (EU) decided to pursue a satellite navigation system independent of GPS designed specifically for civilian use worldwide.

When completed, GALILEO will provide multiple levels of service to users throughout the world. Five services are planned:

1. An *open* service that will be free of direct user charges;
2. A *commercial* service that will combine value-added data to a high-accuracy positioning service;
3. *Safety-of-life* (SOL) service for safety critical users;
4. *Public regulated service strictly for government-authorized users requiring a* higher level of protection (e.g., increased robustness against interference or jamming);
5. Support for *search and rescue*.

The SOL service will authenticate the received satellite signals to assure that they are truly broadcast by GALILEO. Furthermore, the SOL service will include integrity monitoring and notification; that is, a timely warning will be issued to the users when the safe use of the SOL signals cannot be guaranteed according to specifications.

A 30-satellite constellation and full worldwide ground control segment is planned. One key goal is to be fully compatible with the GPS system. Measures are being taken to ensure interoperability between the two systems. Primary interoperability factors being addressed are signal structure, geodetic coordinate reference frame, and time reference system.



**Figure 4 - GALILEO Satellite**

#### **1.4 Russian GLONASS System**

The Global Navigation Satellite System (GLONASS) is the Russian counterpart to GPS. It consists of a constellation of satellites in medium Earth orbit (MEO), a ground control segment, and user equipment. GLONASS was being revamped and the system was undergoing an extensive modernization effort. The constellation had decreased to 7 satellites in 1991 but is currently at 14 satellites. The GLONASS program goals are to have 18 satellites in orbit in 2007 and 24 satellites in the 2010–2011 time frame. A new civil signal has been on orbit since 2003. This signal has been broadcast from two modernized satellites referred to as the GLONASS-M. These two satellites are reported to be test flight satellites. There are plans to launch a total of 8 GLONASS-M satellites. The follow-on satellite to the GLONASS-M is the GLONASS-K, which will broadcast all legacy signals plus a third civil frequency for SOL applications.

As part of the modernization program, satellite reliability is being increased in both the GLONASS-M and GLONASS-K designs. Furthermore, the GLONASS-K is designed to broadcast integrity data and wide area differential corrections.



**Figure 5 - GLONASS-M Satellite**

The Russian government has stated that, like GPS, GLONASS is a dual-use system and that there will be no direct user fees for civil users. The Russians are working with the EU and the United States to achieve compatibility between GLONASS and GALILEO, and GLONASS and GPS, respectively. As in the case with GPS/GALILEO interoperability, key elements to achieving interoperability are compatible signal structure, geodetic coordinate reference frame, and time reference system.



**Figure 6 - GLONASS-K Satellite**

## **1.5 Chinese BeiDou System**

The Chinese BeiDou system is a multistage satellite navigation program designed to provide positioning, fleet-management, and precision-time dissemination to Chinese military and civil users. Currently, BeiDou is in a semi-operational phase with three satellites deployed in geostationary orbit over China. The official Chinese press has designated the constellation as the BeiDou Navigation Test System (BNTS). The BNTS provides a radio determination satellite

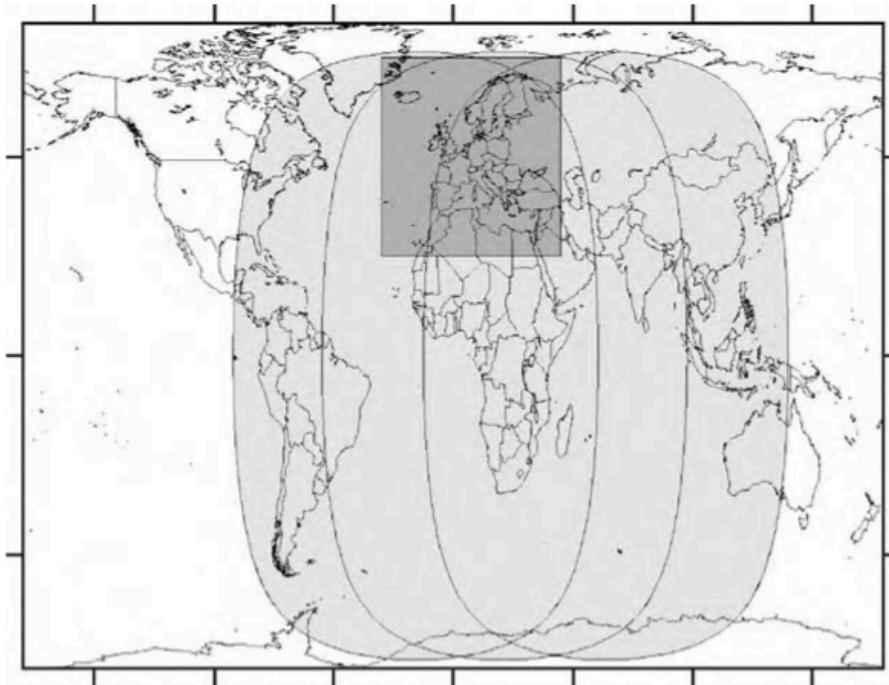
service (RDSS). Unlike GPS, GALILEO and GLONASS, which employ one-way TOA measurements, the RDSS requires two-way range measurements. That is, a system operations center sends out a polling signal through one of the BeiDou satellites to a subset of users. These users respond to this signal by transmitting a signal through at least two of the system's three geostationary satellites. The travel time is measured as the navigation signals loop from operations center to the satellite, to the receiver on the user platform, and back around. With this time-lapse information, the known locations of the two satellites, and an estimate of the user altitude, the user's location can be determined by the operations center. Once calculated, the operations center transmits the positioning information to the user. Since the operations center must calculate the positions for all subscribers to the system, BeiDou can also be used for fleet management and communications.

Current plans call for the BNTS to also provide integrity and wide area differential corrections via a satellite-based augmentation system (SBAS) service. At present, the RDSS capability is operational, and SBAS is still under development. The BNTS provides limited coverage and only supports users in and around China. In the long term, the Chinese plan is to deploy a regional or worldwide navigation constellation of 14–30 satellites under the BeiDou-2 program.

## 1.6 Augmentations

Augmentations are available to enhance stand-alone GPS performance. These can be space-based, such as a geostationary satellite overlay service that provides satellite signals to enhance accuracy, availability, and integrity, or they can be ground-based, as in a network that assists embedded GPS receivers in cellular telephones to compute a rapid position fix. Other forms of augmentations make use of inertial sensors for added robustness in the presence of interference. Inertial sensors are also used in combination with wheel sensors and magnetic compass inputs to provide vehicle navigation when the satellite signals are blocked in *urban canyons* (i.e., city streets surrounded by tall buildings). GPS receiver and sensor measurements are usually integrated by the use of a Kalman filter.

Some applications, such as precision farming, aircraft precision approach, and harbor navigation, require far more accuracy than that provided by stand-alone GPS. They may also require integrity warning notifications and other data. These applications utilize a technique that dramatically improves stand-alone system performance, referred to as differential GPS (DGPS). DGPS is a method of improving the positioning or timing performance of GPS by using one or more reference stations at known locations, each equipped with at least one GPS receiver to provide accuracy enhancement, integrity, or other data to user receivers via a data link. There are several types of DGPS techniques, and, depending on the application, the user can obtain accuracies ranging from meters to millimeters. Some DGPS systems provide service over a local area (10–100 km) from a single reference station, while others service an entire continent. The European Geostationary Navigation Overlay Service (EGNOS) and U.S. Wide Area Augmentation System (WAAS) are examples of wide area DGPS services.



**Figure 7 - EGNOS Geostationary Satellite Coverage**

## 2. Navigation Fundamentals

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From the satellite constellation, the user position can be solved. However, the equations required for solving the user position turn out to be nonlinear simultaneous equations, which are difficult to solve directly. In addition, some practical considerations (i.e., the inaccuracy of the user clock) will be included in these equations. These equations are solved through a linearization and iteration method. The solution is in a Cartesian coordinate system and the result will be converted into a spherical coordinate system. However, the earth is not a perfect sphere; therefore, once the user position is found, the shape of the earth must be taken into consideration. The user position is then translated into the earth-based coordinate system. Finally, the selection of satellites to obtain better user position accuracy and the dilution of precision will be discussed.

### 2.1 Performance Requirements

Some of the performance requirements are listed below:

1. The user position root mean square (rms) error should be 10–30 m.
2. It should be applicable to real-time navigation for all users including the high-dynamics user, such as in high-speed aircraft with flexible maneuverability.
3. It should have worldwide coverage. Thus, in order to cover the polar regions the satellites must be in inclined orbits.
4. The transmitted signals should tolerate, to some degree, intentional and unintentional interference. For example, the harmonics from some narrow-band signals should not disturb its operation. Intentional jamming of GNSS signals is a serious concern for military applications.
5. It cannot require that every GNSS receiver utilize a highly accurate clock such as those based on atomic standards.
6. When the receiver is first turned on, it should take minutes rather than hours to find the user position.
7. The size of the receiving antenna should be small. The signal attenuation through space should be kept reasonably small.

These requirements combining with the availability of the frequency band allocation determines the carrier frequencies of the GNSS signals.

### 2.2 Basic Concepts

The position of a certain point in space can be found from distances measured from this point to some known positions in space. Let us use some examples to illustrate this point. In a one-dimensional case, if the satellite position  $S_1$  and the distance to the satellite  $x_1$  are both known, the user position can be at two places, either to the left or right of  $S_1$ . In order to determine the user position, the distance to another satellite with known position must be measured.

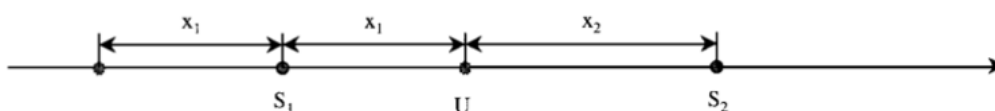
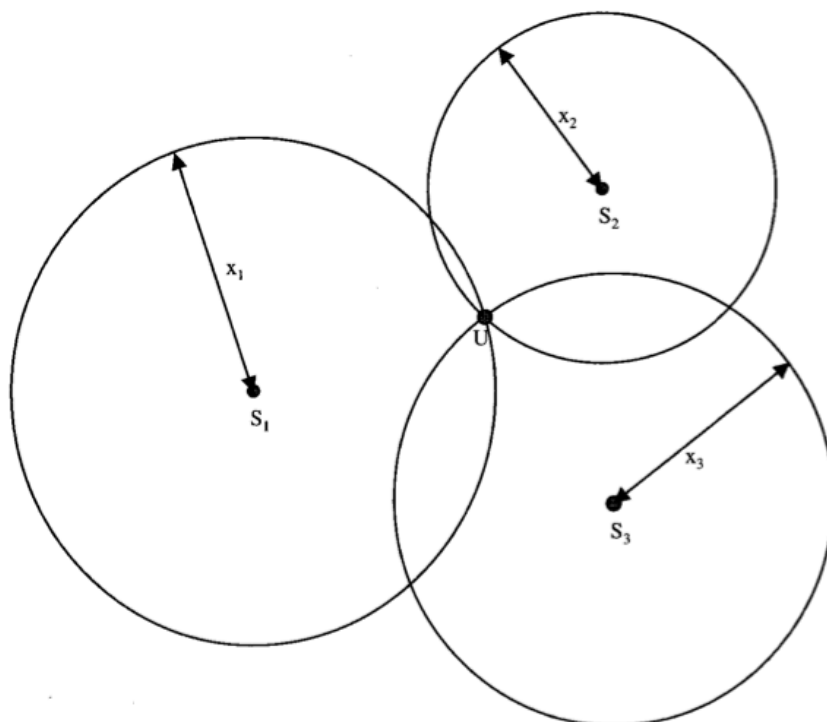


Figure 8 - One-dimensional User Position

In a two-dimensional case, in order to determine the user position, three satellites and three distances are required. The trace of a point with constant distance to a fixed point is a circle in the two-dimensional case. Two satellites and two distances give two possible solutions because two circles intersect at two points. A third circle is needed to uniquely determine the user position.



**Figure 9 - Two-dimensional User Position**

For similar reasons one might decide that in a three-dimensional case four satellites and four distances are needed. The equal-distance trace to a fixed point is a sphere in a three-dimensional case. Two spheres intersect to make a circle. This circle intersects another sphere to produce two points. In order to determine which point is the user position, one more satellite is needed.

In GPS the position of the satellite is known from the ephemeris data transmitted by the satellite. One can measure the distance from the receiver to the satellite. Therefore, the position of the receiver can be determined.

In the above discussion, the distance measured from the user to the satellite is assumed to be very accurate and there is no bias error. However, the distance measured between the receiver and the satellite has a constant unknown bias, because the user clock usually is different from the GPS clock. In order to resolve this bias error one more satellite is required. Therefore, in order to find the user position five satellites are needed. If one uses four satellites and the measured distance with bias error to measure a user position, two possible solutions can be obtained. Theoretically, one cannot determine the user position. However, one of the solutions is close to the earth's surface and the other one is in space. Since the user position is usually close to the surface of the earth, it can be uniquely determined. Therefore, the general statement is that four satellites can be used to determine a user position, even though the distance measured has a bias error. The method of solving the user position is through iteration. The initial position is often selected at the center of the earth. The iteration method will converge on the correct solution rather than the one in space. In the following discussion four satellites are considered the minimum number required in finding the user position.

### **2.3 Equations for finding User Position**

In this section the basic equations for determining the user position will be presented. Assume that the distance measured is accurate and under this condition three satellites are sufficient. There are



three known points at locations  $r_1$  or  $(x_1, y_1, z_1)$ ,  $r_2$  or  $(x_2, y_2, z_2)$ , and  $r_3$  or  $(x_3, y_3, z_3)$ , and an unknown point at  $r_u$  or  $(x_u, y_u, z_u)$ . If the distances between the three known points to the unknown point can be measured as  $r_1$ ,  $r_2$ , and  $r_3$ , these distances can be written as

$$\rho_1 = \sqrt{(x_1 - x_u)^2 + (y_1 - y_u)^2 + (z_1 - z_u)^2}$$

$$\rho_2 = \sqrt{(x_2 - x_u)^2 + (y_2 - y_u)^2 + (z_2 - z_u)^2}$$

$$\rho_3 = \sqrt{(x_3 - x_u)^2 + (y_3 - y_u)^2 + (z_3 - z_u)^2}$$

Because there are three unknowns and three equations, the values of  $x_u$ ,  $y_u$ , and  $z_u$  can be determined from these equations. Theoretically, there should be two sets of solutions as they are second-order equations. Since these equations are nonlinear, they are difficult to solve directly. However, they can be solved relatively easily with linearization and an iterative approach.

In GNSS operation, the positions of the satellites are given. This information can be obtained from the data transmitted from the satellites. The distances from the user (the unknown position) to the satellites must be measured simultaneously at a certain time instance. Each satellite transmits a signal with a time reference associated with it. By measuring the time of the signal traveling from the satellite to the user the distance between the user and the satellite can be found.

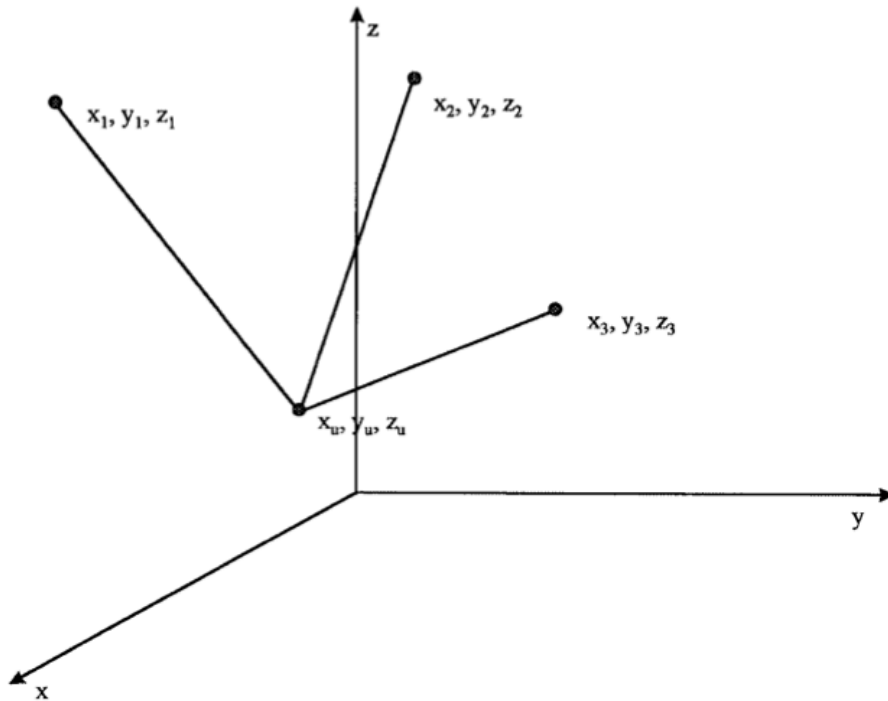


Figure 10 - Use three known positions to find one unknown position

## 2.4 Measurement of Pseudorange

Every satellite sends a signal at a certain time  $t_{si}$ . The receiver will receive the signal at a later time  $t_u$ . The distance between the user and the satellite  $i$  is

$$\rho_{iT} = c(t_u - t_{si})$$

where  $c$  is the speed of light,  $\rho_{iT}$  is often referred to as the true value of pseudo-range from user to satellite  $i$ ,  $t_{si}$  is referred to as the true time of transmission from satellite  $i$ ,  $t_u$  is the true time of reception.

From a practical point of view it is difficult, if not impossible, to obtain the correct time from the satellite or the user. The actual satellite clock time  $t'_{si}$  and actual user clock time  $t'_u$  are related to the true time as

$$\begin{aligned} t'_{si} &= t_{si} + \Delta b_i \\ t'_u &= t_u + b_{ut} \end{aligned}$$

where  $\Delta b_i$  is the satellite clock error,  $b_{ut}$  is the user clock bias error. Besides the clock error, there are other factors affecting the pseudorange measurement.

The measured pseudorange  $\rho_i$  can be written as

$$\rho_i = \rho_{iT} + \Delta D_i - c(\Delta b_i - b_{ut}) + c(\Delta T_i + \Delta I_i + v_i + \Delta v_i)$$

where  $\Delta D_i$  is the satellite position error effect on range,  $\Delta T_i$  is the tropospheric delay error,  $\Delta I_i$  is the ionospheric delay error,  $v_i$  is the receiver measurement noise error,  $\Delta v_i$  is the relativistic time correction.

Some of these errors can be corrected; for example, the tropospheric delay can be modeled and the ionospheric error can be corrected in a two-frequency receiver. The errors will cause inaccuracy of the user position. However, the user clock error cannot be corrected through received information. Thus, it will remain as an unknown. As a result, equations must be modified as

$$\rho_1 = \sqrt{(x_1 - x_u)^2 + (y_1 - y_u)^2 + (z_1 - z_u)^2} + b_u$$

$$\rho_2 = \sqrt{(x_2 - x_u)^2 + (y_2 - y_u)^2 + (z_2 - z_u)^2} + b_u$$

$$\rho_3 = \sqrt{(x_3 - x_u)^2 + (y_3 - y_u)^2 + (z_3 - z_u)^2} + b_u$$

$$\rho_4 = \sqrt{(x_4 - x_u)^2 + (y_4 - y_u)^2 + (z_4 - z_u)^2} + b_u$$

where  $b_u$  is the user clock bias error expressed in distance, which is related to the quantity  $b_{ut}$  by  $b_u = cb_{ut}$ . Four equations are needed to solve for four unknowns  $x_u$ ,  $y_u$ ,  $z_u$ , and  $b_u$ . Thus, in a GNSS receiver, a minimum of four satellites is required to solve for the user position.

## 2.5 Solution of User Position from Pseudorange

It is difficult to solve for the four unknowns in the Equations, because they are nonlinear simultaneous equations. One common way to solve the problem is to linearize them. The above equations can be written in a simplified form as

$$\rho_i = \sqrt{(x_i - x_u)^2 + (y_i - y_u)^2 + (z_i - z_u)^2} + b_u$$

where  $i = 1, 2, 3,$  and  $4$ , and  $x_u, y_u, z_u,$  and  $b_u$  are the unknowns. The pseudo-range  $r_i$  and the positions of the satellites  $x_i, y_i, z_i$  are known.

Differentiate this equation, and the result is

$$\delta \rho_i = \frac{(x_i - x_u)^2 \delta x_u + (y_i - y_u)^2 \delta y_u + (z_i - z_u)^2 \delta z_u}{\sqrt{(x_i - x_u)^2 + (y_i - y_u)^2 + (z_i - z_u)^2}} + \delta b_u$$

$$= \frac{(x_i - x_u)^2 \delta x_u + (y_i - y_u)^2 \delta y_u + (z_i - z_u)^2 \delta z_u}{\rho_i - b_u} + \delta b_u$$

in this equation,  $\delta x_u$ ,  $\delta y_u$ ,  $\delta z_u$ , and  $\delta b_u$  can be considered as the only unknowns. The quantities  $x_u$ ,  $y_u$ ,  $z_u$ , and  $b_u$  are treated as known values because one can assume some initial values for these quantities. From these initial values a new set of  $\delta x_u$ ,  $\delta y_u$ ,  $\delta z_u$ , and  $\delta b_u$  can be calculated. These values are used to modify the original  $x_u$ ,  $y_u$ ,  $z_u$ , and  $b_u$  to find another new set of solutions. This new set of  $x_u$ ,  $y_u$ ,  $z_u$ , and  $b_u$  can be considered again as known quantities. This process continues until the absolute values of  $\delta x_u$ ,  $\delta y_u$ ,  $\delta z_u$ , and  $\delta b_u$  are very small and within a certain predetermined limit. The final values of  $x_u$ ,  $y_u$ ,  $z_u$ , and  $b_u$  are the desired solution. This method is often referred to as the iteration method.

With  $\delta x_u$ ,  $\delta y_u$ ,  $\delta z_u$ , and  $\delta b_u$  as unknowns, the above equation becomes a set of linear equations. This procedure is often referred to as linearization. The above equation can be written in matrix form as

$$\begin{bmatrix} \delta \rho_1 \\ \delta \rho_2 \\ \delta \rho_3 \\ \delta \rho_4 \end{bmatrix} = \begin{bmatrix} \alpha_{11} & \alpha_{12} & \alpha_{13} & 1 \\ \alpha_{21} & \alpha_{22} & \alpha_{23} & 1 \\ \alpha_{31} & \alpha_{32} & \alpha_{34} & 1 \\ \alpha_{41} & \alpha_{42} & \alpha_{43} & 1 \end{bmatrix} \begin{bmatrix} \delta x_u \\ \delta y_u \\ \delta z_u \\ \delta b_u \end{bmatrix}$$

Where

$$\alpha_{i1} = \frac{x_i - x_u}{\rho_i - b_u} \quad \alpha_{i2} = \frac{y_i - y_u}{\rho_i - b_u} \quad \alpha_{i3} = \frac{z_i - z_u}{\rho_i - b_u}$$

The solution of Equation is:

$$\begin{bmatrix} \delta x_u \\ \delta y_u \\ \delta z_u \\ \delta b_u \end{bmatrix} = \begin{bmatrix} \alpha_{11} & \alpha_{12} & \alpha_{13} & 1 \\ \alpha_{21} & \alpha_{22} & \alpha_{23} & 1 \\ \alpha_{31} & \alpha_{32} & \alpha_{34} & 1 \\ \alpha_{41} & \alpha_{42} & \alpha_{43} & 1 \end{bmatrix}^{-1} \begin{bmatrix} \delta \rho_1 \\ \delta \rho_2 \\ \delta \rho_3 \\ \delta \rho_4 \end{bmatrix}$$

This equation obviously does not provide the needed solutions directly; however, the desired solutions can be obtained from it. In order to find the desired position solution, this equation must be used repetitively in an iterative way. A quantity is often used to determine whether the desired result is reached and this quantity can be defined as

$$\delta v = \sqrt{\delta x_u^2 + \delta y_u^2 + \delta z_u^2 + \delta b_u^2}$$

When this value is less than a certain predetermined threshold, the iteration will stop. Sometimes, the clock bias  $b_u$  is not included in equation.

The detailed steps to solve the user position will be presented in the next section. In general, a GPS receiver can receive signals from more than four satellites. The solution will include such cases as when signals from more than four satellites are obtained.

## 2.6 Position Solution with more than four satellites

When more than four satellites are available, a more popular approach to solve the user position is to use all the satellites. The position solution can be obtained in a similar way. If there are  $n$  satellites available where  $n > 4$ , the equation can be written as

$$\begin{bmatrix} \delta\rho_1 \\ \delta\rho_2 \\ \delta\rho_3 \\ \delta\rho_4 \\ \vdots \\ \delta\rho_n \end{bmatrix} = \begin{bmatrix} \alpha_{11} & \alpha_{12} & \alpha_{13} & 1 \\ \alpha_{21} & \alpha_{22} & \alpha_{23} & 1 \\ \alpha_{31} & \alpha_{32} & \alpha_{34} & 1 \\ \alpha_{41} & \alpha_{42} & \alpha_{43} & 1 \\ & \vdots & & \\ \alpha_{n1} & \alpha_{n2} & \alpha_{n3} & 1 \end{bmatrix} \begin{bmatrix} \delta x_u \\ \delta y_u \\ \delta z_u \\ \delta b_u \end{bmatrix}$$

$$\underline{\delta\rho} = \underline{\alpha} \underline{\delta x}$$

Since  $\underline{\alpha}$  is not a square matrix, it cannot be inverted directly. If there are more equations than unknowns in a set of linear equations, the least-squares approach can be used to find the solutions. The pseudoinverse of the  $\alpha$  can be used to obtain the solution. The solution is

$$\delta x = [\alpha^T \alpha]^{-1} \alpha^T \delta \rho$$

From this equation, the values of  $\delta x_u$ ,  $\delta y_u$ ,  $\delta z_u$ , and  $\delta b_u$  can be found. In general, the least-squares approach produces a better solution than the position obtained from only four satellites, because more data are used.

### 3. LAGRANGE 2G Architecture

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The following block diagrams show the current on-going architecture design of the EBB single-board receiver. OCXO and DC-DC are not part of the current EBB R&D development and procurement. Also the RF Front-End (LNAs, filters) are housed in an external box.

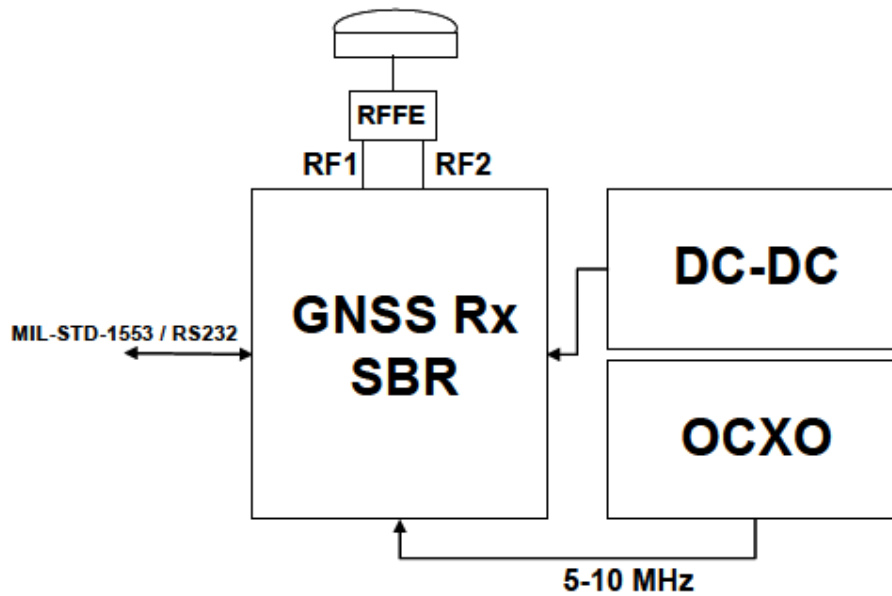
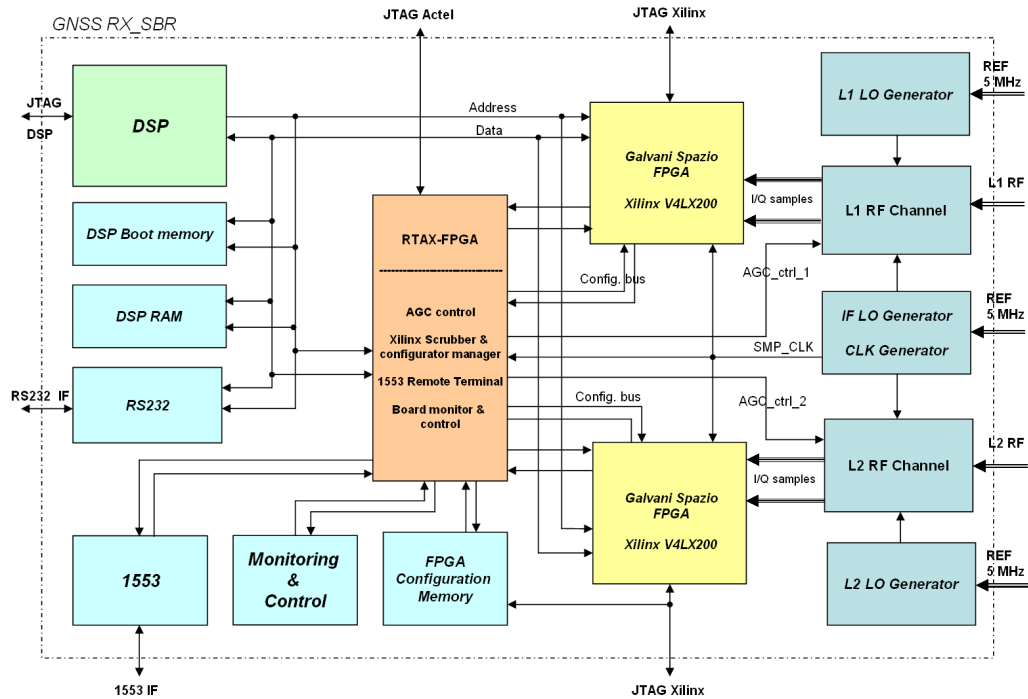


Figure 11 - Overall Lagrange 2G architecture

The single board receiver EBB can be easily divided in four main section, different for functionality and signals:

- DSP section, containing the DSP processor, Boot memory, RAM memory
- Digital channels section, containing the Galvani correlator channel, FPGA firmware PROMs, configuration manager and scrubbing
- RF section, containing the RF down conversion channels, the LO frequencies generator, sampling clock generator
- Communication section, containing the 1553 Remote Terminal and RS232 interface

All the different sections are divided by copper diffusions in order to avoid crosstalk and interference between them. These allow also a good heat conductivity in all the PCB frame.



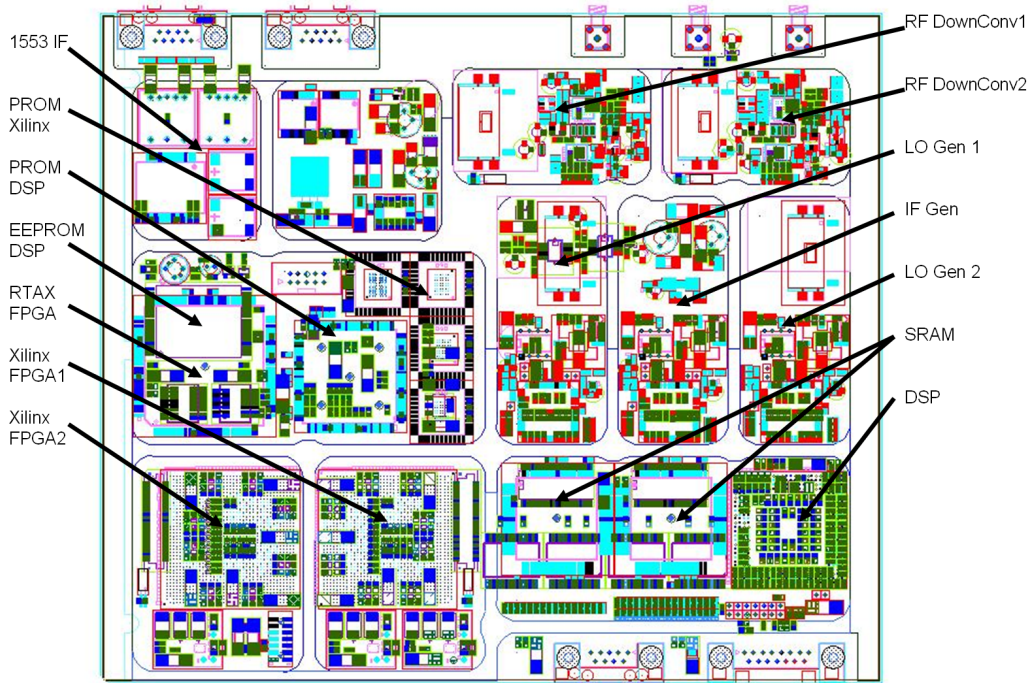
**Figure 12 - EBB Architecture Design**

### 3.1 RF Section

The RF Section includes RF bandpass filter, Low Noise Amplifier, RF-IF downconverter, IF filters, input from reference oscillator, frequency synthesiser, sampling and Analog to Digital converters for the different frequency bands. The PLL LO will be programmable to produce a common IF frequency. The RF Down conversion chains are based on RF ASIC Saphyrion SY1007 and SY1017 which are already space qualified in the frame of ESA programs.

The first ASICs include on a single miniaturized chip the RF/IF LNA, the downconversion section, the frequency synthesizers and PLLs for generation of the Local Oscillators.

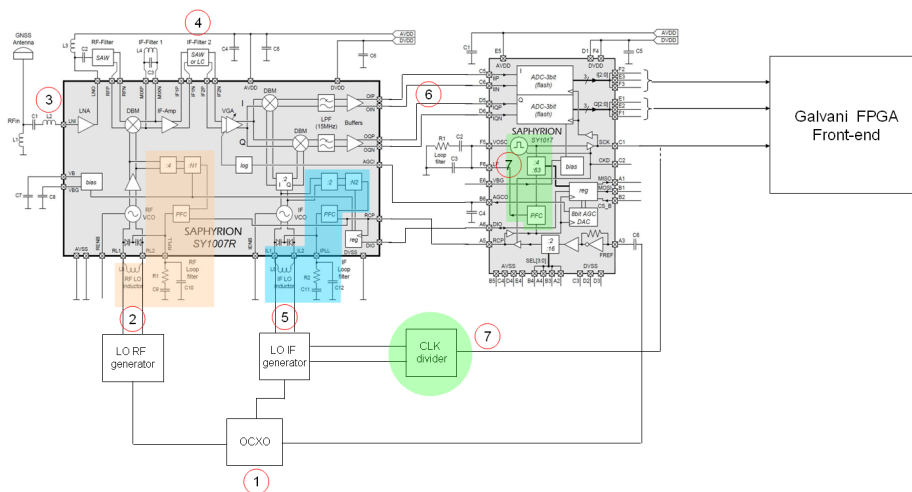
The second chip includes the AD Converters, the DA converter for the gain control, the sampling clock generator. In order to obtain LO frequencies with high precision and high stability, the LOs generator includes inside the ASICs will be disabled. EBB provide three dedicated frequencies generator made by discrete devices as PLL and VCO.



**Figure 13 - EBB Component Layout**

The breadboard HW is designed focusing on COSMO 2G needs in terms of signals, that is GPS L1 + L2P + L2C. However, since the breadboard is considered the basis for future evolutions of space navigation and radio-occultation receivers, the RF section design allow also configurability for the following signals:

- GPS L1, L2c, L5
- Galileo L1, E5a, E5b



**Figure 14 - RF Down Conversion Chain**

The following table shows the frequency plan programmed for each carrier.

	RF Frequency	RF LO Frequency	IF Frequency	IF LO Frequency	I/Q center frequency	Sampling Frequency
GPS L1 C/A	1575,42	1503	72,42	144	0,42	36
GPS L2C	1227,60	1155	72,6	144	0,6	36
GPS L5	1176,45	1105	71,45	144	-0,55	36
Galileo E1	1575,42	1503	72,42	144	0,42	36
Galileo E5 B	1207,14	1135	72,14	144	0,14	36
Galileo E5 A	1176,45	1105	71,45	144	-0,55	36
GPS L1 P(Y)	1575,42	1503	72,42	144	0,42	36
GPS L2 P(Y)	1227,60	1155	72,6	144	0,6	36

Moreover the expandability of the system, towards other similar Lagrange 2G, can be done via dedicated SPI's , which guarantee the inter-process communication for the exchange of data (among multiple receivers).

### 3.2 Digital Channels Section

The digital channels section includes the Galvani Space FPGA implementing the correlation channel, Rad-Hard FPGA implementing functionalities of AGC control, Xilinx's configuration manager and scrubbing.

#### *Galvani for space Application*

The GALVANI design, actually implemented and validated on ESA ground reference receiver programs (GRCN, MBOC, RIMS NG) has been developed on FPGA Xilinx Virtex4 and it is able to process signals as :

- Galileo L1, E6, E5A, E5B, E5AltBoc
- GPS L1, L2C and L5.

The design consist of a common environment with implement the functionality of RF front-end, DSP processor interface, Viterbi decoder. This environment is connected to a matrix of configurable channel that can process the different GNSS signal.

A summary of the different Galvani FPGA implementation are shown in table.

	Galvani GRC N-PRS	Galvani N-PRS MBOC	Galvani L2CL5	Galvani PRS
Signal	32 Galileo E5A,E5B o E5AltBoc	16 SFCs Galileo L1(CBOC/TMBOC) 16 SFCs Galileo E6	20 canali GPS L2(CM,CL) and GPS L5	8 SFCs GioveA, 8 SFCs GioveB
Num. of correlators	640	800	480	320
FPGA resource	78k FF (44%) 72k LUT4 (40%) 83 BRam	84k FF (46%) 99k LUT4 (55%) 99 BRam	58k FF (32%) 69k LUT4 (38%) 67 BRam	43k FF (23%) 44k LUT4 (24%) 60 BRam

Due to the high complexity of Galvani FPGA and to the different requirements of a space application, a critical review of the design was necessary.



Main changes of Galvani\_Space design are :

- implementation of L2P(Y) semi-codeless processing
- reduction of logic complexity and logic elements number
- reduction of the processing frequency inside the correlation channel

The implementation of L2P(Y) inside Galvani Space FPGA avoids the utilization of AGGA2 ASIC in order to reduce the board dimensions and the power consumption. The reduction of the design complexity it's needed for a implementation in a space FPGA due to the low number of resources available and the low performance of these devices. Actually the design of Galvani Space it is able to process only GPS signals as L1, L2P(Y) and L2C(CM/CL) (compliant to the COSMO2 needed). The multi frequency channel contains three single frequency channel able to process the following signal:

- L1 C/A, L1P, L2P
- L1 C/A, L2CM, L2CL
- L1 C/A on all channel

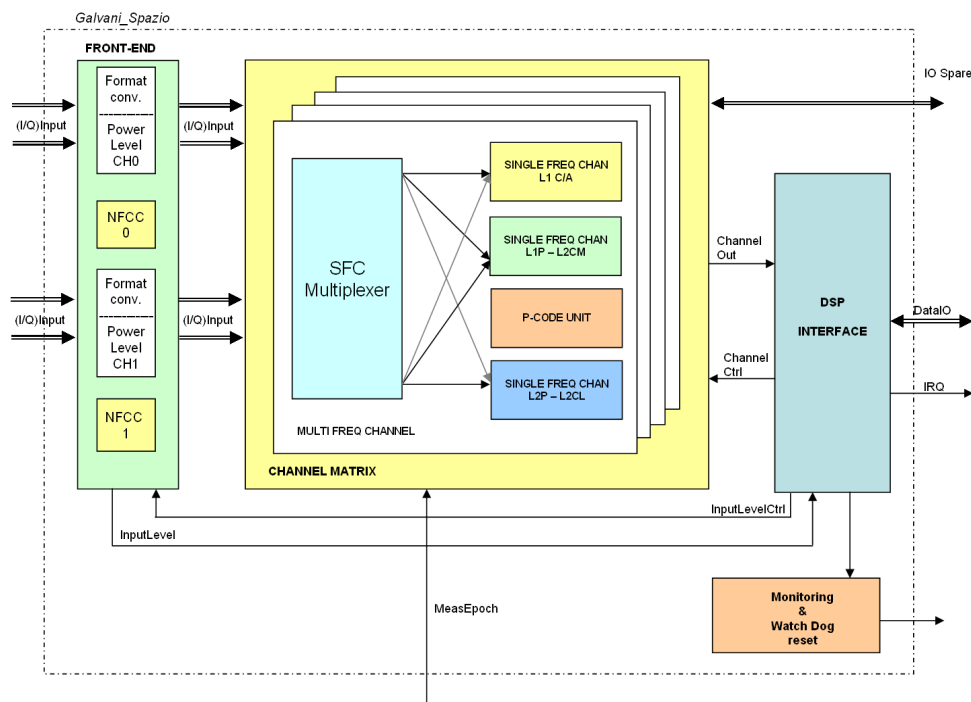


Figure 15 - Galvani Space FPGA

Modifications in the Code Generation Unit are necessary in order to allow the processing of other GPS or Galileo frequencies.

### *Galvani FPGA devices trade-off*

There are basically three types of programming technologies currently in existence: antifuse-based, flashbased, and SRAM-based.

Each type has advantages and disadvantages associated with its use in flight applications.

At present, there is no flash-based FPGA with acceptable radiation tolerance for space applications.

Antifuse-based FPGA are programmed via permanent interconnections, so logic upsets due to radiation effects will not cause programs to be lost. In SRAM-based FPGA radiations may result in Single Event Upsets (SEU) in the FPGA's configuration memory that may alter dramatically the functions carried out by the circuit the FPGA implements.

Radiation-hardened anti-fuse FPGA have limited capacity and performance, which means most of them are unsuitable for achieving integration goals. SRAM-FPGA offer more integration, more resources and high performances.

A complete trade-off from these two family of device are illustrated in [RD18]

### ***Galvani Space Design occupation in FPGA***

For a correct choose of which FPGA must be used in SBR project, must be also consider how the VHDL code may fit the device and what is it occupation and the timing performances.

Considering the same version of VHDL code, the different result of synthesis on Xilinx and Actel devices are summarize in following table (result are obtained using Precision RTL 2010)

Device	Description	Combinatorial modules	Sequential modules	Utilization ratio	Preliminary timing (Max Freq)
RTAX-4000S	Only environment	4612	2536	Comb. 11% Seq. 13%	SMP_CK 36MHz DSP_CK 15 MHz
RTAX-4000S	1 MFC+ Env.	13476	7563	Comb. 33% Seq. 38%	SMP_CK 22MHz DSP_CK 15 MHz
RTAX-4000S	3 MFC + Env.	31283	17708	Comb. 78% Seq. 88%	SMP_CK 32MHz DSP_CK 11 MHz
Xilinx V4LX200	6 MFC + Env. + I/F Edac/Scrub	41173	33007	Comb. 23% Seq. 18%	SMP_CK 120 MHz DSP_CK 150 MHz

The Xilinx device occupation is kept lower than about 25 % because for this device must be implemented the triple module redundancy scheme. This means that the resources occupation of the device will grow near to the maximum values for this device and the timing become worst.

Preliminary timing for RTAX FPGA indicate that part of design must be modified in order to increase the max value of allowed clock frequencies. These modifications can also increase resources utilization of device. Timing performance can also be increase using RTAX-4000D device.

In order to cover the constraints of R&D project, the Galvani Space design can be based on one of the following solution:

- 2 Xilinx Virtex-4 QV devices:
  - o this component offers the advantage of high number of logic resources which allow implementing the channels on two FPGAs. In addition it offers the advantage of being the space grade version of the already used component in TAS-I ground GNSS receivers. As a drawback it is an ITAR component, requires triple redundancy logic

and external scrubbing and requires a dedicated study to find a qualifiable mounting process

- 4 ACTEL RTAX-4000 devices
  - o This component is a space qualified component but with a low number of logic resources, which requires the use of approximately four FPGAs, leading to difficulties in hosting them on a single-board.

As baseline for EBB was choose to develop the Galvani Space FPGA on Virtex 4 Rad-Tolerant devices.

### **RTAX RadHard FPGA**

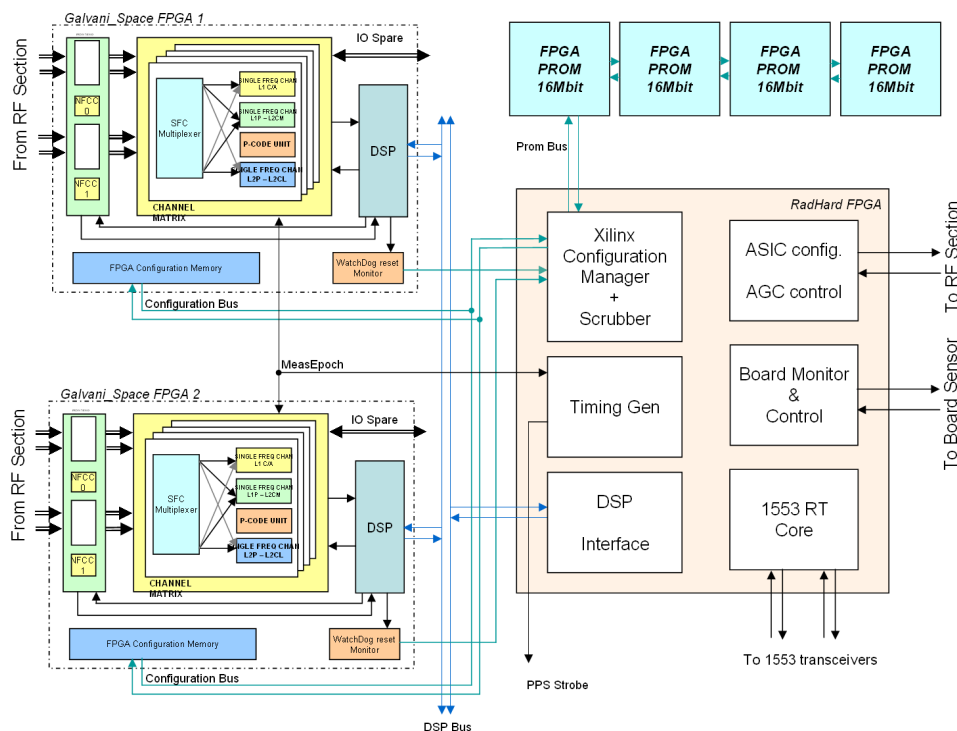
To improve system reliability and to protect the SBR from faults due to SEU or SEFI in Galvani Space FPGA, the RTAX RadHard device it's used as configuration manager and scrubber for Virtex devices.

All user-programmable features inside Virtex-4 devices are controlled by volatile memory cells that must be configured at power-up. These memory cells are collectively known as configuration memory. They define the LUT equations, signal routing, IOB voltage standards, and all other aspects of the user design.

To program configuration memory, instructions for the configuration control logic and data for the configuration memory are provided in the form of a bitstream stored in the FPGA PROM. The bitstream is delivered to the FPGA device through the configuration bus interface.

Upon system power up, the configuration management engine inside the RTAX FPGA, starts programming the Xilinx FPGA; the engine load the configuration data from radiation-hardened PROM devices.

Some signal are monitored at the end of the configuration process to ensure configuration completes successfully. If something goes wrong, the device should be reconfigured



**Figure 16 - Digital Channels Section Overall Architecture**

Upon completion of configuration, the engine start to monitoring and scrubbing FPGA memory for mitigate SEE.

Actel FPGA includes also the following functionalities:

- AGC control and ASIC configuring
- Timing generator for Measurement epoch and PPS strobe signals
- MIL-STD-1553 Remote Terminal Core
- EBB monitor and control

### 3.3 DSP Section

The DSP Section are based on the Texas TMS320 family

Product code	Manufacturer	Architecture	freq. max [MHz]	MFLOP (peak)
TMS320-C6701	TI	32bit	140 (1)	840
TMS320-C6713	TI	32/64bit	200	1200
TMS320-C6727B	TI	32/64bit	250 (1)	1500

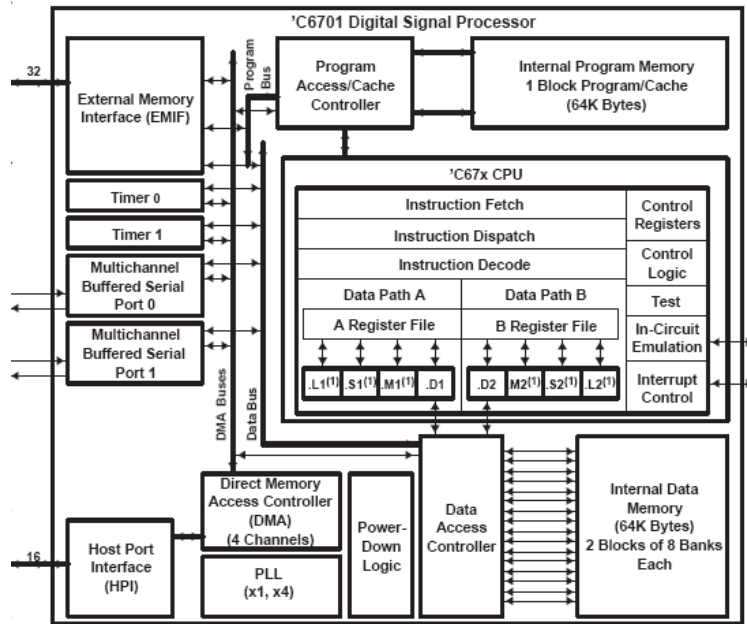
Texas Instruments offer today the SMJ320C6701 in a space qualified QML-V version and this is the baseline choice for the GNSS SBR project.

The device is rad-tolerant. It is latch-up immune, with a total dose hard to 100Krads. The device is under EAR export control.

The SMJ320C6701 device is based on the high-performance, advanced VelociTI™ very-long-instruction-word (VLIW) architecture developed by Texas Instruments (TI), making this DSP an excellent choice for multichannel and multifunction applications. With performance of up to 1 giga floating-point operations per second (GFLOPS) at a clock rate of 140 MHz, the 'C6701 offers cost-effective solutions to high-performance DSP programming challenges. The 'C6701 DSP possesses the operational flexibility of high-speed controllers and the numerical capability of array processors. This processor has 32 general-purpose registers of 32-bit word length and eight highly independent functional units.

The 'C6701 includes a large bank of on-chip memory and has a powerful and diverse set of peripherals. Program memory consists of a 64K-byte block that is user-configurable as cache or memory-mapped program space. Data memory consists of two 32K-byte blocks of RAM. The peripheral set includes two multichannel buffered serial ports (McBSPs), two general-purpose timers, a host-port interface (HPI), and a glue less external memory interface (EMIF) capable of interfacing to SDRAM or SBSRAM and asynchronous peripherals.

The 'C6701 has a complete set of development tools that includes a new C compiler, an assembly optimizer to simplify programming and scheduling, and a Windows™ debugger interface for visibility into source code execution.



**Figure 17 - SMJ320C6701 DSP Block Diagram**

The DSP section is equipped with all the necessary internal volatile and non-volatile memories used for SW achieve and execution:

- SRAM memory up to 32 Mbits
- EEPROM memory up to 8 Mbits
- PROM memory up to 4 Mbits

### 3.4 Communication Section

The GNSS SBR will support MIL-STD-1553 and RS232 serial line (test only) as communication standards. The Core 1553RT, implemented in Actel FPGA, provides a complete, redundant MIL-STD-1553 Remote Terminal. The transceivers required to interface to the bus are implemented on the board.

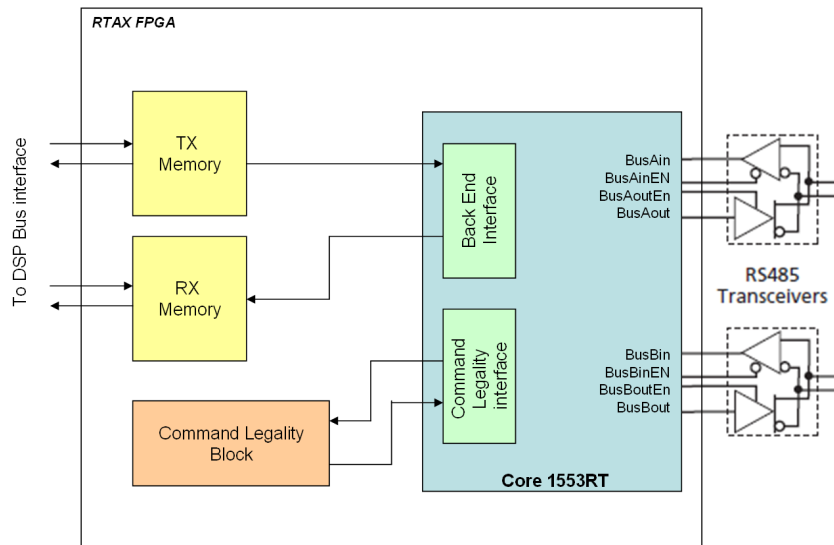


Figure 18 - 1553 Core

## 4. Porting from AD to TI-DSP

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### Code Porting issues

In the following paragraphs the main issues of the RX application code porting would be highlighted. In particular they will be discussed code dependencies from:

- Compiler
- Target processor
- Hardware Environment
- Operating System

and the way to realize a full code abstraction to make application platform independent in order to improve reusability and portability.

### 4.1 General Presentation: Actual Scenario

The RX application is mostly written in ANSI-C, except for those parts strictly related to the hardware interfaces (such as the internal and external memory, the GALVANI block, the RFIF board communication ports), which sometimes need Assembly coded sections to improve functionality, speediness and performances of the application itself.

These are some of the most important issues which do not allow the actual application to work independently from the platform and make the application porting a critical matter.

In the following table a list of assembly coded files is shown.

File name	type	Description	Reference file
memory	s	Global variables and Assembly Function definition PM_copy	Used into boot application
function	s	User defined functions with floating point data and constants for ASM modules	
int_handler	s	Interrupt handlers	
ext_ram_handler_asm	asm	Assembly Functions definition _ext_ram_read_ext _ext_ram_write_byte_asm _ext_ram_read_byte_asm _ext_ram_read _ext_ram_write	ext_ram_handler.c (richiamata da flash.c a sua volta richiamata da monitoring.c)
int_ram_handler	asm	Assembly Function definition: pm_read	tc_tm_def.c
memcpy_s	asm	To avoid AD native memcpy function bug	Used everywhere instead of memcpy function
memory_sp	asm	Define GALVANI (_galvani), flash_dm	

		(_PR_code) , ext_dmda (_ram_in_image) memory spaces and specific variables scope	
real64ops	asm	To realize fast 64 bit add and multiply operations with 64 bit data	Used everywhere the application calls the dadd/dmul functions

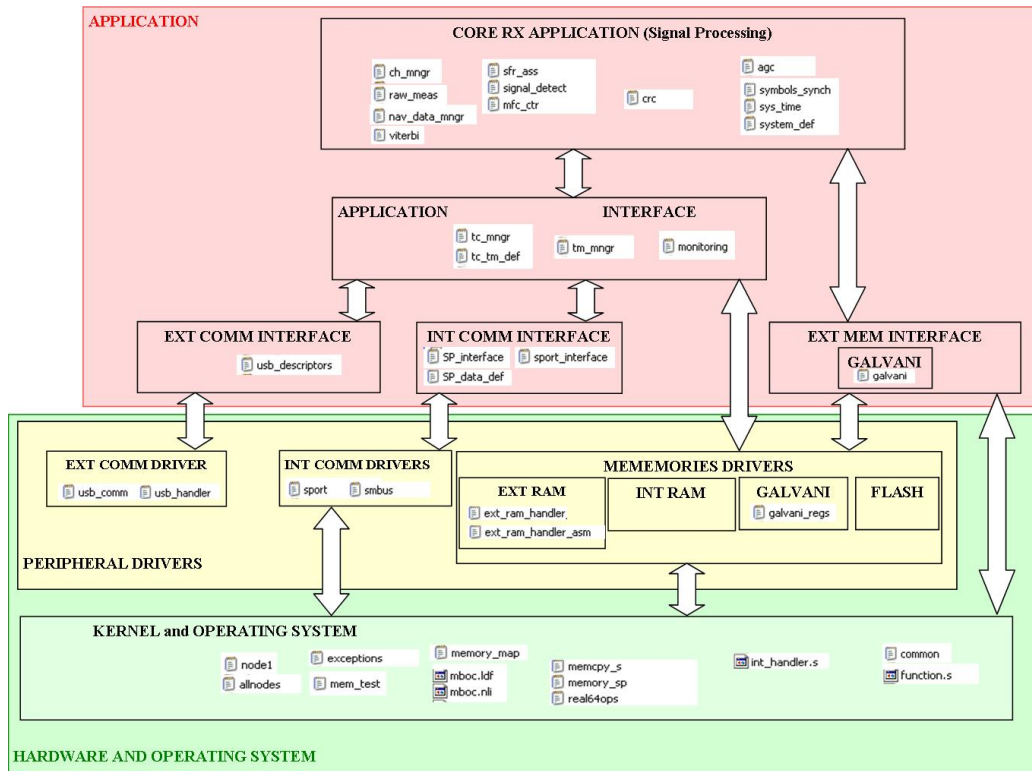


Figure 19 - Layers and files

### Key points

- The application is written in ANSI-C and some Assembly coded sections → Actually it is not possible to recompile the application using a different compiler for a different platform

## 4.2 Compiler Dependency

When porting the code, it should be verified how inline assembly code and standard functions are defined (macro).

### Key points

- inline assembly
- macro
- math libraries and memory management functions (memcpy)



### 4.3 Target Processor Dependency

According to performance requests, the RX application needs to work with extended precision floating point data (40-bit data at least). Also, as code size grows up with RX application complexity and range of tracked signals, data (and code) would partially be stored into external memory, which has to be accessed with the appropriate bus width.

#### Key points

- Data size: compatibility for short/long integer data and mostly for 40 bit data, according to Data and Program memory bus, and the processor access capabilities → remember the use of PX registers for ADSP211xx devices.
- Data endianness: byte ordering into internal memory for each word is different between processors. Each word (2 bytes) is placed in memory differently: for Analog Devices the less significant byte corresponds to the lower address memory location. For a 32-bit word, the less significant word is placed before the most significant word. Vice versa for Texas Instruments processor.

<b>Data Type</b>	<b>Analog Devices Compiler for ADSP211xx processors family (CC21k) data size (bit)</b>	<b>Texas Instruments Compiler for TMS320C67X processors family (C6000) data size (bit)</b>
char	8	8
short	16	16
int	32	32
float	32 - 40	32
long	40	40
long long	64, emulated	64
double	64, emulated	64

### 4.4 Hardware Environment Dependency

#### Key points

- The Signal Processing is strictly related to the hardware (GALVANI FPGA processor) → new address space (memory map changing)
- External memory addressing space
- SMBus / uWire communication

### 4.5 Operating System Dependency

The RX Application software has been written for use on a specific operating system, the Virtuoso OS and even for specific hardware, the ADSP21160 processor.

Hereafter a short reminder of the actual OS services:

<b>THREADS</b>	<b>EVENTS</b>	<b>SEMAPHORES</b>	<b>RESOURCES</b>
INTEPOCH_TH	IEPOCH_EVENT	MEPOCH_SEMA	MEAS_RES
MEPOCH_TH	TIMER_EVENT	DRDY_SEMA	SEQ_RES
MONITORING TH	MONITORING EVENT		SYMBOLS RES

NAVDMGR_TH	NAV_DATA_MNGR_EVENT		SEQ_NUM_RES
TCMGR_TH	RX_MSG_AVAIL_EVENT		TIME_RES
TMMGR_TH	TX_BUFFER_AVAIL_EVENT		SPORT_RES
TRACKINGLOOPS_TH			
AGCHANDLER_TH	AGC_EVENT		
SLAVETRADER_TH	SLAVE_REQ_EVENT		
VITERBIDECODER_TH	VIT_SOFTWARE_DEC_EVENT		VITERBI_RES

When porting the application to run on another OS, the functionality required by that application may be implemented differently (the names of functions, meaning of arguments, etc.) requiring the application to be adapted, changed, or otherwise maintained. To reduce porting costs and allow the highest level of flexibility, the approach will be:

- Design of Application abstraction (Operation System Abstraction)
- Design of Board support packages (specific for each processor to be used).

For example, the migration to the DSP/BIOS OS running on the TMS320C6701 processor requires the substitution of the previously used services according to the following correspondence:

<b>Virtuoso OS</b>	<b>DSP/BIOS OS</b>	<b>Description</b>
KS_TaskStart	TSK_create	Makes a task available for scheduling
KS_EventTestW	Not present. Replace with semaphores	test an event to see if it has been signalled. If not, returns RC_FAIL
KS_EventTestWT	Not present. Replace with semaphores	test an event to see if it has been signaled. If not, waits until the signal arrives
KS_EventSignal	Not present. Replace with semaphores	signals the specified event
KS_ResLockW	Not present. Replace with semaphores	increments the lock level of the logical resource
KS_ResUnlock	Not present. Replace with semaphores	decrements the lock level of the logical resource
KS_SemaTestW	SEM_pend	Waits for the semaphore to be posted by KS_SemaSignal / SEM_post
KS_SemaSignal	SEM_post	Signals a semaphore
KS_WorkloadRead		returns the workload as a number ranging from 0 to 1000
KS_TaskSleep	TSK_sleep	Makes the task sleep for a given number of milliseconds, until timeout expiration (that is when a number of ticks equals the timeout value passed in the system clock)

Note that in this specific case:

1. Event should be replaced by (binary) semaphores (as an event can only be in one of two states, signalled and not signalled)
2. Mutex (resources)

## 4.6 Importance and Design of a generic architecture

### The Method: the OS Abstraction Layer

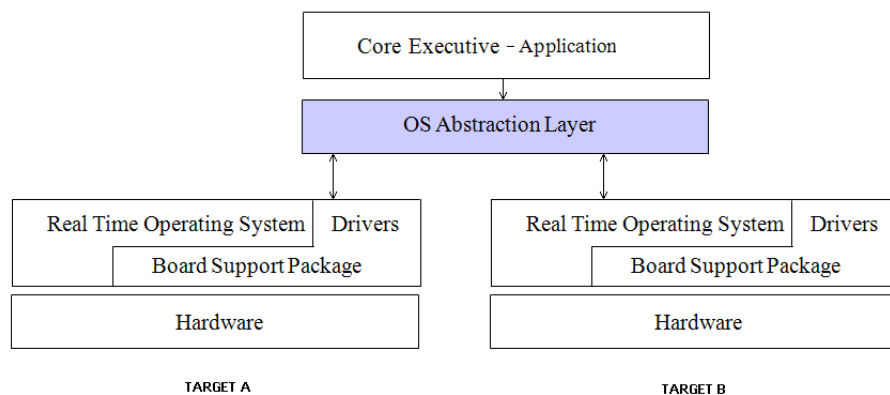
Implementing projects using an Operating System Abstraction allows for development of portable embedded system software that is independent of a particular Real Time Operating System and Hardware specifics, making it reusable and portable for multiple software or hardware platforms.

- **utilities:**
  - A small layer of software that allows programs to run on many different operating systems and hardware platforms
  - Independent of the underlying OS & hardware
  - Self-contained
- **capabilities:**
  - Removes dependencies from any one operating system
  - Promotes portable, reusable software
  - Core Applications can be built for multiple processors and operating systems
  - Example: different missions require different hardware & operating system
- **advantages:**
  - Allows developers to write and maintain one version of code
  - Allows for easy reuse across different missions with different hardware

### Key points

The OS abstraction would provide:

1. an Application Program Interface (API) to an abstract real time operating system. The implementation of this API for the specific Real Time Operating Systems would be provided by the OS Abstraction Layer
2. a Hardware Abstraction Layer, designed to provide a portable interface to hardware devices such as memory, I/O ports, and non-volatile memory
3. A directory structure and set of makefiles that facilitate building a project for a particular OS and hardware platform.



**Figure 20 - OS abstraction**

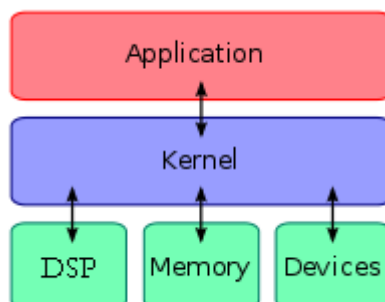
To facilitate the use of these APIs, the source code will be organized with an opportune directory structure and set of makefiles that facilitate building a project for a particular OS and hardware platform.

A **hardware abstraction layer (HAL)** is an abstraction layer, implemented in software, between the physical hardware of a board and the application running on that board. Its function is to hide differences in hardware from most of the operating system kernel, so that most of the kernel-mode code does not need to be changed to run on systems with different hardware. To better understand this abstraction way, think to a PC, where the HAL can basically be considered to be the driver for the motherboard and allows instructions from higher level computer languages to communicate with lower level components, such as directly with hardware.

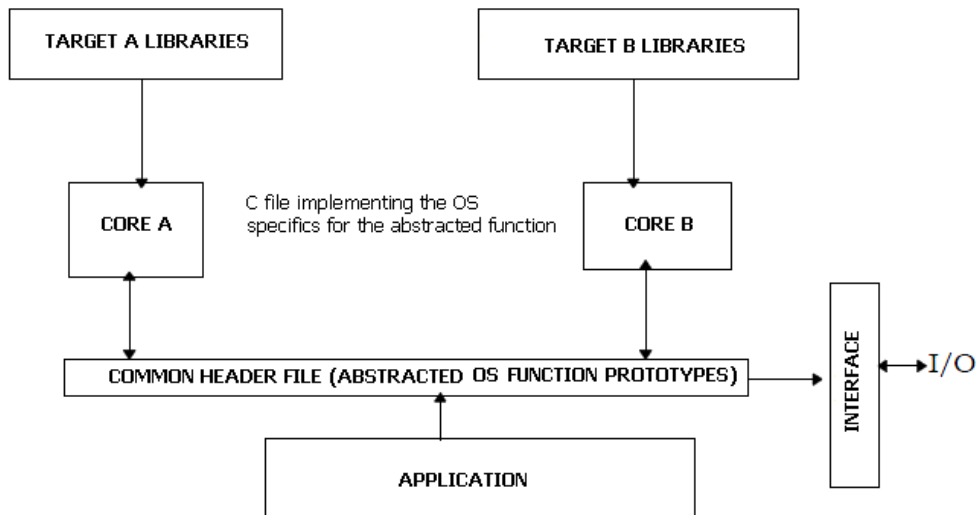
Hardware abstraction layers are of an even lower level than application programming interfaces (API) because they interact directly with hardware instead of a system kernel, therefore HALs require less processing time than APIs.

## 4.7 The Major Layers

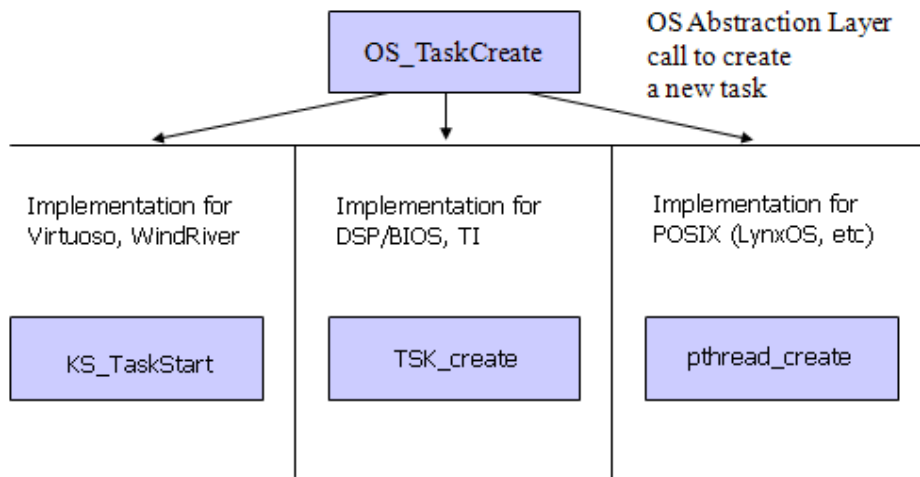
1. **Hardware** → creation of a ‘Board Support Package’ to suit the specific target
2. **Kernel: OS layer** → management of thread schedule, all service requests, interrupts and memory access; connection of application to hardware with the aid of the [firmware](#) and [device drivers](#)
3. **Device Drivers: HAL** → management of devices access at the physical level (hardware).  
Also:
  - interface for communicating with the specific device, through the specific processor bus or communications subsystem that the hardware is connected to, providing commands to and/or receiving data from the device
  - interface to the operating system and software applications
  - specialized hardware-dependent functions which are also operating system specific
  - other operating system kernel functions activation to interact transparently with the hardware device
  - interrupt handling necessary for any necessary asynchronous time-dependent hardware interfacing needs
  - key design goal: [abstraction](#). Every model of hardware (even within the same class of device) is different. The function of the device driver is then to translate these operative system mandated function calls into device specific calls.
4. **Application Program** → user specific program independent of the underlying physical target resources



**Figure 21 - Major Layers**



**Figure 22 - Targets**



**Figure 23 - OS Abstraction Layer**

Note that:

the implementation for a specific target is realized using the makefile, compiling only the files needed for a specific OS/architecture

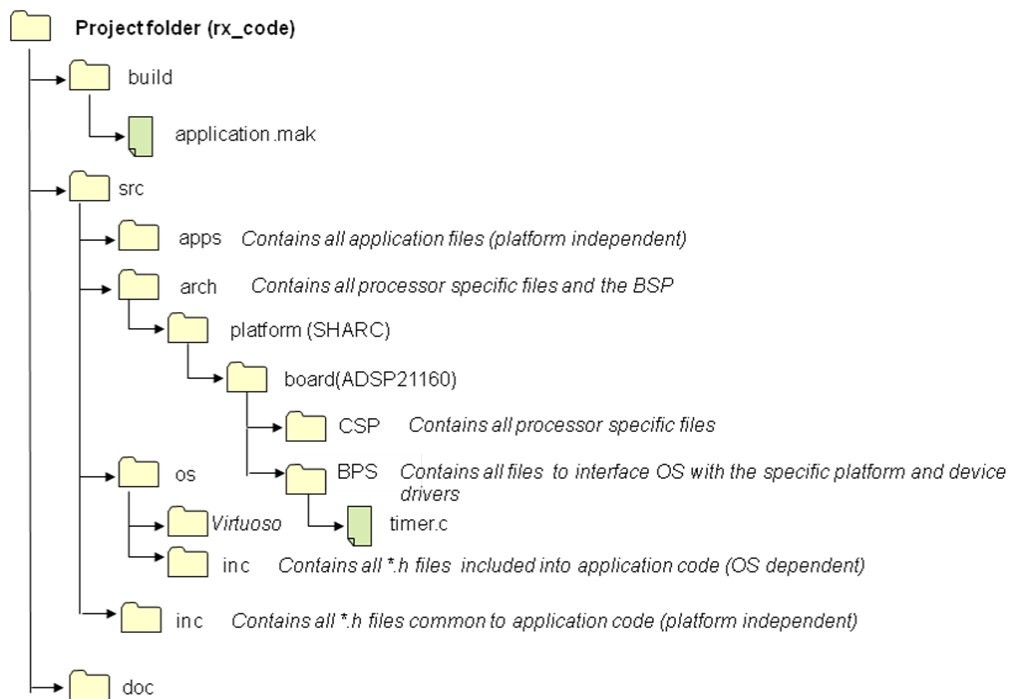
## 4.8 Design of Architecture

Steps to abstraction:

1. Creation of the application path and files tree:

Directory	Description
rx_code	The top level of the project code directory
rx_code/src	contains all source codes and make rules, that is the same application for different platforms (OS and target processor)
rx_code/src/apps	contains the sample application files for the abstracted code
rx_code/src/arch	contains the architecture (processor) specific code as well as the BSP (Board Support Package) code to make the abstracted code run on a particular platform.

	Everything in this directory is used to adapt the abstracted code and Applications to a particular hardware platform.
rx_code/src/inc	contains system wide include files that are used by the abstracted code on all platforms. (i.e. common.h)
rx_code/src/make	contains common makefiles for building the abstracted code and it's applications
rx_code/src/os	contains the implementation of the abstracted code for each supported operating system. There is a sub-directory for each supported operating system in this directory. The abstracted code include files are also contained in this directory (src/os/inc)
rx_code/build	contains a framework for building an abstracted code application The files in this directory allow easy customization and configuration for any supported OS or platform for the abstracted code. By changing a few variables in a file, the abstracted code can be built for any of the supported platforms
rx_code/doc	contains the documentation and release notes for the abstracted code



**Figure 24 - File Tree**

2. Put files in the correspondent folders according to the layers layout (see xxx)
3. Create the kernel. it is linked with the CSP, BSP, and device drivers to create the specific operating system → \os In particular:
  - a. Replace all Operating System service calls with abstract calls, declared in the RTOS.h file, which becomes the OS layer abstraction file (see table below)
  - b. Replace all Operating System data types with standard types
  - c. Create the Application Programming Interfaces (API), which contain the system services and are linked with the application code. The Application Programming Interfaces (API) should include the floating point services to configure floating point responses. The API would take care of:

- i. Scheduler service
- ii. OS libraries

<b>OS Abstraction Layer RTOS.h file</b>	<b>Specialization for Virtuoso OS virtuoso_rtos.c</b>	<b>Specialization for DSP/BIOS OS dsbios_rtos.c</b>
OS_TaskStart	KS_TaskStart	TSK_create
OS_EventTestW	KS_EventTestW	SEM_pend
OS_EventTestWT	KS_EventTestWT	SEM_pend
OS_EventSignal	KS_EventSignal	SEM_post
OS_ResLockW	KS_ResLockW	
OS_ResUnlock	KS_ResUnlock	
OS_SemaTestW	KS_SemaTestW	SEM_pend
OS_SemaSignal	KS_SemaSignal	SEM_post
OS_WorkloadRead	KS_WorkloadRead	
OS_TaskSleep	KS_TaskSleep	TSK_sleep

4. Create a generic makefile who recalls Sub-makefile to compile the various layers → \make
5. Create the Hardware Abstraction Layer to make hardware drivers independent from the specific target → \apps
6. Create the processor family-specific routines, including the floating point, and processor exception handlers. This routines are linked with the OS kernel → \arch\CSP
7. Create the board support package (BSP) as support code for the specific board that conforms to the specific [operating system](#). The BSP contains routines for initializing and controlling hardware on the target system. → \arch\BSP
8. Initialize and manage the hardware
9. Initialize the processor
10. Initialize the bus
11. Initialize / Interface with the interrupt controller
12. Initialize / Interface with the system time (tick timer)
13. Initialize the RAM settings
14. Configure the segments, as per the BSP package
15. Establish virtual address map for onboard I/O
16. Create device drivers to establish direct communication with devices
17. Provide default handlers for error-signaling interrupts
18. Link to the kernel
19. Load and run bootloader from flash

# 5. Software Architecture

In this part of the document we are going to discuss the general software architecture, defining all the necessary layers and their interconnections. In order to keep the code as platform-independent as possible, the application packages will use a set of System APIs to obtain services from the operating system and data access from the Data Pool.

The Data Pool is a system-wide data area, containing all of the necessary structures and variables to accomplish the receiver's tasks.

Inter-operating software layers are :

- Application Layer
- Manager Layer
- Base Layer
- Hardware Layer

Software Architecture

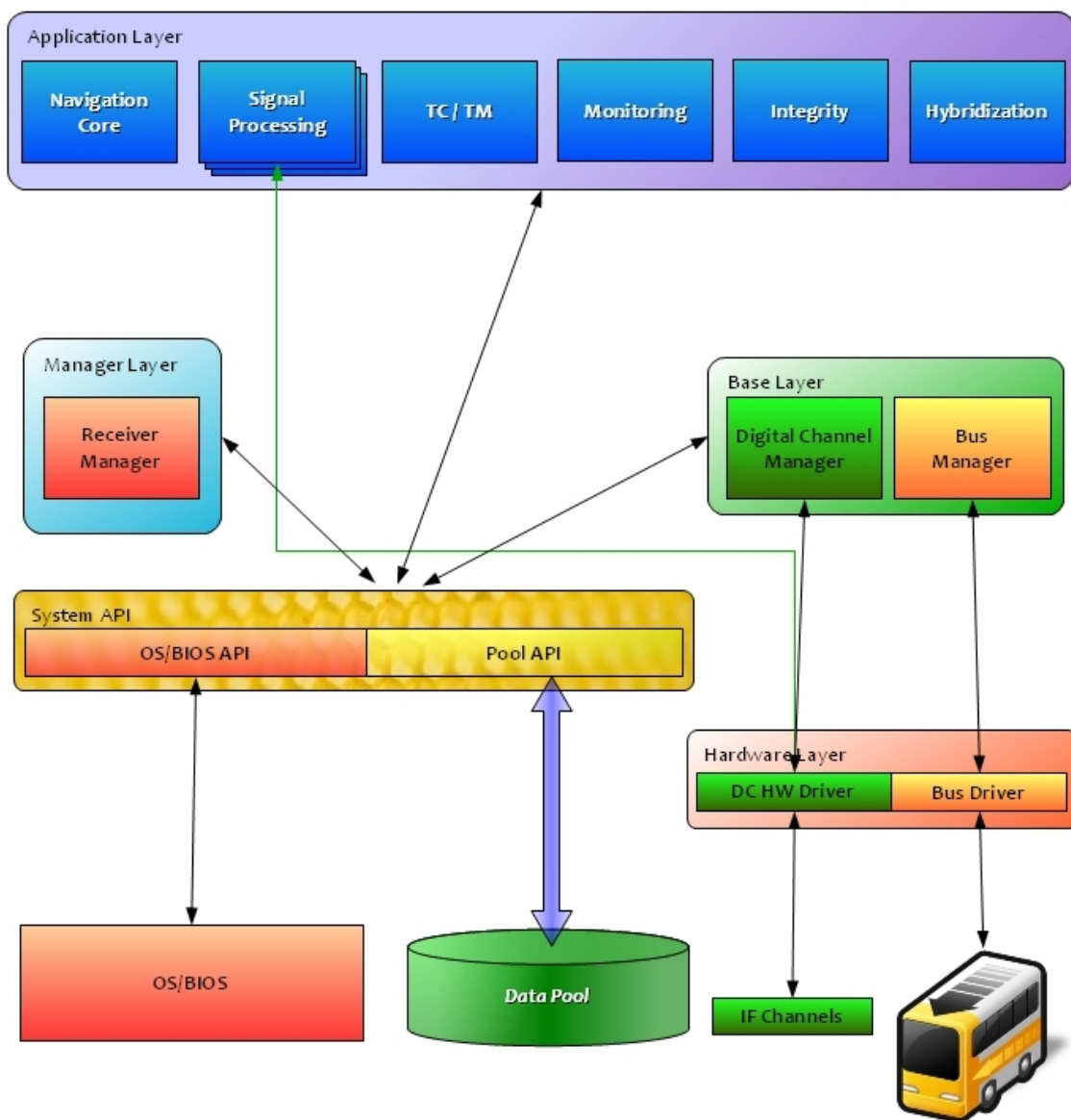


Figure 25 - Software Architecture



Every Application Package can exchange informations with other software packages only through the Data Pool which is accessed for reading or writing purpose using the Pool API included as part of the System API.

Exception is done for the Signal Processing packages which, due to performance issues and strict time requirements, have to be able to directly access the Hardware Layer in order to communicate with IF Channels.

Application Packages that are mainly going to be used are:

- Navigation Core
- Signal Processing (several)
- TC/TM (Telecommunication & Telemetry)
- Monitoring
- Integrity
- Hybridization (or Augmenting in some cases)

Underneath the Application Layer there are Manager Layer and Base Layer.

Manager Layer contains the Receiver Manager package, the one handling the receiver tasks and taking decisions on what has to be running at a certain time, in a certain condition.

The Base Layer contains the Bus Manager and the Digital Channel Manager. The first is in charge of performing operations on the system bus and information storing on the Data Pool. The second one is needed to perform channel assignment policy.

The Base Layer can work properly by using functions and calls provided by the Hardware Layer, which contains the specific drivers to communicate with the system Bus and IF Channels. Hence the Hardware Layer will provide standard-interface functions which will include different code implementations depending on the specific hardware of the receiver.

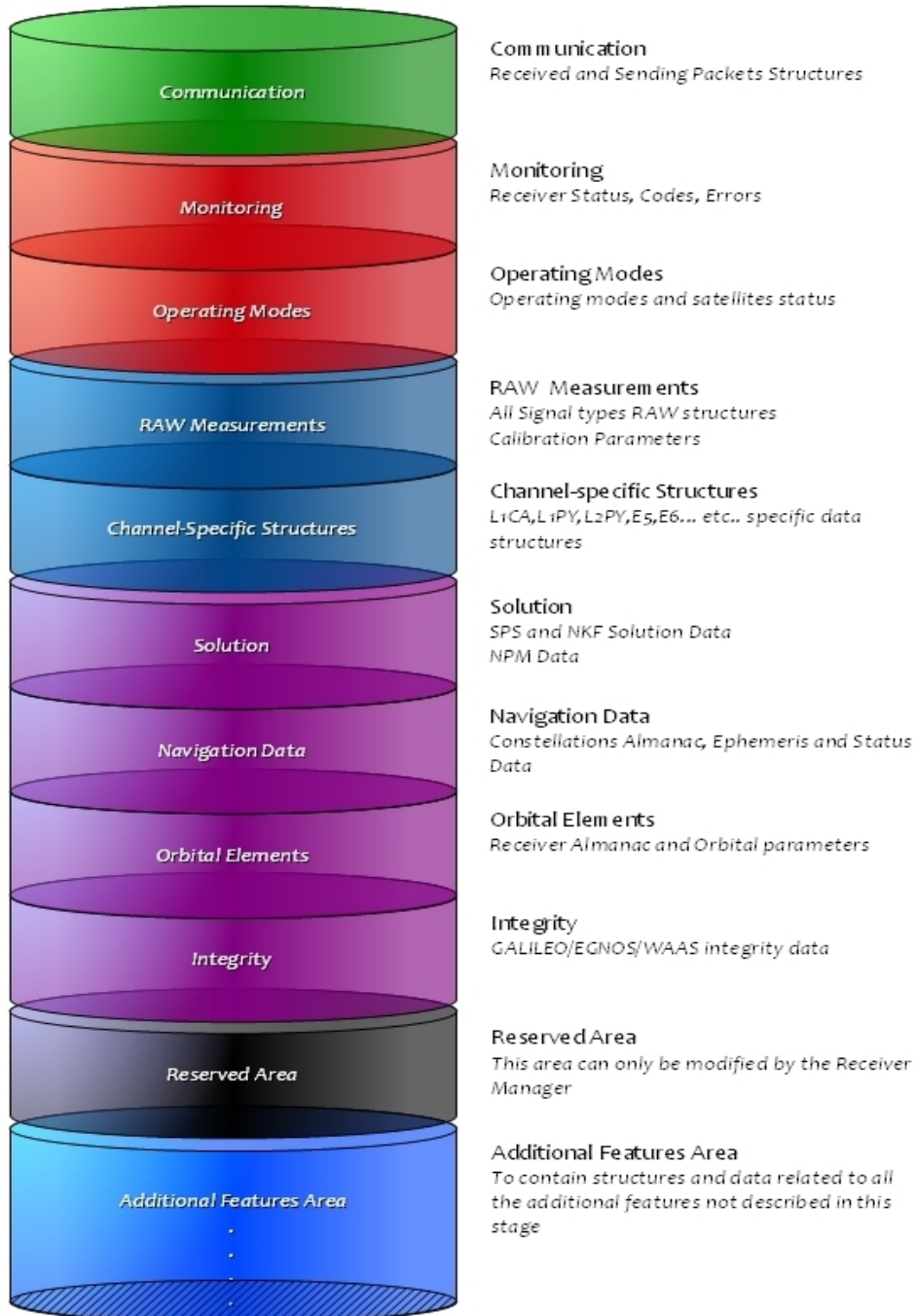
## 5.1 Data Pool

The Data Pool contains all the informations and data structures that have to be available, either for reading and writing operations, by:

- Application Layer
- Manager Layer
- Base Layer

Hardware Layer can't directly access this area.

All kinds of operation on the Data Pool can be performed only via the **Pool API**.



**Figure 26 - Data Pool**

## 5.2 System API

The System API is made of two packages. The OS/BIOS API provides the software packages all the needed functionalities to perform operating system actions, while the Pool API allows to read and write data structures inside the Data Pool if the desired resource is available at the requested time. This API may contain several implementations for the same function, in order to support different OS's and processors, but only one of this replicated functions will be compiled by setting the right preprocessor definitions for the desired platform.

### API Functionalities

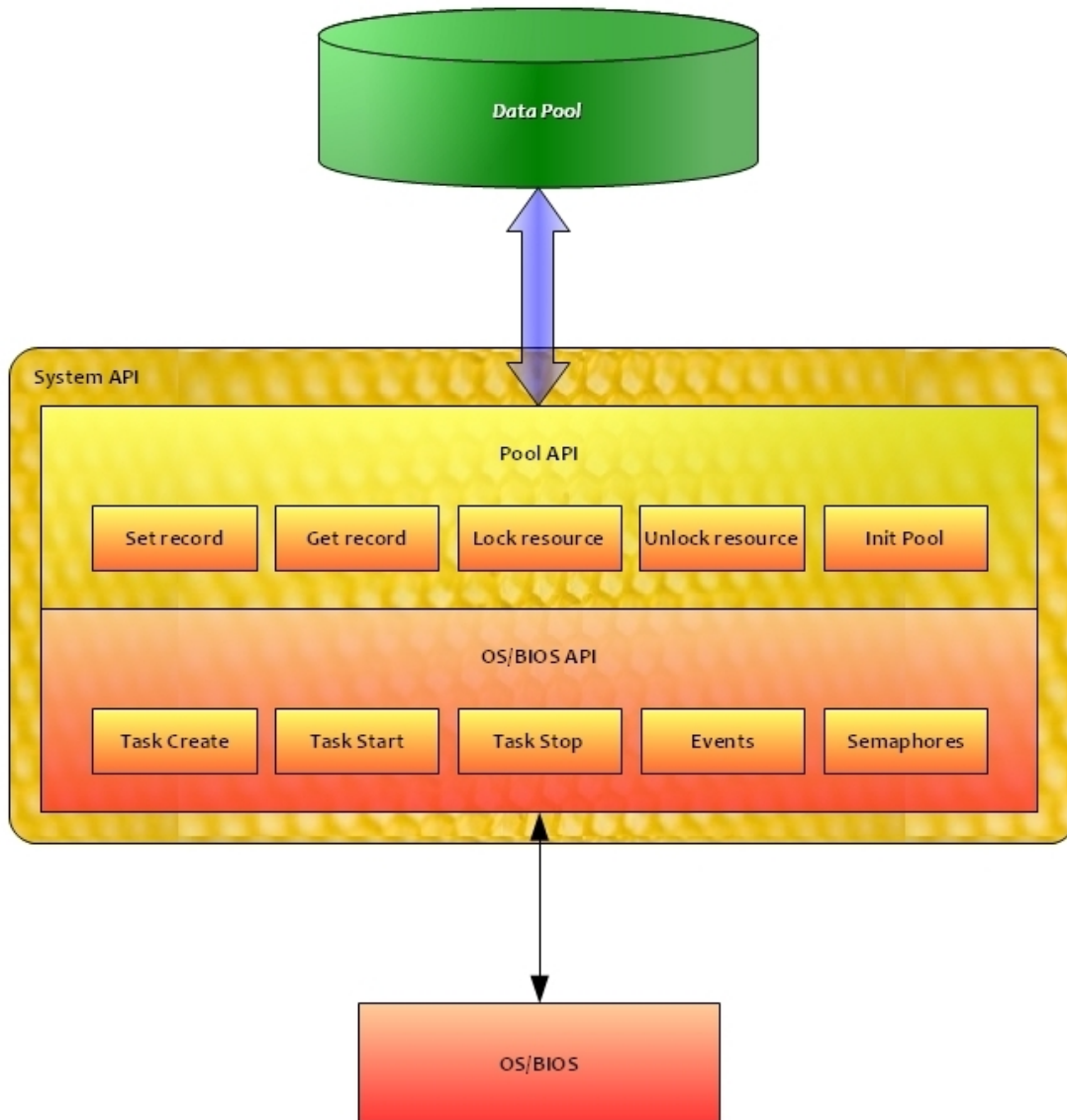


Figure 27 - System API

### 5.3 Base Layer

This layer includes the Bus Manager and the Digital Channel Manager. Both of these packages are able to check system events and read/write data to the pool.

#### Base Layer

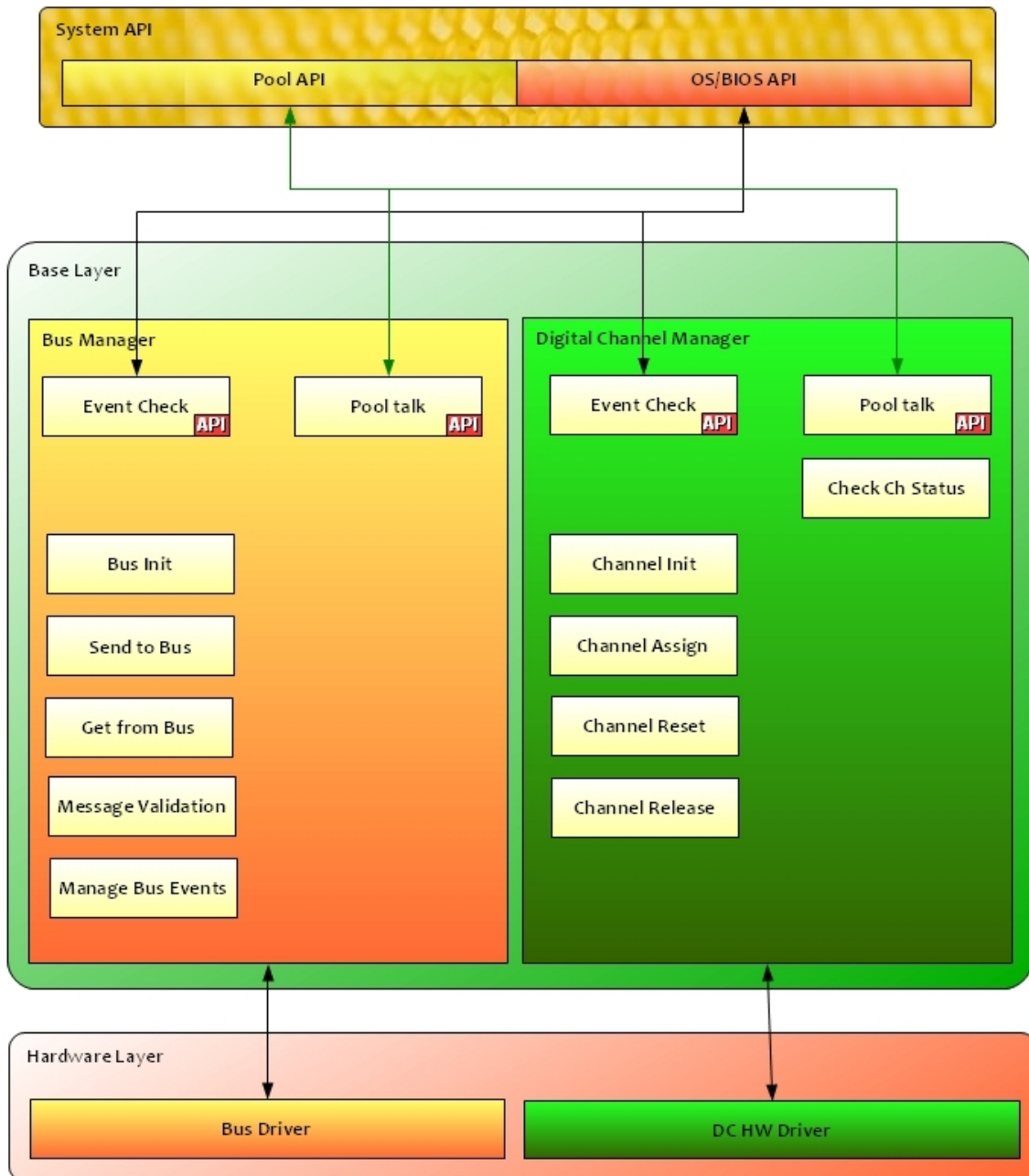


Figure 28 - Base Layer

## 5.4 Hardware Layer

The Hardware Layer consists of all the drivers necessary to use the specific bus type (depending on board version) and to use the implementation of GALVANI on FPGA

### Hardware Layer

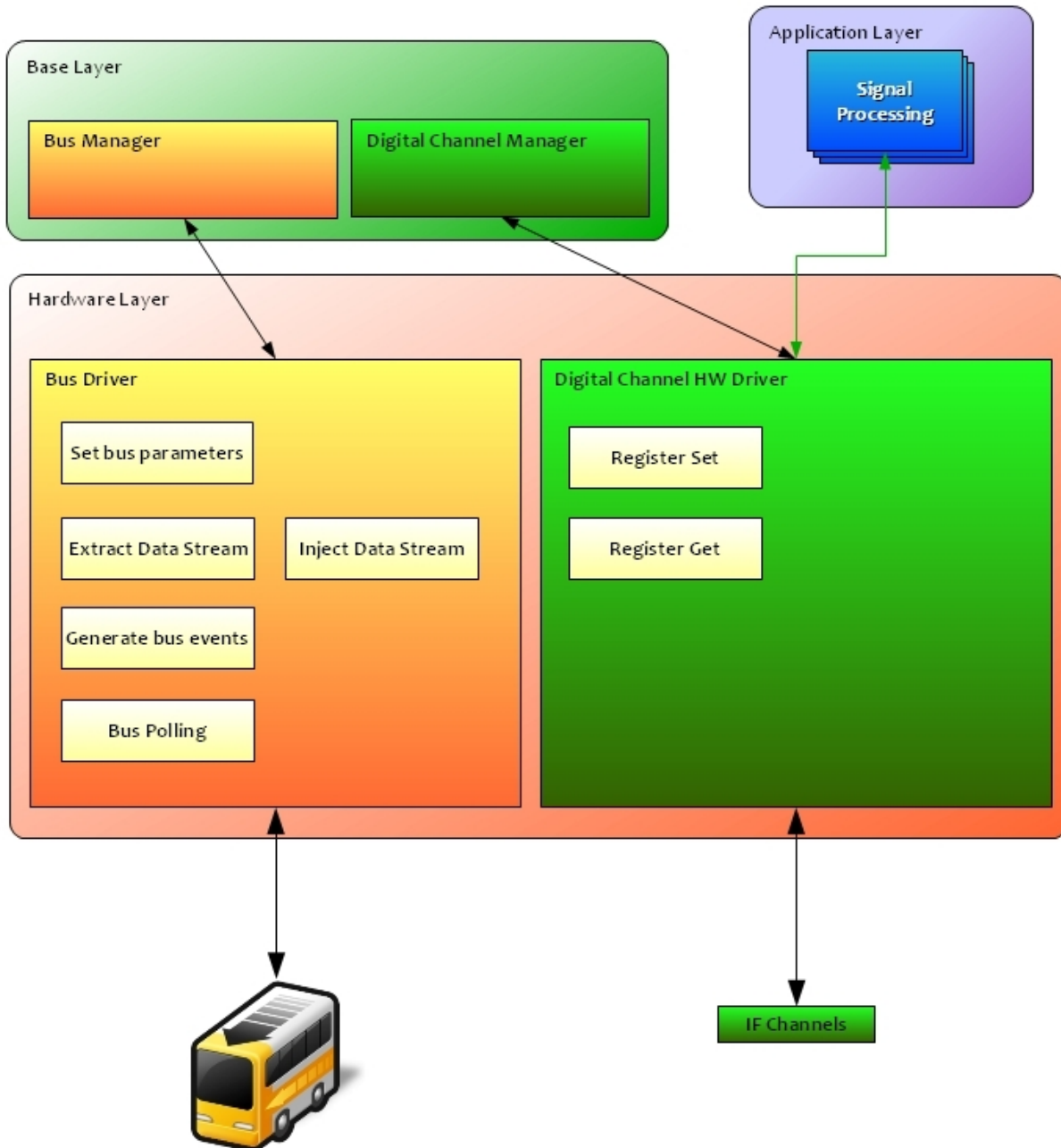
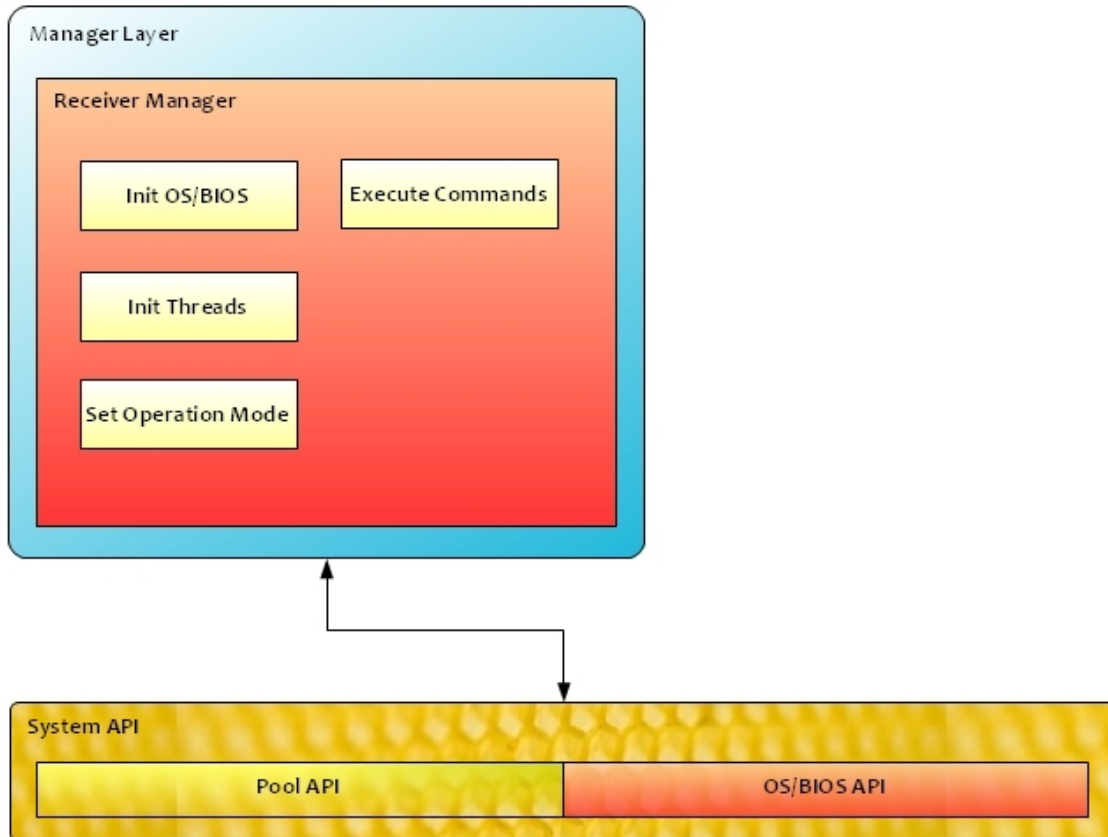


Figure 29 - Hardware Layer

## 5.5 Manager Layer

This is the main package, the one responsible for the software initialization and operation executions.

### Manager Layer



**Figure 30 - Manager Layer**

The Receiver SW is a real-time embedded system application that runs on a real-time operating system.

The Software Development Environment (SDE) is based on PC-based Texas Instruments tools for the T6713 DSP called Code Composer Studio.

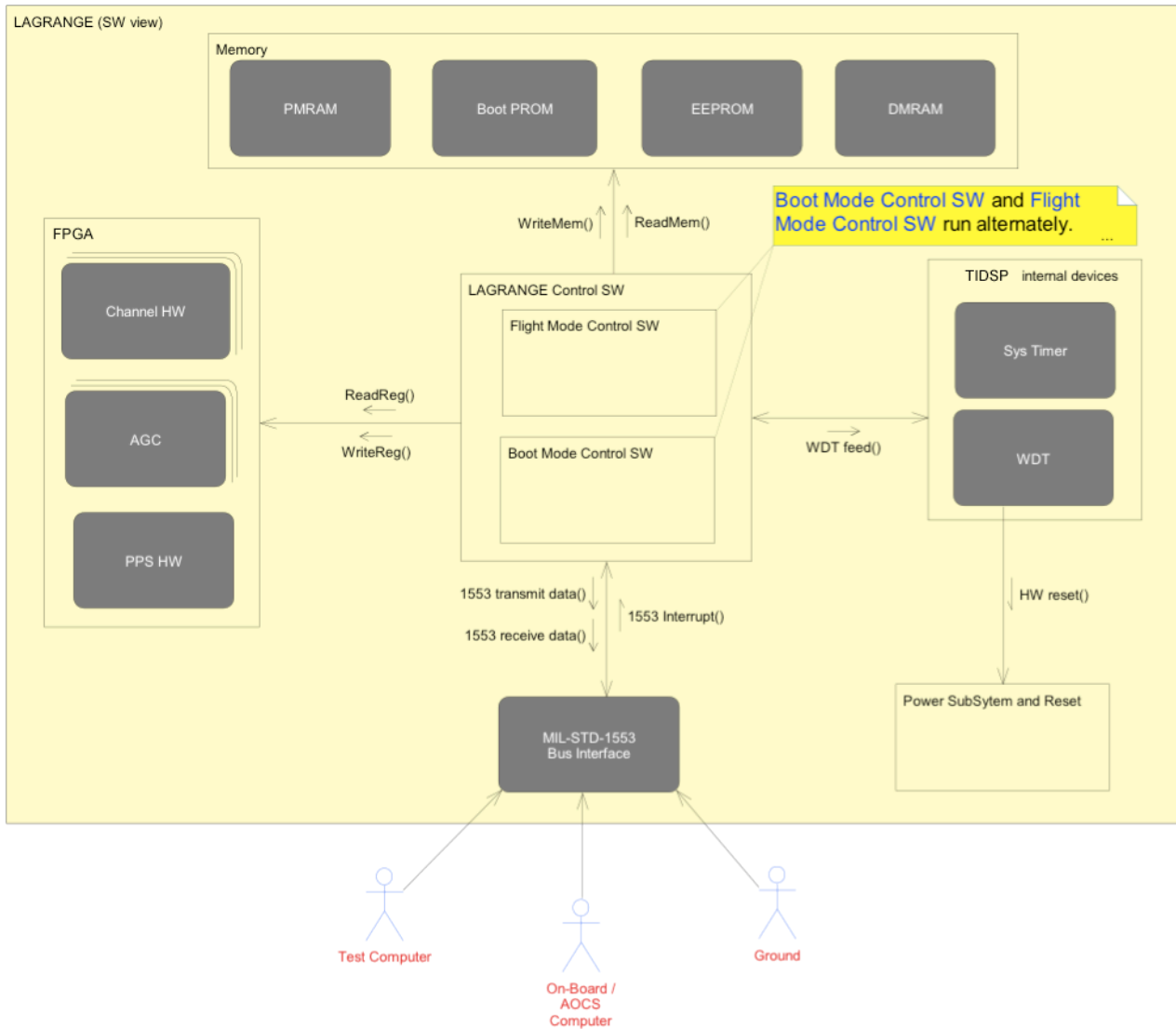
The software is developed in a modular fashion using object-oriented programming techniques so as to improve software robustness, maintainability and readability. The programming language is C, compiled with Code Composer.

The Receiver software includes all functions that are essential to the Receiver operation: from Signal Processing up to position-velocity-time (PVT) solutions.

The software uses TI BIOS, implemented as a library linked to the Receiver SW, that provides all basic operating system functionality as:

- threads scheduling in a pre-emptive or non pre-emptive environment
- resource handling (mutual exclusion synchronization)
- events handling (raising and waiting for events)
- queues handling (queuing and dequeuing data for threads communication)
- timers handling.

In the following diagram the interactions between HW and SW context are illustrated.



**Figure 31 - System Architecture Diagram - Receiver SW view**

## 5.6 Operations Overview

A general view of the main operations of the LAGRANGE 2G Receiver is illustrated in the following figure.

The operations are:

- Management Operations: are related to the User/Receiver interface
- Spacecraft Operations: its main function is the monitoring of the health and status of the Receiver during its work

- Receiver Specific Operations: is the real functionality of the Receiver, which in principle are the acquisition of the observable data from the GNSS SVs and the evaluation of the navigation solution

## 5.7 Receiver/User interface

All data exchanged between the Receiver and the User are passed via the MIL-STD-1553B or an RS232 interface. All the exchanged data are in form of packets. The implementation of the packet schedule is strictly related to the bus utilization.

LAGRANGE 2G instrument acts as a Remote Terminal (RT). It receives commands from the User and provides responses only when solicited by a specific request command from the Bus Controller (BC), i.e. the User.

The spontaneous transmission of data and event or alarm messages from the Receiver to the satellite subsystem is not foreseen for the RT. However some information (for example, navigation solution data, observables data, ...) have to be transmitted at predefined periodic rate. At this scope a special packet scheduling mechanism is defined, named Synchronous Packet Transfer (SPT) protocol.

The protocol is scheduled by the BC, using a Synchronization Broadcast message (Mode Code), sent every 100 msec and containing a frame count number (from 0 to 9, cyclic).

We assume that the Synchronization messages are synchronous with internal Receiver time second, indicated by PPS.

This message subdivides the time in the following time scales:

PPS					1 sec						PPS
100 msec					100 msec						100 msec
SM-0	SM-1	SM-2	SM-3	SM-4	SM-5	SM-6	SM-7	SM-8	SM-9	SM-0	
TS-0	TS-1	TS-2	TS-3	TS-4	TS-5	TS-6	TS-7	TS-8	TS-9		

SM = Synchronization message

TS = Time Slice

1 sec Base period of the Receiver

100 msec Time Slice (frame counters from 0 to 9), composed by 10 Bus Time Slots of 10 msec

10 msec Bus Time Slot (BTS)

The Bus Time Slot (BTS) time is a time unit *external* to the Receiver, i.e. the Receiver can only recognize the Processing frame time (= 100 msec) by means of the Synchronization messages.

The *internal* Receiver timing is a 20 msec RTC time unit, synchronized with the Receiver time.

The synchronization of the communication between BC and RT has the scope of avoiding the contemporary read/write of the sub-addresses. To this scope, the following rules are followed:



- BC can ask for *Periodic Packets* only in BTS-0 of each TS. In this way the Receiver can use all the remaining part of each TS for the S/A preparation
- BC can send a *TC* only in BTS-9 of one TS (for example, odd), and cannot request the response/acknowledge before BTS-9 of the next TS (in this example, even).

In this way the Receiver has 100 msec to prepare the response in the dedicated S/A.

The User must ask for the transmission at the same frequency of the packet's preparation, on the contrary the last prepared packets will be overwritten by new packets, also if not yet read.

For more details on the communications, see the ICD of the project.

## 5.8 Operative Modes

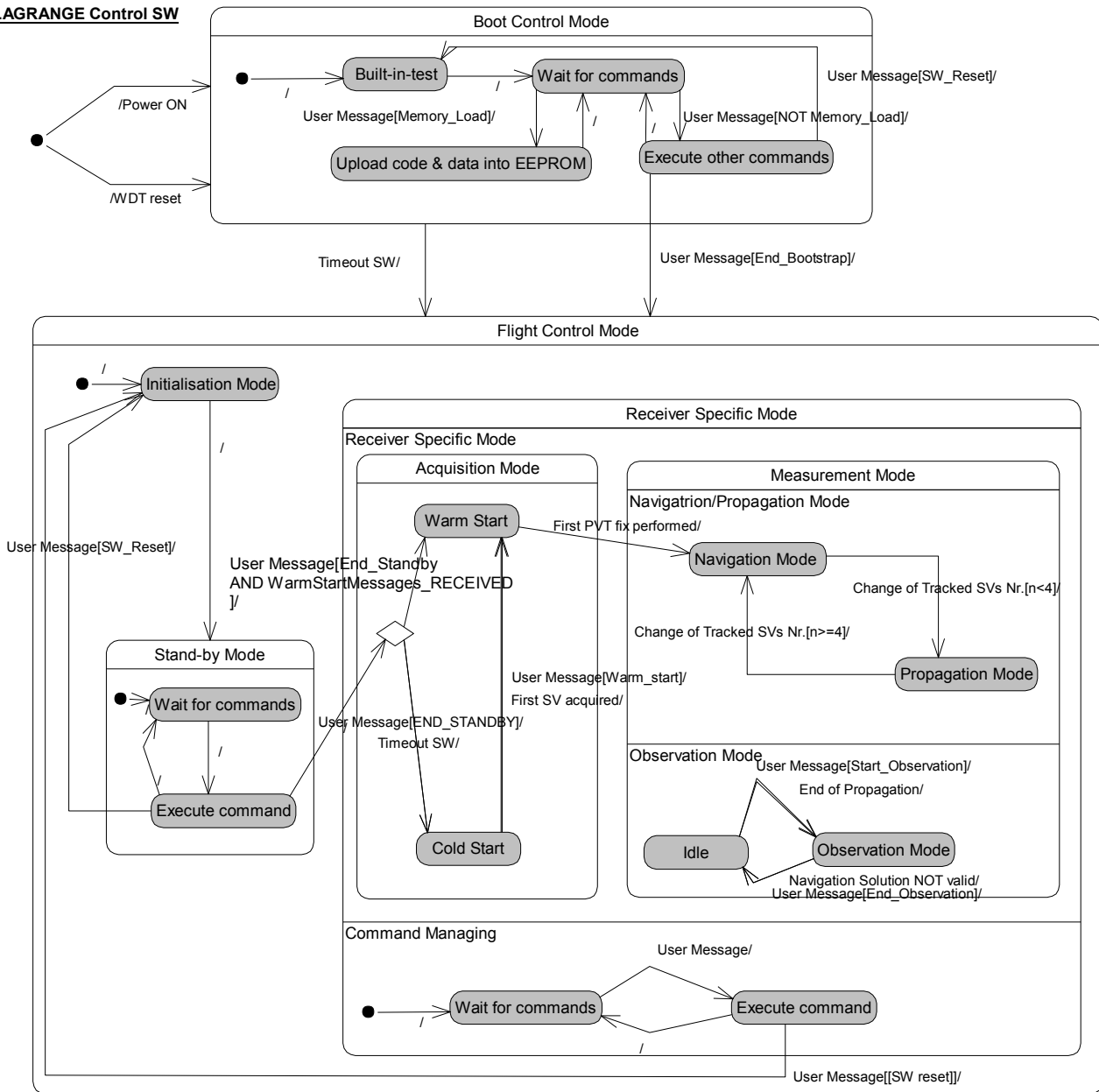
The LAGRANGE 2G functionality includes the following operational modes:

1. Bootstrap & Loader Mode
2. Flight Control Mode, composed by:
  - a) Initialization Mode
  - b) Stand-by Mode
  - c) Receiver Specific Mode
    - i. Acquisition
      - Cold Start
      - Warm Start
    - ii. Measurement Mode
      - Navigation/Propagation Mode

In order to avoid forbidden mode transition, the transitions between modes can be due to:

- A request by the user by means of TC's. These TC's are rejected in case of out-of-scope
- Internal timeout, following the Receiver precise clock, in alternative at previous point, only for the allowed transitions
- Autonomous transition, when recognized by the SW, only for the allowed transitions. This type of transition is not performed following a simple event (for ex. a flag), but checking that all the related causes are present.

**LAGRANGE Control SW**



**Figure 32 – Operative Modes**

## 5.9 Flight Mode

Starting from the general view, the HW/SW interactions during the Flight program are illustrated in the following figure:

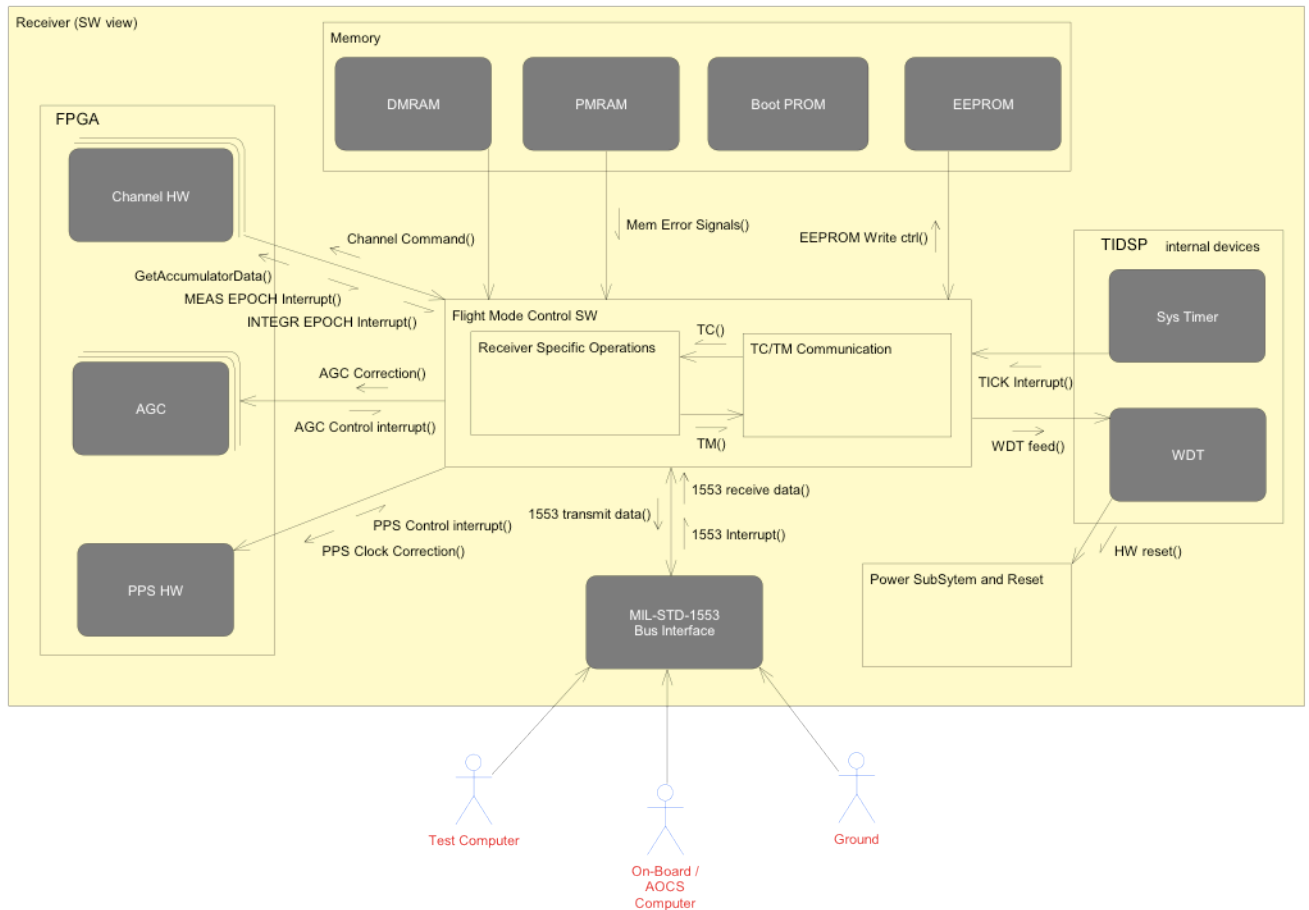


Figure 33 - System Architecture Diagram - Receiver SW view for Flight

From the functional point of view, in the Flight SW we may identify two main logic functions:

### **1. Receiver Specific Operations**

It is the core of the Receiver functionality, which comprises:

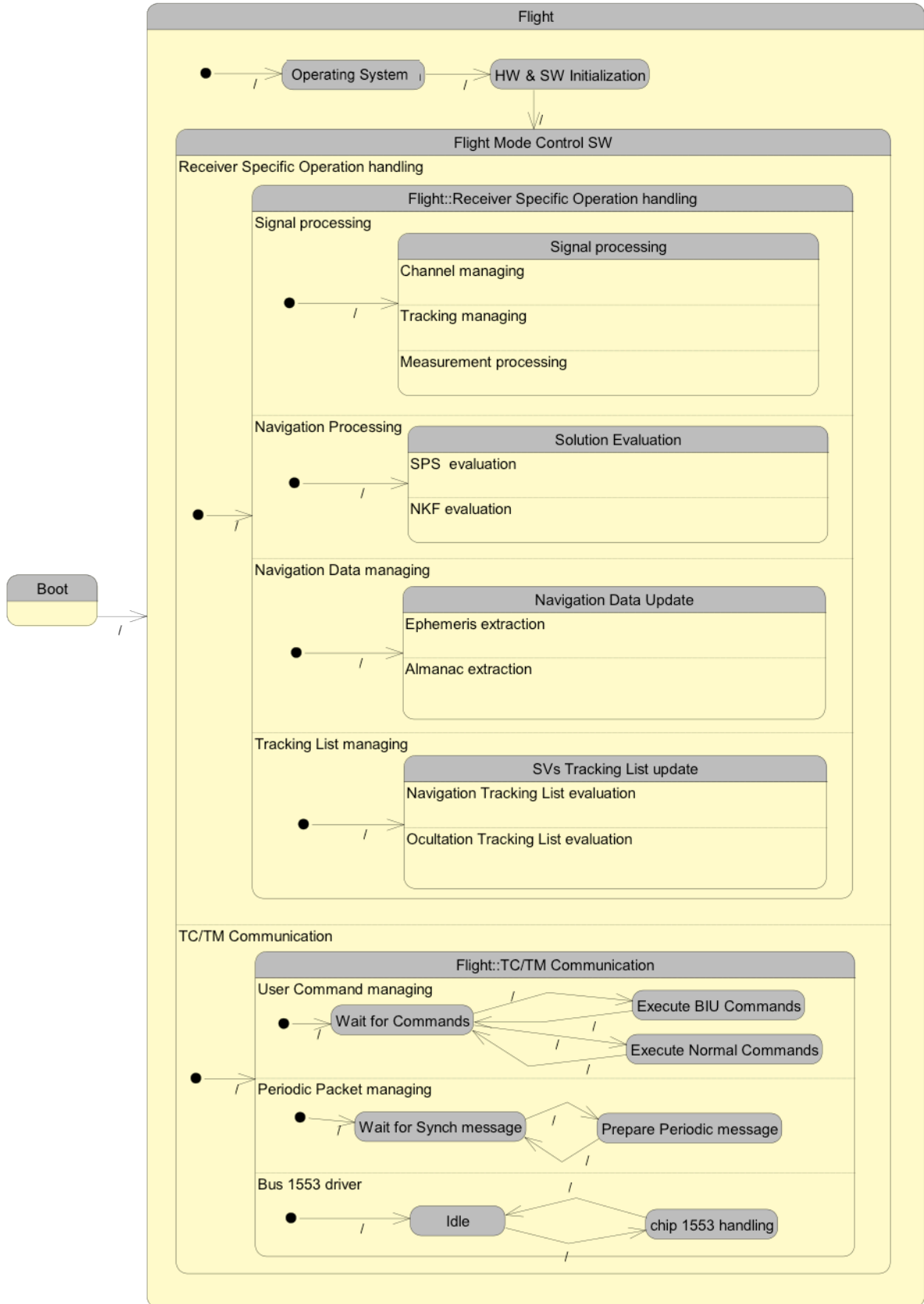
- Allocates HW channels to GNSS satellites
- Receives signals from GNSS satellites
- Obtains and maintains Code Lock and Carrier Lock, demodulates and decodes data message and recovers Navigation Data from each received GNSS satellite
- Performs position, time and velocity calculation based on a Least Squares algorithm and on a filtered navigation solution
- Uses calculated position information to establish geometrical line of sight information of each acquired GNSS satellite with respect to the receiver platform and maintains a tracking list of visible satellites.

### **2. TC/TM Communication**

It comprises the Receiver/User Interface management functions:

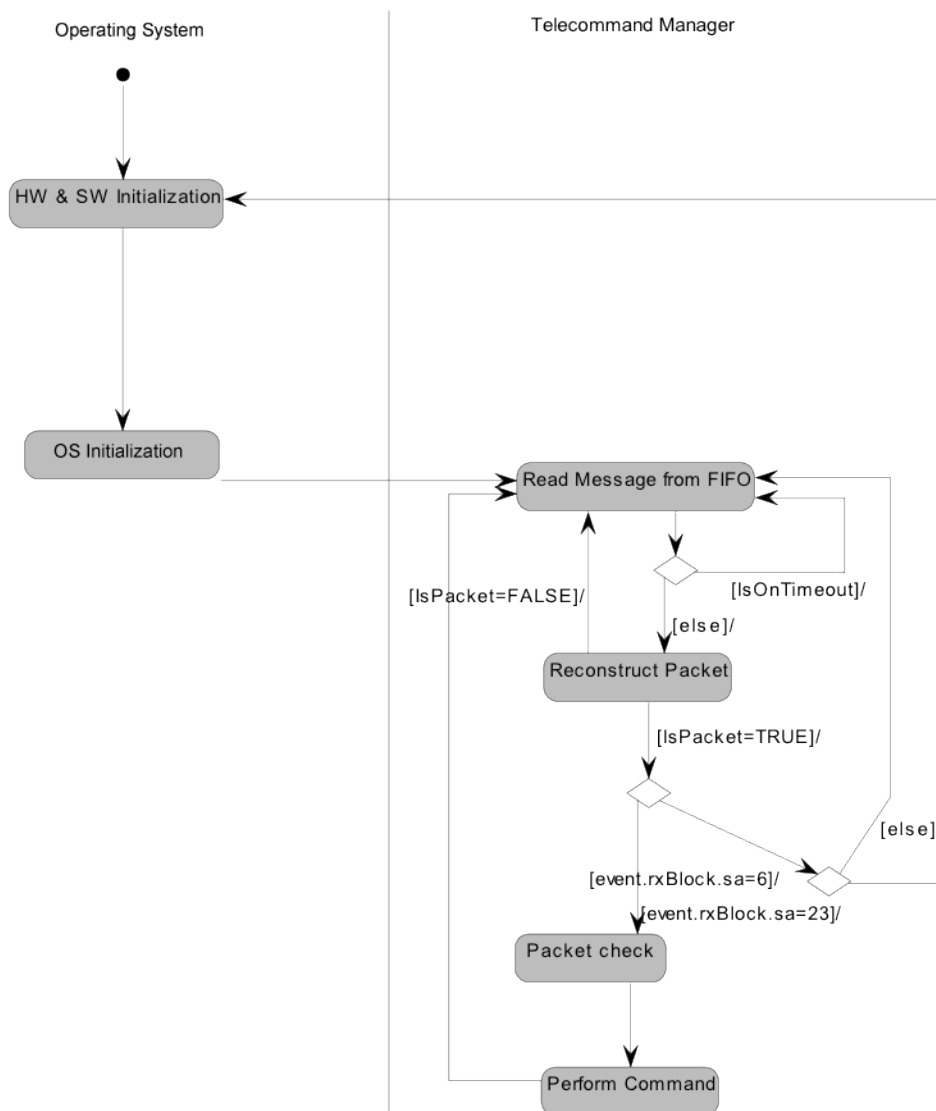
- Monitors and maintains receiver health status
- Allows receiver control from ground through user commands
- Provides Navigation Solution data
- Provides observable data for each GNSS satellite in lock.

**Flight Mode Control SW**



**Figure 34 - State Diagram - Flight Control**

In the following picture a dynamic view of the Management Operations is illustrated:



**Figure 35 - Management Operations - Dynamic View**

### 5.9.1 Commands

During Flight Mode, the allowed User commands are:

- Configuration commands, to program particular parameters into the Receiver
- Warm Start data commands, to instruct the Receiver about the initial search of the SVs
- Diagnostic commands, to have a testing capability. The Memory Dump command is also present at this scope
- System and Solution data commands, to acquire data from the Receiver during the run; these commands can be subdivided into different sections, related to different data:
- System and SPS Solution data
- NKF solution data
- Signal processing Data
- Mode change commands: these commands are used to change the operating mode of the Receiver. They are the SW reset commands and the End of Stand\_by commands, to switch to Measurement Mode.

## 5.9.2 LAGRANGE 2G Specific Operations

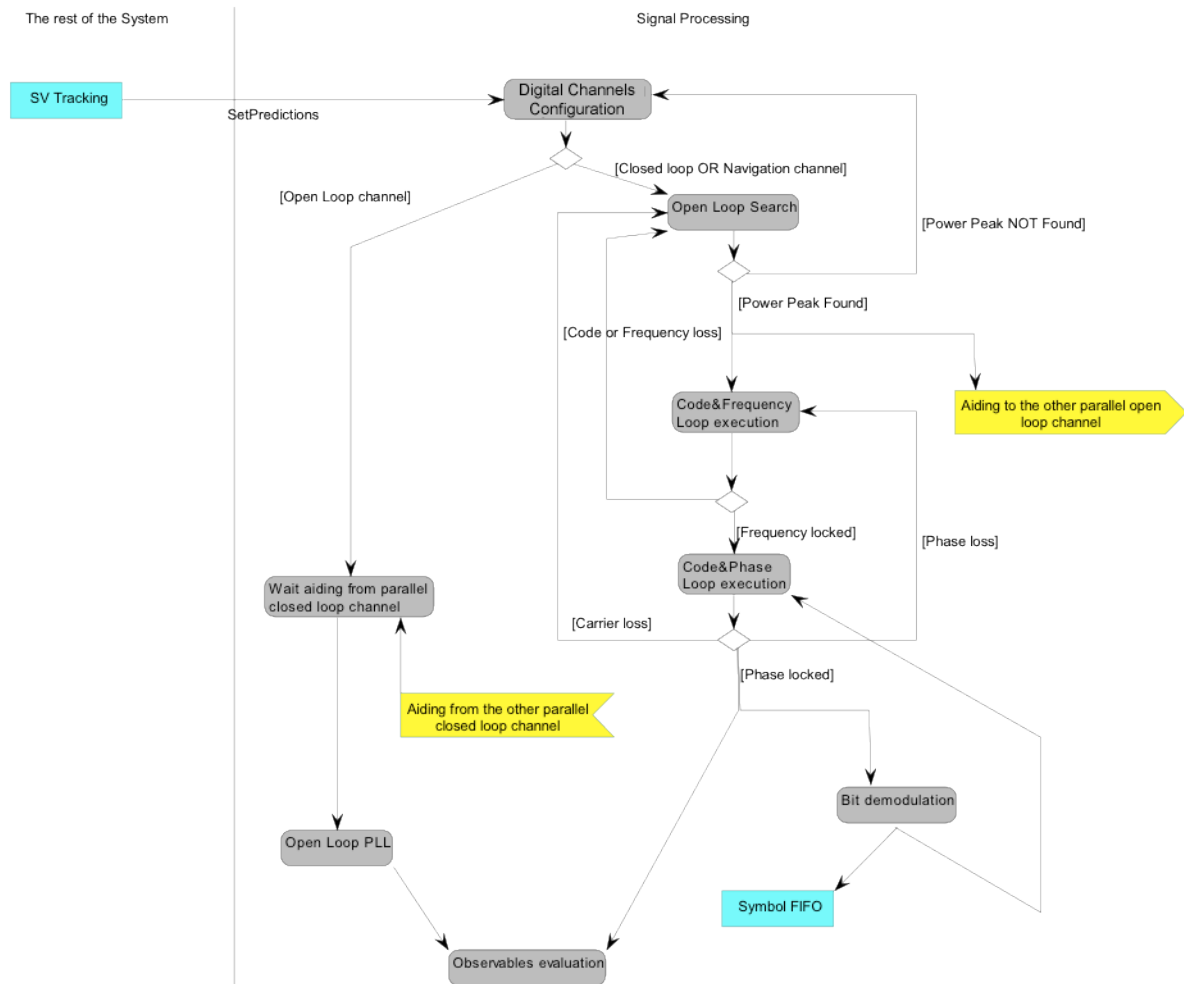
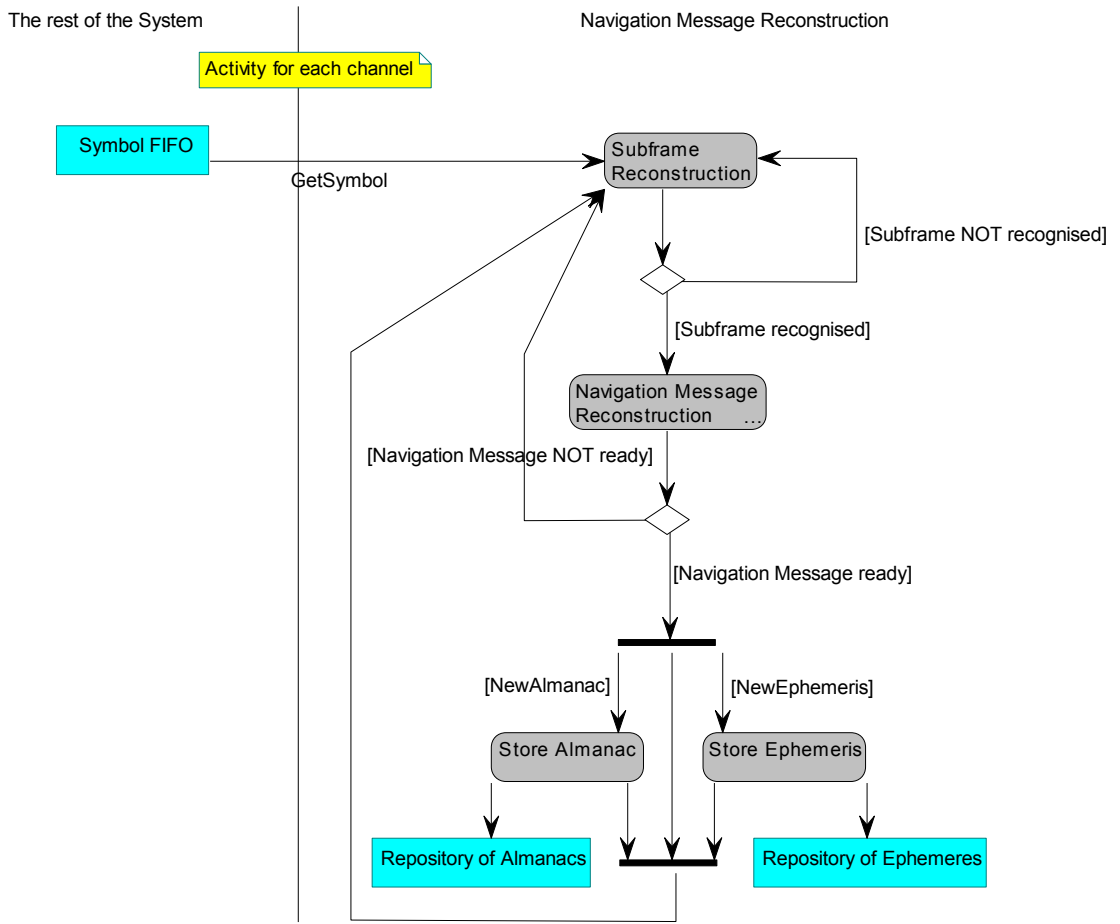
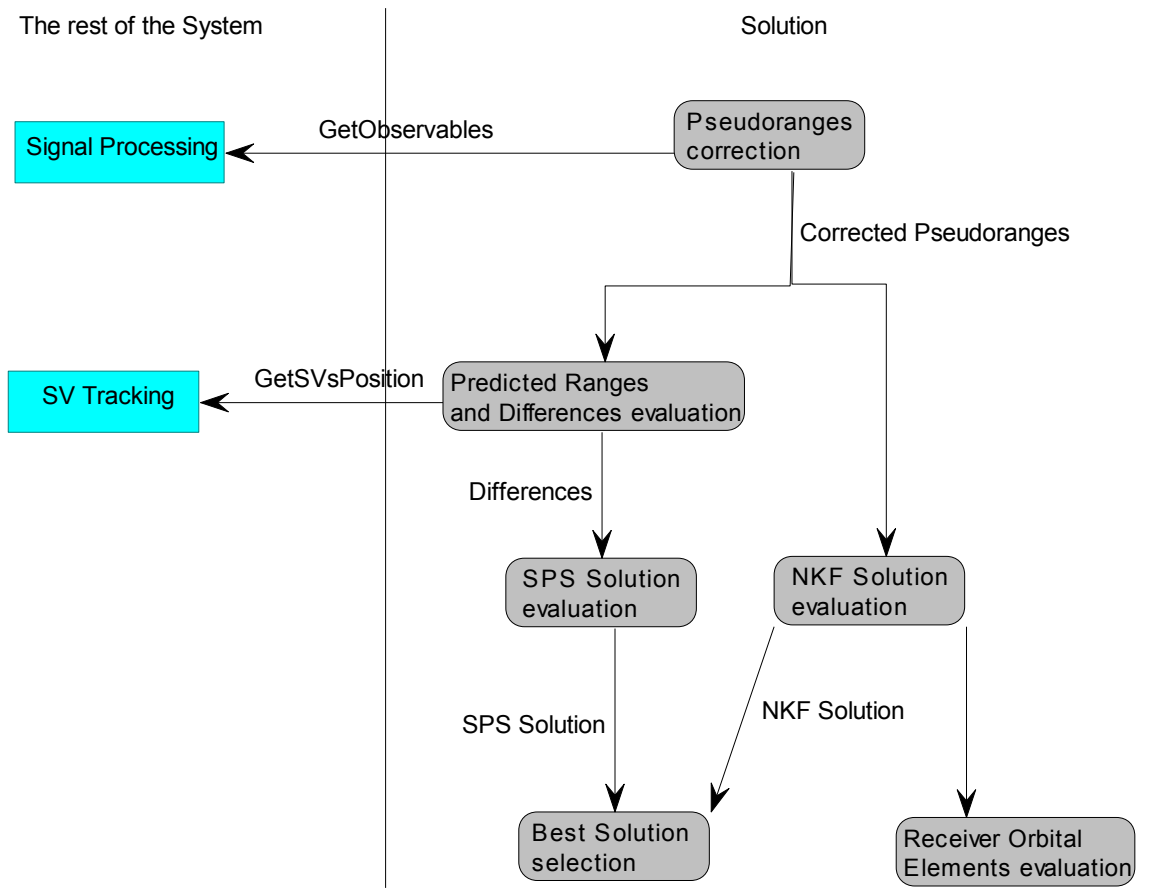


Figure 36 - Signal Processing Management - Dynamic view



**Figure 37 - Navigation Data - Dynamic view**





**Figure 38 - Solution - Dynamic view**

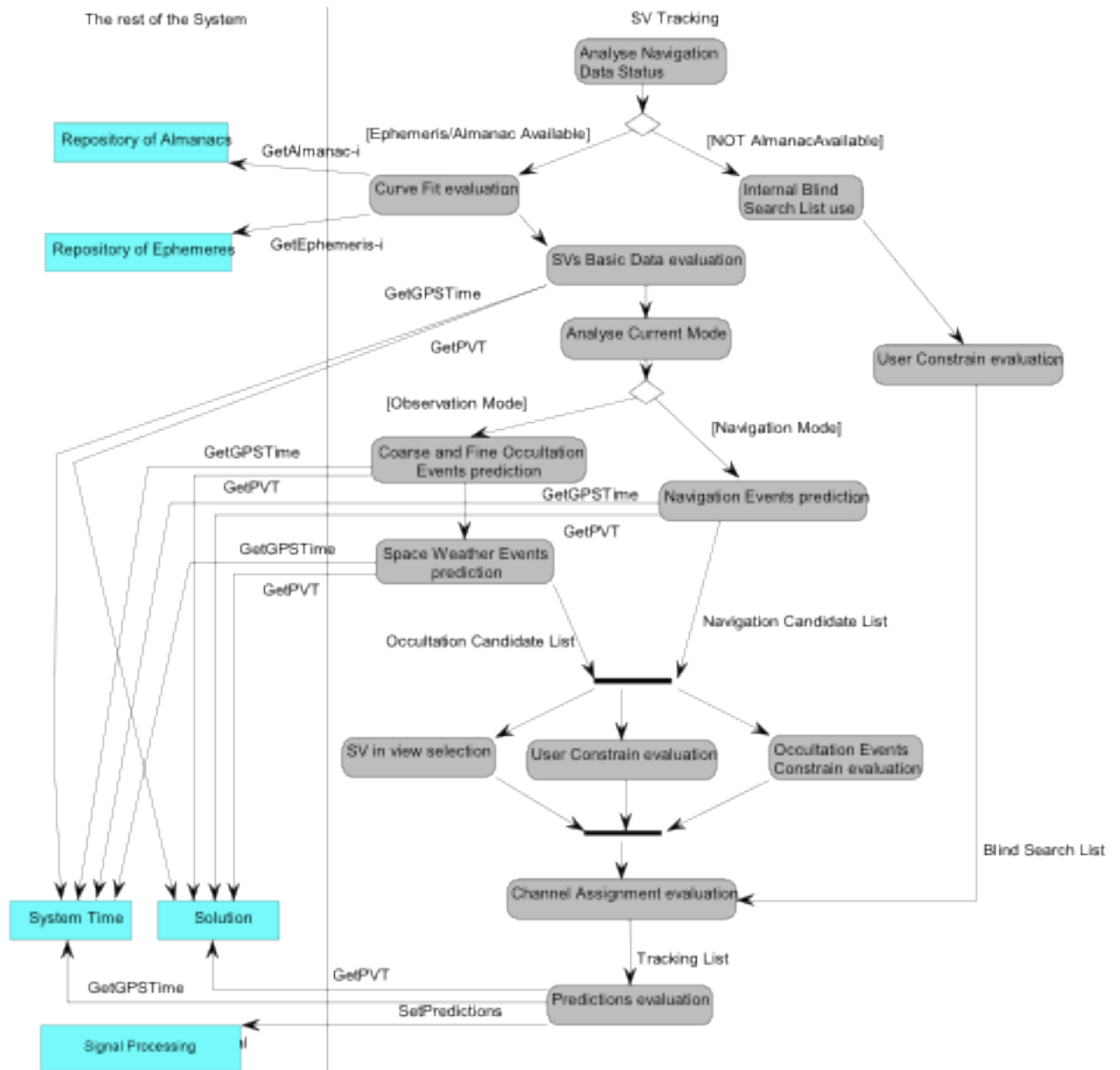
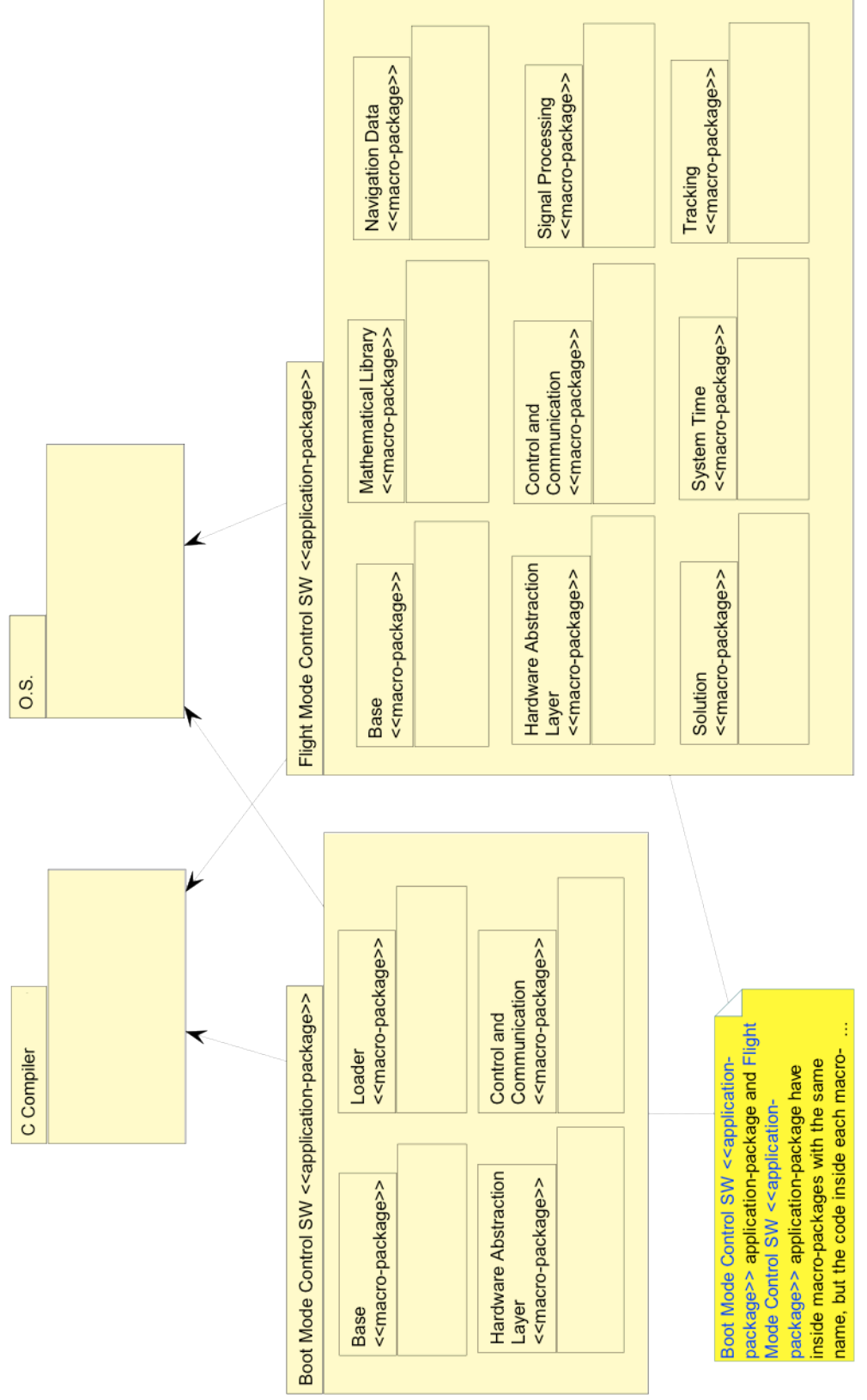


Figure 39 - Tracking - Dynamic view

## 5.10 Package Description

The complete Receiver SW is composed by (see Fig. 4-1):

- Boot Mode Control SW application package (BOOTSTRAP & LOADER program);
- it implements the operations illustrated at par. 3.3
- Flight Mode control SW application package (FLIGHT PROGRAM) ;
- it implements the operations illustrated at par. 3.4
- TI6713 Software development Environment (SDE), include files from C compiler and ASM and library
- TI BIOS Operative System library.



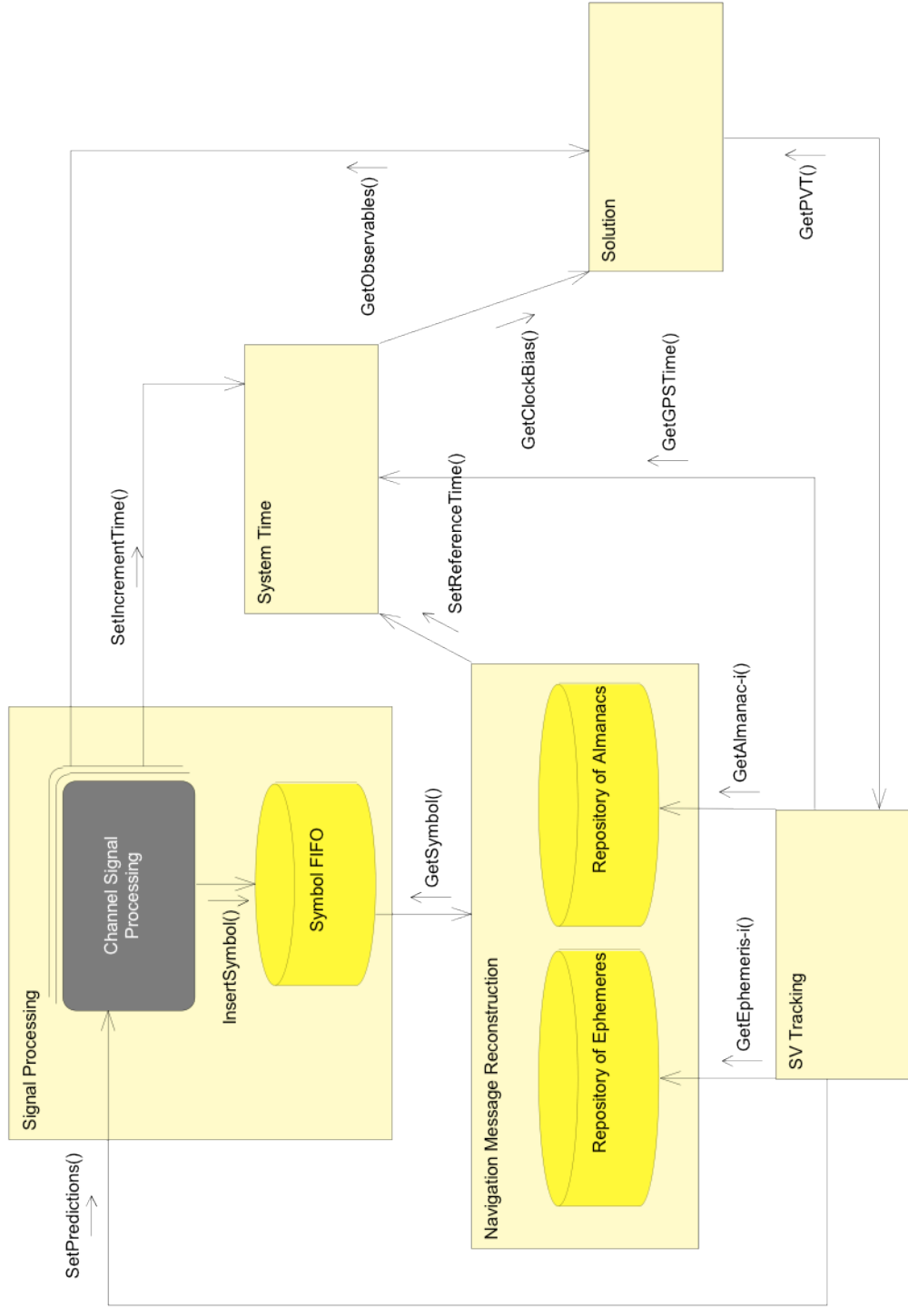
**Figure 40 - I/AGRANGE 2G Complete SW Package**

### 5.10.1 Flight Package

The following list identifies the Flight SW macro packages;

<b>FLIGHT macro package</b>	<b>Description</b>
Base	Contains the basic part of the SW
Signal Processing Modules	<p>Implements all functions related to control of channels operations and processing of the raw data measurements. In particular:</p> <ul style="list-style-type: none"> <li>- Performs acquisition, tracking and demodulation functions for each channel, for L1CA, L1PY, L2PY, L2CM, L2CL</li> <li>- Pre-processing of raw data measurements to produce observables</li> <li>- Collect data bits, subdivided to GPS and GALILEO subframes</li> </ul>
Navigation Data	Computes and maintains updated SVs navigation data (almanacs, ephemeris, time data) separately for each channel.
Solution	<p>The Solution evaluation processing is composed by the following parts:</p> <ul style="list-style-type: none"> <li>- Pre-processing activities needed to produce pseudorange and rate measurements needed to compute the solutions</li> <li>- Standard Positioning Solution (SPS) evaluation, based on All-In-View satellites</li> <li>- Navigation Kalman Filter Solution (NKF) evaluation</li> <li>- Receiver Orbital Elements determination</li> <li>- Receiver status vector management</li> </ul>
Tracking	<p>Implements the satellites selection strategy. Builds and updates the Receiver tracking lists, maintains SVs position and velocity and provides all the necessary information to the Signal Processing in order to perform acquisition and tracking, for Navigation SVs and for Occultation events.</p>
System Time	Performs the operations related to Receiver time and task's control.
Control and Communication	<p>This module performs periodic Receiver monitoring and status reporting, and manages the 1553 communication. It is composed by the following main functions:</p> <ul style="list-style-type: none"> <li>- Handling of high level Receiver operative modes</li> <li>- Receiver monitoring and status reporting</li> <li>- Synchronized messages management</li> <li>- Telecommand management</li> </ul>
Mathematical library	It is a pool of functions, used everywhere in the project, for mathematical evaluations and conversions

<b>FLIGHT macro package</b>	<b>Description</b>
Hardware layer	It implements the HW-SW interfaces: <ul style="list-style-type: none"> <li>- Watch-dog-timer (WDT)</li> <li>- Serial interface</li> <li>- Channel's control, by means of GALVANI FPGA</li> <li>- AGC control by means of GALVANI FPGA</li> <li>- Memory management functions</li> </ul>



**Figure 41 - Flight Mode Control SW - Dynamic interactions**

### 5.10.2 Base

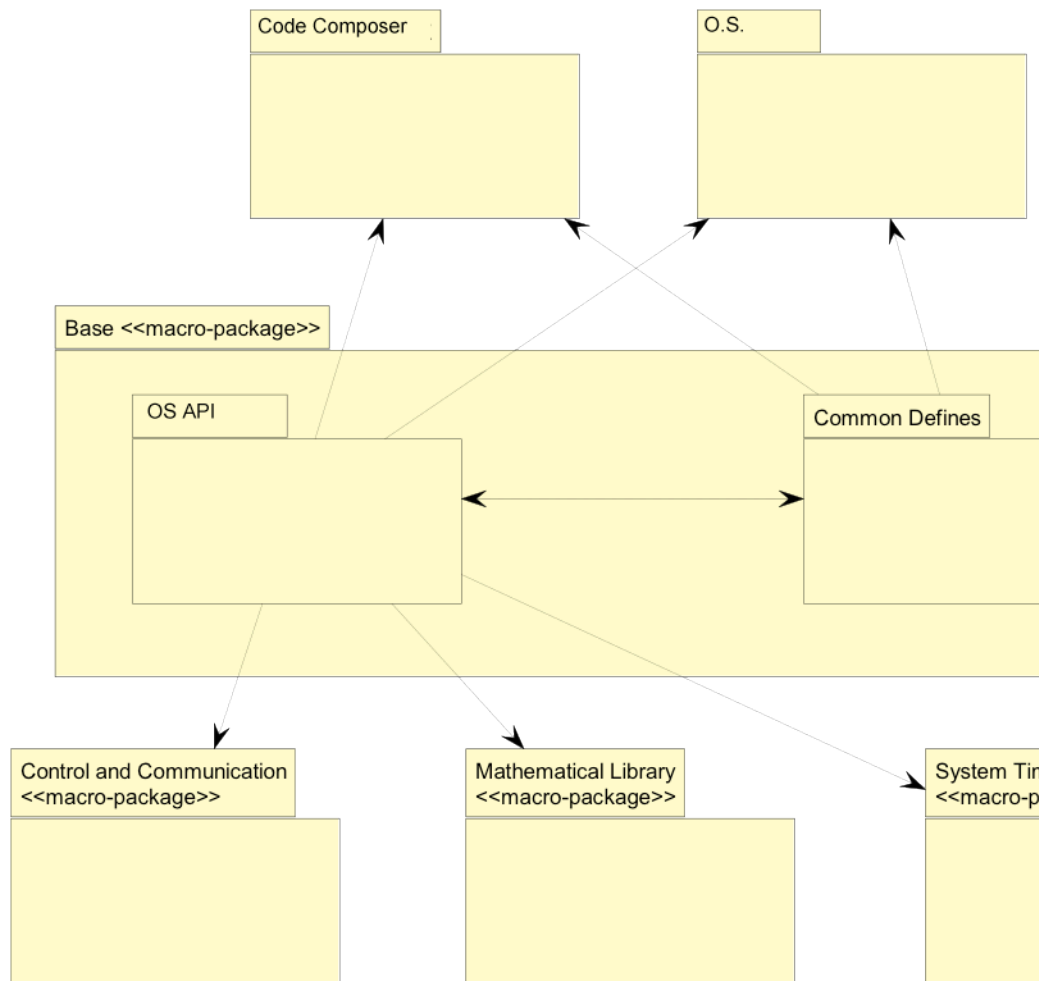


Figure 42 - Flight Base - Macro Package interactions



### **5.10.3 Signal Processing**

The Signal Processing function handles Receiver Channels in order to track the SVs signals and provides the corresponding acquired data (Observables data).

The Signal Processing SW can be divided into three main processes that are tightly coupled:

1. Signal acquisition and tracking functions: aim at acquiring and maintaining lock on received signals, for both frequencies (L1, L2), for Navigation events and for Observation events (see par. 4.2.5 for details on the events).
2. Measurement processing functions: aim at producing the Observables measurements as consequence of the signal tracking.
3. Navigation Message data bit extraction: aim reconstructing the Navigation messages from the tracked SVs.

#### **Signal acquisition and tracking**

This process is triggered by an “Integration Epoch” event (IE) generated independently by each Receiver channel. This event is used to control the channels state machine through its acquisition and tracking phases.

The Integration Epoch is set:

- for Navigation events and for Observation events in closed loop, at 1-msec period during acquisition and 20 (GPS) or 10 (GALILEO) msec during tracking
- for Observation events in open loop, at 10-msec period.

The software essentially includes the following functions:

- Open coarse Code-Frequency search (Navigation/Observation closed loop)

The signal is searched over the full code and over the commanded Doppler range. Code steps shall be in 1-chip increments. Doppler steps shall be in 0.3 Hz increments.

This phase shall be successfully completed when a code-frequency cell that provides good signal correlation power is found.

The discriminator function shall be based on internal determination of the signal power compared to a threshold value. According to the HW capabilities, the channels shall be configured in such a way to allow parallel search of one satellite over different portions of code or over different frequency windows. Search strategy and parameters shall be chosen on the basis of signal dynamics in order to minimize search time.

- Delay Lock Loop (DLL) (Navigation closed loop)

Performs coherent or non-coherent code tracking. It uses early and late or early-minus-late correlators in its discriminator depending on the discriminator type. Sets correlator spacing parameter.

- Carrier Frequency Lock Loop (FLL) (Navigation closed loop)

The purpose of this stage is to find the exact frequency of the incoming signal. This phase shall be successfully completed when the correlation between the incoming signal and the receiver generated signal produce a stable phase over a given sampling period. The discriminator function shall be based on detecting the phase difference between consecutive phase measurements and averaging this difference over a sampling period. The phase error resulting shall be below a

threshold value. The threshold value shall be set in such a way to take into consideration receiver internal phase noise.

- Carrier Phase Lock Loop (PLL) (Navigation closed loop)

The purpose of this stage shall be to get the carrier phase, resulting from the correlation of the incoming signal with the receiver-generated signal, close to zero. This step shall be successfully completed when the absolute phase error resulting from the correlation is below a threshold value over a sampling period. The discriminator function shall be based on measuring the average phase over the sampling period. The threshold value shall be set in such a way to take into consideration receiver internal phase noise.

- Full Tracking Mode (Navigation closed loop)

When in this stage the signal shall be declared to be locked-on. However, some actions and tests shall be performed before declaring signal lock:

- Data bit edge (bit transition) shall be detected with a good confidence
  - Channel tracking parameters shall be set to their final values (e.g. integration periods, correlator spacing, loop filter order, etc.)
  - power shall be above a threshold, indicating a good input signal
- Carrier phase error shall be below a threshold, indicating a good lock.

- Open Loop FLL (open loop)

This mode shall be used for those occultation channels tracking GNSS satellites in the low troposphere.

The Code Loop shall maintain lock by means of the Observation closed loop DLL aiding.

The analytical Atmospheric Model shall provide an estimation of the atmospheric excess frequency shift that, combined with the geometric Doppler, will center the carrier NCO frequency.

The detailed description of this process is in AD[b].

This process is covered by the CHANNEL\_CONTROL part of the package, in details:

- CHANNEL\_CONTROL is the manager of the channels. It maintains a data structure for each active channel, that includes all information relevant to channel operating mode and status, and any other flag that is necessary to the channel operation and processing. It manages also all the polling operation on the GALVANI FPGA.
- L1CA\_CONTROLLER implements the acquisition and tracking loops for the L1 CA code
- L1PY\_CONTROLLER implements the acquisition and tracking loops for the L1 P code
- L2PY\_CONTROLLER implements the acquisition and tracking loops for the L2 P code
- L2CM\_CONTROLLER implements the acquisition and tracking loops for the L2CM code
- L2CL\_CONTROLLER implements the acquisition and tracking loops for the L2CL code

## **Measurement processing**

The measurement processing is triggered by a “Measurement Epoch” event (ME).

A single event is generated for all Receiver channels, so that measurements for all channels are latched at the same time.

The Measurement Epoch is set at a period of 20 msec. This allows to produce high rate measurements that may typically be used for scientific purposes.

Depending on the programmed rate (20 msec, 100 msec, 1 sec), a Measurement Epoch event causes the SW to extract and pre-process measurements that are output to the User through the Observables data packets.

The computed data, for each frequency (L1, L2) are:

- Code phase (pseudorange)
- Integrated Doppler (or accumulated carrier phase)
- Instantaneous Doppler
- Estimated SNR
- Channel tracking status information (cycle slips, etc.)

Once per second, at  $ME = 0$ , the pre-processed measurements data are frozen:

- for the Solution evaluation functions to produce a real-time navigation solution
- for the Synchronized output function to produce the Observable packets.

The ME is controlled by the Receiver SW in order to maintain synchronization with the GPS System Time. Therefore at each GPS 1-sec epoch, the PPS and the Measurement Epoch signals are produced together with a delay of 5 core-clocks (approximately 170 nsec) between each other (see also “System Time” par. at this purpose).

The time tag associated to the measurements is the time of the Measurement Epoch signal expressed in Receiver time.

This process is covered by the RAW\_DATA\_MEAS part of the package.

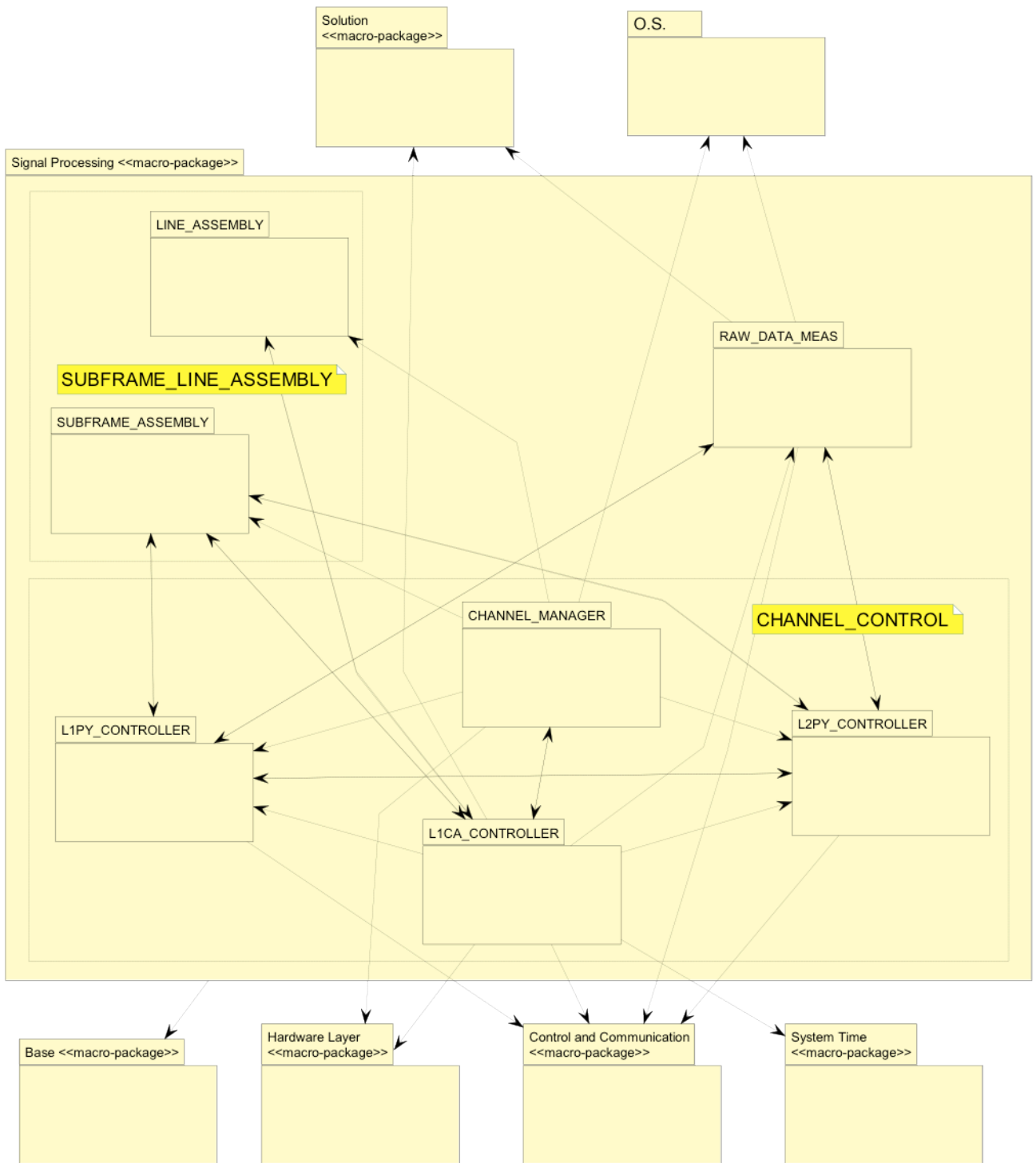
## **Navigation Message data bit extraction**

The Signal processing detects bit transitions and extracts them from the GPS Navigation Message of each SV.

These data are placed in a buffer associated to the channel and flagged as ready for subsequent processing by the Navigation Data Management.

This process is covered by the SUBFRAME\_LINE\_ASSEMBLY part of the package, in details:

- SUBFRAME\_ASSEMBLY implements the GPS subframes extractions
- LINE\_ASSEMBLY implements the GLONASS lines extractions.



**Figure 43 – Signal Processing – Macro package interactions**

The package implements all functions related to control of channels operations and processing of the raw data measurements, both for Navigation and for Radio Occultation.

The package contains the following objects:

CHANNEL_MANAGER	IntegrEpochTh:	cyclic object (0.4999 msec, the RTC of the Flight SW)
	Channels management	
L1CA_CONTROLLER	TrackingLoopsTh:	sporadic object (semaphore activated by IntegrEpochTh)
	L1CA loops management	passive object
L1PY_CONTROLLER	L1PY loops management	passive object
L2PY_CONTROLLER	L2PY loops management	passive object

RAW_DATA_MEAS	MeasEpochTh: Measurements management	sporadic object (semaphore activated by IntegrEpochTh)
SUBFRAME_ASSEMBLY	GPS Navigation message frames management	passive object
LINE_ASSEMBLY	GLONASS Navigation message lines management	passive object

## Navigation Data

The Navigation Data package has the following main functions:

- To manage the extraction and collection of the Navigation Message of each SV from the channels in tracking.

Data bits extracted from the Navigation Message by the Signal Processing are here reconstructed respectively in subframes for GPS SVs and lines from GLONASS Navigation message, as indicated in the respective ICDs.

This function is managed by means of an internal data structure, which maintains the flags and status for the correct data collection from each channel, using the data provided by Signal Processing.

This function is executed every 1 sec, in order to synchronize with GPS subframes preparation (6 sec) or GLONASS lines preparation (2 sec).

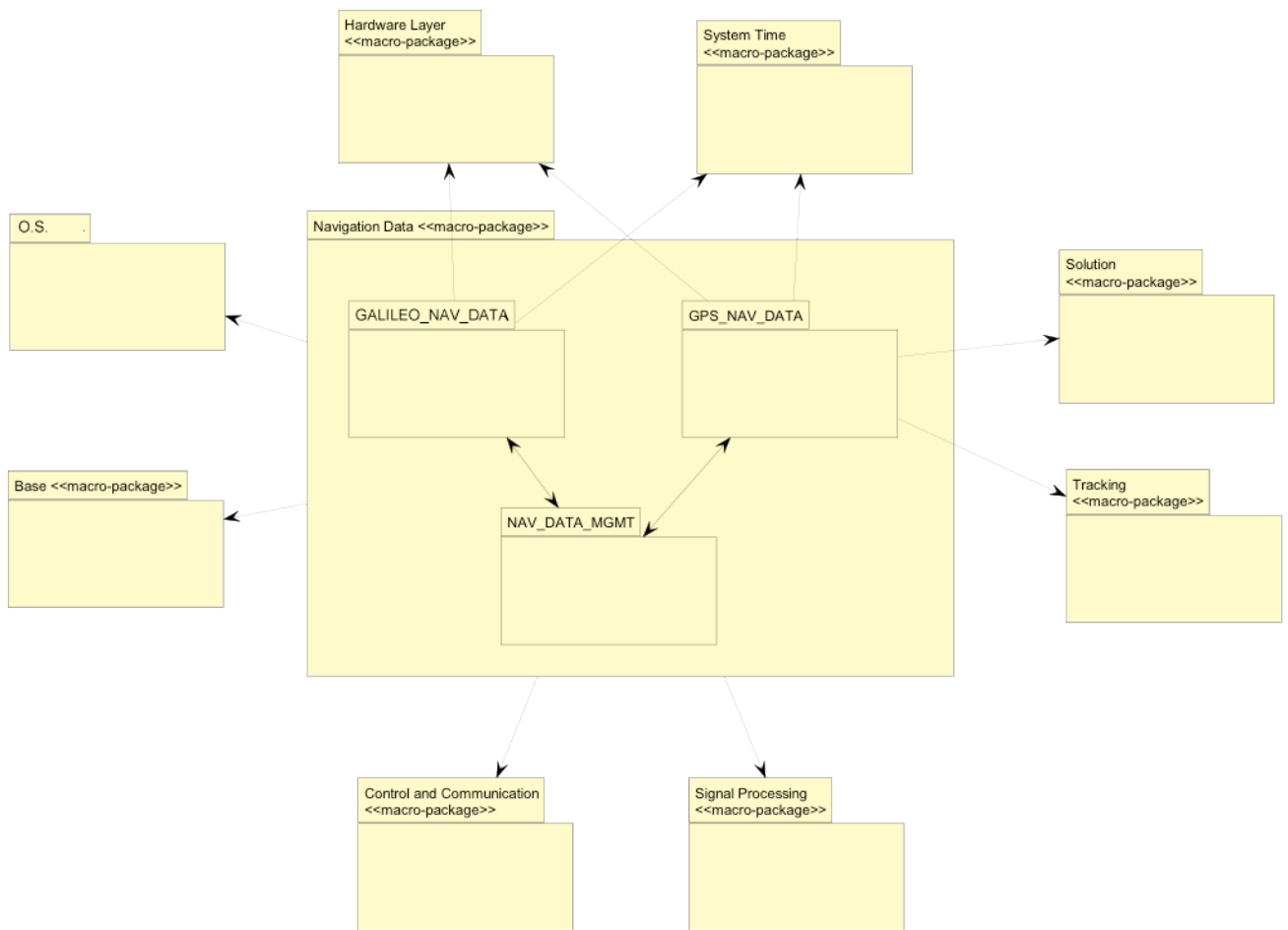
This function is covered by the NAV\_DATA\_MGMT package.

- To keep an updated copy of the GPS Navigation Data from the transmitted GPS Navigation Message. Data are update at every change, that is 2 hours for SVs Ephemeris Data and 24 hours for SV Almanac data.

This function is covered by GPS\_NAV\_DATA package.

- To keep an updated copy of the GALILEO Navigation Data (SVs Ephemeris Data and SV Almanac data) from the transmitted GALILEO Navigation Message; data are updated at every change.

This function is covered by GALILEO\_NAV\_DATA package.



**Figure 44 - Navigation Data - Macro package interactions**

The package computes and maintains updated SVs navigation data (almanacs, ephemeris, etc.) separately for each channel.

The package contains the following objects:

NAV_DATA_MGMT	NavDataMgrTh: Navigation messages management	sporadic object (semaphore activated by MeasEpochTh)
GPS_NAV_DATA	GPS Navigation message management	passive object
GALILEO_NAV_DATA	GLONASS Navigation message management	passive object

## Solution

The Solution package is devoted to compute position, velocity and time of the Receiver (Navigation Solution).

The Navigation solution is performed in two ways:

- The Standard Positioning Solution (SPS), that used pseudo ranges from the all-in-view satellites, performed every sec to generate X, Y, Z position and clock bias.

Further calculation gets the velocity vector and the clock bias rate or drift. This calculation uses the pseudo range rates as measured by the Doppler tracking frequencies for the tracked SVs.

The SPS solution suffers occasional outage when there are less than 4 SVs available. In fact, measurements from at least 4 GPS SVs (with a maximum of 9) are required to get a position and velocity fix, because the Receiver clock bias and drift need to be resolved as well. In this case a clock bias propagator calculation provides an estimate of the clock bias, so that the PPS control can be maintained.

This function is covered by the SPS\_SOL package.

- The Normalized Kalman Filter (NKF) solution, executed once a second, is derived from a 8-state Extended Kalman Filter and consists of position, velocity, clock bias and bias rate. The filter provides the eight-states vector above, in parallel with the standard (SPS) position solution.

The measurement model and filter is performed typically every 10 sec (programmable) and can use any number of pseudo range measurements available from in-view GPS SVs. During this interval, the spacecraft position is propagated (predicted) through the spacecraft dynamic model of the filter that includes an Earth gravitational potential model. The dynamic model propagation is computed at a 1Hz frequency, independently of the number of GPS SVs in tracking.

The NKF uses all available pseudo-range measurements (up to 9). Measurement noise is taken to be random, having a zero mean and Gaussian distribution.

The Navigation Filter provides position data at all times, even if there are less than 4 in-view GPS satellites and SPS solution is not available. This represents the advantage of such an approach: in the temporary absence of four visible satellites to perform the SPS solution, the filter is still capable of providing the output vector with good accuracy.

The filter solution therefore is not subject to outages since it can propagate the solution accurately even without measurements once it processing has converged.

However a SPS solution is required to initialize the Kalman Filter.

Because the C/A code is susceptible to Selective Availability (SA), an intentional degradation of the GPS signal to limit accuracy, the error in position and velocity can be quite high (when SA is on, it is easily the largest error source in the Navigation solution).

One way to reduce the effect of SA is to undersample the measurement to "whiten" the noise (for example, every 30 sec instead of 10 sec), because a too small interval can cause correlated measurements.

This function is covered by the NKF\_SOL package.

The two solutions are always present. The internal Receiver position, velocity and time knowledge (used to perform tracking list maintenance and other Receiver housekeeping activities) are kept updated both by the SPS and by the NKF solution, using the best solution, with the following criteria:

Not in SPACE mode:

if SPS fix => Use SPS solution (only present)

if SPS not fix => Use SPS propagated solution

In SPACE mode (default mode):

NKF converged: Use NKF solution

NKF not converged:

if SPS fix => Use SPS solution

if SPS not fix => Use NKF propagated solution

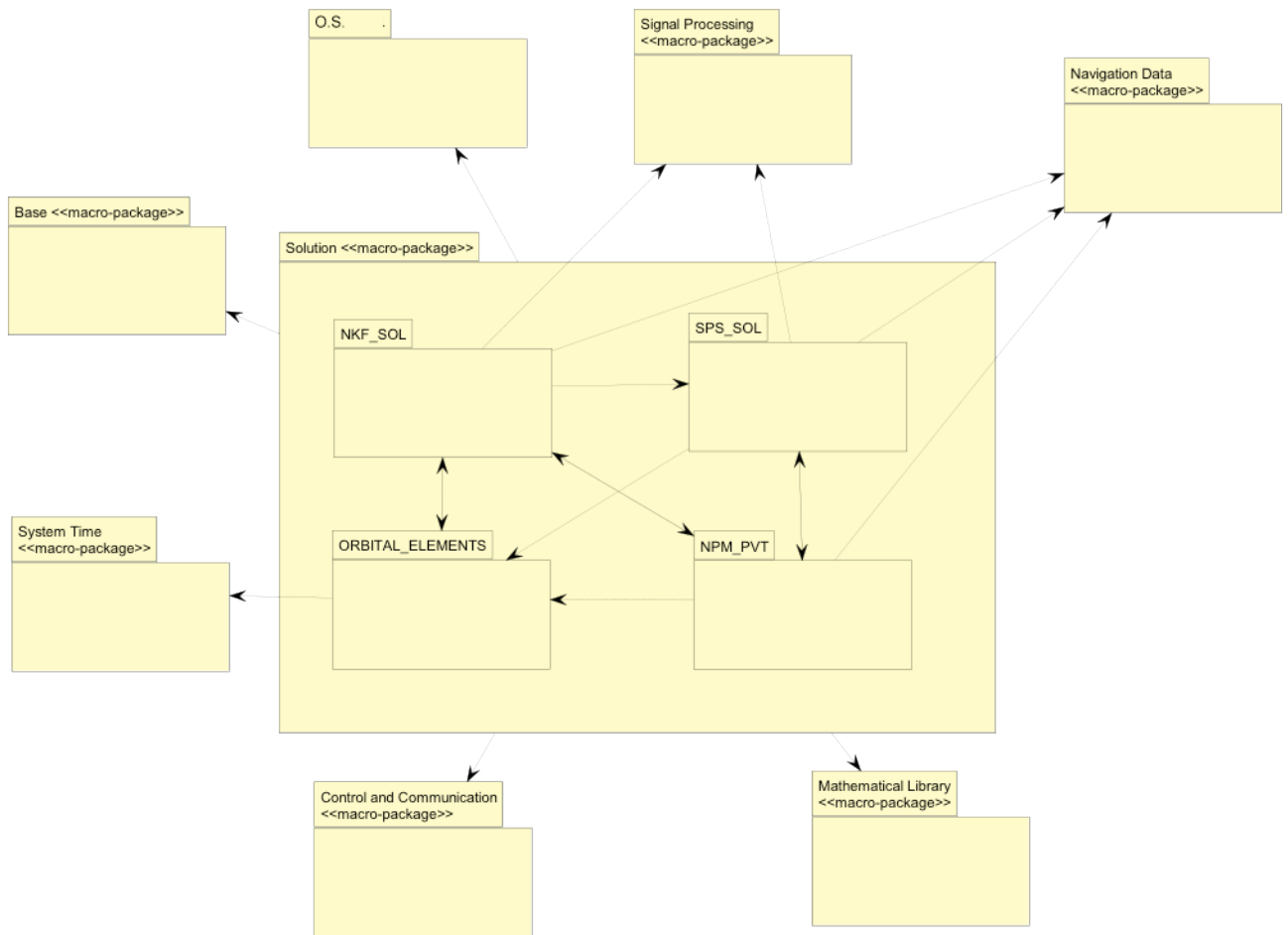
This function is covered by the NPM\_PVT package.

Furthermore, when set in orbital mode, the Receiver Keplerian Orbit Elements, derived from the last computed NKF solution, are evaluated. Keplerian orbital are computed instantaneously (osculating elements) or by averaging over a number of orbit periods (mean orbital elements, typically on 2 orbits).

This function is directly called by the NKF solution function, when the filtered solution is evaluated (once a second).

This function is covered by the ORBITAL\_ELEMENTS package.





**Figure 45 - Solution - Macro Package**

The package produces:

- Standard Positioning Solution (SPS)
- Navigation Kalman Filter Solution (NKF)
- Receiver Orbital Elements
- Receiver status vector management.

The package contains the following objects:

NPM_PVT	PVTsolTh: solutions management	sporadic object (semaphore activated by MeasEpochTh)
SPS_SOL	SPS solution evaluation	passive object
NKF_SOL	NKF solution evaluation	passive object
ORBITAL_ELEMENTS	Rx orbital elements evaluation	passive object

## **Space Weather events prediction**

For what concern the Space weather events prediction, the evaluation, performed every 15 sec (TBC) is simple. In fact:

- Rising events: they are not inserted in the candidate list, because they are the natural continuation of the relative Occultation event
- Setting events: they are inserted in the candidate list, as soon the elevation angle is less than 0 deg. Also for these events the priority data are evaluated, based on:
  - Profile verticality (the z-component of the velocity, correlated with the duration of the event)
  - FOV Azimuth.

The final output of the previous points 1 to 3 is an Observation candidate list, containing, second by second and in priority order, the Observation events that are to be allocated to the channels.

From the theoretical studies, the maximum number of concurrent Observation events in a typical LEO orbit is less than 10 (the dimension of the candidate list is therefore 20, following the considerations on the channel allocation at the beginning of the paragraph).

## **Navigation candidate list evaluation**

This action, always performed in Receiver Specific Mode, is in charge of performing all the necessary processing to find and select visible GNSS SVs for Navigation and POD.

The initial selection process (after End of Stand-by command) is dependent on the type of start performed (Warm or Cold). Finding and selection of satellites may be performed, alternatively:

- In a "blind" mode, if no information is provided to the Receiver (Cold start). SVs are searched in a predefined (fixed) order of search, based on a "probable" list.
- Based on the available GNSS SV positions derived from GNSS ephemeris and/or almanac, estimated Receiver position and time (Warm Start).

The Warm Start operation mode is used to reduce the TTFF. To obtain this operating mode the User is requested to provide the necessary information.

To select between cold or warm start, this function checks for the presence of the necessary pre-defined data, loaded by means of a used command or pre-stored in EEPROM (see ICD AD[g] for details). In the absence of any of the requested data, the Receiver is by default in Cold Start.

The Navigation candidate list is maintained updated by periodically re-building a list of candidate SVs; the evaluation is executed nominally every 15 sec, but this timing can be changed in the following cases:

- when a tracked SV is definitively loss
- when new special data are received from the user (for example: new attitude, new tracking constraints)
- when a big change in RX position is set (typically, at the first position fix).

The candidate list is dimensioned to 16, i.e. the maximum number the allocable channels (in Navigation/Propagation Mode all the channels can be assigned to the Navigation antenna).

The Navigation candidate list update function is based on newly computed elevation angles; the choosing criteria depend on the best elevations between the visible SVs, taking into account the azimuth and the (eventual) User constraints.

### **Tracking list evaluation and Channels assignments**

When the Observation and/or Navigation candidate list is changed, this function performs the final assignment of the new satellites to the different Receiver channels, generating a unique Tracking List.

Following allocation strategy is implemented in order to leave enough channels for the satellites to be tracked. Obviously, results are strongly dependent on orbit height and antenna visibility.

#### **Channel assignment strategy**

Following points a) and b), the channel assignment strategy is therefore the following:

- Occultation events are first to be considered, because they are mandatory; from the theoretical studies, the typical Occultation events concurrency is one, max two, therefore a maximum of four channels are to be allocated for this type of events at a time.

When all the Occultation events are allocated to the necessary channels, if other Observation channels are free, the Space Weather events can be allocated, using the priority data evaluated at point 2 for the decisions.

- In the list of the events defined in the previous point, first the setting channel are to be assigned, because they are more constrained. In fact, due to the fixed antenna assignment, it can happen that all the channels are occupied by other events.

Following cases can happen (order of applied priority):

- If the channels are occupied by Navigation events, they can be freed (if not User forced and if the total number of remaining Navigation SVs is  $\geq 4$ ), with the following criteria, based on elevation angle and azimuth:
  - first worst setting Navigation channels are freed
  - then worst rising Navigation channels are freed
- If the channels are occupied by rising Space Weather events, they can be freed (the Occultation part of the event in this case is already elapsed).

Note that:

- If the channels are occupied by Occultation events, they cannot be freed
- If the channels are occupied by setting Space Weather events, they cannot be freed (the Occultation part of the event in this case is not yet elapsed).

In the theoretical situation when not enough channels are free (for example, all the necessary channels are occupied by Occultation events, or forced by the User), the setting event is skipped (it will be assigned as soon as possible).

Particular situations to be managed, as depicted at the previous point.

In the theoretical situation when not enough channels are free (for example, all the necessary channels are already occupied by Occultation events, or forced by the User), the rising event is skipped (it will be assigned as soon as possible).

## **Predictions evaluations**

At the assignment of a new SV to a channel, and every second for all the satellites in the current Tracking List, the aiding data are evaluated and sent to the Signal Processing, to optimize acquisition and accuracy.

This function aids the Signal Processing, during the acquisition of the GNSS SV signals, with following information:

- N. of Svs and related antenna
- Receiver-SV relative velocity
- Doppler
- Expected search frequency window
- Expected code bin (Occultation only)
- Event type (Rising, Setting, Navigation).

The aiding information are based:

- for Navigation events:
  - at the start-up on User provided warm start information
  - during Receiver Specific Mode on Receiver Navigation Solution and GNSS curve fit coefficients, based on almanac or ephemeris (best case)
- for Observation events:
  - on Receiver computed solution and GNSS curve fit coefficients, based on ephemeris
  - on parameters related to the Atmospheric model.

The package implements the satellites selection strategy, both for Navigation and for Radio Occultation.

TrackingMgrTh: sporadic object (semaphore activated by MeasEpochTh)

## **System Time**

The System Time function has the following main scopes:

### **Receiver internal time management**

The start time is by default the start time of the GPS constellation. The GPS week number reference is week #0 starting January 6, 1980. The seconds count begins at the midnight, which begins each Sunday morning. The roll-over of the GPS week (max number 1024) was in August, 1999.

This time can be modified by the User, indicating the (approximate) current time.

At the first acquisition of the Navigation message from a tracked GPS SVs the real GPS reference time is set.

During the Flight Mode operations, the internal time is then maintained by means of the Measurement Epoch (ME) (see par. 4.4.2 for details), that is used to increment, every 20 msec, the internal time.

### **PPS correction control loop**

The PPS output signal must be exactly synchronized with the GPS time (max error 400 nsec).

Due to the (little) imprecision of the Receiver clock wrt the GPS atomic clock, the internal time scale of the Receiver is not coincident with the GPS one. As a consequence, without a dedicated control, the length of each PPS internally evaluated and the time interval between two following output are not constant.

Scope of this function is to align the PPS output in the two different reference systems, and contemporary to maintain the receiver internal time independent of the GPS time.

The control is executed in three different steps:

- At the first acquisition of the GPS time from a Navigation message a raw correction is executed on the PPS control register, aligning with the precision of  $\pm 20$  msec the PPS output with the GPS time
- At the first Navigation Solution evaluation, the clock bias indicates the real remaining error in msec; this allows a correction using the PPS control register, aligning with a precision of less than 1 msec
- Iteratively during the Measurement Operation Mode the difference, evaluated every sec, between two clock biases are used to refine the correction and to maintain it in the allowed range. Due to the non-sufficient precision of the PPS control register of the AGGA chip, the correction is executed acting on the ME control register (the two registers are strictly related, because the PPS and the Measurement Epoch signals are produced together). This implies varying the length of the Measurement Epoch every time the clock bias indicates an error.

This at the end implies that the internal second can vary at every ME length correction.

PPS correction theory is illustrated in AD[b].

## Oscillator offset evaluation

The Navigation Solution provides also a clock bias rate, indicating the frequency error of the internal clock, typically due to temperature or ageing effects.

To correct this effect, an oscillator offset is evaluated, starting from the clock bias rate, and maintained in non-volatile memory.

This oscillator offset is then used by the SV Tracking function, to evaluate this a better precision the predicted Doppler of the SVs.

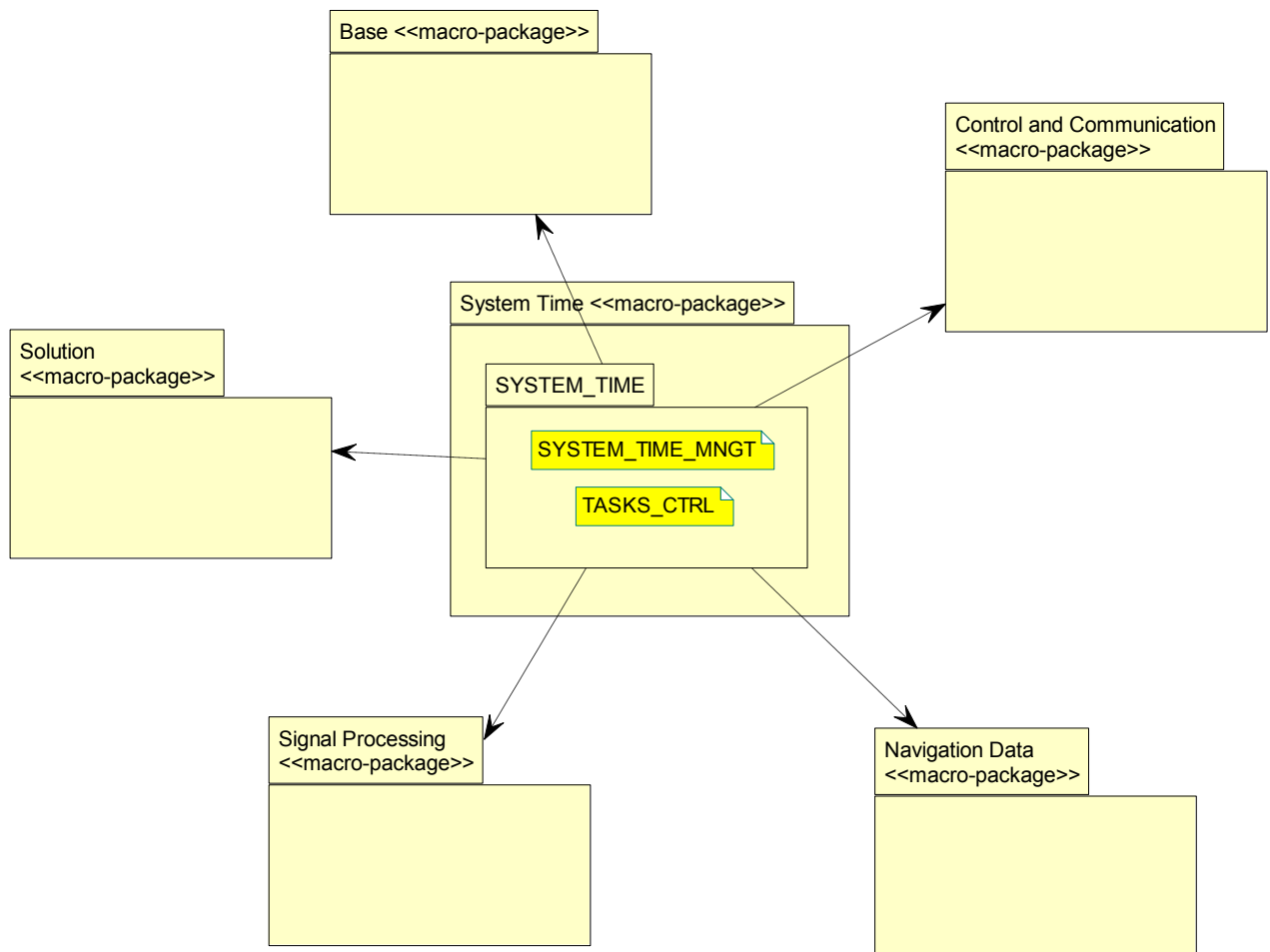
## Threads scheduling

The internal time is used also the re-schedule the periodic threads that are not directly connected to interrupts (see par. 5.2 for details).

At this scope at the  $ME = 0$ , i.e. at the initial point of the internal second, a dedicated function re-activate the threads.

From the package point of view, functions 1 to 3 are inserted in SYSTEM\_TIME part, while function 4 is in TASKS\_CTRL.

Following figures illustrate an overview of the interactions between the macro packages.



**Figure 46 - System Time - Macro package interactions**

The package performs the operations related to Receiver time and task's control.  
Passive object.

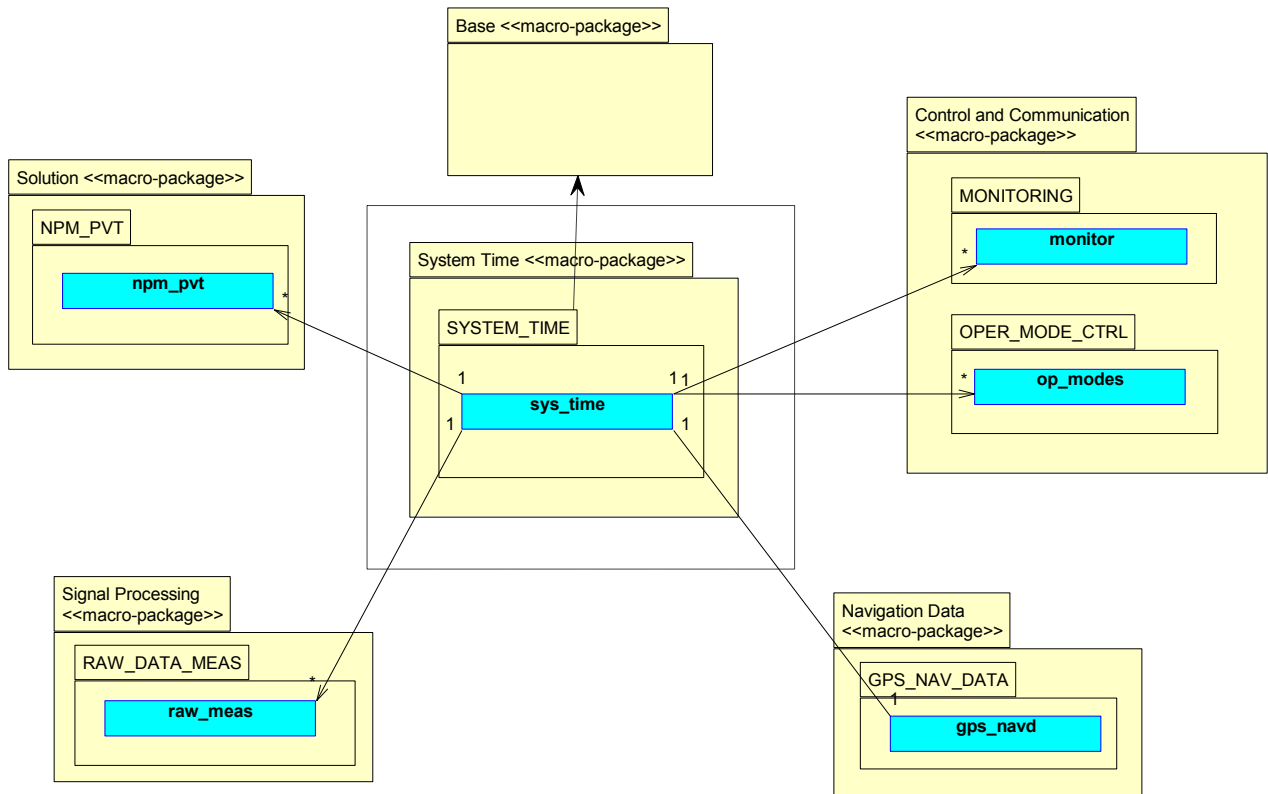


Figure 47 - System Time - Macro package

## Control and Communication

Following the description at par. 3.2.1, three packet types are implemented:

### Telecommand/Telemetry packets

They contain *general information* which can be exchanged between the LAGRANGE 2G and the user and are used in a polling fashion to send information packets to the Receiver (e.g. change a parameter, select a mode, etc.) and get information from the Receiver (i.e. current parameter settings, mode selection, etc...).

### Periodic Telemetry packets

They contain *periodic data*, as *Navigation solution data*, *SVs Observables*, etc... These packets are prepared by the LAGRANGE RO for the transmission to the user at predefined rate.

### BIU commands

These packets are *discrete commands*, pre-defined in special sub-addresses, and therefore are treated differently.

Following macro packages are recognized to cover the requested operations:

#### 1. Communication handling (BUS\_1553)

The command and data interface of the LAGRANGE 2G Receiver is implemented over a MIL-STD-1553B Bus connection, where the LAGRANGE 2G acts as a Remote Terminal at a specified

address. Data are transferred in packet form with a specific structure, as determined by their packet type and/or sub-address.

This package is devoted to the management of the 1553 standard interface.

## 2. TC/TM Management (TC\_MGR)

*TcMgr* function is devoted to process the packets (command, data) received from the User and to prepare the eventually required response packets for the 1553 bus protocol.

It is activated on demand (when a Telecommand from the User is recognized).

The packets prepared by this function are then output by the Communication function.

## 3. Synchronized Message Management (SYNCH\_TM)

*Synch\_TM* function is devoted to the preparation of the synchronized (periodic) telemetry packets, starting from the Navigation Solution data and the Raw Data.

It is activated every second, also in absence of a new solution ready, for the preparation of a new message. When the conditions for performing an SPS or NKF solution are not present (depending on a user option), the output PVT packet is kept unchanged from the previous transmission: the Navigation Solution data is the last evaluated, in the previous cycle.

The packets prepared by this function are then output by the Communication function.

## 4. Modes & parameters management (OPER\_MODES\_CTRL)

This object is a pool of procedures used to maintain the Operative Mode and the parameters related to the Receiver specific functions programming.

Both types of data are set by means of the TC packets recognized at point 2.

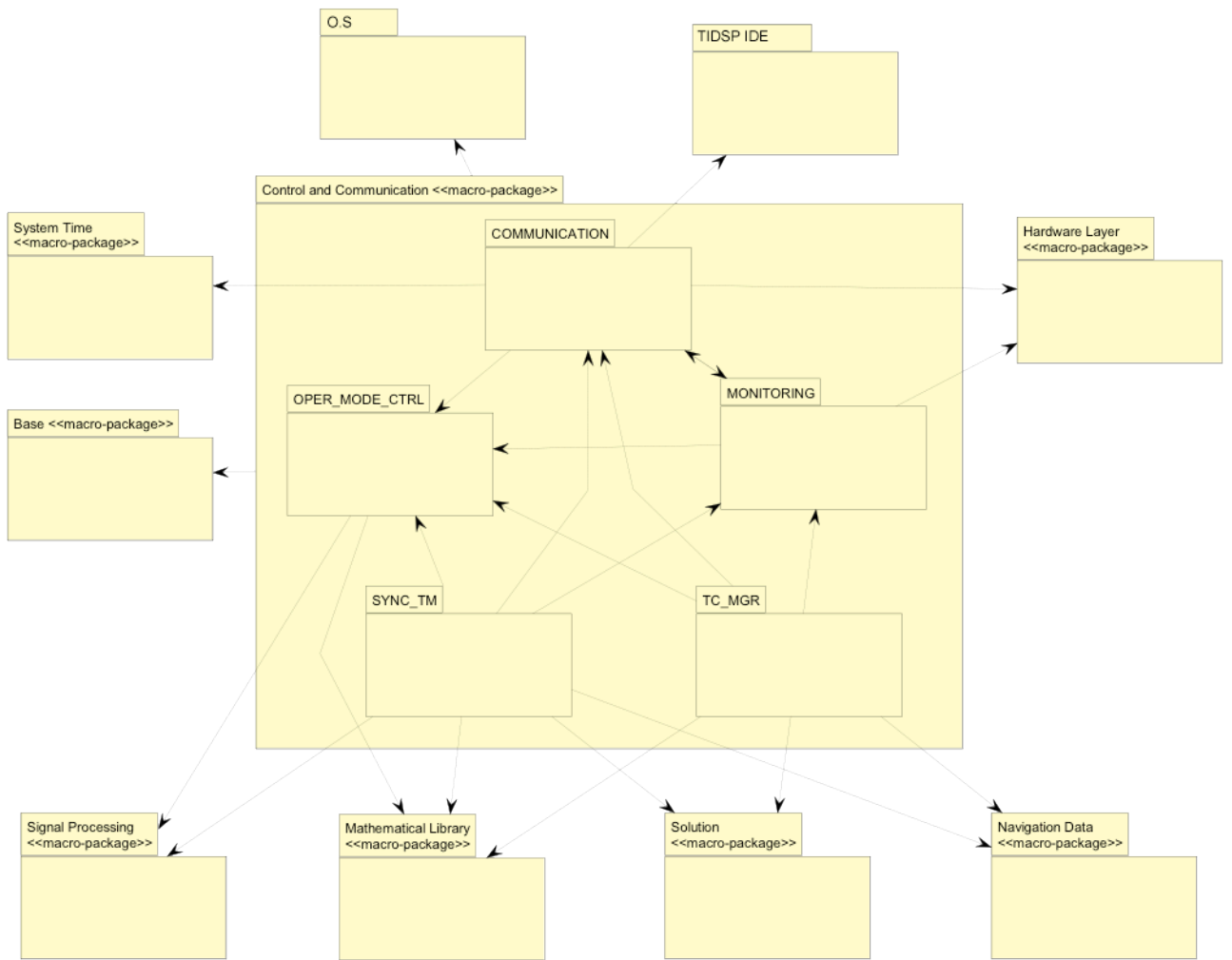
## 5. Monitoring management (MONITORING)

This object is a pool of procedures used to maintain the Receiver Status & Health.

All the Receiver specific functions use this package to have a repository of the current situation of the Receiver.

The status is then used by the SYNCH\_TM function to prepare a periodic packet for the User.





**Figure 48 - Control and Communications - Macro package interactions**

The package performs:

- Handling of high level Receiver operative modes
- Receiver monitoring and status reporting
- Synchronised messages management
- Telecommand management

The package contains the following objects:

OPER_MODES_CTRL	Operative modes management	passive object
MONITORING	Monitoring and status reporting	passive object
SYNCH_TM	SynchTmTh: Synchronised messages management	sporadic object (semaphore activated by Bus1553Th)
TC_MGR	TcMgrTh: Telecommand manager	sporadic object (queue activated by Bus1553Th)
COMMUNICATION	High level 1553 protocol management	passive object

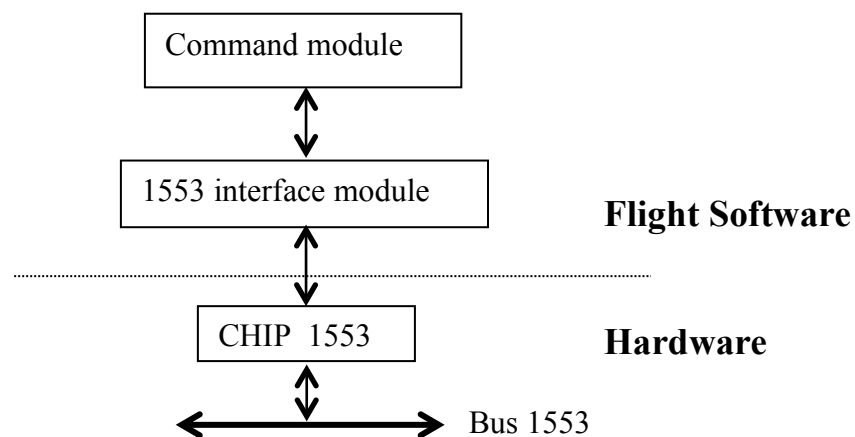
### Communication

The SW handler of the 1553 interface is logically subdivided in two levels:

- Low level: is the real interface with the HW (1553 bus). It is linked to an interrupt, which activates the related thread.

This part executes also the BIU packets handling. In particular, the messages related to Synchronization are immediately serviced at this level.

- High level: provides procedures available for the use by other objects:
  - check for the presence of asynchronous input packets and eventual preparation of the response
  - preparation of the periodic output packet, every Synchronize Message (SPT protocol, see par. 3.2.1).



This package is devoted to the management of the high level 1553 protocol.

### Synchronized Message Management

The Synchronized Message Management is devoted to the periodic packet's preparation and the insertion of the prepared buffer in the dedicated sub-addresses.

When the Receiver is in its nominal operating mode, the periodic packets are prepared with the following schedule:

Message	Rate	TS of preparation (*)
Receiver Detailed Status	1 Hz	TS 1
Navigation Solution	1 Hz	Solution is evaluated using the raw data acquired at msec 0 (internal time) and the related messages are prepared in the 1553 memory in TS 2. If the solution is not re-calculated, the packet contains the last evaluated solution
Observables Data	1 Hz	Observables data are those used for the solution evaluation, and therefore are the same time tag (msec 0). They are prepared in the 1553 memory in TS 1.
Scintillation Observables	10 Hz	See table 4.2.7.2-2
PPS time	1 Hz	TS programmed by the user – 1 (default 8)
TC and related responses	max 4 Hz	Immediately after the reception of the TC from the user (that is in a BTS-9), not synchronized with a TS

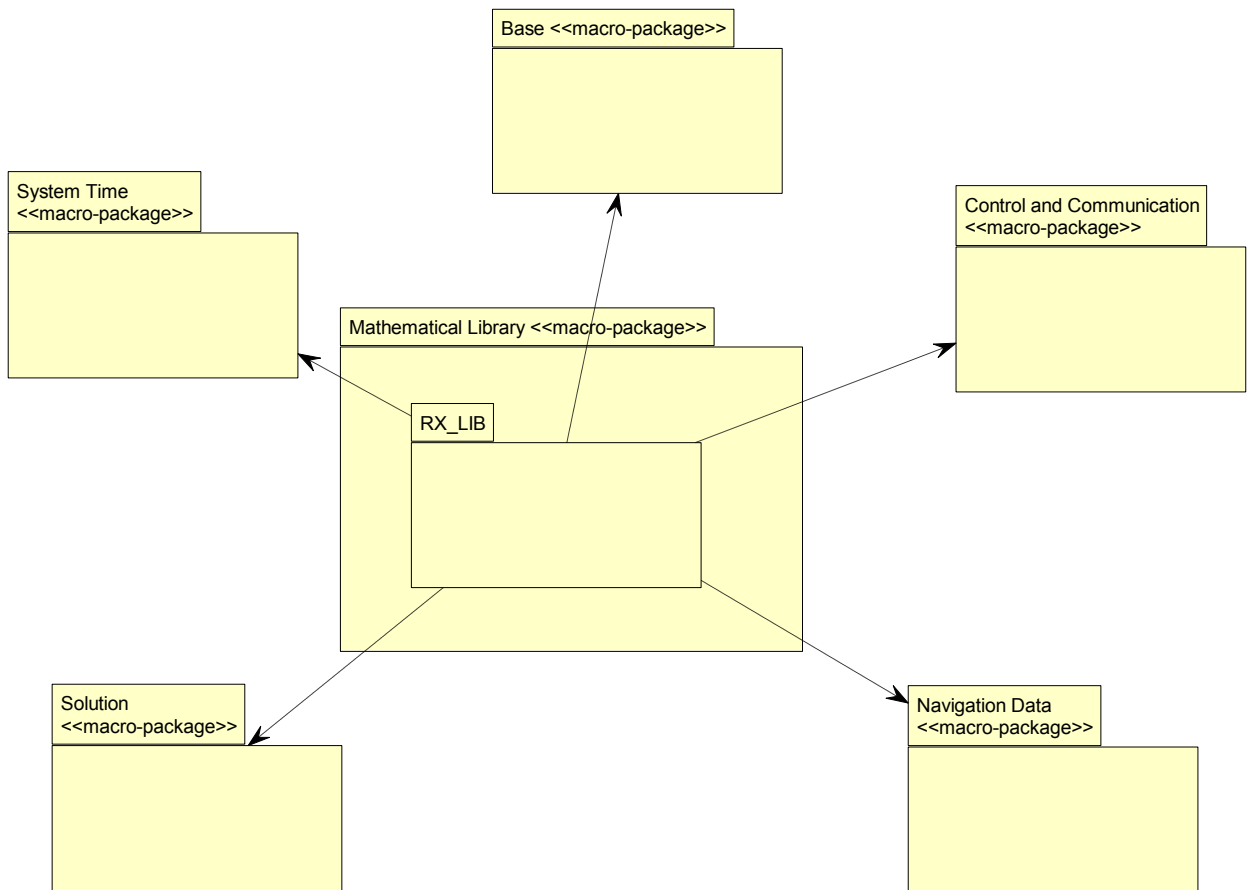
#### Periodic Packets schedule

Transmission rate	TS of preparation (*)	Data Time tag (msec)
10	0	980
	1	080
	2	180
	3	280
	4	380
	5	480
	6	580
	7	680
	8	780
	9	880

#### Mathematical Library

This object is composed by a pool of functions, used everywhere in the project, for mathematical evaluations and conversions.

- The following functions are available:
- Mathematical functions (*math*)
- Matrix functions (*matrix*)
- Conversion functions (*convers*).



**Figure 49 - Mathematical Library**

## Hardware Layer

This macro package contains pools of functions available for the management at low (HW) level of the component from the other packages.

### Watch Dog Timer (WDT)

The Watchdog Reset circuit is used to prevent the locks of the Receiver SW and provides a mean for restarting the Receiver in case of a Receiver SW failure.

The WDT is always active, during all the life of the Receiver SW; if it is not feed in a predefined amount of time (1.04 sec) the Receiver is automatically reset.

From the SW point of view this reset is equal to a power on, i.e. the SW restarts always in Bootstrap & Loader; the WDT reset is indicated in the Detailed Status message (see ICD AD[g]).

The situations that lead to this reset are only due to errors, typically:

- never ending loops: in this case the final effect is the reset and the indication in the Detailed Status message
- error interrupts: in this case, before the reset, there is a special Detailed Status message, indicating the cause of the interrupt (see AD[g] for details).

## Memory management (EEPROM)

This is a pool of Assembly function dedicated to special read/write functions related to EEPROM, PMRAM and DMRAM.

## GALVANI management (GALVANI FPGA)

This is a pool of functions dedicated to read/write of registers related to the AGGA chip.

## 1553 interface (CHIP 1553)

Referring to the definition of the 1553 interface at par. 4.2.7.1, this object is devoted to the HW management of the MIL-STD-1553B bus interface.

Due to the asynchronous nature of the bus, in the RT position (case of the Receiver) it is not possible to control the flow of the blocks that are exchanged on the bus.

For this reason a sequential driver model such as "call to a driver function, wait for a block, return of the block" is not appropriate, because in this case a very short time between subsequent calls of the function is needed.

The adopted model is at "events": each bus activity that concerns the RT is coded as an "event" that is inserted in a queue, from which it will be extracted by dedicated functions.

In this way the data exchange on the bus and the data utilization are uncoupled by means of the event queue.

The possible event types can be:

- Data block reception
- Mode code command reception
- Event queue overrun
- Overrun of a sub-address buffer (in single reception or in broadcast)
- Data block transmission
- Underrun of a sub-address buffer (only in transmission)
- Errors.

Each combination of sub-address and mode (reception, transmission, broadcast reception) is defined "channel"; when each channel is defined, the legalization modes are set. Events related to channels or mode code not legalized are not generated.

## Reception

Following events are accepted in the queue, for a max amount of 50 events:

- reception of data blocks on sub-addresses related to telecommands
- reception of data blocks on sub-addresses related to memory maintenance commands
- reception of BIU discrete commands.

The reception channels related to these commands are defined and legalized. These events are managed by means of the high level functions.

One event, due to particular timing constraints, is directly managed at the reception of the related message, in the low level thread itself, and it is the reception of Mode code Synchronization message (SPT protocol).

## Transmission

The transmission, which really consists on writing in the 1553 RAM, is directly executed when necessary, both for asynchronous packets and for periodic packets.

The transmit events therefore are not added to a queue; the final transmit events are managed at bus (HW) level (SW is not necessary).

The only SW managed part is the preparation of the data block in the sub-address; the transmit blocks are prepared in these cases:

- telemetry packet in response to a telecommand packet, from “TC/TM Management” part
- periodic telemetry packets, synchronized with the SPT protocol, from “Synchronized Message Management” part.

The package implements the HW-SW interfaces.

# 6. GALILEO Message Structure

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## 6.1 Message Format Specification

### 6.1.1 General Navigation Message Contents

#### SISICD-956 : General navigation message content

The Galileo signal-in-space data channels shall transmit four different message types according to the general contents identified in the table below.

F/NAV is the acronym for Freely Accessible Navigation message type and related signal.

I/NAV is the acronym for Integrity Navigation message type and related signals.

C/NAV is the acronym for Commercial Navigation message type and related signal.

G/NAV is the acronym for Governmental Navigation message type and related signals.

Message type	Services	Channel(s)	Message Data Content				
			Navigation	Integrity	Search & Rescue	Supplementary	Service Management
F/NAV	OS	E5a-I	Yes	No	No	No	No
I/NAV	OS/CS/SoL	E5b-I & L1-B	Yes	Yes	Yes	No	Yes
C/NAV	CS	E6-B	No	No	No	Yes	Yes
G/NAV	PRS	E6-A & L1-A	Yes	Yes	No	No	Yes

#### **Integrity**

Integrity is provided by the SoL and PRS services. The SoL service provides global coverage and is able to provide coverage to up to 5 external regions.

For the PRS service only the global coverage is provided.

#### **Search and Rescue**

The Search and Rescue return link provides the capability to send through each single satellite up to 3 Long RLM of 160 bits every 60 seconds or up to 7 short RLM of 80 bits every 60 seconds to a Beacon equipped with a suitable Galileo receiver. This SAR data is sent on the L1-B channel.

#### **Supplementary data**

The Supplementary data is provided as part of the CS only navigation message on E6. The supplementary data is expected to provide weather alerts, traffic information and accident warnings, etc. This data is almost certainly geographically related and so could be shared between satellites.

#### **Service management data**

The Service management data is used to provide key management and other information to enable controlled access to the Galileo signals and message data.

For the CS key management data is required to provide access to the encrypted revenue earning data and to the ranging code on E6. For the SoL service it may also be needed to allow access to integrity information.

#### **SISICD-967 : Navigation data generated on-board for F/NAV, I/NAV and C/NAV**

The navigation data includes both satellite and constellation message data. The satellite shall add to the navigation message the following data generated on-board:

- Time of Week (TOW)
- Week Number (WN)
- Navigation Data Validity Status (DVS)
- C/NAV encryption status parameter (in Word type I/NAV-1)
- CRC
- Dummy message
- Spare data: Spare integrity data (Word type I/NAV-0), spare ERIS data and spare SAR data when the satellite is not connected through C-band to a Galileo ULS.

#### **SISICD-2944 : Navigation data generated on-board for G/NAV**

The satellite shall add, to the received PRS data, the Global region status and the On-board data according to SISICD-2946.

### **6.1.2 Message Data Frames**

#### **SISICD-980 : Message data frames**

The complete navigation message data shall be transmitted on each data channel as a sequence of frames.

A frame is composed of several sub-frames, and a sub-frame in turn is composed of several pages. The page is the basic structure for building the navigation message.

This arrangement allows to accomplish the three different main categories of data to be transmitted, which are repeated at fast (for urgent data, such as integrity), medium (like data required for warm start TTF) and slow rates (like data required for cold start TTF), the corresponding page, sub-frame and frame are used.

### **6.1.3 Page Structure**

#### **SISICD-987 : Page start**

Each page shall start with a page synchronisation field, which contains a fixed synchronization pattern (unique word), allowing the receiver to achieve synchronisation to the page boundary. This synchronisation pattern is applied as unencoded data symbols at the transmitter.

#### **SISICD-994 : Page synchronisation field**

The synchronisation patterns defined in the table below shall be used for F/NAV-, I/NAV- and C/NAV pages.

These synchronisation patterns are not applicable to the G/NAV pages.

<b>Message Type</b>	<b>Services</b>	<b>Number of Symbols</b>	<b>Frame Bit Allocation</b>	<b>Binary Pattern</b>
F/NAV	OS	12	6	101101110000
I/NAV	OS/CS/SoL	10	5	0101100000
C/NAV	CS	16	8	1011011101110000
G/NAV	PRS	NA	NA	NA

#### **SISICD-1001 : Tailbits**

The tail bits field shall include a 6 zero-value bits.



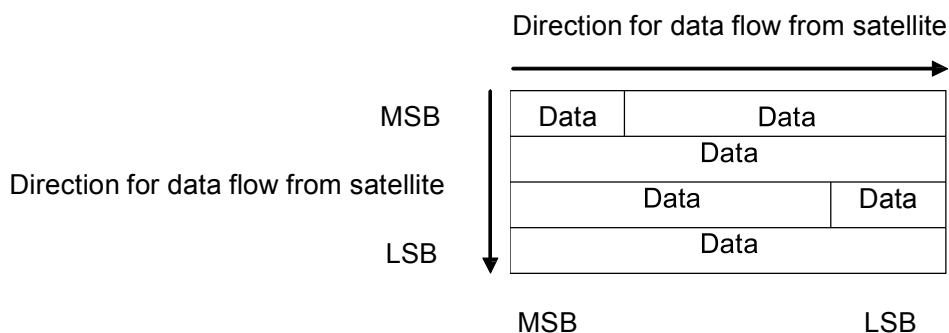
Between the synchronisation field and the tail field are data fields whose structure and contents are specific for each data channel, and being the structure explained in section 6.2 and the contents in chapter 7.

**SISICD-1007 : Bit and byte ordering criteria**

All data values shall be encoded using the following bit and byte ordering criteria:

- for numbering, the most significant bit/byte is numbered as bit/byte 0.
- for bit/byte ordering, the most significant bit/byte is transmitted first.

For data diagrams and tables, the notation used in this document is according to figure 6.1. The most significant bit (MSB) is placed left, the least significant bit (LSB) is placed right, the most significant items top, and the least significant items bottom.



**SISICD-3107 : Spare bits definition**

When not specified otherwise the spare bits added by the satellite in the message structure shall be defined as a sequence of zeros and ones starting with zero on the MSB.

**6.1.4 FEC Coding and Interleaving Parameters**

**SISICD-1042 : Convolutional encoding parameters and Viterbi decoding**

The convolutional encoding for all data channels shall be performed according to the parameters given in the following table.

Code Parameter	Value
Coding rate	1/2
Coding scheme	Convolutional
Constraint length	7
Generator polynomials	G1=171 (Octal), G2=133 (Octal)
Encoding sequence	G1 then G2

### SISICD-1052 : Interleaving parameters

For each message type, the page structure shall be generated according to the values stated in the following table.

Parameter	Message Type			
	F/NAV	I/NAV	C/NAV	G/NAV
Block Interleaver Size (Symbols)	488	240	984	648
Block Interleaver Dimensions (n columns x k rows)	61 x 8	30 x 8	123 x 8	81 x 8

## 6.1.5 Page Processing Sequence

### 6.1.5.1 Emission

#### SISICD-1017 : Page processing sequence before emission for F/NAV, I/NAV and C/NAV

Prior to modulation, the satellite shall build each page according to the following process:

1. Retrieve pages received from the ground and stored on board

Data received from ground
m

with m the number of bits, which depends on the type of the page (F/NAV, I/NAV, C/NAV). Note: data received from ground includes potential ERIS direct uplink data.

2. Add On-board generated data if needed and assemble all page data bits

Data received from ground	Data generated by satellite
m	On-board data n

n is the number of bits of the data generated on-board by the satellite.

3. Calculate and add Checksum field

Data received from ground	Data generated by satellite	
m	On-board data n	CRC 24

4. Add tail bits field (6 bits according to the FEC encoding process)

Data received from ground	Data generated by satellite		
m	On-board data n	CRC 24	Tail 6

5. FEC encodes data bits into page symbols. See table 6.3 for details

Data received from ground and data generated by satellite
FEC symbols
$2x(m+n+24+6)$

6. Interleave the FEC page symbols using a block interleaver with N columns (where data is written) and k rows (where data is read). See table 6.4 for details.

Data received from ground and data generated by satellite
Interleaved FEC symbols
$2x(m+n+24+6) = Nx8$

Note that the FEC symbol page shall contain a number of symbol multiple of 8 to be able to interleave in N blocks of 8 bits.

7. Add synchronization field of K symbols (the size of the synchronization field shall be compatible with the final downlink page structure)

Message page	
Synchronization symbols	Interleaved FEC symbols
K	$2x(m+n+24+6) = Nx8$

**SISICD-2930 : Page processing sequence before emission for G/NAV**

Prior to modulation, each page shall be constructed according to the following process:

1. Receive uplinked page together with its type (nominal page or alert page). The uplinked page has the following format.

Data received from ground	
PRS data	Global region status
283	8

2. Add on board generated data to the uplinked page

Data received from ground	Data generated by satellite	Data received from ground	Data generated by satellite
PRS data	On-board data	Global region status	Tail
283	27	8	6

3. FEC encode the full G/NAV page data into page symbols

FEC encoded symbols
$2x(283+27+8+6) = 648$

4. Interleave pages symbols

FEC encoded and interleaved symbols
$2x(283+27+8+6) = 81x8$

5. Split the symbols page into 6 one-second symbol parts and insert “Initial fields” symbols according to the type of the uplinked page: nominal or alert.

Initial Field	FEC encoded and interleaved symbols part 1/6	Initial Field	FEC encoded and interleaved symbols part 2/6	Initial Field	FEC encoded and interleaved symbols part 3/6	Initial Field	FEC encoded and interleaved symbols part 4/6	Initial Field	FEC encoded and interleaved symbols part 5/6	Initial Field	FEC encoded and interleaved symbols part 6/6
660											

The Initial fields are all 0 except in case of a Page identifier received from ground equals to 0. In that case the Initial fields are all 1.

### 6.1.5.2 Reception

#### SISICD-1029 : Page processing sequence at reception for F/NAV, I/NAV and C/NAV

The user receiver for F/NAV, I/NAV and C/NAV shall perform the following tasks at reception of each page of the respective message data

1. Detect or confirm synchronization pattern
2. De-interleave page symbols. See table 6.4 for details.
3. Diversity combines symbols if required
4. Decode page symbols into data bits using the Viterbi algorithm. See table 6.3 for details.
5. Decrypt data where applicable
6. Calculate and compare received checksum
7. Extract information from page bits

#### SISICD-2943 : Page processing sequence at reception for G/NAV

The G/NAV user receiver shall perform the following tasks at reception of each G/NAV page

1. Reassemble the 6-second symbol page
2. De-interleave the symbol page
3. Decode page symbols into data bits using the Viterbi algorithm. See table 6.3 for details.
4. Process the G/NAV page.

## 6.2 Frame Contents and Page Sequencing

The following sections describe how data is allocated in the different frames, depending on the data channel.

The data items are specified in chapter 7.

### 6.2.1 F/NAV E5a-I Channel Message Data

#### 6.2.1.1 General Page Layout

##### SISICD-1074 : F/NAV E5a-I page layout

The page layout for the F/NAV E5a-I Channel shall be according to the following figure, where the symbols allocation and bits allocation are shown separately.

Sync	Symbols			Total [symbols]
12	488			500

Word			Tail	Total [bits]
Page type	Navigation Data	CRC		
6	208	24	6	244

## 6.2.1.2 Frame Layout

### SISICD-1081 : F/NAV E5a-I message data packet transmission sequence

The F/NAV E5a-I message data packet transmission sequence shall be according to the figure below, where a whole frame is shown.

A frame is composed of 12 sub-frames and lasts 600 seconds. Each sub-frame is composed of 5 pages and lasts 50 seconds. Each page lasts 10 seconds.

	Page type	Page content
Subframe 1	1	SVID, clock correction, SISA, Ionospheric correction, BGD, Signal health status, GST and Data validity status
	2	Ephemeris (1/3) and GST
	3	Ephemeris (2/3) and GST
	4	Ephemeris (3/3), GST-UTC conversion, GST-GPS Conversion and TOW
	5	Almanac for satellite k and almanac for satellite (k+1) part 1
Subframe 2	1	SVID, clock correction, SISA, Ionospheric correction, BGD, Signal health status, GST and Data validity status
	2	Ephemeris (1/3) and GST
	3	Ephemeris (2/3) and GST
	4	Ephemeris (3/3), GST-UTC conversion, GST-GPS Conversion and TOW
	6	Almanac for satellite (k+1) part 2 and almanac for satellite (k+2)
Subframe 3	1	SVID, clock correction, SISA, Ionospheric correction, BGD, Signal health status, GST and Data validity status
	2	Ephemeris (1/3) and GST
	3	Ephemeris (2/3) and GST
	4	Ephemeris (3/3), GST-UTC conversion, GST-GPS Conversion and TOW
	5	Almanac for satellite (k+3) and almanac for satellite (k+4) part 1
Subframe 4	1	SVID, clock correction, SISA, Ionospheric correction, BGD, Signal health status, GST and Data validity status
	2	Ephemeris (1/3) and GST
	3	Ephemeris (2/3) and GST
	4	Ephemeris (3/3), GST-UTC conversion, GST-GPS Conversion and TOW
	6	Almanac for satellite (k+4) part 2 and almanac for satellite (k+5)
Subframe 5	1	SVID, clock correction, SISA, Ionospheric correction, BGD, Signal health status, GST and Data validity status
	2	Ephemeris (1/3) and GST
	3	Ephemeris (2/3) and GST
	4	Ephemeris (3/3), GST-UTC conversion, GST-GPS Conversion and TOW
	5	Almanac for satellite (k+6) and almanac for satellite (k+7) part 1
Subframe 6	1	SVID, clock correction, SISA, Ionospheric correction, BGD, Signal health status, GST and Data validity status
	2	Ephemeris (1/3) and GST
	3	Ephemeris (2/3) and GST
	4	Ephemeris (3/3), GST-UTC conversion, GST-GPS Conversion and TOW
	6	Almanac for satellite (k+7) part 2 and almanac for satellite (k+8)

	Page type	Page content
Subframe 7	1	SVID, clock correction, SISA, Ionospheric correction, BGD, Signal health status, GST and Data validity status
	2	Ephemeris (1/3) and GST
	3	Ephemeris (2/3) and GST
	4	Ephemeris (3/3), GST-UTC conversion, GST-GPS Conversion and TOW
	5	Almanac for satellite (k+9) and almanac for satellite (k+10) part 1
Subframe 8	1	SVID, clock correction, SISA, Ionospheric correction, BGD, Signal health status, GST and Data validity status
	2	Ephemeris (1/3) and GST
	3	Ephemeris (2/3) and GST
	4	Ephemeris (3/3), GST-UTC conversion, GST-GPS Conversion and TOW
	6	Almanac for satellite (k+10) part 2 and almanac for satellite (k+11)
Subframe 9	1	SVID, clock correction, SISA, Ionospheric correction, BGD, Signal health status, GST and Data validity status
	2	Ephemeris (1/3) and GST
	3	Ephemeris (2/3) and GST
	4	Ephemeris (3/3), GST-UTC conversion, GST-GPS Conversion and TOW
	5	Almanac for satellite (k+12) and almanac for satellite (k+13) part 1
Subframe 10	1	SVID, clock correction, SISA, Ionospheric correction, BGD, Signal health status, GST and Data validity status
	2	Ephemeris (1/3) and GST
	3	Ephemeris (2/3) and GST
	4	Ephemeris (3/3), GST-UTC conversion, GST-GPS Conversion and TOW
	6	Almanac for satellite (k+13) part 2 and almanac for satellite (k+14)
Subframe 11	1	SVID, clock correction, SISA, Ionospheric correction, BGD, Signal health status, GST and Data validity status
	2	Ephemeris (1/3) and GST
	3	Ephemeris (2/3) and GST
	4	Ephemeris (3/3), GST-UTC conversion, GST-GPS Conversion and TOW
	5	Almanac for satellite (k+15) and almanac for satellite (k+16) part 1
Subframe 12	1	SVID, clock correction, SISA, Ionospheric correction, BGD, Signal health status, GST and Data validity status
	2	Ephemeris (1/3) and GST
	3	Ephemeris (2/3) and GST
	4	Ephemeris (3/3), GST-UTC conversion, GST-GPS Conversion and TOW
	6	Almanac for satellite (k+16) part 2 and almanac for satellite (k+17)

Note that the odd numbered sub-frames contain the page type 5 and the even numbered sub-frames contain the page type 6. This allows the transmission of the almanacs for three satellites within two successive sub-frames (100 seconds), thus the almanacs of the entire Galileo constellation (36 satellites) within 20 minutes.



## SISICD-1091 : GST and page concordance

The start of transmission of pages at each satellite shall be synchronized with the GST in such a way that the sub-frame ID shall be equal to (SV ID + $\Delta t$ /50) modulo 12, according to the following table.

	SV 1- 13- 25	SV 2- 14- 26	SV 3- 15- 27	SV 4- 16- 28	SV 5- 17- 29	SV 6- 18- 30	SV 7- 19- 31	SV 8- 20- 32	SV 9- 21- 33	SV 10- 22- 34	SV 11- 23- 35	SV 12- 24- 36
T <sub>0</sub>	1 k=1	2 k=1	3 k=1	4 k=1	5 k=1	6 k=1	7 k=19	8 k=19	9 k=19	10 k=19	11 k=19	12 k=19
t <sub>0</sub> +50s	2 k=1	3 k=1	4 k=1	5 k=1	6 k=1	7 k=1	8 k=19	9 k=19	10 k=19	11 k=19	12 k=19	1 k=19
t <sub>0</sub> +100s	3 k=1	4 k=1	5 k=1	6 k=1	7 k=1	8 k=1	9 k=19	10 k=19	11 k=19	12 k=19	1 k=19	2 k=19
t <sub>0</sub> +150s	4 k=1	5 k=1	6 k=1	7 k=1	8 k=1	9 k=1	10 k=19	11 k=19	12 k=19	1 k=19	2 k=19	3 k=19
t <sub>0</sub> +200s	5 k=1	6 k=1	7 k=1	8 k=1	9 k=1	10 k=1	11 k=19	12 k=19	1 k=19	2 k=19	3 k=19	4 k=19
t <sub>0</sub> +250s	6 k=1	7 k=1	8 k=1	9 k=1	10 k=1	11 k=1	12 k=19	1 k=19	2 k=19	3 k=19	4 k=19	5 k=19
t <sub>0</sub> +300s	7 k=1	8 k=1	9 k=1	10 k=1	11 k=1	12 k=1	1 k=19	2 k=19	3 k=19	4 k=19	5 k=19	6 k=19
t <sub>0</sub> +350s	8 k=1	9 k=1	10 k=1	11 k=1	12 k=1	1 k=1	2 k=19	3 k=19	4 k=19	5 k=19	6 k=19	7 k=19
t <sub>0</sub> +400s	9 k=1	10 k=1	11 k=1	12 k=1	1 k=1	2 k=1	3 k=19	4 k=19	5 k=19	6 k=19	7 k=19	8 k=19
t <sub>0</sub> +450s	10 k=1	11 k=1	12 k=1	1 k=1	2 k=1	3 k=1	4 k=19	5 k=19	6 k=19	7 k=1	8 k=19	9 k=19
t <sub>0</sub> +500s	11 k=1	12 k=1	1 k=1	2 k=1	3 k=1	4 k=1	5 k=19	6 k=19	7 k=19	8 k=19	9 k=19	10 k=19
t <sub>0</sub> +550s	12 k=1	1 k=1	2 k=1	3 k=1	4 k=1	5 k=1	6 k=19	7 k=19	8 k=19	9 k=19	10 k=19	11 k=19
t <sub>0</sub> +600s	1 k=19	2 k=19	3 k=19	4 k=19	5 k=19	6 k=19	7 k=1	8 k=1	9 k=1	10 k=1	11 k=1	12 k=1
t <sub>0</sub> +650s	2 k=19	3 k=19	4 k=19	5 k=19	6 k=19	7 k=19	8 k=1	9 k=1	10 k=1	11 k=1	12 k=1	1 k=1
t <sub>0</sub> +700s	3 k=19	4 k=19	5 k=19	6 k=19	7 k=19	8 k=19	9 k=1	10 k=1	11 k=1	12 k=1	1 k=1	2 k=1
t <sub>0</sub> +750s	4 k=19	5 k=19	6 k=19	7 k=19	8 k=19	9 k=19	10 k=1	11 k=1	12 k=1	1 k=1	2 k=1	3 k=1
t <sub>0</sub> +800s	5 k=19	6 k=19	7 k=19	8 k=19	9 k=19	10 k=19	11 k=1	12 k=1	1 k=1	2 k=1	3 k=1	4 k=1
t <sub>0</sub> +850s	6 k=19	7 k=19	8 k=19	9 k=19	10 k=19	11 k=19	12 k=1	1 k=1	2 k=1	3 k=1	4 k=1	5 k=1
t <sub>0</sub> +900s	7 k=19	8 k=19	9 k=19	10 k=19	11 k=19	12 k=19	1 k=1	2 k=1	3 k=1	4 k=1	5 k=1	6 k=1
t <sub>0</sub> +950s	8 k=19	9 k=19	10 k=19	11 k=19	12 k=19	1 k=19	2 k=1	3 k=1	4 k=1	5 k=1	6 k=1	7 k=1
t <sub>0</sub> +1000s	9 k=19	10 k=19	11 k=19	12 k=19	1 k=19	2 k=19	3 k=1	4 k=1	5 k=1	6 k=1	7 k=1	8 k=1
t <sub>0</sub> +1050s	10 k=19	11 k=19	12 k=19	1 k=19	2 k=19	3 k=19	4 k=1	5 k=1	6 k=1	7 k=1	8 k=1	9 k=1
t <sub>0</sub> +1100s	11 k=19	12 k=19	1 k=19	2 k=19	3 k=19	4 k=19	5 k=1	6 k=1	7 k=1	8 k=1	9 k=1	10 k=1
t <sub>0</sub> +1150s	12 k=19	1 k=19	2 k=19	3 k=19	4 k=19	5 k=19	6 k=1	7 k=1	8 k=1	9 k=1	10 k=1	11 k=1

### 6.2.1.3 Page Contents

The following requirements and tables specify the contents of the pages above allocated.

#### SISICD-1098 : F/NAV E5a page type 1: SVID, Clock correction, SISA, Ionospheric correction, BGD, GST, Signal health and Data validity status

This data shall be formatted in page identified as 1 according to the values stated in the following figure.

Type=1	SV <sub>ID</sub>	IOD <sub>nav</sub>	Clock correction				SISA(L1,E5a)	Ionospheric correction					BGD(L1,E5a)	E5a <sub>HS</sub>	GST		E5a <sub>DVS</sub>	Spare	CRC	Tail	Total [bits]			
			t <sub>oc</sub>	a <sub>f0</sub>	a <sub>f1</sub>	a <sub>f2</sub>		Az			Ionospheric disturbance flag				WN	TOW								
								a <sub>i0</sub>	a <sub>i1</sub>	a <sub>i2</sub>	Region 1	Region 2										Region 3	Region 4	Region 5
6	6	10	14	31	21	6	8	11	11	14	1	1	1	1	1	10	2	12	20	1	26	24	6	244

#### SISICD-1105 : F/NAV E5a page type 2 and 3: Ephemeris (1/3) with GST and Ephemeris (2/3) with GST

This data shall be formatted in pages identified as 2 and 3 according to the values stated in the following figures.

- Page type 2: Ephemeris (1/3) and GST

Type=2	IOD <sub>nav</sub>	Ephemeris (1/3)							GST		CRC	Tail	Total
		M <sub>0</sub>	OMEGADOT	e	A <sup>1/2</sup>	OMEGA <sub>0</sub>	IDOT	WN	TOW				
6	10	32	24	32	32	32	32	14	12	20	24	6	244

- Page type 3: Ephemeris (2/3) and GST

Type=3	IOD <sub>nav</sub>	Ephemeris (2/3)							GST				Tail	Total		
		i <sub>0</sub>	OMEGA	Δn	C <sub>UC</sub>	C <sub>US</sub>	C <sub>RC</sub>	C <sub>RS</sub>	t <sub>oe</sub>	WN	TOW	Spare			CRC	
6	10	32	32	16	16	16	16	16	16	14	12	20	8	24	6	244

**SISICD-1112 : F/NAV E5a page type 4: Ephemeris (3/3), GST-UTC conversion, GST-GPS conversion and TOW**

The clock shall be repeated in page identified as 4 according to the values stated in the following figure.

Type=4	IOD <sub>nav</sub>	Ephemeris (3/3)		GST-UTC Conversion								GST-GPS Conversion				TOW	Spare	CRC	Tail	Total
		C <sub>IC</sub>	C <sub>IS</sub>	A <sub>0</sub>	A <sub>1</sub>	Δt <sub>LS</sub>	t <sub>0t</sub>	WN <sub>t</sub>	WN <sub>LSF</sub>	DN	Δt <sub>LSF</sub>	t <sub>0G</sub>	A <sub>0G</sub>	A <sub>1G</sub>	WN <sub>0G</sub>					
6	10	16	16	32	24	8	8	8	8	3	8	8	16	12	6	20	5	24	6	244

**SISICD-1119 : F/NAV E5a-I Page Type 5 and 6: Almanac**

The data packets with almanac and satellite health status shall be allocated in the 5<sup>th</sup> page of each sub-frame.

Two pages are needed to transmit the almanac for 3 satellites according to the following scheme.

- F/NAV page type 5: Almanac with Week Number and Time of almanac

Type=5	IOD <sub>a</sub>	WN <sub>a</sub>	t <sub>0a</sub>	SV <sub>SVID1</sub>								SV <sub>SVID2</sub> (1/2)				CRC	Tail	Total					
				SVID1	Δ(A <sup>1/2</sup> )	e	OMEGA	δ <sub>i</sub>	OMEGA <sub>0</sub>	OMEGADOT	M <sub>b</sub>	a <sub>r0</sub>	a <sub>r1</sub>	E5a <sub>HS</sub>	SVID2				Δ(A <sup>1/2</sup> )	e	OMEGA	δ <sub>i</sub>	OMEGA <sub>0</sub> (1/2)
6	4	2	10	6	13	11	16	11	16	11	16	16	13	2	6	13	11	16	11	4	24	6	244

- F/NAV page type 6: Almanac

Type=6	IOD <sub>a</sub>	SV <sub>SVID2</sub> (2/2)						SV <sub>SVID3</sub>						Spare	CRC	Tail	Total					
		OMEGA <sub>0</sub> (2/2)	OMEGADOT	M <sub>0</sub>	a <sub>r0</sub>	a <sub>r1</sub>	E5a <sub>HS</sub>	SVID3	Δ(A <sup>1/2</sup> )	e	OMEGA	δ <sub>i</sub>	OMEGA <sub>0</sub>					OMEGADOT	M <sub>0</sub>	a <sub>r0</sub>	a <sub>r1</sub>	E5a <sub>HS</sub>
6	4	12	11	16	16	13	2	6	13	11	16	11	16	11	16	16	13	2	3	24	6	244

**SISICD-3169 : Dummy F/NAV definition**

During the initialization phase when no data is uplinked via the C-band to the satellite, the satellite shall generate and downlink the dummy message on E5a replacing the pages in the nominal sequencing, according to the following format.

Type=63	Dummy sequence	CRC	Tail	<b>Total</b>
6	208	24	6	244

where the dummy sequence is composed by:

[AF3B C301 3D9C 46FE 184D C21A 84B0 53E1 F01E D31A A937 812F 3AE1]  
(hex).

**6.2.2 I/NAV Channel Message Data**

The I/NAV message structures for channels E5b-I and L1-B use the same page layout, since the service provided on these frequencies is a dual frequency service, using frequency diversity. Only the page sequencing is different, with page swapping between both channels in order to allow a fast reception of data by a dual frequency receiver. Nevertheless, the frame is designed to allow receivers to work also with a single frequency.

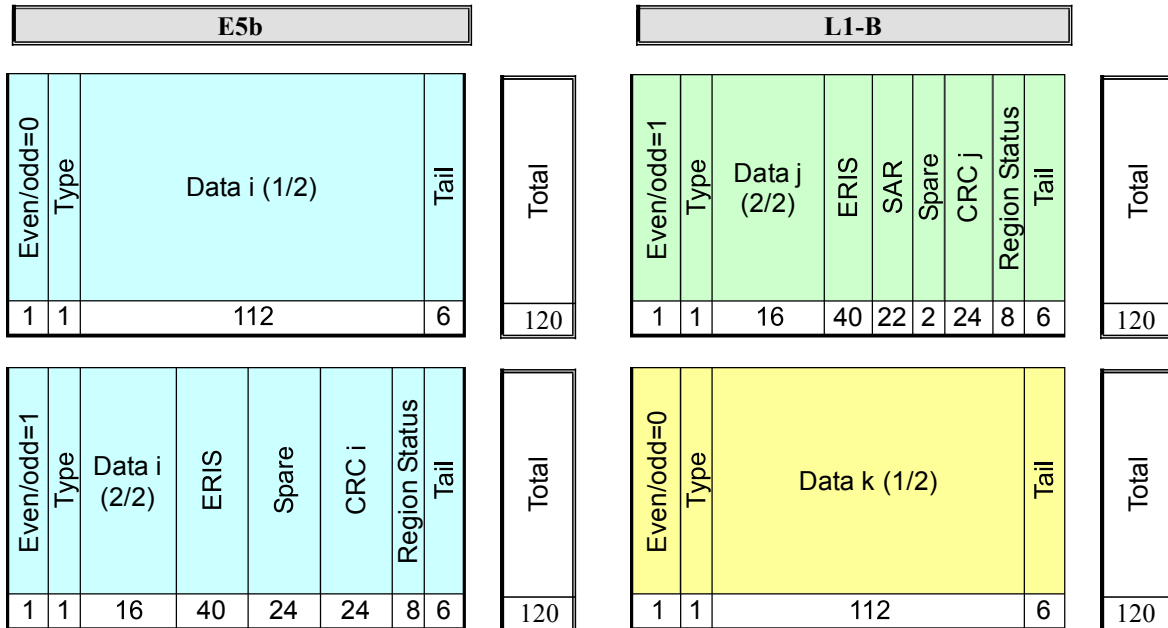
**6.2.2.1 General Page Layout**

Two types of page are defined:

- a nominal page having a duration of 2 seconds transmitted independently on each of the frequencies E5b and L1, and
- an alert page having a duration of 1 second. Alerts are repeated so they appear fully on both frequencies.

### SISICD-1151 : I/NAV nominal page layout

In nominal mode the page layout for the I/NAV channels shall be according to the following figure, where the page contents are transmitted independently on each frequency (E5b and L1) within 2 seconds.

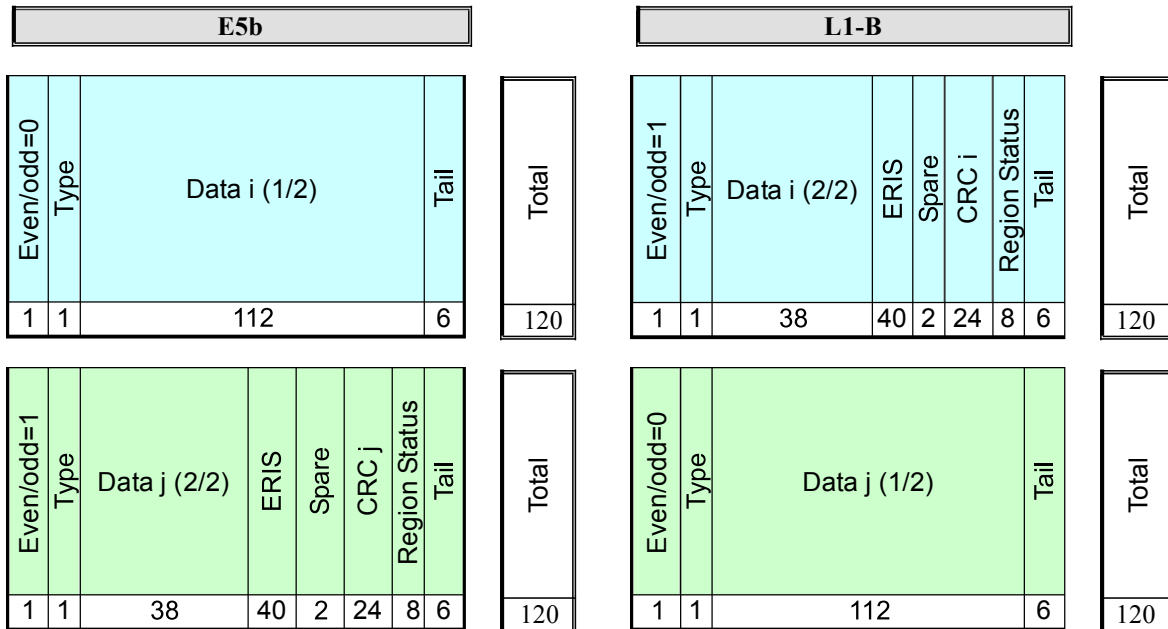


The parameters for the nominal page shall have the following meaning and related values:

- Even/Odd field: to indicate the part of the page (0 = even / 1 = odd) that is broadcast
- Type (1 bit) equal to 0 to indicate the nominal page type
- Data (112 bits +16 bits = 128 bits): composed of a nominal word of 128 bits
- ERIS (40 bits) composed of ERIS data
- SAR (22 bits) composed of SAR RLM data on L1-B only
- CRC (24 bits) computed on the Page Type, Even/Odd field, Data fields, ERIS, SAR and Spare. In nominal mode the CRC is computed for the Even/Odd page of the same frequency (“vertical CRC”) and is always broadcast on the second part of the vertical page
- Region status (8bits). This field is not protected by the CRC.
- Tail bits (6bits). This field is not protected by the CRC.

### SISICD-1168 : I/NAV alert pagelayout

In alert mode the page layout for the I/NAV channels shall be according to the following figure, where the page contents are spread over the two channels. The alert page is divided in two parts (Data 1/2 and Data 2/2) which are transmitted at the same epoch over the channels E5b and L1-B respectively. This process is repeated at the next epoch but switching the two parts between the channels.



The parameters for the alert page shall have the following meaning and related values:

- Even/Odd field: to indicate the part of the page (0 = even / 1 = odd) that is broadcast
- Type (1 bit) equal to 1 to indicate the alert page type
- Data (112 bits +38 bits = 150 bits): composed of an alert word of 150 bits max
- ERIS field of 40 bits allocated to ERIS data
- CRC (24 bits) computed on the Page Type, Even/Odd field, Data fields, ERIS and Spare. In alert mode the CRC is computed for the Even/ Odd pages of both frequencies E5b and L1- B (“horizontal CRC”).
- Region status (8bits). This field is not protected by the CRC.
- Tail bits (6bits). This field is not protected by the CRC.

### 6.2.2.2 Nominal Sub-Frame Layout

#### SISICD-1180 : I/NAV E5b-I and I/NAV L1-B carrier message data packet transmission sequence

In nominal mode, the page sequence for the I/NAV E5b-I and I/NAV L1-B in every sub-frame shall be according to the following figure, where  $T_0$  is synchronized with GST origin modulo 30 seconds.

$T_0$ (GST <sub>0</sub> sync.)	E5b sub frame ID	E5b page	E5b content					L1-B content					L1-B page	L1-B sub frame ID
0 s	N	Even	Word 1 (1/2)					Spare Word (2/2)	ERIS	SAR	CRC	Region status	Odd	N-1
1 s	N	Odd	Word 1 (2/2)	ERIS	Spare	CRC	Region status	Word 2 (1/2)					Even	N
2 s	N	Even	Word 3 (1/2)					Word 2 (2/2)	ERIS	SAR	CRC	Region status	Odd	N
3 s	N	Odd	Word 3 (2/2)	ERIS	Spare	CRC	Region status	Word 4 (1/2)					Even	N
4 s	N	Even	Word 5 (1/2)					Word 4 (2/2)	ERIS	SAR	CRC	Region status	Odd	N
5 s	N	Odd	Word 5 (2/2)	ERIS	Spare	CRC	Region status	Word 6 (1/2)					Even	N
6 s	N	Even	Word 7 or 9 (1/2)					Word 6 (2/2)	ERIS	SAR	CRC	Region status	Odd	N
7 s	N	Odd	Word 7 or 9 (2/2)	ERIS	Spare	CRC	Region status	Word 7 or 9 (1/2)					Even	N
8 s	N	Even	Word 8 or 10 (1/2)					Word 7 or 9 (2/2)	ERIS	SAR	CRC	Region status	Odd	N
9 s	N	Odd	Word 8 or 10 (2/2)	ERIS	Spare	CRC	Region status	Word 8 or 10 (1/2)					Even	N
10 s	N	Even	Word 11 (1/2)					Word 8 or 10 (2/2)	ERIS	SAR	CRC	Region status	Odd	N
11 s	N	Odd	Word 11 (2/2)	ERIS	Spare	CRC	Region status	Word 12 (1/2)					Even	N
12 s	N	Even	Word 13 (1/2)					Word 12 (2/2)	ERIS	SAR	CRC	Region status	Odd	N
13 s	N	Odd	Word 13 (2/2)	ERIS	Spare	CRC	Region status	Word 14 (1/2)					Even	N
14 s	N	Even	Word 15 (1/2)					Word 14 (2/2)	ERIS	SAR	CRC	Region status	Odd	N
15 s	N	Odd	Word 15 (2/2)	ERIS	Spare	CRC	Region status	Word 11 (1/2)					Even	N
16 s	N	Even	Word 12 (1/2)					Word 11 (2/2)	ERIS	SAR	CRC	Region status	Odd	N
17 s	N	Odd	Word 12 (2/2)	ERIS	Spare	CRC	Region status	Word 13 (1/2)					Even	N
18 s	N	Even	Word 14 (1/2)					Word 13 (2/2)	ERIS	SAR	CRC	Region status	Odd	N
19 s	N	Odd	Word 14 (2/2)	ERIS	Spare	CRC	Region status	Word 15 (1/2)					Even	N
20 s	N	Even	Word 2 (1/2)					Word 15 (2/2)	ERIS	SAR	CRC	Region status	Odd	N
21 s	N	Odd	Word 2 (2/2)	ERIS	Spare	CRC	Region status	Word 1 (1/2)					Even	N
22 s	N	Even	Word 4 (1/2)					Word 1 (2/2)	ERIS	SAR	CRC	Region status	Odd	N
23 s	N	Odd	Word 4 (2/2)	ERIS	Spare	CRC	Region status	Word 3 (1/2)					Even	N
24 s	N	Even	Word 6 (1/2)					Word 3 (2/2)	ERIS	SAR	CRC	Region status	Odd	N
25 s	N	Odd	Word 6 (2/2)	ERIS	Spare	CRC	Region status	Word 5 (1/2)					Even	N
26 s	N	Even	Spare Word (1/2)					Word 5 (2/2)	ERIS	SAR	CRC	Region status	Odd	N
27 s	N	Odd	Spare Word (2/2)	ERIS	Spare	CRC	Region status	Spare Word (1/2)					Even	N
28 s	N	Even	Spare Word (1/2)					Spare Word (2/2)	ERIS	SAR	CRC	Region status	Odd	N
29 s	N	Odd	Spare Word (2/2)	ERIS	Spare	CRC	Region status	Spare Word (1/2)					Even	N
30 s	N+1	Even	Word 1 (1/2)					Spare Word (2/2)	ERIS	SAR	CRC	Region status	Odd	N

The full almanac shall be sent with words 7, 8, 9 or 10 as defined in SISICD-1194.

### 6.2.2.3 Nominal Frame Layout

#### SISICD-1194 : I/NAV Sub-frame sequencing

The I/NAV sub-frames containing almanacs data shall be sequenced according to the following figure.

<b>T<sub>0</sub> [s]</b>	<b>Sub-frame ID</b>	<b>E5b</b>	<b>L1B</b>
0	1	Word 7: Almanac SV 1 (1/2)	Word 7: Almanac SV 19 (1/2)
		Word 8: Almanac SV 1 (2/2) + almanac SV 2 (1/2)	Word 8: Almanac SV 19 (2/2) + almanac SV 20 (1/2)
30	2	Word 9: Almanac SV 2 (2/2) + almanac SV 3 (1/2)	Word 9: Almanac SV 20 (2/2) + almanac SV 21 (1/2)
		Word 10: Almanac SV 3 (2/2)	Word 10: Almanac SV 21 (2/2)
60	3	Word 7: Almanac SV 4 (1/2)	Word 7: Almanac SV 22 (1/2)
		Word 8: Almanac SV 4 (2/2) + almanac SV 5 (1/2)	Word 8: Almanac SV 22 (2/2) + almanac SV 23 (1/2)
90	4	Word 9: Almanac SV 5 (2/2) + almanac SV 6 (1/2)	Word 9: Almanac SV 23 (2/2) + almanac SV 24 (1/2)
		Word 10: Almanac SV 6 (2/2)	Word 10: Almanac SV 24 (2/2)
120	5	Word 7: Almanac SV 7 (1/2)	Word 7: Almanac SV 25 (1/2)
		Word 8: Almanac SV 7 (2/2) + almanac SV 8 (1/2)	Word 8: Almanac SV 25 (2/2) + almanac SV 26 (1/2)
150	6	Word 9: Almanac SV 8 (2/2) + almanac SV 9 (1/2)	Word 9: Almanac SV 26 (2/2) + almanac SV 27 (1/2)
		Word 10: Almanac SV 9 (2/2)	Word 10: Almanac SV 27 (2/2)
180	7	Word 7: Almanac SV 10 (1/2)	Word 7: Almanac SV 28 (1/2)
		Word 8: Almanac SV 10 (2/2) + almanac SV 11 (1/2)	Word 8: Almanac SV 28 (2/2) + almanac SV 29 (1/2)
210	8	Word 9: Almanac SV 11 (2/2) + almanac SV 12 (1/2)	Word 9: Almanac SV 29 (2/2) + almanac SV 30 (1/2)
		Word 10: Almanac SV 12 (2/2)	Word 10: Almanac SV 30 (2/2)
240	9	Word 7: Almanac SV 13 (1/2)	Word 7: Almanac SV 31 (1/2)
		Word 8: Almanac SV 13 (2/2) + almanac SV 14 (1/2)	Word 8: Almanac SV 31 (2/2) + almanac SV 32 (1/2)
270	10	Word 9: Almanac SV 14 (2/2) + almanac SV 15 (1/2)	Word 9: Almanac SV 32 (2/2) + almanac SV 33 (1/2)
		Word 10: Almanac SV 15 (2/2)	Word 10: Almanac SV 33 (2/2)
300	11	Word 7: Almanac SV 16 (1/2)	Word 7: Almanac SV 34 (1/2)
		Word 8: Almanac SV 16 (2/2) + almanac SV 17 (1/2)	Word 8: Almanac SV 34 (2/2) + almanac SV 35 (1/2)
330	12	Word 9: Almanac SV 17 (2/2) + almanac SV 18 (1/2)	Word 9: Almanac SV 35 (2/2) + almanac SV 36 (1/2)
		Word 10: Almanac SV 18 (2/2)	Word 10: Almanac SV 36 (2/2)
360	13	Word 7: Almanac SV 19 (1/2)	Word 7: Almanac SV 1 (1/2)
		Word 8: Almanac SV 19 (2/2) + almanac SV 20 (1/2)	Word 8: Almanac SV 1 (2/2) + almanac SV 2 (1/2)
390	14	Word 9: Almanac SV 20 (2/2) + almanac SV 21 (1/2)	Word 9: Almanac SV 2 (2/2) + almanac SV 3 (1/2)
		Word 10: Almanac SV 21 (2/2)	Word 10: Almanac SV 3 (2/2)
420	15	Word 7: Almanac SV 22 (1/2)	Word 7: Almanac SV 4 (1/2)
		Word 8: Almanac SV 22 (2/2) + almanac SV 23 (1/2)	Word 8: Almanac SV 4 (2/2) + almanac SV 5 (1/2)
450	16	Word 9: Almanac SV 23 (2/2) + almanac SV 24 (1/2)	Word 9: Almanac SV 5 (2/2) + almanac SV 6 (1/2)
		Word 10: Almanac SV 24 (2/2)	Word 10: Almanac SV 6 (2/2)
480	17	Word 7: Almanac SV 25 (1/2)	Word 7: Almanac SV 7 (1/2)
		Word 8: Almanac SV 25 (2/2) + almanac SV 26 (1/2)	Word 8: Almanac SV 7 (2/2) + almanac SV 8 (1/2)
510	18	Word 9: Almanac SV 26 (2/2) + almanac SV 27 (1/2)	Word 9: Almanac SV 8 (2/2) + almanac SV 9 (1/2)
		Word 10: Almanac SV 27 (2/2)	Word 10: Almanac SV 9 (2/2)
540	19	Word 7: Almanac SV 28 (1/2)	Word 7: Almanac SV 10 (1/2)
		Word 8: Almanac SV 28 (2/2) + almanac SV 29 (1/2)	Word 8: Almanac SV 10 (2/2) + almanac SV 11 (1/2)
570	20	Word 9: Almanac SV 29 (2/2) + almanac SV 30 (1/2)	Word 9: Almanac SV 11 (2/2) + almanac SV 12 (1/2)
		Word 10: Almanac SV 30 (2/2)	Word 10: Almanac SV 12 (2/2)
600	21	Word 7: Almanac SV 31 (1/2)	Word 7: Almanac SV 13 (1/2)
		Word 8: Almanac SV 31 (2/2) + almanac SV 32 (1/2)	Word 8: Almanac SV 13 (2/2) + almanac SV 14 (1/2)
630	22	Word 9: Almanac SV 32 (2/2) + almanac SV 33 (1/2)	Word 9: Almanac SV 14 (2/2) + almanac SV 15 (1/2)
		Word 10: Almanac SV 33 (2/2)	Word 10: Almanac SV 15 (2/2)
660	23	Word 7: Almanac SV 34 (1/2)	Word 7: Almanac SV 16 (1/2)
		Word 8: Almanac SV 34 (2/2) + almanac SV 35 (1/2)	Word 8: Almanac SV 16 (2/2) + almanac SV 17 (1/2)
690	24	Word 9: Almanac SV 35 (2/2) + almanac SV 36 (1/2)	Word 9: Almanac SV 17 (2/2) + almanac SV 18 (1/2)
		Word 10: Almanac SV 36 (2/2)	Word 10: Almanac SV 18 (2/2)



#### **6.2.2.4 Handling of I/NAV Integrity Alert Messages**

The transmission sequences shown above for I/NAV do not include the presence of integrity alerts.

##### **SISICD-1203 : Handling of a single I/NAV alert message**

The integrity alert messages will be transmitted on demand and shall take priority over normal message transmissions.

The pages with the alert messages shall replace the scheduled nominal pages due for transmission.

##### Note:

The process to repeat an Integrity alert is not managed by the satellite but by the Ground Segment.

When an alert is raised, a page containing the alerts shall be sent, and repeated once on each channel. Also, the two parts of the page shall be alternated between the E5b and L1-B channels to allow a fast reception when a dual frequency receiver is used.

When the integrity alert messages have been sent, the sequence continues skipping the non-transmitted nominal pages in order to keep the predefined synchronism between the satellites.

##### **SISICD-1211 : Handling of I/NAV alerts when another alert page is being transmitted**

When a new alert is raised during transmission of another alert page, the page with the new alert message shall replace the alert pages already scheduled for transmission. Thus the interrupted alert page is not repeated.

The new alert transmission shall be handled as for a single alert.

##### **SISICD-2079 : Even/Odd pages synchronisation**

The transmission of alerts shall not modify the Even / Odd page sequencing.

##### **SISICD-2080 : Integrity alert computation**

Alerts shall be relative to the last completely broadcast integrity table.

##### **SISICD-2081 : Integrity alert retransmission**

Any alert received during the transmission of a new integrity table shall be taken to be valid, and shall refer to the integrity table completely transmitted in the previous sub-frame.

##### **SISICD-2082 : Integrity alert information**

Alerts shall be raised only to indicate a degradation of the integrity status. The potential improvement of the integrity status is indicated only in the next integrity table transmitted.

### SISICD-3108 : Nominal transmission recovery after an Integrity alert

After the transmission of an Integrity alert the nominal sequencing should be recovered as detailed in the next two figures.

$T_0$	E5b (L1B) page	E5b (L1B) content				L1B (E5b) content				L1B (E5b) page	
n-1	Even	Word j (1/2)				Word i (2/2)	ERIS	SAR	Vertical CRC	Region status	Odd
n	Odd	Word j (2/2)	ERIS	Vertical CRC	Region status	Word k (1/2)				Even	
n+1	Even	Alert (1/2)				Alert (2/2)		ERIS	Horizontal CRC	Region status	Odd
n+2	Odd	Alert repetition (2/2)	ERIS	Horizontal CRC	Region status	Alert repetition (1/2)				Even	
n+3	Even	Word n (1/2)				Spare [16 bits]	ERIS	SAR	Vertical CRC	Region status	Odd
n+4	Odd	Word n (2/2)	ERIS	Vertical CRC	Region status	Word p (1/2)				Even	

$T_0$	E5b (L1B)				L1B (E5b)											
n+3	Even/odd=0	Type	Word n (1/2)		Tail	Total	Even/odd=1	Type	Spare	ERIS	SAR	Spare	CRC	Region Status	Tail	Total
	1	1	112		6	120	1	1	16	40	22	2	24	8	6	120

Where CRC (vertical CRC) sent at the epoch  $T_0=n+3$  on L1-B (E5b) is computed over the data transmitted on L1-B (E5b) during  $T_0=n+2$  and  $T_0=n+3$ : Even/odd fields, type fields, Alert repetition (1/2), spare bits (both 16 and 2 bits fields), ERIS and SAR.

Note: In the figures 6.17 and 6.18, the SAR data are replaced by Spare data on the E5b frequency.

### 6.2.2.5 Page Contents

The figure below shows how the integrity alerts are inserted into the I/NAV message frames for the above cases.

#### SISICD-1228 : I/NAV alert page with alert coded on 1 bit

In case of satellite failure only, this alert shall be transmitted through this page formatted according to the values stated in the following figure.

Type=2	Clever Word	IA1	IA2	IA3 ... IA34	IA35	IA36	Spare	Total [bits]
3	3	1	1	32	1	1	108	150

The parameters of the alert pages with alert coded on 1bit shall be

- Type (3 bits): indicates the type of broadcast alert page
- Clever word (3 bits): is used for the computation of the CRC for the integrity table
- Spare (108 bits): Spare bits
- IA<sub>i</sub> (1 bit): is used for the signaling of the Integrity Alert from the satellite i which has the following definition.

Value	IA <sub>i</sub>
1	OK
0	NOK

#### SISICD-1248 : I/NAV alert with SISMA page with alert coded on 4 bits

In case of Ground Segment failure, this alert shall be transmitted through this page formatted according to the values stated in the following figure.

Type=1	Clever Word	IA1	IA2	IA3 ... IA34	IA35	IA36	Total [bits]
3	3	4	4	128	4	4	150

The parameters of the alert with SISMA page with alert coded on 4 bits shall be

- Type (3 bits): indicates the type of broadcast alert page
- Clever word (3 bits): is used for the computation of the CRC for the integrity table
- IA<sub>i</sub> (4 bits): is used for the signaling of the Integrity Alert from the satellite i as described in SISICD-2271.

**SISICD-1268 : I/NAV Ephemeris, Clock correction, Ionospheric correction, GST, signal health and data validity status, and C/NAV encryption status**

These words shall be formatted according to the values stated in the following figures.

- Word Type 1: Ephemeris (1/4) and C/NAV Encryption status

Type=1	IOD <sub>nav</sub>	Ephemeris (1/4)				C/NAV encryption status	Spare	Total [bits]
		t <sub>0e</sub>	M <sub>0</sub>	e	A <sup>1/2</sup>			
6	10	14	32	32	32	1	1	128

- Word Type 2: Ephemeris (2/4)

Type=2	IOD <sub>nav</sub>	Ephemeris (2/4)				Spare	Total [bits]
		OMEGA <sub>0</sub>	I <sub>0</sub>	OMEGA	IDOT		
6	10	32	32	32	14	2	128

- Word Type 3: Ephemeris (3/4) and SISA(L1,E5b)

Type=3	IOD <sub>nav</sub>	Ephemeris (3/4)						SISA(L1,E5b)	Total [bits]
		OMEGADOT	Δn	C <sub>UC</sub>	C <sub>US</sub>	C <sub>RC</sub>	C <sub>RS</sub>		
6	10	24	16	16	16	16	16	8	128

- Word Type 4: SVID, Ephemeris (4/4) and Clock correction parameters

Type=4	IOD <sub>nav</sub>	SV <sub>ID</sub>	Ephemeris (4/4)		Clock correction				Spare	Total [bits]
			C <sub>IC</sub>	C <sub>IS</sub>	t <sub>oc</sub>	a <sub>f0</sub>	a <sub>f1</sub>	a <sub>f2</sub>		
6	10	6	16	16	14	31	21	6	2	128

- Word Type 5: Ionospheric correction, BGD, signal health and data validity status, and GST

Type=5	Ionospheric correction			Ionospheric disturbance flag					BGD(L1,E5a)	BGD(L1,E5b)	E5b <sub>HS</sub>	L1B <sub>HS</sub>	E5b <sub>DVS</sub>	L1B <sub>DVS</sub>	GST		Spare	Total [bits]
	Az	a <sub>i0</sub>	a <sub>i1</sub>	Region 1	Region 2	Region 3	Region 4	Region 5							WN	TOW		
6	11	11	14	1	1	1	1	1	10	10	2	2	1	1	12	20	23	128

### SISICD-1275 : I/NAV GST-UTC conversion parameters

This word shall be formatted according the values stated in the following figure.

- Word Type 6: GST - UTC conversion parameters

Type=6	GST-UTC conversion parameters								TOW	Spare	Total [bits]
	A <sub>0</sub>	A <sub>1</sub>	Δt <sub>LS</sub>	t <sub>ot</sub>	WN	WN <sub>LSF</sub>	DN	Δt <sub>LSF</sub>			
6	32	24	8	8	8	8	3	8	20	3	128

Figure 6.27: Bits allocation for I/NAV Word type 6

### SISICD-1282 : I/NAV Almanac Parameters and GST-GPS conversion parameters

The almanac for 3 satellites shall be transmitted on 4 pages formatted according to the values stated in the following figures.

- Word Type 7: Almanac for SVID1 (1/2), almanac reference time and almanac reference week number

Type=7	IOD <sub>a</sub>	WN <sub>a</sub>	t <sub>oa</sub>	SV <sub>SVID1(1/2)</sub>								Spare	Total [bits]
				SVID1	$\Delta(A^{1/2})$	e	OMEGA	$\delta_i$	OMEGA <sub>0</sub>	OMEGADOT	M <sub>0</sub>		
6	4	2	10	6	13	11	16	11	16	11	16	6	128

- Word type 8: Almanac for SVID1 (2/2) and SVID2 (1/2)

Type=8	IOD <sub>a</sub>	SV <sub>SVID1(1/2)</sub>				SV <sub>SVID2(1/2)</sub>						Spare	Total [bits]	
		a <sub>i0</sub>	a <sub>r1</sub>	E5b <sub>HS</sub>	L1B <sub>HS</sub>	SVID2	$\Delta(A^{1/2})$	e	OMEGA	$\delta_i$	OMEGA <sub>0</sub>			OMEGADOT
6	4	16	13	2	2	6	13	11	16	11	16	11	1	128

- Word Type 9: Almanac for SVID2 (2/2) and SVID3 (1/2)

Type=9	IOD <sub>a</sub>	WN <sub>a</sub>	t <sub>oa</sub>	SV <sub>SVID2(2/2)</sub>					SV <sub>SVID3(1/2)</sub>				Total [bits]	
				M <sub>0</sub>	a <sub>i0</sub>	a <sub>r1</sub>	E5b <sub>HS</sub>	L1B <sub>HS</sub>	SVID3	$\Delta(A^{1/2})$	e	OMEGA		$\delta_i$
6	4	2	10	16	16	13	2	2	6	13	11	16	11	128

- Word Type 10: Almanac for SVID3 (2/2) and GST-GPS Conversion parameters

6	Type=10	SV <sub>SVID3(2/2)</sub>							GST-GPS conversion parameters				Total [bits]
		IOD <sub>a</sub>	OMEGA <sub>0</sub>	OMEGADOT	M <sub>0</sub>	a <sub>f0</sub>	a <sub>f1</sub>	E5b <sub>HS</sub>	L1B <sub>HS</sub>	A <sub>0G</sub>	A <sub>1G</sub>	t <sub>0G</sub>	
4		16	11	16	16	13	2	2	16	12	8	6	128

### SISICD-1299 : I/NAV Integrity table

These pages are formatted according to the values stated in the following figures

- Word Type 11: ToC and Integrity table for SV<sub>1</sub> to SV<sub>16</sub>

6	Type=11	ToC		SV <sub>1</sub>	SV <sub>2... SV15</sub>	SV <sub>16</sub>	Spare	Total [bits]	
		SNF	IF	SNF/IF	SNF	IF			
8		3	4	98		3	4	2	128

- Word Type 12: Integrity table for SV<sub>17</sub> to SV<sub>33</sub>

6	Type=12	SV <sub>17</sub>		SV <sub>18... SV32</sub>	SV <sub>33</sub>	Spare	Total [bits]	
		SNF	IF	SNF/IF	SNF			IF
3		4	105		3	4	3	128

- Word Type 13: Integrity table for SV<sub>34</sub> to SV<sub>36</sub>, Clever Word and Authentication (1/3)

Type=13	SV <sub>34</sub>		SV <sub>35</sub>		SV <sub>36</sub>		Clever Word	Authentication (1/3)	Total [bits]
	SNF	IF	SNF	IF	SNF	IF			
6	3	4	3	4	3	4	3	98	128

- Word Type 14: Authentication (2/3)

Type=14	Authentication (2/3)	Total [bits]
6	122	128

- Word Type 15: Authentication (3/3) and TOW

Type=15	Authentication (3/3)	TOW	Spare	Total [bits]
6	100	20	2	128



### SISICD-2882 : Spare word – INAV 0

When no integrity messages (word types 11 to 15) are available to be downlinked in E5b or L1B band, the satellite shall generate and downlink the Word type 0 to substitute those words according to the following figure.

Type=0	Time	Spare*	WN	TOW	Total [bits]
6	2		88	12	

\* The spare bits shall be generated as sequence of zeros and ones ('010101...') starting with the MSB.

The 'Time' field will be set by the satellite to '10'. When the field 'Time' is not set to '10', corresponding to the case where the I/NAV-0 word is uplinked from ground, the fields WN and TOW do not contain valid data.

This word (Word Type 0) should also replace the Spare words described in SISICD-1180 when no other data is specified to be downlinked.

### SISICD-2579 : Dummy message definition

During the initialisation phase when no data is uplinked via the C-band to the satellite, the satellite shall generate and downlink the dummy message on E5b/L1 replacing the pages in the nominal sequencing, according to the following format.

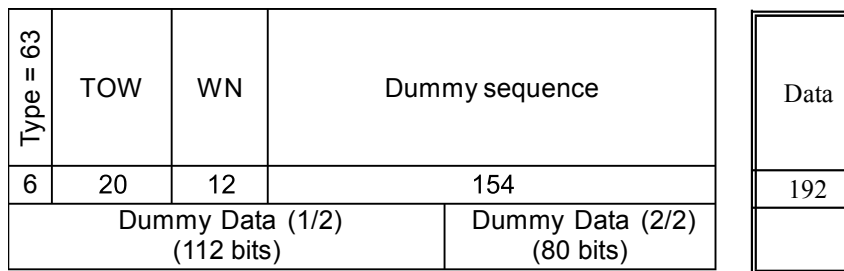
E5b						L1B									
Even/odd=0	Type=0	Dummy data (1/2)				Tail	Total	Even/odd=1	Type=0	Dummy data (2/2)		CRC <sub>L1B</sub>	Spare	Tail	Total
1	1	112				6		120	1	1	80	24	8	6	
Even/odd=1	Type=0	Dummy data (2/2)		CRC <sub>E5b</sub>	Spare	Tail	Total	Even/odd=0	Type=0	Dummy data (1/2)			Tail	Total	
1	1	80		24	8	6		120	1	1	112				6

With

- Even/Odd (1 bit): to indicate the part of the page (0=even/1=odd) that is broadcast
- Type (1 bit) equal to 0 to indicate the nominal page type
- Dummy Data (192 bits = 80 bits +112 bits): composed of dummy data
- CRC (24 bits) computed on the Type field, Even/Odd field and Data field. In this mode the CRC is computed for the Even/Odd page of the same frequency (“Vertical CRC”) and it is always broadcast on the second part of the vertical page.
- Spare (8 bits). This field is not protected by the CRC.
- Tail bits (6bits). This field is not protected by the CRC.

**SISICD-2582 : Dummy data description**

The dummy data word (192 bits) shall be formatted according to the following figure.



With

- Word Type (6 bits): to indicate the word type dummy message, which is defined as type 63 (Type=111111)
- TOW (20 bits): to broadcast the on-board Time of Week (time with 1second accuracy)
- WN (12 bits): to broadcast the on-board Week Number
- Dummy sequence (154 bits): this is an arbitrary sequence to be checked by the ground.

The dummy sequence shall be: A372EC4D3B4F84DCBB134ED3E1372EC4D3B4F8 coded on hexadecimal plus two bits at the end which shall be ‘00’.

### 6.2.2.6 ERIS and SAR Bit Structure

#### SISICD-2148 : ERIS field structure

The ERIS field is 40 bits in length in the I/NAV page for nominal and alert pages. For both modes the ERIS fields are to be formatted according to the figures below.

ERIS data					Total [bits]
ERIS 1	ERIS 2	ERIS 3	ERIS 4	ERIS 5	
8	8	8	8	8	40

#### SISICD-2889 : Spare ERIS data

When no ERIS data is received in the C-band the satellite shall fill in the ERIS data field in the downlink with all zeros [0000 0000(binary)] for each region for which no data is available taking into account any direct uplinks from ERIS ULS.

#### SISICD-2613 : SAR field structure

When a Galileo Alert is present, the SAR data will not be transmitted simultaneously.

In nominal mode the SAR RLM is transmitted only in the L1-B channel.

The SAR field structure for the L1-B channel in nominal mode shall be formatted according to the values stated in the following figure.

SAR data			Total
Start Bit	Short/Long RLM identifier	SAR RLM Data	
1	1	20	22

The RLM identifier bit is described in the following table.

RLM identifier value	Description
0	Short RLM
1	Long RLM



- Long RLM

Part (1/8)		Part (2/8)		Part (3/8)		Part (4/8)		Part (5/8)		Part (6/8)					
Start bit = 1	Long RLM	SAR RLM data	Start bit = 0	Long RLM	SAR RLM data	Start bit = 0	Long RLM	SAR RLM data	Start bit = 0	Long RLM	SAR RLM data				
	Beacon ID (1/3)			Beacon ID (2/3)		Beacon ID (3/3)	Message code	Parameters (1/5)		Parameters (2/5)					
1	1	20	1	1	20	1	1	4	16	1	1	20	1	1	20
22		22		22		22		22		22		22			

Part (7/8)		Part (8/8)			
Start bit = 0	Long RLM	SAR RLM data	Start bit = 0	Long RLM	SAR RLM data
	Parameters (4/5)			Parameters (5/5)	
1	1	20	1	1	20
22		22			

## 6.2.3 C/NAV E6-B Channel Message Data

### 6.2.3.1 General Page Layout

#### SISICD-1329 : C/NAV page layout

The C/NAV page layout shall be according to the values stated in the following figure, where the symbols allocation and bits allocation are shown separately.

Sync	Symbols			Total [symbols]
16	984			1000

Page type	Word	CRC	Tail	Total [bits]
14	Commercial Data / key Management	24	6	492

#### SISICD-3133 : C/NAV message - C/NAV-0

When no valid C/NAV messages are available or during the satellite initialisation, the satellite shall generate and disseminate the following dummy C/NAV message (C/NAV-0).

Page type	Spare Data	CRC	Tail	Total [bits]
14	448	24	6	492

where

- Page type (14 bits): shall be generated containing the sequence: '00 1010 1100 1001' (binary). This sequence means no commercial data available.
- The spare data field (448 bits) shall be generated containing the following random sequence: [AF3B C301 3D9C 46FE 184D C21A 84B0 53E1 F01E D31A A937 812F 3AE1 84B0 D31A 46FE AF3B 3AE1 AF3B 53E1 46FE C301 D31A 184D 812F FD21 1234 CD21] hex

Note:

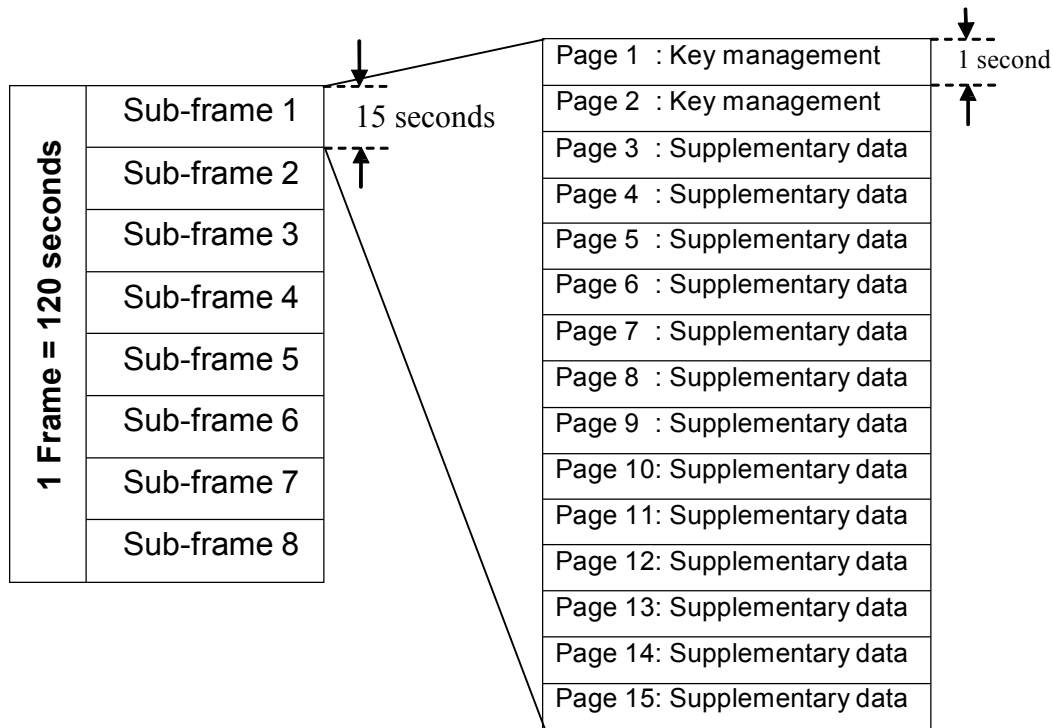
CRC shall be computed as per any other C/NAV message received from ground, this means over the 'Commercial data' plus the 'Page Type' fields or over the 462 bits spare data respectively.

**SISICD-1336 : C/NAV E6-B carrier message data packet transmission sequence**

The page sequence for the C/NAV E6-B channel shall be according to the figure below, where the frame content is shown (120s frame length).

The E6-B C/NAV message frame is structured as following:

- Each message frame of E6-B C/NAV is composed of 8 sub-frames.
- Each sub-frame is composed of 15 pages.
- Each page has a duration of transmission of 1 second.



Note: The subframes 2 ... 8 contain the same structure as subframe 1.

## 6.2.4 G/NAV Channels Message Data

### 6.2.4.1 General Page Layout

#### SISICD-2918 : G/NAV Nominal Page Layout

The page layout for the G/NAV Channels shall be according to the following figure, where the symbols allocation and bits allocation are shown separately.

Initial field	Symbol page (1/6)	Initial field	Symbol page (2/6)	Initial field	Symbol page (3/6)	Initial field	Symbol page (4/6)	Initial field	Symbol page (5/6)	Initial field	Symbol page (6/6)	Total [symbols]
2	108	2	108	2	108	2	108	2	108	2	108	

Word			Tail	Total [bits]
PRS data	On-board data	Global region status		
283	27	8	6	324

The G/NAV pages are 324 bits long. These bits are split on 4 fields:

- PRS data (283 bits): it is received from ground and contains the encrypted data described in section 6.2.4.4
- On-board data (27 bits): this data is added on board and described in section 7.1.5.4
- Region Status (8 bits): this data is added on board and described in section 7.2.3
- Tail bits (6 bits)

#### SISICD-3095 : Initial field description

The initial field is defined at symbol level. Its value depends on PRS data disseminated according to the following table.

Initial field symbols	PRS data
00	Other data than PRS alerts
11	PRS alerts



### 6.2.4.2 Nominal Frame Layout

#### SISICD-2922 : G/NAV nominal frame layout

In nominal mode (no alert), the page sequence for the G/NAV E6-A and G/NAV L1-A is distributed in 12 consecutive sub-frames each one composed of 5 pages as described in the figure below.

	Sub-frame ID	Page ID	T <sub>0</sub>	E6A content	L1A content	T <sub>0</sub>
Frame	Sub-frame 1	1	0 s	G/NAV-1	G/NAV-2	3s
		2	6 s	G/NAV-3	G/NAV-4	9s
		3	12 s	G/NAV-5	G/NAV-6	15s
		4	18 s	G/NAV-7	G/NAV-8	21s
		5	24 s	G/NAV-9	G/NAV-9	27s
	Sub-frame 2	1	30 s	G/NAV-2	G/NAV-1	33s
		2	36 s	G/NAV-4	G/NAV-3	39s
		3	42 s	G/NAV-6	G/NAV-5	45s
		4	48 s	G/NAV-8	G/NAV-7	51s
		5	54 s	G/NAV-9	G/NAV-9	57s
	Sub-frame 3	1	60 s	G/NAV-1	G/NAV-2	63s
		2	66 s	G/NAV-3	G/NAV-4	69s
		3	72 s	G/NAV-5	G/NAV-6	75s
		4	78 s	G/NAV-7	G/NAV-8	81s
		5	84 s	G/NAV-9	G/NAV-9	87s
	⋮	...	...	...	...	...
	Sub-frame 12	1	330s	G/NAV-2	G/NAV-1	333s
		2	336s	G/NAV-4	G/NAV-3	339s
		3	342s	G/NAV-6	G/NAV-5	345s
		4	348s	G/NAV-8	G/NAV-7	351s
5		354s	G/NAV-9	G/NAV-9	357s	

## SISICD-3098 : G/NAV nominal sub-frame layout

In nominal mode (no alert), the page sequence for the G/NAV E6-A and G/NAV L1-A is distributed in a single sub-frame as described in the figure below.

T <sub>0</sub> [s]	E6A Page ID	E6A page part	E6A content		L1A content		L1A page part	L1A Page ID
			Initial field=00	Symbol page (x/6)	Initial field=00	Symbol page (x/6)		
0	1	1/6	Initial field=00	Symbol page (1/6)	Initial field=00	Symbol page (4/6)	4/6	5
1	1	2/6	Initial field=00	Symbol page (2/6)	Initial field=00	Symbol page (5/6)	5/6	5
2	1	3/6	Initial field=00	Symbol page (3/6)	Initial field=00	Symbol page (6/6)	6/6	5
3	1	4/6	Initial field=00	Symbol page (4/6)	Initial field=00	Symbol page (1/6)	1/6	1
4	1	5/6	Initial field=00	Symbol page (5/6)	Initial field=00	Symbol page (2/6)	2/6	1
5	1	6/6	Initial field=00	Symbol page (6/6)	Initial field=00	Symbol page (3/6)	3/6	1
6	2	1/6	Initial field=00	Symbol page (1/6)	Initial field=00	Symbol page (4/6)	4/6	1
7	2	2/6	Initial field=00	Symbol page (2/6)	Initial field=00	Symbol page (5/6)	5/6	1
8	2	3/6	Initial field=00	Symbol page (3/6)	Initial field=00	Symbol page (6/6)	6/6	1
9	2	4/6	Initial field=00	Symbol page (4/6)	Initial field=00	Symbol page (1/6)	1/6	2
10	2	5/6	Initial field=00	Symbol page (5/6)	Initial field=00	Symbol page (2/6)	2/6	2
11	2	6/6	Initial field=00	Symbol page (6/6)	Initial field=00	Symbol page (3/6)	3/6	2
12	3	1/6	Initial field=00	Symbol page (1/6)	Initial field=00	Symbol page (4/6)	4/6	2
13	3	2/6	Initial field=00	Symbol page (2/6)	Initial field=00	Symbol page (5/6)	5/6	2
14	3	3/6	Initial field=00	Symbol page (3/6)	Initial field=00	Symbol page (6/6)	6/6	2
15	3	4/6	Initial field=00	Symbol page (4/6)	Initial field=00	Symbol page (1/6)	1/6	3
16	3	5/6	Initial field=00	Symbol page (5/6)	Initial field=00	Symbol page (2/6)	2/6	3
17	3	6/6	Initial field=00	Symbol page (6/6)	Initial field=00	Symbol page (3/6)	3/6	3
18	4	1/6	Initial field=00	Symbol page (1/6)	Initial field=00	Symbol page (4/6)	4/6	3
19	4	2/6	Initial field=00	Symbol page (2/6)	Initial field=00	Symbol page (5/6)	5/6	3
20	4	3/6	Initial field=00	Symbol page (3/6)	Initial field=00	Symbol page (6/6)	6/6	3
21	4	4/6	Initial field=00	Symbol page (4/6)	Initial field=00	Symbol page (1/6)	1/6	4
22	4	5/6	Initial field=00	Symbol page (5/6)	Initial field=00	Symbol page (2/6)	2/6	4
23	4	6/6	Initial field=00	Symbol page (6/6)	Initial field=00	Symbol page (3/6)	3/6	4
24	5	1/6	Initial field=00	Symbol page (1/6)	Initial field=00	Symbol page (4/6)	4/6	4
25	5	2/6	Initial field=00	Symbol page (2/6)	Initial field=00	Symbol page (5/6)	5/6	4
26	5	3/6	Initial field=00	Symbol page (3/6)	Initial field=00	Symbol page (6/6)	6/6	4
27	5	4/6	Initial field=00	Symbol page (4/6)	Initial field=00	Symbol page (1/6)	1/6	5
28	5	5/6	Initial field=00	Symbol page (5/6)	Initial field=00	Symbol page (2/6)	2/6	5
29	5	6/6	Initial field=00	Symbol page (6/6)	Initial field=00	Symbol page (3/6)	3/6	5
0	1	1/6	Initial field=00	Symbol page (1/6)	Initial field=00	Symbol page (4/6)	4/6	5
1	1	2/6	Initial field=00	Symbol page (2/6)	Initial field=00	Symbol page (5/6)	5/6	5
2	1	3/6	Initial field=00	Symbol page (3/6)	Initial field=00	Symbol page (6/6)	6/6	5

T<sub>0</sub> indicates the time when the 'Initial field' and the Symbol page (x/6) are transmitted. It shall be equal to GST modulo 30 seconds.

## SISICD-2925 : G/NAV almanacs nominal dissemination

The G/NAV almanacs shall be disseminated depending on the satellite and the epoch when the sub-frame ID is transmitted according to the following table.

Frame ID	Sub-frame ID	T <sub>0</sub> [s]	SV1, 4, 7 ...34	SV2, 5, 8 ...35	SVJ, 6, 9 ...36
Q	1	0	Almanac for Satellite 1	Almanac for Satellite 13	Almanac for Satellite 25
	2	30	Almanac for Satellite 2	Almanac for Satellite 14	Almanac for Satellite 26
	3	60	Almanac for Satellite 3	Almanac for Satellite 15	Almanac for Satellite 27
	4	90	Almanac for Satellite 4	Almanac for Satellite 16	Almanac for Satellite 28
	5	120	Almanac for Satellite 5	Almanac for Satellite 17	Almanac for Satellite 29
	6	150	Almanac for Satellite 6	Almanac for Satellite 18	Almanac for Satellite 30
	7	180	Almanac for Satellite 7	Almanac for Satellite 19	Almanac for Satellite 31
	8	210	Almanac for Satellite 8	Almanac for Satellite 20	Almanac for Satellite 32
	9	240	Almanac for Satellite 9	Almanac for Satellite 21	Almanac for Satellite 33
	10	270	Almanac for Satellite 10	Almanac for Satellite 22	Almanac for Satellite 34
	11	300	Almanac for Satellite 11	Almanac for Satellite 23	Almanac for Satellite 35
	12	330	Almanac for Satellite 12	Almanac for Satellite 24	Almanac for Satellite 36
R	1	360	Almanac for Satellite 13	Almanac for Satellite 25	Almanac for Satellite 1
	12	690	Almanac for Satellite 24	Almanac for Satellite 36	Almanac for Satellite 12
S	1	720	Almanac for Satellite 25	Almanac for Satellite 1	Almanac for Satellite 13
	12	1050	Almanac for Satellite 36	Almanac for Satellite 12	Almanac for Satellite 24
T	1	1080	Almanac for Satellite 2	Almanac for Satellite 14	Almanac for Satellite 26
	2	1110	Almanac for Satellite 1	Almanac for Satellite 13	Almanac for Satellite 25
	3	1140	Almanac for Satellite 4	Almanac for Satellite 16	Almanac for Satellite 28
	4	1170	Almanac for Satellite 3	Almanac for Satellite 15	Almanac for Satellite 27
	5	1200	Almanac for Satellite 6	Almanac for Satellite 18	Almanac for Satellite 30
	6	1230	Almanac for Satellite 5	Almanac for Satellite 17	Almanac for Satellite 29
	7	1260	Almanac for Satellite 8	Almanac for Satellite 20	Almanac for Satellite 32
	8	1290	Almanac for Satellite 7	Almanac for Satellite 19	Almanac for Satellite 31
	9	1320	Almanac for Satellite 10	Almanac for Satellite 22	Almanac for Satellite 34
	10	1350	Almanac for Satellite 9	Almanac for Satellite 21	Almanac for Satellite 33
	11	1380	Almanac for Satellite 12	Almanac for Satellite 24	Almanac for Satellite 36
	12	1410	Almanac for Satellite 11	Almanac for Satellite 23	Almanac for Satellite 35
U	1	1440	Almanac for Satellite 14	Almanac for Satellite 26	Almanac for Satellite 2
	12	1770	Almanac for Satellite 23	Almanac for Satellite 35	Almanac for Satellite 11
V	1	1800	Almanac for Satellite 26	Almanac for Satellite 1	Almanac for Satellite 14
	12	2130	Almanac for Satellite 35	Almanac for Satellite 11	Almanac for Satellite 23

Note: T<sub>0</sub> is on-board time modulo 2160 seconds and indicates the epoch when the sub-frame ID is transmitted.

### **SISICD-3102 : G/NAV-9 packets dissemination**

Each satellite shall disseminate the G/NAV-9 packets received, in a continuous sequence on both frequencies.

<b>E6-A</b>	<b>L1-A</b>
G/NAV-9 packet 1	G/NAV-9 packet 2
G/NAV-9 packet 3	G/NAV-9 packet 4
...	...
G/NAV-9 packet n	G/NAV-9 packet n+1
...	...
G/NAV-9 packet 2	G/NAV-9 packet 1
G/NAV-9 packet 4	G/NAV-9 packet 3
...	...
G/NAV-9 packet n+1	G/NAV-9 packet n

All the G/NAV-9 packets shall be transmitted on both frequencies.

### **SISICD-3106 : G/NAV-9 packets dissemination**

When the satellite does not receive through the C-band the G/NAV-7 or G/NAV-8 the downlink sequence shall be substituted by G/NAV-9 based on the sequence described in SISICD-3102.

#### **6.2.4.3 Handling of G/NAV Integrity Alert Messages**

The alerts dissemination is based on the same approach as per I/NAV. Only one region is concerned in the G/NAV message.

### **SISICD-2956 : Order of alert packet transmission**

In case of alert, the first 1-second symbol page of the alert shall be transmitted on the E6 carrier.

### **SISICD-2957 : Handling of G/NAV alert messages**

Each second, the dual frequency PRS receiver shall check if the last 6 1-second symbol pages received correspond to a G/NAV alert or not.

### **SISICD-2958 : PRS alert interleaving**

The PRS alert shall interrupt the nominal sequencing being interleaved on the second.

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### SISICD-2959 : Handling of PRS alert Messages

The pages with the alert messages shall replace the scheduled nominal page parts due for transmission each second. After the integrity alert messages have been sent, the sequence continues skipping the non-transmitted nominal pages.

Note:

The following figure depicts the page sequencing in case of alert. In this example, the alert is raised at epoch 2 second and its repetition at epoch 5.

T <sub>0</sub> [s]	E6-A Page ID	E6-A page part	E6-A content		L1-A content		L1-A page part	L1-A Page ID
-3	n-1	4/6	Initial field=00	Symbol page n-1 (4/6)	Initial field=00	Symbol page k (1/6)	1/6	k
-2	n-1	5/6	Initial field=00	Symbol page n-1 (5/6)	Initial field=00	Symbol page k (2/6)	2/6	k
-1	n-1	6/6	Initial field=00	Symbol page n-1 (6/6)	Initial field=00	Symbol page k (3/6)	3/6	k
0	n	1/6	Initial field=00	Symbol page n (1/6)	Initial field=00	Symbol page k (4/6)	4/6	k
1	n	2/6	Initial field=00	Symbol page n (2/6)	Initial field=00	Symbol page k (5/6)	5/6	k
2	n	3/6	Initial field=11	Symbol alert 1 Page (1/6)	Initial field=11	Symbol alert 1 Page (2/6)	6/6	k
3	n	4/6	Initial field=11	Symbol alert 1 Page (3/6)	Initial field=11	Symbol alert 1 Page (4/6)	1/6	k+1
4	n	5/6	Initial field=11	Symbol alert 1 Page (5/6)	Initial field=11	Symbol alert 1 Page (6/6)	2/6	k+1
5	n	6/6	Initial field=11	Symbol alert 1 Page (2/6)	Initial field=11	Symbol alert 1 Page (1/6)	3/6	k+1
6	n+1	1/6	Initial field=11	Symbol alert 1 Page (4/6)	Initial field=11	Symbol alert 1 Page (3/6)	4/6	k+1
7	n+1	2/6	Initial field=11	Symbol alert 1 Page (6/6)	Initial field=11	Symbol alert 1 Page (5/6)	5/6	k+1
8	n+1	3/6	Initial field=00	Symbol page n+1 (3/6)	Initial field=00	Symbol page k+1 (6/6)	6/6	k+1
9	n+1	4/6	Initial field=00	Symbol page n+1 (4/6)	Initial field=00	Symbol page k+1 (1/6)	1/6	k+2
10	n+1	5/6	Initial field=00	Symbol page n+1 (5/6)	Initial field=00	Symbol page k+1 (2/6)	2/6	k+2
11	n+1	6/6	Initial field=00	Symbol page n+1 (6/6)	Initial field=00	Symbol page k+1 (3/6)	3/6	k+2
12	n+2	1/6	Initial field=00	Symbol page n+2 (1/6)	Initial field=00	Symbol page k+1 (4/6)	4/6	k+2
13	n+2	2/6	Initial field=00	Symbol page n+2 (2/6)	Initial field=00	Symbol page k+1 (5/6)	5/6	k+2
14	n+2	3/6	Initial field=00	Symbol page n+2 (3/6)	Initial field=00	Symbol page k+1 (6/6)	6/6	k+2

In this scenario, the data n, n+1 on E6-A, k and k+1 on L1-A (see nominal sequencing) are lost: 4 nominal pages are lost (this is the worst case).

#### 6.2.4.4 Page Contents

##### SISICD-2964 : G/NAV alert page with alert coded on 1 bit

In case of satellite failure only, the alert shall be transmitted through the data formatted according to the figure below.

Type=2	Clever Word	IA1	IA2	IA3 ... IA34	IA35	IA36	Spare	CRC	Total [bits]
4	3	1	1	32	1	1	109	12	164

The parameters for G/NAV alert page with alert coded on 1 bit are:

- Clever word (3 bits)
- CRC is the 12 MSB of the CRC defined in section 7.1.5.3.
- IA<sub>i</sub> (1 bit) for Integrity alert which has the following definition.

Value	IA <sub>i</sub>
1	OK
0	NOK

##### SISICD-2970 : G/NAV alert page with alert coded on 4 bits

In case of Ground Segment failure, this alert shall be transmitted according to the figure below.

Type=1	Clever Word	IA1	IA2	IA3 ... IA34	IA35	IA36	Spare	CRC	Total [bits]
4	3	4	4	128	4	4	1	12	164

The parameters for G/NAV alert page with alert coded on 4 bits are:

- Clever word (3 bits)
- CRC is the 12 MSB bits of the CRC defined in section 7.1.5.3
- IA<sub>i</sub> (4 bits) for Integrity alert as described in requirement SISICD-2271

### SISICD-2974 : G/NAV navigation data pages

The navigation useful data (Ephemeris, Clock corrections and Time parameters) shall be formatted in the encrypted nominal pages according to the figures below.

Type=1	IOD <sub>nav</sub>	SV <sub>ID</sub>	Clock correction				Ephemeris (1/3)			Spare	Total [bits]
			t <sub>oc</sub>	a <sub>10</sub>	a <sub>11</sub>	a <sub>12</sub>	t <sub>e</sub>	M <sub>0</sub>	OMEGADOT		
4	10	6	14	31	21	6	14	32	24	2	164

Type=2	IOD <sub>nav</sub>	Ephemeris (2/3)					E6-A <sub>HS</sub>	L1-A <sub>HS</sub>	Spare	Total [bits]
		e	A <sup>1/2</sup>	OMEGA <sub>0</sub>	I <sub>0</sub>	Δn				
4	10	32	32	32	32	16	2	2	2	164

Type=3	IOD <sub>nav</sub>	Ephemeris (3/3)								SISA(L1-A,E6-A)	Total [bits]
		OMEGA	IDOT	C <sub>UC</sub>	C <sub>US</sub>	C <sub>RC</sub>	C <sub>RS</sub>	C <sub>IC</sub>	C <sub>IS</sub>		
4	10	32	14	16	16	16	16	16	16	8	164

**Figure 6.58: Bits allocation for G/NAV page type 3**

Type=4	BGD(L1A,E6A)	Ionospheric correction					GST-UTC Conversion							Spare	Total [bits]				
		AZ			Ionospheric disturbance flag		A <sub>0</sub>	A <sub>1</sub>	Δt <sub>LS</sub>	t <sub>bt</sub>	WN <sub>t</sub>	WN <sub>LSF</sub>	DN			Δt <sub>LSF</sub>			
		a <sub>10</sub>	a <sub>11</sub>	a <sub>12</sub>	Region 1	Region 2													
4	10	11	11	14	1	1	1	1	1	32	24	8	8	8	8	3	8	10	164

Type=5	GST-GPS Conversion				Spare	Total [bits]
	$t_{0G}$	$A_{0G}$	$A_{1G}$	$WN_{0G}$		
4	8	16	12	6	118	164

### SISICD-2987 : Almanac pages

The Almanac useful data shall be formatted in the encrypted nominal page according to the figure below.

Type=6	IOD <sub>a</sub>	WN <sub>a</sub>	t <sub>oa</sub>	Almanac										Spare	Total [bits]			
				SVID	$\Delta(A^{1/2})$	e	OMEGA	$\delta_i$	OMEGA <sub>0</sub>	OMEGADOT	M <sub>0</sub>	a <sub>i0</sub>	a <sub>r1</sub>			E <sub>6</sub> -A <sub>HS</sub>	L <sub>1</sub> -A <sub>HS</sub>	
4	4	2	10	6	13	11	16	11	16	11	16	16	16	13	2	2	11	164

### SISICD-2988 : G/NAV Integrity Table

The G/NAV integrity table useful data shall be formatted in the encrypted nominal pages according to the figure below.

Type=7	ToC	SV <sub>1</sub>		SV <sub>2</sub> ... SV <sub>17</sub>								SV <sub>18</sub>		Spare	CRC	Total [bits]
		SNF	IF	SNF/IF								SNF	IF			
4	8	3	4	112								3	4	2	24	164



Type=8	SV <sub>19...SV<sub>36</sub></sub>			Clever Word	Spare	CRC	Total [bits]
	SNF/IF						
4	126			3	7	24	164

**SISICD-2993 : Page type 9**

The page type 9 pages shall be formatted in an encrypted page according to the figure below.

Type=9	N/A			Total [bits]		
4	see [RD.17]			see [RD.17]		

# Bibliografy

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- [1] Kaplan – Understanding GPS
- [2] Tsui JB-Y - Fundamentals of global positioning system (GPS)
- [3] AD-08 GAL-ICD-GLI-SYST-A-0258