Operation of the Radio Occultation Mission in KOMPSAT-5

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Korea multi-purpose satellite-5 (KOMPSAT-5) is a low earth orbit (LEO) satellite scheduled to be launched in 2010. To satisfy the precision orbit determination (POD) requirement for a high resolution synthetic aperture radar image of KOMPSAT-5, KOMPSAT-5 has atmosphere occultation POD (AOPOD) system which consists of a space-borne dual frequency global positioning system (GPS) receiver and a laser retro reflector array. A space-borne dual frequency GPS receiver on a LEO satellite provides position data for the POD and radio occultation data for scientific applications. This paper describes an overview of AOPOD system and operation concepts of the radio occultation mission in KOMPSAT-5. We showed AOPOD system satisfies the requirements of KOMPSAT-5 in performance and stability.

**Keywords:** atmosphere occultation precision orbit determination, integrated GPS occultation receiver, precision orbit determination, radio occultation, Korea multi-purpose satellite-5

1. INTRODUCTION

Korea multi-purpose satellite-5 (KOMPSAT-5) should have a very high level of orbit determination precision by the precise observation requirements of the synthetic aperture radar (SAR) which is the main payload. For this, Korea Astronomy and Space Science Institute (KASI) is to install the atmosphere occultation precision orbit determination (AOPOD), as a sub-payload, consisting of integrated global positioning system occultation receiver (IGOR), space-borne dual frequency GPS receiver, and a laser retro reflector array (LRRA) which is for the satellite laser ranging (SLR) used in the orbit determination verification, and carrying out the research on the installation of the AOPOD system, performance verification and the operation strategy.

We performed the establishment of the ground test bed using IGOR engineering model (EM) and carried out electrical test bed (ETB) test. Based on these, we conducted various test including flight model (FM) performance test, system integration and EMI/EMC (Montenbruck et al. 2005). We are also performing researches, based on the results, on the operation strategies for the individual scenarios for the IGOR operation. In this article, we introduce the AOPOD system that is supposed to be installed to the KOMPSAT-5 as the sub-payload and present the results of the study about the operation strategies for the effective GPS radio occultation data gathering which is the satellite mission firstly performed in Korea. GPS radio occultation data can be utilized in various scientific applications including monitoring of atmosphere and ionosphere of the earth as well as weather forecast (Wickert et al. 2001).

In Section 2 of this article, we describe the composition and functions of the space-borne dual frequency GPS receiver as well as the operation strategies depending on the operation phase and mode of the KOMPSAT-5. Section 3 presents the study of the GPS radio occultation operation strategies. Finally, the conclusions and future works are described in Section 4.
2. THE SPACE-BORNE DUAL FREQUENCY GPS RECEIVER

2.1 Composition of the space-borne dual frequency GPS receiver (IGOR)

The AOPOD system of KOMPSAT-5 is composed of the IGOR, the space-borne dual frequency GPS receiver (Fig. 1a), and the LRRA for SLR (Fig. 1b). The space-borne dual frequency GPS receiver, produced by Broad Reach Engineering (BRE), USA, is based on the BlackJack receiver developed by NASA/JPL of which performance and stability was already verified as it was installed to the successful low earth orbit (LEO) satellite programs including JASON-1, SAC-C, CHAMP, GRACE, COSMIC and TerraSar-X (Williams et al. 2002). The space-borne dual frequency GPS receiver employs two occultation antennas (Fig. 2a) and two POD antennas (Fig. 2b).

The laser reflector in Fig. 1b, constructed by connecting the prism type reflectors in a certain form, is the...
4-corner cube laser reflector produced by GeoForschungsZentrum (GFZ) Potsdam, Germany.

The basis specifications of the IGOR receiver are shown in Table 1. As shown in Fig. 3, IGOR consists following 5 parts: the RF receiving part to receive 4 RF signals, the digital part where the GPS signals are digitalized, the data storage device part consisting of a 128 M byte solid state recorder (SSR), the 1553B interface part for the MIL-STD-1553B communication with the spacecraft, and the ground test interface part for the ground test and RS-422 communication. In particular, all the parts except the RF receiving part are duplexed to secure the receiver stability (KASI 2009b). In the case of KOMPSAT-5, a total of 4 filter/preamp assemblies are installed in between the RF input port and the antenna in order to reduce the signal interference caused by the SAR signal. Fig. 1a shows one filter/preamp assembly installed to the top of the receiver of the IGOR. Two POD antennas and two occultation antennas are connected to the four RF input ports of the IGOR receiver (Lee et al. 2007).

### Table 1. KOMPSAT-5 IGOR specification.

<table>
<thead>
<tr>
<th>IGOR</th>
<th>Specification</th>
</tr>
</thead>
<tbody>
<tr>
<td>Dimension</td>
<td>21.8 × 24.0 × 14.4 cm</td>
</tr>
<tr>
<td>Mass</td>
<td>4.20 kg</td>
</tr>
<tr>
<td>Peak power</td>
<td>~ 25 W</td>
</tr>
<tr>
<td>RF port</td>
<td>4 × RF input</td>
</tr>
<tr>
<td>GPS channels</td>
<td>12 max. on each RF port</td>
</tr>
<tr>
<td>S/C bus I/F</td>
<td>MIL-STD-1553B</td>
</tr>
<tr>
<td>Internal data storage</td>
<td>128 M byte solid state recorder</td>
</tr>
</tbody>
</table>

KOMPSAT-5: Korea multi-purpose satellite-5, IGOR: integrated GPS occultation receiver, RF: radio frequency, GPS: global positioning system.

![Fig. 3. Integrated GPS occultation receiver interface diagram.](http://jansss.kr)
2.2 IGOR data gathering and function test

The GPS signals received by the GPS antenna are stored in the SSR, the data storage device part, through the RF receiving part and the digital part. Since the capacity of the SSR data storage device is limited, the data is overwritten from the initial storage space of the SSR if the capacity of the received GPS data exceeds the SSR capacity. The current storage address of the raw data can be known through the telemetry. The GPS raw data stored in this way is transferred to the mass memory of KOMPSAT-5 and then transferred to and stored in the data storage server of the ground data center. The stored GPS raw data is transferred to the data processing server which processes the data to the receiver independent exchange (RINEX) format, the standard GPS data format, and store it. The GPS data processed in the ground data center can be used in various studies of the atmosphere and ionosphere including determination of satellite orbit and estimation of the temperature and pressure, vapor distribution and electron density in the atmosphere. The function of the IGOR is to provide the POD data for the determination of the precise satellite orbit and the GPS radio occultation data for scientific application research. KASI and Korea Aerospace Research Institute (KARI) carried out the tests to verify the performance and functions of the IGOR using GSS7700, the GPS signal simulator produced by Spirent, the 1553B control PC which is the data input/output interface, and the IGOR EM. Currently, KASI is carrying out the test of FM. The key test items are listed in Table 2 and the ETB for the IGOR EM test is shown in Fig. 4 (Choi et al. 2008).

3. GPS RADIO OCCULTATION OPERATION

3.1 GPS radio occultation

Radio occultation refers to the phenomenon where the celestial body such as a planet or star of which apparent size is small is occulted by the celestial body of which apparent size is large such as the moon or Jupiter. The signal delay phenomenon caused by the refraction of the radio wave by the atmosphere of a planet that occurs when the radio wave passes through the planet’s atmosphere is also referred to as radio occultation. The GPS signal that is transferred from the GPS satellites at the altitude of approximately 20,200 km to the LEO satellites at the altitude of 250-1,500 km may also undergo refraction as it pass through the earth’s atmosphere depending on the geometric arrangement of the two satellites. This is the GPS radio occultation that is found in the LEO satellites and Fig. 5 shows the basic principle of it (Wickert et al. 2001).

![Fig. 4. Integrated global positioning system occultation receiver electrical test bed test.](image)

Table 2. IGOR test items and descriptions.

<table>
<thead>
<tr>
<th>Test Item</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>POD data reception</td>
<td>Data acquisition for POD</td>
</tr>
<tr>
<td>GPS data storage</td>
<td>Storing GPS data in IGOR</td>
</tr>
<tr>
<td>GPS data format</td>
<td>Translation IGOR’s raw data into the GPS RINEX data format</td>
</tr>
<tr>
<td>GPS tracking channels</td>
<td>Assignment the 12 GPS tracking channel</td>
</tr>
<tr>
<td>Occultation data reception</td>
<td>Data acquisition for GPS radio occultation</td>
</tr>
<tr>
<td>Application code upload</td>
<td>Return to the initial status of receiver or IGOR’s firmware upgrade</td>
</tr>
<tr>
<td>IGOR redundancy</td>
<td>High availability for IGOR’s stability</td>
</tr>
<tr>
<td>Spacecraft BUS I/F</td>
<td>Interface between the satellite and the ground station with the command/telemetry</td>
</tr>
<tr>
<td>Data Interval</td>
<td>Changing the GPS data interval rate</td>
</tr>
<tr>
<td>Occultation parameters</td>
<td>Setting the parameters values for occultation</td>
</tr>
</tbody>
</table>

POD: precision orbit determination, GPS: global positioning system, IGOR: integrated GPS occultation receiver.
Eq. (1) can be arranged to Eq. (2), as the equation with respect to atmospheric refraction index, by the Abelian transformation (Fjeldbo et al. 1971, Hajj et al. 2002).

\[
\alpha(a) = 2 \int_{a_{1}}^{a} d\alpha = 2a \int_{a_{1}}^{a} \frac{1}{\sqrt{r^2 - a^2}} \frac{d \ln(n)}{dr} dr 
\]

(1)

\[
n(r) = \exp \left[ \frac{1}{\pi} \int_{a_{1}}^{a} \frac{\alpha}{\sqrt{r^2 - a^2}} da \right]
\]

(2)

where \( a_{1} = nr \).

Using the atmospheric refraction index derived from the bending angle \( \alpha \) through the signal delay considering Doppler’s effect, the temperature, pressure and the amount of vapor can be calculated. These coefficients are necessary in constructing global atmospheric model and usefully applied in weather forecast and climate monitoring. In addition to the atmospheric refraction index, the total electron density (TEC) of the ionosphere can be calculated from the signal delay to apply it to the ionosphere modeling and the space environment forecast.

Lee et al. (2007) estimated the number of GPS radio occultation occurrences obtainable in one day by KOMP-SAT-5 using the GPS radio occultation simulation software, end-to-end GNSS occultation performance simulator 4 (EGOPS 4). Considering the geometric arrangement of the GPS satellite and KOMP-SAT-5 and the signal bending effect using the exponential atmospheric model, the number of GPS radio occultation occurrence obtainable from the occultation antennas installed to the satellite afterward and forward was 500, approximately. However, the actual number of GPS radio occultation occurrence may be less than 400 because, in the actual operation in the orbit, the field of view of the antennas is limited by the main body of the satellite and the solar cell plate, and the data-obtaining rate of the afterward antenna is lower than that of the forward antenna.

### 3.2 Operation of KOMP-SAT-5 IGOR

The system operation phase of KOMP-SAT-5 is constituted as shown in Fig. 6 (KARI 2008). The pre-launch phase is the ground test stage before the satellite launching and the test stage of the current KOMP-SAT-5. The launch and early operation phase is the stage after the initial satellite launching but just before the satellite begins the normal mission in the normal orbit. Finally, the mission operation phase is the stage where KOMP-SAT-5 carries out its mission in the normal orbit. In this study, the IGOR operation scenario was constituted with the two phases and eight modes shown in Table 3 based on the KOMP-SAT-5 operation phases in Fig. 6. The POD only phase is the stage that is operated in the case where the basic performance status of the IGOR receiver and the basic constitution status are verified and only POD data is collected. The POD+OCC phase is the operation stage to obtain POD and occultation data together and

![Fig. 5. Global positioning system radio occultation geometry.](image)

![Fig. 6. Korea multi-purpose satellite-5 system operation phases.](image)

**Table 3. IGOR operation phases & modes.**

<table>
<thead>
<tr>
<th>Phase</th>
<th>Mode</th>
</tr>
</thead>
<tbody>
<tr>
<td>POD only phase</td>
<td>POD primary (default mode)</td>
</tr>
<tr>
<td></td>
<td>POD redundant</td>
</tr>
<tr>
<td>POD+OCC phase</td>
<td>POD primary + OCC forward</td>
</tr>
<tr>
<td></td>
<td>POD primary + OCC afterward</td>
</tr>
<tr>
<td></td>
<td>POD redundant + OCC forward</td>
</tr>
<tr>
<td></td>
<td>POD redundant + OCC afterward</td>
</tr>
<tr>
<td></td>
<td>POD primary + OCC forward + OCC afterward</td>
</tr>
<tr>
<td></td>
<td>POD redundant + OCC forward + OCC afterward</td>
</tr>
</tbody>
</table>

POD: precision orbit determination, OCC: occultation.
it generally follows POD only phase. In addition, the operation modes of the individual phases were constituted depending on the performed functions in relation to the duplexing of the internal system of the IGOR.

During the initial operation, the IGOR works in the POD primary mode of the POD only phase in the digital B board. When the POD primary is working abnormally, the mode is converted to the POD redundant mode of the digital A board. Abnormal IGOR operation include the cases when an abnormal electric potential is applied to the IGOR receiver, when the GPS signal is not received continually for a certain duration after the initial booting of the IGOR receiver, and when the GPS signal is not received continually after the GPS signal that has been received normally by IGOR is cut. The conversion from the primary mode to the redundant mode is not automatically performed but by the remote command transmission, because an abnormal IGOR power supply to the IGOR can cause malfunction of the primary mode and the automatic conversion to the redundant mode can cause malfunction of the redundant mode as well, and thus affect the entire IGOR receiver. The POD primary mode and the redundant mode of the IGOR POD cannot be operated at the same time, but only either of them can. In addition, the occultation cannot be performed independently, but always together with the POD primary or redundant mode performance. Table 4 shows the five operation command categories that were constituted to operate the phases and modes of the IGOR and the individual operation command categories are composed of the remote command sets.

The IGOR operation is conducted in the following four modes in order: booting, fast search, slow search and normal operation. The fast search is the stage to find the basic GPS satellite signals for the IGOR operation and the slow search is the mode where the GPS signals are received using all the channels including the GPS signals received in the fast search mode and the Doppler values are calculated. Following the initial power supply to IGOR, all the steps are automatically conducted in order from the booting to the normal operation. The time flow status according to the general IGOR operation is shown in Table 5. The receiver operation status according to the IGOR operation shown in Table 5 can be changed depending on the KOMPSAT-5 environment and the arrangement of the GPS satellites (KASI 2009c).

As shown in Table 6, IGOR should set the initial parameters to perform the basic functions of the GPS receiver. The IGOR carries out the functions as it is under operation by applying the values in Table 6, and the parameters can be varied depending on the operation scenario if necessary. After the initial booting of the IGOR, one POD antenna is activated and the other antennas are in the inactivated state as shown in Table 6. Hence, for the operation, the ground station of the KOMPSAT-5 should transmit remote commands related to the antennas to convert the antenna state to the one that is appropriate to the operation scenario.

### 3.3 IGOR occultation parameter setting

The operation of the GPS radio occultation of the IGOR receiver is for the effective gathering of various scientific

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**Table 4. IGOR command categories.**

<table>
<thead>
<tr>
<th>Items</th>
<th>Command sets</th>
</tr>
</thead>
<tbody>
<tr>
<td>Receiver control</td>
<td>IGOR power on/off</td>
</tr>
<tr>
<td></td>
<td>Setting default configuration</td>
</tr>
<tr>
<td></td>
<td>Rebooting sequence</td>
</tr>
<tr>
<td></td>
<td>Application code upload</td>
</tr>
<tr>
<td></td>
<td>Setting the output data</td>
</tr>
<tr>
<td>POD operation</td>
<td>Primary POD operation</td>
</tr>
<tr>
<td></td>
<td>Redundant POD operation</td>
</tr>
<tr>
<td></td>
<td>Data sampling interval</td>
</tr>
<tr>
<td>Occultation operation</td>
<td>Forward occultation operation</td>
</tr>
<tr>
<td></td>
<td>Afterward occultation operation</td>
</tr>
<tr>
<td></td>
<td>Forward + afterward occultation operation</td>
</tr>
<tr>
<td></td>
<td>Setting the occultation parameters</td>
</tr>
<tr>
<td></td>
<td>Create the occultation parameter</td>
</tr>
<tr>
<td>Antenna configuration</td>
<td>Setting antenna configuration</td>
</tr>
<tr>
<td></td>
<td>Check antenna configurations</td>
</tr>
<tr>
<td>Status check</td>
<td>Check IGOR’s default setting value</td>
</tr>
<tr>
<td></td>
<td>Check output ports</td>
</tr>
<tr>
<td></td>
<td>Check occultation parameters</td>
</tr>
<tr>
<td></td>
<td>Check IGOR’s directory information</td>
</tr>
</tbody>
</table>

IGOR: integrated GPS occultation receiver, POD: precision orbit determination.

**Table 5. IGOR start-up and boot timeline.**

<table>
<thead>
<tr>
<th>Elapsed time (min:sec)</th>
<th>Activity</th>
</tr>
</thead>
<tbody>
<tr>
<td>From power-on</td>
<td>For each activity</td>
</tr>
<tr>
<td>0:00</td>
<td>- IGOR power on or reset</td>
</tr>
<tr>
<td>2:00</td>
<td>- Boot mode begins</td>
</tr>
<tr>
<td>2:13</td>
<td>- IGOR initializes to saved or default settings</td>
</tr>
<tr>
<td>3:53</td>
<td>- Typical end of fast search</td>
</tr>
<tr>
<td>5:23</td>
<td>- Typical end of slow search</td>
</tr>
</tbody>
</table>

IGOR: integrated GPS occultation receiver.
data to be used in the monitoring of the atmosphere and ionosphere of the earth as well as weather forecast. It consists of control of the receiver constitution status, remote commanding, monitoring of the receiver and data status, trouble-shooting and alteration of the occultation parameters. In Table 3, the POD+OCC phase is divided into six modes depending on the GPS radio occultation functions of the IGOR and the KOMPSAT-5 operation scenarios. Additionally, for the effective occultation in each mode, four sets of occultation parameters were generated: setting atmospheric occultation (OCCAFT), rising atmospheric occultation (OCCFWD), setting ionospheric occultation (IONOAFT) and rising ionospheric occultation (IONOFWD).

As shown in Table 7, the parameter sets for the individual occultation functions were divided into nine data fields and the values for each data field was set by considering the KOMPSAT-5 orbit and the occultation events (KASI 2009a).

RegionBottom, the key occultation parameter, means the altitude where the data gathering is started or finished by the occultation antenna referring the limb of the earth. RegionTop means the altitude where the data gathering is started or finished by the occultation antenna referring the limb of the earth or the angle of the satellite from the local horizontal.

The parameters in Table 7 can be modified or constituted into new parameters sets depending on the KOMPSAT-5 and the space environment (KASI 2009b). In the IGOR FM test using the occultation parameters in Table 7, the generation of the GPS radio occultation data was verified depending on the antenna setting and the parameters.

### Table 6. IGOR default setting values.

<table>
<thead>
<tr>
<th>Parameters</th>
<th>Default setting values</th>
</tr>
</thead>
<tbody>
<tr>
<td>Delivery rate of observables</td>
<td>1 Hz for POD and OCC observables</td>
</tr>
<tr>
<td>Internal rate of navigation solution</td>
<td>1 Hz</td>
</tr>
<tr>
<td>Output rate of navigation solution</td>
<td>0.1 Hz</td>
</tr>
<tr>
<td>Elevation mask for POD acquisition</td>
<td>10 above local horizon</td>
</tr>
<tr>
<td>Antenna configuration</td>
<td>ANTO (RF1) : Enabled, POD default</td>
</tr>
<tr>
<td></td>
<td>ANT1 (RF2) : Disabled, POD red</td>
</tr>
<tr>
<td></td>
<td>ANT2 (RF3) : Disabled, OCC FWD</td>
</tr>
<tr>
<td></td>
<td>ANT3 (RF4) : Disabled, OCC AFT</td>
</tr>
<tr>
<td>Number of satellites for POD &amp; OCC</td>
<td>POD : 10 (PODMaxSats)</td>
</tr>
<tr>
<td>Occultation mode</td>
<td>Disabled</td>
</tr>
<tr>
<td>AFT (setting) occultation</td>
<td>Enabled</td>
</tr>
<tr>
<td>FWD (rising) occultation</td>
<td>Disabled</td>
</tr>
</tbody>
</table>


### Table 7. KOMPSAT-5 IGOR occultation parameter set values.

<table>
<thead>
<tr>
<th>Field type</th>
<th>Field name</th>
<th>Parameter set</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>Char[4]</td>
<td>Antenna</td>
<td>RF4</td>
<td>For internal use - do not change</td>
</tr>
<tr>
<td>Double</td>
<td>Region bottom</td>
<td>-190</td>
<td>Altitude relative to the earth’s limb at which tracking the occultation satellite will cease, in km.</td>
</tr>
<tr>
<td>Double</td>
<td>Region top</td>
<td>135</td>
<td>Altitude at which setting/rising occultations begin. In km relative to the earth’s limb. Maximum is 250 km, min is 0 km</td>
</tr>
<tr>
<td>Double</td>
<td>DDBottom Limit</td>
<td>-15</td>
<td>Altitude at which software will switch from &quot;closed loop&quot; to &quot;open loop&quot; tracking. Highest altitude is +20 km, the lowest altitude is -100 km</td>
</tr>
<tr>
<td>Float</td>
<td>RegionAz</td>
<td>55</td>
<td>Azimuth half-angle from the anti-velocity vector. Maximum value is 75.</td>
</tr>
<tr>
<td>Bool</td>
<td>Enable</td>
<td>True</td>
<td>If true, occultations are enabled</td>
</tr>
<tr>
<td>Char</td>
<td>CARate</td>
<td>0</td>
<td>Frequency bias in Hz of the open loop atmospheric model</td>
</tr>
<tr>
<td>Char</td>
<td>P1Rate</td>
<td>3</td>
<td>Maximum number of occultation tracks (min = 0, max = 4)</td>
</tr>
<tr>
<td>Char</td>
<td>P2Rate</td>
<td>0</td>
<td>Range bias in 10 meter units, of the open loop atmospheric model</td>
</tr>
</tbody>
</table>

rameter set constitution, and the information needed to make the occultation plans for the emergent situations during the KOMPSAT-5 operation in the future was obtained.

4. CONCLUSIONS AND FUTURE WORKS

KOMPSAT-5 is a LEO earth-observation satellite of which main mission is to obtain high-precision images by the earth observation and it will be launched in 2010. According to the requirements of such a high-precision observation, the AOPOD system consisting of the spaceborne dual frequency GPS receiver and a LRRA for SLR is supposed to be installed to it for the first time in Korea. Particularly, the GPS radio occultation data that will be obtained by the AOPOD system will provide the vertical distribution of the physical values of the atmosphere and the ionosphere in a global scale.

In this article, the AOPOD system, the sub-payload of the KOMPSAT-5, and its functions were introduced and the operation strategy for the GPS radio occultation was described. Two phases and eight modes were established for the GPS radio occultation operation based on the KOMPSAT-5 operation phases and the various functions of IGOR. In addition, five IGOR operation categories were established and applied for the effective data gathering and each of the categories were constituted by the combination of various remote commands to perform the basic IGOR functions as well as the POD and occultation missions.

The KOMPSAT-5 occultation parameters referring to the KOMPSAT-5 orbit operation scenarios and the IGOR characteristics and they will be used in the AOPOD system operation when KOMPSAT-5 is operated in the future. KASI has developed KASI radio occultation processing system (KROPS), a GPS radio occultation data processing system, and it is under test, currently. The vertical distribution of the physical quantities in the earth's atmosphere will be obtained using the KOMPSAT-5 GPS radio occultation operation strategies suggested in this article. It will contribute to the study of the atmosphere and ionosphere as it is connected to the results that can be obtained from other space programs related to GPS radio occultation.

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