Introduction to Radio Frequency Interference Prediction and Mission Planning in KARI

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ABSTACT

Currently, the Korea Aerospace Research Institute (KARI) operates five low earth orbit (LEO) satellites and three geostationary earth orbit (GEO) satellites. The S-band frequency is used to transmit satellite commands and check status data, and the X-band frequency is used to receive satellite image. Recently, as the number of satellites in orbit increases, the radio frequency interference (RFI) in orbit is increasing dramatically, and as a result, satellite image reception and processing were frequently failed. RFI from the ground objects also exists, but interference mainly by space objects in orbit accounts for a large proportion. KARI is using parabolic antenna for satellite communication and RFI occurred at a high elevation angle, thus it is estimated to be RFI with an orbital object by showing periodicity. RFI has even occurred between GEO satellite and LEO satellites operated by the KARI, predicting and mitigating RFI between potential satellite groups and operating satellites to receive more stable satellite information. Potential satellite groups are added based on the satellite's frequency information or managed through geometric analysis at the time of actual RFI, and geometrical analysis between about 15,000 space objects is performed, especially when actual RFI occurs. The geometrical analysis between the potential satellite group and the operating satellite thus derived predicts when RFI is expected, and at that point, the operating satellite adopted a concept of operations that temporarily stops receiving images. In this study, the case study of RFI between KARI's satellites and other satellites was introduced, and the methodology for mitigating RFI and the satellite operation concept were described.

1. INTRODUCTION

The Korea Aerospace Research Institute is a Korean space development institution that operates a total of nine satellites as of August 2023, starting with KOMPSAT-1 in 1999. Figure 1 shows the current status of operating satellites and plans for new satellites in the future, and it is expected to operate more than 80 satellites by 2030 due to continuous launches.

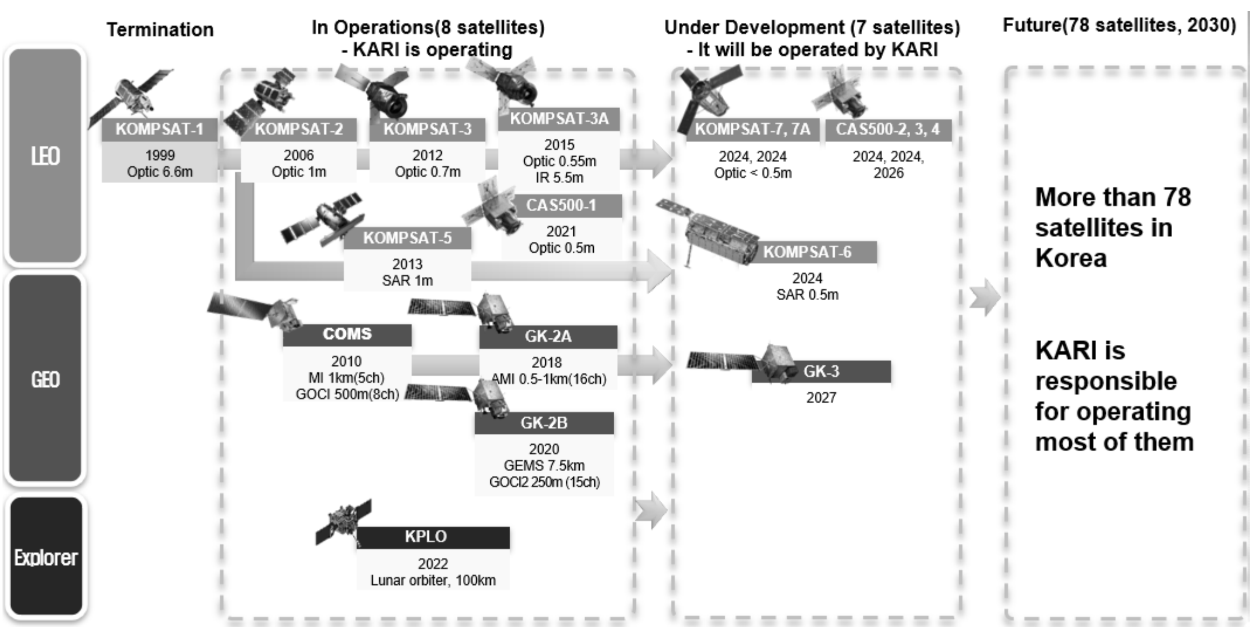

Fig. 1 Satellites Operations in KARI

In the case of low-orbit satellites, KOMPSAT-2, 3, 3a, and CAS500-1, the main mission is to acquire images using optical payloads, and KOMPSAT-5 uses SAR (Synthetic Aperture Radar) payloads to acquire images. In the case of geostationary satellites, the COMS satellite was launched in 2010 and is performing communication, ocean, and meteorological missions. In the case of GEO-KOMPSAT-2A, it is a satellite specialized for meteorological missions and GEO-KOMPSAT-2B is performing ocean mission mainly. These GEO satellites are operating near 128.15 degrees longitude. In the case of the lunar probe, it succeeded in launching in 2022 and is currently on a mission in lunar orbit.

As such, the ground station network as shown in Figure 2 is operated for the mission of various satellites. In the case of low-orbit satellites, the Jeju National Satellite Operation Center, which opened in 2022, is usually performing mission control and image reception, and Daejeon Ground Station uses them to launch and early operation phase of new satellites or recover satellite from abnormalities. In the case of low-orbit satellites, it is difficult to secure image reception time acquired due to the short communication time with ground stations, so it is carrying out image reception missions using the Svalbard ground station and DLR ground station. Meanwhile, in the case of geostationary tracks, Daejeon Ground Station is used as the main ground station and antenna, where installed in Yeoju, is used for lunar mission.

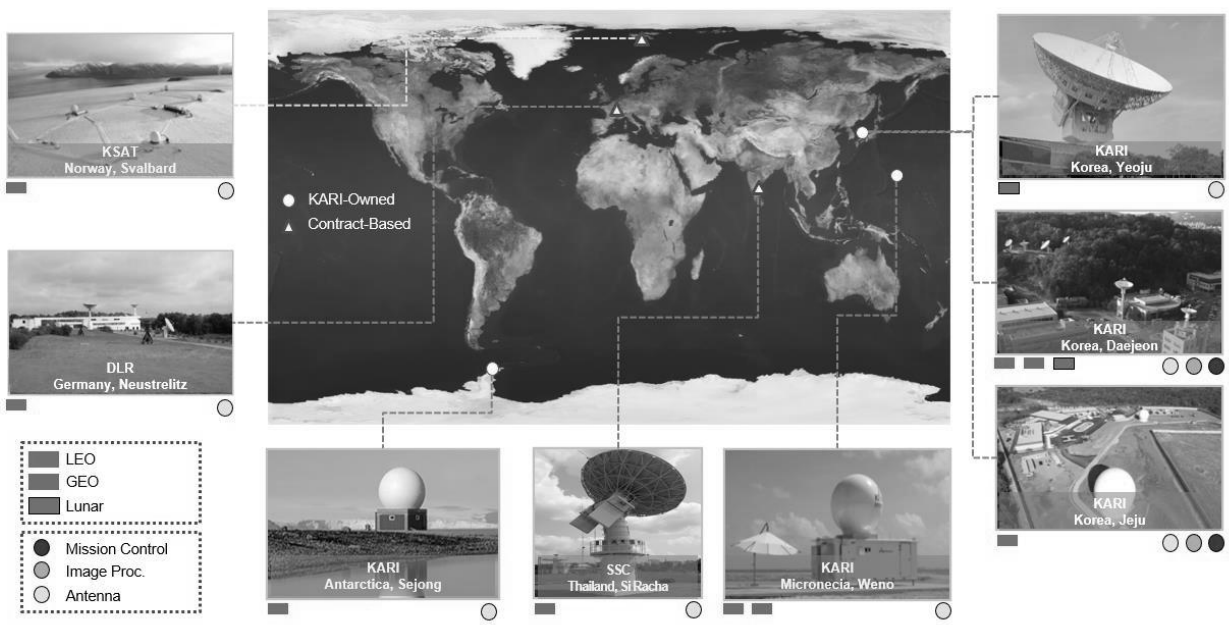

Fig. 2 KARI SOCN (Satellite Operations and Communication Network)

In the case of low-orbit satellites, the frequency of the S-band is used to receive telecommands sent to satellites and telemetries coming down from satellites, and in the case of satellite images reception, the X-band frequency is used to receive them.

Recently, problems that did not occur in the past have occurred in the process of satellite operation, and the representative phenomenon is the RFI (Radio Frequency Interference). Image reception fails have occurred due to the inflow of signals by the sun or other operating satellites, and image quality has deteriorated or cannot be processed, and damage such as opportunity costs is gradually increasing in the event of an emergency image.

This paper introduced actual cases that occurred in the process of operating KARI satellites and described procedures to prevent such RFI. After that, the limitations of the current operation method were considered and the direction of improvement of the procedure was introduced in preparation for the future operation status and the increase of satellites in orbit.

2. RFI PREDICTION HISTORY AND STATUS OF KARI

The initial appearance of RFI from KARI satellites was observed in September 2019, following the launch of GK-2A, a geostationary satellite. During this incident, an X-band interference signal disrupted the image reception process of GK-2A. Subsequently, two more instances of a similar nature were encountered, leading to failures in image reception. This marked the onset of a pattern wherein image reception failure due to RFI started happening once or twice a month. Consequently, efforts were initiated to identify the sources of interference through frequency analysis.

The area where radio interference took place was a ground station situated in Daejeon, Korea. As no radio interference was reported at ground stations in other parts of Korea, our initial investigation focused on the LEO satellites operated by the KARI.

Consequently, as illustrated in the figure 3 below, it was verified that during the occurrence of radio interference on October 26, the Daejeon ground station and the KOMPSAT-2, which is LEO satellite, and GK-2A, managed by the KARI, were positioned in a straight line geometrically. This implies that the angle formed by the ground station-K2 and ground station-GK-2A vectors was small from the ground station's perspective. As a result, it was deduced that significant signal interference transpired when the angle was below approximately 0.7 degrees. Subsequently, the intervening angle was projected, and measures were implemented to curtail image reception from Low Earth Orbit (LEO) satellites when the angle descended below 0.7 degrees. Similarly, Sun interference prediction started to be addressed by proposing image reception through geometric analysis.

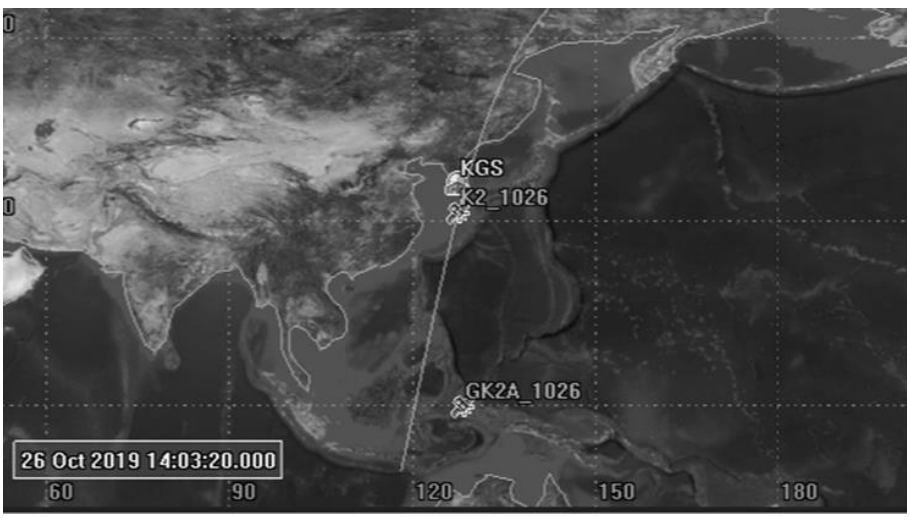

Fig. 3 Position of ground station, KOMPSAT-2 and GK-2A at 2019.10.26 14:03:20 (LOS angle 0.1 deg)

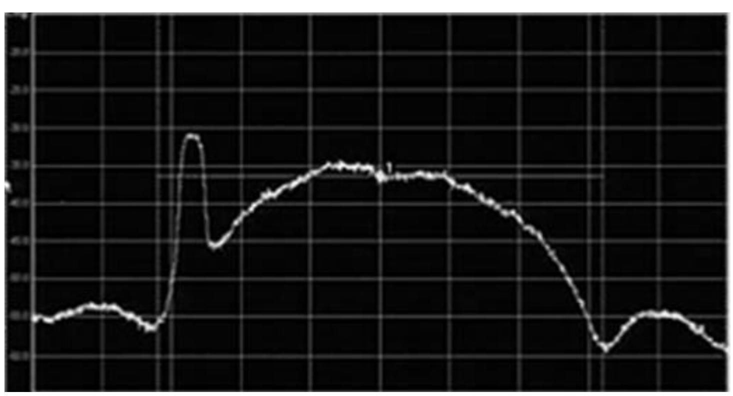
Fig. 4 GK-2A RFI event caused by KOMPSAT-2 from spectrum analyzer

All of the LEO satellites managed by KARI follow sun-synchronous orbits and traverse the Korean Peninsula at approximately the same times each day. Owing to this trait, recurring RFI is anticipated. As a result, an assessment of the angle between GK-2A and five low-orbit satellites was conducted over a three-month period. GK-2A is functioning within the station keeping box, maintaining an angle range of +/-0.05 degrees in relation to 128.25 degrees. Table 1 shows the orbital information for LEO satellites.

Table. 1 Orbit information for KARI constellation satellites

	KOMPSAT-2	KOMPSAT-3	KOMPSAT-5	KOMPSAT-3A	CAS500-1
Orbit Type	Sun Sync.	Sun Sync.	Sun Sync.	Sun Sync.	Sun Sync.
Altitude (km)	685	685	550	528	497
Repeat Day (day)	28	28	28	28	29
Repeat Orbit (rev)	409	409	421	423	441
LTAN (HH:MM)	10:50	13:30	06:00	13:30	11:00

Following the examination of the LOS(Light Of Sight) angle between low-earth orbit satellites and GK-2A, with the Daejeon ground station as the reference point, it was observed that KOMPSAT-2 had a total of 406 contact time with ground station where the LOS angle was less than 1 degree: 5 cases for KOMPSAT-2, 2 cases out of 406 contacts for KOMPSAT-3, and no occurrences out of 368 cases for KOMPSAT-5, with only one occurrence out of 363 cases for KOMPSAT-3A. Notably, a heightened frequency of such instances was detected with KOMPSAT-2. This pattern, as illustrated in the figure below, demonstrated a recurring occurrence of intersecting angles within a range of 3 degrees.

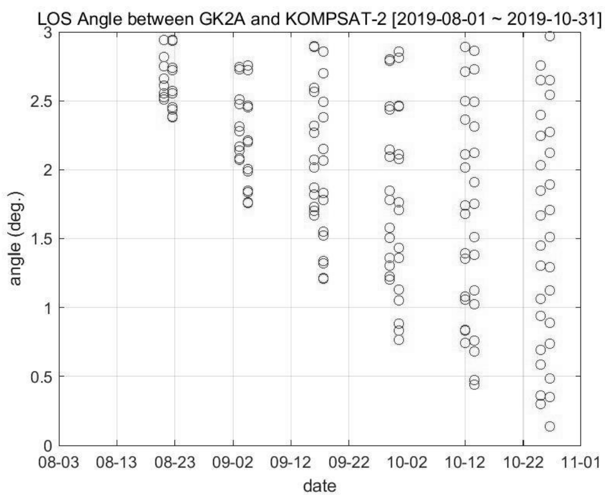

Fig. 5 LOS angle between GK-2A and KOMPSAT-2

Consequently, satellite operations were sustained by addressing the issue through the adjustment of image reception timings for LEO satellites, mitigating RFI problems between the KARI satellites. Figure 6 depicts the anticipated occurrences of RFI from both the Sun and the satellite, as components of the satellite event prediction outcomes generated by the flight dynamics system. This information is relayed to the Mission Planning System (MPS) and is employed to temporarily halt image reception during those periods.


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    </Property>
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Fig. 6 Event prediction example for RFI from Sun and other satellites
(i.e., left – Sun interference period, right – Object interference period)

In July 2020, another instance of RFI affecting KOMPSAT-5 occurred. The LOS angles of the LEO and GEO satellites of KARI during the RFI incident were examined, but no abnormal factors were identified. Utilizing the Satellite Catalog (SATCAT) data, active satellites were singled out, focusing solely on entities associated with the LEO. Consequently, approximately 10,000 objects were chosen for analysis. Among these, the objects traversing the Korean Peninsula at the time of the RFI were investigated, and the satellites responsible for the RFI were sought by scrutinizing the LOS angles of the final shortlisted objects.
Consequently, it was verified that the LOS angle between China's HAIYANG 2B satellite and KOMPSAT-5 for KGS ground station was exceedingly small, measuring 0.056 degrees. Recognizing that satellites from countries other than those operating KARI satellites could potentially contribute to RFI when utilizing comparable frequencies, additional operational protocols were established. Subsequently, adjustments to image reception times were made by identifying satellites that posed interference risks, such as FENGYUN, TIANHUI, JILIN, CFOSAT, and ZHANGZHENG. The presence of Chinese satellites, hailing from a neighboring country, is notably significant, and this observation is analyzed considering the geopolitical landscape. As of now, a total of 58 disruptive satellites have been identified, and the process of analyzing RFI involving the Sun and satellites is carried out on a daily basis in the subsequent sequence.

*** Object Interference Prediction**

A. Obtain bulk Two-Line Element (TLE) data from space-track.org.
B. Extract TLE data for interfering satellites. (59 satellites)
C. Predict orbits for KARI operational satellites (5 low orbits, 3 geostationary orbits) and interfering satellites for a span of 4 days.
D. Estimate contact time between ground stations (Arctic, Germany, Korean Peninsula) receiving images and KARI operational satellites.
E. Identify objects passing over the ground station during each contact time.
F. Analyze LOS angles, and if they fall within the criteria value (0.7 degrees), generate and transmit event data.
G. Repeat step F for all objects identified in step E.
H. If any new satellites prone to interference are identified during satellite operation, add them to the list of satellites susceptible to interference and incorporate this into future predictions for analysis.

*** Sun Interference Prediction**

A. Predict orbits for KARI operational satellites (5 in low orbit, 3 in geostationary orbit) for a span of 4 days.
B. Estimate contact time between ground stations (Arctic, Germany, Korean Peninsula) receiving images and KARI operational satellites.
C. Analyze the angles between the Sun and LOS at each communication instance; generate and transmit event data if the angle falls within the specified criteria value (0.7 degrees).

3. LIMITATIONS AND FUTURE PLAN

The RFI prediction for operational satellites is carried out daily using the aforementioned procedure, but the calculation process is quite time-consuming, even for the analysis of only five satellites. The current operational approach involves selecting a target satellite after an RFI incident occurs, which can be considered a somewhat passive response method. To mitigate the risk of image reception failures, it would be highly beneficial to define all available satellites as subjects of analysis. This could be achieved by actively expanding the analysis scope to include low Earth orbit or even full Earth orbit satellites, allowing for proactive prediction and response. Furthermore, given that KARI aims to operate over 80 satellites by 2030, the ability to rapidly calculate RFI becomes increasingly important. Due to the differing orbital paths of these satellites, the RFI results cannot be uniformly applied across the board. Consequently, as the number of operational satellites increases, the necessary calculation time will also rise proportionally.
The emergence of New Space presents an additional significant challenge. With the potential launch of numerous commercial satellites offering a variety of services, the likelihood of frequency interference surpassing current levels is substantial. Consequently, surpassing the limitations on computing capacity becomes a crucial endeavor.
In response to these challenges, KARI is actively working to transcend the existing limitations through research into novel analysis methods, such as geometric approaches like Voronoi diagrams.