J. Astron. Space Sci. 15(2), 417–425 (1998)

MONTE CARLO ANALYSIS FOR FIRST ACQUISITION AND TRACKING OF THE KOMPSAT SPACECRAFT

Byoung-Sun Lee and Jeong-Sook Lee
Satellite Comm. Department., Electronics and Telecommunications Research Institute
Yusong P.O.Box 106, Taejon 305-600, Korea
e-mail : lbs@mail.etri.re.kr, jsooklee@mail.etri.re.kr

(Received October 28, 1998; Accepted November 14, 1998)

ABSTRACT

Monte Carlo analysis is performed for the first acquisition and tracking of the KOMPSAT spacecraft in GSOC tracking station after separation from Taurus launch vehicle. The error bounds in position and velocity vector in Earth-fixed coordinate system at injection point are assumed based on the previous launch mission. Ten thousands injection orbital elements with normal distribution are generated and propagated for Monte Carlo analysis. The tracking antenna pointing errors at spacecraft rising time and closest approach time at German Space Operations Center(GSOC) Weilheim tracking station are derived. Then the tracking antenna scanning angles are analyzed for acquisition and tracking of the KOMPSAT signal.

1. INTRODUCTION

The first acquisition of the spacecraft signal after separation from launch vehicle is especially important in mission operations. The survival of the spacecraft and the performance of the launch vehicle are verified by the acquisition of the spacecraft telemetry. For the acquisition of the signal, the tracking antenna has to point toward the spacecraft path. The tracking antenna pointing data, such as azimuth and elevation angle, are calculated based on the spacecraft injection parameters provided by the launch operations team. Errors in injection parameters affect the tracking antenna pointing angle for the first acquisition and tracking of the spacecraft. When the pointing errors are small enough to acquire the signal of the spacecraft, the tracking antenna can automatically track the spacecraft. When the pointing errors are large, the ground station antenna has to scan the sky based on the predicted position for the acquisition of signal. In the worst situation, ground station antenna even fail to acquire the spacecraft signal.

In this paper, the tracking antenna pointing errors according to the initial injection state errors are analyzed for the KOMPSAT spacecraft. Similar analysis was performed by the same authors, Lee & Lee(1998), based on the errors in Keplerian orbital elements using random errors with uniform distributions. In this paper, position and velocity errors in Earth-Centered Fixed(ECF) coordinate are assumed based on the previous Taurus launch mission (Duquette 1998). Monte Carlo simulations are performed for tracking of the KOMPSAT spacecraft at Weilheim station operated by GSOC. Ten thousands random injection orbit states with normal distribution are generated and ten thousands antenna pointing errors are obtained at spacecraft rising time and the closest approach time in GSOC Weilheim station. Distributions of the pointing errors in azimuth and elevation angles are obtained. Also, tracking antenna scanning angles required for the acquisition and tracking of the KOMPSAT spacecraft are derived.

2. INJECTION OF THE KOMPSAT SPACECRAFT

Korea Multi-Purpose Satellite(KOMPSAT) will be launched in 1999 and used for cartography of Korean peninsula, ocean color monitoring, high energy particle detection, and ionosphere study. Taurus launch vehicle by Orbital Sciences Corporation will be used for injecting the KOMPSAT spacecraft into the Sun-synchronous orbit of 685 km altitude. Taurus will be launched at Vandenberg Air Force Base, California, U.S.A. The KOMPSAT spacecraft will be injected into the orbit at the Earth's equator of about 230° East longitude. The KOMPSAT launch window will be opened every day for about ten minutes and the spacecraft will be directly inserted into the mission orbit(OSC 1996). The estimated nominal position and velocity vector of the KOMPSAT in ECF coordinates at injection time, and the worst case uncertainty from previous Taurus T4 mission(Duquette 1998) are shown in Table 1.

Table 1. ECF position and velocity at injection point and worst case uncertainty.

Injection Epoch(year/month/day hour:min.:sec.)		1999/07/01 07:28:00	
Longitude and Latitude		30.19° E, 0.0°	
	X	Y	Z
ECF Position(km)	-4491.435	-5448.496	-0.0247
Worst Case Uncertainty(km)	±34	±38	±17
ECF Velocity(km/s)	-1.216673	1.03293	-7.443964
Worst Case Uncertainty(km/s)	±0.020	±0.024	±0.042

Figure 1 shows the ground track of the KOMPSAT for 12 hours after injection. In the course of the first orbit, the KOMPSAT can be contacted at Antarctica, Africa, and European countries. Currently, the first acquisition of the signal of the KOMPSAT will be occurred at GSOC Weilheim station in Germany. Figure 1 shows antenna coverage of Weilheim station and TaeJon station. The KOMPSAT will be contacted at Weilheim station in ascending pass of orbit number 1, 2, and 3. After that, the spacecraft will be contacted at Taejon station in descending pass to orbit number 5 and 6. The ascending pass is local morning time and the descending pass is local nighttime. Table 2 shows the location of the Weilheim station and TaeJon station(GSOC 1986).

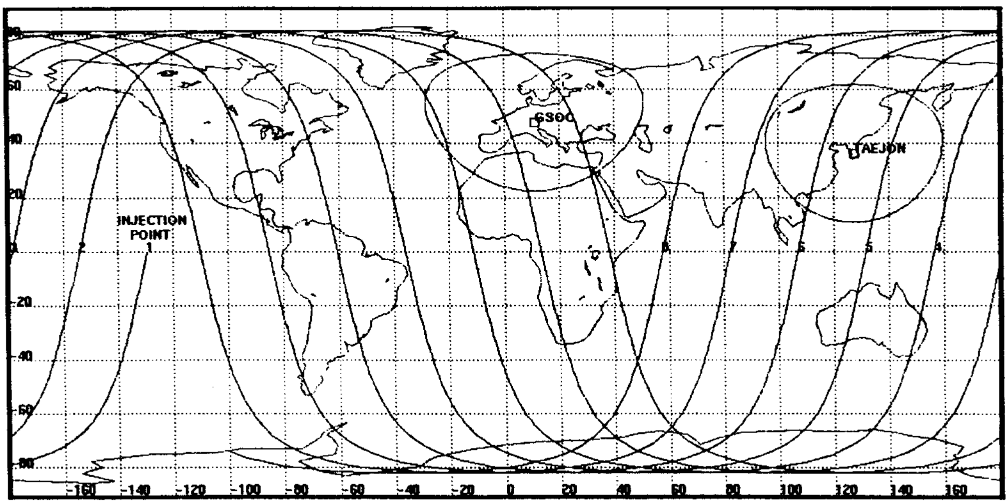

Figure 1. Ground Track of the KOMPSAT for 12 hours after injection.

Table 2. Geodetic Location of the GSOC and TaeJon Station.

Station	Longitude(° E)	Latitude(° N)	Height(m)	Antenna Diameter(m)
GSOC	11.085	47.880	662.143	15
TaeJon	127.3547	36.3748	93.507	9

3. MONTE CARLO ANALYSIS

Random numbers with normal distributions of 3-sigma values are generated using FORTRAN IMSL library functions(IMSL 1987). The worst case uncertainty values in Table 1 are considered as 3-sigma values. Ten thousands injection position and velocity vector sets in ECF coordinate system are generated and transformed to osculating Keplerian six elements to be used for orbit propagator. Table 3 shows the statistics of the ten thousands random position and velocity vector sets in ECF coordinate at injection time.

Table 3. Statistics of the ten thousands random position and velocity vector in ECF coordinate.

ECF coordinates	X(km)	Y(km)	Z(km)	VX(km/s)	VY(km/s)	VZ(km/s)
Nominal Value	-4491.435	-5448.496	-0.0247	-1.216673	1.003293	-7.443964
Mean Value	-4491.371	-5448.342	-0.160	-1.2165	1.0033	-7.4438
Standard Deviation	11.3465	12.5723	5.6981	6.7695E-3	8.0168E-3	0.0139
Minimum	-4530.772	-5499.2620	-21.7140	-1.2471	0.9719	-7.5034
Maximum	-4445.574	-5398.8440	21.1610	-1.1852	1.0339	-7.3936

Table 4. Statistics of the ten thousands random Keplerian orbital elements.

	a (km)	e	i (°)	Ω (°)	ω (°)	M (°)	$\omega + M$ (°)
Nominal Value	7072.423	1.60137E-3	98.120	81.415	179.996	0.006	180.002
Mean Value	7071.973	3.7905E-3	98.119	81.415	181.909	181.183	180.004
Standard Deviation	35.699	2.49310E-3	0.0578	0.0954	129.963	129.963	0.1285
Minimum	6942.754	2.51E-5	97.901	81.034	0.023	0.009	179.583
Maximum	7209.176	1.85E-2	98.316	81.782	359.991	359.999	180.464

Table 4 shows the statistics of the ten thousands random Keplerian orbital elements sets at injection time. Although the distributions of argument of perigee(ω) and mean anomaly(M) are very wide, the sum of ω and M varies within a certain boundary. In near circular orbit, the position of the spacecraft is defined by osculating ω and M.

Figures 2, 3, and 4 show the histogram of semi-major axis, eccentricity, and sum of argument of perigee and mean anomaly, respectively. The solid line in the Figures shows Gaussian curve based on the mean and standard deviation of the histogram. The histogram of the eccentricity in Figure 3 is somewhat biased because there are no minus values.

The tracking data such as azimuth and elevation at Weilheim station are predicted using ten thousand Keplerian injection orbital elements in Table 4. The orbit of the KOMPSAT is propagated using Markely & Jeletic(1991)'s analytical formula considering only J2 geopotential term. The spacecraft orbit propagation errors caused by using only J2 term are not important in this case because the propagation time is very short, i.e. about an hour, and the nominal values for comparison are also generated by using the same propagator. The topocentric azimuth and elevation angles are derived from the geocentric right ascension and declinations using standard coordinate transformation formula (Escobal 1975).

The statistics of the estimated tracking parameters at spacecraft rising time are shown in Table 5. The nominal values are calculated based on nominal injection parameters without errors. The off-axis angles are calculated base on the deviation from nominal azimuth and elevation. The Half-Power-Beam-Width(HPBW) of the 15-m tracking antenna at Weilheim station is calculated about 0.636° when S-band frequency is used (Lee & Lee 1998). When the off-axis angle is increased to half of the HPBW, the signal power is decreased to a half of maximum power. Only 472 out of ten thousands off-axis angles are found within the half of the HPBW of the 15-m tracking antenna. It means that the 4.72 % of acquisition probabilities are estimated when the 15-m tracking antenna

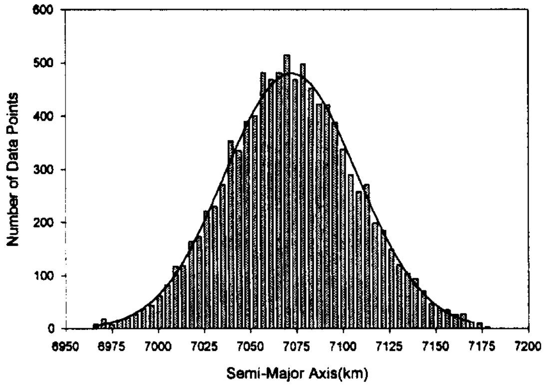

Figure 2. Histogram of Semi-Major Axis

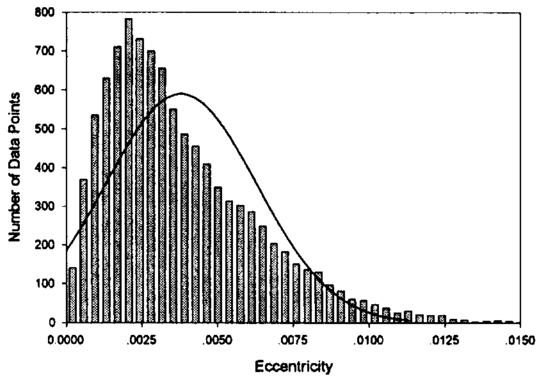

Figure 3. Histogram of Eccentricity

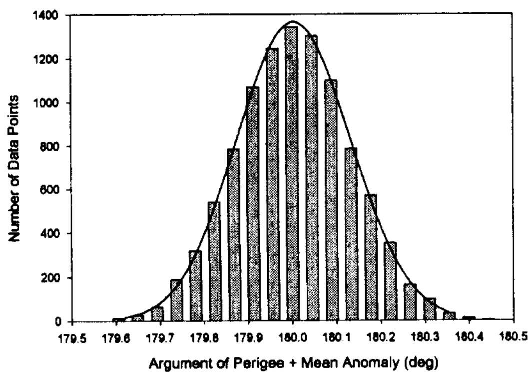

Figure 4. Histogram of the sum of ω and M.

in Weilheim station is directed fixed to the nominal azimuth and elevation in Table 5. In order to compensate the small acquisition probabilities, the tracking antenna should scan around the nominal pointing value at spacecraft rising time.

Table 5. Statistics of the tracking parameters at spacecraft rising time.

	Time	1999/07/01 08:27:00	
	Azimuth(°)	Elevation(°)	Off-axis angle(°)
Nominal Value	125.227	7.878	0.0
Mean Value	124.877	7.891	2.621
Standard Deviation	3.185	0.997	2.044
Minimum	107.782	5.002	7.0e-3
Maximum	132.975	12.591	17.795

Figures 5, 6, and 7 show the histogram of azimuth, elevation, and off-axis angles at spacecraft rising time. The solid line in the Figure also shows Gaussian curve based on the mean and standard deviation of the histogram. Distribution of the azimuth angles is three times wider than that of the elevation angles.

The statistics of the estimated tracking parameters at the closest approach time are shown in Table 6. The closest approach time is the maximum elevation time at the tracking station. Only 84 out of ten thousands off-axis angles are found within the half of the HPBW of the 15-m tracking antenna. It is 0.84 % of acquisition probabilities at the closest approach time to the tracking station. The signal of the spacecraft is hardly acquired when the tracking antenna points fixed to the nominal direction in Table 6.

Table 6. Statistics of tracking parameters at closest approach time.

	Time	1999/07/01 08:31:20	
	Azimuth(deg)	Elevation(deg)	Off-axis angle(deg)
Nominal Value	67.938	28.028	0.0
Mean Value	67.567	27.247	9.052
Standard Deviation	12.416	1.991	6.698
Minimum	26.397	14.391	0.027
Maximum	108.007	30.407	40.306

The results show that the scanning area of the tracking antenna for acquisition of the signal should be increased according to the elevation angle. The acquisition probability at maximum elevation angle is smaller than that at spacecraft rising time. It means that the tracking operation at the spacecraft rising time is very critical when there are errors in injection orbital elements. It is based on the assumption that the spacecraft signal power is enough to be detected by the tracking antenna in low elevation angles, i.e. the longer distances. When the tracking antenna fails to track the spacecraft at the beginning of the rising time, it is very difficult to scan and acquire the spacecraft signal at later time.

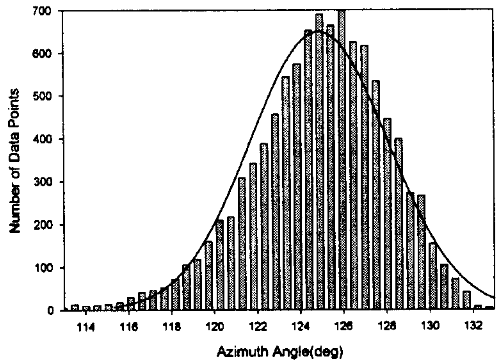

Figure 5. Azimuth angles at rising time

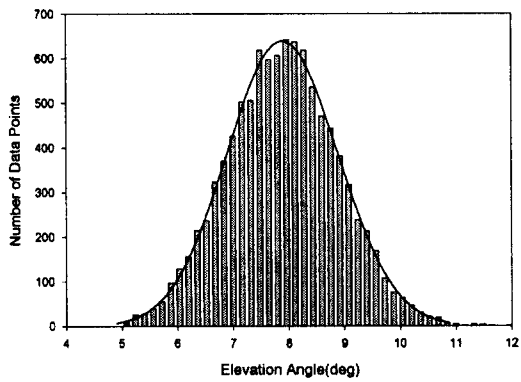

Figure 6. Elevation angles at rising time

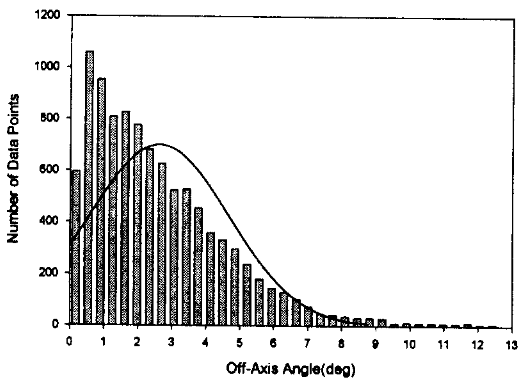

Figure 7. Off-axis angles at rising time

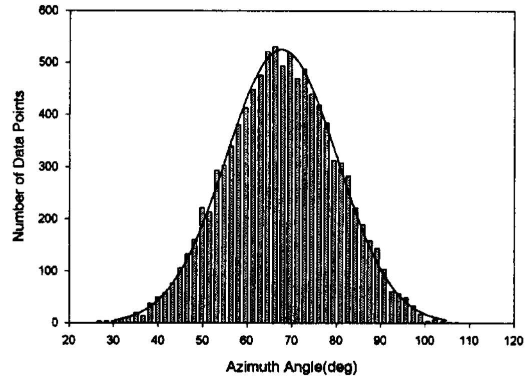

Figure 8. Azimuth angles at closest time.

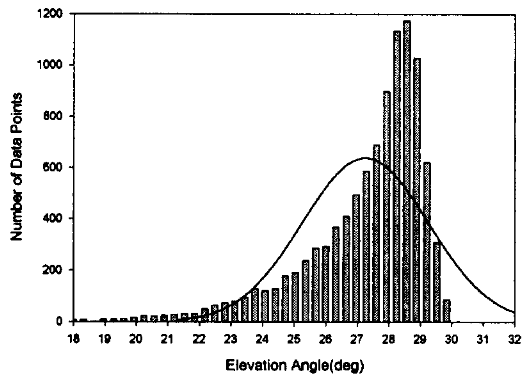

Figure 9. Elevation angles at closest time.

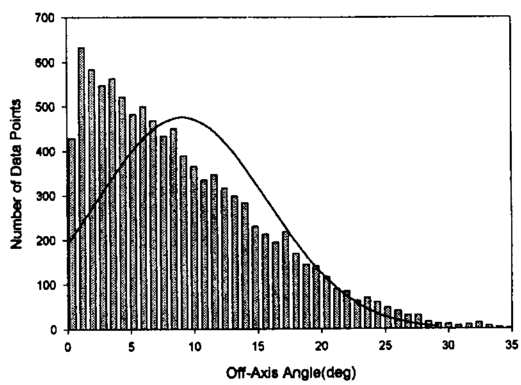

Figure 10. Off-axis angles at closest time.

Figures 8, 9, and 10 show the histogram of azimuth, elevation, and off-axis angles at the closest approach time. The solid line in the Figure also shows Gaussian curve based on the mean and standard deviation of the histogram. The distribution of the azimuth angles is six times wider than that of the elevation angles. The histogram of the elevation angles shows abnormal shape because the elevation angles are decreased after the closest approach time.

4. CONCLUSIONS

The tracking antenna pointing errors according to the initial injection orbit state errors are analyzed for the KOMPSAT spacecraft using the Monte Carlo simulation. Ten thousand orbital elements with normal distributions are used for estimating the off-axis angles at spacecraft rising time and the closest approach time in GSOC Weilheim tracking station. The results indicate that the tracking operation at the spacecraft rising time is very important for the KOMPSAT spacecraft when using the Taurus launch vehicle. The standard deviation of about two degrees off-axis angles are expected at the KOMPSAT rising time in GSOC Weilheim tracking station. Scanning and searching capabilities are required for the acquisition of the KOMPSAT signal at GSOC Weilheim station. The scanning angles in azimuth direction should be more wider because the distributions of the azimuth angles are three times bigger than that of elevation angles. The results of the analysis should be used for establishing the initial tracking operation scenarios. Monte Carlo analysis for estimating total delta-velocity requirement to the nominal mission orbit after injection should be performed for establishing launch and early orbit phase scenario.

ACKNOWLEDGEMENTS: This work was supported by Korea Ministry of Information and Communication(MIC).

References

Duquette, M. 1998, Predicted Accuracy of the T4 IMU State Vector in Cartesian Coordinates, Taurus Memorandum, TAR-9807-070

Escobal, P. R. 1975, Methods of Orbit Determination, 2nd ed.(John Wiley & Sons : New York), pp.318-359

GSOC 1986, The GSOC Ground Station Network User's Guide(GSOC:Oberpfaffenhofen), pp. 1-40.

IMSL 1987, User's Manual STAT/LIBRARY Vol.3 (IMSL:Houston), pp. 945-1062

Lee, B.-S. & Lee, J.-S. 1998, Proceedings of the KSAS Spring Annual Meeting '98, pp.557- 561

Markely, F. L. & Jeletic, J. F. 1991, J. of Guidance., 14, 473

OSC 1996, Taurus Configuration Overview for the KOMPSAT Mission, Presented to KARI June 26