Ranging Data Accuracy in K13 S-Band Antenna

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Abstract: Ranging and 2-way Doppler measurements are very essential source for orbit determination in LEOP (Launch and Early Operation). This paper shows ranging system features of 13M TT&C antenna and test results recently acquired with KOMPSAT-1. Ranging and 2-way Doppler measurements were compared with KOMPSAT-1 GPS telemetry data. Through comparison, it was found that constant and accurate ranging measurements are available with 13M antenna system. Ranging and Doppler measurement function is expected to be used for KOMPSAT-1 and KOMPSAT-2.
Key words: RANGING, DOPPLER, KOMPSAT, LEOP

1. Introduction

Most S-Band TT&C antenna system provides function to acquire tracking data as well as communication link provision. Such tracking data is very essential in LEO operation in that orbit determination can be performed by tracking data directly.

In general, tracking data consists of 3 elements; antenna angle measurement data, ranging measurement data, Doppler measurement data. These measurements are recorded in standard tracking file format like NASA UTDF, GEOS-C, and CCSDS with measurement time information in parallel.

Normally antenna angle measurement data is only valid when auto-tracking is made during pass because both wrong and inaccurate angle information can be totally useless.

Ranging measurement is distance measurement between spacecraft and ground station. For ranging measurement spacecraft should be configured to be coherent mode by ground command in advance.

Doppler measurement is to measure Doppler frequency of downlink frequency. For higher accuracy, 2-way Doppler measurement is preferred to 1-way method. 2-way Doppler measurement also requires coherent mode operation in on-board transponder system.

In KOMPSAT operation, ranging and Doppler measurement is not common because accurate GPS receiver is mounted in KOMPSAT. Very accurate position and velocity information is always available in telemetry data. But this kind of tracking function can be very critical in LEOP because GPS telemetry is not available in general and NASA TLE data is not available in timely manner in LEOP and end-user should perform orbit determination as soon as possible. Also there is a requirement to provide standard tracking data for TT&C support from other agencies. Currently operational K09 antenna has a feature to provide tracking data in GEOS-C format since 1999.

To increase antenna system availability, KARI added S-Band function into K13 antenna using FSS sub-reflector and S-Band auto-track feed assembly located in focal points of main reflector. After installation, only command and telemetry function were verified since tracking data itself was not critical at that time.

In 2004, KARI decided to verify tracking data accuracy in GEOS-C format gathered from K13 antenna system for TT&C supports of incoming KOMPSAT2 and other missions.

This paper includes ground/on-board calibration of ranging system, ranging/Doppler measurements. Especially ranging/Doppler measurement accuracy was compared in 2 ways; directly with GPS position data, indirectly with orbit determination results.

2. Ranging System

Ranging measurement can be provided in two ways: tone ranging and code ranging. Latter is adopted in GPS system while former is conventional way used in most satellite.

In tone ranging, a major tone frequency like 100kHz or 500kHz is used for higher accuracy and multiple minor tone frequency like 20kHz, 4kHz, 800Hz, 160Hz, 40Hz, 8Hz is used for phase ambiguity resolution [1].

In general, ranging measurement accuracy relies on ground equipment and its processing algorithm because spacecraft only bypasses uplink ranging tone to downlink after frequency translation per coherent mode ratio like 221/240 in ESA and STDN standard.

In tone ranging system, ranging measurement equipment acts as precise phase-meter and both ground and on-board calibration is pre-requisite for accurate ranging measurement because overall ranging measurement value acquired from equipment includes unnecessary distance component like ground loop and on-board loop. Ground loop includes internal delay of measurement box, frequency converters, PA, lots of cables. Also on-board loop has delays from cables and transponder.

These ground and on-board delays values should be subtracted from overall ranging measurement to provide accurate values.

1) Ground/On-Board Calibration Value

Ground delay comes from several components like measurement equipment, frequency converters, PA, LNA, cables. Especially, K13 antenna has very long cables between antenna feed assembly and RF/IF boxes, which is about 120m in total.

To measure accurate ground turn-around delay value, specially designed test loop translator for coherent mode of 221/240 defined in ESA/STDN standard was inserted between PA output and test cable connected in downlink path in feed assembly in antenna hub in RF loop.

Also 70MHz IF loop configuration was used for the measurement of internal processing delay time of FEP system.

Ranging measurement function in ground station FEP was activated to measure the ranging value in both ground RF loop and ground IF loop configuration.

Table 1 shows measured ground delay value provided in both configurations.

Table 1. Ground Delay Value, measured

	Case	Delay Time	Unit	Remark
1	GS RF loopback measurements	75297	nsec	
2	TLT+Cable attribute	33	nsec	
3	Net GS RF loopback measurement	75264	nsec	1-2
4	IF 70MHz loopback	74180	nsec	
5	Turnaround delay w/o FEP	1084	nsec	3-4

For on-board ranging delay calibration, turn-around delay value of 1140nsec measured for 100kHz in pre-launch phase was considered.

2) Ranging Calibration Value Set-Up

Ranging delay phase values for on-board and ground station was recalculated from overall ranging delay values.

Overall ranging delay value is about 76404nsec, which is summation of net GS RF loop-back value and on-board delay value. Considering speed of light, equivalent distance of 22905.343m is derived from 76404nsec. From equivalent distance, ranging calibration phase was derived for each virtual ranging tone values as shown in table 2.

Each calibration phase values for all ranging tone components as shown in table 2 were made as a configuration file and uploaded to used in FEP to provide accurate ranging measurement data.

Table 2. Calibration phase for virtual ranging tone

Virtual Ranging Tones	Phase value	
100kHz	230.5440	deg
20kHz	190.1088	deg
4kHz	110.0218	deg
4.8kHz	132.0261	deg
4.16kHz	114.4226	deg
4.04kHz	111.1220	deg
4.008kHz	110.2418	deg

3) Higher Time-Tagging Resolution

For precise tracking data, accurate time tagging is mandatory in tracking file like GEOS-C. Unlike time-tagging resolution of msec in K09 antenna system, K13 system was developed to provide minimum accuracy of micro-sec in time-tagging, which guarantee better data integrity. Micro-second time tagging leads ranging data error boundary in expression less than 3m while 300m in msec time-tagging system in LEO.

3. Test Results

Several ranging measurement was performed with KOMPSAT using K13 tracking antenna system. Ranging duration was 3 min. and 2-way Doppler measurement was performed simultaneously to analyze the accuracy and necessity of calibration bias in Doppler measurement.

Table 4 shows measured ranging values and calculated distance between spacecraft and ground station antenna at a given time. In theory, ranging measurement and calculated distance should be close as much as possible. Distance calculation was based on ECEF position data of spacecraft and ECEF position data of K13 antenna. The ECEF coordinate of K13 antenna is shown in table 3.

Table 3. ECEF coordinate of K13 antenna, WGS84

Ant_X, km	Ant_Y, km	Ant_Z, km
-3119.49526	4086.64698	3762.21064

Table 4. Relative Ranging Accuracy to GPS telemetry

Date	Time (UTC)	S/C position from GPS telemetry, ECEF X_pos, km	Y_pos, km	Z_pos, km	Range Computed	Range Measured	Delta (Com.-Mea.)
2004-Aug-05	15 00 13	-3000 632568	4432 585938	4582 176758	897 856633	897 868000	-0 011
	15 00 45	-3037 928955	4589 695801	4400 099121	816 463649	816 468000	-0 004
	15 01 17	-3070 983643	4741 650879	4212 873535	796 542859	796 544000	-0 001
	15 01 49	-3099 778076	4888 248535	4020 740967	842 491393	842 483000	0 008
	15 02 21	-3124 309814	5029 304688	3823 905029	944 686682	944 672000	0 015
2004-Aug-07	14 31 25	-3617 137451	4206 788086	4345 717285	776 248442	776 254480	-0 006
	14 31 57	-3667 939941	4351 854492	4157 041992	725 960324	725 961870	-0 002
	14 32 29	-3713 817383	4492 095703	3963 506592	747 079323	747 088450	-0 009
	14 33 01	-3754 762451	4627 349609	3765 363281	834 226395	834 218720	0 008
	14 33 33	-3790 732666	4757 414063	3562 816650	969 662879	969 649240	0 014
2004-Aug-09	15 38 37	-2174 009766	4594 049316	4880 829102	1550 066839	1550 094000	-0 027
	15 39 09	-2189 532471	4764 630859	4708 041992	1489 660991	1489 679000	-0 018
	15 39 41	-2201 734375	4929 755371	4529 758301	1463 641419	1463 651000	-0 010
	15 40 13	-2210 624512	5089 210938	4346 179199	1473 838456	1473 846000	-0 008
	15 40 45	-2216 224121	5242 806641	4157 529785	1519 500289	1519 503000	-0 003
	15 41 17	-2218 555420	5390 341797	3964 015869	1597 509972	1597 513000	-0 003

It was shown that ranging phase calibration was done correctly from distance difference between ranging measurement and calculation. Constant accurate results had been acquired for other tracking passes.

Fig. 1 shows difference between range rate derived from ranging measurements and Doppler data measured at a given time. Basically, these 2 values should be same. If not, this means there is a bias. Table 4 shows constant bias of about 39.6m/sec in Doppler measurement. For accurate tracking data in K13 antenna, K13 tracking data processing software was updated to handle this bias

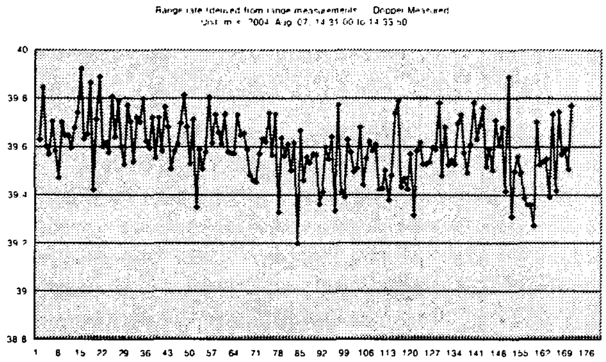

Fig. 1 Bias between Range Rate and Doppler data

Table 5 shows ranging measurement accuracy from orbit determination's view points[2]. Orbit determination was done by tracking data and GPS telemetry data, respectively and difference between them was displayed in RMS value. Orbit determination using tracking data were done in 3 cases: ranging only, ranging + Doppler, Doppler only. It was shown that accuracy of OD using range and Doppler data can be enhanced when Doppler bias is considered. OD accuracy from Doppler data only is worse than range data only case.

Table 5. Accuracy of OD from tracking data compared to precise OD from GPS telemetry

OP period	Measurement Data Size (Range/Dop.)	Range + Dop.		Range only	Dop. only
		Before Bias Processing	After Bias Processing		After Bias processing
2004/8/6 ~ 8/8	900 /900	265.6	13.6	17.2	77.4
2004/8/7 ~ 8/9	900 /900	371.5	28.6	25.1	154.5
2004/8/8 ~ 8/10	900 /900	234.5	15.3	18	69.9
2004/8/9 ~ 8/11	1080 /1080	272.5	37.1	41	58.8
2004/8/18 ~ 8/20	1080 /1080	492.9	31.9	41.9	94.4
2004/8/19 ~ 8/21	1080 / 1080	280.3	27.5	20.3	223.4
2004/8/20 ~ 8/22	1080 / 1080	325	26.6	30.6	125.6
Average		320.3 m	25.8 m	27.7 m	114.8 m

From table 5, it was confirmed that Doppler bias compensation routine is effective.

4. Conclusion

Ranging system in K13 antenna system was described and test results were shown in this paper.

From comparison between measurement and calculation values, it was verified ranging phase calibration was done correctly and this was also confirmed again in accuracy of OD from tracking data.

Doppler bias of around 39.6m/sec was found and tracking processing software handling Doppler measurement was updated and verified to be accurate as much as ranging data.

KARI believes tracking function in K13 antenna will be very useful in LEOP of KOMPSAT2 and other missions.

1-Way Doppler measurement is less accurate but widely used in other space agency due to its compactness KARI will focus on developing technology related to 1-way Doppler data application in soon future

References

[1] ESA document, Ranging Standard, TTC-A-04-Issue1, July, 1980

[2] H.D.Kim, S.I.Ahn, I.H.Koo. "Evaluation of Orbit Determination and Prediction Accuracy using S-Band Ranging Data for 13m and 1.5m Antenna," Proc. KSAS, Fall, 2004.