Advances in Ka-band Communication System for CubeSats and SmallSats

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Abstract – *A study was performed that evaluated the feasibility of Ka-band communication system to provide CubeSat/SmallSat high rate science data downlink with ground antennas ranging from the small portable 1.2m/2.4m to apertures 5.4M, 7.3M, 11M, and 18M, for Low Earth Orbit (LEO) to Lunar CubeSat missions . This study included link analysis to determine the data rate requirement, based on the current TRL of Ka-band flight hardware and ground support infrastructure. Recent advances in Ka-band transceivers and antennas, options of portable ground stations, and various coverage distances were included in the analysis. The link/coverage analysis results show that Cubesat/Smallsat missions communication requirements including frequencies and data rates can be met by utilizing Near Earth Network (NEN) Ka-band support with 2 W and high gain (>6 dBi) antennas.*

Keywords: Ka-Band, High Performance Communication System, CubeSats, SmallSats, High Data Rates.

1 Introduction

This paper analyzes Ka-band end-to-end communication system performance for CubeSats and SmallSats with ground antennas ranging from the small portable 1.2m/2.4m to apertures 5.4M, 7.3M, 11M, and 18M, for Low Earth Orbit (LEO) to Lunar CubeSat mission. CubeSats and SmallSats provide a cost-effective, high return on investment for conducting science missions by using miniaturized scientific instruments. Thirteen CubeSats were selected for Exploration Mission-1 (EM-1), the first integrated launch of the Space Launch System (SLS) rocket and an uncrewed Orion spacecraft [7]. As the scientific community continue to leverage the growing capabilities of CubeSats and SmallSats to address fundamental scientific, technological, and educational investigations; high performance/higher data rate communication system will be required to downlink science data. This study will be extended with EM-2 missions when they are selected.

As reported in [6] and [1], most CubeSat data rates are in kbps and operating in Amateur Radio bands, while very few are using S-band (< 10 Mbps data rates). What are the capacities and data volumes for future CubeSats/SmallSats? Recent advances in miniaturized high performance CubeSat Ka-band transceivers and antennas would enable CubeSats to communicate in tens to hundreds of Mbps.

In a "Study for Optimum Space-to-Ground Communication Concept for CubeSat and SmallSat Platforms," [2] we performed detailed simulations, analyses, and identifying technologies (TRL of S-, X-, and Ka-Band transceivers and antennas), and developed optimum communications concepts for CubeSat/SmallSat Space Network (SN)/NEN end-to-end communications. Also, [2] recommended that CubeSat communication hardware standardization and compatibility with SN, NEN, and ground infrastructure would attract more NASA science missions.

One of the key advantage of Ka-band is frequency allocation. Frequency allocation is really limited at S-band and in X-band space science missions. Ka-band has the advantage of both more bandwidth and gain, hence significance increase in data rates. Also, the Ka-band communication systems are much more compact and can easily fit into the CubeSat form factor. The analysis in [1] and [3] focused on S- and X-Band communication system for CubeSats and SmallSats. This paper presents our study results focusing on NASA Near Earth Network (NEN) Ka-band CubeSat/SmallSat end-to-end communication system.

2 CubeSat Ka-Band Flight Hardware and Ground Systems

Very promising Ka-band transceivers and high gain antennas have been demonstrated. Table 1 gives examples of Ka-band transceivers considered in this analysis. Tethers Unlimited (TUI)'s CubeSat Ka-band transmitter SWIFT-KTX SDR [8], is designed to provide high-throughput downlink in Ka-band, 2W Tx with 100 MHz bandwidth, and arbitrary waveform/modulation/coding (SQPSK, 8 PSK, 16 PSK).

Table 1 - Ka-Band Transceivers for CubeSats

Transceiver Name/Vendor	Size (cm)	Mass (g)	Max. Data Rate	Modulation /FEC
Canopus Systems/ Ames Ka-band Tx	18 x 10 x 8.5	820	125 Mbps	{Q,8,16A,32A}PSK, DVB-S2, CSSDS, LDPC Concatenated with BCH
Tethers Unlimited	8.6 x 4.5 (0.375U)	500	300 Mbps	{Q,8,16A,32A}PSK, DVB-S2, CSSDS

Table 2 - Ka-Band Antennas for CubeSats

Antenna Name/Vendor	Freq	Gain (dBi)	Dimensions	Mass
Canopus System Horn	Ka	23	18 cm	820g
JPL Ka-band parabolic deployable antenna (KaPDA)	Ka	42	(10x10x15) cm	
JPL ISARA	Ka	33.5	(33.9x8.26) cm	

The antennas range from patch arrays, reflectarrays [4] and [11], mesh reflectors [12], and inflatable antennas. The Ka-band parabolic deployable antenna (KaPDA) shown in Table 2 uses a folding rib design where the ribs deploy like an umbrella, achieving a gain of 42-dB [5]. A similar design to the KaPDA was used in the AENEAS NanoSat mission.

2.1 CubeSat Ka-Band Communication Analysis Parameters Assumptions

We conducted a survey for portable 1.2m/2.4m Ka-band tracking antenna in the market, i.e in Table 3. Then performed link analysis to determine the data rate requirement, based on COTS Ka-band flight hardware EIRP and portable 1.2m/2.4 Ka-band antenna G/T. The support stations are assumed at Wallops and Fairbanks, Alaska.

Examples of Ka-band transceivers and antennas supporting NASA Ka-band frequencies are shown in Tables 1 and 2. Other assumptions included, NEN planned network enhancements/upgrades to Ka-band. The assumptions detailed in section 2.1 were used in calculating the CubeSat link budgets.

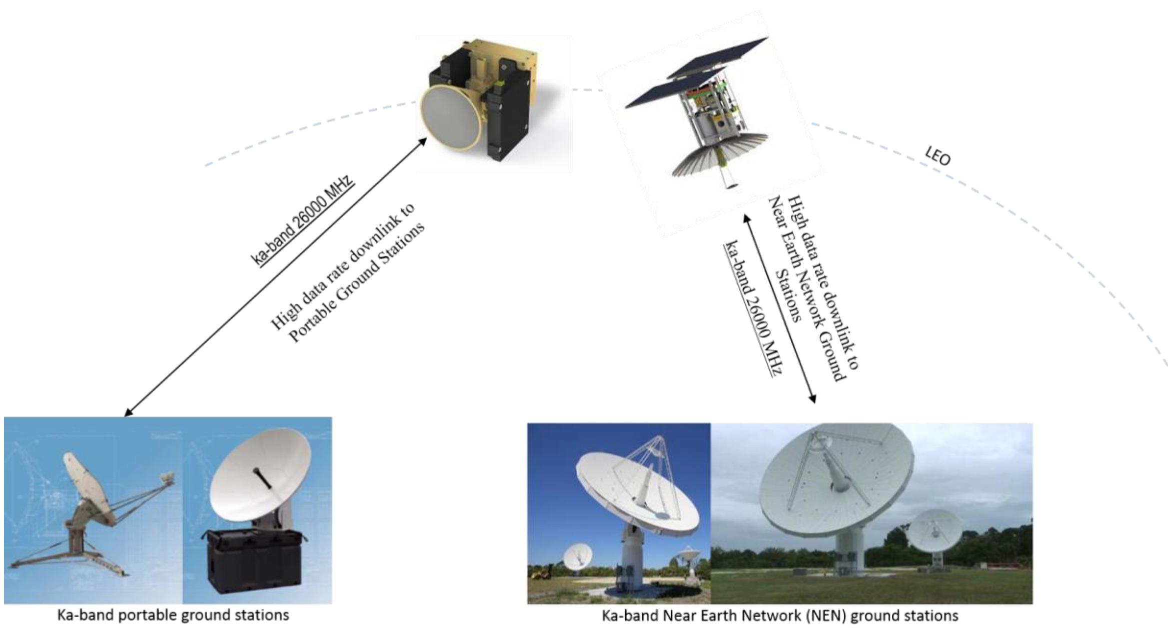

Figure 1. Ka-band End-to-End Communication for CubeSats and SmallSats

Also, this analysis looked at the "Canopus Systems/NASA Ames Miniature Ka-band Transmitter CKAT-10" - integrated Ka-band transceiver with high gain horn antenna offering 23dB at the operational frequency of 26.8 GHz.

The parameters used in performing link analysis based on the Canopus System are given in Figure 2 and Table 3 (downlink parameters section).

Characteristics	Performance
Nominal operational frequency	26.8 GHz
Horn gain	23dB
Maximum transmit power	12.5 W
RF output power	0.7 W
High speed data input	Low voltage differential signaling
Modulation and coding	Full DVB-S2 specification
Volume envelope	(18 x 10 x 8.5) cm
Mass	820 g

Figure 2. Canopus Systems/NASA Ames Miniature Ka-band Transmitter CKAT-10

Table 3 - Parameter Assumptions for Ka-band Communication System Analysis

Ka-band Downlink Parameters	**Portable Ka-band 1.2-Meter at Fairbanks, Alaska Ground Station**	**Portable Ka-band 2.4-Meter at Fairbanks, Alaska Ground Station**
S/C Altitude: 625 km and 600 km	Latitude: 64.8586° N	Latitude: 64.8586° N
Atmospheric and Rain Attenuation: ITU-R P.618-10, ITU-R P.676-8	Longitude: 147.8550° W	Longitude: 147.8550° W
Rain Availability: 95% and 99% (Ka-band)	Minimum elevation: 10°	Minimum elevation: 10°
Frequency: 26000 MHz	Ka-band Received Antenna Gain: 46.5 dBi (with 42% EFF)	Ka-band Received Antenna Gain: 51.7 dBi (with 35% EFF)
Transmit Power: 2 Watts	System Temperature: 138 °K (clear sky; reference at antenna port)	System Temperature: 129 °K (clear sky; reference at antenna port)
Passive Loss: 1 dB	Ka-band Feed Loss: 0.5 dB	Ka-band Feed Loss: 0.5 dB
Earth Coverage Antenna Gain: 4 dBi	Ka-band T_{LNA} : 60 °K	Ka-band T_{LNA} : 60 °K
Polarization: RHCP	Antenna Noise: 90 °K (clear sky and 10º elevation angle)	Antenna Noise: 89 °K (clear sky and 10º elevation angle)
Polarization Loss: 0.1 dB	Ka-band G/T: 23.7 dB/K (clear sky and 10º elevation angle)	Ka-band G/T: 28.88 dB/K (clear sky and 10º elevation angle)
Modulation: OQPSK	Ka-band Implementation Loss: 2.4 dB (OQPSK)	Ka-band Implementation Loss: 2.4 dB (OQPSK)
Data Format: NRZ-L	Notes : 1. 1.2-m antenna used in this analysis is the "Ultra-lightweight General Dynamics SATCOM Technologies 1.2-meter Quick Deploy Motorized Auto-Acquire (QDMA) Antenna." Antenna Gain at Ka-Band , dBi: Rx 43.60, Tx 45.30. 2. 2.4-m antenna used in this analysis is the "General Dynamics SATCOM Technologies lightweight 2.4-meter motorized flyaway antenna." Antenna Gain at Ka-band, dBi: Rx 52.30, Tx 55.20.	
Telemetry Coding: Rate 1/2 LDPC		
Required Eb/No: 2.29 dB (OQPSK at BER=10^{-9}@ CCSDS Rate 1/2 LDPC Decoder)		

3 CubeSat Ka-Band Communication Analysis Results

A summary of Ka-band CubeSat communication system is given in Table 4, showing achievable data rates at Ka-band with ground antennas ranging from the small portable 1.2m/2.4m to apertures 5.4M, 7.3M, 11M, and 18M for Low Earth Orbit (LEO) to Lunar CubeSat missions.

For the analysis, the 18M station is at White Sands Complex (WSC) and the other antenna apertures are assumed at Alaska Facility (ASF). There are two kinds of CubeSat Ka-band flight systems used for the analysis. One is a Commerical Off-the-shelf (COTS) SDR Ka-band transceiver with a 2W PA and an earth coverage antenna of 4 dBi gain. The second is a Ka-band DVB-S2 transmitter system with a high gain horn antenna of 23 dBi and a 0.7 W PA for the LEO CubeSat mission and the same antenna but with a 2 W PA for the Lunar CubeSat mission. Modulation is Quadrature Phase Shift Keying (QPSK) with CCSDS rate 1/2 LDPC coding for the COTS transceiver. The DVB-S2 transmitter has its own rate ½ LDPC coding scheme. Rain Availability is assumed 99% at ASF and 95% at WSC at 10 degrees elevation angle.

As indicated in the table, achievable data rates are from 477.5 kbps to 55.847 Mbps with the 1.2m/2.4m portable antenna system depending on whether a COTS or NASA Canopus Systems is used. The achievable data rates with the 5.4m/7.4m/18m antenna system are from 4.3 Mbps to 1125 Mbps for the LEO missions with these Ka-band flight systems. It is capable of supporting lunar mission with achievable data rates from 10.6 kbps to 629.5 kbps.

The utilization of power efficient rate ½ LDPC coding reduces the EIRP requirement to achieve higher data rate for CubeSat mission in LEO and Lunar orbits.

Table 4 - Achievable Data Rate at Ka Band.

Ground Antenna	LEO Data Rate QPSK*	Data Rate LEO DVB-S2 **	Data Rate Lunar***
ASF 1.2 m	477.5 kbps	16.943 Mbps	--
ASF 2.4 m	1.574 Mbps	55.847 Mbps	--
ASF 5.4 m	4.3 Mbps	153.4 Mbps	10.6 kbps
ASF 7.3 m	6.6 Mbps	233.2 Mbps	16.1 kbps
ASF 11 m	25.2 Mbps	892.9 Mbps	61.5 kbps
WSC 18 m	257.5 Mbps	1.125 Gbps	629.5 kbps

* LEO (625 km) COTS QPSK Transceiver, 2W PA, earth coverage antenna of 4 dBi gain
** LEO (625 km) DVB-S2 Transceiver, 0.7 W PA, horn antenna of 23 dBi gain
*** Lunar (400,000 km) DVB-S2 Transceiver, 2 W PA, horn antenna of 23 dBi gain

4 Conclusions

Based on the simulations and analyses, signal trade studies, and technology assessment; Ka-band communication system is feasible for near future CubeSat/SmallSat high rate science data downlink with ground antennas ranging from the small portable 1.2m/2.4m to apertures 5.4M, 7.3M, 11M, and 18M, for Low Earth Orbit (LEO) to Lunar CubeSat mission. As science missions on CubeSats and SmallSats continue to become more sophisticated, yielding significant returns, CubeSats will likely transition from UHF- and S-band to X- and Ka-band frequencies.

Simulation results also show that CubeSats with PA of 0.7 – 2 W and antenna gain of > 6 dBi have significant margin to close the link from LEO. Also, using portable smaller apertures can be an option for low data rate CubeSat missions could free up larger apertures for critical missions when needed. Utilization of power efficient coding (i.e. rate ½ LDPC) can reduce the EIRP requirement to achieve higher data rate for CubeSat missions in LEO and Lunar orbits.

Ka-band systems offer compact, reliable and high date rate communication solutions for Flight and Ground Communication Systems compared to S and X-bands.
Since smaller Ka –band Ground systems offer high gains with smaller dishes, they can be located at different locations to provide better global coverage. Although the scope of this paper does not include inter-satellite links, the same hardware can be serve as a good baseline.

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