Development Status of Small-Sized Ka-band Mobile Terminal for Maritime Broadband Communications

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Abstract. Most recent development status of small-sized Ka-band mobile communications terminal is presented. The terminal is designed to operate at a minimum target speed of 5 Mbps to/from a Ka-band geostationary satellite, and will eventually be used for the purpose of research activity to explore marine resources within the Exclusive Economic Zone (EEZ) of Japan. The terminal is placed on Autonomous Surface Vehicle (ASV). Because the ASV is "unmanned" and is primarily controlled from a remote ground control station, several mechanisms are embedded into the design for safe and successful operations of the Ka-band terminal. Those key mechanisms are introduced in this paper as they make fault diagnosis easier and increase overall system reliability in case of primary communication channel failure.

Keywords: Mobile communications · Ka-band terminal · Auto-tracking antenna

1 Introduction

Autonomous Surface Vehicle (ASV), as shown in Fig. 1, is an unmanned vessel on the ocean and is currently under development by JAMSTEC (Japan Agency for Marine-Earth Science and Technology) [1]. Target specifications of ASV are tabulated in Table 1.

The primary function of ASV is to relay a communication signal to/from one or multiple Autonomous Underwater Vehicles (AUVs) which can cruise 3,000 m deep seafloors in search for precious marine resources or evidence for earthquake. For this purpose, every ASV has a Ka-band terminal with auto-tracking antenna onboard and is designed to communicate with Ka-band geostationary satellite. The AUV weighs a few tons and can be remotely controlled by ground control station or directly controlled by Research Vessel (RV). On the other hand, Remotely Operated Vehicle (ROV) works at much deeper ocean floors, taking high-definition class pictures and sampling marine

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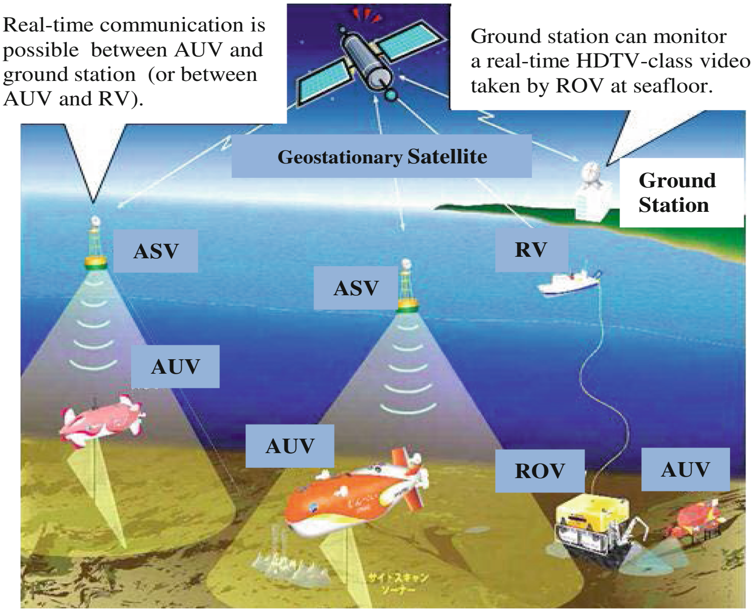

Fig. 1. ASV, AUV, RV, and ROV operations (conceptual view)

Table 1. ASV specifications (target values) [2]

Parameter	Spec
Dimension (L, W, H)	6 m × 2.6 m × 3.2 m
Weight	<3 tons
Operating hours	48 h
Vessel speed	2 knot (cruise), 5 knot (max)
Operating condition	≤Sea State 4, ≤Wind speed 15 m/s

resources. ROV is mechanically cabled to RV and communicates with RV through optical fiber. Figure 2 shows a conceptual view of those operations.

The Ka-band mobile communications terminal will be mounted on ASV, and RF system of the terminal consists of beacon-tracking antenna subsystem and transmit/receive RF subsystem. The antenna subsystem tracks a Ka-band geostationary satellite (WINDS satellite [3] in this case) with tight pointing accuracy and, if the error exceeds the limit, it is designed to immediately cease RF transmission and avoid unnecessary RF interference to neighboring satellites.

The Ka-band terminal is also equipped with a commercially available Machine to Machine (M2M) remote access system, capable of changing a transmission data rate to a lower data rate, for instance, during a heavy rain fade to ensure communication connectivity with a Ka-band satellite. The remote access system also accepts a switch-over command to a redundant Block Up Converter (BUC) in case of a primary BUC failure for some reason.

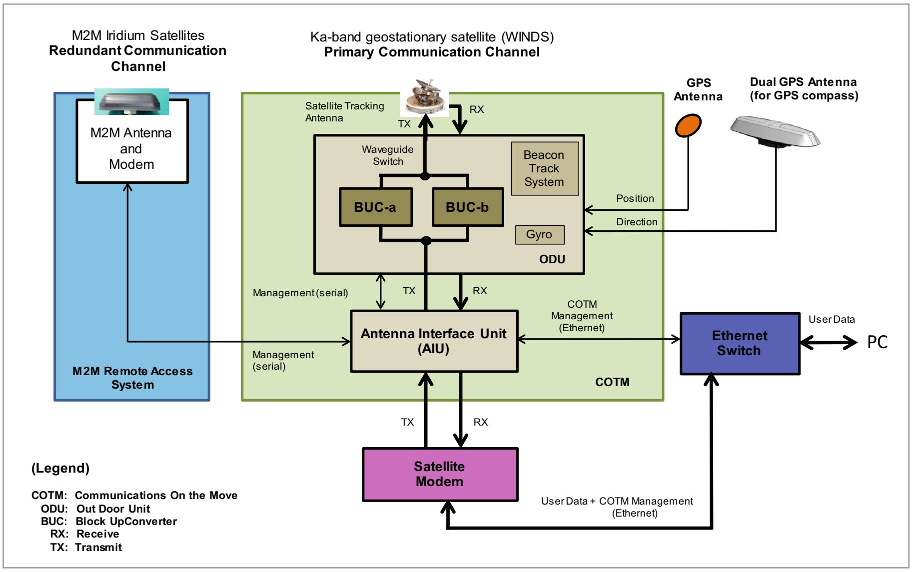

Fig. 2. Overall system diagram of Ka-band terminal

2 Overall System Diagram

Figure 2 shows overall system diagram of Ka-band communications terminal. The system is mainly divided into Communications On The Move (COTM) and Machine to Machine (M2M) Remote Access System. The COTM is further divided into Antenna Auto-Tracking System and RF Transmit/Receive system and they are explained in the following paragraphs. See legend in Fig. 2 for acronyms used in the paragraph.

2.1 Antenna Auto-tracking System

Beacon tracking system (BTS) is employed for Ka-band antenna auto-tracking to realize the tight antenna pointing requirement (i.e. $\pm 0.2°$) while operating on the ocean. It is commonly known that BTS uses three axis control (i.e. azimuth, elevation, and polarization) and the reason for having the fourth axis, or ex-elevation axis, is to avoid a "Keyhole Effect". During a primary mode of antenna pointing control, Antenna Control Unit (ACU) drives a motor in each axis based on the sum and difference signals supplied from the BTS system.

The antenna system is also designed to have an "interlock function", which allows RF transmission only when the system locks onto the stable Ka-band beacon and pointing error stays within $\pm 0.2°$ limit. Outside the limit, the system is designed to cease RF transmission to avoid unnecessary RF interference to neighboring satellites. Antenna Auto-Tracking System has the following three modes of operations:

Open Loop Pointing Mode: Based on the information from Inertial Navigation Unit (INU, or Gyro), the system scans a tracking antenna in Az/El directions and captures a target satellite in quite a short time. Once beacon lock is confirmed, the system automatically transfers to Beacon Tracking Mode.

Beacon Tracking Mode: Antenna tracks a satellite beacon by beacon track system (or mono-pulse tracking system). The system constantly monitors a small pointing error from the satellite beacon and corrects the error by adjusting antenna directions in closed loop control. When the beacon is lost for any reasons, the system automatically transfers to Gyro-based Holding Mode.

Gyro-Based Holding Mode: When the satellite beacon signal is lost or in poor signal quality, the system maintains the last antenna position. When the beacon is received again, the system automatically transfers to Beacon Tracking Mode. When this mode continues beyond timeout period and does not regain beacon lock, it automatically transfers to Open Loop Pointing Mode and starts searching for a satellite.

2.2 RF Transmit/Receive System

The RF Transmit/Receive System mainly consists of a driver amplifier and BUC. The BUC mainly consists of up-conversion mixer and solid state power amplifier (SSPA) and shows a slightly higher failure rate than other components in the RF Transmit/Receive system. Since whole Ka-band terminal requires higher level of operational reliability and survivability on severe sea state conditions, we have decided to incorporate a "redundancy scheme" (BUC-a and BUC-b) into the BUC design as shown in Fig. 2. Selecting GaN SSPA, instead of GaAs SSPA, is a part of those efforts because GaN shows a better power added efficiency (typically 25%) and lower heat dissipation, leading to a smaller failure rate. Table 2 shows GaAs and GaN performances in Ka-band frequency. Estimated value of system MTBF (Mean Time Between Failures) is examined in Sect. 3.

Table 2. GaAs and GaN performances (Ka-band)

Parameter	GaAs	GaN
Supplier	Triquint	Triquint
DC input	36 W (6 A at 6 V)	36 W (1.5 A at 24 V)
RF output (saturation)	6 W	9 W
Thermal dissipation	30 W	27 W
Power Added Efficiency (PAE)	15%	25%
Format	Chip or package, 6 W	Chip, 9 W
Linear RF power	1–2 W (backed off)	3 W (backed off)
	3–4 W (with lenealizer)	6 W (with lenealizer)

As a result, the Ka-band terminal has "dual BUCs" as shown in Fig. 2 with a primary BUC (i.e. BUC-a in the figure) producing 20 W of RF power by combining four RF outputs of GaN device and a redundant BUC (BUC-b in the same figure) in standby mode. If a failure occurs in primary BUC, then redundant BUC automatically comes on line. Redundant BUC can also be commanded on line by remote operator's command through Iridium Short Burst Data Service (SBD), which is explained in Sect. 2.3. A waveguide-type RF power combiner is used for combining GaN RF outputs because of its lower RF combining loss and excellent design heritage.

A design method to produce a target EIRP was discussed in detail in a previous paper [4]. Therefore, using the same method described in the reference, EIRP, G/T, and satellite link margin are estimated to establish a 5 Mbps satellite link. Result is shown in Table 3 (below) for a Ka-band terminal having a 54 cm diameter antenna. Note that $EIRP_{ASV}$ = 51 dBW in Table 3 is operational EIRP with output back-off of 1.8 dB included.

Table 3. Estimated EIRP, G/T, and satellite link margin

Parameter	Value (predicted)	Notes
EIRPasv	51 dBW	G_{TX} = 41.9 dBi@28.33 GHz, Psat = 20 W (13 dBW), OBO = 1.8 dB
G/Tasv	13 dB/K	D = 0.54 m
Satellite link margin for 5 Mbps	3.3 dB (ASV to land) 4.9 dB (land to ASV)	FEC 1/2 QPSK; Assumed a 3 dB rain attenuation in satellite uplink link calculation (ASV to land). The same amount of rain effect is assumed in satellite downlink calculation (land to ASV)

2.3 M2M Remote Access System

Machine to Machine (M2M) communication is a technology that allows both wireless and wired machines to speak to, monitor, and control other machines of the same type. There are many M2M services available today, offering superior geographical service coverage with an extremely affordable cost for users.

The reason a redundant communication channel is introduced into our Ka-band terminal design is that M2M communication can provide an alternative communication path in case of a primary communication channel failure. The failure could be a Ka-band transponder failure, hardware failure, and/or software malfunction of Ka-band terminal. Without M2M communication, those situations can be serious for ASV operations: Those failures may leave an unmanned ASV in a helpless situation on the ocean, and it is certainly a problem not knowing where the troubled ASV is located and what kind of operational state the ASV is in. Therefore, to increase overall system availability and reliability, Iridium Short Burst Data Service (SBD) is selected and implemented. Note that Iridium SBD is mainly used to diagnose and recover the overall system performance, and is not suitable for transferring a large amount of data of the primary communication channel.

The following are what redundant M2M communication channel can perform:

Normal Operations: The redundant M2M channel is active and critical system status messages (i.e. current values and alarm status) for each subsystem (i.e. COTM terminal, Ethernet Switch, Satellite Modem, and redundant communication channel) are sent via Iridium SBD once a day. Critical parameters are to be defined. Self-test on Iridium SBD is performed several times a day. System generates alarms/notifications if faults/failures are detected.

Failures: Catastrophic failure prevents the system from being accessed remotely via the primary communication channel, and it can be detected by the system or by human operators. A failure in COTM terminal can be detected and diagnosed by firmware.

Operation After Failure: If a failure occurs, Iridium SBD messages indicating failure will be sent via Iridium satellite network periodically. Remote host may receive a status message or the host can detect a loss of communication over the primary channel. In either case, operator sends diagnostic commands or system recovery commands via Iridium system.

Operation After System Recovery: The system sends SBD message indicating failure is cleared.

3 System MTBF Calculation

Table 4 shows an MTBF (Mean Time Between Failures) value calculated in accordance with MIL-HDBK-217F Notice 2 in a 40°C Naval Sheltered environmental condition. The failure rate is determined by calculating and summing the failure rate of each component in the terminal. Each component has a base failure rate depending on its type (resistor, capacitor, etc.) which is then multiplied by coefficients based on variables such as temperature, component quality, environmental conditions and power rating, as part of the MIL-HDBK-217F Notice 2 standard. Once failures per million hours (fpmh) are thus estimated, MTBF is obtained by calculating 10^6 (h)/fpmh.

Table 4. MTBF of Ka-band Terminal

	Dual BUC, redundant DC converters	
	Commercial	Experimental
Failure rate (fpmh)	352	110
MTBF (hours)	2,838	9,035

During experimental phase of ASV operations, it is assumed that every ASV will go to the ocean and work continuously for two weeks and that the operation repeats six times a year. In the meantime, there is a chance of periodic maintenance for each ASV, which is scheduled four times a year. Based on the operational scenario, 9,035 h is believed to be a good number for the current operational purpose.

The commercial MTBF, on the other hand, assumes continuous operation of ASV in a Naval Sheltered state, showing a smaller value than experimental.

4 Summary

The most recent development status of small-sized, Ka-band mobile communications terminal was discussed for successful operations of Autonomous Surface Vehicle (ASV). The goal is to establish reliable broadband mobile communications between ASV vessel and ground station through a Ka-band geostationary satellite. Having "redundancy scheme" in a BUC design is considered useful to increase overall system survivability of the Ka-band terminal. The authors also believe that incorporating M2M communication into Ka-band terminal design greatly enhances fault diagnosis capability. Finally, MTBF is computed for Ka-band terminal equipped with dual BUC and redundant DC convertor system. Calculated MTBF value is considered adequate for current experimental purpose.

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