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## A Ka-Band High Data Rate Shipboard Satellite Terminal


M. Rupar

David Beering

D. Hoder

# A Ka-band High Data Rate Shipboard Satellite Terminal

Michael A. Rupar
U.S. Naval Research Laboratory
Code 5554
4555 Overlook Ave. SW
Washington, DC 20375-5337

David R. Beering
Infinite Global Infrastructures, LLC
618 Maplewood Drive
Wheaton, IL 60187-1400

***Abstract* - A fully articulated shipboard satellite antenna system operating at Ka-band (30/20 GHz) was designed, developed, and tested by engineers from the Naval Research Laboratory (NRL), NASA's Glenn Research Center, and a number of industry partners. A series of tests conducted in October of 1998 on Lake Michigan (in the Chicago area), using NASA's Advanced Communications Technology Satellite (ACTS), achieved an unparalleled full-duplex data rate transmission of 45 megabits per second (Mbps) between a moving vessel at sea and a fixed-earth station. Network and application layer tests were run concurrently with the data rate transmission trials, examining TCP/IP file transfers, video and voice transfer technologies, and Asynchronous Transfer Mode (ATM) networking techniques.**

**This demonstration, called the Shipboard ACTS Ka-band Experiment (SHAKE), utilized a combination of commercial-off-the-shelf (COTS) and government hardware and clearly illustrated the viability of high data rate (HDR) Ka-band systems for ship-to-shore communications. Understanding of how emerging satellite services can best be used to meet Naval requirements, and how the Navy can best be positioned to use these emerging services was a critical component of this work. Underlying networking, protocol, terminal, and bandwidth-on-demand issues, combined with variable bit rate service and HDR capabilities, present challenges not typically addressed in current Naval SATCOM systems.**[*]

## I. Introduction

The NASA's Advanced Communications Technology Satellite (ACTS) was launched in September of 1993 to accelerate the advancement of satellite communications systems. ACTS operates in geostationary orbit at 100°W. The satellite and its associated ground systems are managed by the NASA Glenn Research Center (GRC) in Cleveland, OH. System attributes once considered unique to ACTS that are now becoming common in modern satellite systems include operation in the Ka-Band, the use of high-gain spot beams, a high-gain steerable antenna, and a family of high data rate, very small aperture terminals.

Using current technology, the Navy cannot link HDR shipboard local area networks (LANs) to terrestrial networks at comparable HDR speeds while ships are away from port. This problem is exacerbated on the smaller deck combatants, where there is not a large amount of space for the installation of a satellite antenna system and its associated below decks electronics. Recent evolution of the Global Broadcast System (GBS) into Ka-band service has enabled a one-way HDR channel from a hub out to the fleet. By transitioning to Ka-band, with transmit and receive frequencies at approximately 30 and 20 GHz, respectively, the aperture size necessary for two-way communication links is reduced substantially compared to existing systems. For example, the performance of a 2.4m parabolic reflector antenna at C-band is comparable to a 0.5m antenna at Ka-band.

The Satellite and Wireless Technology Section (Code 5554) at NRL has been tasked to develop and demonstrate techniques to enable HDR WAN satellite and wireless connectivity from ships. HDR satellite communications is a critical component of many of these programs. NRL teamed with engineers at GRC to explore the opportunities for shipboard communications in Ka-band. The goal was to create an experiment that would demonstrate both the feasibility of a HDR full-duplex satellite link between a shipboard platform and a shore installation, and to take quantitative and qualitative measurements of the shipboard terminal performance.

To date, several mobile experiments (e.g. [1]-[2]) have been performed with ACTS using a variety of different terminals supporting data rates ranging from 10 kilobits per second up to two Megabits per second. These experiments

[*] NRL was sponsored by the Office of Naval Research (ONR), Code 313.



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have been performed on a variety of vehicles ranging from aircraft, land mobile vehicles, a commercial seismic acquisition vessel, and a US Naval vessel (an Aegis cruiser). The highest ship-to-shore satellite data rate demonstrated during these experiments was a link operating at two megabits per second between the MV Geco Diamond and NASA's Jet Propulsion Laboratory, using the latter's slotted waveguide mobile antenna system [3]. This was performed in conjunction with the American Petroleum Institute's ARIES project in February of 1996.

To enable such a great leap in performance (without a significant expense to the government), NRL and NASA enlisted the participation of a number of leaders in the fields of satellite technology and HDR networking. Infinite Global Infrastructures, of Chicago, IL, was a partner in the system and testbed development. The satellite terminal was assembled using a 1.0m antenna system provided by SeaTel, Inc., of Concord, CA. Sea-Tel was a part of the terminal development team and provided on-site support and assistance. Hill Mechanical Group provided the test vessel, designed and built the antenna mounting structure and provided a base of operations and assistance in Chicago. Equipment was also provided by FORE Systems, of Pittsburgh, PA; Xicom Technologies, Santa Clara, CA; Raytheon Marine Company, Manchester, NH; and Comsat Laboratories, Clarksburg, MD

## II. EXPERIMENTATION

The NRL-NASA Shipboard ACTS Ka-band Experiment (SHAKE) was performed on a 45-ft. Bayliner. Tests establishing a two-way, 45 Mbps ATM link between the ship and the Hub at GRC in Cleveland, OH, were conducted off the coast of Chicago, IL, on Lake Michigan during the period of October 9-23, 1998, using the ACTS spacecraft. A picture of the vessel underway is shown in Fig. 1.

The fixed station was an existing ACTS HDR station equipped with a NASA-developed custom Up/Downconverter and an EF Data SDM-9000 satellite modem with a DS-3 interface. The satellite link was optimized by the use of a COMSAT ALE-2000 ATM Link Enhancer using ATM Cell-Level Reed-Solomon Forward Error Correction. The COMSAT ALE was situated between the EF Data Modem and a FORE Systems ASX-200BX ATM switch. Connected to the ATM switch was a Sun Ultra1 workstation, and as well as ATM video and audio adapters that were also provided by FORE Systems.

The 1.0m SeaTel shipboard terminal was originally configured for operation at Ku-Band. This antenna system was integrated for Ka-band operation by a team of engineers and technicians from SeaTel, NASA GRC and NRL, incorporating hardware contributions by all three organizations. The terminal included a NASA-designed primary Up/Downconverter, conscan tracking, a Xicom 120W Ka-band power amplifier, and the same modems as used by the fixed station. Terminal heading stabilization was attained by a precision gyro compass manufactured by the Raytheon Marine Company.

The end-to-end communications system supported the transmission and reception of high-speed TCP/IP data transfers, interactive TCP/IP data, production-quality video, and CD-quality audio. A block diagram of the test configuration is provided in Fig. 2.

Ship pedestal performance was measured at a number of points in the system. Ship motion was recorded on the bridge (pitch, roll, yaw, linear acceleration), received signal level (downconverted to IF) was measured at the receiver, and modem data performance parameters (bit energy-to-noise ratio, or Eb/No, Raw BER, Corrected BER and carrier detect) were recorded as well. An example of ship motion and the corresponding terminal system performance is given in Figures 3 and 4.

Taking data for so many system parameters was done to gain an understanding of the effects of tracking on a network, and how long the current pedestal and HDR modem technology takes to recover from a tracking interruption. A more thorough discussion and presentation of results can be found in [4].

## III. TRACKING PERFORMANCE

It was noted that the tracking performance of the pedestal appeared to be detrimentally affected by a) the limitations of the gyrocompass to track heading, and b) linear acceleration by the vessel. In sea states with great variations in pitch and roll, the pedestal often maintained not only track of the satellite downlink, but also a good Eb/No and consistant performance at the ATM layers at each end of the link.

While the gyrocompass was quite accurate, it exhibited a tracking limitation of approximately 5°/second, When turns were made at rates higher than that limitation, ther terminal was unable to maintain track of the satellite, and the signal level disappeared entirely. The terminal would automatically reacquire the signal once the rapid turn was ceased (unless the seas were rough), usually within one minute.

Tracking performance of the Ka-band terminal was often compromised when the vessel was accelerated, especially when the heading was directly towards or away from the azimuth look angle to the satellite. It is believed that this was because of the large weight of the power amplifier (PA) and corresponding counterweight mounted on the pedestal with the antenna. To get maximum power level to the antenna, both the primary Up/Downconverter stages and the power amplifier were mounted behind the reflector,. The entire assembly was weight balanced so that the antenna could be maneuvered with minimal motor control. However, during acceleration of the vessel, the antenna assembly was believed to lag the motion of the base of the terminal, creating a rearward motion of the reflector and breaking the track of the satellite. This loss of lock was not observed during deceleration.

## IV. Network layer experimentation

NRL and NASA SHAKE researchers conducted application experiments concurrently with the transmission trials. These included:

1. TCP/IP file transfers, which simulated the high speed transfer of imagery, as well as strategic and tactical theater information to and from Navy ships. This data transfer technique is also applicable to a host of near-Earth orbit NASA spacecraft that routinely transmit data from space to ground using Geostationary relay satellites. Data transfer tests were conducted in disk-to-disk, disk-to-tape, and tape-to-disk configurations.

2. Technologies for real-time video and voice delivery. These technologies can be used for video conferencing, crisis response, telemedicine, mentoring, education, telephony, and entertainment.

3. Tracking performance testing of the current system in the Ka-band with the satellite in an inclined-orbit environment was evaluated.

Experiments in transferring data via ACTS from a workstation disk drive on the Entropy (while underway) to another workstation (or a tape drive) at GRC achieved single stream user data rates of 40.5 Mbps. Multiple web-based data transfers were also conducted on board the Entropy. Ten independent web-based data streams were simultaneously sent from a server at GRC to the vessel, each operating at 500 kbps. The commercial interenet was also accessed via ACTS through GRC to NRL and other sites on the web.

The video technology used was Motion JPEG, running at 17 Mbps in both directions. Full-duplex Motion JPEG was operating concurrently with the other experimentation except for the high data rate (40.5 Mbps) data transfers. The CD-quality audio was embedded within the video data stream.

ATM layer performance was excellent when the link maintained and Eb/No of 5.8 dB or better. Reed-Solomon encoding/decoding (RS) was employed at the modems for a majority of the testing (with the remainder using RS at the ATM Link Enhancers), with the result that when the Eb/No dropped to 5 dB or lower, the link went down completely.

## V. Conclusions

The NRL-NASA Shipboard ACTS Ka-band Experiment (SHAKE) provided a significantly greater data rate than the current Navy shipboard standard, demonstrating data rates of 45 Mbps and user application (file transfers, video teleconference) data rates of above 40 Mbps, significantly higher than the current 1.5 Mbps or 64 kbps standards. While future Navy systems may not require 45Mbps to a single platform, it is likely data rates in the 1-2 Mbps range, with the ability to increase as required, will be required on a larger number of ships and combatants than is currently available today.

The SHAKE test bed demonstrated the capability that exists today in the commercial world (albeit not “off-the-shelf”) to meet the future needs of HDR Satellite networking at sea. The experiment also illustrated a number of developments that are still necessary before such a system is ready for operational deployment, such as improved radomes and primary reflectors for Ka-band, lighter weight power amplifiers (such as Microwave Power Module, or MPM, technology), rotary joint dependability, and the need for more sophisticated tracking algorithms.

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[4] M. Rupar, D. Beering and D. Hoder, “A Ka-band Shipboard Satellite Terminal,” Proceedings for the Fifth Ka Band Utilization Conference, Taormina, Italy, October 18 - 20, 1999, in press.

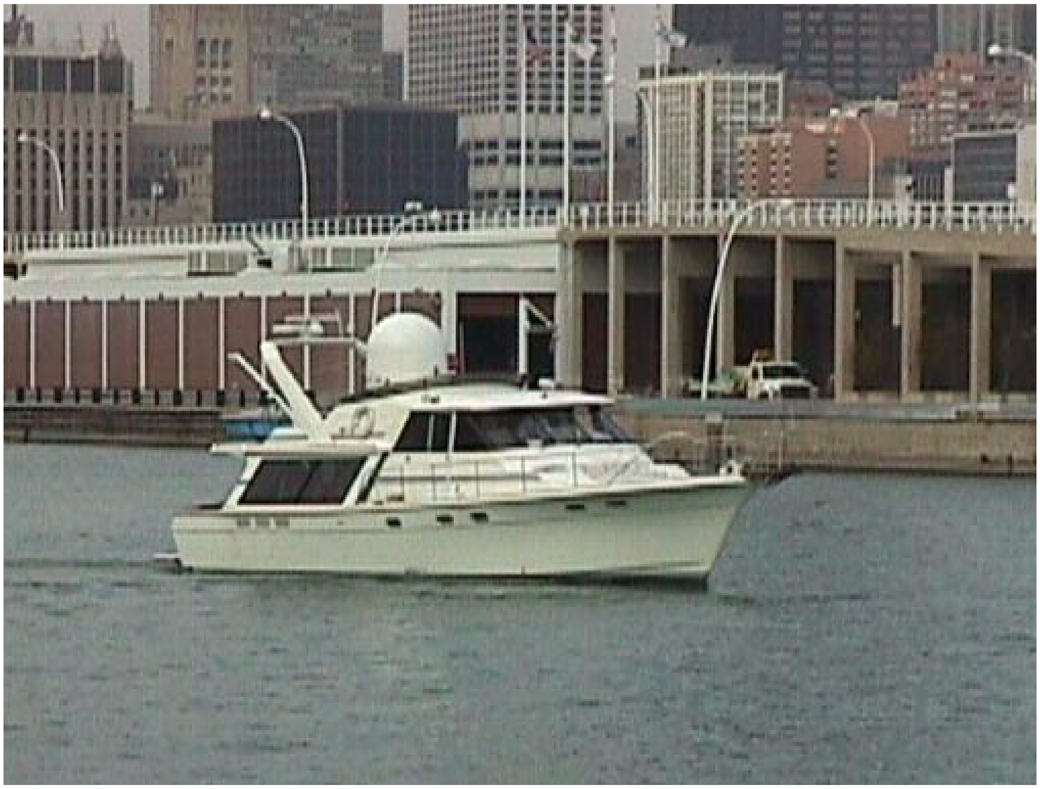

Figure 1: The Entropy at sea on Lake Michigan near Navy Pier, Chicago, IL, with the 1.0m Ka-band satellite terminal

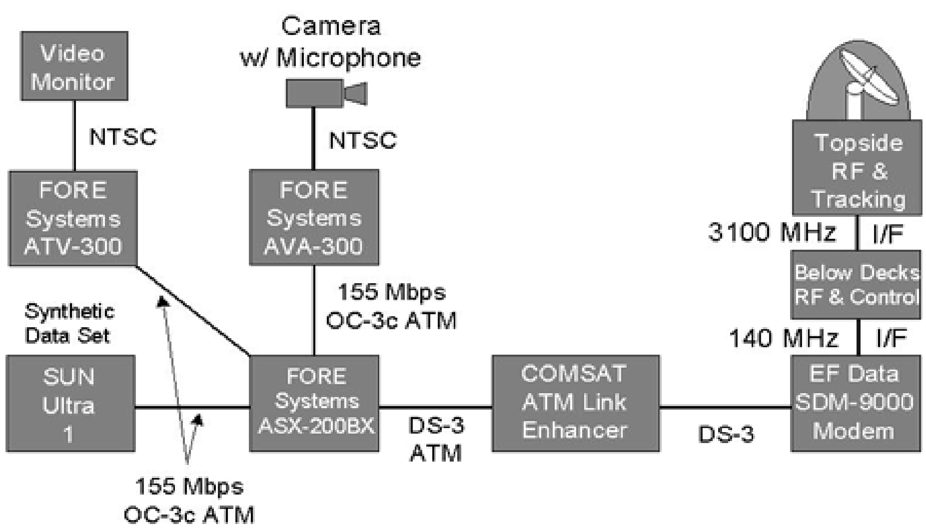

Figure 2: SHAKE shipboard HDR network system diagram

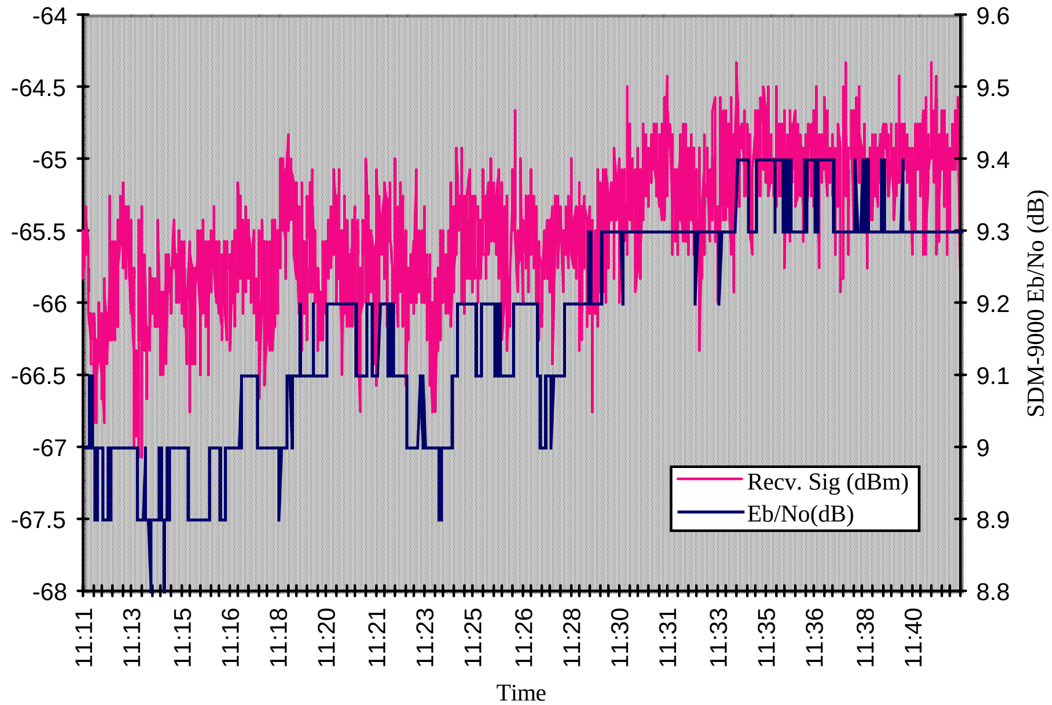


Figure 3: Measured Signal Strength at IF and processed Eb/No at modem for SHAKE Ka-band system aboard Entropy while underway, October 22, 1998.

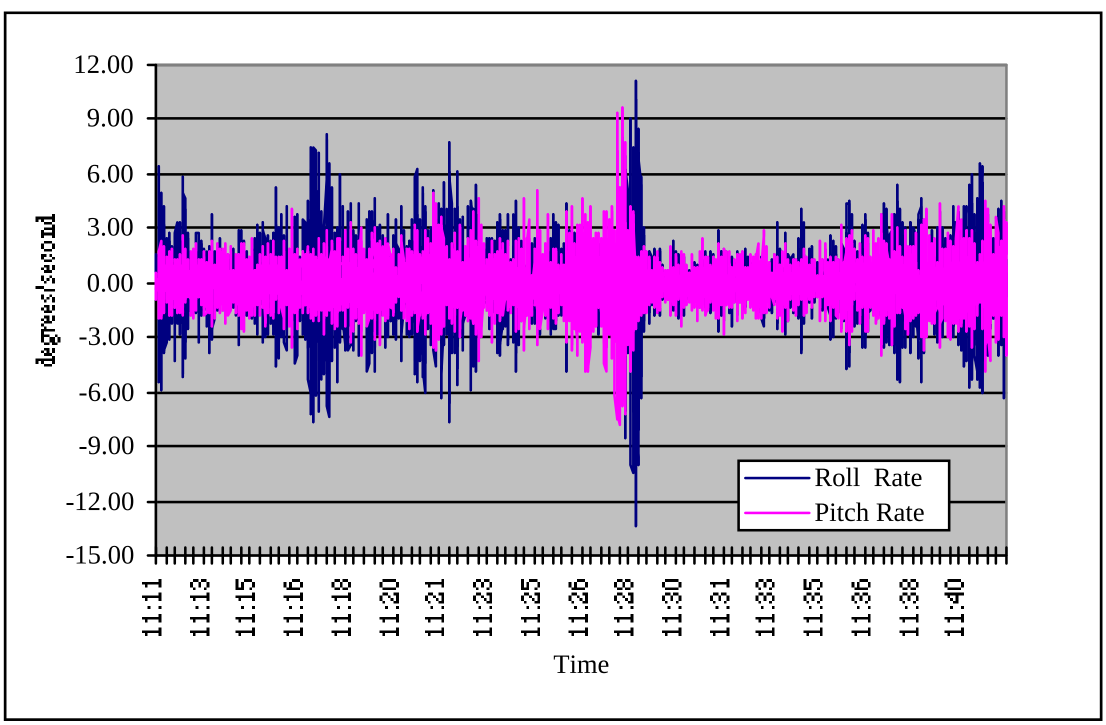


Figure 4: Measured vessel motion for Entropy, October 22, 1998, corresponding to terminal performance shown in Fig. 3.



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