3.5 - Advanced Shipboard Communications Demonstrations with ACTS

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Abstract

For ships at sea, satellites provide the only option for high data rate (HDR), long haul communications. Furthermore the demand for HDR satellite communications (SATCOM) for military and commercial ships, and other offshore platforms is increasing. Presently the bulk of this maritime HDR SATCOM connectivity is provided via C-band and X-band. However, the shipboard antenna sizes required to achieve a data rate of, say T1 (1.544 Mbps) with present C-/X-band SATCOM systems range from seven to ten feet in diameter. This limits the classes of ships to which HDR services can be provided to those which are large enough to accommodate the massive antennas. With its high powered K/Ka-band spot beams, the National Aeronautics and Space Administration's (NASA) Advanced Communications Technology Satellite (ACTS) was able to provide T1 and higher rate services to ships at sea using much smaller shipboard antennas. This paper discusses three shipboard HDR SATCOM demonstrations that were conducted with ACTS between 1996 and 1998.

The first demonstration involved a 2 Mbps link provided to the seismic survey ship M/V *Geco Diamond* equipped with a 16-inch wide, 4.5-inch tall, mechanically steered slotted waveguide array antenna developed by the Jet Propulsion Laboratory. In this February 1996 demonstration ACTS allowed supercomputers ashore to process *Geco Diamond's* voluminous oceanographic seismic data in near real time. This capability allowed the ship to adjust its search parameters on a daily basis based on feedback from the processed data, thereby greatly increasing survey efficiency.

The second demonstration was conducted on the US Navy cruiser USS *Princeton* (CG 59) with the same antenna used on *Geco Diamond*. *Princeton* conducted a six-month (January-July 1997) Western Hemisphere solo deployment during which time T1 connectivity via ACTS provided the ship with a range of valuable tools for operational, administrative and quality-of-life tasks. In one instance, video teleconferencing (VTC) via ACTS allowed the ship to provide life-saving emergency medical aid, assisted by specialists ashore, to a fellow mariner - the Master of a Greek cargo ship.

The third demonstration set what is believed to be the all-time SATCOM data rate record to a ship at sea, 45 Mbps in October 1998. This Lake Michigan (Chicago area) demonstration employed one of ACTS' fixed beams and involved the smallest of the three vessels, the 45-foot Bayliner M/V *Entropy* equipped with a modified commercial-off-the-shelf one-meter antenna. A variety of multi-media services were provided to *Entropy* through a stressing range of sea states. These three demonstrations provided a preview of the capabilities that could be provided to future mariners on a more routine basis when K/Ka-band SATCOM systems are widely deployed.

1.0 Introduction

Recent years have seen an increased demand for full-duplex, high data rate (HDR) digital communications services for maritime customers. These customers include the commercial cruise ship industry, the oil exploration and drilling industry and the military. Because the space available on ships and offshore platforms is limited, satellite communications (SATCOM) in the 30/20 GHz bands is an attractive option for providing HDR services to maritime customers. The National Aeronautics and Space Administration (NASA) launched the Advanced Communications Technology Satellite (ACTS) in September 1993. Now scheduled for a June 2000 de-orbit, ACTS afforded the maritime community its initial opportunities to demonstrate the potential of high-power K/Ka-band satellites to provide full-duplex HDR services with shipboard terminal equipment possessing significantly smaller aperture sizes than those presently required to provide equivalent data rates in the C- and X-bands. This paper discusses three shipboard HDR SATCOM demonstrations that were conducted with ACTS between 1996 and 1998. It also considers the near future of 30/20 GHz SATCOM in the United States Department of Defense (DoD) with a brief discussion of the Wideband Gapfiller Satellite (WGS) System. DoD is scheduled to launch its first WGS satellite in the fourth quarter of 2003. Lessons-learned from the shipboard ACTS experiments have effected the US Navy's WGS terminal plans.

1.1 Potential Benefits of K/Ka-Band SATCOM for Maritime Customers

Besides the obvious benefit of smaller terminal equipment for already overcrowded topsides, K/Ka-band SATCOM is also attractive from an electromagnetic interference (EMI) standpoint in the maritime environment, particularly aboard military ships. The 30/20 GHz bands are well above the bands used by current maritime radar systems. The same cannot be said about the C- and X-bands. Today, naval C- and X-band shipboard SATCOM terminals require supplemental EMI rejection filters to allow them to operate in a battle group environment, especially in close proximity with Aegis surface combatants. In the demonstration of the Jet Propulsion Lab's (JPL) ACTS Mobile Terminal (AMT) aboard the Aegis cruiser USS *Princeton* described below in this paper, supplemental filtering was not required. The AMT was unaffected by any of *Princeton's* radar systems. This was one of the most significant findings of the demonstration on *Princeton*.

Another warship concern for which K/Ka-band SATCOM can provide benefit is reduced radar cross section (RCS). It is not the case that navies expect to make their warships entirely invisible to radar. Rather the elimination of highly reflective hot spots in a warship's topside is of paramount importance in the face of threats from increasingly sophisticated sea-skimming anti-ship cruise missiles. The smaller a topside SATCOM antenna system is, the less it will contribute to a ship's RCS.

An obvious benefit of K/Ka-band SATCOM for all users, commercial and military alike is the additional bandwidth. The C- and X-bands each have 500 MHz of bandwidth and they are already crowded with users. The government and non-government K/Ka-band allocations form a contiguous 3.5 GHz band. The entire government K/Ka-band allocation (30.0-31.0 GHz Earth-to-space and 20.2-21.2 GHz space-to-Earth) is designated for fixed and mobile SATCOM services (FSS and MSS) on a co-primary basis. Portions of the non-government K/Ka-bands are also allocated for MSS. In the space-to-Earth band (17.7-20.2 GHz) a 500 MHz segment (19.7-20.2 GHz) has been allocated for FSS and MSS on a co-primary basis. However, in the Earth-to-space band, only a 100 MHz segment (29.9-30.0 GHz) has been allocated for MSS uplinks on a co-primary basis with FSS uplinks. In the 400 MHz segment from 29.5 to 29.9 GHz, MSS uplinks are allowed, but they have secondary status whereas FSS has primary status. See [18] for further discussion of this MSS/FSS allocation issue.

All SATCOM frequency bands have pros and cons for delivering maritime wideband services. Table 1 lists the pros and cons of these frequency bands from the perspective of the US Navy.

1.2 Non-Government K/Ka-Band SATCOM and the DoD

On 5 August 1998, the DoD SATCOM Senior Steering Group (SSG) tasked the Navy and the Defense Information Systems Agency (DISA) to co-lead, with joint participation, the evaluation of commercial business cases for emerging commercial SATCOM systems in K/Ka-band. Navy members of the DoD study team have published a paper [17] that summarizes their first year of work. Their observations thus far include the fact there is no consensus on what the potential total market is, let alone confident predictions of which particular commercial K/Ka-band SATCOM offerings may become profitable. Therefore, it is difficult to defend decisions that might lock DoD into any particular commercial SATCOM venture that is unproven in the marketplace. DoD is currently reluctant to enter into anchor tenancy agreements that would require significant Government capital investments prior to the establishment of a sustaining commercial customer base. This reluctance has been reinforced by the recent unfortunate experience with the now defunct Iridium LEO system.

The DoD study team met with several companies planning to launch commercial K/Ka-band systems. None of the emerging commercial K/Ka-band ventures studied by the team is yet planning to provide MSS, let alone MMSS (Maritime Mobil Satellite Service) services. Furthermore, none of them are yet planning to include steerable satellite antennas that could provide not only part time open ocean coverage, but also would allow them to respond to contingencies anywhere within a satellite's field-of-view for any type of potential customer (DoD, humanitarian relief or otherwise). These findings are discouraging from DoD's perspective and the study effort is on hiatus in Fiscal Year 2000.

Table 1. PROS AND CONS OF VARIOUS WIDEBAND SATCOM BANDS FROM THE US NAVY'S PERSPECTIVE

Band	Pros	Cons
L	• Worldwide open ocean coverage without the need to re-point spot beams • Terminal technology mature • Allocated for MMSS • Little rain fade loss • Allied interoperability	• Service costs are high • Geolocation vulnerabilities • Throughput limited to 64 kbps/channel (INMARSAT B HSD) • EMI from maritime radars
C	• Worldwide open ocean coverage without the need to re-point spot beams • Terminal technology mature • Little rain fade loss	• Not allocated for Gov use • Not allocated for MSS • Transponder leasing is expensive • EMI from maritime radars • Possible EMI with/from FS users • Large terminal equipment

X	• Dedicated DoD space segment (DSCS)
	  • Worldwide coverage
	  • Allocated for Gov use
	  • Allocated for MSS
	• Terminal technology mature
	• Large existing terminal population
	• Little rain fade loss
	• Potential for increased Allied interoperability
		• Limited available bandwidth
		• EMI from maritime radars
		• EMI from various terrestrial users in some locations outside of the United States
		• EMI from Gov X-band FS users
		• Medium to large terminal equipment

Ku	• Terminal technology mature • Smaller terminal equipment • Possible SATCOM and tactical data link shipboard terminal equipment commonality • Moderate rain fade loss • Transponders on aging INTELSAT satellites may be available at reduced cost	• Not all Ku bands allocated for Gov use • Not all Ku bands allocated for MSS • Transponder leasing is expensive • Limited open ocean coverage • EMI from maritime radars • Many transponders are linearly polarized, a complicating factor for mobile users
K/Ka (Non Gov)	• Smaller terminal equipment • Ample available bandwidth • Little EMI from maritime radars • Some allocation for MSS	• Not allocated for Gov use • Unknown if MSS services will be offered • Service arrangements uncertain • No open ocean coverage planned • Terminal technology maturing • Considerable water vapor & rain fade losses • Increased Doppler shifts for mobile platforms compared to lower bands

K/Ka (Gov)	• Smaller terminal equipment
	• Ample available bandwidth
	• Dedicated DoD space segment
	  • Near worldwide coverage with WGS
	  • Likely worldwide coverage with AWS
	  • Allocated for Gov use
	  • Allocated for MSS
	• Little EMI from maritime radars
		• Terminal technology maturing
		• Considerable water vapor & rain fade losses
		• Increased Doppler shifts for mobile platforms compared to lower bands

Band Definitions	Earth-to-Space (GHz)	Space-to-Earth (GHz)
L	1.6265 - 1.6605	1.5250 - 1.5590
C	5.925 - 6.425	3.700 - 4.200
X	7.90 - 8.40	7.25 - 7.75
Ku	Various	Various
K/Ka (Non Gov)	27.5 - 30.0	17.7 - 20.2
K/Ka (Gov)	30.0 - 31.0	20.2 - 21.2

Acronyms

AWS - Advanced Wideband Satellite System (DoD, 2008 time frame)
DSCS - Defense Satellite Communications System (DoD, currently deployed)
EMI - Electromagnetic Interference
FS - Fixed Service (Line-of-Sight Microwave Links)
HSD - High Speed Data
INMARSAT - International Maritime Satellite
MMSS - Mobile Maritime Satellite Service
MSS - Mobile Satellite Service
WGS - Wideband Gapfiller Satellite System (DoD, 2004 time frame)

Note It should be recognized that the ability to support higher data rates with smaller shipboard terminals comes at the expense of the need to point spot beams. For instance, while it is necessary to use a large shipboard antenna at C-band, it is not necessary to schedule the movements of C-band spot beams. On the other hand, narrow spot beams allow frequency re-use that is not possible with Earth coverage beams.

1.3 Government K/Ka-Band SATCOM - DoD's Wideband Gapfiller Satellite (WGS) System

The DoD's use of the government 30/20 GHz bands will expand rapidly after the launch of the Wideband Gapfiller Satellite (WGS) System starting in the fourth quarter of 2003. WGS was designated an ACAT ID[1] program on 15 October 1999 by the Under Secretary of Defense for Acquisition and Technology (USD(A&T)) [15]. From [14]: "This system is intended to support a worldwide terminal population with greatly increased system capacity relative to current military systems and the addition of a two-way Ka-band[2] capability. The Gapfiller satellites, in conjunction with the remaining [X-band] Defense Satellite Communications System (DSCS) satellites and [K/Ka-band] Global Broadcast Service (GBS) capabilities on UHF Follow-On (UFO) satellites, will sustain a significant level of worldwide wideband satellite connectivity for the Department of Defense (DoD) until the advent of an Advanced Wideband System [in the 2008 time frame]. The [WGS] satellite system consists of at least three geosynchronous satellite configurations and ground equipment and software associated with Gapfiller payload and platform control." The most likely orbital positions for the three WGS satellites are 60 East, 175 East and 12 West.

WGS will be a dual-band SATCOM system supporting terminals operating in the Government K/Ka-bands and X-band (see Table 1). In the baseline conceptual design, the K/Ka-band portion of each satellite will support from 4 to 6 "narrow coverage areas" (NCAs) and 1 to 2 "expanded narrow coverage areas" (ENCAs) [14], [16]. The NCAs and ENCAs will be covered with ~1.5° and ~4° (respectively) beams that are steerable anywhere within the field of view of the satellite. (The NCA beams will be slightly broader than ACTS' steerable beam, which was ~1° at 20 GHz.) As of this writing, the detailed specifications of the WGS satellites have not been finalized. Nonetheless, it is expected that the satellite's K-band EIRP will approach 60 dBW per carrier in the NCAs, similar to ACTS. The uplink G/T in the NCAs will likely be in the neighborhood of 10 dB/K at Ka-band, also similar to ACTS.

The US Navy's shipboard SATCOM terminal for use with the Defense Satellite Communication System (DSCS) X-band space segment is the AN/WSC-6(V). The newest variants of the WSC-6, the (V)7 (7.75-foot diameter parabolic reflector) and (V)9 (5-foot diameter parabolic reflector) have pre-planned product improvement (P3I) options to add 30/20 GHz transmit/receive capabilities for the Government K/Ka-band portion of WGS.

2.0 Advanced Shipboard Communications Demonstrations with ACTS

This section describes three high data rate shipboard SATCOM demonstrations/experiments that were conducted with ACTS in the 1996-1998 time frame. These efforts have been reported previously - references are provided. An attempt has been made to include previously unpublished material and discuss the long-term significance of the work rather than specific details, which are available in the references.

2.1 JPL's ACTS Mobile Terminal on M/V *Geco Diamond*

Seismic survey ships search for structures in the ocean floor that are consistent with oil reserves. The ships tow hydrophone arrays that pick up the echoes of acoustic impulses (compressed air blasts from the ship at regular intervals, e.g., 15 seconds) from layers of the ocean bottom. The data are fed into computationally intensive seismic deconvolution routines to produce an estimate of the impulse response of a layered earth model. Experts must then interpret these estimates to select sites that are worthy of the expense of exploratory drilling.

A typical seismic survey vessel might collect 100's of Gbytes of data per day. In the past, these data have been stored on tapes and analyzed ashore, sometimes months after they were collected. A more economically competitive approach would evaluate the data in near-real time. This would enable the ship to re-examine initially promising areas, perhaps with varied acoustic array parameters to elevate the level of confidence about the possible presence of oil. What if the data could be sent from the ship via a wideband SATCOM link to a supercomputer center ashore as they were collected?

On 26 February 1996, the American Petroleum Institute hosted a press conference at the National Press Club in Washington, DC. At the front of the room was a large projection screen, a few racks of equipment behind a curtain and a panel of people seated at a long table. Two of the authors of this paper participated in this press conference, Axford as an attendee and Jedrey aboard the M/V *Geco Diamond* operating in the Gulf of Mexico.

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[1] Acquisition Category (ACAT) I programs are major defense acquisition programs, defined as programs estimated by the USD(A&T) to require eventual expenditure for RDT&E of more than $355 million (FY 1996 constant dollars) or procurement of more than $2.135 billion (FY 1996 constant dollars), or those designated by the USD(A&T) to be ACAT I. The USD(A&T) is designated the milestone decision authority (MDA) for ACAT ID programs. In other words, DoD is making a significant investment in WGS.

[2] In the DoD, the 30/20 GHz bands are referred to collectively as "Ka-band."

The following is the relevant weekly report segment that Axford wrote for his management chain on 6 March 1996.

> "I attended the ARIES (ATM Research and Industrial Enterprise Study) demonstration and press conference at the National Press Club in Washington, DC on 26 February 1996. This was the "Shipboard ATM Demo" described in e-mails forwarded on 22 & 23 February. It came off as advertised and oil exploration researchers located in San Francisco, Houston and Minneapolis really did interact with the seismic acquisition vessel M/V *Geco Diamond* (at sea collecting data in the Gulf of Mexico) in real time. In addition, a telemedicine demonstration connected Dr. Michael DeBakey from the Texas Medical Center with a dramatized cardiac arrest case aboard M/V *Geco Diamond*. The proceedings (live audio & video, computer graphics) were displayed on a SPARC 20 and shown to the audience on a large screen above the stage during the course of the two-hour demonstration. The shipboard link operated over NASA's ACTS Ka-band satellite at a data rate of 2 Mbps, full duplex. However, the effective throughput to the ship was roughly 4 Mbps in each direction thanks to the COMSAT ATM Link Accelerator, which performs both adaptive forward error correction coding (FEC), and data compression on an ATM-cell by ATM-cell basis. (Mr. David Beering, the ARIES Coordinator and Chair of the ATM Forum Enterprise Network Roundtable, referred to this COMSAT device as "a golden spike.") The punch line at the end of the demonstration was the display of a "first pass" of processing (performed at the Minneapolis Supercomputer Center) on the seismic data that M/V *Geco Diamond* had been collecting *during the course of the press conference.* "Ladies and gentlemen, welcome to the era of real time seismic oil exploration." This same shipboard terminal, owned and operated by NASA/JPL is scheduled for an ONR [Office of Naval Research] -sponsored demonstration/experiment aboard USS *Princeton* (CG-59) this summer."

The terminal used in both the *Geco Diamond* and USS *Princeton* demonstrations was the "Broadband Aeronautical Terminal" described on pp. 182-187 of [1]. The two-axis (elevation over azimuth), mechanically steered transmit/receive antenna used in both demonstrations is shown in Figure 15 on p. 187 of [1]. The antenna's manufacturer has also built a Ku-band receive-only version based on the same approach (slotted waveguide array) for the in-flight DBS reception market [10]. (However, it appears that the aeronautical DBS antenna with which this manufacturer has had the most commercial success to date is a version of a simple parabolic reflector [11].)

The *Geco Diamond* demonstration has also been described in [2] and [3]. The significance of this demonstration for the job of searching for oil under the ocean lies in the reduced overall cycle time for acquiring, processing and interpreting seismic data and making decisions based on interpretations. If the only way to do this is to employ supercomputers ashore, then this demonstration showed that it could be done. However, considering the rapidly decreasing cost/performance ratio of computers, a likely future architecture would include some degree of "supercomputing" capability aboard the seismic survey vessel itself. Perhaps the onboard computers could process the data to the point where near-real-time analysis by experts ashore could be supported by SATCOM links on the order of 200-500 kbps.

2.2 JPL's ACTS Mobile Terminal on USS *Princeton* (CG 59)

Following the successful demonstration on *Geco Diamond*, JPL's ACTS Mobile Terminal (AMT) was installed on USS *Princeton*, a San Diego, CA homeported Aegis guided missile cruiser (CG). Personnel from the Space and Naval Warfare Systems Center, San Diego and JPL completed the installation in July 1996. The AMT remained onboard through weekly "work-up" operations in San Diego waters that fall, and continued to serve *Princeton* during a six-month solo deployment off the Pacific and Caribbean coasts of Latin America in support of US Coast Guard law enforcement operations, January - July 1997. The AMT was finally de-installed from *Princeton* in September 1997 and then went on to an aeronautical SATCOM demonstration described in [6] using Italy's ITALSAT F1 K/Ka-band satellite. With the full-duplex T1 (1,536 kbps aggregate user data rate) connectivity made possible by ACTS and the AMT, *Princeton* became a node on the US Navy wideband Naval Tactical Network (NAVTACNET), the first CG to do so[3]. This enabled *Princeton* to have eight toll quality phone lines (including secure telephone units), general-purpose TCP/IP connectivity (e-mail, World Wide Web,

[3] Until that point in time, the only NAVTACNET ships were large decks with X- and/or C-band SATCOM terminals: aircraft carriers (CV, CVN), helicopter assault ships (LHA, LHD) and command ships (LCC, AGF).

FTP and Telnet) and video teleconferencing (VTC) with various shore-based support facilities via the synchronous serial circuits of a programmable multiplexer. This connectivity should be compared to what *Princeton* would have had on that deployment without the AMT: an INMARSAT-A terminal for general-purpose 9600 baud data communications (via modem over an analog connection) and MILSATCOM terminals (UHF and EHF) for special purpose, low rate data communications. Unlike *Geco Diamond*, *Princeton* did not use ATM protocols over ACTS.

The demonstration of JPL's ACTS Mobile terminal on USS *Princeton* has been described previously in [4] and [5]. Since these papers were written, CDR Matthew Sharpe, USN, who was *Princeton's* Executive Officer for the duration of the AMT's time onboard, has made available some of the e-mail messages that he sent to his wife via ACTS during the six-month deployment (January-July 1997). Here is an excerpt from 10 February 1997 that describes a deviation from *Princeton's* routine that occurred earlier that same day.

> "We just participated in a rescue and medical evacuation. The 66-year-old master of a Greek freighter took ill. We closed at best speed throughout the night, then launched one of our helicopters to intercept. My air boss [commanding officer of *Princeton's* air detachment, LCDR Joe Beal, USN] had to fly in a high hover, slipping sideways into the wind for over thirty minutes while the crewman lowered by hoist to the deck 120 feet below. We pulled up the master, then my crewman.
>
> Back aboard *Princeton*, we hooked him up to the "crash cart," a vital signs monitor and EKG unit. We ran a blood sample through our new blood analyzer. Diagnosed a swollen prostate that had pinched his urethra and prevented urination for several days. My corpsman started an IV, inserted a catheter and his bladder was back in business. Unfortunately, the blood analysis showed that the master's kidneys had responded to the blockage by shutting down. His blood potassium level was dangerously high and he had developed an unusual abdominal rash.
>
> We established a video-teleconference [via ACTS] with the urology staff at Naval Medical Center San Diego. They were able to examine our patient, view his vital signs, and review our lab work. It was reassuring that they could confirm my corpsman's diagnosis and treatment decisions. The VTC would have been much more important if we needed to perform surgery to place the catheter. (Surgery? You bet. When we are the only game in town, we do what we need to.)
>
> The next morning, the master was feeling better, not quite out of the woods, and we flew him to La Paz [the capital city of Baja California Sur, Mexico] for further treatment. We learned later that our intervention saved his life. Always glad to help a fellow mariner."

The demonstration of JPL's ACTS Mobile Terminal on *Princeton* showed how high-power K/Ka-band satellites like ACTS can enable the US Navy to bring a full spectrum of communications services to a broader range of ship classes than previously possible. Indeed, the K/Ka-band portion of DoD's X/K/Ka-band Wideband Gapfiller Satellite (WGS) System will bring "ACTS-like" wideband SATCOM capabilities to small aperture mobile terminals to support a wide variety of missions. Furthermore, the successful *Princeton* demonstration led directly to the US Navy's ultra small aperture terminal (USAT) project, which is developing phased array antenna technology for both the Government and non-Government 30/20 GHz bands as described in [12] and [13]. However, the most gratifying long-term effect of the demonstration on *Princeton* for the project team was the opportunity to help an individual in medical distress.

2.3 The NASA/NRL "SHAKE" Experiment on M/V *Entropy*

The "Shipboard ACTS Ka-band Experiment" (SHAKE) performed by personnel from the NASA Glenn Research Center and the Naval Research Lab (NRL) over a two-week period in October 1998 has been described previously in [7], [8] and [9] and was significant for at least two reasons. Firstly, this experiment set what is believed to be the all-time SATCOM data rate record to a ship at sea, 45 Mbps. "In order to achieve full-duplex data rates of 45 Mbps using a 1 meter dish, there were many optimizations that needed to be performed. The experiment team documented about ten additional optimizations that we would do the next time, if we were to be able to repeat the *Entropy* experiment." [19]

Secondly, NRL and NASA instrumented the experiment heavily and performed more extensive communications performance measurements than those taken in either of the two previous shipboard demonstrations with ACTS described in this paper. Communications performance data were collected simultaneously on (1) ship's pitch, roll and yaw and the received RF signal level (thereby evaluating the tracking performance of the antenna), (2) DS-3 layer port statistics, (3) ATM layer statistics, and (4) application performance. Analysis of these data sets is ongoing (beyond what has yet been published and as time allows) and a future comprehensive publication is expected.

The US Navy recognizes the importance of knowing the statistics of shipboard SATCOM system performance, including statistics as simple as link utilization (user traffic volume, e.g., bytes/day in each direction, ship to shore and vice versa). How else can one establish metrics to judge the performance of system upgrades? The SHAKE instrument suite was a model for that which might be adopted for Navy shipboard communications systems developers and evaluators. How much more effectively would taxpayers' money be spent if the information gathered by such a suite was analyzed for each battle group deployment as a matter of routine, and the results then used to guide the selection of communications techniques for fleet insertion?

3.0 Conclusions

It is safe to say that the long term effects of these three experiments will continue to be felt in the civilian and military maritime SATCOM communities for some time to come. At the moment, the chief impediment to the proliferation of large numbers of shipboard K/Ka-band SATCOM terminals is the lack of K/Ka-band space segment providing open ocean coverage. Commercial systems planners must tailor their designs to maximize return on investment and concentrate capacity at revenue generating population centers. How the maritime community might successfully lobby with K/Ka-band SATCOM systems planners to provide steerable beams for ocean coverage is an open question that probably has a simple answer. When will market projections for broadband maritime SATCOM services furnish an incentive to provide the needed technical capabilities on K/Ka-band spacecraft? Are there other markets that require the same technical capabilities on the spacecraft?

Regardless of the frequency band employed, the oil industry recognizes the need to provide its seismic survey ships with the capabilities to access computing facilities ashore. According to David R. Beering, coordinator of both the *Geco Diamond* demonstration and the SHAKE experiment:

> "One long-term impact of the *Diamond* deployment is that the oil industry now includes special real-estate high up on the mast of new seismic vessels reserved for relatively large satellite antennas [presumably for any frequency band with available space segment]. In the case of Geco-Prakla, their "Vessel 2000" ship was not only equipped with this prime real estate for one antenna, but additionally, the vessel was equipped with a second spot high on the mast for "something yet to come." This reference is to some Ka-Band advanced SATCOM capability not presently commercially available. ... It's interesting to note that a commercial company, Space Data International, has filed for permission to use NASA's Tracking & Data Relay Satellite System (TDRSS) for use supporting seismic acquisition vessels at-sea." [19]

In looking back at the opportunities ACTS provided for verifying new technologies for wideband shipboard communications, we commend the visionary decisions made by NASA that led to such an adaptable spacecraft. Our only regrets are that we didn't do more mobile maritime experiments and demonstrations with ACTS, and that there won't be an "ACTS II."

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