Advanced Communications Project

Operational Evaluation of a DGPS / SATCOM VTS

DTRS-57-93-C-00005

Final Report

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Table of Contents

Table of Figures

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(edited by David Pietraszewski, USCG R&D Center)

A. Requirement

Marine transportation is vital to the economic well-being of the United States. The capability of periodic automatic communications of precise vessel position and course over ground information in controlled waters such as harbors and high density shipping corridors provides a key ingredient to improved safety of the public and the protection of the environment. This capability provides for real-time management of the waterways, to provide timely alerts that can be used to prevent catastrophic incidents (such as the *Exxon Valdez* grounding), as well as, to provide quick and effective responses to control and mitigate those incidents that do occur.

For a Vessel Traffic Service (VTS) to provide effective management, the position reporting system must provide accurate and timely reports of the location of all mandatory participant vessels. It must provide dependable and timely communications over a wide variety of environmental, geographic, and operational conditions.

An automatic vessel position reporting system can:

- Help prevent collisions and groundings of vessels,
- Improve the traffic flow efficiency,
- Be used to automate some vessel traffic center functions, and
- Improve the tactical capabilities of emergency response assets.

Terrestrial VHF and HF communications frequencies have limitations due to channel capacity, geographic coverage, and signal propagation characteristics when applied to VTS communications. New technologies, such as Digital Selective Calling (DSC), are improvements, but they are still limited.

B. Purpose

Satellite communications (SATCOM), using code division multiple access (CDMA) modulation and burst messaging, provides a new dimension to communications channel capacity, operating dependability, and area of coverage. This technology, together with differential GPS (DGPS) electronics for vessel location and course over ground (COG) determination, provides a strong yet flexible foundation for implementing asset management systems, such as a VTS, in a cost effective manner. This paper reports the test and evaluation of an integrated SATCOM prototype system. This SATCOM system can support VTS operations in one locale while providing aircraft flight following in another (such as International Iceberg Patrol in the North Atlantic), through a common base station.

Technical management of this project was performed by the U.S. Coast Guard Research & Development Center (R&DC). The US Army Space Command (ARSPACOM) also participated actively in this program. As the project was implemented, the aviation flight following portion addressed helicopter operations, both Coast Guard and Army. Short burst messaging addresses an acute need for long range communications with helicopters flying nap-of-the-earth.

C. Potential Commercial Applications

The system has a variety of applications, both government and commercial. Government markets include:

- Military/Law Enforcement
- Search and Rescue
- VTS Operations
- Iceberg Tracking
- Forest Fire Management

Commercial markets include:

- Vessel fuel management, crew scheduling
- Helicopter equipment performance monitoring (HUMS)
- Flight Following (Fixed wing and helicopter)
- Medivac operations, both ground and airborne
- Hazardous cargo tracking/monitoring
- Automated dependent surveillance (ADS) or automatic vehicle tracking (AVT)
- Aircraft and vessel security

D. Technical Objectives

This project was a test and evaluation of the Newcomb Mobile Satellite Messaging system as applied to vessel traffic service requirements. In addition, the adaptability of the system to also accommodate other (non-VTS) Coast Guard missions was evaluated.

The technical objectives of this project were:

- To establish a seamless, composite VTS messaging capability, integrating existing formats into a wide area SATCOM-based fleet management system.
- To establish and validate the operational concepts, procedures, and protocols for a multi-purpose central operations center for VTS, SAR or other operations.
- To validate the dependability, functionality and fitness of the Newcomb Vessel Tracking Unit equipment for maritime (and aviation) applications.

E. System Description

E.1. *Overview*

Newcomb Communications, Inc. has developed a communications technology for direct support of transportation management systems. It uses existing communication satellites for tracking and management of remote mobile assets such as aircraft, ships, or ground vehicles. As an aircraft flight follower system it has significant potential for both fixed wing and rotor-wing aircraft operations. Combining GPS with satellite communications provides a real-time, accurate, and dependable fleet management system. The area of coverage and dependability provided by this satellite-based system greatly exceeds conventional terrestrial radio networks.

The use of CDMA, spread spectrum, techniques provides significant performance benefits:

- A large quantity (thousands) of mobile terminals share the same communications channel without interference, and
- Reliable communications can be conducted with a low probability of errors being introduced or information being intercepted.

The user's central console can use conventional public switched telephone networks (PSTN) or the Internet to connect to the satellite gateway. For fleet management and control of operations, information aboard the vessel (or aircraft), such as location, coarse over ground, fuel aboard, estimated arrival times, etc. can be provided on a real-time basis to management. Timely information supports management actions to improve operating efficiencies, equipment and crew utilization, and customer services.

Messaging: There are several types of messages exchanged between a mobile terminal and the central console.

1. For fleet tracking, the mobile terminal uses its internal Global Positioning System (GPS) receiver to determine its location. It then transmits this GPS position, together with Terminal ID, to the central console (via the Fixed Earth Station/Gateway and telecommunications service provider).
2. The mobile terminals monitor vessel equipment and send measurements to the central console on a periodic-plus-alarm basis to support "Management By Exception."
3. The vehicle crew may exchange text messages with the central console operator using a keyboard and display.

From the operations point-of-view, the central console represents effective real-time supervision of the fleet over very large geographic areas.

E.2. *Performance Advantages*

The use of CDMA technology affords significant and unique advantages over other mobile communication systems. The technology has been received with strong interest in both government and commercial transportation markets. Some of the strengths of CDMA technology are:

- Dependable and predictable wide-area, long range communications with a variety of assets, including ground vehicles, vessels, and aircraft.
- Accurate, automatic GPS-based position reporting keeps a reliable current picture of fleet assets, continent-wide.
- High volume real-time communication throughput; i.e., the channel is virtually always available to every mobile terminal for immediate transmit-on-demand. In fact, the time to receive a message at an operations center is about a second (when using a dedicated connection

to the Earth Station/Gateway). A delay of a few seconds is normal when using an Internet connection.

- Omnidirectional flat-plate antennas require no mechanical or electronic steering.
- Secure, error-free communications result from use of spread spectrum CDMA coding and forward-error-correction techniques.

E.3. System Configuration

The system is composed of four (4) principal elements:

1. Remote mobile terminals,
2. Satellite transponders,
3. Satellite earth station/gateways,
4. User's operations consoles.

The relationship between these elements are illustrated in Figure 1.

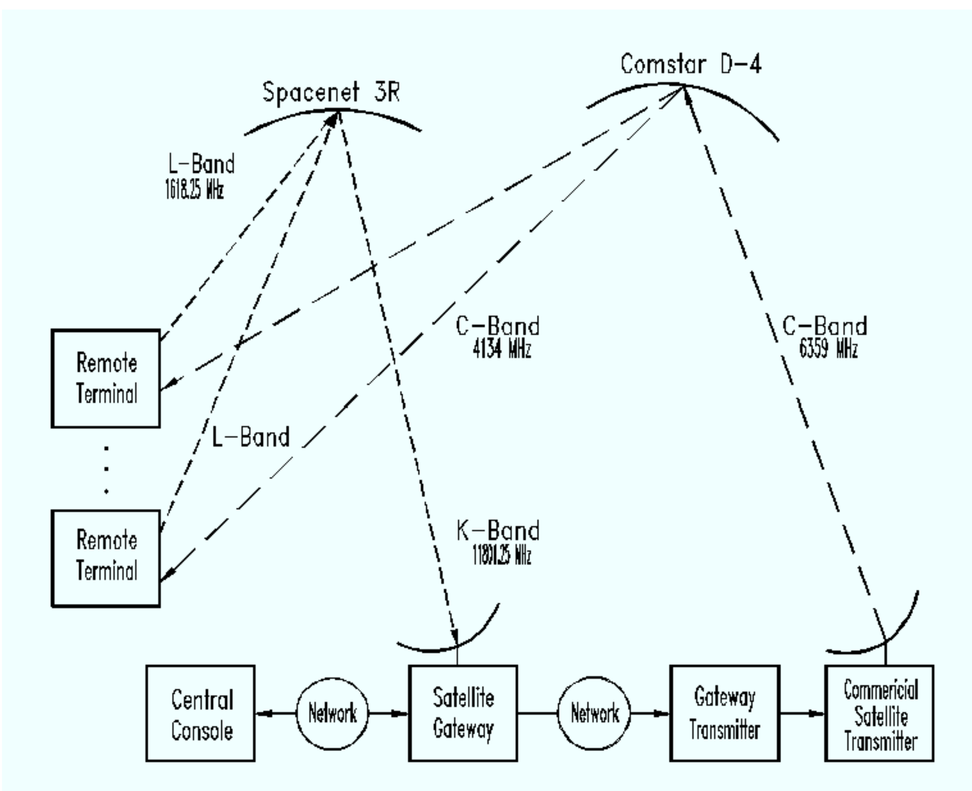

Figure 1 – Newcomb Satellite System Schematic

E.3.1. Mobile Terminal Functions

The mobile terminal performs a number of functions:

1. The terminal periodically reports its ID and geographic position via the satellite gateway to the user console.
2. The terminal transmits messages to and receives messages from either the satellite gateway itself or the user console (via the gateway).
3. It monitors and controls a variety of user's on-board systems interfaced with the mobile terminal.
4. The mobile terminal may also function as a mobile or remote control console. It may contain programs that log, display, and analyze the locations and status of the fleet of other mobile assets in a manner similar to that provided in the central console. For example, it could become a mobile command post.

The full duplex AV-2 transceiver provides two-way (transmit/receive) data messaging between mobile assets and central operations.

The CP-1 terminal, a precursor to the AV-2 terminal, is a transmit-only unit with an internal GPS receiver. Data Sheets for both CP-1 and AV-2 are included in the Appendix. A photograph of the CP-1 is shown as Figure 2.

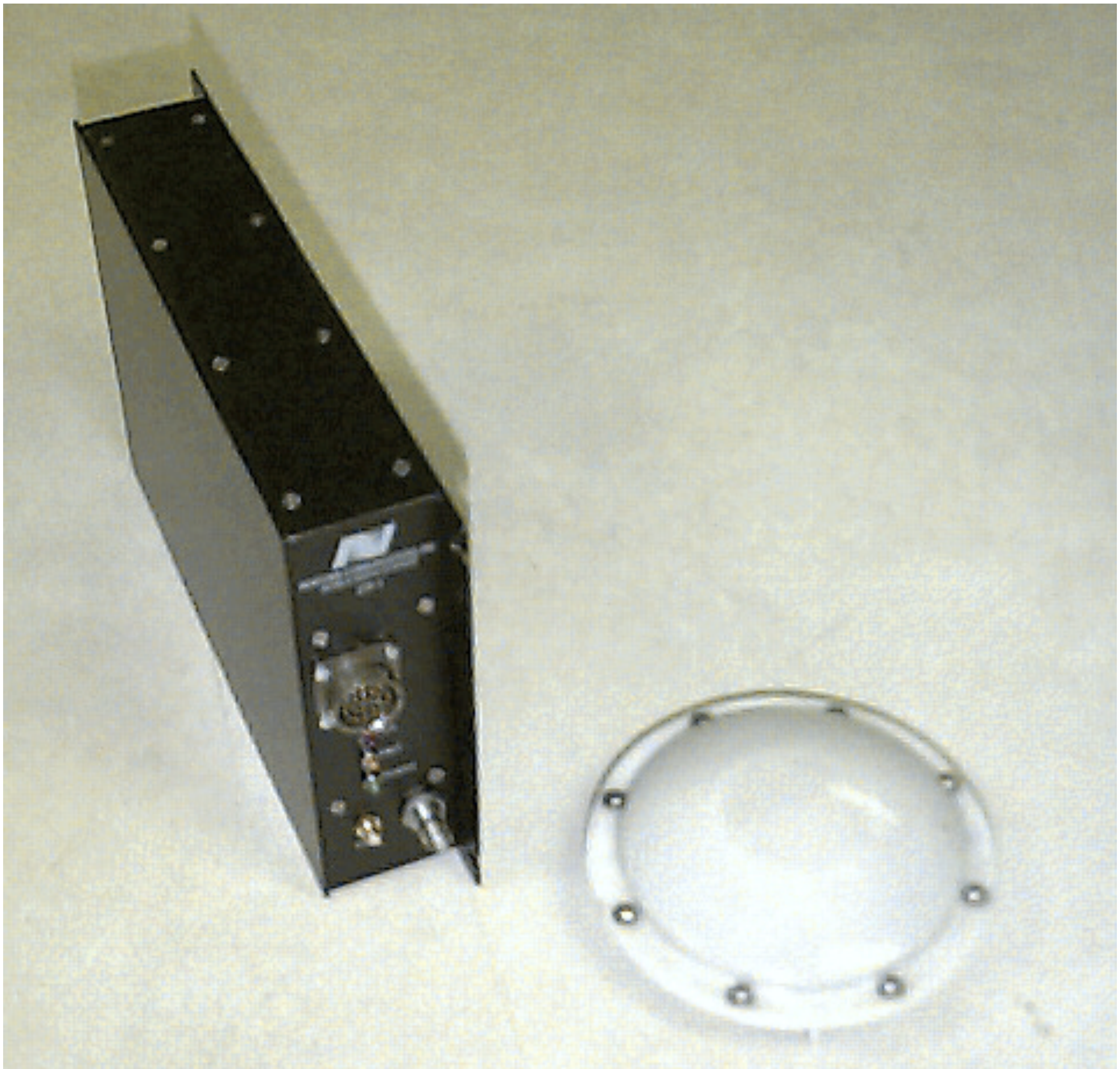

Figure 2 — Newcomb CP-1 Transmitter and Antenna

E.3.2. Mobile Terminal Description

The mobile terminal is composed of subsystems connected by an internal local area network, as illustrated in Figure 3.

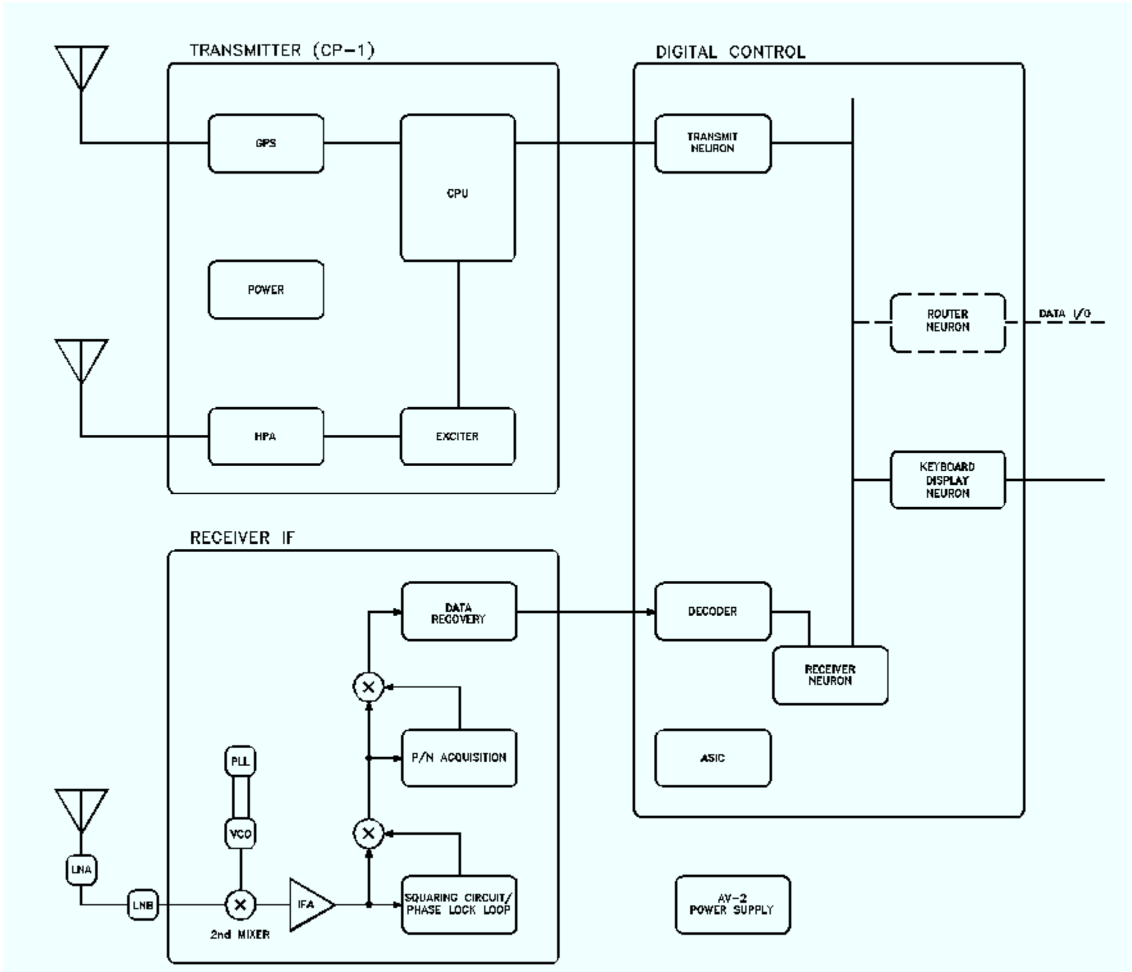

Figure 3 – Newcomb AV-2 Subsystems

E.3.2.1. *Transmitter Subsystem*

The Transmitter Subsystem accepts messages from the GPS, Keyboard / Display Unit (KDU), and Equipment Monitoring subsystems as well as acknowledgments from the receiver subsystem. It then combines these messages into a stream of packets that are transmitted across the satellite network to the satellite gateway (Fixed Earth Station). The transmitter may also accept control messages from the satellite gateway (via the Receiver Subsystem). The transmitter also controls the power supply to enable a short (20–68 ms) burst of power sufficient to transmit each packet. The transmitter operates in a Direct Sequence Spread Spectrum mode. It spreads the signal using a pseudo-random noise (PN) generator based on the 2^{17}-1 Gold codes with 256 chips per symbol. In addition it uses a rate $^1/_2$ convolutional encoder with constraint length 7 to provide forward error correction (FEC). As a result, the transmitter's information rate of 15,625 bits per second is expanded to a transmission rate of 8 M chips per second (i.e., 2x for FEC and 256x for PRN spreading). Transmissions are sent in short (20 to 68 msec.) bursts as frequently as every 10 seconds, but more typical is every few minutes. The data content of each packet is limited to 94 bytes; therefore, for messages greater than 94 bytes, the transmitter will break the message apart into segments of 94 characters or less, and send the message as an ordered sequence of packets. The transmitter conforms to the transmit side of an open systems interconnection (OSI) model communications stack up through the transport layer. This technique provides exceptional messaging dependability and security.

An example of the encoding of a message is shown in Figure 4. Here, a free text message is typed on the keyboard. The transmitter ID and location are added to the message. Then, the error checking CRC bits are added. At that point, each byte (8 bits) goes through convolutional encoding and is converted to 16 symbols. Finally, each of these symbols is converted to 256 “chips” for spreading across the 16 MHz. frequency band.

```
The message:                                      Get me outta here!

"Mail" protocol:   HQ,N4302,Position,etc.         Get me outta here!

Error Checking:   length  HQ,N4302,Position,etc.  Get me outta here! CRC
                                                  |
Convolutional Encoding:                           |
    Each byte,                                    G
        is 8 bits:                                01000111
            encoded to 16 'symbols':              0110100011010010
                                                  |
Direct Sequence Spreading:                        |
    Each symbol modulates 256 'chips':            |
                                                  |
                           0110100010010010100100101001010100010000100
                           1111100100111101001011000111100100110001110
                           1001001110010101001010100100100101100100100
                           1110111001001111101010101001011011001110101
                           0101010111100101100101100100101010110100101
                           1010101001011001010 0

Carrier Modulation:
    Each change in chip value causes a 180 degree phase shift in the
    carrier frequency.
```

Figure 4 – Example of Message Encoding

E.3.2.2. *Receiver Subsystem*

The Receiver Subsystem in the AV-2 receives messages from the satellite Gateway over a separate spread spectrum satellite link in C-band. The received signal is converted to an intermediate frequency (IF) where it is despread to baseband data and sent to either the keyboard/display unit (KDU), the transmitter, or the equipment monitoring subsystems.

The received C-band signal is spread using a pseudo-random noise (PRN) generator at the satellite gateway based on a 1024-bit code with 512 chips per symbol. It uses a rate $^1/_2$ Viterbi coder with either constraint length 3 or 7 to implement forward error correction. The resulting data rate is 1200 bps.

E.3.2.3. *GPS Receiver Subsystem*

The GPS receiver subsystem determines geographic position, altitude, velocity, and time from signals generated by at least four GPS satellites. Positional accuracy is 100 meters 2DRMS using full accuracy C/A code and better than 10 meters 2DRMS using optional differential GPS corrections that conform to the RTCM SC-104 format (such as those broadcast by the USCG DGPS service). The GPS subsystem updates the transmitter and KDU subsystems with this information every second.

E.3.2.4. *Keyboard/Display Unit Subsystem*

The KDU (Keyboard/Display Unit) subsystem displays the last several messages received and provides the operator with the ability to compose or select previously prepared messages to be sent. It may also display the most recent GPS position, altitude, velocity, and/or time measurements. In addition, any of the readings presented by the equipment monitoring subsystem may also be displayed. Furthermore, it may assert changes in actuator or controller nodes in the equipment monitoring system.

E.3.2.5. *Equipment Monitoring Subsystem*

The equipment monitoring subsystem provides the capability to network with intelligent control devices (nodes) associated with the equipment, process, or conditions being monitored. The variety of nodes is unlimited. For example, devices such as proximity sensors, pressure sensors, flow meters, motion detectors, chemical sensors, and actuators such as switches, solenoids, and relays could be used. Nodes may also include intelligent controllers that both provide readings and control other processes.

The AV-2 interface specification is included in the Appendix. This specification describes the physical and logical interfaces to the terminal, including its interaction with programs operating at the user's base station operations console. The connections between nodes are easily configured from a wide range of media, such as twisted pair, RF, power line, RS485, coax, infrared, or fiber optic. The network topology may be either bus, ring, star, or free topology.

E.3.2.6. *Antenna Subsystem*

The standard SATCOM antenna for non-aviation applications is a transmit/receive omnidirectional flat plate, as shown above. The transmit antenna element consists of a patch or quadrifiler device with left-hand circular polarization and a gain of 3 dB (Figure 5). The receive element is co-axial with the transmit section. Gain, 13 dB., is provided by the pre-amplifier. The internal GPS receiver uses a separate patch antenna.

E.3.3. Space Segment (Satellites)

The mobile terminals transmit on L-band, in a frequency band from 1610 MHz to 1626.5 MHz., to the Spacenet III satellite. The satellite acts as a simple "bent pipe". The energy received in this pass-band is amplified and re-transmitted on Ku-band back to Earth, where the signal detection, decoding, and processing is all performed at the satellite gateway, a fixed earth station.

The outbound link to the mobile terminal is a C-band transmission from the satellite gateway facility to a geostationary satellite (not the Spacenet III satellite), then a re-transmission in C-band from this satellite to the mobile terminal. Bandwidth for outbound messaging is 2.5 MHz. Messaging capacity on the outbound channel is much less than the L-band channel.

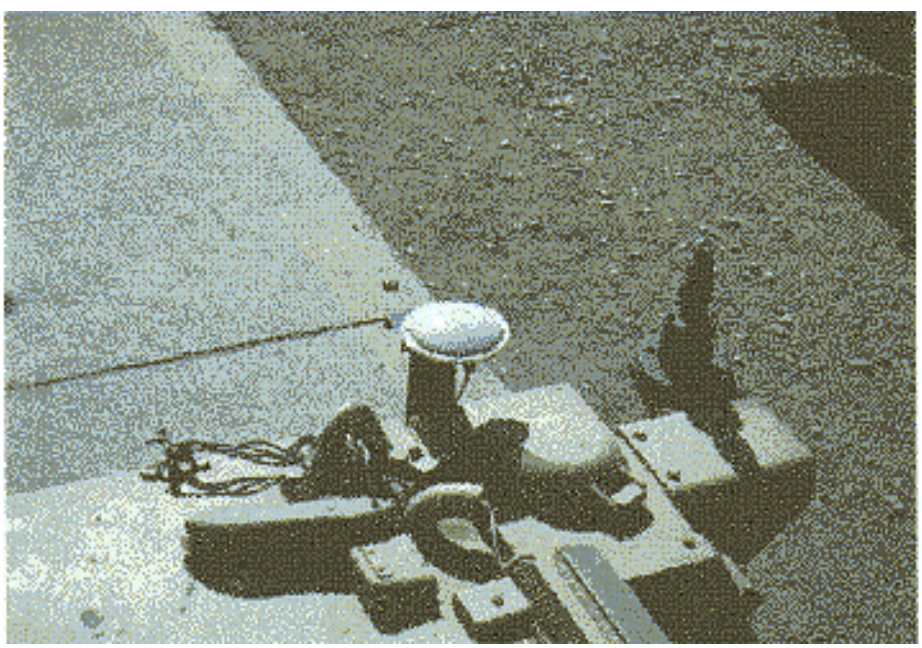

Figure 5 – Newcomb AV-2 Antenna

E.3.4. Fixed Earth Station / Satellite Gateway System

The satellite gateway is a signal detection and message processing facility. It is also a message switching system. It passes digital messages between each customer's respective fleet of remote terminals and their base station operations console. In addition, it provides a control point for the satellite network. Through it, the appropriate adjustments can be made to keep satellite communications and the remote terminals functioning smoothly. It provides an administrative system for measuring message traffic and providing billing functions based on usage. Finally, it automatically logs fleet locations and status for all its customers. Newcomb Communications began developing its own Fixed Earth Station (FES) to operate in conjunction with the Newcomb mobile terminals. The FES reception and decoding subsystems were developed and a prototype was demonstrated to the Coast Guard and Army in May of 1993. This demonstration included the ability to detect, decode, and display messages transmitted by a CP-1 unit via the Spacenet III satellite using Geostar PN coding and the Mobile Datacom (MDC) Earth Station (located in Clarksburg, MD). Then, using a different PN code, the same demonstration was given using the Newcomb prototype FES.

Subsequent to this major milestone, the Company established an agreement with Mobile Datacom Corporation (MDC) whereby the Company would use MDC's Earth Station and satellites. This provided the opportunity to focus the Company's engineering resources on the development of the mobile terminal products, while MDC addressed the operation of the satellite and Fixed Earth Station.

E.3.5. Central Control Console (Base Station Operations Console)

The Central Control Console is located at a user's operations center. It includes the systems necessary to enable the operator to supervise, control, and track his fleet of operational assets (vessels, aircraft, etc.). It includes the necessary systems for interfacing with his other transportation management information systems, as well as providing the communication processor functions for coordination with the FES Gateway. A monitor is available with map and data display for operator visibility of geographic location and fleet status.

The Company developed the Newcomb Supervisory Control and Tracking (NSCAT) software package, which runs on a PC in a Windows NT environment, to provide these functions; however, for this project the Coast Guard R&D Center provided its own console and software for message communications and display. Newcomb provided the Army with copies of its NSCAT software, operating in PCs provided by the Army.

E.3.6. FCC Authorization

Effective May 24, 1993, the Federal Communications Commission (FCC) authorized Newcomb Communications service for up to 10,000 mobile terminals operating through the Spacenet III or GSTAR 3 geostationary satellites. Prior to that authorization, Newcomb had been operating under a Special Temporary Authority (STA). This new authorization requires Newcomb to demonstrate non-interference with future Big LEO (Low Earth Orbiting) satellite systems as a condition for continuing operations in this RDSS frequency band, when the first duly licensed Big LEO satellite is launched.

In 1995, the FCC authorized three Big LEO systems; namely, IRIDIUM, Odyssey, and Globalstar. Now that specific Big LEO systems have been approved, Newcomb is addressing the issue of non-interference. The FCC issued rules (November 1994) whereby the TDMA systems (such as IRIDIUM) shall occupy the top 4 MHz of the band, and the CDMA systems (Odyssey and Globalstar) shall share the lower 12 MHz. This allocation of the band can be readily accommodated in the Newcomb system. It merely requires a shift in the center carrier frequency of Newcomb units by 2 MHz and a reduction in the utilized bandwidth from 16 MHz. to 12 MHz.

F. Operational Evaluation by US Coast Guard and US Army

Extensive and varied field trials and operational evaluations of CP-1 mobile satellite communications systems were performed in a variety of applications, on land, sea, and air. Information on these exercises was readily provided to the Company by both the Coast Guard and the Army Space Command, and was invaluable to the development of the products functions and features.

F.1. U.S. Army Testing

F.1.1. Army UH-60 Tests

After the initial flight tests of the CP-1 terminal on a Beech Baron (fixed wing) aircraft, a unit was installed on an Army UH 60A Blackhawk helicopter at the 160th SOAR Regiment in Ft. Campbell, KY. This first installation on a helicopter was an invaluable experience, providing insights that made for simplification of equipment installation and checkout. This was particularly true regarding installation and integration of GPS and SATCOM antennas in proximity to the helicopter’s main rotor shaft. Flight tests were conducted by the Army in a variety of weather conditions. INTRANSIT Flight Tracking consoles were provided by Volpe National Transportation Systems Center at both Ft. Campbell and at Army Space Command in Colorado Springs, CO. These consoles were connected through the INTRANSIT data fusion center at Cambridge, MA, to the MDC Fixed Earth Station.

F.1.2. Army Space Command Tests

The US Army Space Command (ARSPACOM) has tested the equipment in a variety of hostile, rugged environments on a broad array of Army vehicles:

- In the Winter of 93/94, CP-1 terminals were installed on Army **snowmobiles** of the 10th Special Forces (Figure 6). These units were used during Exercise Arctic Warrior, a joint exercise with Canadian and British military, north of Great Slave Lake in the North West Territories of Canada.

Figure 6 — Army snowmobile with Newcomb CP-1 installed.

- Summer 1994. CP-1 terminals were installed on a variety of Army armored vehicles at Ft. Hood and Ft. Bliss, TX for Exercise Roving Sands, with the 1st Cavalry Division.
- In August 1995, terminals were installed on battle tanks and support vehicles (Figure 7) for the Focused Dispatch Armored Warfare Exercise at Ft. Knox, KY. The live tracking data was displayed on Virtual Reality Simulators over 100 miles away as “Picture of the Battlefield”.

Figure 7 – Army Vehicle Testing of Newcomb CP-1

In each of these operations, the Newcomb equipment operated reliably, providing real-time tracking of assets in the field, while operating in severe simulated battlefield environments. The only reported failures of Newcomb SATCOM equipment were:

- a snowmobile hitting a tree, broke its antenna mast, and
- at Ft. Bliss, a HUMVEE was submerged in a creek, placing its CP-1 terminal under more than 1 meter of water.

F.2. *U.S. Coast Guard Testing*

F.2.1. Coast Guard HH-60 Tests

Subsequently, a CP-1 SATCOM terminal was installed on a Coast Guard HH 60 helicopter (Figure 8) at Elizabeth City, NC. This unit went through extremely rigorous flight tests. Objectives of this flight test program were:

- Validate compatibility with existing helicopter systems and equipment, and

- Characterize GPS and SATCOM as a function of aircraft operations, such as speed, heading, attitude (pitch, yaw and roll), rotor blade interference.

Figure 8 – Coast Guard HH-60 Jayhawk Helicopter

The system performance was excellent, providing dependable real-time messaging from the helicopter flying nap-of-the-earth. In addition, detailed analysis of the flight test data by the Coast Guard revealed an anomaly in the SATCOM antenna's radiation pattern; a previously unknown "blind spot" of approximately 5 degrees in azimuth. When this was brought to the attention of the antenna manufacturer, the anomaly was readily corrected.

F.2.2. Coast Guard Maritime Tests

Maritime operations were addressed by the Coast Guard R&D Center in a VTS evaluation program conducted for several weeks during the Summer and Fall of 1994 in Narragansett Bay, RI (Figure 9). Three different communication systems were installed on a commercial vessel:

- Digital Selective Calling (DSC) VHF-FM Radio
- Cellular Telephone
- Newcomb CP-1 SATCOM

The vessel used for this program, the *Vista Jubilee* (Figure 10), is a commercial cruise ship operating in Narragansett Bay. The CP-1 operated flawlessly and was maintenance-free for the entire test period (1 Aug. –14 Dec. 1994).

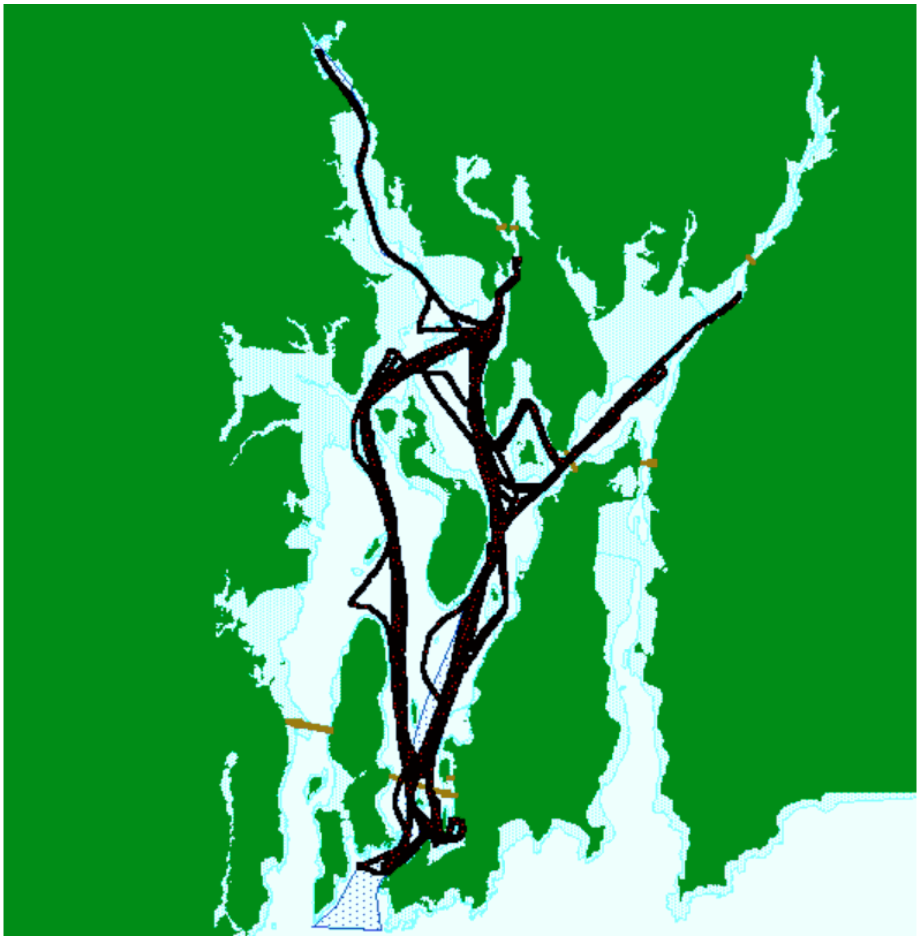

Figure 9 — Track of CP-1 equipped Vista Jubilee in the Narragansett Bay

Figure 10 — Photograph of the Vista Jubilee, Warren RI

F.2.3. OPA-90 Demonstration - New Orleans, LA

A VTS demonstration of automated dependent surveillance was conducted by the Coast Guard R&D Center as part of the OPA '90 Port Demonstration in New Orleans, LA, in December 1994 (Figure 11). Newcomb mobile terminals were installed on the Cajun Queen river boat on the Mississippi River, as well as the Coast Guard cutter Saginaw operating between New Orleans, LA and Mobile Bay, AL. Live demonstrations of real-time tracking of both vessels were conducted simultaneously at the Coast Guard booth on the show floor in New Orleans and at the "VTS Gateway" at the USCG R&D Center in Groton, CT.

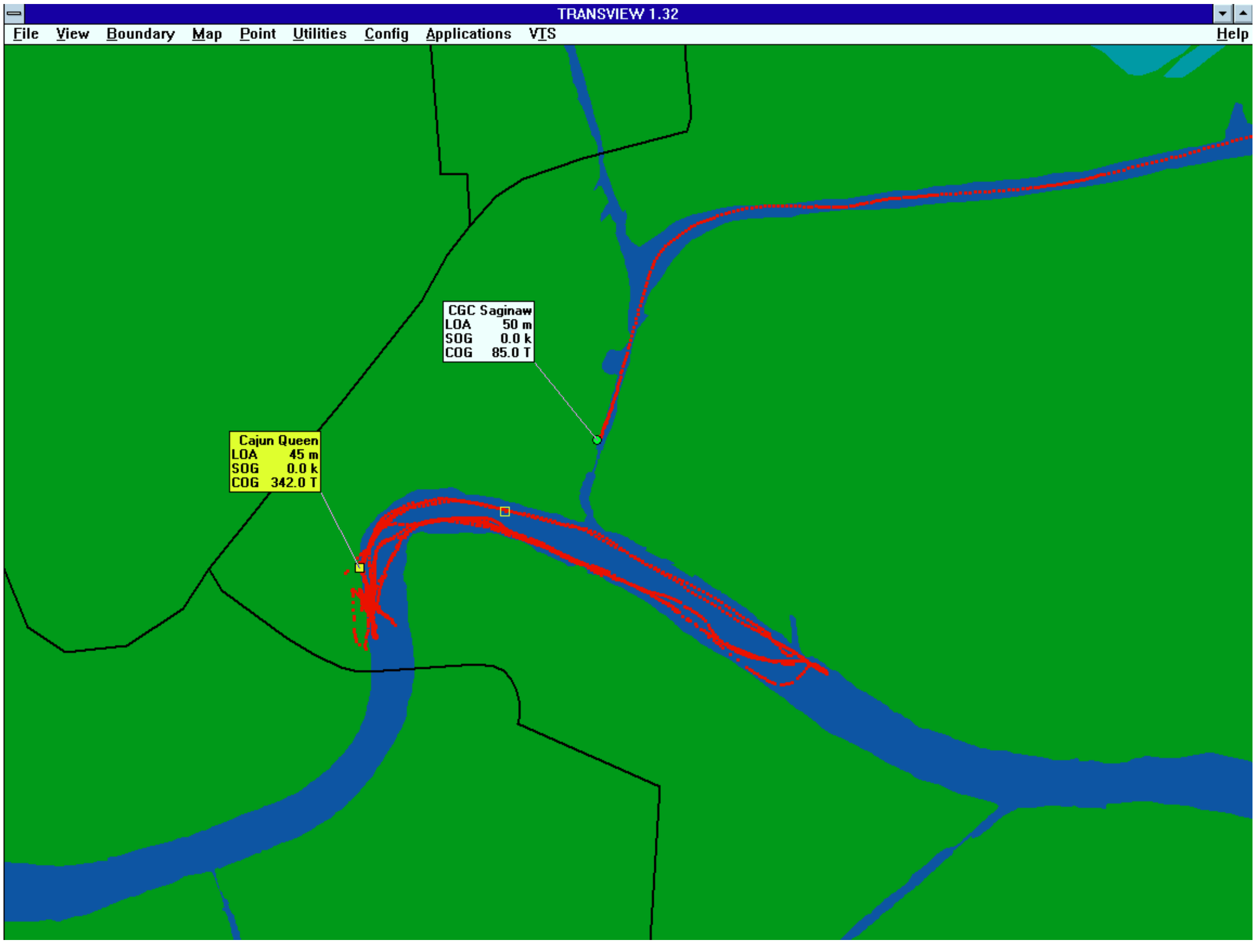

Figure 11 — New Orleans testing

F.2.4. VTS and OPA-90 Demonstration - New York, NY

A successful operational test of two Newcomb units was done in conjunction with the integration of automated dependent surveillance with the USCG vessel traffic service equipment in New York during the summer and fall of 1995, and winter of 1995-1996. One unit was installed aboard the tug A.J. Britannia. This vessel operated throughout the upper New York harbor and rivers. The other unit was installed aboard the Delta Shuttle II ferry (see Figure 12) operating primarily along the East River. Although a higher percentage of messages were not received during this test when compared to the previous tests in Connecticut, Rhode Island, and Louisiana, the units did provide the needed position reports. In October of 1995, a successful live demonstration of the Newcomb capabilities was part of a three day OPA '90 New York Port Demonstration.

Figure 12 — Delta Shuttle II, underway in NY Harbor

F.2.5. R&D Center Tests

In addition to the above operational evaluations, the Coast Guard R&D Center has been performing extended life tests on a CP-1 at Groton. For these tests, a CP-1 was programmed to transmit its location and identity every 10 seconds, continually around the clock. This unit was turned on the first week of August 1994. It has been in continuous operation, reporting its ID and internal GPS-derived location, 24 hours a day, 7 days a week, for the past 20 months, without a failure. As of the 1st of March 1996, this unit has transmitted over **5 million messages** and is still working!

F.3. AV-2 Testing

Field testing of the full two-way AV-2 terminal was significantly delayed due to difficulties in the development of the SATCOM receiver portion of the system, although the **inbound** messaging (from the mobile terminal) has been as good as the above-discussed CP-1 performance. This is discussed further in Section G.

G. Technical Issues

G.1. Satellite Issues

Present coverage by the "inbound" L-band transponder on Spacenet III includes most of the northern half of the western hemisphere. This is an oval roughly between about 70° N (Alaskan North Slope) and 10° S (northern Brazil) and between 10° W (Ireland) and 155° W (Hawaii). The expected "outbound" C-band coverage is less extensive, roughly an oval covering the lower 48 United States and about 200–300 miles offshore. During the SBIR Phase 2 program, satellite availability for C-band coverage has been a major problem.

Spacenet III, owned by GE Americom, is a commercial communications satellite, providing both C-band and Ku-band video and data feeds. It also has the L-band RDSS transponders (1610 MHz to 1626.5 MHz) originally used by Geostar. These L-band transponders are being used by Newcomb, under an FCC Authorization granted in May 1993. A backup satellite, also with Geostar transponders, is GSTAR 3, also operated by GE Americom.

Spacenet III is in a geostationary orbit, in the equatorial plane, at 87° West Longitude. The geosynchronous altitude is 22,800 miles (36,000 Km). The satellite was launched in March 1988, and has a useful life until at least the year 2000. The satellite is providing extraordinary coverage, from the Equator to the North Slope of Alaska.

The Mobile Terminals receive messages via different geostationary satellites on C-band. The satellite being used during the development of the AV-2 transmit/receive terminal was SATCOM F-2R, also owned by GE Americom. Frequency bandwidth used on this satellite was 2.5 MHz centered at 4184 MHz. SATCOM F-2R, originally owned and operated by RCA, was also in a geostationary orbit, at 72° West Longitude. This satellite provided consistent, dependable coverage of the Continental U.S. (CONUS). However, it reached end-of-life and was turned off in February 1995. At that time (February 1995), SATCOM F-2R was replaced with COMSTAR D4, an older satellite which, although still available for service, reached the end of its nominal mission lifetime in 1988. It is in a geosynchronous, but inclined, orbit at 76° West. The inclination is in the North-South axis only, and results in a cyclical variation in its transmit antenna pattern (footprint) on the surface of the Earth. The available frequency band on this satellite is centered at 4134 MHz. As discussed above, this change from 4184 MHz to 4134 MHz was readily accomplished in the mobile terminal.

As shown in the **Space News** article, November 14, 1994, (included in the Appendix herein) the launch failure of AT&T's Telstar 402 satellite in September 1994, coupled with the end-of-life retirements of several C-band satellites (like SATCOM F-2R) in 1995, caused a major shortage in C-band capacity. This shortage caused lease prices for C-band transponders to escalate dramatically. To provide CONUS coverage with a relatively new, stable satellite would, for at least 1 to 2 years, cost over $125,000 per month.

It was this economic reality that caused the decision to revive COMSTAR D4, a satellite that currently has a North/South inclination in excess of ±7 degrees. However, because of this inclination, C-band capacity is available and affordable on this satellite.

G.2. *Earth Station / Gateway*

As discussed in section E. above, the development of a Newcomb Fixed Earth Station (FES) was carried through to the point of a successful proof-of-concept demonstration. At that point, it was temporarily shelved, and service is being provided using the Mobile Datacom (MDC) FES/Hub. Newcomb plans to resume work on an FES product after the completion of mobile terminal product engineering.

The MDC Earth Stations were originally built by COMSAT for the Geostar system in the late 1980's. The technology used for signal acquisition/decode is Surface Acoustic Wave (SAW) delay lines. SAW delay lines were used because Digital Signal Processing (DSP) devices were not yet available. MDC has re-installed this FES/Hub system on the COMSAT campus at Clarksburg, MD. They have also installed a modulator for the outbound (C-band) messaging at a commercial common carrier earth station located in Carteret, NJ. The facility is connected to the MDC Hub by a leased telephone line.

Newcomb has installed a data base management system (DBMS) at Manchester, NH. This DBMS has autodial capability for connections to the MDC Hub, either through an Internet connection (most economical) or the Public Switched Telephone System (PSTN). Data is archived at Newcomb in addition to the normal 36 hour storage provided by MDC.

The Internet link to the MDC FES/Hub, although quite convenient and economical, was not designed for minimum delay of messages. Operational systems that depend on minimal latency **must** have dedicated connections, such as leased line or VSAT, to the appropriate Hub from the user's operations center.

G.3. *Mobile Terminals*

The AV-2 transmit/receive mobile terminal design requirements and product development plans were based on the experience of the founders of Newcomb Communications in the application of the Geostar system to transportation operations on land, sea, and air. As a small start-up company with limited resources and financing, a pragmatic approach was adopted that recognized the limited resources, lack of test equipment, and budget constraints. These constraints, however, were to a large part offset by the knowledge, experience, and close-knit working relationship of the design team.

Development of the mobile terminal was accomplished in two product steps:

1. A transmit-only (beacon) terminal (CP-1) that includes: a GPS engine, wide-band spread spectrum encoder, SATCOM transmitter and antenna, and equipment power and packaging;
2. Adding the receiver subsystem and TX/RX control processor for the full (AV-2) transmit/receive terminal, based upon the production and field integration/operation experience of the CP-1 transmit beacon.

As discussed in section F. above, the CP-1 transmit beacon has been a very dependable product, and has enjoyed success in a variety of transportation applications. The receiver subsystem development for the AV-2, on the other hand, has been plagued with difficulties, as discussed below in this section.

G.3.1. GPS/DGPS Subsystem

Both Rockwell and Trimble GPS/DGPS engines are used in the mobile terminals. The minimal latency (1 to 2 seconds) on receiving messages at an operations center enables fleet operations to take full advantage of the GPS precision in the location reports.

G.3.2. Satcom Transmit Subsystem

The mobile terminal transmits real-time in L-band, via Spacenet III, a very robust satellite. This satellite is providing a wide coverage area, and is a solid performer, as discussed further under Satellite Issues.

Messaging dependability of the CP-1 system is well in excess of 99%. Automatic repeat of messages provides further enhancements, in a manner that is transparent to the user.

G.3.3. CP-1 Mobile terminal Qualification tests, DO 160C

An independent testing laboratory, Associated Technical Services, of Acton, MA, has fully environmentally tested and qualified the CP-1 mobile terminal against RTCA Spec. DO 160C, the standard for avionics equipment for commercial passenger aircraft operating under FAA Part 121 or Part 135.

G.3.4. Satcom Receive Subsystem

The full transmit/receive system, the AV-2 terminal, has experienced a series of difficulties during development. The AV-2 product development expanded on the experience base of CP-1, both in its equipment design and in field installation and operation. The AV-2 **technical problems** are related to the analog receiver RF front end. This unit was designed, tested , and successfully demonstrated to the Coast Guard, working with signals from the SATCOM 2R satellite, in September 1994. Based on this successful performance at “bench test”, the design was released (November 1994) for printed circuit board layout and fabrication. While this board layout/design was in process at a subcontractor, the SATCOM 2R satellite went off the air, in February 1995, and was replaced by the COMSTAR D4 satellite (both are C-band geostationary satellites). As a result of this change in satellites, it was necessary to change the receive carrier frequency, from 4184 MHz to 4134 MHz. This frequency change was readily accommodated in the AV-2 design and was implemented without difficulty. It was expected that the COMSTAR D4 satellite performance would otherwise be comparable to the previous SATCOM 2R.

The initial board design for the analog receiver was a multilayer board, which proved to be unsuitable for use with low level microwave signals. The internal circuit paths within the board material created parasitic noise and crosstalk, thwarting any dependable signal acquisition or processing.

With the **lack of test equipment** for properly synthesizing the received satellite signal, developmental testing relied on the satellite itself as the signal source for testing of receiver circuits. Unfortunately, COMSTAR D4 is an old satellite, in an inclined orbit. New England is at (or beyond) the 3 dB. satellite’s edge of coverage. The **nominal** Effective Isotropic Radiated Power (EIRP) of this satellite was about 3 dB below that of SATCOM 2R. Also, indications are that, at Manchester. NH, the signal strength from the satellite varies by about 6 dB. (peak-to-peak) daily, with an additional 2 dB day-to-day variation. These variations in signal are in **addition to** this lower nominal EIRP.

Additional technical difficulties were experienced with the C-band to IF downconverter. Initial engineering evaluation units were purchased that worked well, but were followed by production units that failed to meet performance specifications. Newcomb Communications worked with six different suppliers of downconverters before a satisfactory product could be obtained. The principal difficulties pertained to frequency drift and phase noise. Some of these anomalies were compensated in software, but not all. Fortunately, a qualified source for downconverters has now been established.

The end result is that there is insufficient signal/noise ratio in the system. Attempting to use the satellite to test receiver acquisition under these conditions has been frustrating, at best, and has resulted in additional schedule delays.

G.3.5. Mobile Terminal Summary

As can be seen from the field experiences of both the Coast Guard and Army, the Newcomb mobile equipment enclosure for CP-1 and AV-2 is quite rugged and suitable for a variety of mobile applications, including qualifying for DO-160C. The CP-1 and AV-2 antennas for aviation applications are FAA approved.

The current SATCOM receive system has a serious shortfall in signal strength with the COMSTAR D4 satellite. This satellite is well beyond end-of-life. It was officially retired in 1988. This deficiency in signal strength is only partially compensated by increased gain and lower noise figure in the AV-2 receiver. Two (2) AV-2 prototypes were “tuned” and optimized sufficiently to receive messages through the satellite at those times of day when the satellite provides coverage of New England. These two (2) terminals were delivered to the Coast Guard in November ‘95, and have operated at the Coast Guard R&D Center. However, further mobile terminal receiver design needs to follow the replacement of this satellite.

H. Phase 3 Opportunities

H.1. *Domestic Operations*

The CP-1 mobile terminal has been implemented for a variety of flight-following applications, both commercial and government, both fixed wing and helicopter. One of these applications is discussed in the Rotor & Wing magazine article included in the Appendix.

As discussed in section E.3.6, the program for validating compatibility with the licensed CDMA Big LEO systems, to provide continuous operations after Big LEO launches, are underway. In addition, Newcomb is pursuing the adaptation of the mobile terminals to operate through other future satellite constellations.

H.2. *International Expansion*

The frequency agility of the mobile terminals provides the capability to implement systems in geographic locales other than North America, by using available satellite capacity in different frequencies and bandwidths than the RDSS band currently being used in North America. A program is being pursued to use existing Russian or other international satellites to expand coverage to Europe, the Mid-East, the western Pacific Ocean and Asia.

The AV-2 technology provides the flexibility to readily adapt mobile satellite messaging systems to support a variety of customer needs. As future service is expanded beyond the initial service area, additional satellite channels will be needed to extend the coverage "footprint". The plan is to use available channels on existing satellites, either geosynchronous or LEO, leased from commercial providers, for both inbound and outbound services. To facilitate this expansion, Newcomb Communications designed its mobile terminals to be frequency agile over a range of frequencies sufficient to provide a rich menu of candidate satellite transponders (when paired with appropriate antennas).

Appendices

CP-1, AV-2 Product Data Sheets

AV-2 Interface Specification, April 21, 1995

AV-2 Mechanical Drawing No. OWE 59

Preliminary Phase 1 Test Plan for the AV-2, 6/29/95

Space News article

Rotor & Wing Article