L-BAND MARITIME EXPERIMENTS

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Summary. The authors have directed the technical portion of the MARAD maritime communications experiments using the NASA ATS-6 satellite. The MARAD experiments were conducted with satellite terminals placed on two commercial ships for evaluation of the communication service similar to that which will be available with the maritime commercial satellite system. These experiments also evaluated the benefits to fleet management through utilization of the communications services. Furthermore, evaluation of position determination using satellites was also made. These experiments were conducted from the MARAD earth station located at Kings Point, N. Y., and the NASA earth station at Rosman, N. C. Three modems having voice and digital data and a stabilized shipboard L-band antenna system were evaluated.

Present results indicate that future commercial communications satellite systems will provide the expected high-quality service, particularly when attention is given to improving the reliability of components, such as the vertical reference system used by the shipboard antenna.

The results of the experiments conducted indicate that the ship antenna demonstrated successful tracking of the satellites for test period intervals of 4 to 6 hours without the need for operator adjustment. The ship position determination tests show good

measurement repeatability, but with significant bias errors which may result from satellite ephemeris.

Finally, the data analyzed demonstrated the ability of future commercial satellite systems to achieve a probability of bit error of better than 10^{-5}. Further data analysis is needed to completely confirm these digital data results.

Introduction. This paper will describe the U. S. Maritime Administration (MARAD) maritime experiments conducted from June of 1974 through May of 1975. MARAD has the continuing responsibility for improving the economic viability of the U. S. Merchant Fleet. As one means of meeting this responsibility, MARAD has chosen to explore methods of improving the exchange of information between shore and ship and to determine the economic importance associated with this improved message and information flow. An obvious tool for achieving this goal is the future commercial maritime service to be provided by the MARISAT satellite. In order to prepare for this satellite service, MARAD planned a series of economic and technical experiments using the NASA ATS-6 satellite.

The objectives of this experiment were:

1. To measure and evaluate the economic benefits accrued to fleet operators through the use of satellite-based communications and radiodetermination services.

2. To evaluate performance criteria for shipboard terminal equipments needed to establish and maintain various grades of fleet operations services using commercial satellite systems.

3. To determine the effects of signal propagation, ship radio frequency noise, and ship antenna pointing on the maritime communications and navigation channel.

4. To evaluate various modems for the transmission and reception of voice, data, and position location signals via satellite systems.

Much of the data obtained during these experiments is still under evaluation. Preliminary results of the technical experiments conducted, except those of the voice tests, will be presented in this paper.

Experiment Implementation

Satellite and Ground Systems. The experiment was implemented using the NASA ATS-6 satellite operating in the L-band fan beam mode. The satellite was located at approximately 94°W longitude at synchronous altitude. The position determination experiments used the synchronous NASA ATS-5 satellite at 105°W, also operating at L-band. A number of experimenters, including NASA, DOT, CANADA, and ESRO shared the use of the ATS-6 satellite with MARAD during the L-band experiments.

The MARAD earth terminal was located at the U. S. Merchant Marine Academy at Kings Point, N. Y. Figure 1 shows the configuration used in these experiments.

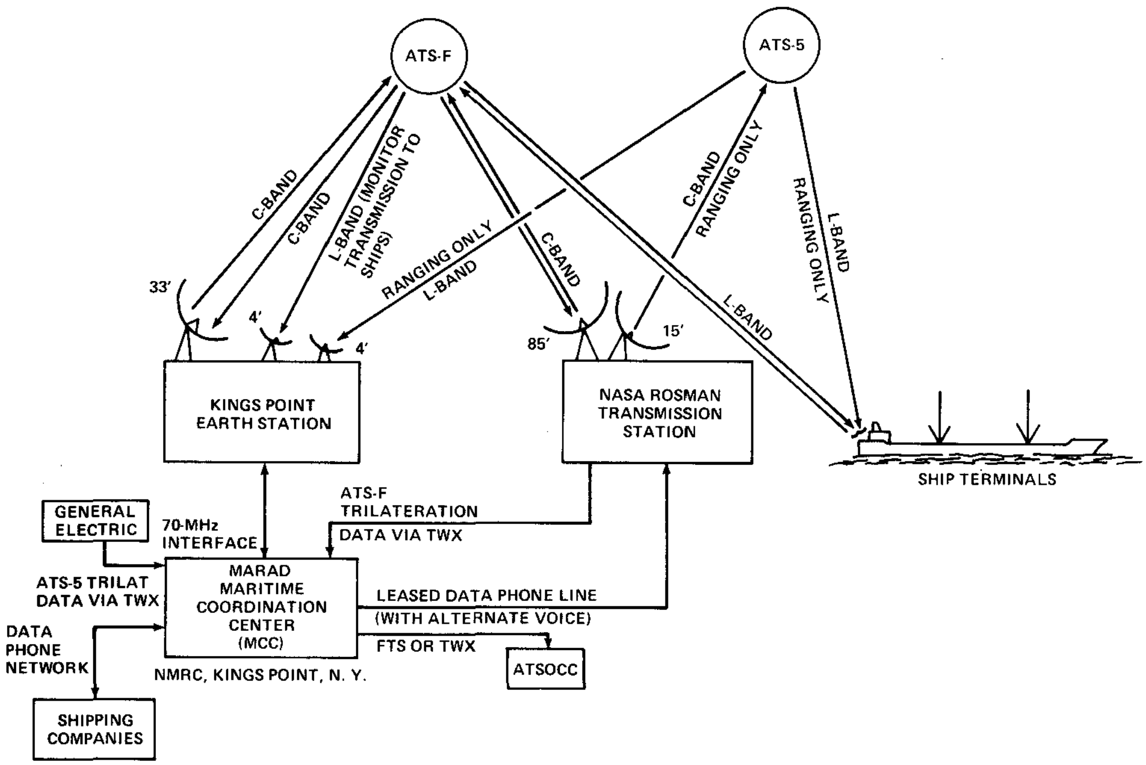

Fig. 1 - MARAD L-Band Experimental Configuration

The NASA Rosman ground station operated simultaneously with transmissions from Kings Point, allowing other experimenters to share the available ATS-6 satellite time. The press for available satellite time required that NASA encourage integration of experiments to utilize the available hours to the best advantage. The integration of MARAD experiments was achieved by displacing the MARAD frequency 9 MHz above that used by the other experimenters and reducing the available MARAD satellite downlink power to at least 10 dB below that utilized by the other experimenters to minimize interaction between the simultaneous transmissions. The L-band communications frequencies used by MARAD were at 1659 and 1559 MHz for the ship-to-satellite and satellite-to-ship up and down links respectively. Since MARAD required various levels of carrier-to-noise density (C/No) at both the ship and Kings Point to evaluate system performance, it was necessary to vary the transmitted signal power at C-band from Kings Point to change the MARAD L-band downlink C/No at the ship and varying the ship transmitted power to change the power and the resulting C/No at the Kings Point earth station (KPES).

Signal control by transmitter power adjustment was more difficult to establish and maintain than using attenuators or noise injection sources at the receiver ports, but uncertainty introduced by such devices and the possibility of masking important affects, such as shipboard interference on modem performance, caused selection of this transmitter power adjustment and control.

In addition to the C-band links to ATS-6, Kings Point monitored the L-band downlink from ATS-6 for downlink frequency adjustment to enable the ship terminals to maintain lock and to provide round trip range through ATS-6 for the ship position computation.

The position determination sequence used the Rosman C-band transmission to the ATS-5 satellite which was initiated by means of a leased data phone line from Kings Point to the Rosman ground station. A modulator using a PRN sequence for navigation was enabled and sequenced by means of the data line. The ATS-5 signal was used only for position determination. The second L-band antenna at Kings Point was used to receive ATS-5 and a comparison of the resulting range measured enabled determination of the delay between the Kings Point ATS-5 range signal initiation and the actual Rosman C-band ATS-5 transmission.

Ship Terminal Description. Ship terminals were installed on the U. S. Lines American Ace and on the Prudential Lines LASH Atlantico and tested as a part of this experiment. Each terminal used a four axis stabilized four foot L-band antenna. Figures 2 and 3 show a typical ship installation on the American Ace. Figure 4 shows in diagram form the ship satellite terminal. The terminal receives satellite signals at 1559 MHz and downconverts these with a synthesizer system to a 70 MHz center frequency where the modem interface is established. Similarly a 70 MHz modem IF transmit signal is upconverted to a 1659 MHz and transmitted to the satellite. The terminals operate with a G/T of -5dB/°K and a maximum EIRP of 36dBW.

Modem Description. Three separate modems were evaluated during this experiment. The AII Systems modem was placed on both ships, the COMSAT modem was located only on the American Ace, and the Magnavox modem was located on the LASH Atlantico. All modem equipment interfaced with the ship and ground equipment at 70 MHz.

COMSAT Modem. The COMSAT modem tested was developed by COMSAT Laboratories for evaluation of candidate modem techniques for use with the MARISAT satellite. The COMSAT equipment was tested during a voyage of the American Ace between August 16 and September 9, 1974 from the USA to France and return. The COMSAT modem operated with a duplex FM voice using pre-emphasis and companding. In addition, the modem contained two separate data modulation systems -- frequency shift keying (FSK) and differentially encoded phase shift keying (DEPSK). The FSK was

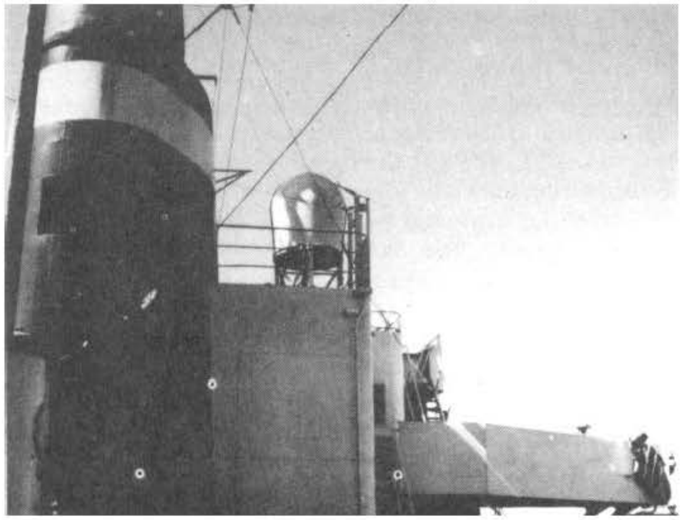

Fig. 2 - Ship Antenna Terminal on the American Ace.

Fig. 3 - Satellite Terminal Equipment on the American Ace,.

implemented for a low speed 50 baud teletype transmission in each direction. The DEPSK transmissions were tested at 1200 bits per second in the shore-to-ship direction and 4800 bits per second in the ship-to-shore direction. These DEPSK data transmissions were intended to evaluate the TDM/TDMA access scheme chosen by COMSAT for implementation in their MARISAT system.

Magnavox Modem. The MX-330 Magnavox modem tested (Reference 1) used bi-phase DEPSK for data transmission and pulse duration modulation (PDM) for duplex voice transmission. This is the only voice modem tested which used digital techniques for processing the voice signals. This modem was originally developed by Magnavox Research Laboratories for the U. S. Navy. A block diagram of this modem is shown in Figure 5. The digital modem is designed to operate at 1200, 2400, 4800, 8000 and 9600

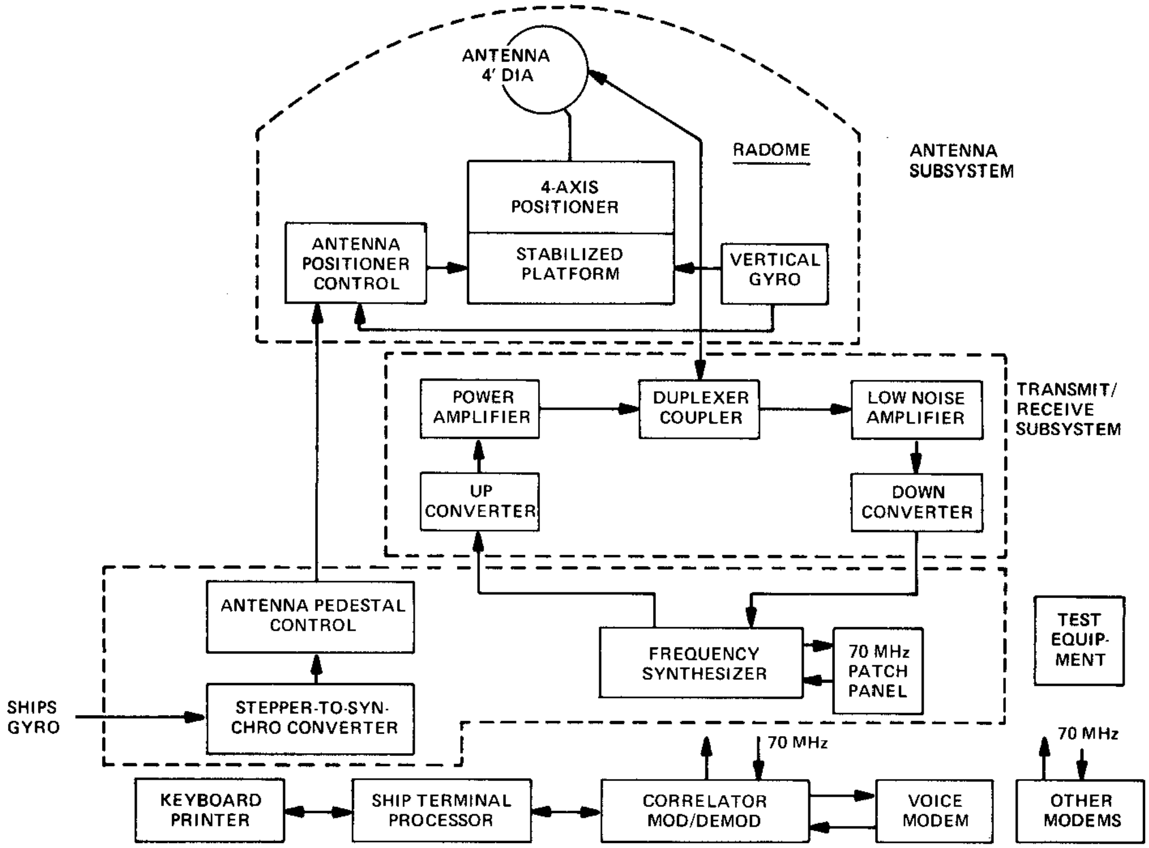

Fig. 4 - Simplified Diagram of Ship Communications Terminal

bits per second rates. The 3.5 kHz voice analog baseband signal is sampled at a 9.6 kHz rate. The resulting pulse width of the sampled signals is a linear function of the baseband signal amplitude. The digitized PDM waveform takes on a zero or a one state which allows transmission as a digital data stream. The resultant PDM data stream is phase shift modulated on the 70 MHz carrier to form the bi-phase, phase shift keyed transmitted signal. The digital portion of the modem uses differential encoding to resolve phase ambiguity in the synchronous demodulator.

AII Systems Modem. This modem was an extension of a previous design by AII Systems of Moorestown, N. J. which was used in a MARAD ranging and data experiment at C-band. The AII Systems modem is capable of performing NBFM voice transmission with clipping, DEPSK data transmission at 1099 bits/second in the shore-to-ship direction and 586 bits/second in ship-to-shore direction. (References 2 and 3) The data is differentially encoded and modulo two added to a PRN code which contains 4095 chips, and which is generated at a 100k chip/sec rate. The resultant bit stream is then PSK modulated on the carrier. The code allows for accurate satellite ranging measurements which are then used to obtain ship position. A NBFM voice signal is then introduced in the first null of the PSK signal at 100 kHz from center frequency to minimize interference between the code and data stream and the voice signal.

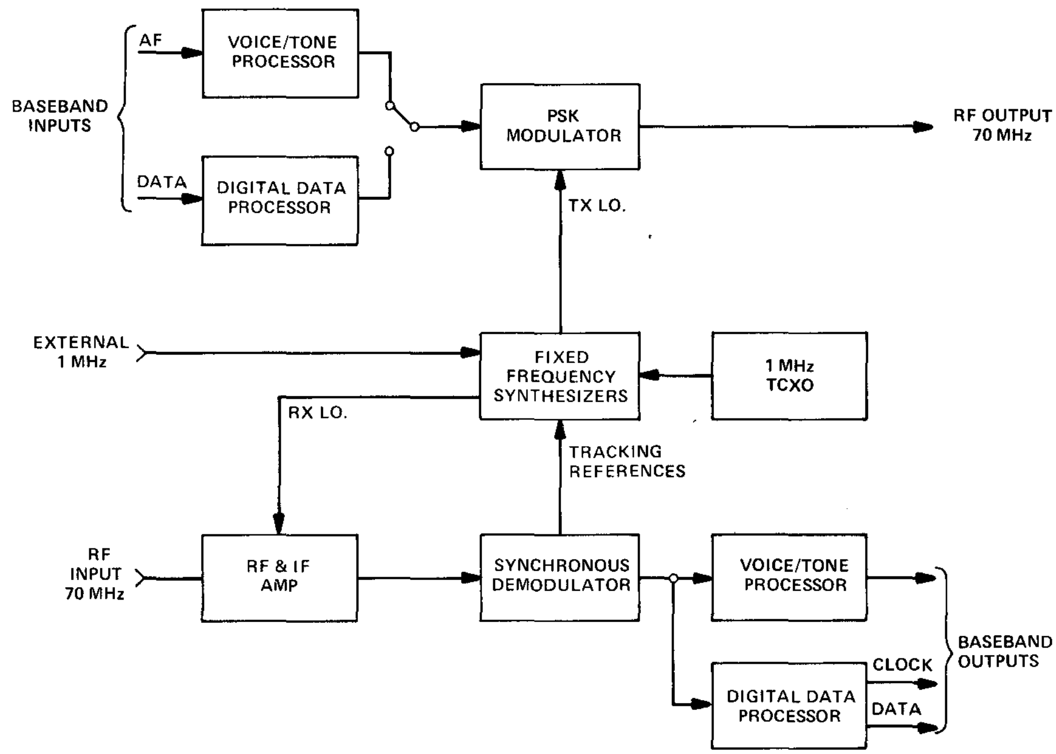

Fig. 5 - Simplified Magnavox Modem Block Diagram.

Technical Performance Tests

Stabilized Ship Antenna Performance. These antenna terminals are four axis stabilized with a gyro stabilization used for the vertical axis and azimuth pointing derived from the ship's gyrocompass. Initial antenna pointing was achieved by a terminal operator using tables giving satellite azimuth and elevation as a function of ship position. Once the ship has achieved acquisition of the satellite, fine pointing of the antenna was made by peaking the received signal level. Typical operation in the North Atlantic showed a period of about 5 hours before a signal degradation of 1 dB due to pointing loss resulting from ship motion occurred (Reference 4). Figure 6 shows signal degradation as a function of time with antenna pointing up ate.

The measurement of signal amplitude level was derived from the change in carrier-to-noise density measured with a spectrum analyzer. This method of antenna pointing and tracking clearly requires operator update more frequently than every 24 hours to ensure successful operation. It should be noted however, that the four foot stabilized antenna was able to maintain track of the satellite signals for the duration of the four to six hour test periods used. It must be emphasized that the method of tracking used by these antennas is different from the steptrack system expected for use with commercial MARISAT operation. The commercial MARISAT ship antennas are designed to maintain satellite track without needing any operator supplied update once the satellite signal has been acquired.

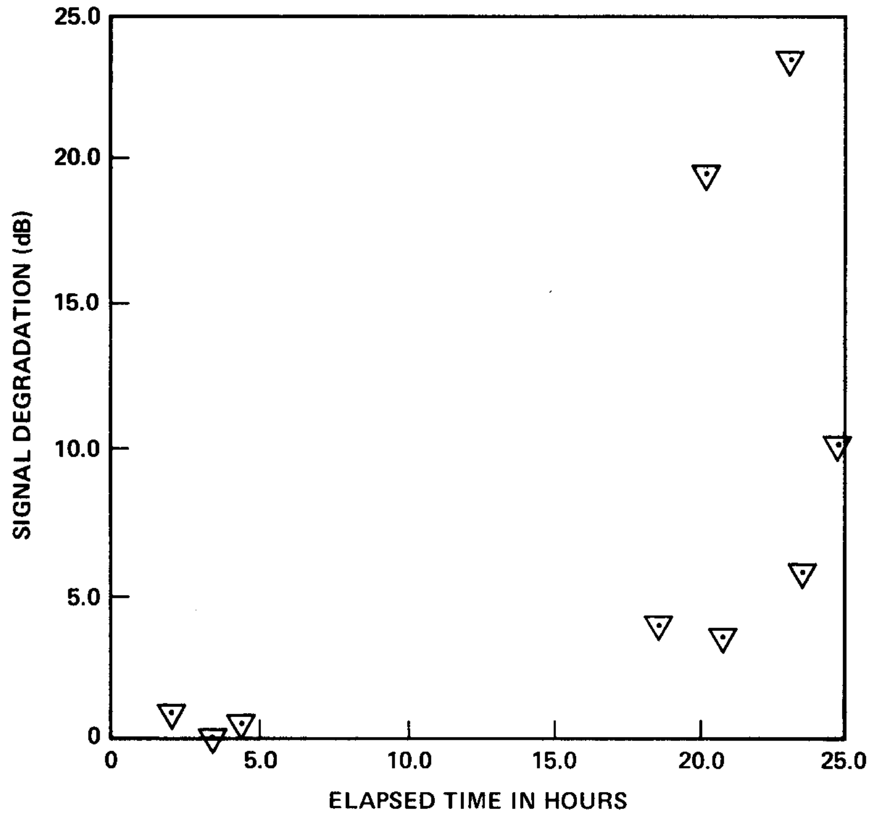

Fig. 6 - Change in Average Signal Level vs Elapsed Time in Hours Between Ship Antenna Pointing Updates

When operating correctly, the short term signal fluctuation for the experimental antennas was as great as 2 dB peak-to-peak on some occasions and was 0.5 dB on other occasions. These short term fluctuations exhibited a periodicity equal to that of the ship's pitch and roll, but the peak-to-peak magnitude of the signal fluctuations did not seem well correlated with the magnitude of the ship's pitch and roll, sea state or elevation angle.

Some test periods exhibited very large signal fluctuations (>10 dB) which were usually attributed to faulty vertical reference gyro performance. The large signal fluctuations disappeared when gyro replacement was made. Further analysis of short term signal fluctuations will be performed during subsequent data reduction.

Position Determination. The position determination experiment utilized a PRN sequence of 4095 chips which was transmitted via ATS-6 to the ship. The ship acquired the code sequence by generating a replica of the code and performing a correlation operation which consisted of time shifting the locally generated code and noting the amount of shift necessary to achieve agreement reached between the received code and the locally generated code. The positioning procedure is shown in Figure 7. Each position determination cycle consists of making four measurements which are indicated below. Each cycle takes approximately two minutes. Note that these four measurements provide

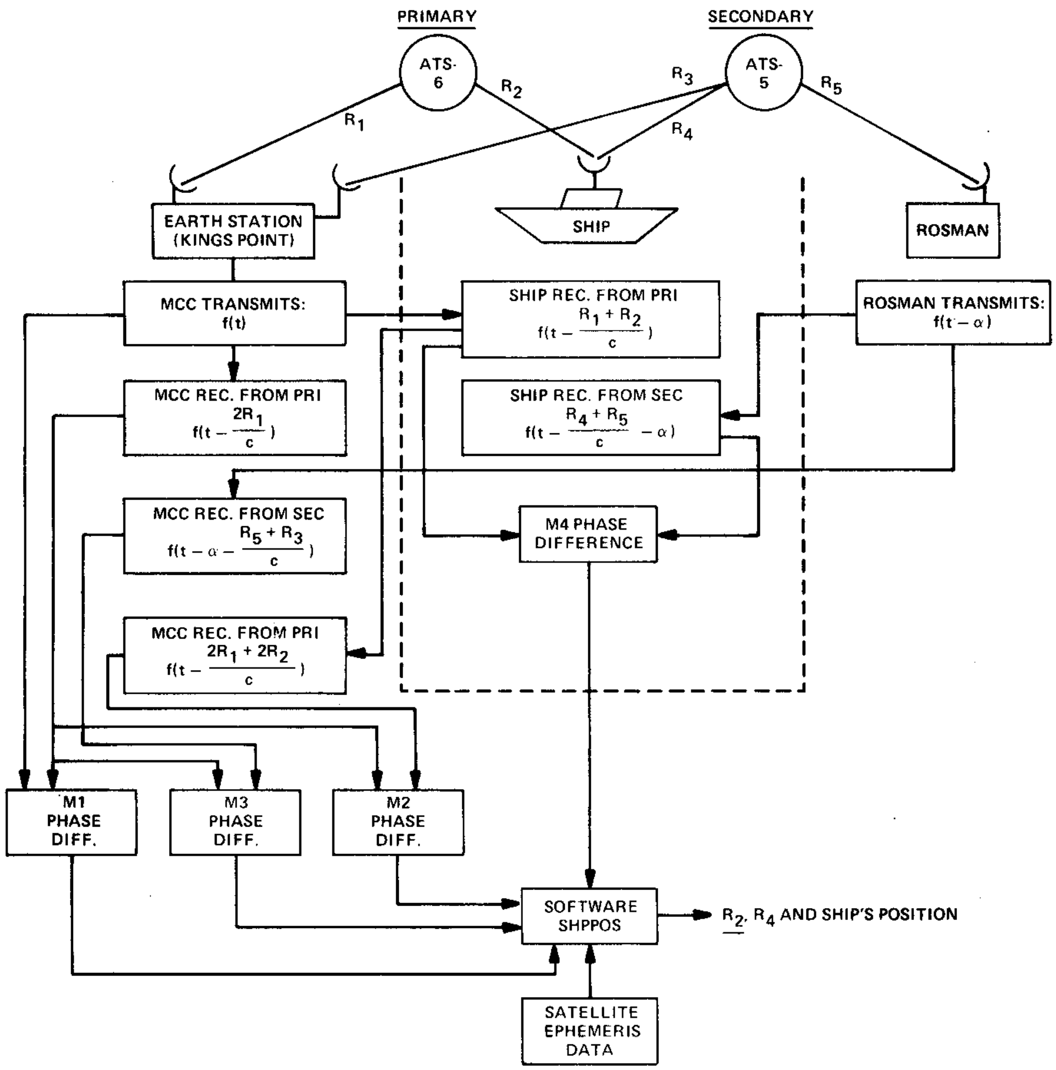

Fig. 7 - Position Determination Block Diagram.

four equations and six unknowns R_1 thru R_5 and α.

$$M_1 = 2\,R_1/c \qquad M_3 = \alpha + (R_3 + R_5\,/c$$
$$M_2 = 2\,(R_1 + R_2)/c \qquad M_4 = \alpha + (R_4 + R_5 - R_1 - R_2)/c$$

The first measurement (M_1) is the round trip range between Kings Point and ATS-6. Next, the ship receives, correlates and retransmits its correlated code sequence to Kings Point allowing ground measurement of $2\,R_1 + 2\,R_2$.

The third measurement (M_3) is performed when Kings Point initiates the ranging modem at Rosman for transmission through to ATS-5. The delay α in the terrestrial circuits used to initiate the modem is included in the overall delay measured for the ATS-5 down-link for Kings Point to Rosman to ATS-5 and back to Rosman.

Upon completion of this measurement, the ship is commanded to move its antenna to a pre-programmed location for ATS-5. The ship measures the differential path delay between the received ATS-6 and the ATS-5 signals. This measurement (M_4) is relayed back to Kings Point through a digital link.

The remaining two unknowns, R_3 and R_5, are ranges from Kings Point to ATS-5 and Rosman to ATS-5; these are derived from satellite ephemeris data supplied by NASA.

Figure 8 shows a portion of navigation data giving the position of the LASH Atlantico as determined while the ship was in Charleston Harbor. The overall position error from the ship's position estimated by visual sighting to shore, based on objects of known location, is about 6 n miles in longitude and about 1.5 n miles in latitude. Further work will analyze the bias errors present in the data. The RMS errors are about 0.25 n miles in longitude and 0.25 n miles in latitude.

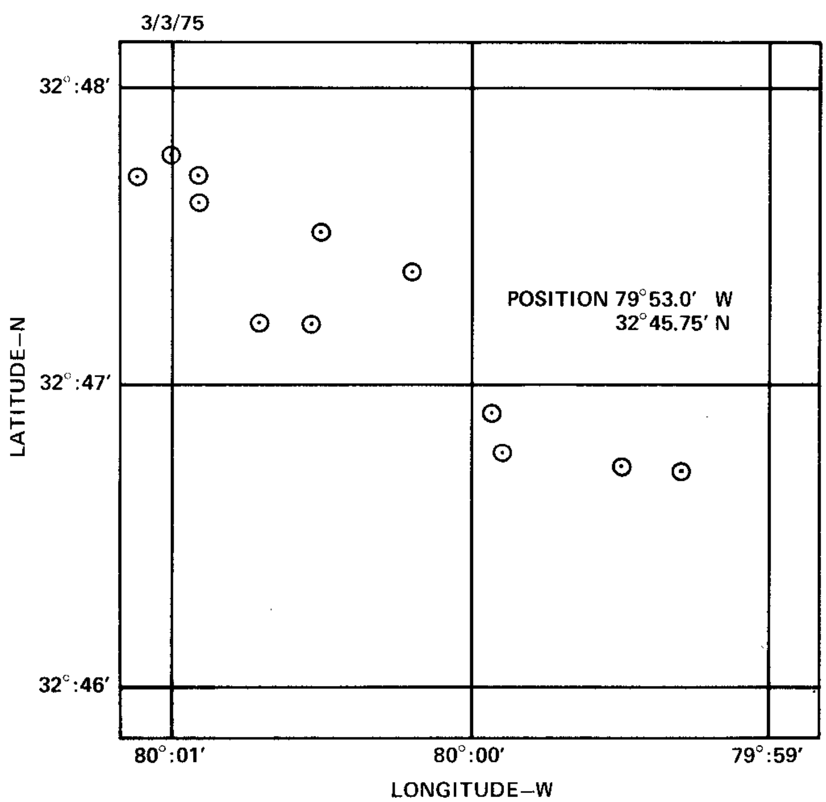

Fig. 8 - Dispersion of Measured Position of the Lash Atlantico, Anchored in Charleston, S. C. on 2/19/75.

Data Tests. The data tests were principally designed to evaluate bit error rate (BER) performance; however, several character error rate (CER) tests were also run with the All Systems modem. The BER tests were performed in forward (KPES-ATS 6-ship) and return (ship-ATS 6-KPES) directions for all modems, while the CER tests were performed only in the return direction.

The AII Systems modem was not optimized for bit error rate performance since its characteristics were modified to provide position location information. The modem BER performance therefore, was not as sensitive to changes in the link characteristics and is not treated in this paper.

The Magnavox modem was evaluated at 1200, 2400, 4800, 8000, and 9600 bps. The 9600 bps data rate has been selected for presentation in this paper because of greater number of data points available.

The shipboard terminal instrumentation block diagram for the data tests is shown in Figure 9. A similar set-up was configured at the Kings Point earth station, except that the ATS-6 L-band return link was monitored and recorded. The data transmitter/receiver used at the ship and at the MCC was the Fredericks Data Transmission Set 600A, supplemented by the Fredericks 600-A2 printer/clock.

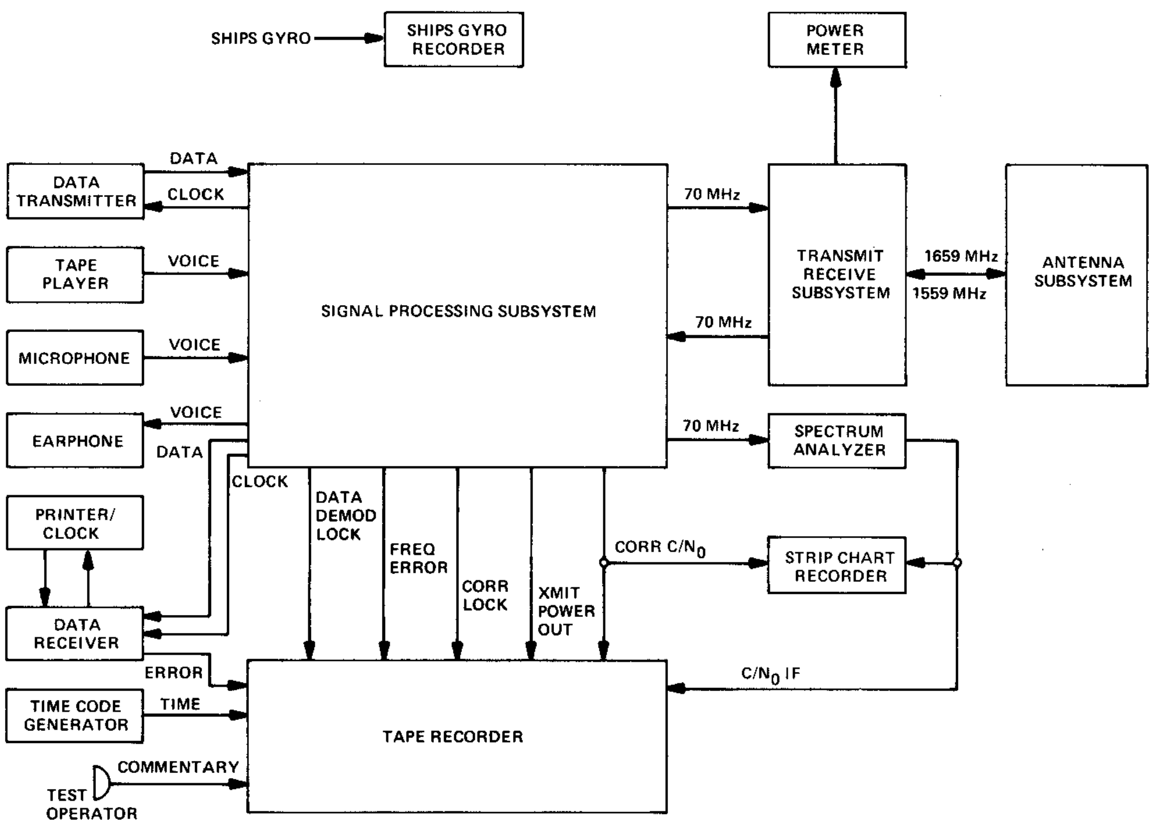

Fig. 9 - LASH Atlantico Shipboard Instrumentation for Data Tests.

For convenience of test coordination between the MCC and the shipboard terminal, most of the tests were performed in simplex mode: KPES-to-ship or ship-to-KPES. A test run consisted of continuous transmission of PRN sequence of data bits by the data transmitter from one end and recording the number of received errors in a given number of bits (from 10^3 to 10^7) at the other end. The errors were observed on the data receiver and then printed on the printer/clock. Prior to the start of the test a CW signal was transmitted, and the received C/N_0 was monitored on spectrum analyzer at the other end of the link. The transmitted signal was adjusted, by voice instructions from receiving end, for proper C/N_0. During the test, the power spectrum of the received modulated signal was monitored and recorded. Upon completion of the test, the C/N_0 was again checked using the CW signal to determine the change in signal level. If the level drifted up or down by more than several tenths of a dB, the test was repeated.

The Magnavox modem was only available on the LASH Atlantico. Unfortunately, this shipboard terminal experienced severe problems with antenna gyroscope and other equipment malfunctions which severely limited the quality of the significant digital data collected while the ship was crossing the Atlantic Ocean.

Most of the data presented in this paper was obtained either when the ship was docked at U. S. ports or with the terminal located at AII Systems facility in Moorestown, New Jersey. The tests at AII Systems facility were used for calibrating the modem performance in the absence of interference by HF radio, degradation due to system phase noise, and antenna pointing oscillations due to pitch and roll of the ship.

The data collected while the terminal was placed aboard ship and during the calibration tests at AII Systems is presented in Figures 10 and 11. Figure 10 depicts the results obtained at the shipboard terminal and Figure 11 shows them for the KPES. In each Figure four sets of data are presented: (1) closed loop ground tests of the entire terminal, including the RF equipment; (2) link performance through the ATS-6 between the KPES and the shipboard terminal at AII Systems; (3) same link performance but with the shipboard antenna deliberately oscillating about 2 dB in peak-to-peak gain; and (4) link performance while the modem was aboard ship.

The closed loop tests were run in order to re-check that modem performance has not degraded from baseline performance (i. e. , obtain calibration data) and to determine that it is not affected by terminal phase noise or any spurious signals. The tests between the shipboard terminal at AII Systems and the MCC were done in order to assure that the satellite phase noise is not degrading the performance of the modem. Testing with oscillating shipboard antenna was performed in order to simulate the test conditions during ship's trans-atlantic crossing when antenna gyroscope was malfunctioning.

It should be noted that the curves depicted in Figures 10 and 11 are not the actual measured probability of error points but are the result of a least square error logarithmic parabolic fit to the means of the probability of error obtained, i.e., $P_e = \exp [a + b (E/N_0) + c (E/N_0)^2]$.

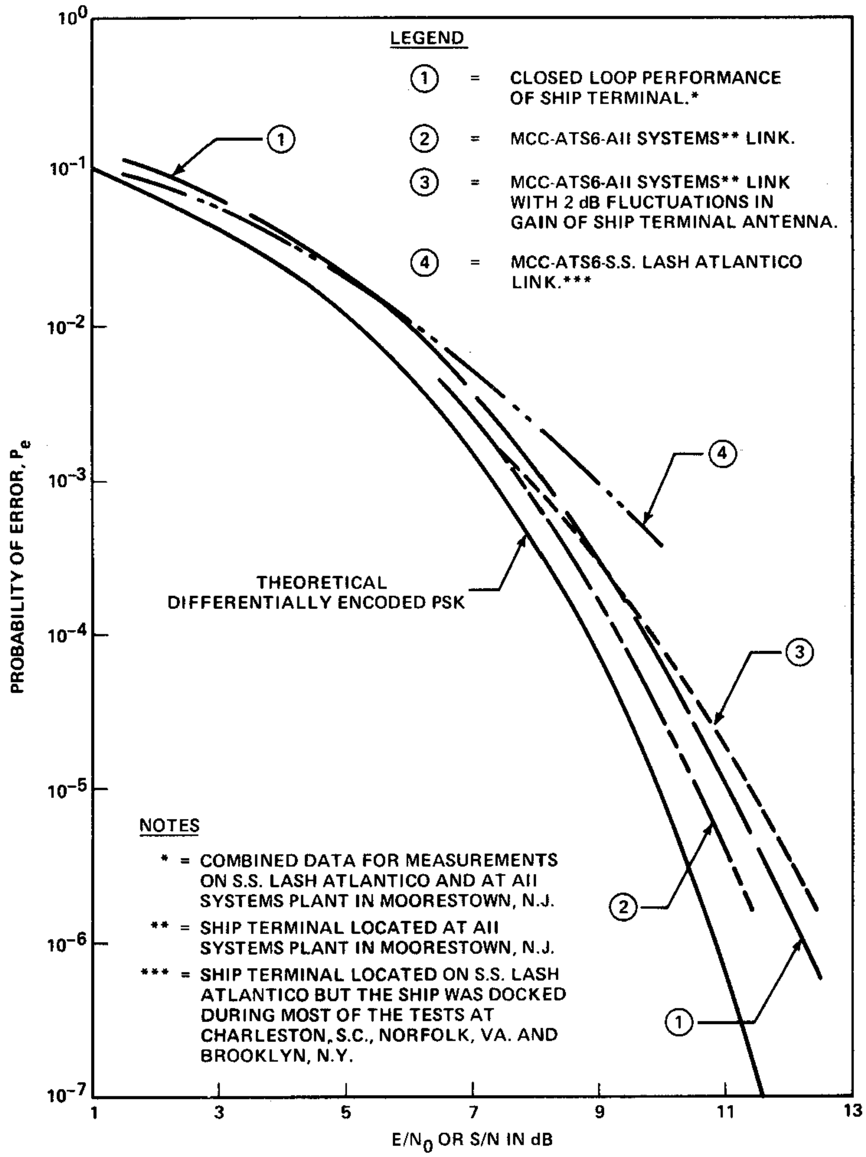

Fig. 10 - Ship Terminal Performance of Magnavox Modem at 9600 BPS.

Conclusions. The ship antenna demonstrated successful tracking of the satellites for test period intervals of 4 to 6 hours without the need for operator adjustment. Reliability problems with mechanical components, particularly vertical reference gyros, caused large signal fluctuations during a portion of the testing. Relatively stable signal levels were achieved with the terminal on the American Ace, but highly variable signal levels were noted within the terminal on the LASH Atlantico. These variable signal levels degraded digital data performance of the Magnavox data modem at sea. Position determination results are still being analyzed. Preliminary results show good measurement repeatability, however, significant bias errors are present which may be a result of satellite ephemeris.

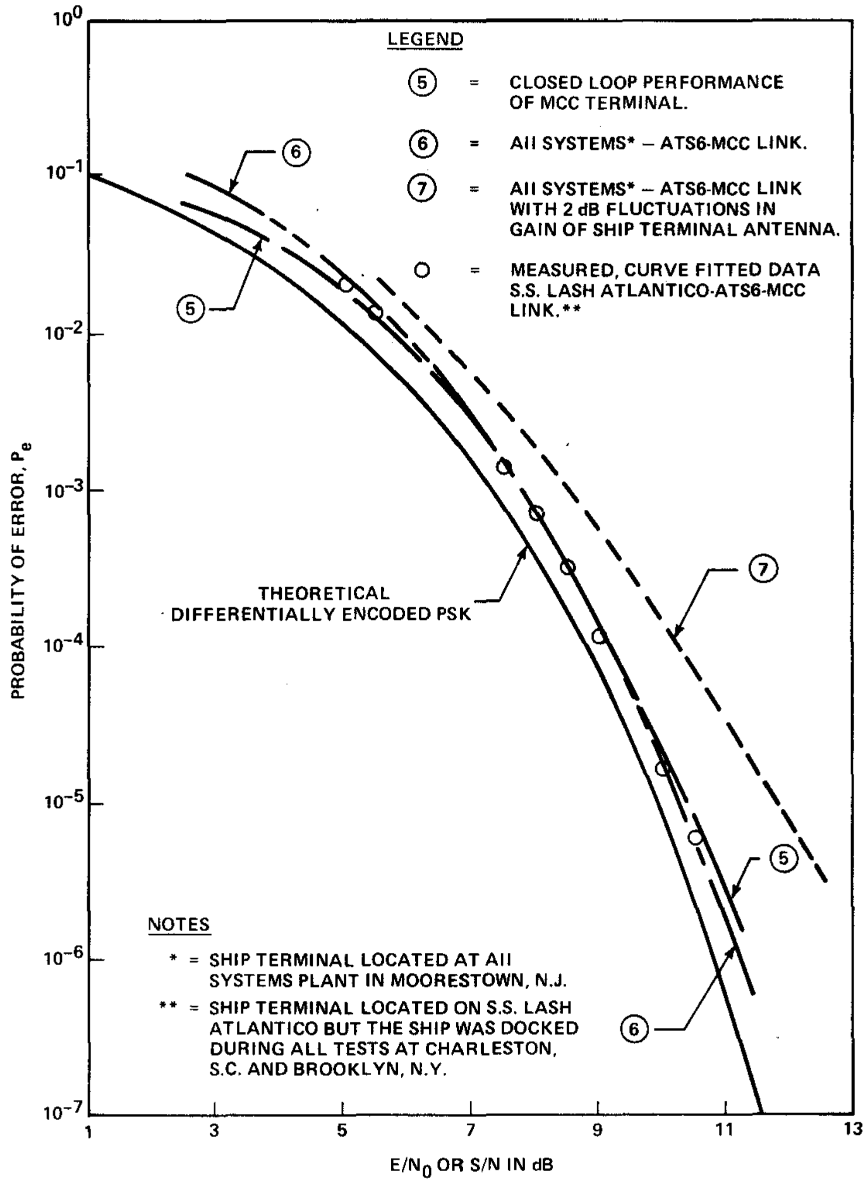

Fig. 11 - Maritime Coordination Center (MCC) Performance of Magnavox Modem at 9600 BPS.

For the limited data analyzed here, data performance was adequate to demonstrate the ability to achieve a probability of bit error of better than 10^{-5} in both the forward and return directions through the satellite for the LASH terminal at Moores town, N. J. and for the LASH at anchor in the return direction.

There is a perceptible tendency for the measured probability of error in the forward direction to deviate by an increasing amount from the theoretical performance curves at the higher E/N_0 levels.

The noticeable deviation of the measured data from the theoretical curves in the forward direction are presently ascribed to a variety of hypothetical causes. Among these are possible spurious signals generated in the ship terminal downconverter stages, phase noise in the terminal, RFI from the HF and radar equipment on the ship, and signal fluctuation from improper ship antenna stabilization. Another possible source of degradation is signal fluctuation from ATS-6, due to power sharing in the satellite. The possibility of data degradation due to multipath is considered highly unlikely because the data presented was obtained for elevation angles above 30 degrees with a ship antenna having a beamwidth of 11 degrees.

The result of signal fluctuation obtained by dithering the ship antenna (oscillating antenna tests) shows significant deviation from theoretical performance particularly with higher signal levels.

The measured data analyzed and taken with the ship at dock, shows a probability of bit error in the forward direction slightly better than 10^{-3}.

The measured data in the forward and return direction with the ship terminal at Moorestown, N. J. , has shown that modem performance within 1 dB of theoretical is achievable.

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1. Final Technical Report for MX-330 A/B/Q Modem Magnavox Research Laboratory, (No. R-4992) prepared for U.S. Navy, 20 December 1974.

2. System Design Plan for Modifications of the Maritime Satellite System (Phase III). Maritime Administration, U. S. Department of Commerce Report No. MAR 044P-002A, (USA), 7 December (1973).

3. Maritime Satellite Navigation/Communication Program (Volume II). Maritime Administration, U. S. Department of Commerce Report No. MA-RD-900-74022, (USA), 15 November (1973).

4. Results of Ship Antenna Re-orientation Tests. All Systems Information Memo, III-75-0-61, 25 April (1975).