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Technical Report 1701
May 1995

Use of the AN/WSC-3 External Modem Interface for
High-Data-Rate UHF Digital Communication
Experimental Results

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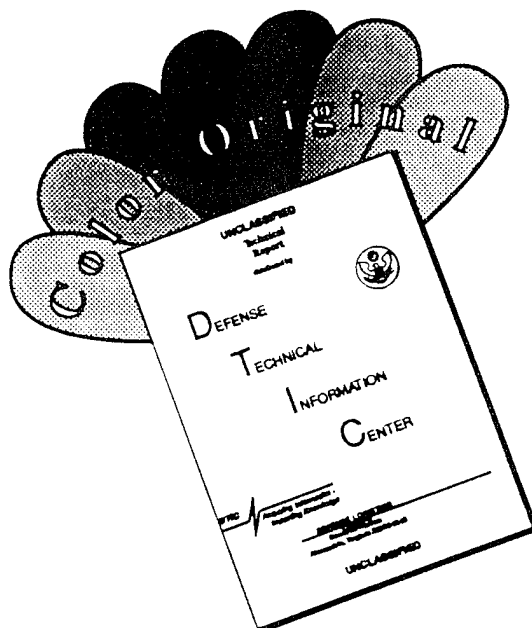
- Naval Command, Control and Ocean Surveillance Center
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Use of the AN/WSC-3 External Modem Interface for High-Data-Rate UHF Digital Communication

Experimental Results

R. C. North, W. D. Bryan, R. A. Axford, Jr.,
K. C. Owens, D. R. Butts, B. Watkins, P. D. Donich

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ADMINISTRATIVE INFORMATION

The work detailed in this report was performed by the Naval Command, Control and Ocean Surveillance Center, RDT&E Division, Communication Technology and Systems Branch, Code 824, for the Office of Naval Research (ONR), Arlington, Virginia 22217-5000, the Aegis Program Manager, PMS 400ED3, Arlington, Virginia 22242-5165, and the Naval Medical Information Management Center (NMIMC), Bethesda, Maryland 20889-5605. Funding was provided under program element 062232N and project number CC75.

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EXECUTIVE SUMMARY

OBJECTIVES

This report describes two separate High-Data-Rate (HDR), Ultra-High-Frequency (UHF), Line-of-Sight (LOS) digital radio communication experiments and demonstrations conducted during FY 95 and the instruments used to support these demonstrations. The development of the HDR UHF LOS capabilities is sponsored by what was formerly the Office of Naval Technology, now the Office of Naval Research (ONR), Arlington, Virginia, under a communication block program at the Naval Command, Control and Ocean Surveillance Center (NCCOSC), RDT&E Division (NRaD) in San Diego, California. It began in FY 93 with the goal of exploring the possibilities of providing for T1 (1.544 Mbps) digital communications between ships in the 225- to 400-MHz, UHF band. The instruments used to support the demonstrations in this report represent Phase 1 of a planned three phases of instrument evolution. The Phase 1 instruments are based around the use of the AN/WSC-3 external modem interface and existing shipboard antenna couplers, RF cabling, and omnidirectional antennas. This system is proven by these demonstrations to provide reliable communications at fractional T1 data rates (256 kbps to 576 kbps) to a maximum range of about 18 nmi between ships at sea.

RESULTS

Commander, Destroyer Squadron 33 and Commander, Naval Surface Forces Pacific (CNSP) sponsored a series of experiments and demonstrations with the USS *Rentz* and the USS *Abraham Lincoln* Battle Group with funding from the Aegis Program Manager, PMS 400ED3 (described in section 4) and the Naval Medical Information Management Center (NMIMC) (described in Appendix A). Their goal was to provide technical, medical, and administrative support to the fleet more efficiently through voice, ethernet, and video teleconferencing. This report describes experiments on board the USS *Rentz* that were critical to the integration of the HDR UHF LOS communication system into the shipboard environment. The USS *Abraham Lincoln*, USS *Princeton*, and USS *John Paul Jones* demonstrated intership communication at 256 kbps and 576 kbps during a 6-month deployment. In addition, the USS *Princeton* and the USS *John Paul Jones* demonstrated an extension of the Satellite Communications (SATCOM) assets on board the USS *Abraham Lincoln* by routing voice and video teleconferencing channels through the HDR UHF LOS communication system to the USS *Abraham Lincoln*, and then through both the Naval Tactical Network (NAVTACNET) and a commercial C-band SATCOM system that connected the USS *Abraham Lincoln* to various shore sites. Maximum reliable LOS communication ranges of about 18 nmi were recorded for ship-to-ship communication.

The Advanced Research Projects Agency (ARPA) sponsored a second demonstration to provide for voice and secure ethernet connectivity from shore to the USS *Peleliu* operating in southern California waters during the Kernel Blitz 1995 exercise. A 384-kbps, ship-to-shore digital link was demonstrated by transmitting with the HDR UHF LOS communication system from a mobile site at Mt. Thirst, San Clemente Island, to the USS *Peleliu*. From San Clemente Island, the LOS data was time-division multiplexed with another Kernel Blitz demonstration being supported by Fleet Combat Training Center Pacific (FCTCPAC) and then transported back over an existing DS3 (45 Mbps) microwave link operated by Fleet Air Control and Surveillance Facility (FACSFAC), San Diego, to NRaD. While the operational results of this demonstration were only marginal, for reasons discussed in this report, the communication demonstration by itself was extremely important. It provided a 256-kbps ethernet connection and a 64-kbps voice channel between the shore communication site and the USS *Peleliu* operating at maximum ranges of about 35 nmi off San Clemente Island.

RECOMMENDATIONS

Finally, this report concludes with a discussion of issues that need to be resolved before any future deployments of HDR UHF LOS communication systems. These issues include range extension, system timing, frequency/bandwidth management for multiple simultaneous users (media access controller), security, and equipment configuration control.

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GLOSSARY

ARPA	Advanced Research Projects Agency
AIAA	American Institute of Aeronautics and Astronautics
BER	Bit Error Rate
BERT	Bit-Error-Rate Tester
BW	Bandwidth
CNET	Chief of Naval Education and Training
CNSP	Commander, Naval Surface Forces Pacific
COMDESRON	Commander, Destroyer Squadron
CSSQT	Combat Systems System Qualification Trial
DCTN	Defense Commercial Telecommunication Network
EFS	Error-Free Seconds
EMI	Electromagnetic Interference
FACSFAC	Fleet Air Control and Surveillance Facility
FCTCPAC	Fleet Combat Training Center Pacific
FDM	Frequency-division Multiplexing
GPS	Global Positioning System
HDR	High Data Rate
HMMWV	High Mobility Manned Wheeled Vehicle
IP	Internet Protocol
LNA	Low-Noise Amplifier
LOS	Line-of-Sight
MTN	Maritime Telecommunications Network
NAVTACNET	Naval Tactical Network
NCCOSC	Naval Command, Control and Ocean Surveillance Center
NMIMC	Naval Medical Information Management Center
ONR	Office of Naval Research
PACER	Post-operational Analysis Critique and Exercise Review
PBX	Private Branch Exchange
PN	Pseudo-Random Noise
POTS	Plain Old Telephone System
PSK	Phased-Shift-Keyed
RDT&E DIV	Research, Development, Test and Evaluation Division
RS	Reed-Solomon
RSL	Received Signal Level

SATCOM	Satellite Communications
SNAP III	Shipboard Nontactical Automated Data Processing System
TDM	Time-Division Multiplexed
UHF	Ultra High Frequency
UPS	Uninterruptible Power Supply
VSWR	Voltage Standing Wave Ratio
VTC	Video Teleconferencing

1. INTRODUCTION

This report describes the test results of two separate at-sea demonstrations that were conducted during FY 95 and used High-Data-Rate (HDR), Ultra-High-Frequency (UHF), Line-of-Sight (LOS) digital radio communication. Commander Destroyer Squadron 33 and Commander Naval Surface Forces Pacific (CNSP) sponsored the first demonstration with the USS *Rentz* and the USS *Abraham Lincoln* Battle Group. The goal was to provide technical, medical, and administrative support to the fleet more efficiently through voice, ethernet, and video teleconferencing communications services. The Advanced Research Projects Agency (ARPA) sponsored the second demonstration that was conducted during the Kernel Blitz 1995 exercise to provide for voice and secure ethernet connectivity from a shore communication site to the USS *Peleliu* operating in southern California waters.

The core development of the HDR UHF LOS capabilities is sponsored by Dr. Sherman Gee of the Office of Naval Research (ONR) under a communication block program at the Naval Command, Control and Ocean Surveillance Center (NCCOSC), Research, Development, Test and Evaluation Division (RDT&E DIV), referred to as NRaD in this report. It began in FY 93 with the goal of exploring the possibilities of providing for T1 (1.544 Mbps) digital communication between ships in the 225- to 400-MHz UHF band. References (Bryan, North & Axford, Jr., 1993; North & Axford, Jr., 1994; North, Bryan, & Axford, Jr., 1994, 1995) provide more information on the accomplishments of the HDR UHF LOS program. The instruments supporting the demonstrations in this report represent Phase 1 of three planned phases of instrument evolution. The Phase 1 instruments are based around existing military equipment (transceivers [AN/WSC-3], antenna couplers [OA-9123], radio frequency [RF] cabling, and antennas [AS-1735, AS-3021, AS-390, etc.]) for an easy-to-install, inexpensive capability. The system provides reliable communications at data rates from 256 kbps to 576 kbps for a maximum range up to about 18 nmi between ships at sea. The system is extremely flexible and supports any data rate (with 1-bps resolution) from 4.8 kbps to E1 (2.048 Mbps), including T1 (1.544 Mbps). Further evolution of the instruments will increase the reliability and the range. Phase 2 of the instruments is currently being developed and is expected to be completed during FY 96.

2. INSTRUMENT CONFIGURATION AND PERFORMANCE

2.1 TRANSMIT AND RECEIVE INSTRUMENT CONFIGURATION

Figure 1 identifies the instruments and their configuration for a HDR UHF LOS, digital communication, full-duplex link. The Comstream Model CM701 modem is capable of transmitting simple phased-shift-keyed (PSK) modulations (BPSK or QPSK) with numerous coding options at any data rate from 4.8 kbps to 2.048 Mbps. Table 1 summarizes the performances of the various coding options for the QPSK modulation of an R bps data rate signal. The coding gain in the last column is computed using

$$\text{coding gain} = \frac{E_b}{N_o} \Big|_{\text{BER}=10^{-6}}^{\text{uncoded}} - \frac{E_b}{N_o} \Big|_{\text{BER}=10^{-6}}^{\text{coded}} \quad (1)$$

and data supplied by the manufacturer. The concatenated coding scheme provides 2.4- to 2.7-dB additional coding gain over the convolutional code alone. Bandwidth expansion by the additional coding is minimal. The coding scheme chosen for these demonstrations consists of using the rate 239/256 Reed-Solomon (R-S) block code with a rate 3/4 convolutional code. This scheme gives a 6.6-dB coding gain over the uncoded QPSK case and a spectral efficiency of 1.4 bps/Hz.

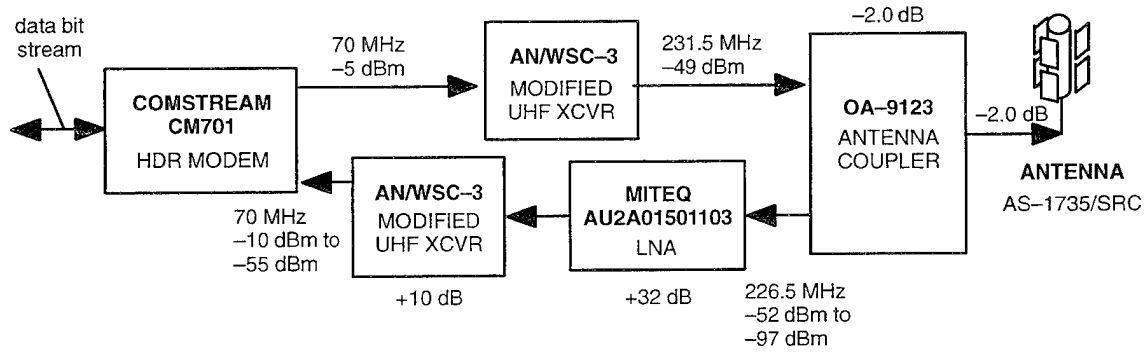


Figure 1. Shipboard instrumentation for a HDR UHF LOS, full-duplex, digital communication link.

Table 1. Summary of the characteristics for some of the forward error-correcting code options that are available with the CM701 modem using QPSK modulation on an R bps data rate signal.

Reed-Solomon Code Rate	Conv. Code Rate	Channel Bit Rate (bps)	Approx. Transmit 3-dB BW (Hz)	E_b/N_o Required for BER = 10^{-6}	Coding Gain
—	—	$1.00 R$	$0.50 R$	10.6 dB	0
—	1/2	$2.00 R$	$1.00 R$	5.7 dB	4.9 dB
—	3/4	$1.33 R$	$0.67 R$	6.7 dB	3.9 dB
—	7/8	$1.14 R$	$0.57 R$	7.8 dB	2.8 dB
239/256	1/2	$2.14 R$	$1.07 R$	3.2 dB	7.4 dB
239/256	3/4	$1.43 R$	$0.72 R$	4.0 dB	6.6 dB
239/256	7/8	$1.22 R$	$0.61 R$	5.4 dB	5.2 dB

Table 2 summarizes the transmission characteristics of several common data rates using this concatenated coding scheme. The maximum interleave time is computed with the CM701 modem interleave depth parameter set at its maximum value (16 bytes) and the data rate. Interleaving is an important component to the successful implementation of block codes. Interleaving decorrelates short bursts of errors, which are caused by random signal fluctuations or pulsed noise, and allows for the maximum performance of the block code.

Table 2. Summary of the transmission characteristics for some common data rates with rate 239/256 Reed-Solomon code and rate 3/4 Viterbi codes with QPSK modulation.

Data Rate	R-S Output/Input (Rate 239/256 Code)	TX/RX Symbol Rate (QPSK w/ Rate 3/4 Vit. Code)	Approx. TX 3-dB BW	Max. Interleave Time
144,000 bps	154,243 bps	102,829 sps	103 kHz	888.9 μ s
256,000 bps	274,209 bps	182,806 sps	183 kHz	500.0 μ s
384,000 bps	411,314 bps	274,209 sps	275 kHz	333.3 μ s
512,000 bps	548,418 bps	365,612 sps	366 kHz	250.0 μ s
576,000 bps	616,971 bps	411,314 sps	411 kHz	222.2 μ s
1,544,000 bps	1,653,824 bps	1,102,549 sps	1103 kHz	82.9 μ s

The AN/WSC-3 is used as a UHF transceiver for the external CM701 modem. The transceiver is a half-duplex radio that translates the 70-MHz IF signal into and out of the UHF 225- to 400-MHz band. Separate AN/WSC-3s are therefore required for simultaneous transmit and receive paths since full-duplex communications are required for these tests. New designs in Version 15 (and later) of the AN/WSC-3 improve the linearity of the translator and transmitter modules that improves system performance significantly with respect to earlier AN/WSC-3 versions (Bryan, North & Axford, Jr., 1993). The transmit AN/WSC-3 has pin 48 and pin 49 connected in the J2 connector and the Test Key = ON to allow for constant keying of its T/R switch to enable constant transmission of the CM701 external modem signal. Both the transmit and the receive AN/WSC-3s have the following settings: Comm Mode = LOS; Freq. Select = manual; Control = local; Modulation = external modem.

A small modification is made to the Version 15 transmitter module (A1) in the AN/WSC-3 to reduce the sensitivity of the control circuitry to reflected power during transmissions. The control circuitry determines the load voltage standing wave ratio (VSWR) by comparing the forward power-sense signal with the reverse power-sense signal; The output is turned off if the VSWR becomes too great. In the present Version 15 transmitter module design, the time constant of the reverse signal is less than that for the forward signal. This time constant difference causes the VSWR to appear to be larger during switching transients than it actually is. This problem is aggravated by the higher data rates used in these demonstrations than those for which the AN/WSC-3 was originally designed. A 1000-pF capacitor is added across pins 12 and 13 of U6A in the control protect circuit A1A1A10 to equalize the time constants. The 1000-pF capacitor matches the voltage and temperature characteristics of the capacitor used in the forward power-sense circuit.

The sensitivity and noise figure of the receive AN/WSC-3 is improved by adding a low-noise amplifier (LNA) in the signal path before the receive module of the AN/WSC-3. The MITEQ AU-2A-0150-1103 +30 dB LNA with a noise figure of less than 1.5 dB is used here. A jig was constructed to house the LNA and a power regulator circuit was then mounted inside the AN/WSC-3 chassis in place of the 225- to 400-MHz broadband filter. This provides an ideal placement since the

LNA is surge-protected by the T/R switch of the AN/WSC-3, DC power (+28 volts), grounds are easily accessible, and the LNA is easily field-inserted. The 225- to 400-MHz filter is not required since the OA-9123 antenna coupler is being used as a narrowband, tunable, preselector filter. It is estimated from laboratory measurements that the incorporation of the LNA improves the receiver noise figure by about 4 dB.

The OA-9123 is the U.S. Navy standard for LOS antenna couplers. It consists of four parallel, independently tuned, narrowband filters and one antenna port. The OA-9123 antenna coupler helps to reduce out-of-band emissions caused in part by nonlinearities in the transmit AN/WSC-3 and acts as a "narrowband" preselector filter for the receiver AN/WSC-3. Measurements have shown the 3-dB bandwidth (BW) of the OA-9123 antenna coupler to be about 0.4% of the center frequency (900 kHz at 225 MHz and 1.6 MHz at 400 MHz) and the 40 dB BW to be about 1.2% of the center frequency (2.7 MHz at 225 MHz and 4.8 MHz at 400 MHz). Insertion loss varies between 1.2 and 1.8 dB. The filters can be tuned to within 3 MHz of each other without causing an alarm condition, which can be overridden if desired.

2.2 SYSTEM PERFORMANCE

Figure 2 is the test setup used to measure the bit-error-rate (BER) performance of the HDR UHF LOS digital communication system. Figures 3 and 4 plot the measured BER performance versus E_b/N_0 and the received signal level (RSL), respectively. Note that the OA-9123 antenna coupler and the antenna are absent from the test setup. All receive instruments were enclosed in an electromagnetic interference (EMI) free shelter and the E_b/N_0 was set at an RF frequency of 255 MHz by a Noise/Comm UFX-BER-255. The transmit data rate of T1 (1.544 Mbps) was used in the UFX-BER-255 configuration to establish the desired E_b/N_0 value.

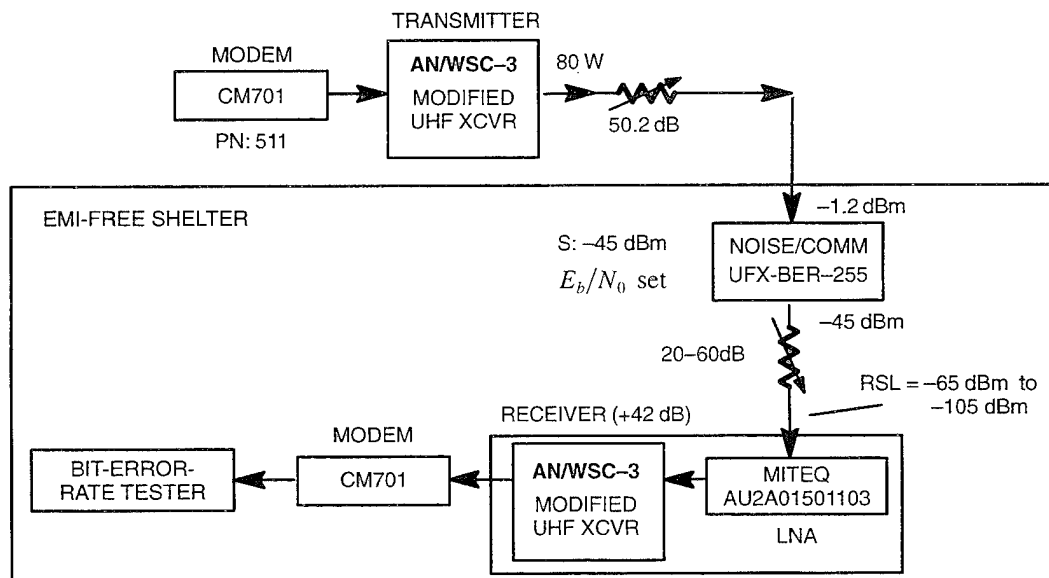


Figure 2. Test setup for BER performance measurements.

In figure 3, the measured data is plotted in solid lines while the theoretical BER performance is plotted in dashed lines. The RSL is fixed at -65 dBm. It can be seen from the figure that the HDR UHF LOS communication system exhibits an implementation loss of 3 to 4 dB at a BER = 10^{-6} . The E_b/N_0 performance of the Comstream CM701 modem is known to be within about 0.5 dB of theoretical; therefore, the additional 2.5 to 3.5 dB of performance degradation is caused by the

transmitter and the receiver. Other tests have linked much of the performance degradation to nonlinearities in the AN/WSC-3 translator and transmitter modules (Bryan, North & Axford, Jr., 1993). These nonlinearities also cause spectral spreading (see figures 5-7 described later) that can cause adjacent channel interference. Measurements were also conducted at 384 kbps with only slight variations in the BER versus E_b/N_0 performance.

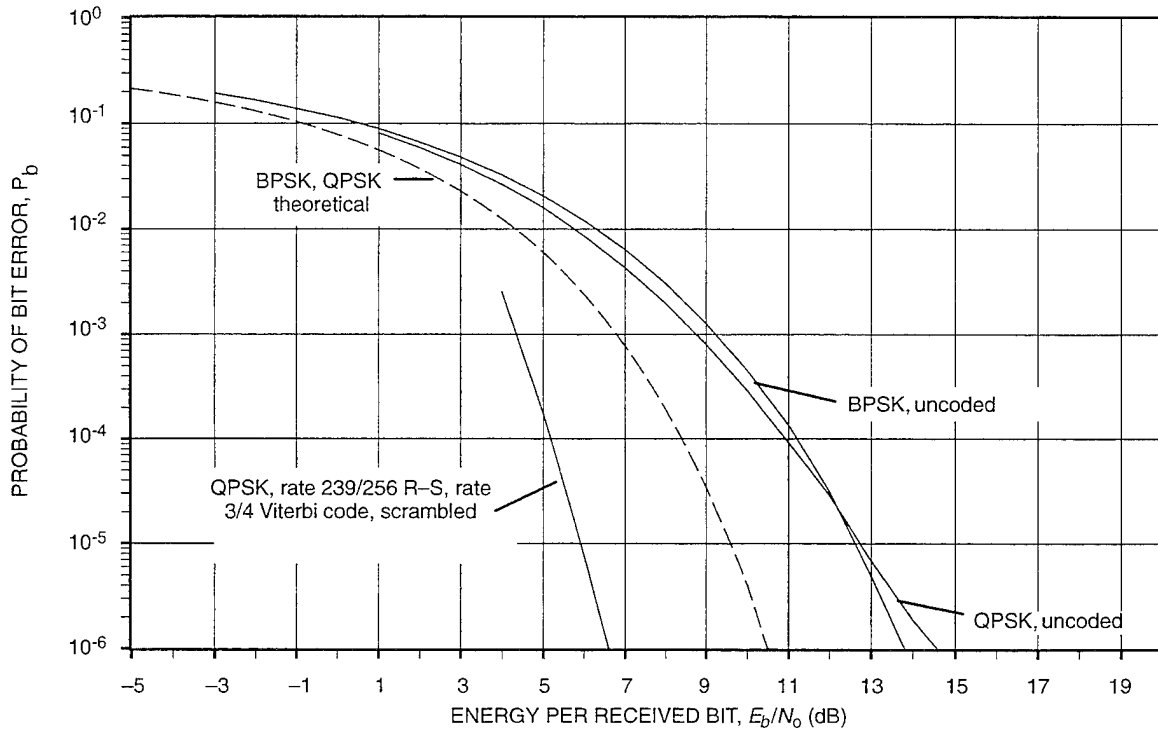


Figure 3. E_b/N_0 performance for T1 (1.544 Mbps) at 255 MHz for the configuration in figure 4 without the antenna or the antenna coupler.

Figure 4 plots the BER of the HDR UHF LOS communication system as a function of the total RSL at the input to the receiver. For these tests, the value of the E_b/N_0 ratio at the output of the Noise/Comm UFX-BER-255 is fixed at 15 dB while the attenuation between the UFX-BER-255 and the receiver is adjusted. At the output of the UFX-BER-255, the energy per bit is given by

$$E_b = \frac{S}{R} = 10^{-13.69} \text{ (joules)}, \quad (2)$$

where $S = -45 \text{ dBm}$ is the signal power, and $R = 1.544 \text{ Mbps}$ is the data rate (Recall that a *joule* is a *Watt/Hz*). The noise temperature at this point is determined by equation (2) and the E_b/N_0 ratio from

$$T_{N_0} = \left(\frac{E_b}{k} \right) \frac{1}{\left(\frac{E_b}{N_0} \right)} = 4.7 \times 10^7 \text{ (kelvins)}, \quad (3)$$

where $k = 1.38 \times 10^{-23} \text{ joules/kelvins}$ is Boltzmann's constant. The value of the E_b/N_0 ratio at the output of the attenuator (shown in figure 2) is modified by the noise added from the attenuation; thus,

the E_b/N_0 ratio at the input to the receiver can be written from Gagliardi (1978) as

$$\left(\frac{E_b}{N_o}\right)_{rec-input} \approx \frac{E_b L}{k [T_{N_o} L + 290 (1-L)]}, \quad (4)$$

for an attenuation value of $L < 1$ and for the effective noise temperature of the attenuation of 290 K. Equation (4) is only an approximate expression since it has not included the effects of the receiver noise temperature. It is seen from figure 4 that for uncoded BPSK, a $RSL \geq -86$ dBm (corresponding to an $E_b/N_0 \approx 14.7$ dB from equation [4]) is required to obtain a BER better than 10^{-6} , but for the concatenated rate 236/259 Reed-Solomon code and rate 3/4 rate Viterbi coded QPSK, a $RSL \geq -102$ dBm (corresponding to an $E_b/N_0 \approx 8.9$ dB from equation [4]) is required to obtain a BER of 10^{-6} or better. These results clearly illustrate the advantages of forward error-correcting codes.

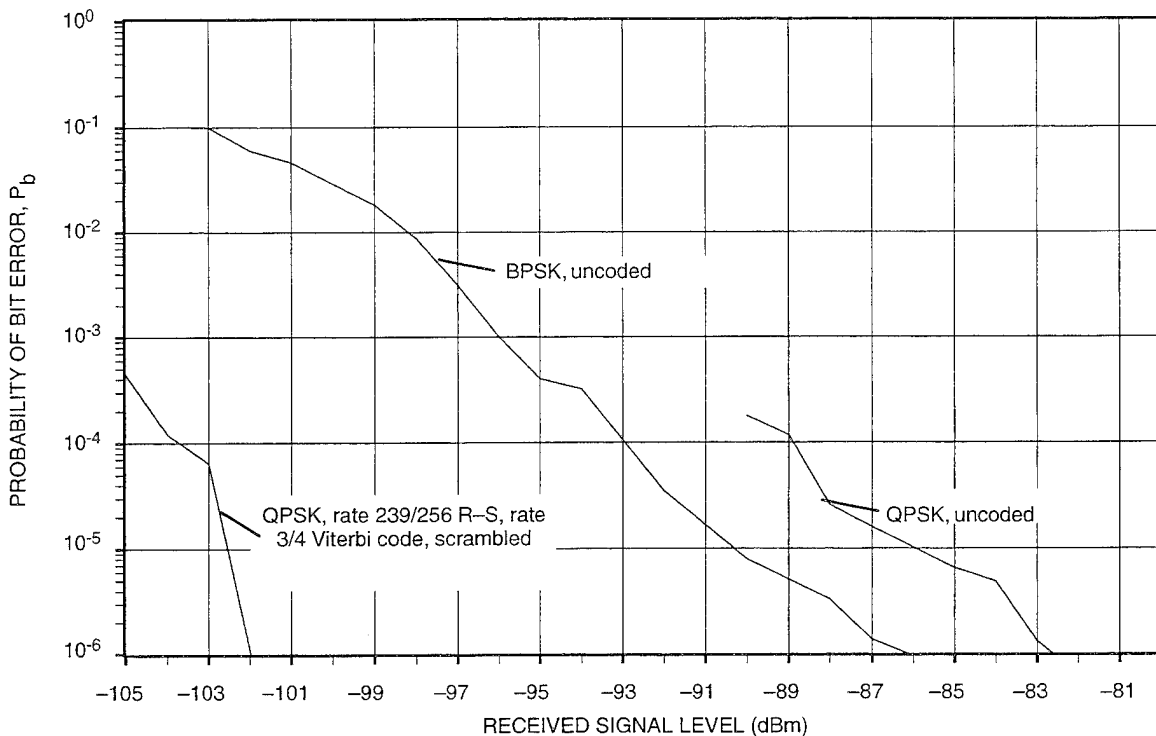


Figure 4. Received-signal-level performance for T1 (1.544 Mbps) at 255 MHz for the configuration in figure 5 without the antenna or the antenna coupler

From these results, other data rates can be estimated by recalling that $E_b = S/R$, where S is the total transmitted signal power and R is the data rate; thus, by decreasing the data rate while maintaining the same transmitted signal power, the energy per received bit, E_b , is increased and the receive E_b/N_0 ratio is increased since the noise power spectral density, N_0 , is (approximately) a constant; for example, decreasing data rates from 1.544 Mbps to 144 kbps results in an increase in the received E_b/N_0 value of 10.3 dB ($= 10 \log [1544/145]$). It is clear that by reducing the data rate while keeping all other variables constant, the received E_b/N_0 value is increased, thereby improving the system BER performance.

Figures 5, 6, and 7 plot the output spectrums of the transmitted signals at the CM701 modem output, the AN/WSC-3 transmitter output, and the OA-9123 antenna coupler output for 384-kbps,

uncoded BPSK signals, respectively. The effect of nonlinearities in the AN/WSC-3 transmitter is apparent in the gross spectral spreading observed in figure 6. This signal is unsuitable for transmission in a shipboard environment where other co-located users operating in the same UHF band would be overwhelmed by the additive noise. This adjacent channel interference becomes manageable by using the filtering characteristics of the OA-9123 antenna coupler to minimize the out-of-band emissions.

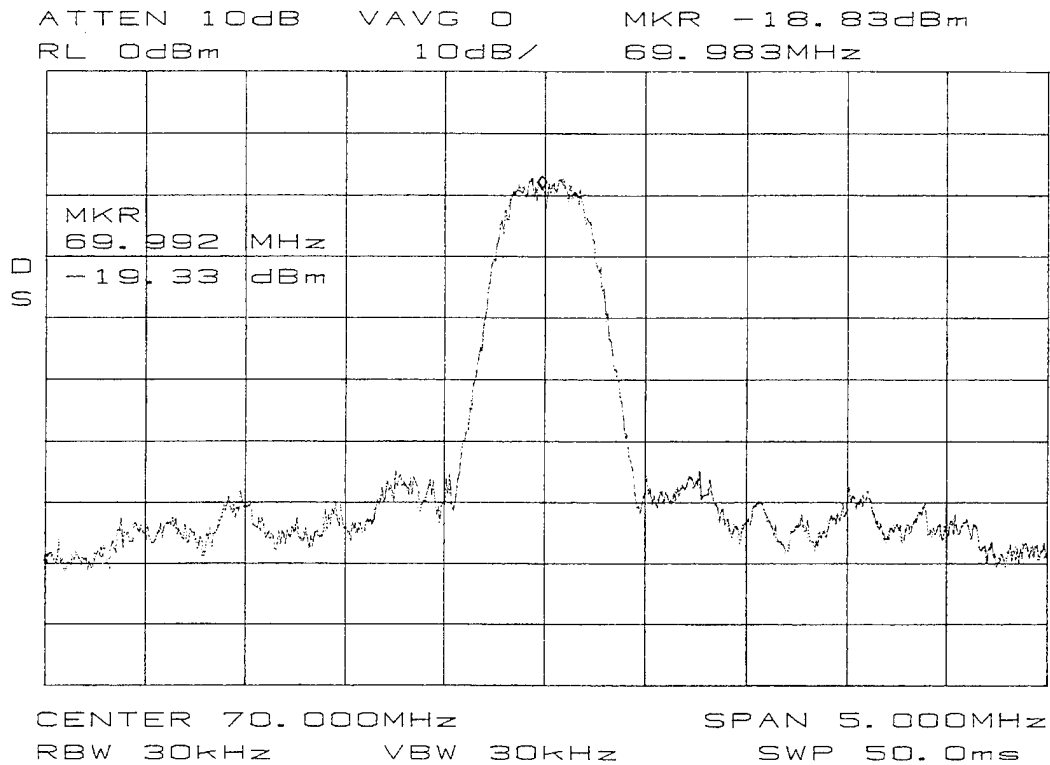


Figure 5. Output Spectrum from CM701 modem with 384-kbps, uncoded BPSK.

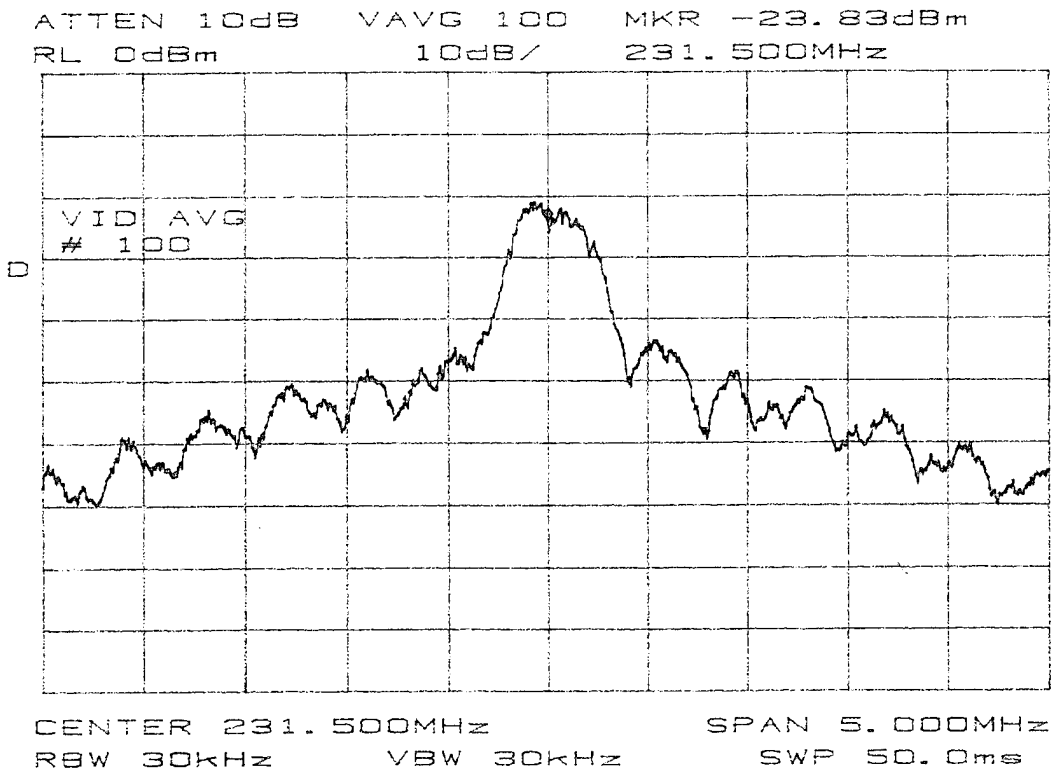


Figure 6. Output Spectrum from AN/WSC-3 transceiver with 384-kbps, uncoded BPSK.

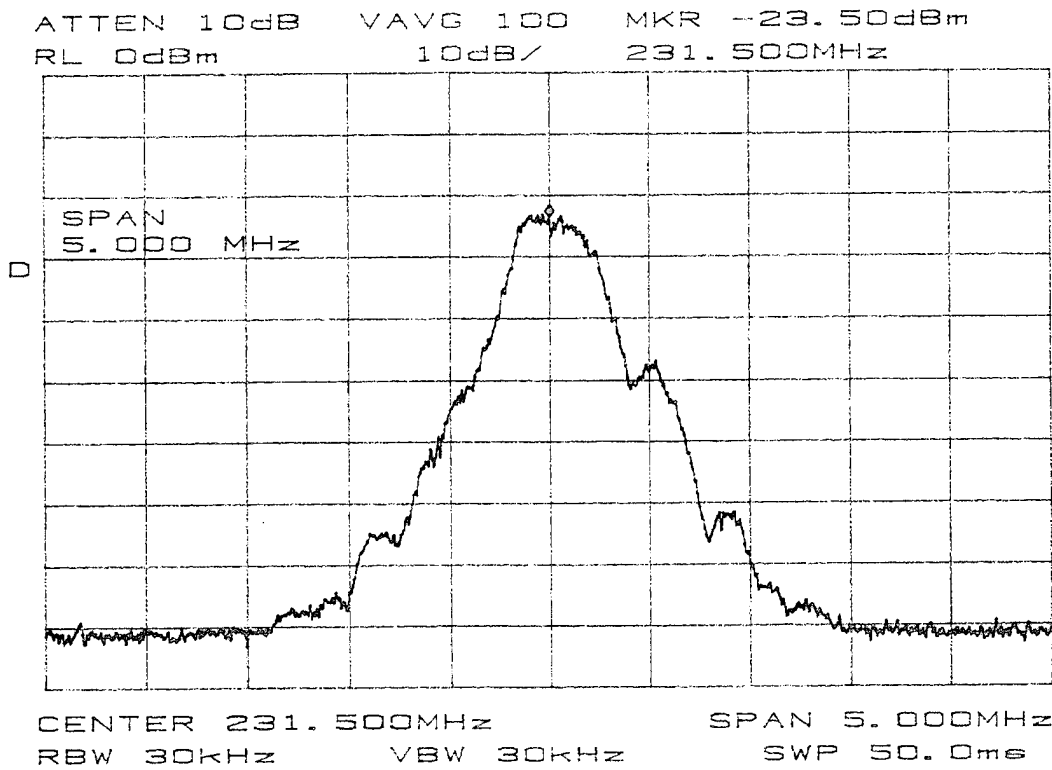


Figure 7. Output Spectrum from OA-9123 antenna coupler with 384-kbps, uncoded BPSK.

This is seen more clearly in figure 8 where the noise increase is plotted as a function of the difference between the transmit and the receive frequencies. Figure 8 represents the worst case scenario by measuring the noise increase in a receiver that is connected to the same OA-9123 antenna coupler as the transmitter. The channel symbol rates are varied from 64 kbps to 512 kbps for comparison. This data would suggest, for example, that all receivers connected to the same OA-9123 antenna coupler as a 256-kbps signal should be tuned to a frequency that is at least 7 MHz apart from the HDR UHF transmitted signal. One of the main goals of the Phase 2 HDR UHF LOS instruments is to improve system performance by eliminating many of the nonlinearities found in the AN/WSC-3 transceivers. For comparison, figure 9 plots the noise increase in the receiver when the transmitter consists of the present design of the Phase 2 instruments. Considerable decrease in the out-of-band emissions results in vastly improved, adjacent channel, interference characteristics.

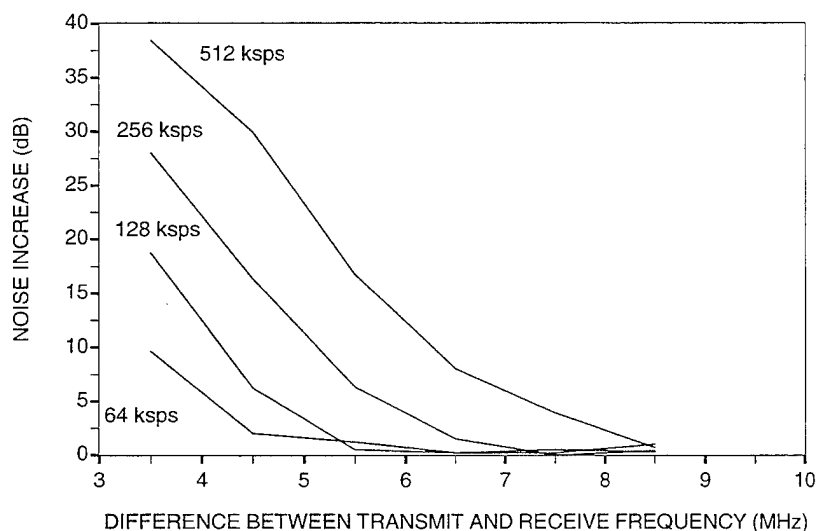


Figure 8. Effect of the transmitter on the receiver when feeding the same OA-9123 antenna coupler with HDR UHF LOS Phase 1 communication system based on AN/WSC-3 transceiver.

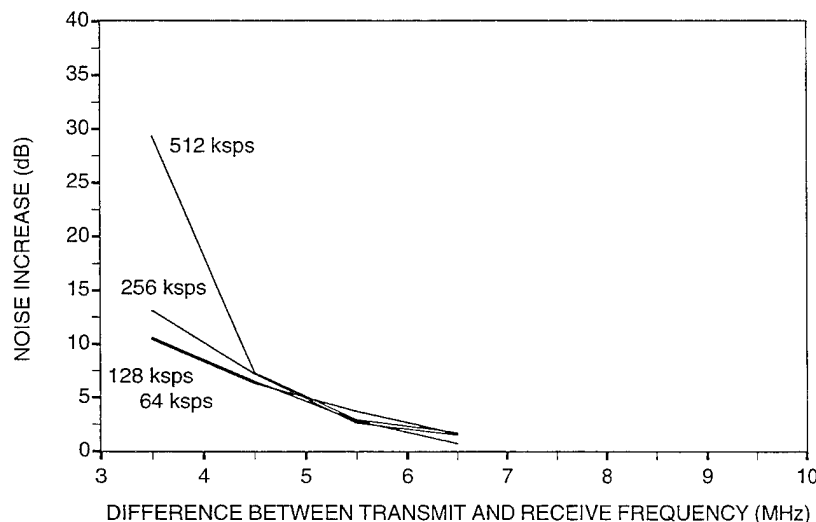


Figure 9. Effect of the transmitter on the receiver when feeding the same OA-9123 antenna coupler with HDR UHF LOS Phase 2 communication system based on MITEQ upconverter (UP-70-313-46516) and Amplifier Research HPA (100W1000M1).

3. PREDICTED TEST RESULTS

3.1 EXPECTED PROPAGATION AND FADING CONDITIONS

The median received signal level (*RSL*) is determined by the total transmitted power, free-space propagation loss, diffraction by the earth, antenna heights, cable losses, and antenna losses or gains. Figures 10 and 11 plot the median propagation loss of LOS communications at 231.5 MHz and 400 MHz, respectively, for three different communication links with standard propagation conditions, $K = 4/3$. More details on propagation conditions and notation are provided in North and Axford, Jr. (1994), Saveskie (1980), and Ritcher (1986). The three communication links include ship-to-ship (ship antennas are assumed to be approximately 25 m [82 ft] above sea level), ship-to-NRaD (a commonly used platform at NRaD is approximately 120 m [393 ft] above sea level), and ship-to-San Clemente Island (Mt. Thirst on San Clemente Island is approximately 600 m [1968 ft] above sea level). These data are smoothed from estimates made with SLAM/CHBDL (James & Rockway, 1990). The divergence from the free-space propagation loss (dashed lines) is due to diffraction by the earth surface.

The radio LOS range (sometimes called the radio horizon) can be defined as the range at which the direct RF path grazes the earth surface for some value of equivalent earth radius, K . For $K = 4/3$, the ship-to-ship link has a radio horizon of about 41 km (22.1 nmi), the ship-to-NRaD link has a radio horizon of about 65.5 km (35.4 nmi), and the ship-to-San Clemente Island has a radio horizon of about 121.7 km (65.8 nmi).

Over the air, the *RSL* fluctuates in a random fashion about this median level. The reliability of a LOS digital radio is a function of the magnitude and the rate of these *RSL* fluctuations (called the fade rate). The reliability is defined as

$$\text{reliability}(\%) = 100\% - \text{outage}(\%) \quad (5)$$

where the outage is usually expressed in percentage of seconds in which the BER is worse than 10^{-6} . For example, a reliability of 99.0% results in an average of 864 seconds/day (14.4 minutes/day) of outage induced by atmospheric conditions. Table 3 illustrates the relationship between reliability (%), sometimes called availability, and outage time. Ship and antenna movement will cause fluctuations in the *RSL*. Variations from the median *RSL* can also be caused by numerous atmospheric conditions, as shown in figure 12, that include (from Ritcher, 1986):

- a. Enhanced or reduced *RSLs* that are due to an *evaporation duct* close to the water surface. The *RSL* can be enhanced (or reduced) if the receive antenna is (or is not) within the duct.
- b. Multipath interference that is due to *refraction* of the transmitted signal off the troposphere. Refraction tends to create frequency-nonspecific (i.e., flat), rapid fading which becomes more severe as the path distance increases.
- c. Multipath interference that is due to *reflection* of the transmitted signal off the surface of the water. Reflection tends to create frequency-selective, slow fading which can be a function of the sea state.
- d. Obstruction of the earth that is due to *diffracting* subrefractive conditions. Diffraction essentially creates a shadowing effect sometimes called earth bulging since the rays of the transmitted signal bend away from the earth.

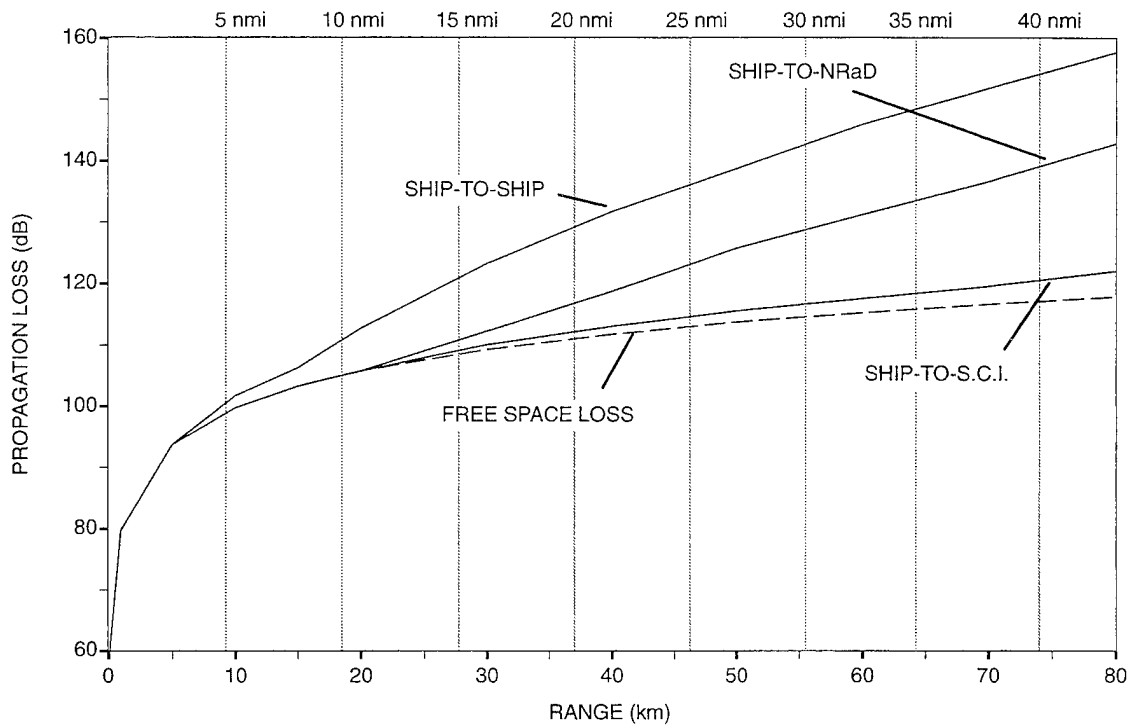


Figure 10. Median total propagation loss (solid) and free-space loss (dashed) for carrier frequencies of 231.5 MHz for $K=4/3$.

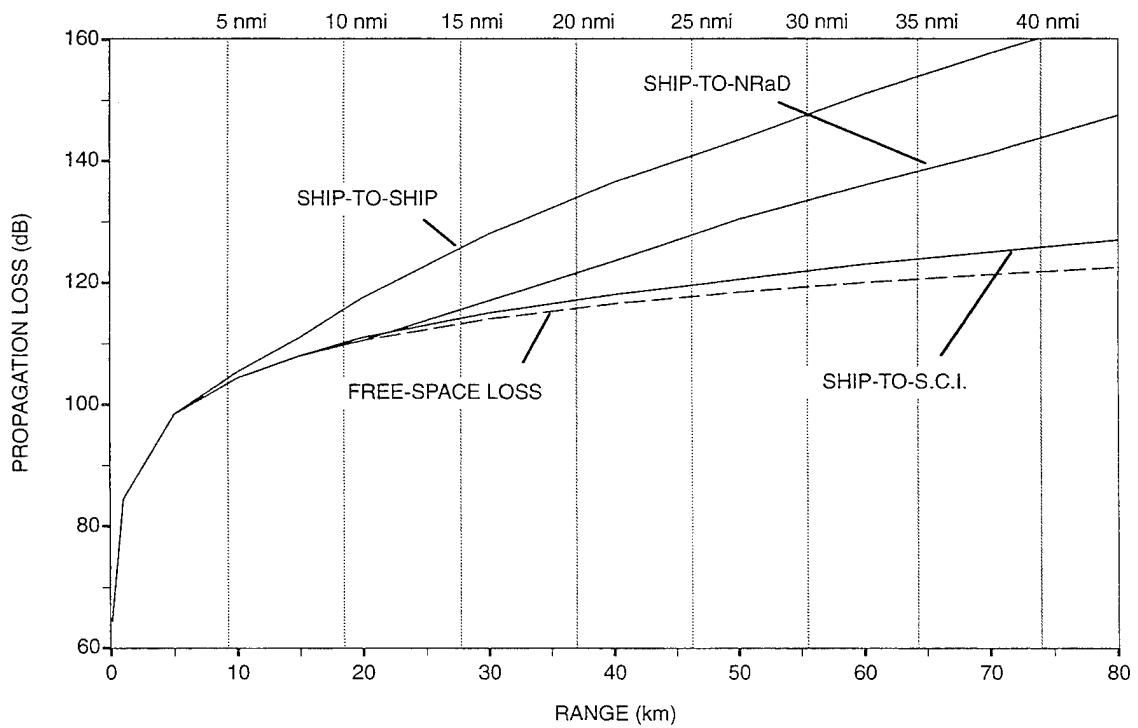


Figure 11. Median total propagation loss (solid) and free-space loss (dashed) for carrier frequencies of 400 MHz for $K=4/3$.

Table 3. Relationship between reliability and outage time.

Reliability (%)	Outage (%)	Outage Time		
		Year	Month	Day
0	100	8760 Hours	720 Hours	24 Hours
50	50	4380 Hours	360 Hours	12 Hours
80	20	1752 Hours	144 Hours	4.8 Hours
90	10	876 Hours	72 Hours	2.4 Hours
95	5	438 Hours	36 Hours	1.2 Hours
98	2	175 Hours	14 Hours	29 Minutes
99	1	88 Hours	7 Hours	14.4 Minutes
99.9	0.1	8.8 Hours	43 Minutes	1.44 Minutes
99.99	0.01	53 Minutes	4.3 Minutes	8.6 Seconds
99.999	0.001	5.3 Minutes	26 Seconds	0.86 Seconds
99.9999	0.0001	32 Seconds	2.6 Seconds	0.086 Seconds

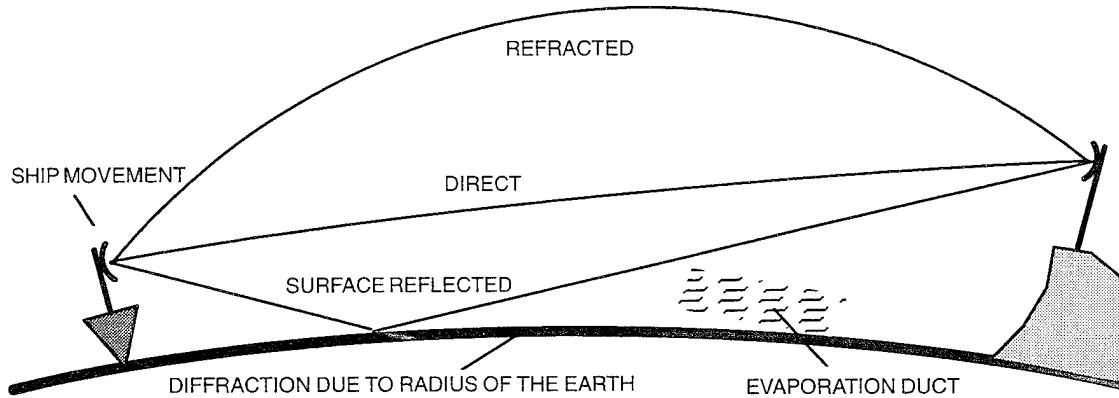


Figure 12. Possible atmospheric conditions that effect the received signal level.

Figure 13 shows the cumulative distribution of the refractivity gradient for San Diego for the months of February, May, August, and November from historical records (Bean et al., 1996). Also shown in the figure are the regions of the four atmospheric conditions discussed above. The reflective multipath condition is by far the most prevalent condition in the San Diego vicinity, with a reasonable chance of refractive multipath and ducting occurring during the winter months.

The figure also predicts that the most common atmospheric condition will be reflected multipath fading for $K \approx 4/3$. This condition is represented by a two-path channel model: one direct path and one surface reflected path. In general, the surface reflection point (area actually) is dependent on K as will be the differential path length; however, a flat earth approximation can be used to estimate the differential path length. With this assumption, it can be shown that the differential path length is

$$\begin{aligned}
 d_{\Delta}^{\text{reflected}} &= d_{\text{reflected}} - d_{\text{direct}} \\
 &= \sqrt{(h_1 + h_2)^2 + d^2} - \sqrt{(h_1 - h_2)^2 + d^2} \\
 &\approx 2 \frac{h_1 h_2}{d} \quad \text{for } d \gg h_1, h_2,
 \end{aligned} \tag{6}$$

where h_1 and h_2 are the two antenna heights and d is the range between antennas (Yacoub, 1993). The delay spread of this channel is $\tau_{\Delta} = d_{\Delta}/c$, where $c \approx 3 \times 10^8$ m/s is the speed of light. Figure 14 plots the differential path length (in meters) and the delay spread (in nanoseconds) for $h_1 = 25$ m (82 ft) and $h_2 = 25$ m (82 ft), 120 m (393 ft), or 600 m (1983 ft) corresponding to the ship-to-ship, ship-to-NRaD, or the ship-to-San Clemente Island links, respectively. Note that the reflected, multi-path delay spread decreases with path distance.

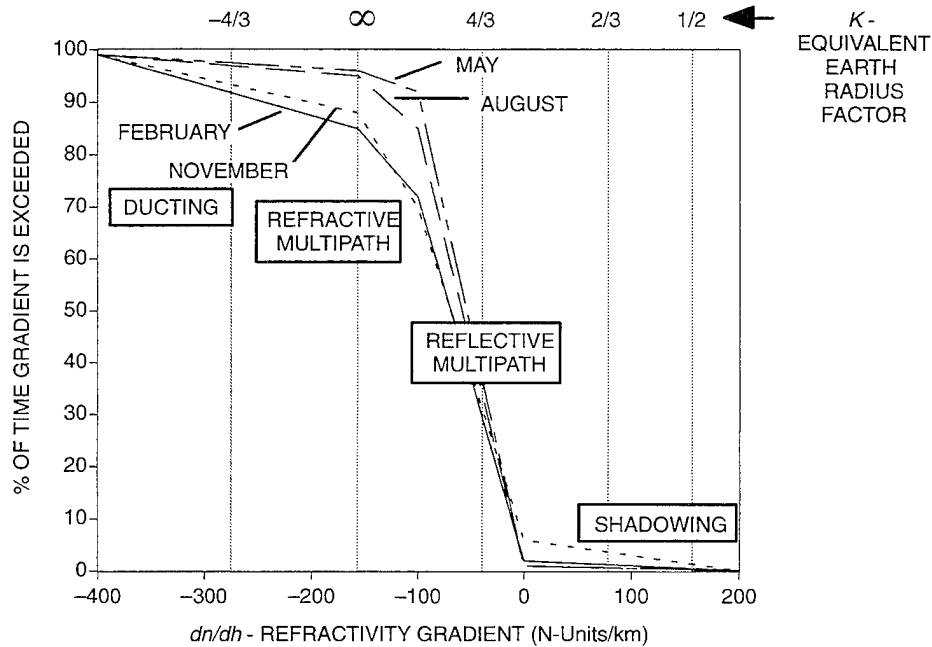


Figure 13. Refractivity gradient cumulative distributions for San Diego from Bean et al. (1966).

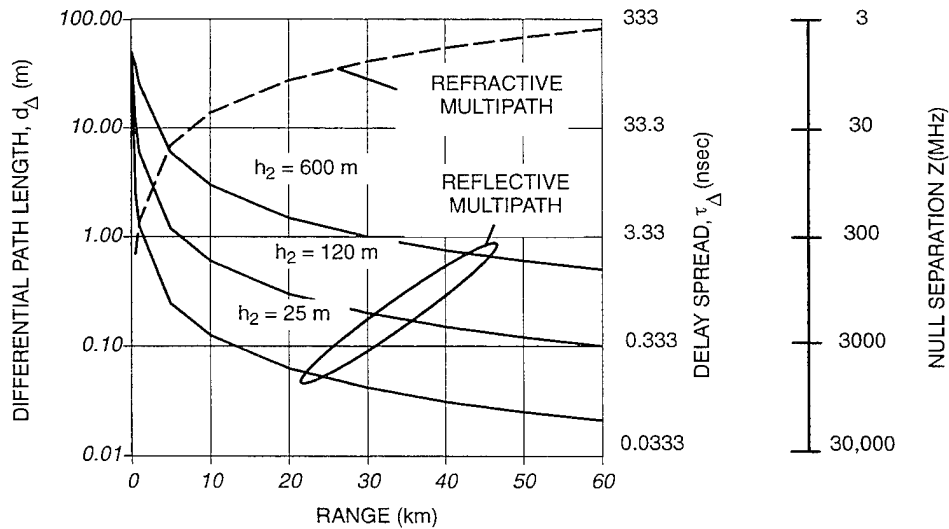


Figure 14. Differential path length, delay spread, and null separation for antenna #1 (height equal to 25 m) and antenna #2 (height equal to 25 m, 120 m, or 600 m).

From figure 13, there is a much smaller chance that a refractive multipath condition could appear. The differential path length between a refracted path of 3 degrees (approximately the largest refraction angle possible) and the direct path is given by

$$d_{\Delta}^{refracted} = d_{refracted} - d_{direct} \approx d \left(\frac{1}{\cos(3^{\circ})} - 1 \right) \quad (7)$$

and is also plotted in figure 14. Note that for the refracted multipath, the delay spread increases with path distance.

When the reflected path has a small scattering, as is typical from smooth surfaces, the multipath fading results in a frequency-selective, channel-frequency response with null separation given by

$$\text{null separation} = \frac{1}{\tau_{\Delta}} \text{ (Hz) ,} \quad (8)$$

and spectral peak-to-null difference given by

$$\text{peak-to-null} = 20 \log_{10} \frac{1 + |r|}{1 - |r|} \text{ (dB) ,} \quad (9)$$

where $|r|$ is the magnitude of the reflection coefficient. The magnitude of the reflection coefficient for a calm sea can be as high as 0.98, which results in as much as a 40-dB, spectral peak-to-null difference (Saveski, 1980). When the transmitted spectrum is much less than the null separation given by equation (8), as is the case with the demonstrations discussed in this report, the channel appears as a flat fading channel with up to 40 dB, as computed by equation (9), of *RSL* fluctuations depending on the sea state.

Figure 15 displays a nomogram for computing the maximum fade rate for a moving vehicle on land (Casas & Leung, 1988); for example, assume that a vehicle is traveling at 50 km/h (27 knots) and transmitting at 300-MHz carrier frequency to a stationary receiver. By drawing a line between known values in figure 15, a worst case fade rate of about 13 Hz is predicted. The authors are unaware of a similar nomogram for moving vehicles in the maritime environment, but it is expected to be similar. One clear advantage of the 225- to 400-MHz UHF band with respect to higher frequencies is the reduced fade rate.

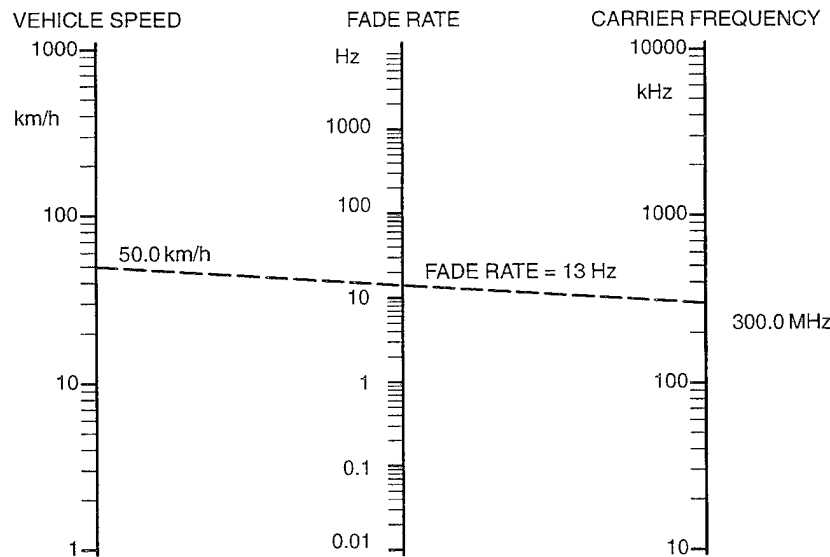


Figure 15. Example of a nomogram showing the relationship between terrestrial vehicle speed, maximum fade rate, and carrier frequency (Casas & Leung, 1988).

3.2 LINK BUDGETS AND ESTIMATED RELIABLE COMMUNICATION RANGES

The primary means for maintaining a reliable communication link, when the fading is flat and a single, omnidirectional antenna is being used, is to increase the fade margin. This is discussed at some length for terrestrial, LOS, digital links in Brockel (1991). The amount of fade margin required for a given reliability is determined by the severity of the fading. In Brockel (1991), the terrestrial environment for San Diego is described as “difficult” due to the influence of the ocean with the atmosphere. The corresponding approximate fade margins required to maintain a given reliability are plotted in figure 16. The authors are unaware of a corresponding plot for any maritime LOS environments; however, one might expect that the fading could be equal to or *worse* than a “very difficult” terrestrial environment that is plotted in figure 17. Using figures 16 and 17, it can be seen that a minimum fade margin of 5 to 15 dB is required to maintain a reliable communication link at a useful range.

To estimate reliable communication ranges, it is necessary to compute link budget calculations. For 1.544 Mbps (T1), these are tabulated in table 4 for uncoded, QPSK, and table 5 for the rate 239/256 Reed–Solomon and rate 3/4 Viterbi coded QPSK. Propagation loss information comes from figure 10. Two fade margins, 5 and 15 dB, are used in the calculations to give a best-case range estimate and a more conservative range estimate. Figure 18 plots the estimated ranges for the three LOS links considered in this report as a function of data rate using similar calculations. A fixed-fade margin of 15 dB is used in these first-order approximations. A more accurate estimate would include a fade margin that increases with distance as determined by figures 16 and 17. Figure 18 clearly shows that the advantages of lower data rates and higher antennas result in an increased range of reliable communication. *The effects of co-channel and adjacent channel interference are not included in these estimates*, but are typically an important factor in limiting reliable communication ranges.

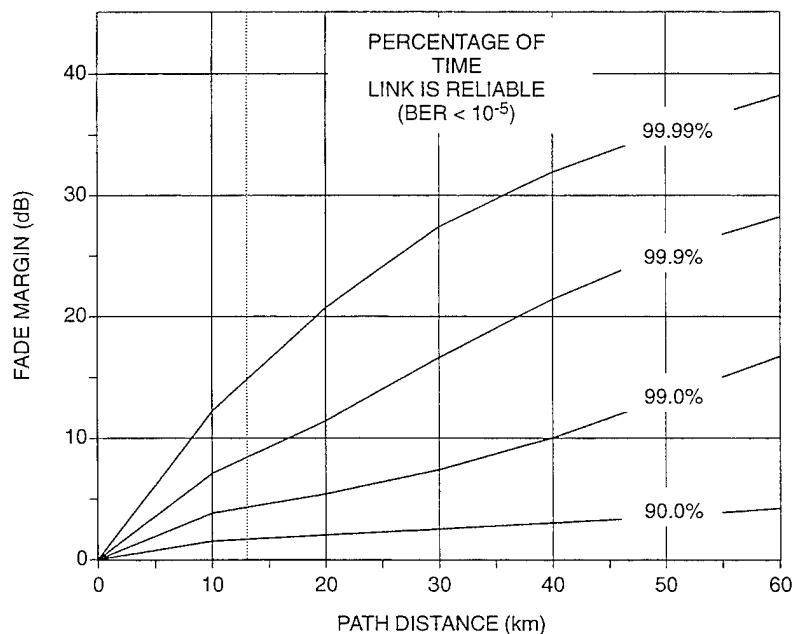


Figure 16. Approximate fade margins required for a “difficult” terrestrial, LOS link with flat fading. The path distance is assumed to be within the radio horizon, and the carrier frequency is 300 MHz. (Data from table 6-1 of Brockel, 1991)

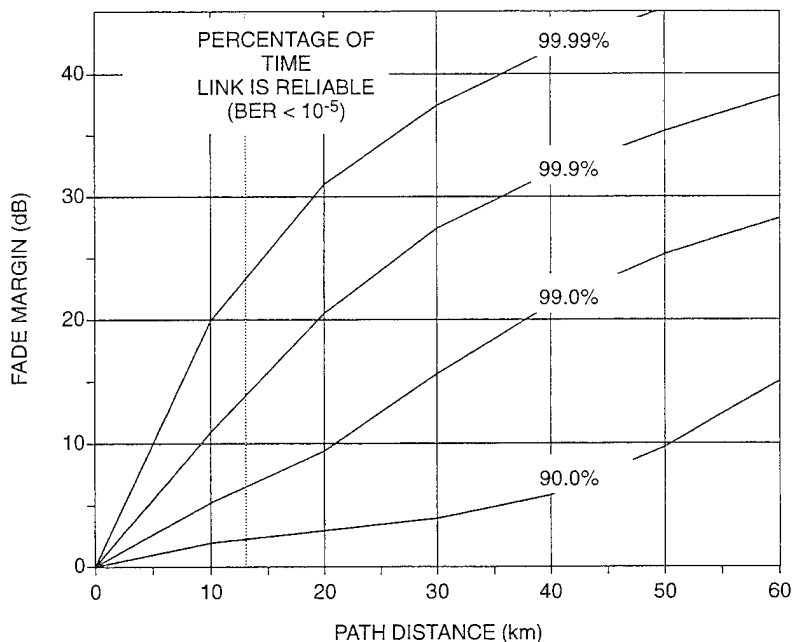


Figure 17. Approximate fade margins required for a “very difficult” terrestrial, LOS link with flat fading. The path distance is assumed to be within the radio horizon, and the carrier frequency is 300 MHz. (Data from table 6-1 of Brockel, 1991)

Table 4. Link budget for a T1 (1.544 Mbps), uncoded QPSK signal.

Modulation	uncoded QPSK
Data rate/symbol rate	1.544 Mbps/772 ksps
Power amplifier output	+49.0 dBm/80 W
OA-9123 Filter loss (900-kHz, 3-dB BW)	-2.0 dB
EST. Cable loss (20-ft RG214; 100-ft Heliac)	-2.5 dB
Approx. Transmit power	+44.5 dBm/28.2 W
Minimum <i>RSL</i> for BER=10 ⁻⁶	-82 dBm
EST. Cable loss (20-ft RG214; 100-ft Heliac)	-2.5 dB
OA/9123 Filter loss (900-kHz, 3-dB BW)	-2.0 dB
Fade margin	-15.0 -> -5.0 dB
Max. propagation loss	107 -> 117 dB
EST. Range ship-to-ship	14 km (7.6 nmi) -> 22 km (11.9 nmi)
EST. Range ship-to-NRaD	18.5 km (10.0 nmi) -> 35 km (18.9 nmi)
EST. Range ship-to-S.C. Island	20 km (10.8 nmi) -> 45 km (24.3 nmi)

Table 5. Link budget for a T1 (1.544 Mbps), rate 239/256 Reed–Solomon and a rate 3/4 Viterbi coded QPSK signal.

Modulation	rate 2539/256 R-S, rate 3/4 Viterbi QPSK
Data rate/symbol rate	1.544 Mbps/1.544 Msps
Power amplifier output	+49.0 dBm/80 W
OA–9123 Filter loss (900-kHz 3-dB BW)	–2.0 dB
EST. Cable loss (20-ft RG214, 100-ft Heliac)	–2.5 dB
Approx. transmit power	+44.5 dBm/28.2 W
Minimum <i>RSL</i> for BER=10 ^{–6}	–102 dBm
EST. Cable loss (20-ft RG214; 100-ft Heliac)	–2.5 dB
OA/9123 Filter loss (900-kHz, 3-dB BW)	–2.0 dB
Fade margin	–15.0 -> –5.0 dB
Max. propagation loss	127 -> 137 dB
EST. Range ship-to-ship	32 km (17.3 nmi) -> 42 km (22.9 nmi)
EST. Range ship-to-NRaD	48 km (25.9 nmi) -> 90 km (48.6 nmi)
EST. Range ship-to-S.C. Island	83 km (44.8 nmi) ->

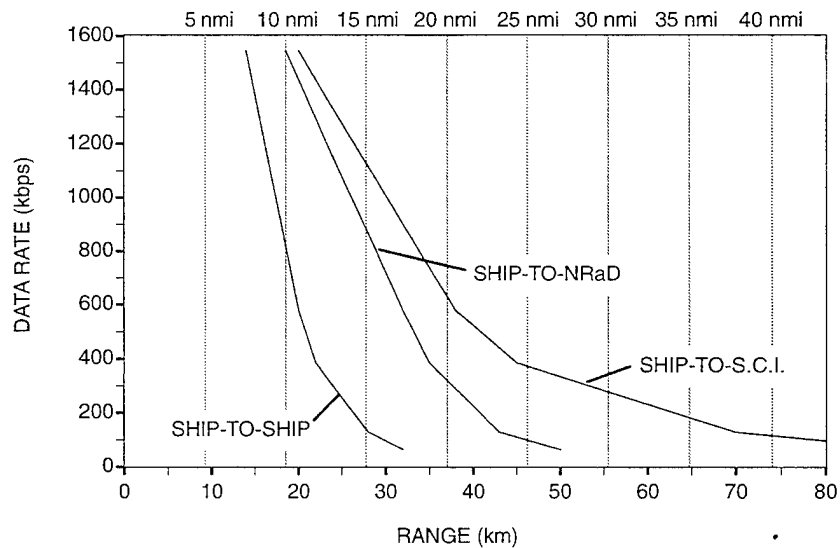


Figure 18. Estimated range for an uncoded QPSK signal with a fade margin of 15 dB, carrier frequency of 300 MHz, and standard propagation conditions (i.e., $K=4/3$). Estimates based on a minimum *RSL* = –82 dBm for BER = 10^{–6}.

Several steps can be taken to increase the ranges: (1) use antennas as high on the ship as possible to reduce diffraction losses; (2) use transmit and receive frequencies as low as possible in the UHF band (close to 225 MHz) to reduce propagation losses and reduce fade rates; (3) use the narrowband OA–9123 antenna couplers with transmit and receive frequencies at least 8 MHz apart to minimize adjacent channel frequency interference from your own transmitter (see figure 19); (4) select frequency bands that are clear of interference; (5) minimize cable losses in the transmitting and receiving RF paths, (6) assure that the antenna coupler and antenna have low VSWRs to maximize the radiated

power; (7) select an antenna that has as much gain as possible; (8) get as much gain as possible from the forward error-correcting codes; (9) reduce data rate, if possible, and (10) increase transmit power.

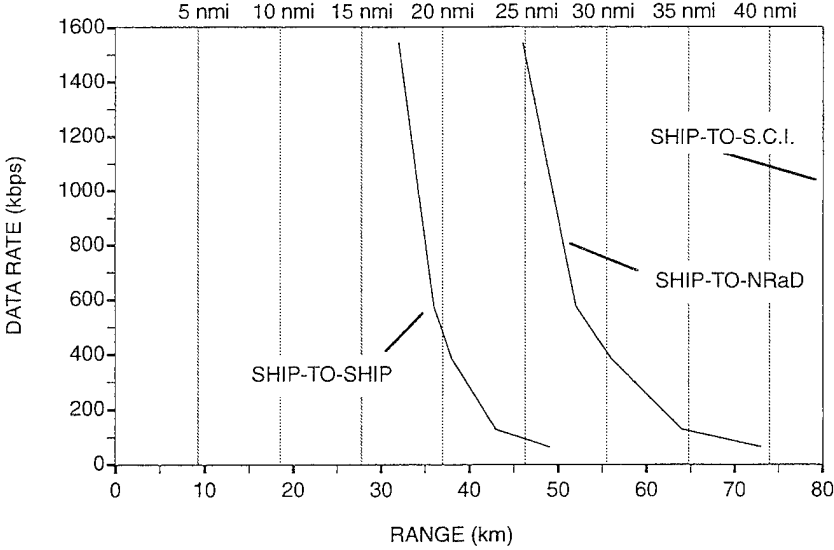


Figure 19. Estimated range for a rate 239/256 Reed–Solomon and rate 3/4 Viterbi coded QPSK signal with a fade margin of 15 dB, carrier frequency of 300 MHz, and standard propagation conditions (i.e., $K=4/3$). Estimates based on a minimum $RSL = -102$ dBm for $BER = 10^{-6}$.

4. USS *RENTZ* AND USS *ABRAHAM LINCOLN* BATTLE GROUP DEMONSTRATIONS

4.1 TEST OVERVIEW AND OBJECTIVES

The USS *Rentz* and the USS *Abraham Lincoln* Battle Group demonstrations were initiated by LT Richard Stakelum, USN, of Commander Destroyer Squadron 33 and by Commander Naval Surface Forces Pacific (CNSP). The demonstrations were funded by PMS 400ED3 with the intent to extend high-quality, 384-kbps video teleconferencing (VTC), ethernet data link, and voice between ships at sea and back to shore through an HDR commercial SATCOM link. (Refer to Appendix A for a discussion of an extension of the demonstrations reported here.) Figure 20 shows a block diagram of the instruments and their interconnections supporting these applications.

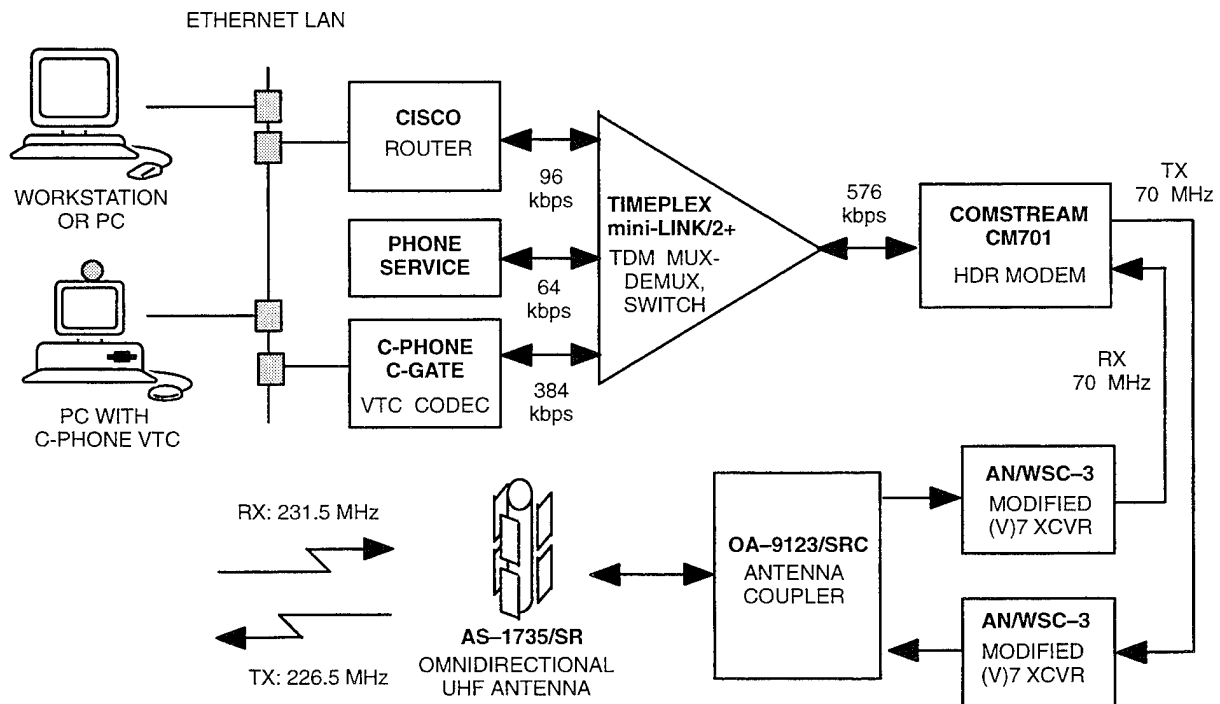


Figure 20. Instrumentation required to support the 576-kbps intership radio links with the HDR UHF LOS communication system.

In a series of experiments beginning in August 1994, the USS *Rentz* (FFG-46) and crew played the primary role as the vehicle for working the bugs out of both the HDR UHF LOS link and a HDR, Ku-band, commercial SATCOM link. Both the LOS and the SATCOM systems are now considered as reliable prototypes, and as such, they will be undergoing more extensive testing during deployment. The USS *Rentz* was originally scheduled to be deployed with the USS *Abraham Lincoln* Battle Group, but was reassigned to a different deployment at the last minute. As a result, the USS *Rentz* deployed in March 1995 with only a Ku-band HDR SATCOM system as shown in figure 21. This will allow the USS *Rentz* to establish a ship-to-shore connection to NRaD, San Diego. The discussion of the SATCOM system is beyond the scope of this report.

In April 1995, the USS *Princeton* (CG-59), the USS *John Paul Jones* (DDG-53), and the USS *Abraham Lincoln* (CVN-72) were each deployed with a single HDR UHF LOS communication system as depicted in figures 20 and 22. This allows for one full-duplex link to be operational at a single

time. Thus, any two ships can be communicating at any one time. The aggregate data rate on the HDR UHF LOS communication links was reduced to 256 kbps for better BER performance by eliminating the router channel (also easing funding constraints by eliminating the purchase of routers) and by reducing the VTC channel to 128 kbps (2 x 64 kbps). The USS *Abraham Lincoln* has several SATCOM assets in operation including the SHF QUICKSAT/NAVTACNET and the SPRINT operated "sailor phone". Technically, it is a simple operation to route LOS channels through the NAVTACNET because both the SHF SATCOM and the LOS links share the same Timeplex multiplexer. (Note that the Timeplex LINK/2+ family of multiplexers performs a variety of functions, including, multiplexing channels into an aggregate data link, demultiplexing channels out of an aggregate data link, and switching channels from one aggregate data link to another aggregate data link.) However, bandwidth on the NAVTACNET is typically limited from 64 to 256 kbps. The USS *Abraham Lincoln* also sailed with the capability to expand the bandwidth of the SPRINT "sailor phone" if the proper details are worked out while the ships are deployed. (This was accomplished in September of FY 95 and is described in Appendix A.)

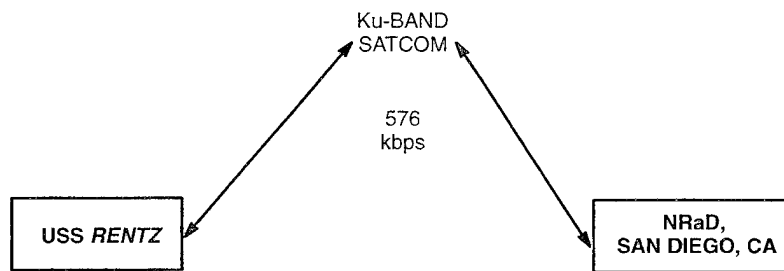


Figure 21. HDR SATCOM link capability deployed with the USS *Rentz* in March 1995.

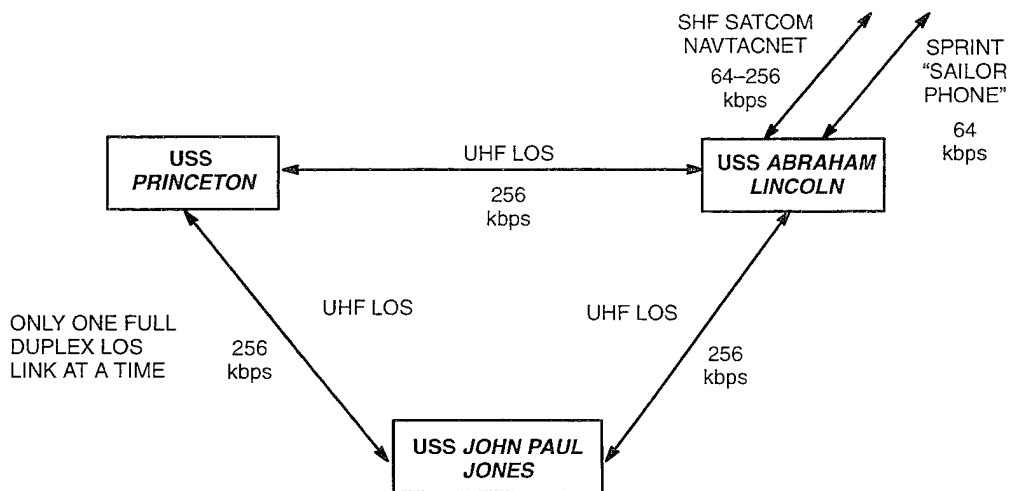


Figure 22. HDR LOS links deployed with the USS *Abraham Lincoln* Battle Group in April 1995.

4.2 SHIPBOARD VTC NETWORK

The VTC system deployed on the USS *Rentz* is illustrated in figure 23. It is a PC-based unit called *C-Phone* made by TwinCom, Wilmington, North Carolina, with supporting software made by TRW Avionics and Surveillance Group, Midwest City, Oklahoma. The system allows for up to 64 nodes to be connected within each analog video LAN and supports full-motion, analog video teleconferencing

(NTSC format) within the analog video LAN (standard 75-ohm TV cable). All analog video communications are set up and initiated using the ethernet LAN, the so-called "signaling channel". With this system, each ship is required to have both an analog video LAN and an ethernet LAN to support the C-Phone VTC system.

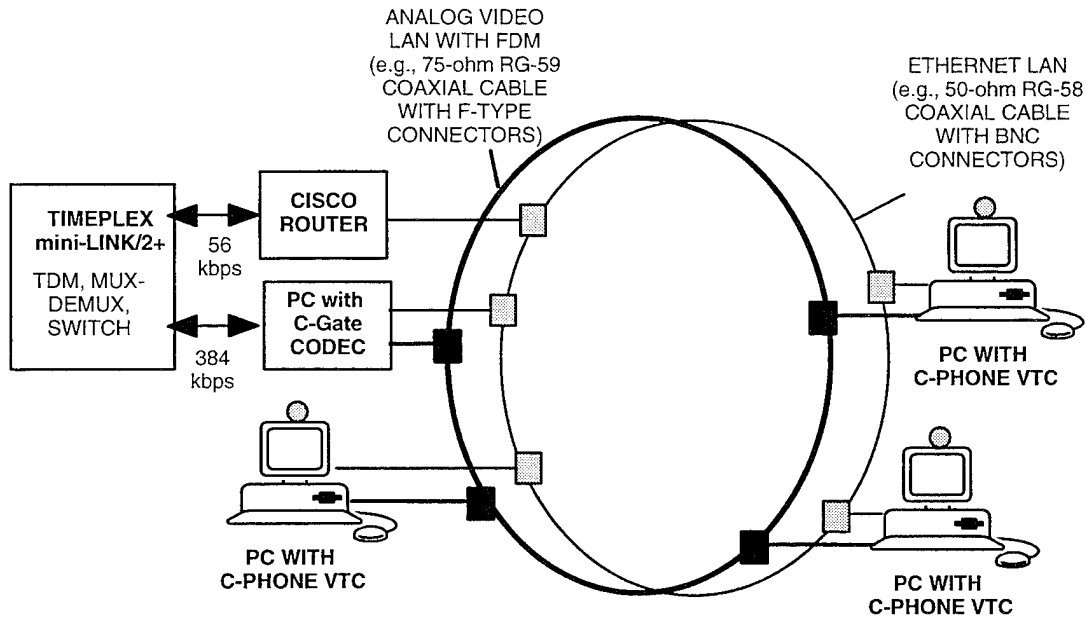


Figure 23. Shipboard, C-Phone, analog video teleconferencing system and its digitization hardware deployed on the USS *Rentz*.

The USS *Abraham Lincoln* Battle Group deployed with an improved C-Phone system that integrates the analog video LAN into a standard 50-ohm ethernet LAN. With the new system, frequency-division multiplexing (FDM) is used within the ethernet cable to keep the video traffic separate from the normal ethernet traffic.

The C-Phone system supports the H.320 codec standard so it can communicate with other VTC systems that also support the H.320 codec standard (like the CLI Rembrant system frequently used within the Defense Commercial Telecommunications Network [DCTN] or PictureTel). One of the nice features of the C-Phone VTC System is that it can accept any other analog video input that is in the NTSC video standard format; for example, a hand-held camcorder could be wired into a C-Phone node to transmit live, full-motion video to any other node in the analog video LAN, or its output could be digitized and transmitted to another ship or shore installation. This opens the door to all kinds of possible system applications.

4.3 HDR UHF LOS COMMUNICATIONS INSTRUMENTS

Figure 20 shows the basic instruments used in all demonstrations. The USS *Princeton*, USS *John Paul Jones*, and USS *Abraham Lincoln* were deployed without routers because of funding limitations. Thus, data transfers must be completed by other means, such as using standard phone modems on a voice channel or through the VTC. The H.320 VTC codec and voice channels were time-division multiplexed (TDM) by a Timeplex miniLINK/2+ into a 256-kbps, full-duplex, aggregate data stream. Up to four separate voice channels, each at 64 kbps, 16 kbps, or 8 kbps were possible with the hardware supplied (a single FXS/NTM voice card). The 256-kbps data rate supported either a 128-kbps (2 x 64 kbps) VTC channel plus 96 kbps of voice or a 192-kbps (3 x 64 kbps) VTC channel

plus 32 kbps of voice. The flexibility of the system allows the specific channel configurations to be determined by the ships depending upon their needs at a given time.

The 256-kbps, Timeplex multiplexer output data stream fed a Comstream CM701 modem on the USS *Princeton* and USS *John Paul Jones* and a ComQuest 248a modem on the USS *Abraham Lincoln*. The ComQuest 248a modem is an enhanced version of the Comstream CM701 modem used in the SHF QUICKSAT/NAVTACNET installations. These two modems are compatible and interchangeable when configured as described in this report. The CM701 and CQM248a modems output and input a 70-MHz IF carrier signal. The modulated transmit or receive IF signals were upconverted or downconverted by AN/WSC-3 transceivers modified by NRaD to allow HDR communications (see section 2.1). Both transmit and receive RF signals were filtered by the OA-9123 antenna coupler which was connected to standard shipboard omnidirectional UHF LOS antennas. The USS *Princeton* and the USS *John Paul Jones* were able to utilize two unused channels in existing OA-9123 antenna couplers. These OA-9123 antenna couplers fed AS-1735 omnidirectional UHF antennas located high on top of the main mast. The USS *Abraham Lincoln* used an AS-390 omnidirectional UHF antenna originally installed for a HAVEQUICK modified AN/WSC-3 radio. Its location was believed to provide good omnidirectional coverage, but this should be verified at a later date because many of the UHF LOS antennas on the USS *Abraham Lincoln* seemed to have partially obstructed LOS views. The USS *Abraham Lincoln* did not have unused channels in its existing OA-9123 antenna couplers, so an extra OA-9123 coupler was installed for the HDR UHF LOS communication system. Another unique feature of the USS *Abraham Lincoln* installation was the 400-ft separation between the Timeplex multiplexer and the CQM248a modem that required an extremely long cable run of the 12 shielded, twisted-pair cable.

Tables 6 and 7 list the configuration parameters of the Timeplex multiplexer and the CM701 modem, respectively. The QPSK modulation was used with a concatenated forward error-correcting code scheme using a rate 239/256 Reed-Solomon block outer code and a rate 3/4 convolutional inner code. This resulted in a 1.4 bps/Hz spectral efficiency; thus, the 256-kbps data rate was transmitted at a 182.806-kbps symbol rate that required a 3-dB bandwidth of about 183 kHz.

During the first few weeks of deployment, the system timing changed from a looped-timed system (similar to that used during the Kernel Blitz demonstration described in Section 5.3) to an independently timed system. The timing change was a result of excessive reacquisition time required by the Timeplex multiplexer after the ships came within LOS range. The CM701 or CQM248a modem at each ship provide an internal clock for its transmitted data bits with independently timed nodes. This same clock is used to clock the received data out of the modem buffer, and therefore, the Timeplex is always connected to a synchronous data channel (receive clock rate is equal to transmit clock rate), regardless of the status of the LOS link. The problem with this timing configuration is that the buffers will eventually overflow because the transmit clocks from each ship remain slightly different from one another. A buffer overflow or underflow causes a glitch in the VTC channel, thus requiring that a C-phone, VTC connection should be reinitialized. This is not noticed by voice channels. The rate of the buffer overflows or underflows is a function of the accuracy of the modem's internal clocks and buffer size. Laboratory tests with a 2048-bit buffer size show that the buffer overflowed or underflowed at a rate of once every 4 to 5 hours. In addition, the 2048-bit buffer created an additional 8-msec delay in the data link when transmitting at a data rate of 256 kbps. The accuracy of the data clock can be enhanced with the addition of a ComQuest-manufactured, high stability, clock card to the CM701 or CQM248a modem or the addition of station timing to the Timeplex multiplexer. This will allow for both a decrease in buffer size and a reduction in the buffer overflow or underflow rate.

Table 6. Timeplex multiplexer configuration for USS *Abraham Lincoln*, USS *Princeton*, and USS *John Paul Jones*.

Function	USS <i>Abraham Lincoln</i> (LINK/2+ 1 nest)	USS <i>Princeton</i> (miniLINK/2+)	USS <i>John Paul Jones</i> (miniLINK/2+)
NCL/System	v.9	v.11	v.11
Node identification number	172	113	114
System connect retry	02	00	00
ILC out-of-service timer	08	16	16
System maximum phasor size	14	14	14
Clock fallback list	dlr 3 , dit 3 , skp	dri 3, skp , skp	dri 3, skp , skp
Clock qualification tolerance	N/A	Hi	Hi
Clock switching option	N/A	Quick	Quick
ILC.2 (LOS data)	slot 7	slot 3	slot 3
Data rate	256 kbps	256 kbps	256 kbps
Source of Tx Clock	SND	SND	SND
Line driver	EXT	EXT	EXT
Frame mode	02	02	02
Satellite buffer	none	none	none
ARQ	3200	3200	3200
Sync characters and level	08/L1	08/L1	08/L1
Master/slave	Slave	Master/slave	Master
Subrate multiplexing	NO	NO	NO
Group assignment	1234567	1234567	1234567
Logical node translation	off	off	off
Link framing module	none	none	none
Out-of-service timer	SYS	SYS	SYS
QSP.2 (VTC channel)	slot 9:1	slot 5:1	slot 5:1
Originator/terminator	terminator	originator/terminator	originator
Data rate	128 kbps	128 kbps	128 kbps
ABM profile	default	default	default
Connect priority	01	01	01
Delay threshold	07	07	07
Interface type	DCE	DCE	DCE
Mode of transporting EIA	outband	outband	outband
Phasor size	MX	MX	MX
CTS generation	trans	trans	trans
Connection type	off	off	off
Out-of-service operation	mark	mark	mark
Military interface	D-B, F-B	D-B, F-B	D-B, F-B
Polarity	D-N, F-N	D-N, F-N	D-N, F-N
Special features	none	none	none
DSR control	ON	ON	ON

Table 6. Timeplex multiplexer configuration for USS *Abraham Lincoln*, USS *Princeton*, and USS *John Paul Jones*. (Continued)

Function	USS <i>Abraham Lincoln</i> (LINK/2+ 1 nest)	USS <i>Princeton</i> (miniLINK/2+)	USS <i>John Paul Jones</i> (miniLINK/2+)
FXS (voice service)	slot 17:1 or slot 18:1	slot 11:1	slot 11:1
Originator/terminator	terminator	originator/terminator	originator
ABM profile	default	default	default
Speed	64 kbps	64 kbps	64 kbps
Connection priority	01	01	01
Delay threshold	07	07	07
Phasor size	08	08	08
Code law	mu-law	mu-law	mu-law
Ones density	off	off	off
A-bit filter/ B-bit filter	1	1	1
Out-of-service operation	force busy	force busy	force busy
Echo canceler	enable, 32 msec	enable, 32 msec	enable, 32 msec
Center clipper	enable	enable	enable
Tone disable	on	on	on
Single frequency signalling	none	none	none
Transmit TLP	-5 dBm	-5 dBm	-5 dBm
Receive TLP	-5 dBm	-5 dBm	-5 dBm
Impedance	600 ohms	600 ohms	600 ohms
Loop start or ground start	loop start/ auto ringdown	loop start/ auto ringdown	loop start / auto ringdown

Table 7. Modem configuration for USS *Abraham Lincoln*, USS *Princeton*, and USS *John Paul Jones*.

Function	USS <i>Abraham Lincoln</i> (CQM248)	USS <i>Princeton</i> (CM701)	USS <i>John Paul Jones</i> (CM701)
5: R-S Coder /Interleaver			
R-S loopback	disable	disable	disable
R-S Bypass	off	off	off
Deinterleave depth	16	16	16
Interleave depth	16	16	16
Dec data bytes	239	239	239
Enc data bytes	239	239	239
Rx IN	274209 bps	274209 bps	274209 bps
Rx OUT	256000 bps	256000 bps	256000 bps
Tx OUT	274209 bps	274209 bps	274209 bps
Tx IN	256000 bps	256000 bps	256000 bps
6: Demod			
RxDataRate	274209 bps	274209 bps	274209 bps

Table 7. Modem configuration for USS *Abraham Lincoln*, USS *Princeton*, and USS *John Paul Jones*. (Continued)

Function	USS <i>Abraham Lincoln</i> (CQM248)	USS <i>Princeton</i> (CM701)	USS <i>John Paul Jones</i> (CM701)
Rx Scrambling	CMSTR-RS	CMSTR-RS	CMSTR-RS
Acquisition	normal	normal	normal
RxFilterType	CMSTRM	CMSTRM	CMSTRM
RxDiffDecode	on	on	on
RxModType	QPSK	QPSK	QPSK
RxCodeType	Vit. 3/4	Vit. 3/4	Vit. 3/4
RxSymRate	182806 sps	182806 sps	182806 sps
Rx Freq.	70000.000 kHz	70000.000 kHz	70000.000 kHz
7: Mod			
TxDataRate	274209 bps	274209 bps	274209 bps
Tx Scrambling	CMSTR-RS	CMSTR-RS	CMSTR-RS
TxClockSource	Int	Int	Int
TxPureCarrier	off	off	off
TxPowerLevel	-5.0 dBm	-5.0 dBm	-5.0 dBm
TxFilterType	CMSTRM	CMSTRM	CMSTRM
TxDiffDecode	on	on	on
TxModType	QPSK	QPSK	QPSK
TxCodeType	Vit. 3/4	Vit. 3/4	Vit. 3/4
TxSymRate	182806 sps	182806 sps	182806 sps
Tx Freq.	70000.000 kHz	70000.000 kHz	70000.000 kHz
3: BUFFER			
Bufr Size(Bits)	2048	2048	2048
Buffer	reset	reset	reset
Buffer Mode	buffer	buffer	buffer
Buffer Clk Sel	IntClk	IntClk	IntClk
1: CLK REF			
Reference Option	off	on	n/a
Reference Source	ext	int	n/a
CM701 timing:			
ML	0 (term timing)	0 (term timing)	0 (term timing)

4.4 TEST RESULTS AND LESSONS LEARNED

Numerous experiments have been conducted in FY 94 and FY 95 during the development of the Phase 1 and Phase 2 HDR UHF LOS communication instruments. Many of these experiments are described in North, Bryan and Axford, Jr. (1995) that provides a more detailed description of the evolution of the HDR UHF LOS communication instruments. This report concentrates on the Phase 1 instruments which are based on a modified AN/WSC-3 UHF transceiver.

Two preliminary experiments were conducted on board the USS *Rentz* to help debug shipboard integration issues. The first experiment was conducted from 23 to 27 January 1995. The purpose

was to verify that the HDR UHF LOS transmitter would not interfere with existing communications or any other electronic instruments. The instruments installed on the USS *Rentz* included a Bit-Error-Rate Tester (BERT), a CM701 modem, and an AN/WSC-3(V)15 transceiver configured as a transmitter. A spare filter on the ship's OA-9123 antenna coupler was used as a narrowband RF filter. The system continuously transmitted a $2^{15}-1$ pseudo-random noise (PN) sequence at a data rate of 576 kbps using uncoded BPSK modulation during the 5-day deployment. While the HDR UHF LOS communication system was found not to interfere with any existing systems, a VSWR cutoff problem was uncovered in the modification to the transmitter module of the AN/WSC-3(V)15. Essentially, the original 100-pF capacitor used for decreasing the sensitivity of the VSWR detection circuitry was found to be too small a value (refer to section 2.1), and this limited the transmitter power to about 20 Watts during this experiment. Laboratory measurements conducted later, found that a capacitor value of 1000 pF allowed for the full 100 Watts to be transmitted. This is the value used in the present transmitter module modification, and it has apparently solved the VSWR cutoff problem.

The second experiment was conducted from 13 to 16 February 1995 to test a ship-to-ship HDR UHF LOS data link. The same equipment, as was tested on 23 January 1995, was installed on the USS *Rentz*, except for the transmitter module that was modified to allow the full 100 Watts to be transmitted. The USS *John Paul Jones* was installed with a BERT, a CM701 modem, and both transmit and receive AN/WSC-3(V)15 transceivers. The USS *Rentz* continuously transmitted a 576-kbps, PN sequence with the concatenated rate 239/256 Reed-Solomon outer code and the rate 3/4 Viterbi inner code with QPSK modulation. This signal was received by the USS *John Paul Jones* and the BER performance was recorded. In addition, the USS *John Paul Jones* was continuously transmitting a 576-kbps, data rate signal to simulate a full-duplex, EMI environment. The test was very successful, with the exception that the Global Positioning System (GPS) recording device failed to log the ship position from which accurate range information could be extracted. Neither ship observed any interference or reduced performance as a result of the HDR UHF LOS transmissions. On several occasions, error-free operation was recorded over time spans lasting several hours. Synchronization losses and BERs worse than 10^{-6} were frequently recorded at ranges beyond approximately 15 nmi. These test results suggest that the maximum LOS range between ships, transmitting a 576-kbps signal with this system, is about 15 nmi. This value falls about 4 nmi short of the value predicted by figure 19.

The test results and lessons learned from these two experiments were critical to the successes in the USS *Abraham Lincoln* Battle Group that deployed on 11 April 1995 for 6 months. Due to various reasons, installations on all three ships were still being completed hours before deployment. In-port testing was conducted only between the USS *John Paul Jones* and the USS *Princeton* because these two ships are based in San Diego, while the USS *Abraham Lincoln's* home port is at the Alameda Naval Air Station, Alameda, California. Severe interference from Mexican radio stations and signal blockage by other pier-side ships made in-port testing difficult and somewhat unreliable. Needless to say, the first several weeks after deployment were spent debugging multiple problems that included a faulty C-phone codec and system timing problems; however, once these problems were solved, the HDR UHF LOS communication system provided a reliable data link at a rate of 256 kbps and a maximum range up to about 18 nmi. This value is consistent with previous tests between the USS *Rentz* and the USS *John Paul Jones*; the extra 3 nmi came from the reduction in data rate from 576 kbps to 256 kbps (resulting in an increase of 3.5 dB in the received E_b/N_0). This value also falls about 4 nmi short of the value predicted by figure 19. In the Indian Ocean, radio propagation conditions were ideal for UHF transmissions and maximum communication ranges of 26 nmi to 30 nmi were recorded on several occasions.

4.5 LAND-BASED SUPPORT

An extensive network of Timeplex multiplexers has been installed at shore sites within the last few years and it is continuing to evolve and be upgraded. Figure 24 shows a diagram of the intermachine links that presently exist in the NRaD Timeplex Multiplexer Network. Communication support to ships at sea is provided by any of the several SATCOM assets, including UHF DAMA, EHF, SHF X-band, or commercial SHF Ku-band, connected to the network. The commercial SHF Ku-band terminal was used to support connectivity to the USS *Rentz*. Note that a channel was defined from the Timeplex node 82 to the Defense Commercial Telecommunications Network (DCTN). This allows any H.320-compatible, VTC channel (like the C-phone) in the Timeplex Network to be connected to any VTC center in the DCTN (over 240 worldwide locations). A ship at sea could therefore be connected into the DCTN for medical assistance, technical assistance, or for any other purposes. Additional medical assistance is available through a direct connection to the Balboa Naval Medical Center, San Diego, California. The difficulties in passing VTC signals over satellites are increased by the cost of the required bandwidth in commercial SATCOM systems and the lack of available bandwidth in many Naval SATCOM systems.

Figure 25 shows the intermachine links in the NAVTACNET Timeplex Multiplexer Network. This network is based on the SHF QUICKSAT SATCOM terminals that are being installed on most of the larger platforms. Note that the USS *Abraham Lincoln* is node number 172. The HDR UHF LOS data links provide the possibility of extending the NAVTACNET to other ships when they are within LOS range of a NAVTACNET-equipped ship. This RF networking was demonstrated on the USS *Princeton* by routing voice channels through the NAVTACNET port on the USS *Abraham Lincoln*. (Refer to Appendix A for other RF networking demonstrations.) Also note that the NRaD Timeplex network is connected to the NAVTACNET Timeplex network through NISE East Coast Detachment Norfolk, Shore Communications Laboratory, node 166.

4.6 DISCUSSIONS

The USS *Abraham Lincoln* Battle Group demonstrations were very successful having the benefit of many lessons learned from previous experiments and demonstrations. It provided a reliable 256-kbps data link for HDR ship-to-ship communication when the ships were within about a 18 nmi range. Most of the traffic was limited to voice and VTC. In the future, however, the addition of other serial services, such as ethernet, should be straightforward. While in the Indian Ocean, the USS *Princeton* demonstrated the extension of the SATCOM assets of the USS *Abraham Lincoln* by routing a 8-kbps voice channel through the HDR UHF LOS system from the USS *Princeton* to the USS *Abraham Lincoln*, and then through the NAVTACNET to a land-based Private Branch Exchange (PBX).

The USS *Abraham Lincoln* Battle Group demonstration proved that the Phase 1 HDR UHF LOS instruments could provide reliable HDR, ship-to-ship communication at modest ranges. Future evolution of the instruments should concentrate on extending the maximum range to the radio horizon (about 22 nmi). System timing issues seem to have been put to rest with independent timing of each modem. To further improve the timing performance, future modems should be equipped with the ComQuest, high stability, clock card, and station clocks should be used at the Timeplex multiplexer. Frequency management issues arose when multiple ships wanted to be operating at the same time. Future developments should strive to reduce the transmitted spectrum beyond the present 1.4 bps/Hz value and should develop a media access controller that automatically monitors and controls data

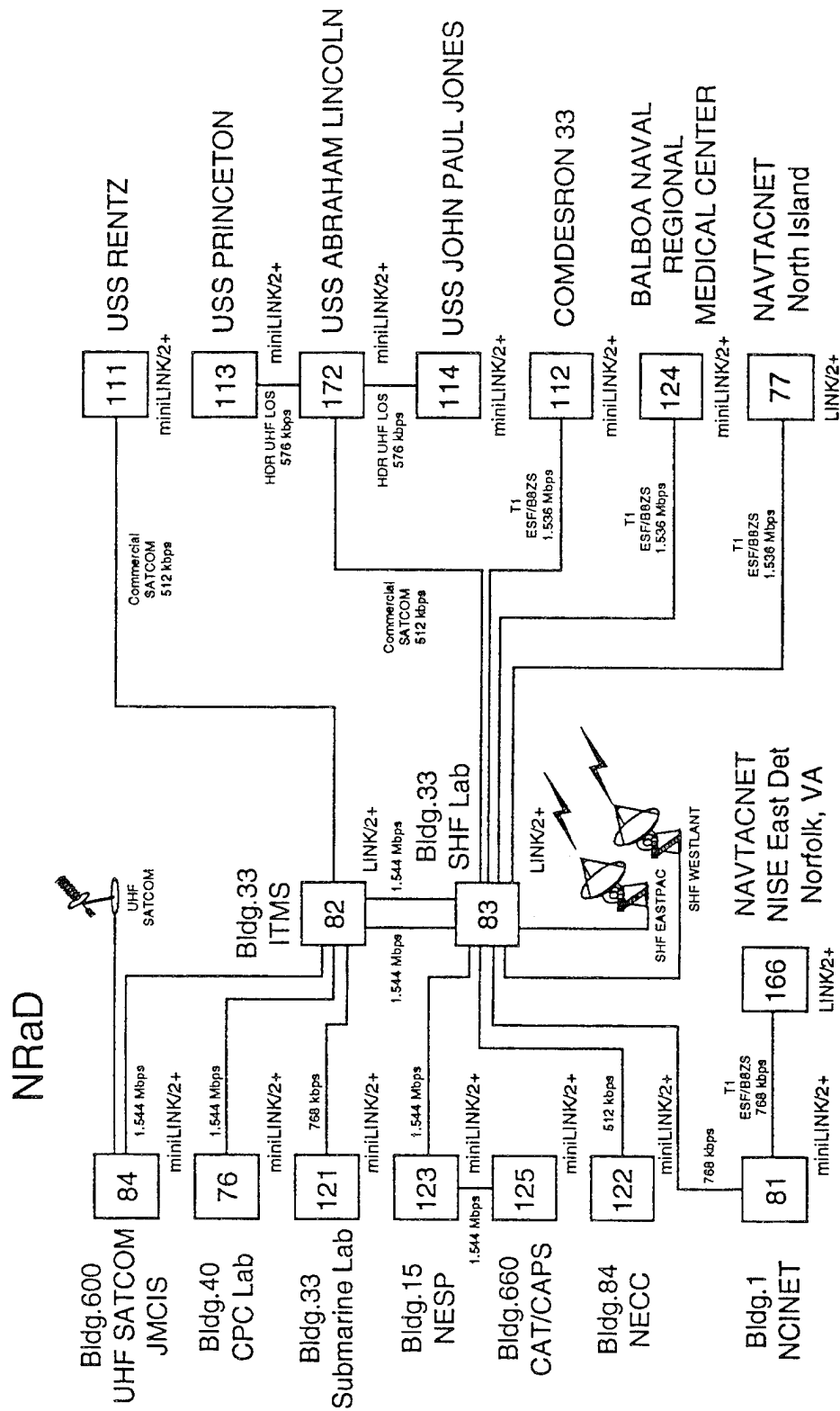


Figure 24 Intermachine links in the NRaD Timeplex Multiplex Network.

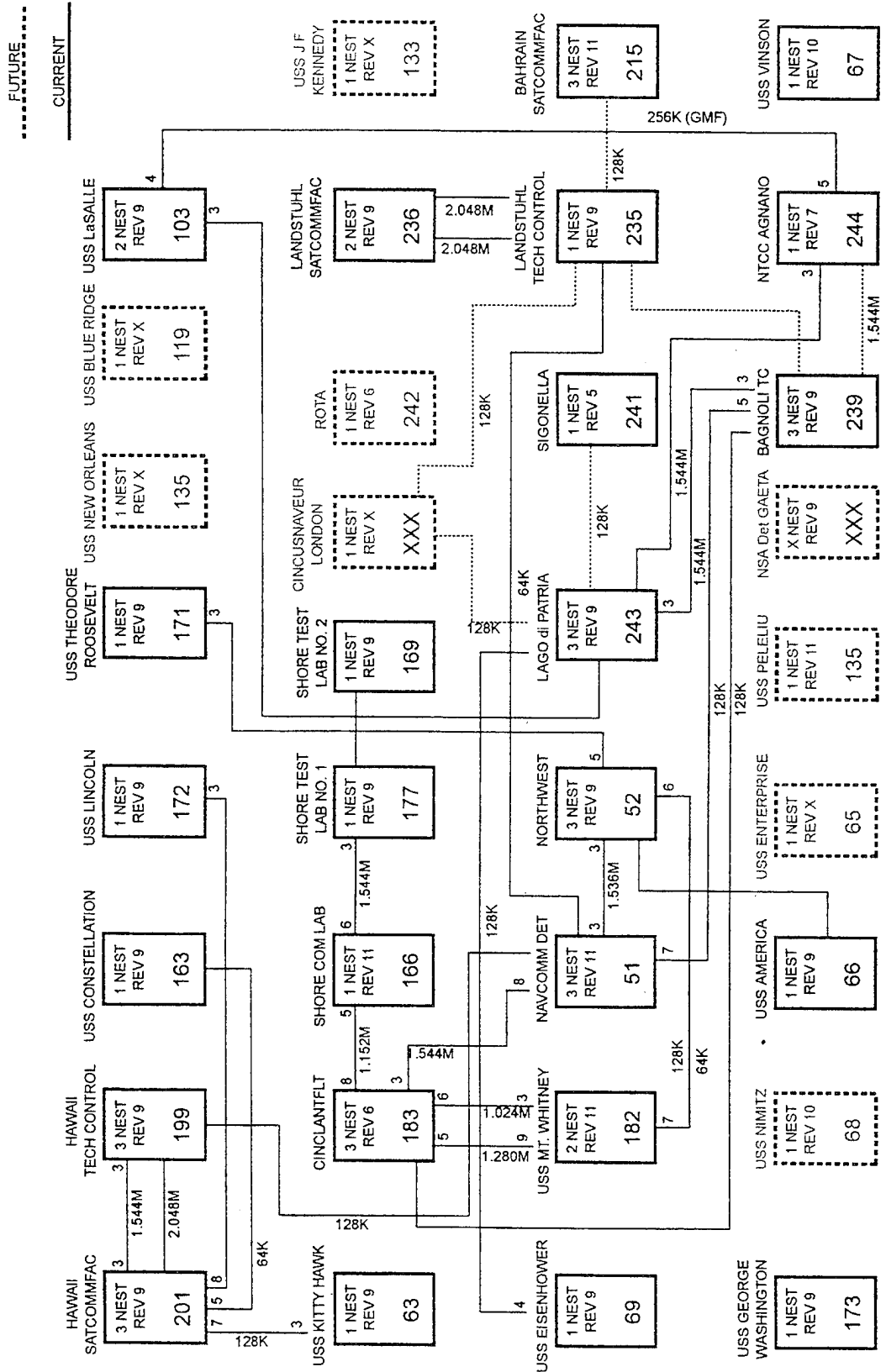


Figure 25. Intermachine NAVTACNET Timeplex Multiplex Network.

rates, transmit and receive frequencies, and transmit power. Integrating a media access controller into the C-phone, dial-up software would seem to make the most logical sense.

5. KERNEL BLITZ DEMONSTRATION

5.1 TEST OVERVIEW AND OBJECTIVES

The Kernel Blitz 95 demonstration was initiated by Ray Glass of NRaD and was funded by ARPA with the objective of providing both an HDR ethernet connection and a voice service between the USS *Peleliu* (LHA-5) and the shore communication sites. Applications written by Draper Labs were designed to access various shore-based databases using the Internet Protocol (IP) over the HDR UHF LOS communication link. The receive HDR UHF LOS instruments were installed in a High Mobility Manned Wheeled Vehicle (HMMWV), located on Mt. Thirst (1968 ft above sea level), San Clemente Island, as shown in figure 26. This location provided significantly better LOS coverage than did the secondary site at Camp Pendleton (100 ft above sea level) due to the higher elevation and to the expected navigational position of the USS *Peleliu* during the exercise. At San Clemente Island, the LOS data was time-division multiplexed with another Kernel Blitz demonstration being supported by FCTCPAC, and then the aggregate of the two data streams was “piggy-backed” on a DS3 (45 Mbps) microwave link, which was operated by FASCFAC, back to San Diego. The result was a 256-kbps ethernet connection from the USS *Peleliu* to the Internet and a 64-kbps voice channel from the USS *Peleliu* to the NRaD PBX for both data and voice access to the world.

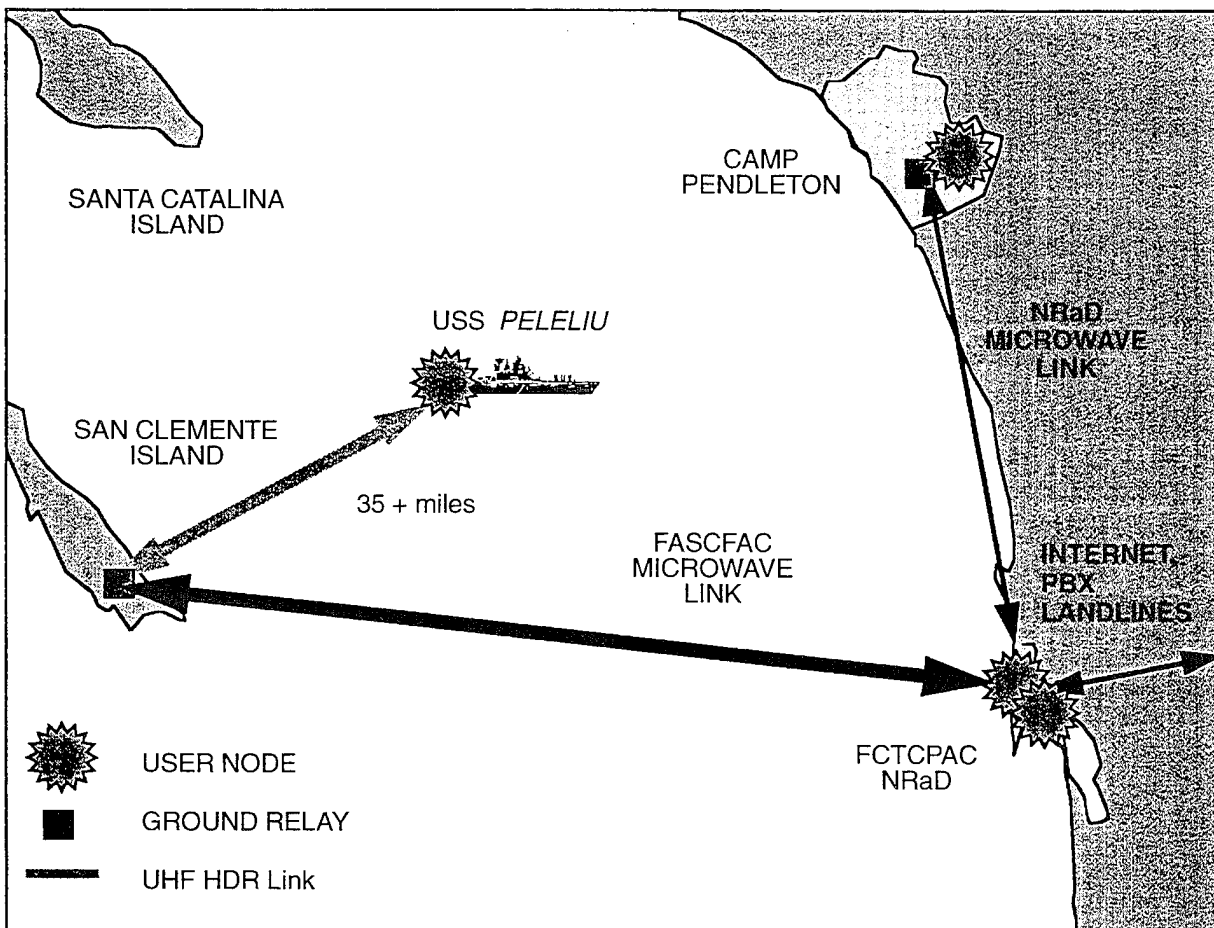


Figure 26. USS *Peleliu* ship-to-shore communication link during Kernel Blitz 95.

5.2 HDR UHF LOS COMMUNICATIONS INSTRUMENTS

Figure 27 shows a functional block diagram of the HDR UHF LOS communication instruments on the USS *Peleliu*, and figure 28 depicts the instruments required to support the HDR UHF LOS connection in the HMMWV located on San Clemente Island. Figures 29 and 30 show the HMMWV and the instruments sheltered by the HMMWV, respectively. The 256-kbps ethernet traffic, 64-kbps phone service, and a 32-kbps Bit-Error-Rate Tester (BERT) serial streams were time-division multiplexed by a Timeplex miniLINK/2+ into a 384-kbps, full-duplex, aggregate data stream. This aggregate data stream was fed to a Comstream CM701 modem whose 70-MHz IF output was upconverted, transmitted, and subsequently received and downconverted by AN/WSC-3 transceivers modified by NRaD to allow for high-data rate communications. (Refer to section 2.1.) The RF signal was transmitted through the OA-9123 antenna coupler to band-limit the broad band signal, then transmitted through standard shipboard omnidirectional UHF antennas. Two unused channels of an existing OA-9123 antenna coupler were used for the HDR UHF LOS communication demonstration to reduce the time and complexity of the shipboard installation. The Draper Labs applications were executed from a Sun Microsystems Voyager workstation that was installed in the USS *Peleliu*'s flag plot area and connected with a 200-ft, 50-ohm signal cable to the instruments located in the radio room. This equipment was operated 24 hours a day by three Draper Labs engineers for the duration of the Kernel Blitz exercise.

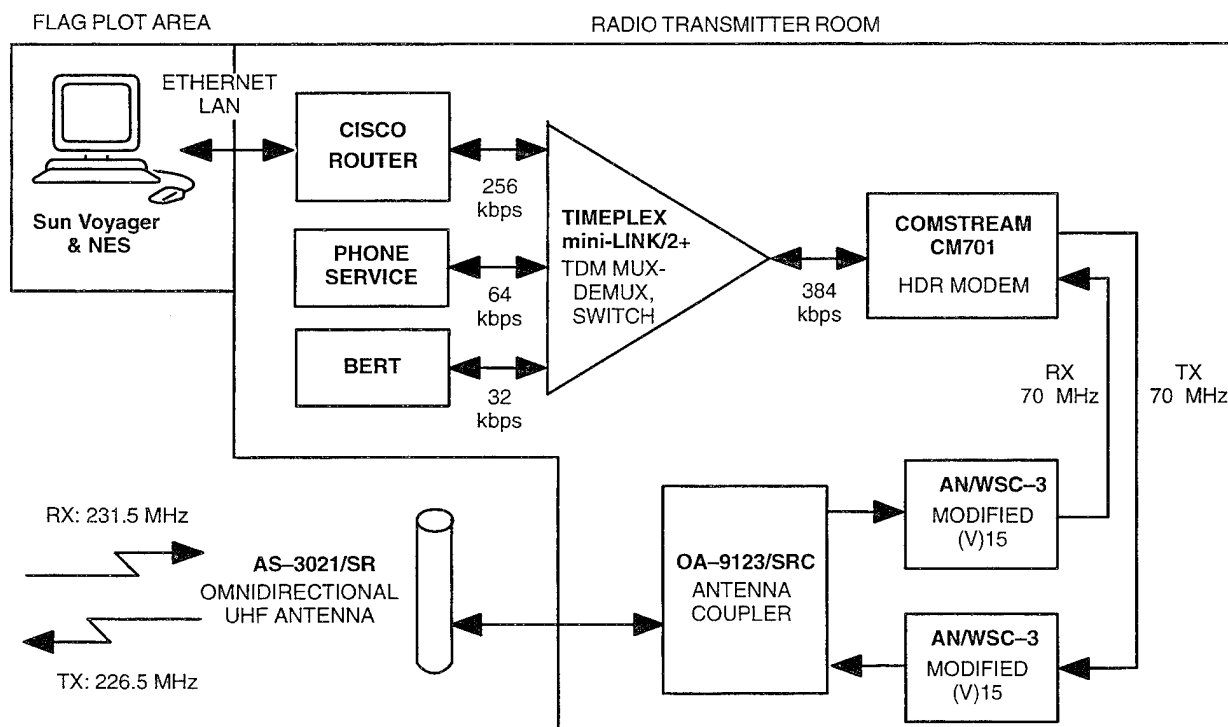


Figure 27. Instrumentation on the USS *Peleliu*.

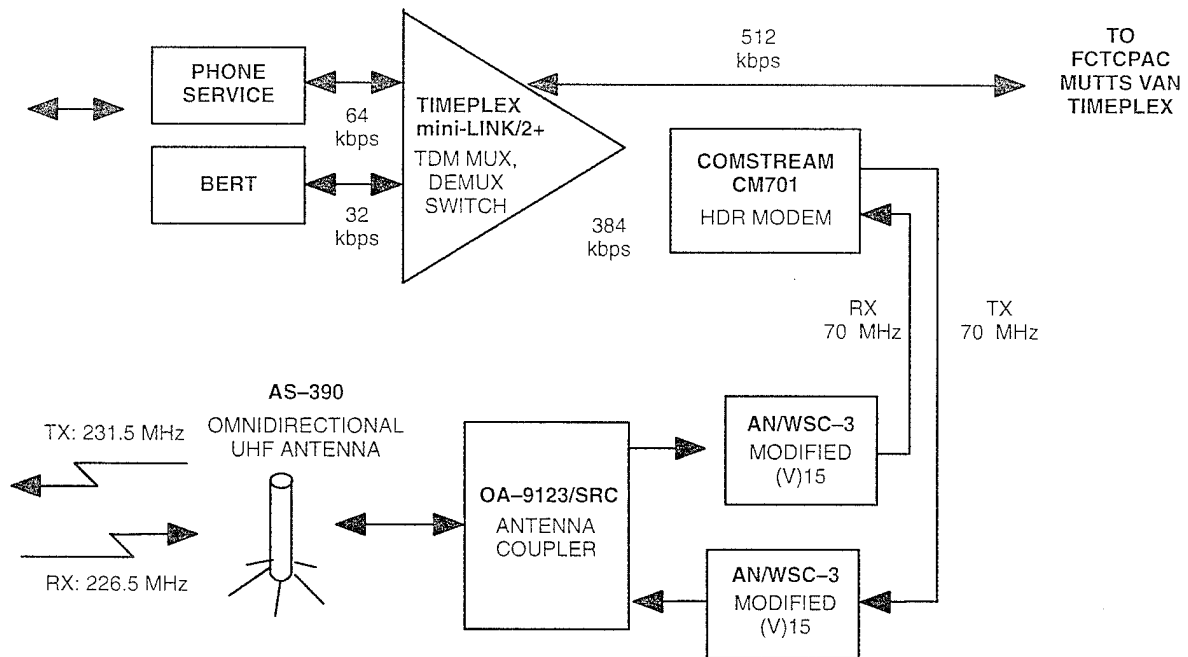


Figure 28. Instrumentation in the HMMWV located on Mt. Thirst, San Clemente Island.

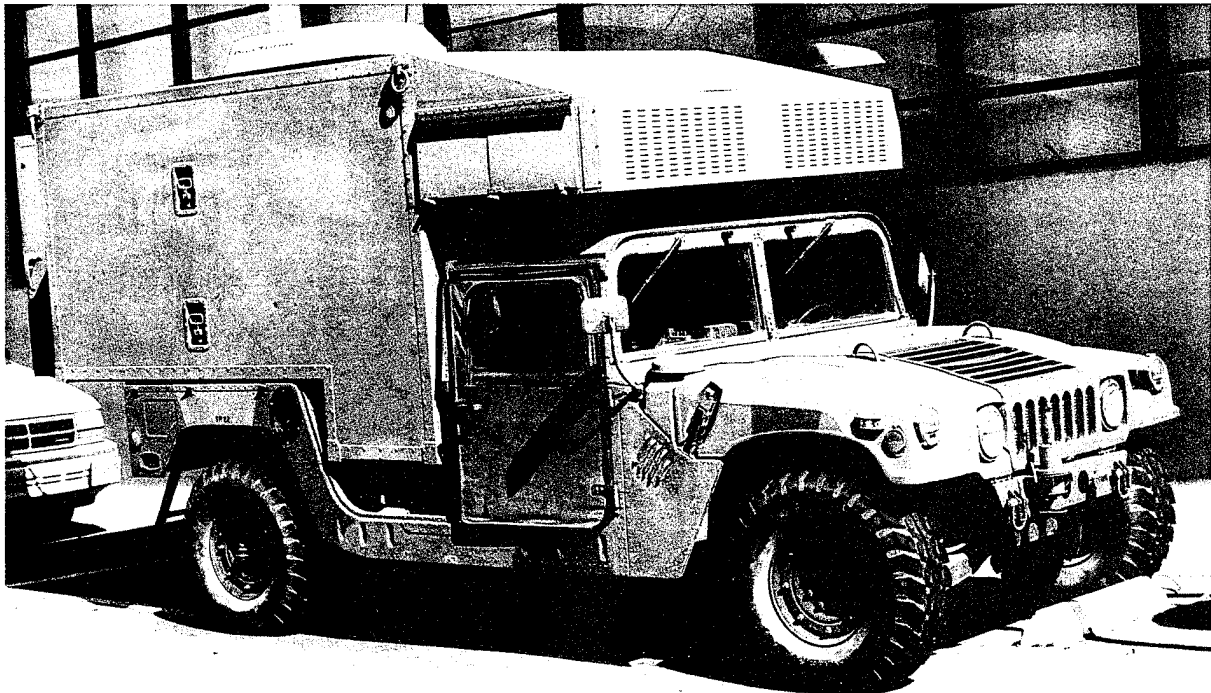


Figure 29. HMMWV used for transporting and sheltering the HDR UHF LOS communication instruments.

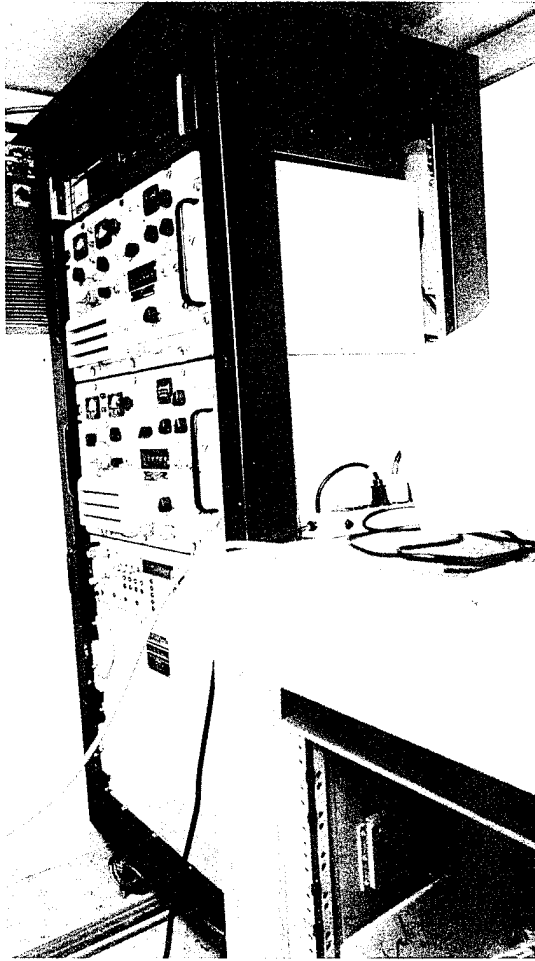


Figure 30. Some of the communication instrumentation located in the rack inside the HMMWV (from the bottom to the top positions are an OA-9123/SRC antenna coupler, two AN/WSC-3 transceivers, and a CM701 modem).

The HMMWV acted as a relay and terminated the BERT equipment (results presented in section 5.3). Data from the HMMWV were passed to the FCTCPAC MUTTS Van, then combined with the FCTCPAC Timeplex data into a T1 (1.544 Mbps) data stream, and were fed into the FASCFAC DS3 (45 Mbps) microwave link for the 65-mile journey back to Point Loma. The microwave link terminates in building 24 of FCTCPAC where the NRaD/FCTCPAC data stream was demultiplexed. The NRaD data then traveled by fiber-optic cable to the ITMS laboratory at NRaD where the ethernet connection was made to the Internet land line and the phone connections (one originating from the USS *Peleliu* and one originating from the HMMWV) were connected to the PBX land lines.

Tables 8 and 9 list the configuration parameters of the Timeplex multiplexer and the CM701 modem, respectively. Note that QPSK modulation was used with a concatenated forward error-correcting code scheme using a rate 239/256 Reed-Solomon block outer code and a rate 3/4 convolutional inner code that resulted in a 1.4 bps/Hz spectral efficiency. The 384-kbps data rate was thus transmitted at a 274.209-ksps symbol rate, which required a 3-dB bandwidth of about 274 kHz. System timing was designed for the Timeplex in the HMMWV to recover an accurate clock from the FCTCPAC MUTTS VAN and then to send that clock back to the USS *Peleliu*.

Table 8. Timeplex miniLINK/2+ multiplexer configuration for USS *Peleliu*, NRaD HMMWV, and FCTCPAC MUTTS van.

Function	USS <i>Peleliu</i>	NRaD HMMWV	FCTCPAC MUTTS VAN
NCL/System	v.9	v.9	v.4
Node identification number	71	70	69
System connect retry	02	02	
ILC out-of-service timer	08	08	
System maximum phasor size	14	14	
Clock fallback list	d1r 3 , d1t 3 , skp	d1r 5, skp , skp	d1r 3, skp , skp
Clock qualification tolerance	N/A	N/A	N/A
Clock switching option	N/A	N/A	N/A
ILC.2 (data, to <i>Peleliu</i>)			
Data rate	384 kbps	384 kbps	N/A
Source of Tx Clock	SND	SYS	
Line driver	EXT	EXT	
Frame mode	02	02	
satellite buffer	none	none	
ARQ	3200	3200	
Sync characters and level	04/L1	04/L1	
Master/slave	Slave	Master	
Subrate multiplexing	NO	NO	
Group assignment	1234567	1234567	
Logical node translation	off	off	
Link framing module	none	none	
Out-of-service Timer	SYS	SYS	
ILC.2 (data, to MUTTS)			
Data Rate	N/A	512 kbps	512 kbps
Source of Tx Clock		SYS	SYS
Line driver		EXT	EXT
Frame mode		02	02
satellite buffer		none	none
ARQ		9600	9600
Sync characters and level		04/L1	04/L1
Master/Slave		Master	Slave
Subrate multiplexing		NO	NO
Group assignment		1234567	1234567
Logical node translation		off	off
Link framing module		none	none
Out-of-service timer		SYS	SYS
QSP.2 (router channel)			
Originator/terminator	terminator	originator	
Data rate	256 kbps	256 kbps	

Table 8. Timeplex miniLINK/2+ multiplexer configuration for USS *Peleliu*, NRaD HMMWV, and FCTCPAC MUTTS van. (Continued)

Function	USS <i>Peleliu</i>	NRaD HMMWV	FCTCPAC MUTTS VAN
ABM profile	default	default	
Connect priority	01	01	
Delay threshold	07	07	
Interface type	DCE	DCE	
Mode of transporting EIA	inband	inband	
Phasor Size	MX	MX	
CTS generation	auto	auto	
CTS delay	28	28	
Connection type	off	off	
Out-of-service operation	mark	mark	
Military Interface	D-B, F-B	D-B, F-B	
Polarity	D-N, F-N	D-N, F-N	
Special features	none	none	
DSR Control	ON	ON	
FXS (voice service)			
Originator/terminator	terminator	originator	
ABM profile	default	default	
Speed	64 kbps	64 kbps	
Connection priority	01	01	
Delay threshold	07	07	
Phasor size	08	08	
Code law	mu-law	mu-law	
Ones density	off	off	
A-bit filter/ B-bit filter	1	1	
Out-of-service operation	force busy	force busy	
Echo canceler	enable, 32 msec	enable, 32 msec	
Center clipper	enable	enable	
Tone disable	on	on	
Single frequency signalling	none	none	
Transmit TLP	-5 dBm	-5 dBm	
Impedance	600 ohms	600 ohms	
Loop start or ground start	loop start/ auto ringdown	loop start/ auto ringdown	

Table 9. Comstream CM701 modem configuration for USS *Peleliu* and the NRaD HMMWV.

Function	USS <i>Peleliu</i>	NRaD HMMWV
5: R-S Coder/Interleaver		
R-S loopback	disable	disable
R-S Bypass	off	off
Deinterleave depth	16	16
Interleave depth	16	16
Dec data bytes	239	239
Enc data bytes	239	239
Rx IN	411314 bps	411314 bps
Rx OUT	384000 bps	384000 bps
Tx OUT	411314 bps	411314 bps
Tx IN	384000 bps	384000 bps
6: Demod		
RxDataRate	411314 bps	411314 bps
Rx Scrambling	CMSTR-RS	CMSTR-RS
Acquisition	normal	normal
RxFilterType	CMSTRM	CMSTRM
RxDiffDecode	off	off
RxModType	QPSK	QPSK
RxCodeType	Vit. 3/4	Vit. 3/4
RxSymRate	274209 sps	274209 sps
Rx Freq.	70000.000 kHz	70000.000 kHz
7: Mod		
TxDataRate	411314 bps	411314 bps
Tx Scrambling	CMSTR-RS	CMSTR-RS
TxClockSource	loop	ext
TxPureCarrier	off	off
TxPowerLevel	-5.0 dBm	-5.0 dBm
TxFilterType	CMSTRM	CMSTRM
TxDiffDecode	off	off
TxModType	QPSK	QPSK
TxCodeType	Vit. 3/4	Vit. 3/4
TxSymRate	274209 sps	274209 sps
Tx Freq.	70000.000 kHz	70000.000 kHz
1: BUFFER		
Bufr Size(Bits)	1024	1024
Buffer	reset	reset
Buffer Mode	bypass	buffer
Buffer Clk Sel	TxCIk	TxCIk
CM701 timing:		
ML	0 (term timing)	0 (term timing)
LT	0	0

5.3 LESSONS LEARNED

Even though there were short periods of time when all parts of the demonstration worked successfully user-to-user, in general, the test results of this demonstration were marginal due to several of the following factors:

First, for various unforeseen reasons, none of the personnel trained on the operation of the HDR UHF LOS communication instruments departed with the USS *Peleliu*. This made debugging instrument problems extremely difficult for all involved. Theoretically, the lack of trained personnel should not have been a problem since the system was set up and operational (from the Timeplex on the USS *Peleliu* to the Timeplex at NRaD) for the week prior to the departure of the ship; however, problems with configuring the Sun Voyager workstation, NES encryption device, and routers were never solved before the USS *Peleliu* set sail. As a result, complete user-to-user tests were not completed while the ship was in port. This proved to be a very important lesson learned since the applications, routers, and HDR UHF LOS communication instruments had never before been operationally configured together.

Second, on at least two separate occasions, some unknown person(s) on the USS *Peleliu* disconnected RF cables, turned equipment off, and changed configuration parameters of the HDR UHF LOS communication instruments. This necessitated the intervention of the untrained riders to reconnect and reconfigure the instruments. It seemed as if they had to "baby-sit" the instruments to keep them from being tampered with. The instruments normally do not need operator intervention.

Third, a timing problem arose that had not been observed in laboratory tests or in land-line operation. The chosen timing scheme attempted to push the timing from the HMMWV Timeplex, through the HDR UHF LOS communication link, to the USS *Peleliu* Timeplex; however, since LOS radio links are dependent upon being within LOS range, they are prone to long periods of outages whenever the mobile platforms are out of LOS range. During this period of outage, the Timeplex on the USS *Peleliu* obviously could not recover the receive data clock from the LOS link so it entered an internal clock fallback mode. When the USS *Peleliu* came back within LOS range, the Timeplex often seemed to take an exorbitant amount of time to sense that the link had been reestablished, even though the CM701 modems showed a solid link had indeed been established. This timing problem has since been confirmed in laboratory experiments, and its solution has been formulated. The solution relies on independently timing each side of the LOS link by using the CM701 modem internal clock. In this timing scheme, the Timeplex recovers the clock from the local CM701 modem and is always stable regardless of the status of the LOS link. This timing scheme has been working successfully for the USS *Abraham Lincoln* Battle Group demonstration. (Refer to Section 4 for more details.)

Fourth, on a few occasions, the CM701 modems did not properly synchronize when the USS *Peleliu* came back within LOS range even though the AGC monitor signaled that there was sufficient power in the receive signal to establish a link and interference appeared to be absent. This was confirmed in laboratory tests. QPSK modulation without differential encoding/decoding (as used during the Kernel Blitz demonstration) can occasionally become erroneously demodulated. It is speculated that the QPSK symbol constellation sometimes gets flipped by ± 90 degrees during the demodulation process, thereby causing the symbol-to-bits mapping to result in incorrect output data bits. Adding differential encoding/decoding makes the demodulation process unique even though it does reduce the BER performance of the modem slightly (less than 0.5 dB). This scheme has also been incorporated into the configuration setup being used by in the USS *Abraham Lincoln* Battle Group and has apparently solved this problem.

Finally, the electrical power at Mt. Thirst, San Clemente Island was unreliable, and on several occasions, power failed completely for several hours at a time. The Uninterruptible Power Supply (UPS) used in the HMMWV provided about 3 hours of battery back-up power and power conditioning to the CM701 modem, Timeplex, and all baseband instruments; however, the AN/WSC-3 transceivers were directly affected by power interruptions whose effects resulted in link outages.

5.4 TEST RESULTS

Figures 31 through 38 plot one of the more pertinent parameters collected from the BERT data during the exercise, the Error-Free Seconds (EFS) (as defined by the CCITT Recommendation G.821) during a 15-minute (900 s) interval. Several intervals were observed with exceptionally good performance, for example, from 0900 to 1200 on 4 April 1995. When the causes for outages are known, notes are added to the plots.

A recording device that was designed to log the GPS navigational position of the ship every 15 minutes so that range information could be correlated with the BERT data was mounted on the USS *Peleliu*. Unfortunately, the device failed to operate correctly due to loss of power once the ship departed port. Evidently, the topside electrical outlet, which was used for GBS power, is not normally powered on when the ship is at sea and is operating on internal power; however, range information collected while the HDR UHF LOS communication system was operating indicated that the range was at times 35 nmi or greater. This range falls considerably short of the value that was predicted by figure 19 whose predicted range was greater than 45 nmi.

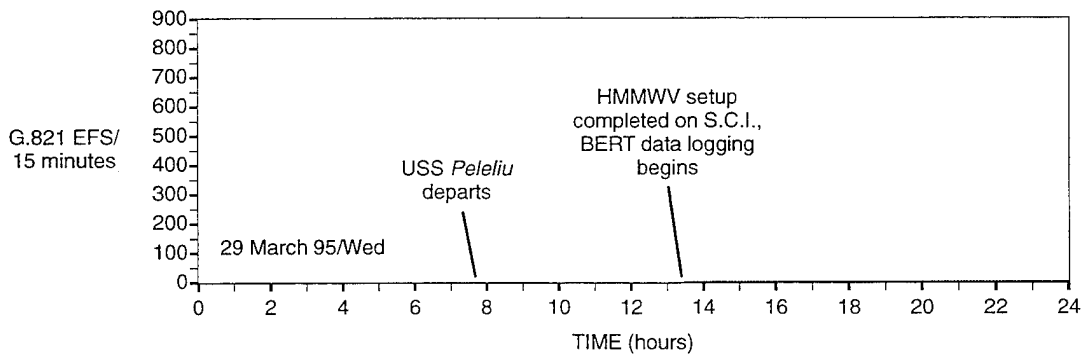


Figure 31. G.821 EFS for USS *Peleliu*-to-S.C.I. on Wednesday, 29 March 1995.

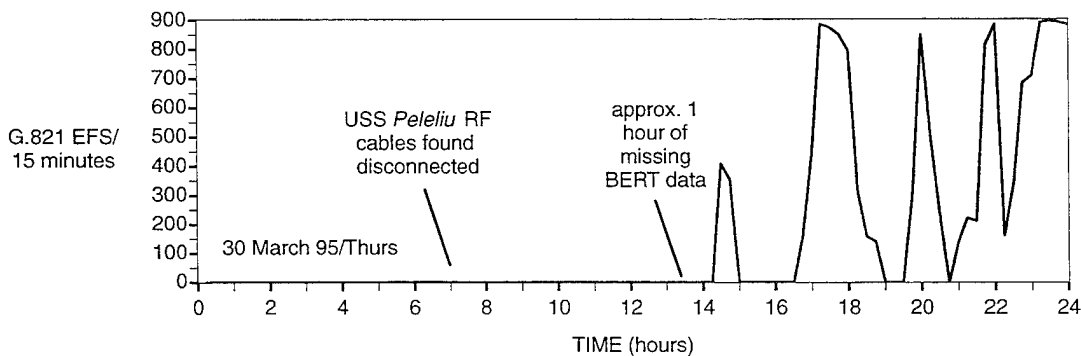


Figure 32. G.821 EFS for USS *Peleliu*-to-S.C.I. on Thursday, 30 March 1995.

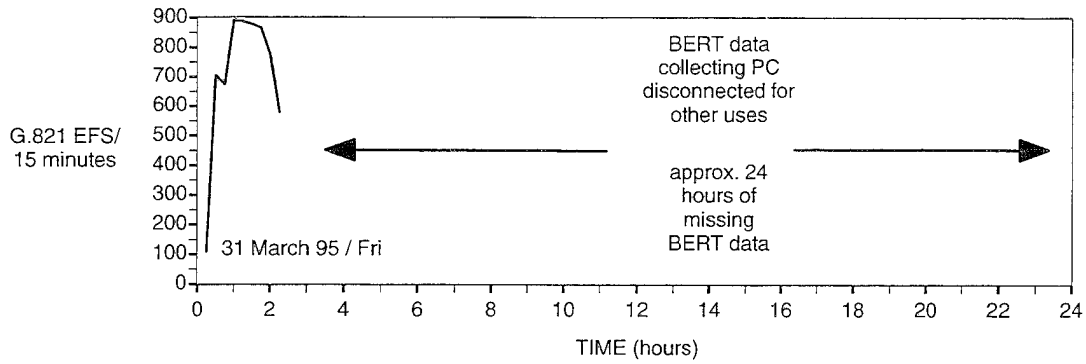


Figure 33. G.821 EFS for USS *Peleliu*-to-S.C.I. on Friday, 31 March 1995.

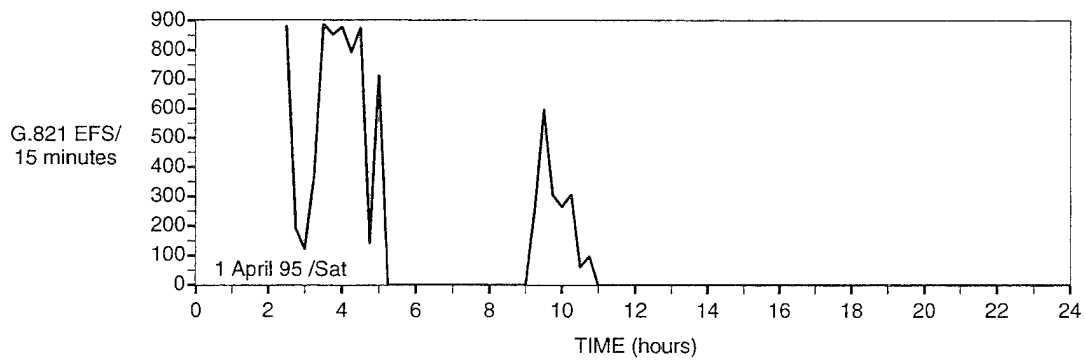


Figure 34. G.821 EFS for USS *Peleliu*-to-S.C.I. on Saturday, 1 April 1995.

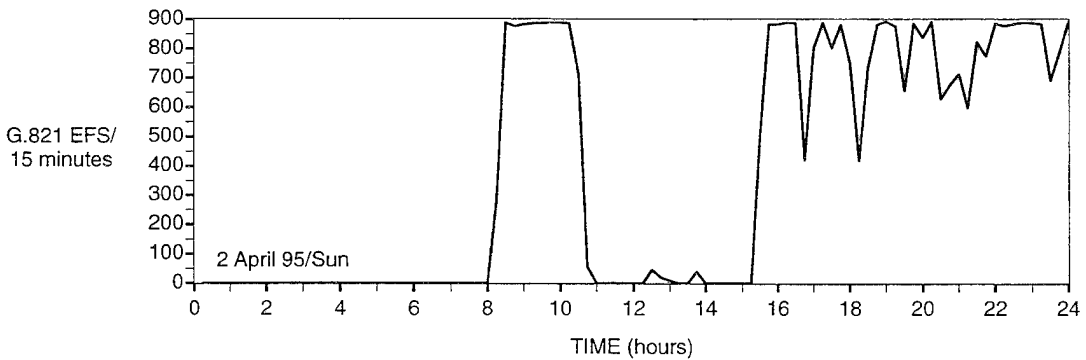


Figure 35. G.821 EFS for USS *Peleliu*-to-S.C.I. on Sunday, 2 April 1995.

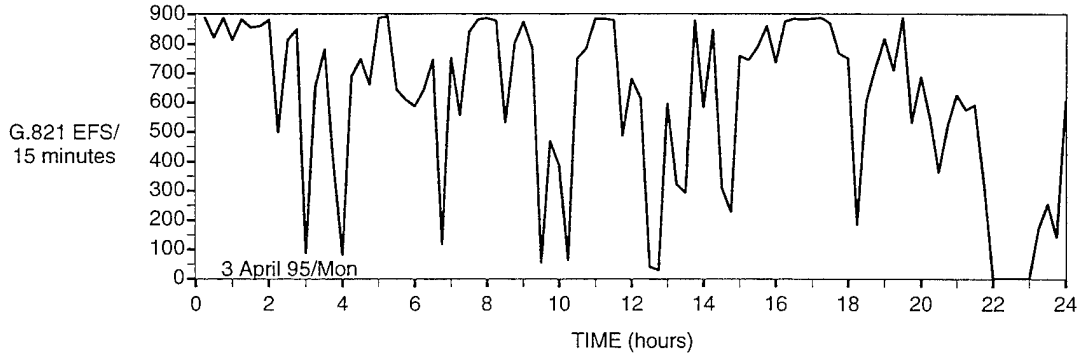


Figure 36. G.821 EFS for USS *Peleliu*-to-S.C.I. on Monday, 3 April 1995.

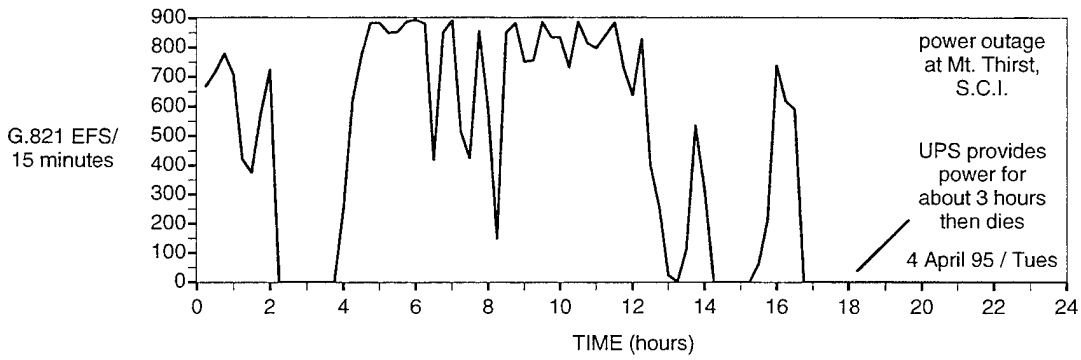


Figure 37. G.821 EFS for USS *Peleliu*-to-S.C.I. on Tuesday, 4 April 1995.

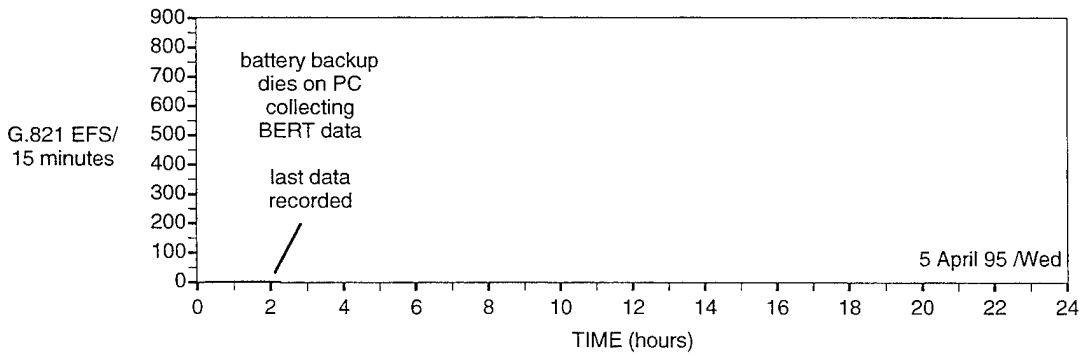


Figure 38. G.821 EFS for USS *Peleliu*-to-S.C.I. on Wednesday, 5 April 1995.

5.5 DISCUSSIONS

Although the results of this demonstration were only marginal, the demonstration itself proved extremely important: first, it demonstrated a huge jump in LOS data rate communications (384 kbps as compared to existing systems which operate at 4.8 kbps or less); second, it provided a test to discover and solve many of the system integration problems that plagued the real-life implementation, but were not observed in laboratory back-to-back tests. Kernel Blitz was an important step in the development of a LOS communication system that can provide reliable HDR communication between ships and ship-to-shore. Using the data and the lessons learned here, it is felt that a 384-kbps, or higher, HDR service could be offered to ships operating in southern California waters when they are operating within about 45 nmi of San Clemente Island. This improved communication link could greatly reduce the satellite traffic created by non-deployed forces and could allow for additional communication services (for example, training or medical assistance through VTC connections, IP traffic, etc.).

6. CONCLUSIONS

This report describes two HDR UHF LOS digital radio communication experiments and demonstrations conducted during FY 95 with Phase 1 instruments. The Phase 1 instruments are based around the use of the AN/WSC-3 external modem interface and existing shipboard RF antenna couplers, RF cabling, and omnidirectional antennas. The communication system has been proven by these demonstrations to provide reliable communications at fractional T1 data rates (256 kbps to 576 kbps) to a maximum range of 18 nmi between ships at sea. In addition, a ship-to-shore link demonstrated the flexibility and versatility of the HDR UHF LOS communication system.

Several outstanding issues that require research and development before future deployments of the HDR UHF LOS communication system are also outlined in this report. First, measured maximum ranges were found to be less than predicted by laboratory measurements and considerably less than the radio horizon. Presumably, the noise floor as seen by a receiver located on a ship is greater than that of the laboratory measurements. If true, this would limit the sensitivity of the receiver and limit the range. Other causes could have been interference and multipath fading. The exact cause should be investigated further and corrected in the Phase 2 instruments.

System timing proved to be a troubling issue during the Kernel Blitz demonstration. While it appears as if the independent timing of each node is the correct timing scheme for LOS connections, this scheme requires extremely accurate clocks (stratum 1) at every node. The ComQuest high stability card, which fits into either the CM701 modem or the CQM248 modem, is most likely a part of the solution, but other solutions should be further investigated.

Eventually, the HDR UHF LOS communication links will help mesh together multiple ships with multiple SATCOM assets. This introduces several new difficulties that only just surfaced during the point-to-point demonstrations conducted here. First, frequency and bandwidth management become more difficult because the UHF band is already crowded with multiple users. Methods of reducing the footprint of the transmitted spectrum emitted from each HDR UHF LOS communication system should be pursued. In addition, a media access controller could be developed, perhaps in conjunction with and similarly to the VTC software. Ideally, the user would choose the desired services (e.g., VTC, voice, ethernet, etc.), the desired data rates, and the destinations of each service from a menu, and the remainder of the radio actions would be done automatically. This would also eliminate user errors during reconfiguration of all the radio system components. Another difficulty comes with the Timeplex multiplexer that assumes a land-based stationary network. Constant redefining of channel routing, connection terminator/originator and link master/slave designators, etc., is confusing and time consuming even for a Timeplex expert. Perhaps a media access controller could also redefine the multiplexer/demultiplexer/switch and other baseband instruments, or perhaps a better, more integrated, solution exists. Further research and development will be required to devise a solution that solves all of these issues efficiently.

Operational Navy RF communication circuits all require link encryption. None of the demonstrations or laboratory tests conducted so far have included link encryption. The addition of such encryption will surely surface additional timing, equipment control, and management issues that must be resolved before operational deployment of HDR UHF LOS communications will be possible.

Even with these outstanding issues, the success of the RF communication demonstrations described in this report are proof of the rapid progress made since the inception of the HDR UHF LOS communications program in FY 93. These demonstrations prove for the first time that in an operational setting, data rates consisting of hundreds of kbps can be achieved between ships and from ship-to-shore.

7. REFERENCES

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APPENDIX A
HDR SATELLITE COMMUNICATION EXTENSION OF THE HDR LOS
NETWORK IN USS *ABRAHAM LINCOLN*
BATTLE GROUP TO SHORE

TEST OVERVIEW AND OBJECTIVES

This appendix describes a high-data-rate (HDR) satellite communication link that extended the USS *Abraham Lincoln* Battle Group's HDR LOS network described in section 4 to the shore. The HDR SATCOM link was funded by the Naval Medical Information Management Center (NMIMC), Bethesda, Maryland, and was sponsored by LT Richard Stakelum of Commander Naval Surface Forces Pacific (CNSP). (This effort and related efforts have been commonly referred to as FORCE 21 Single Pipeline Demonstration by CNSP.) It was operated from 19 to 29 September 1995 and on 6 October 1995.

The objectives of the tests were to provide video teleconferencing (VTC) and San Diego local Plain Old Telephone System (POTS) to the USS *Abraham Lincoln*, USS *Princeton*, and USS *John Paul Jones*. Medical personnel at NMIMC, Bethesda, Maryland, and Balboa Naval Medical Center, San Diego, California, desired high quality VTC (384 kbps or better) connectivity for the appropriate medical personnel on board the USS *Abraham Lincoln* to provide the ship with expert consultations when needed. The San Diego local POTS lines were desired by the ships to reduce the cost of their long-distance telephone calls.

COMMUNICATIONS INSTRUMENTS

The HDR SATCOM link provided a 512- to 768-kbps, full-duplex link from the USS *Abraham Lincoln* to shore. Satellite service was initiated to the ship, while it was still deployed in the West Pacific Ocean, by utilizing RF instruments installed by Maritime Telecommunications Network (MTN), Fairfield, New Jersey, to support the SPRINT "Sailor Phone." The Sailor Phone system provides 8 commercial pay telephones (upgradable to 16) on the ship for personnel to call anywhere in the United States for \$1.00 per minute. When the USS *Abraham Lincoln* is in the Pacific Ocean, the system uses transponder #88 of the commercial, C-band, INTELSAT 511 satellite (located at 180 degrees East) with a global beam pattern for seamless coverage. This HDR SATCOM system and the identical system installed on the USS *Nimitz* can both be upgradable to a full T1 (1.544 Mbps) HDR SATCOM system as is presently installed on the USS *George Washington*.

The block diagram in figure A-1 illustrates how, by using frequency-division multiplexing (FDM), the RF instruments used to support the Sailor Phone were also used to support the separate 512-kbps, HDR SATCOM link without disrupting the operation of the Sailor Phone. The Timeplex LINK/2+ operates as a multiplexer-demultiplexer and a switch for the 384-kbps VTC, telephone, and other serial-service channels. Refer to chapter 4.2 for a description of the instruments on the USS *Princeton* and USS *John Paul Jones* used for connecting to the USS *Abraham Lincoln* through HDR UHF LOS communication links. All data links on the USS *Abraham Lincoln* terminated in its Timeplex so that connections could be easily routed by software from the LOS ships to shore. Together these ships formed a small RF network allowing multiple ships to use the expensive SATCOM assets on the USS *Abraham Lincoln*.

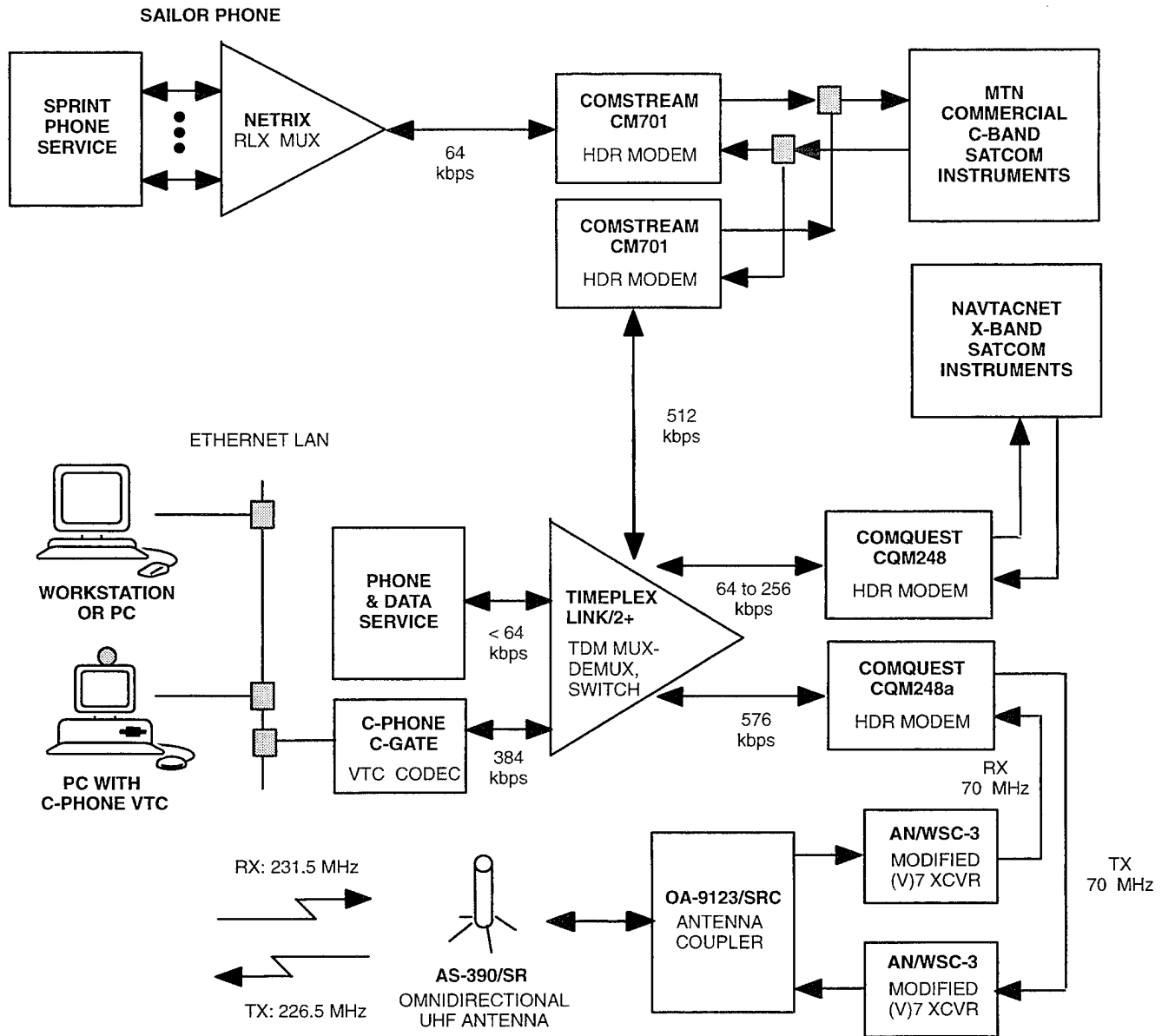


Figure A-1. Instrumentation on the USS *Abraham Lincoln* used to support HDR UHF LOS communications, and HDR C and X-band satellite communications.

The satellite shore site for both the Sailor Phone and the HDR SATCOM links was the ICG Steele Valley Earth Station, Perris, California. A T1, leased phone line (1.544 Mbps, B8ZS line coding, Extended Super Frame network framing) was installed from ICG Steele Valley Earth Station to NRaD to configure the HDR SATCOM link into the NRaD Timeplex Network as described in figure A-2. Once inside the NRaD Timeplex Network, a 384-kbps VTC connection could be established directly to either the Balboa Naval Medical Center or to the Commander Destroyer Squadron (COM-DESRON) 33, San Diego, California, or indirectly to any of the more than 240 VTC centers inside the Defense Commercial Telecommunication Network (DCTN), VTC network. All direct connections could be made by the ships at-sea (as well as by NRaD personnel) so that in the event of an emergency requiring remote assistance, a VTC connection could be established immediately by personnel on the ship.

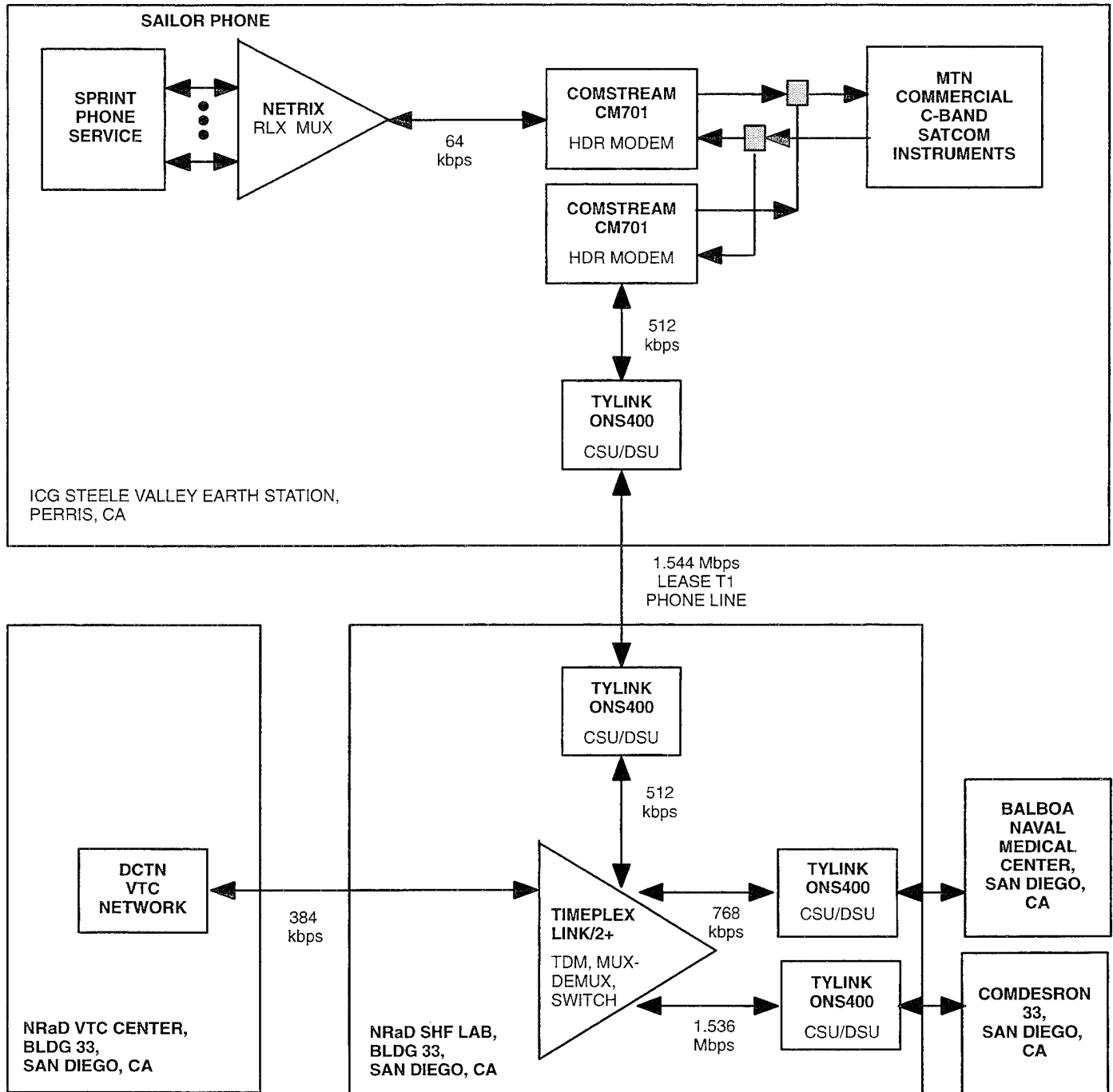


Figure A-2. Instrumentation at shore sites used to support the HDR UHF LOS communication and commercial C-Band SATCOM tests with the USS *Abraham Lincoln* Battle Group.

Tables A-1, A-2, and A-3 list the parameter configurations for the Timeplex LINK/2+ multiplexers, ComStream CM701 modems, ComQuest CQM248a modems, and the Tylink ONS400 CSU/DSU instruments, respectively. Of particular importance is the timing scheme used throughout the system and the forward error-correcting code used on the SATCOM modems. The timing scheme used for this system made use of the extremely accurate 1.544-MHz, stratum-1, station clock available at NRaD. This clock was pushed through the system from NRaD to the USS *Abraham Lincoln* Timeplex. This same clock was recovered at the CQM248a modem on the ship and used to clock data on

the return trip back to NRaD. It was not used for timing the ship's Timeplex multiplexer since this demonstration was only operational for a short period of time, and it was important not to impact the normal operational circuits on the ship. A 1024-bit buffer on the CM701 modem located at the ICG Steele Valley Earth Station compensated for Doppler shifts due to satellite motion. The forward error-correcting code scheme chosen for the satellite links was a rate 239/256 Reed-Solomon block outer code, interleave depth of 4, and rate 1/2 Viterbi decoded convolutional inner code. This was scrambled, differentially encoded, and transmitted with QPSK modulation. The reason for this coding scheme, which is less bandwidth efficient than the scheme chosen for the HDR UHF LOS communication links (see section 4.2), was that the SATCOM link was power limited instead of bandwidth limited like the UHF LOS communication links.

Table A-1. Timeplex multiplexer configuration for USS *Abraham Lincoln* and NRaD.

Function	USS <i>Abraham Lincoln</i> (LINK/2+ 1 nest)	NRaD (LINK/2+ 2 nest)
NCL/System	v.9	v.11
Node identification number	172	83
System connect retry	02	02
ILC out-of-service timer	08	08
System maximum phasor size	14	14
Clock fallback list	dlr 3, dlt 3, skp	ST-1, ST-2, dlr 7
Clock qualification tolerance	N/A	Hi
Clock switching option	N/A	Slow
Station Clock	N/A	1544.000 kbps
ILC.2 (SATCOM data)	slot 8	slot 17
Data rate	512 kbps	512 kbps
Source of Tx Clock	SND	SND
Line driver	EXT	EXT
Frame mode	02	02
Satellite delay	1	2
Satellite buffer	none	none
ARQ	9600	9600
Sync characters and level	08/L1	08/L1
Master/slave	Slave	Master
Subrate multiplexing	NO	NO
Group assignment	1234567	1234567
Logical node translation	off	off
Link framing module	none	none
Out-of-service timer	SYS	SYS

Table A-2. ComStream CM701 modem and ComQuest CQM248 modem configurations for the USS *Abraham Lincoln* and the ICG Steele Valley Earth Station.

Function	USS <i>Abraham Lincoln</i>	ICG Steele Valley Earth Station
5: R-S Coder/Interleaver		
R-S Loopback	disable	disable
R-S Bypass	off	off
Deinterleave depth	4	4
Interleave depth	4	4
Dec data bytes	239	239
Enc data bytes	239	239
Rx IN	548418	548418
Rx OUT	512000	512000
Tx OUT	548418	548418
Tx IN	512000	512000
6: Demod		
RxDataRate	548418	548418
Rx Scrambling	CMSTR-RS	CMSTR-RS
Acquisition	normal	normal
RxFilterType	CMSTRM	CMSTRM
RxDiffDecode	on	on
RxModType	QPSK	QPSK
RxCodeType	Vit. 1/2	Vit. 1/2
RxSymRate	548418 sps	548418 sps
Rx Freq.	57852.500 kHz	60270.000 kHz
7: Mod		
TxDataRate	548418	548418
Tx Scrambling	CMSTR-RS	CMSTR-RS
TxClockSource	loop	ext
TxPureCarrier	off	off
TxPowerLevel	-12.0 dBm	-6.0 dBm
TxFilterType	CMSTRM	CMSTRM
TxDiffDecode	on	on
TxModType	QPSK	QPSK
TxCodeType	Vit. 1/2	Vit. 1/2
TxSymRate	548418 sps	548418 sps
Tx Freq.	60270.000 kHz	57852.500 kHz
1: BUFFER		
Bufr Size(Bits)	1024	1024

Table A-2. ComStream CM701 modem and ComQuest CQM248 modem configurations for the USS *Abraham Lincoln* and the ICG Steele Valley Earth Station. (Continued)

Function	USS <i>Abraham Lincoln</i>	ICG Steele Valley Earth Station
Buffer	reset	reset
Buffer Mode	bypass	buffer
Buffer Clk Sel	TxCIk	TxCIk
CM701 timing:		
ML	0 (terminal timing)	0 (terminal timing)

Table A-3. Tylink ONS400 CSU/DSU configurations for the ICG Steele Valley Earth Station and NRaD.

Function	ICG Steele Valley EarthStation	NRaD
MOD CONFIG MENU		
Aggregate Config		
Network timing	loop (slave)	ST clock 1544.000 kHz
Network framing	ESF-54016	ESF-54016
Network line code	B8ZS	B8ZS
Network interface	CSU	CSU
LBO setting	-7.5 dB	-7.5 dB
DTE CH multiples	all rates	all rates
Density monitor	none	none
Channel Config		
CH #1 TYPE: RS-449		
Channel density	None (clr ch)	None (clr ch)
Channel data rate	512K/#DS-0: 8	512K/#DS-0: 8
Starting DS0 number	DS-0: 1	DS-0: 1
Channel timing	loop 2	loop 2
Clock invert	off	off
Data invert	off	off
CTS control	on (DCE CTL)	on (DCE CTL)
DIAGNOSTICS MENU		
Channel LED display	channel 1	channel 1
Local Ch #1 loopback	off	off
Local aggregate loopback	off	off
Local network loopback	off	off
Remote CSU loopback	off	off
Remote aggregate loopback	off	off

Table A-3. Tylink ONS400 CSU/DSU configurations for the ICG Steele Valley Earth Station and NRaD.

Function	ICG Steele Valley EarthStation	NRaD
Remote Ch #1 loopback	off	off
511 Test pattern	ch 1: off	ch 1: off
FRONT PANEL LIGHTS (NORMAL OPERATION)		
Network		
Test	off	off
Carrier	green	green
Sync	green	green
Alarm	off	off
Channel		
Test	off	off
Transmit Data (TD)	green	green
Receive Data (RD)	green	green
Request To Send (RTS)	green	green
Carrier Detect (CD)	green	green

TEST RESULTS AND DISCUSSIONS

The test results were very successful and numerous new communication capabilities were demonstrated with deployed naval forces. One of the most significant reasons for the success of these tests was that the SATCOM link was extremely stable. The C-band SATCOM instruments, installed and maintained by Maritime Telecommunications Network to support the SPRINT Sailor Phone, had been operational for the entire deployment of the USS *Abraham Lincoln*. All antenna tracking "kinks" and other typical shipboard SATCOM "show-stoppers" had been worked out of the system long before. Adding the additional carrier to the system was relatively straightforward and only required minor power and frequency adjustments to properly balance the support of both the 64-kbps Sailor Phone and the 512-kbps FORCE 21 systems. Another important reason for the extremely reliable SATCOM link was the method chosen for timing the system that was previously discussed.

One of the new communications capabilities demonstrated was the establishment of the first ever, general-purpose, HDR, intraforce RF network. The HDR, intraforce RF network was established by the HDR UHF LOS communication links for intraship communication and it allowed the USS *Princeton* and the USS *John Paul Jones* to share the HDR SATCOM assets on the USS *Abraham Lincoln*. LOS communication links offer smaller ships all the benefits of the HDR SATCOM assets typically found only on the larger ships, like aircraft carriers, without actually having these systems on board. SATCOM systems are notorious for being very expensive to maintain (mostly in leasing satellite space segments) and for being difficult to stabilize on smaller ships. The intraforce, RF network allowed the sharing of these SATCOM systems between several ships for the first time, creating the possibility of cost sharing solutions. This addition of multiple HDR SATCOM links (X-band and C-band) throughout of the battle group greatly increases the reliability of all user-to-user

connections. The Timeplex multiplexers have the ability to automatically reroute user-to-user connections through other data link paths if a single link fails; for instance, if the X-band SATCOM link fails, the highest priority user-to-user connections (POTS, VTC, or other serial services) would be automatically rerouted through the C-band SATCOM link; likewise, the rerouting could be over a HDR UHF LOS communication link to a SATCOM asset on another ship if it existed. This rerouting capability was tested on several occasions when one or the other HDR SATCOM systems failed due to the RF signal being blocked.

The VTC connectivity offered between ships at sea and shore sites was also novel. The USS *Abraham Lincoln* had three C-Phone VTC sites located in the communications control room, medical examination room, and the wardroom; the USS *Princeton* had two VTC, C-Phone sites located in the medical examination room and the wardroom; the USS *John Paul Jones* had one C-Phone VTC site in the medical examination room. Any of these VTC sites could be connected to any of the three C-phone VTC sites at Balboa Naval Medical Center (Radiology reading room, Ears-Nose-and-Throat clinic, and Emergency room), or any of the two C-phone VTC sites at COMDESRON 33 (medical/chaplain room, conference room), or any of the over 240 VTC sites in the DCTN, worldwide VTC network. Some of the VTC connections established during these tests were as follows:

- Admiral Jeremy Boorda, Chief of Naval Operations, gave a welcome home address from the DCTN VTC site at Naval Air Depot – North Island, San Diego, California, to the USS *Abraham Lincoln* (the taped address was later transmitted to the USS *John Paul Jones*);
- Live Laparoscopy surgery video from the USS *Abraham Lincoln* was sent to the Bureau of Medicine, Washington, DC, DCTN VTC site for use in providing real-time medical assistance;
- USS *John Paul Jones* conducted VTC with Naval Undersea Warfare Center Detachment Hawaii, Wainae, Hawaii, to receive Post-operational Analysis Critique and Exercise Review (PACER) and Combat Systems System Qualification Trial (CSSQT) debrief demonstration through DCTN connections;
- USS *John Paul Jones* conducted VTC though DCTN with Naval Surface Warfare Center, Port Hueneme, California, to demonstrate technical assistance capabilities;
- The Commanding Officer and other ship personnel on the USS *Princeton* conducted numerous VTC briefs with CNSP, COMDESRON 33, and NRaD personnel at COMDESRON 33, San Diego, California, with their C-phone VTC sites;
- Several family visits were conducted between ship personnel on the USS *Abraham Lincoln* and family members at Oakland Army base, DCTN VTC center, Oakland, California;
- The Commanding Officer, Combat Systems Officer, and other ship personnel on the USS *John Paul Jones* conducted numerous VTC briefs with various individuals at the COMDESRON 33, San Diego, California, C-phone VTC site, including the Commodore, the Chaplain, and medical officers of COMDESRON 33;
- All three ships made routine VTC consultation calls with Balboa Naval Medical Center, San Diego, California;
- All three ships conducted data transfers, including word processing documents, still video snapshots, scanned data, medical records, shipboard nontactical automated data processing system (SNAP III) reports, and supply requisition information.

Other uses of the VTC connectivity, which were not fully exploited in these tests due to the time limitations, include remote education and training through the Chief of Naval Education and Training (CNET) VTC network, and remote technical assistance and maintenance. All three ships were able to feed their site TV systems with the C-Phone VTC output so that all members of the ship could enjoy the benefits of the system when desired.

CONCLUSION

This appendix has described the test results of an HDR satellite communication link that extended the USS *Abraham Lincoln* Battle Group's HDR LOS network to the shore. The test results were very successful and demonstrated high quality, 384-kbps VTC and San Diego local POTS connections to the USS *Abraham Lincoln*, USS *Princeton*, and USS *John Paul Jones* while deployed in the West Pacific Ocean. Numerous new communication capabilities were demonstrated, including the creation of the first general-purpose, HDR intraforce RF network. This was established with HDR UHF LOS communication links, and it allowed the USS *Princeton* and the USS *John Paul Jones* to share the HDR SATCOM assets on the USS *Abraham Lincoln*. All three ships enjoyed a plethora of VTC connectivity from ship-to-shore, including Commander Destroyer Squadron 33, Balboa Naval Medical Center, and any of the more than 240 VTC sites in the DCTN worldwide VTC network. Similar capabilities could be demonstrated from the USS *Nimitz* and the USS *George Washington* Battle Groups and soon to other battle groups with the progress of Challenge Athena (Shaw & Williams, 1995) and other programs (Zeigler, 1995). It is expected that from the success of these tests and demonstrations, the Navy will be better able to define and support the needs and requirements of its deployed forces in the near future.

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13. ABSTRACT (Maximum 200 words) This report describes two separate High-Data-Rate (HDR), Ultra-High-Frequency (UHF), Line-of-Sight (LOS) digital radio communication experiments and demonstrations conducted during FY 95. The communication instruments used to perform these demonstrations were the AN/WSC-3 external modem interface and existing shipboard antenna couplers, RF cabling, and omnidirectional antennas. Experiments on board the USS <i>Rentz</i> were critical to the integration of the HDR UHF LOS digital communication system into the shipboard environment. The USS <i>Abraham Lincoln</i> , USS <i>Princeton</i> , and USS <i>John Paul Jones</i> demonstrated intership digital communication at 256 kbps and 576 kbps during a 6-month deployment. Also during this deployment, the USS <i>Princeton</i> and the USS <i>John Paul Jones</i> demonstrated an extension of the Satellite Communications (SATCOM) assets on board the USS <i>Abraham Lincoln</i> through the HDR UHF LOS digital communication system. A 384-kbps, ship-to-shore data link was demonstrated with the USS <i>Peleliu</i> during the Kernel Blitz 1995 exercise. The results and lessons learned from these experiments and demonstrations are detailed in this report, as well as recommendations for concentrating research and development efforts on identified issues before future deployments of the HDR UHF LOS digital communication system.					
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