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WET END SYSTEM TEST BED (WESTBED) FY 78 DESIGN EFFORT.(U)

JUN 79 F P ARMOGIDA, H A IWAMOTO, D C SMITH

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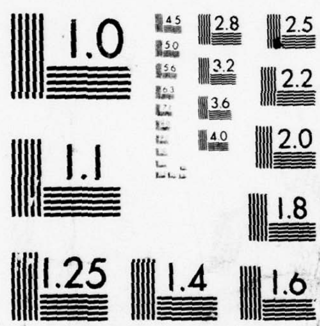

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WET END SYSTEM TEST BED (WESTBED) FY 78 DESIGN EFFORT

FP Armogida, HA Iwamoto, DC Smith,
DW Murphy, and Dr JM Stallard

June 1979

Final report - FY78

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AN ACTIVITY OF THE NAVAL MATERIAL COMMAND

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This report documents the FY 78 design and testing effort supporting the Wet End System Test Bed (WESTBED). The effort was directed toward redesign of WESTBED to facilitate the hardwiring of experiments at the surface of the ocean and demonstration of the data acquisition subsystem electronics.

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EXECUTIVE SUMMARY

The Wet End System Test Bed (WESTBED) is a deep ocean data acquisition system comprised of a shore terminal interconnected by submarine cable to remote data terminals which will accommodate the connection of experiment packages. The FY 78 effort was directed toward redesign of WESTBED to facilitate the hardwiring of experiments at the surface of the ocean and demonstration of the data acquisition subsystem electronics.

The WESTBED/experiment interface design effort resulted in the description of the mechanical characteristics of the WESTBED branch structures, the operations envisioned for their installation and maintenance, and the operations envisioned for the installation and removal of experiments.

The data acquisition subsystem effort concentrated on the demonstration of the high-frequency data telemetry channel and its interaction with the low-frequency power and command/control channels. For the first time, a 6.3-megabit-per-second (Mbps) digital signal was transmitted over 8 nautical miles of the candidate submarine coaxial cable (SD-C cable) in the presence of power and command/control signals. Bit error rates within acceptable limits were achieved (better than 1 error in 10^8 bits).

BACKGROUND

Currently, experiments that require equipment to be implanted in the deep ocean are complex and expensive. Tradeoffs must be made in terms of dollars for various aspects such as security, deployment time, operational versatility, reliability, and deployment platform capability. All these aspects affect the experimenter's primary objective, that of collecting data. The WESTBED was conceived as a permanent data acquisition system that allows various deep-ocean experiments to share a common trunk to shore. As illustrated in figure 1, the WESTBED was originally envisioned as a series of underwater junction boxes which could be extended into the deep ocean by plugging one into another. The junction boxes would contain inductive ports into which experiments could be plugged using an underwater vehicle. As a result of this year's effort, the WESTBED is now comprised of a repeatered trunk cable interconnecting undersea remote data terminals (RDT's) with a shore facility, illustrated in figure 2. Each RDT is capable of accommodating several separate experiments, each at the end of a cable branch (figure 3). Each branch is retrievable at the surface for easy connection or removal of the experiment. The cable system supports data telemetry from the experiments, and provides command/control (C^2) and power to the experiments. The shore facility provides a modest processing capability, plus recording and satellite communications for post-real-time and real-time processing, respectively, at facilities such as the Advanced Research Projects Agency Research Center and NOSC San Diego.

The WESTBED concept incorporates four technically challenging innovations:

1. The ability to quickly and economically retrieve and deploy individual branches from the surface using vessels that are sized to the particular experiment.

2. The use of long lengths of submarine coaxial cable (SD-C) to transmit high-bit-rate digital data.

3. The simultaneous transmission of high speed data shoreward and command, control, and power seaward (i.e., full duplex operation).

4. The three-way branching of power and telemetry.

The FY 78 efforts were aimed at the redesign of WESTBED to facilitate the easy hardwire connection of experiments at the surface of the ocean and the demonstration of the data acquisition subsystem electronics. A description of the service lead concept is given in the Service Lead Concept section. The data acquisition subsystem electronics and the successful demonstration of the data telemetry are described in the Data Acquisition Subsystem Test section.

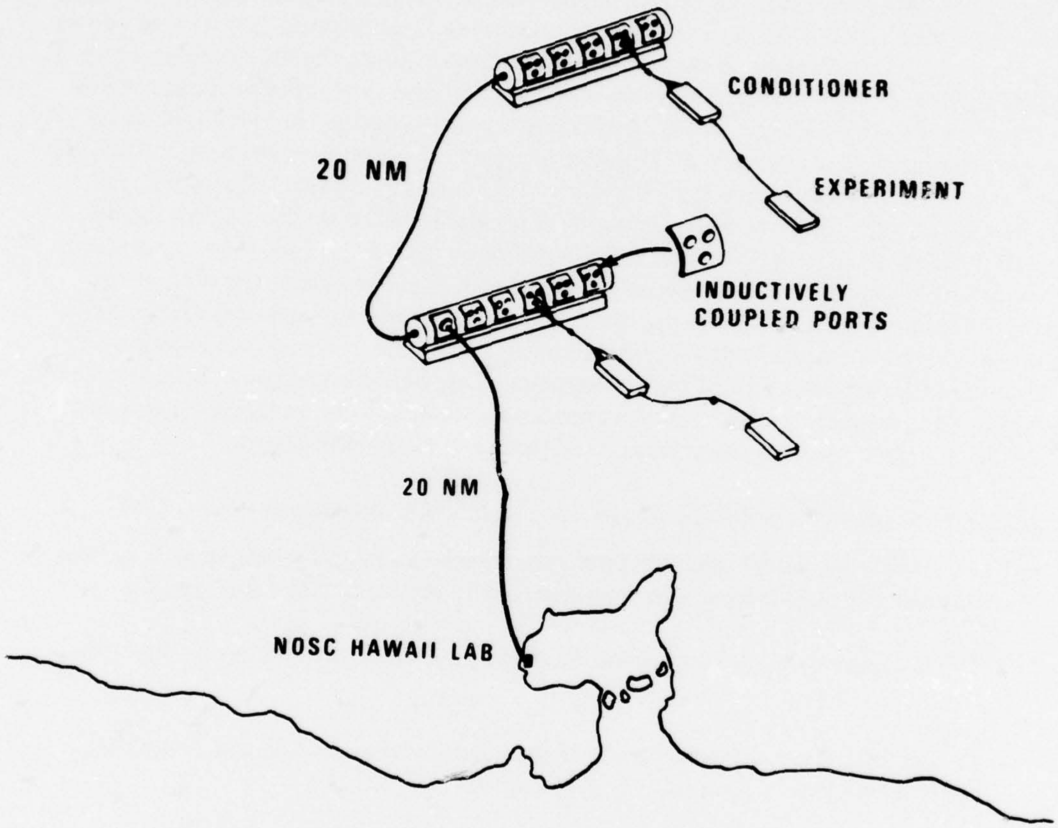


Figure 1. Original WESTBED concept.

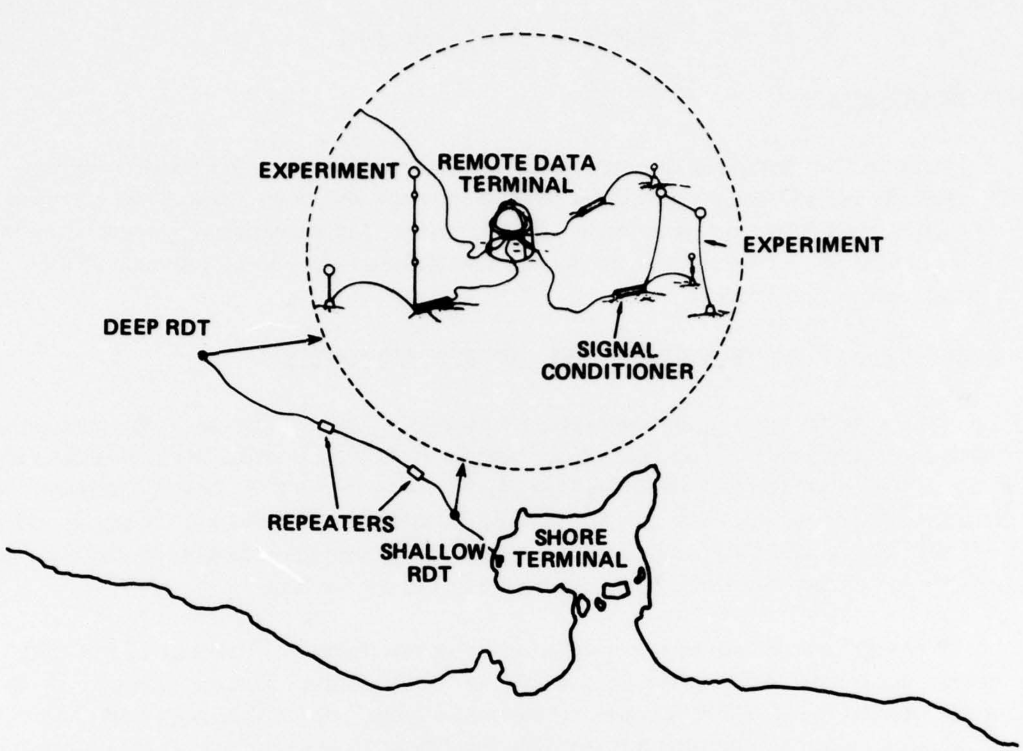


Figure 2. Wet end system test bed (WESTBED).

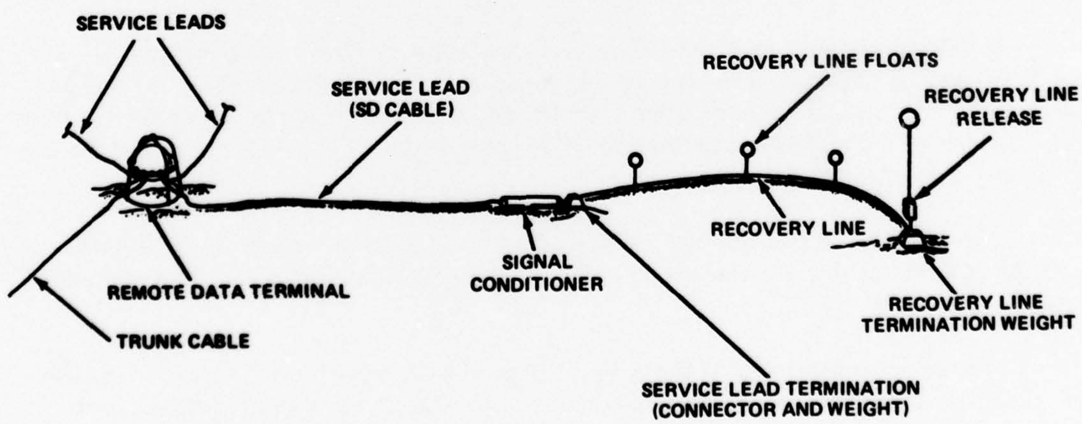


Figure 3. WESTBED service lead assembly.

SERVICE LEAD CONCEPT

INTRODUCTION

This section describes the mechanical characteristics of the WESTBED branch structures, the operations envisioned for their installation and maintenance, and a typical operation for installation and removal of an experiment. The operational approaches reflect the desire to simplify experiment installation/removal and the use of proven, reliable techniques whenever possible.

SERVICE LEAD AND RECOVERY LINE CHARACTERISTICS

Each service lead is unarmored type SD cable (see figure 2). Initial static line handling calculations (see appendix A) indicate that a length of 17,500 ft will allow lifting the end of the service lead to the surface while limiting cable tension to 5,600 lb (safety factor of 3.4). When raised to the surface from a depth of approximately 2,500 fathoms, the upper end of a 17,500-ft service lead must remain within a circle about one nautical mile in diameter in order to avoid excessive tension being developed in the service lead.

The service lead recovery line will have a stepped diameter. The first 12,000 ft of line extending out from the service lead would be "Power Braid" Samson Line (1.125" in diameter) while the last 9,500 ft would be Kevlar "Uniline" (0.375" in diameter). This mechanical design approach permits a reasonably-sized float to raise the end of the recovery line to the surface and maintains the line in a vertical orientation even with relatively large surface currents. The assumed current profile is 3 knots from the surface to 1000 ft, 1 knot over depths of 1000 to 4500 ft and 0.2 knot in the depth range from 4500 ft to the bottom; however, the actual current profile will be established during initial site studies. The small diameter line near the surface allows the float and the line to rise through the high surface currents and to maintain a near vertical orientation near the surface. The small line is then used to acquire the end of the larger diameter line, which in turn has sufficient strength to lift the major portion of the service lead to the surface.

The recovery float used in the initial sizing calculations has a positive buoyancy of 1,500 pounds. The float was assumed to be configured as an elliptical body of revolution displacing 47 ft^3 and constructed from 32-lb/ft^3 syntactic foam (such as Emerson Cummings type EL32 with a 20,000-ft operating depth). A conservative CDA of 5 ft^2 was used for the float drag calculation.

The recovery line is also buoyed along its entire length to keep it off the bottom. The floats used for this purpose could either be syntactic foam or of the Benthos glass sphere type.

The release mechanism at the outboard end of each recovery line assembly consists of dual (fully-redundant) acoustic release units such as those manufactured by AMF or Ocean Research Equipment, Inc. The units would be mounted in such a manner that actuation of either acoustic release would separate the recovery float from its anchor weight.

An alternative to the acoustic release or an additional level of redundancy could be obtained by incorporating a pyrotechnic release at the outboard anchor. This would require electrical conductors within the recovery line (not an overly difficult task); however, the vulnerability of these conductors to damage during line handling operations must be investigated before such an approach is recommended.

WESTBED INSTALLATION

At the outset, the length and type of cable being used demands that a cable-laying ship be used for initial installation of the WESTBED. Since cable ships are few in number and their time is at a premium, WESTBED installation concepts are based on the use of one cable ship supported, if necessary, by other types of surface craft (e.g., ships, barges, tugs, etc.).

Installation of the main trunk cable from the shore facility to the test sites is viewed as a straightforward operation using standard methods. However, installation of the RDT's and the service leads at each site is far from standard. Since each of the three service lead assemblies is about 49,000 ft in overall length, the chances for tangling and fouling the equipment during installation are significant and must be minimized. Two approaches for equipment installation at each site have been conceptualized to serve as a point of departure for future discussions. This is an area where much communication with the deep-ocean cable system community will be required before the techniques and methods are finalized.

In the initial concept, the WESTBED installation ship would implant a deeply-moored buoy field upon arrival at the site. The buoy spacing, buoy displacement and mooring scope would be selected to establish the WESTBED equipment geometry desired at the site (see figure 4). Service lead cables would then be installed between the outer buoys and the central buoy; the interim situation depicted in figure 4 presents a profile view of the buoy field supporting the service leads. After the service leads are laid between the buoys, the cable ship would recover the main trunk cable. The main trunk cable and the service leads would then be connected to the remote data terminal on board the cable laying ship. The RDT would then be lowered to the bottom with the trunk cable and all three service leads attached. The last sketch in figure 4 shows the system configuration after the RDT has been lowered into position. The cable ship, or a support craft such as the SSP KAIMALINO, would then deploy the recovery line assembly for the RDT. Upon completion of this task, each of the individual service leads would be installed in place, together with its associated recovery line, floats, anchor and acoustic release mechanism.

The second conceptual approach is similar to that described above but would not employ the outer buoys. Instead, the service leads would be installed directly on the sea floor together with their recovery lines, anchors, floats and acoustic release mechanisms. The inboard end of each service lead would be temporarily attached to the central buoy (see figure 5). The cable ship would then recover the main trunk, connect it and the service leads to the RDT, and then lower the entire assembly to the sea floor. After the RDT's recovery line is installed, each of the service leads would be recovered and pulled into its proper position.

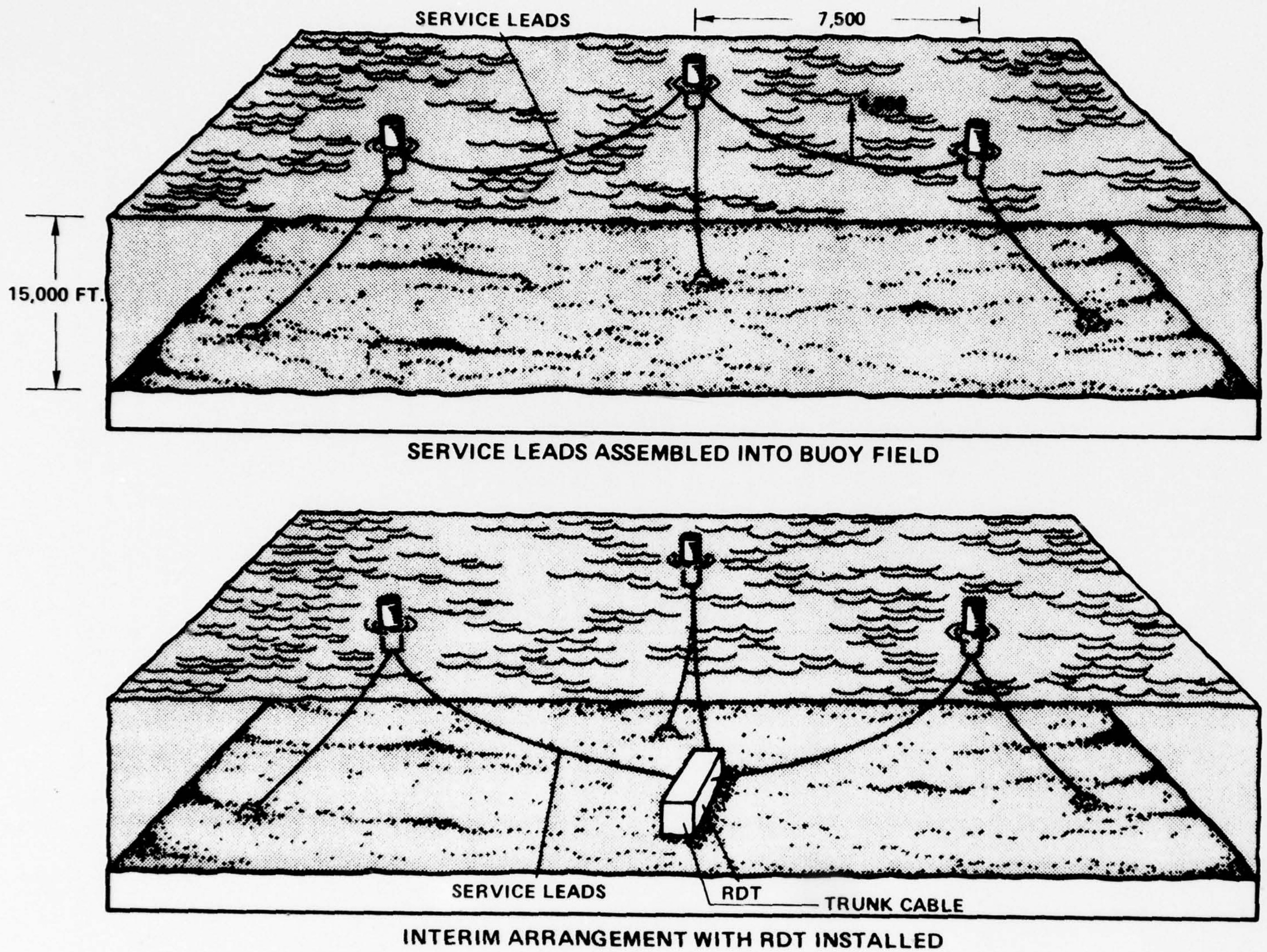


Figure 4. WESTBED installation concept using deeply-moored buoy field.

EXPERIMENT INSTALLATION AND REMOVAL

Recovery of the service lead for experiment installation/removal purposes begins when the support craft arrives in the vicinity of the desired cable end. When the ship is within sonar transmission range, it will send an acoustic command to the dual acoustic release units at the outboard end of the service lead recovery line. The acoustic command will actuate the release causing the outer end of the recovery line to rise to the surface. The buoyed end of the recovery line is then retrieved aboard the support ship and the signal conditioning module (SCM) end of the service lead is hauled to the surface. After the SCM and a short section of the service lead are brought aboard the support craft, the new experiment can be connected or the old one removed. During installation and/or removal operations, the ship must maintain its position within a prescribed area (typically 1 nmi in diameter) in order to prevent excessive tensions in the service lead.

The actual connection of experimental hardware to the SCM will be accomplished aboard the servicing ship. Once attached, the end of the service lead together with the experimental system will be deployed to its desired position. Depending on the experiment's complexity, the new experimental hardware could be deployed:

- -- from the support craft in conjunction with and as a continuation of the service lead reinstallation procedures;
- -- from the same support ship, but separately after the service lead has been reinstalled (i.e., through the use of a long connecting cable); or
- -- from a separate ship or barge.

Regardless of the arrangement used to install the experimental hardware, the recovery line assembly for the service lead must be reinstalled. In most instances, the recovery line will probably be used to reinstall the service lead and the cable connecting the SCM to the experiment (i.e., lower the service lead, SCM and connecting cable to the bottom). After the service lead and SCM have reached the ocean floor, the recovery line would be kept in place by its own float while the remainder of the experiment is implanted. Subsequently, the support ship would return to the recovery line float, attach new acoustic release mechanisms and mechanical termination hardware, and then reinstall the recovery line assembly in a predetermined location.

The first several experiment installations will be complex and unfamiliar undertakings. Hence, operation plans will be carefully designed through the use of scale models, computer simulations and subsystem trials. Contingency plans (table 1) will be developed for those faults or failures which have maximum impact upon the installation. These plans will be thoroughly evaluated during practice runs and work-up exercises with changes made, as necessary, to correct any deficiencies or shortcomings noted in the trials.

Experiment removal is a more straightforward operation. After the SCM and service lead have been brought aboard, the connecting cable would be removed from the SCM. If no other experiment were to be installed at this WESTBED port, the SCM terminations would

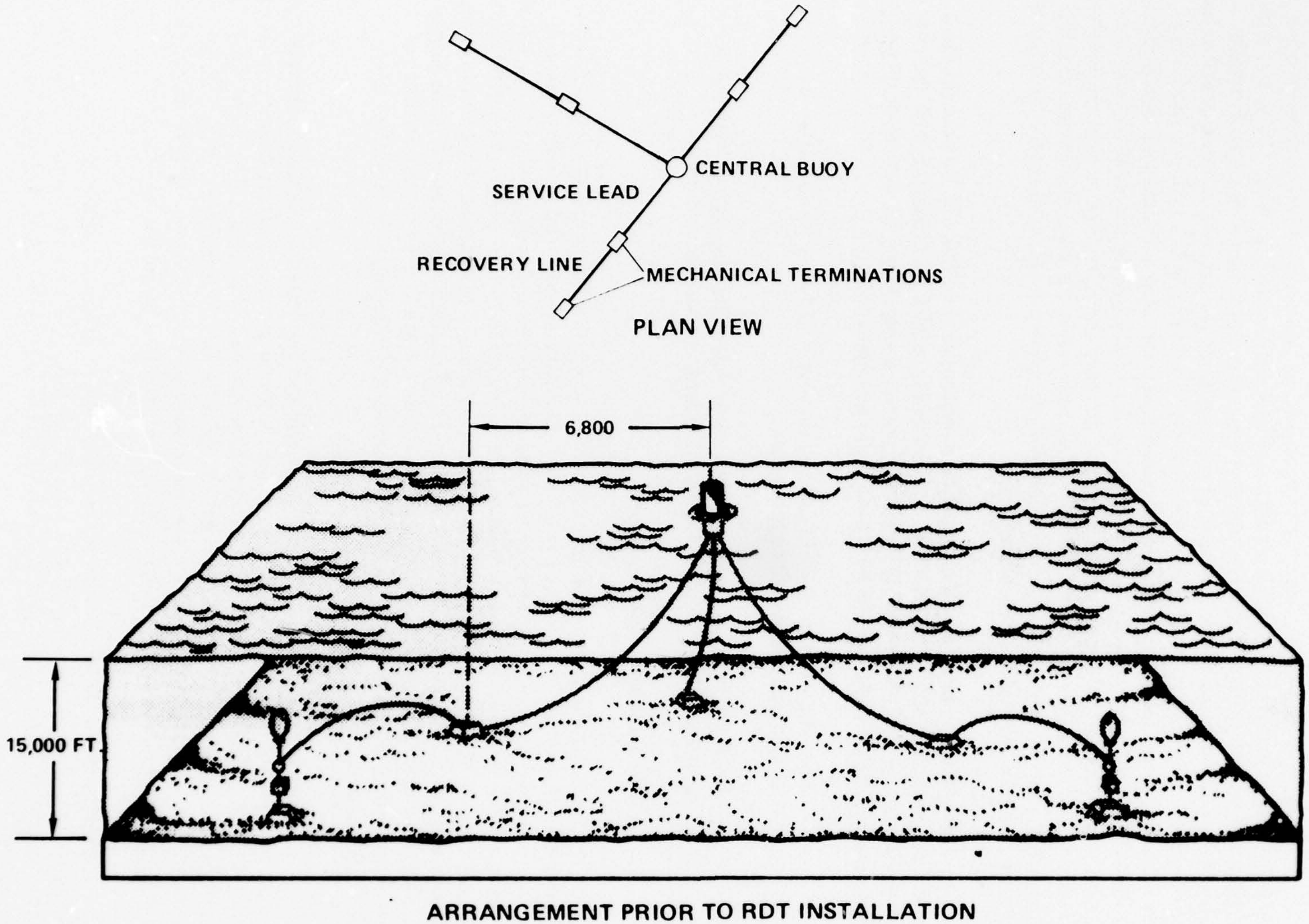


Figure 5. WESTBED installation concept using one central buoy.

be secured with a pressure resistant seal (i.e., the service lead would be "stubbed off"). The service lead would then be reinstalled with its own recovery line. The free end of the experiment connecting cable would be buoyed off temporarily while the service lead and its associated recovery line assembly were being reinstalled.

Alternately, the free end of the experiment connecting cable would be secured to a winch aboard the servicing ship (or some other support craft) while the service lead was being reinstalled. After the SCM and service lead were returned to the sea floor, the service lead's recovery line could be buoyed off temporarily with the recovery float while the servicing ship removed the experimental apparatus. Subsequently, the service lead recovery line would be reinstalled in a predetermined position.

Table 1. WESTBED wet end fault conditions and associated repair actions.

Potential Failure Mode	Repair Action
1. Acoustic release malfunction.	1. Grapple for recovery line, raise system and replace acoustic release.
2. Loss of recovery line buoying.	2. Grapple for recovery line.
3. Fouling of recovery line or service lead.	3. Utilize another service lead, clear the fouled lead using a submersible.
4. Recovery line failure.	4. Attach a new line with a submersible grapple for the service lead.
5. Service lead damage.	5. A. Don't use again. B. Make leads replaceable–possibly every so many years the field would be raised and all of the leads replaced and equipment refurbished.
6. Remote data terminal (RDT) failure.	6. Replace the RDT by recovering it and attaching a new RDT into the system. This would require disconnecting the service leads and possibly raising the individual experiments.

MAINTENANCE AND REPAIR

From an operational viewpont, maintenance of the wet end can be viewed in terms of two basic situations: faults within the RDT, and problems with the main cable or the service leads. The potential problems and plausible repair actions are summarized in table 1. As indicated in the table, faults within the RDT have the most significant impact on the operation of the system and require major system repair. Although the remote data terminal will be designed to satisfy very demanding reliability requirements, it is possible that an equipment failure may occur which severely degrades the system. Access to the RDT may also be required at some indefinite future date in order to upgrade the data telemetry process. Hence, the ability to recover and replace the RDT will be included in the system's mechanical design. Operationally, the recovery sequence would be as follows:

a. Upon arrival at the site, the service lead/RDT disconnect mechanisms would be remotely actuated to disconnect the service leads from the RDT.

b. A release command would then be transmitted to actuate the acoustic release mechanism at the outboard (float) end of the RDT's recovery line. The mechanism would release the recovery float, which would then raise the recovery line to the surface.

c. The RDT and main trunk cable would then be hauled to the surface using the recovery line.

Aboard the recovery craft one of the several procedures could be followed:

-- The RDT could be removed from the main trunk cable, repaired on shore, and then reinstalled; or

-- A new RDT unit could be connected to the trunk cable after removing the faulty unit.

If the RDT were removed, the main trunk cable would be "stubbed off" and then lowered back to the ocean floor for future recovery and reconnection. In the latter case, new service leads (or the old ones if they were recovered and found to be in acceptable condition) would be connected to the RDT prior to reinstallation. Depending upon the operations plan, individual service leads would be recovered independently (using their own acoustic releases and recovery lines) either before or after the RDT recovery event.

SUPPORT EQUIPMENT

Support equipment needed for experiment installation/removal and WESTBED maintenance includes surface craft, heavy-duty winches and cranes, and navigation equipment. Since experiment installation/removal events are relatively infrequent, there does not appear to be a need for a surface ship dedicated to the WESTBED's use. However, since maintenance and repair may be required at any time, all winches and cranes needed for repair actions should be available on short notice, if such items are not dedicated to the WESTBED's use.

At present, a Navy-owned barge appears to be the most cost-effective surface craft for WESTBED support purposes. The WESTBED range-support barge would be outfitted with the available complement of winches and cranes together with special-purpose equipment handling gear (e.g., racks, storage compartments, recovery line storage reels, handling fixtures, etc.). If the barge were only available on an as-required basis, the same sort of deck equipment would be arranged in a modular fashion for rapid mobilization and would be stored in a location close to the barge staging area. Tugboats and other support equipment would be leased "on call" as the need arose.

At least one (and perhaps two) heavy duty winches should be purchased as dedicated WESTBED support equipment. One winch should be capable of handling both the 0.375-inch and 1.125-inch diameter recovery lines. This winch should be able to recover line at variable rates from 0 to 60 ft/min under loads of 6000 lb. The maximum pulling capacity should be at least 10,000 lb. The second winch will be required to handle the service lead (Type SD unarmored coaxial cable) and similar cables. This winch will require larger diameter drums than the line handling winches due to the larger bend radius constraint imposed by the SD cable. Since the need for the second winch should not occur very often, it would be cost effective to obtain the winch from one of the Navy equipment pools. A candidate winch for this function is the 20,000-lb, two-drum Pingo winch that should be available on a loan basis from the NAVFAC Emergency Salvage Support Materials (ESSM) pool.

Surface and subsurface navigation systems will be needed for accurate positioning of surface craft, submersibles, connections and experimental targets. Navigation aids are needed so that surface craft can return to the site locations for placement of system components and/or acoustic experiments. Since the navigation aids must be reliable and accurate for the lifetime of the WESTBED, primary reliance will be placed on the surface navigation system for geodetic positioning. It will be used as the master reference to establish the locations of bottom-moored acoustic transponders.

Accurate placement of items on the seafloor will require the use of a subsurface acoustic navigation system. This system will be deployed on an as-required basis, using recoverable acoustic transponders. The transponder field might be interrogated from the RDT location, the service lead terminations (SCM's) or the surface ship. Suitable acoustic navigation systems are readily available and include the ATNAV II system, manufactured by AMF, and the TRANSNAV system, manufactured by Ocean Research Equipment, Inc. (ORE). To establish the exact position of individual WESTBED components installed on the ocean floor, a broadband hydrophone will be incorporated on each major component in order to transmit acoustic navigation signals.

DATA ACQUISITION SUBSYSTEM TEST

The data acquisition subsystem test demonstrated the capability to transmit digital data at 6.3 megabits per second over 8 nautical miles of SD-C cable in the presence of power and command/control (C^2) signals. While the power level was a fraction of that required to support wet end experiments, the crucial accomplishment was the transmission of high rate digital data over long lengths of coaxial cable with low bit error rates (less than 1 error in 10^8 bits). Navy standard type SD-C cable was selected over SF and SG types because it was made available for testing at no cost to the project by the Naval Electronic System Command (PME-124). This same SD-C cable is the most likely WESTBED trunk cable.

TEST DESCRIPTION

A breadboard of the telemetry subsystems was taken to Simplex Wire and Cable Company in Portsmouth, New Hampshire, for demonstration and evaluation with SD-C cable. The test setup (figure 6) duplicated the most important basis components of the complete WESTBED system (figure 7).

The experiment package contained a data generator which produced the digital data and an oscilloscope which monitored the power and command/control signals. The conditioner contained a driver that amplified the digital signals and a signal separator consisting of two parallel sections, each passing desired signals by selective filtering. The shore station package contained another signal separator and an AM modulator which produced the command and control signal that was amplitude-modulated on the power signal. The equalizer compensated for the amplitude and phase distortion introduced by the cable while the synchronizer regenerated the digital data. The bit error rate detector provided a quantitative assessment of performance by comparing the received data with the data transmitted by the data generator. The following sections describe the results and details of the tests.

TEST RESULTS

Basically, two telemetry tests were conducted with the SD-C cable: (1) data transmitted alone; and (2) data transmitted simultaneously with control signals. These tests demonstrated, first, that 6.3 Mbps of digital data can be transmitted over SD-C coaxial cable with low bit error rates (BER). Measurements of cable attenuation, equalization, group delay, eye patterns, and received signal level added confidence to the low error rates obtained. A bit error rate of 10^{-8} was achieved (one error in every 10^8 bits) with a pseudo-random bit pattern 2^{23} -1 bits long. This low bit error rate per repeater section will lead to an overall system bit error rate of 10^{-7}, which will provide a very high quality data transmission system for WESTBED users. Also, low bit error rates during the second test showed that a command/control channel below 10 kHz gives negligible interference with the digital telemetry signal. These conclusions were supported by measurements of the signal separator attenuation characteristics.

DETAILS OF THE TELEMETRY DEMONSTRATION

EQUIPMENT SETUP

The telemetry equipment was interconnected as shown in figure 8. The data generator outputs a pseudo-random sequence of nonreturn-to-zero-level (NRZ-L) digital data. The encoder converts the NRZ-L data to a bipolar signal with three-zero substitution (B3ZS). B3ZS format was chosen because it has a few low frequency components, and therefore would reduce interference with the command and control channel centered at 10 kHz. The driver amplifies the bipolar B3ZS signal to ± 7 volts pk-pk and passes it onto the cable (figure 9A).

At the other end of the cable, the signal passes through the equalizer (figure 9C) and is then filtered and amplified to a usable level (figure 9D). The digitizer provides an

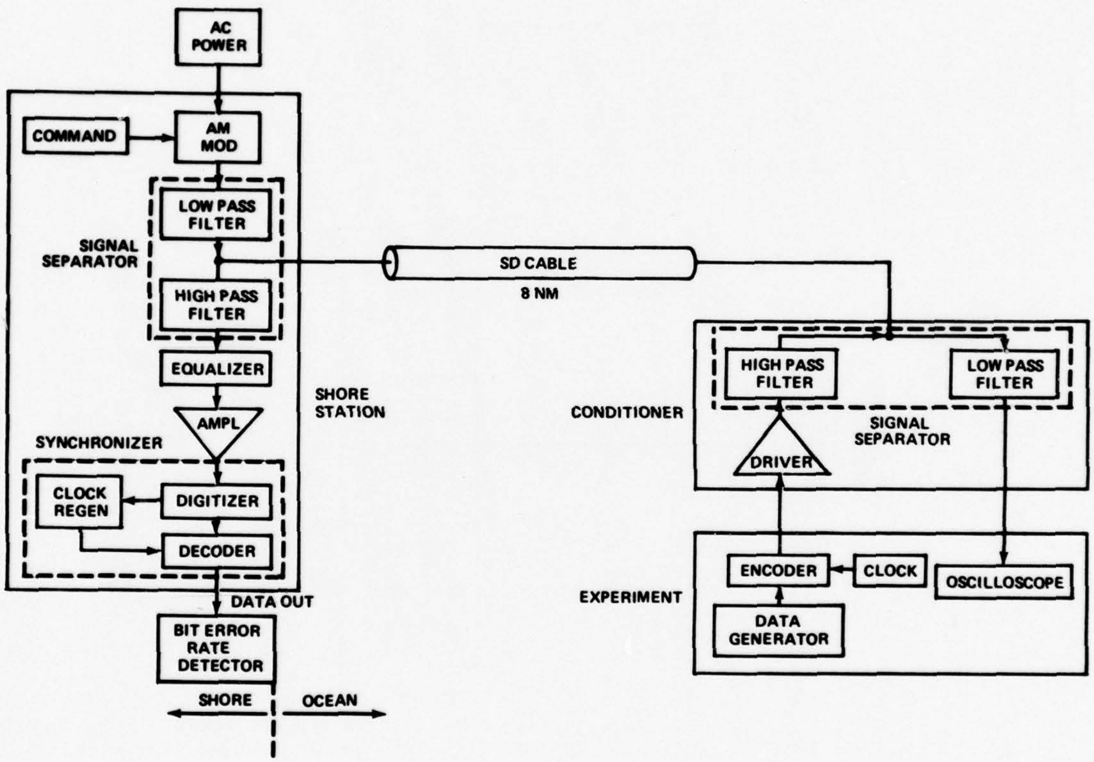


Figure 6. Telemetry with command and control.

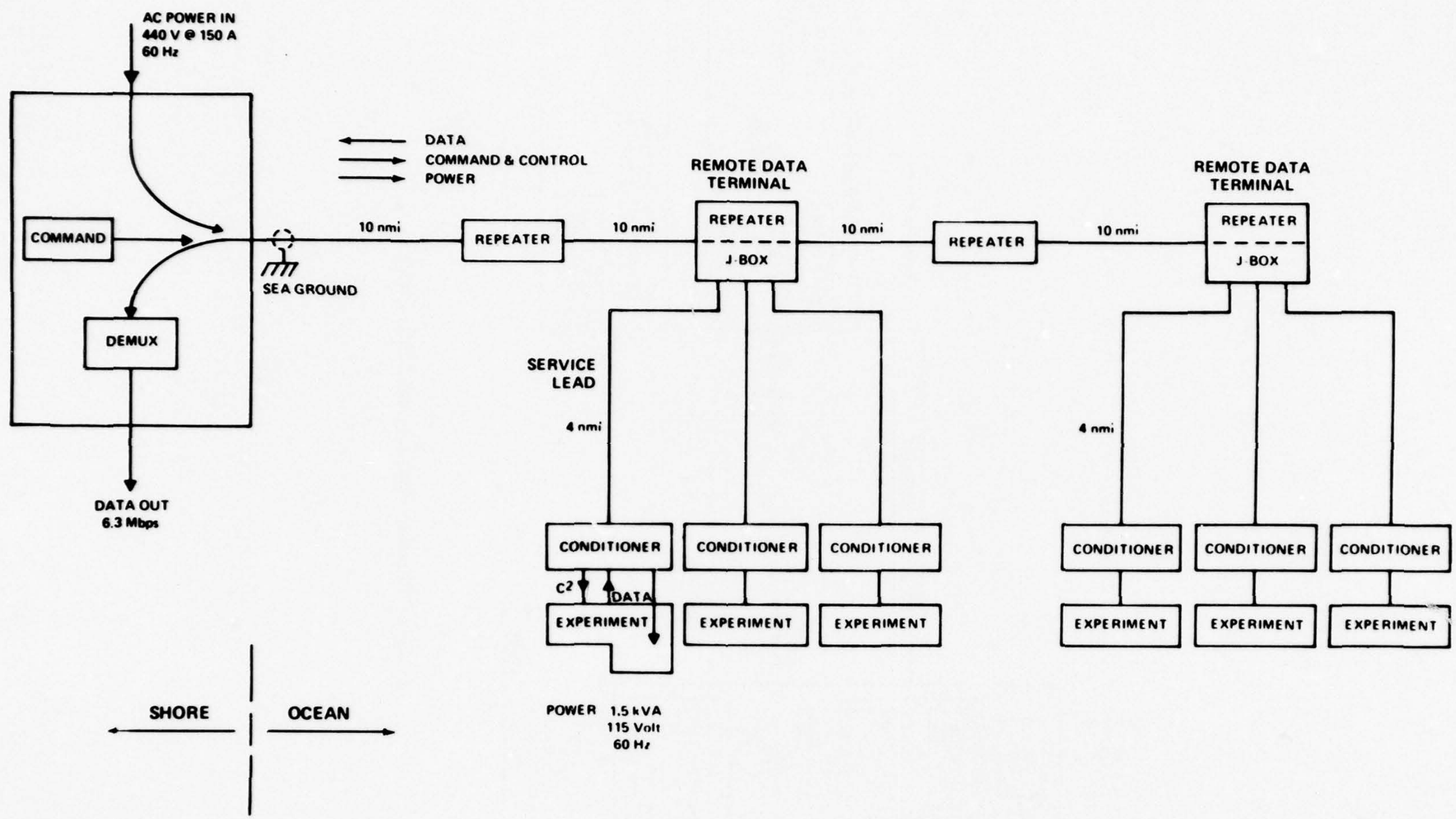


Figure 7. WESTBED block diagram.

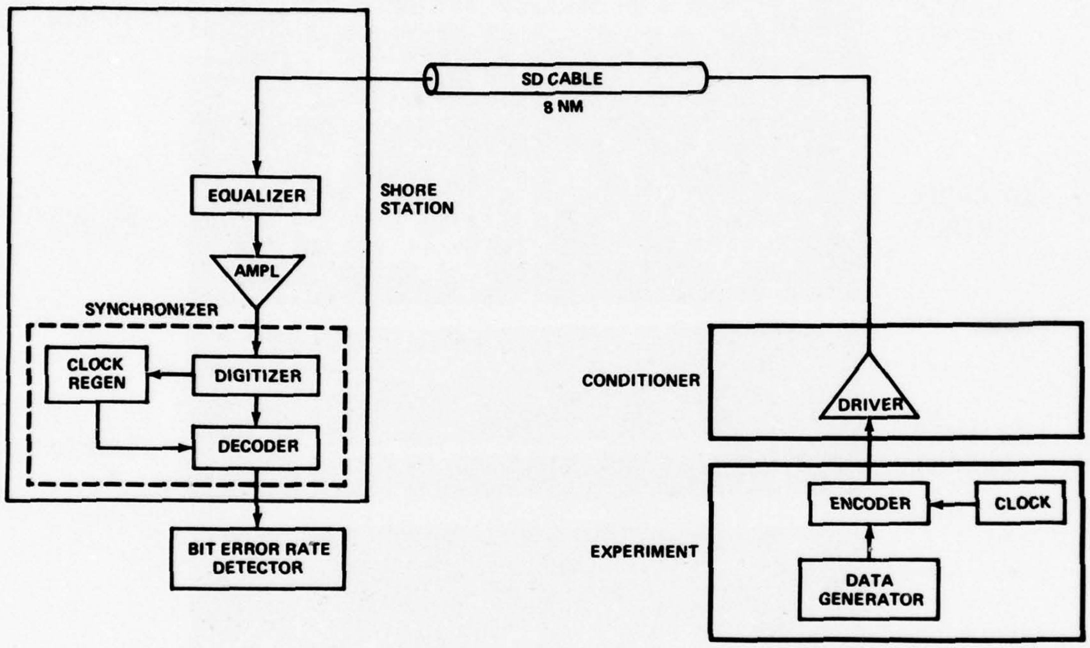


Figure 8. Telemetry.

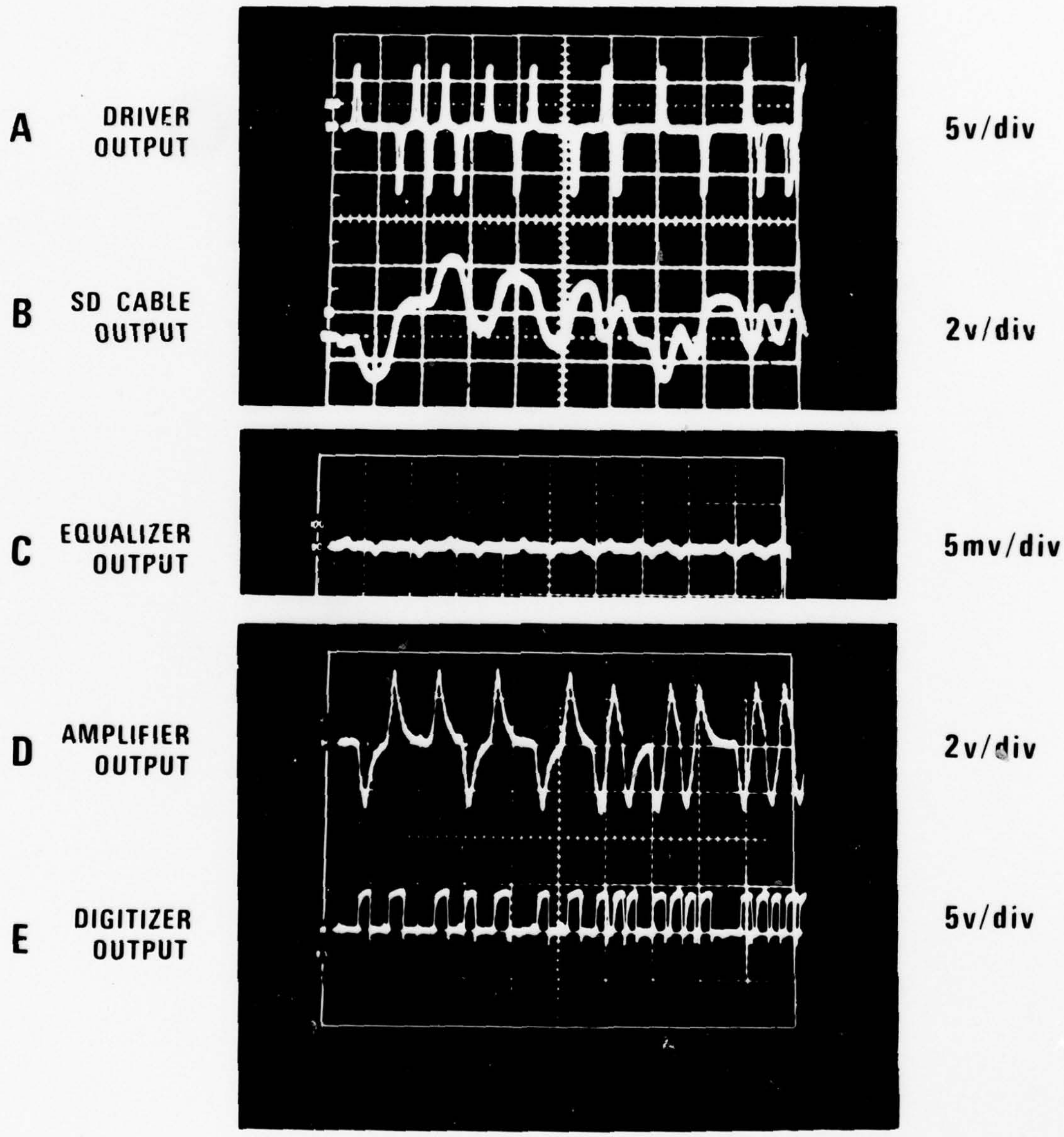


Figure 9. Telemetry waveforms.

interface to the decoder and the clock regeneration circuitry (figure 8). The decoder, in conjunction with the clock regenerator, provides the bit error rate detector with the needed NRZ-L digital signal.The bit error rate detector compares the decoder output to an internally-generated pseudo-random bit pattern identical to the output of the data generator.

As stated earlier, bit error rates of less than 10^{-8} were regularly obtained with various pseudo-random bit patterns, the longest being 2^{23}-1 bits.

SD CABLE ATTENUATION

Prior to these tests, there was no available attenuation versus frequency data of long lengths of SD cable below 10 kHz or above 1 MHz. In order to design attenuation equalizers that would enable digital data to be transmitted over the cable, the attenuation versus frequency characteristic was extrapolated from existing data. The attenuation of the test cable was measured at Simplex prior to the telemetry test to verify the computer-extrapolated data. Figure 10 shows the close agreement between the predicted and measured attenuation curves (A and B).

EQUALIZER MEASUREMENT

Cable equalizers are necessary to compensate for the cable's inherent attenuation characteristics. The equalizer characteristic (figure 10C) was designed using the predicted cable characteristics in order that the sum of the cable and equalizer provide a constant attenuation at all frequencies within the band of interest. Figure 10D shows that the measured attenuation for the cable and equalizer is flat within the pass band and no amplitude distortion results because all the frequency components of a waveform are attenuated equally.

GROUP DELAY MEASUREMENT

Group delay measurements were made on the cable system with and without the equalizers. Phase distortion results in a transmission medium when the phase shift through it is a nonlinear function of frequency. A convenient indication of nonlinear phase shift is group delay. If the phase shift through the channel is a linear function of frequency, the group delay will remain constant and the signal is transmitted without phase distortion. Figure 11 shows the equipment setup for the group delay measurement. The phase of the modulating signal is compared with the phase of the demodulated signal as the carrier frequency is swept through the band of interest 20 kHz - 4 MHz, which is the bandwidth required for 6.3 Mbps of data. The group (time) delay of the carrier frequency is then calculated from this phase difference and is plotted in figure 12. It is seen that in the equalized system, the group (time) delay is flatter when compared to the nonequalized system.

EYE PATTERNS

In a digital telemetry system, eye patterns are unsynchronized oscilloscope waveforms that indicate the quality of the received data. The eye pattern is a composite of all the incoming pulses and the distortion associated with them.

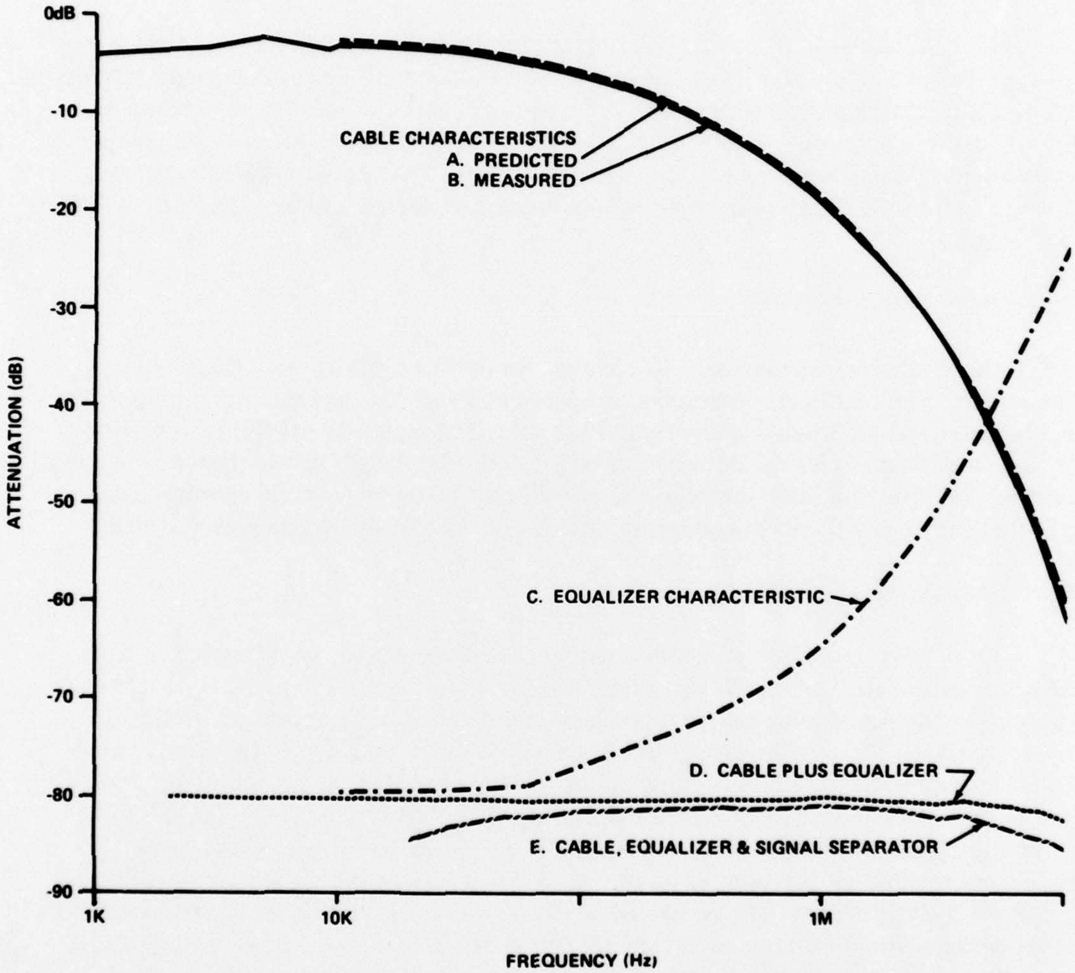


Figure 10. SD cable characterization (8nm).

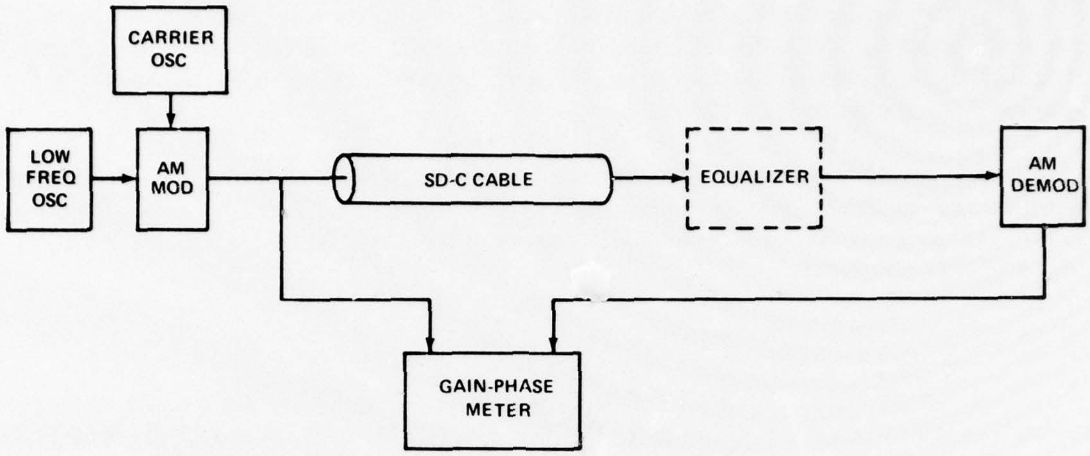


Figure 11. Group delay measurement.

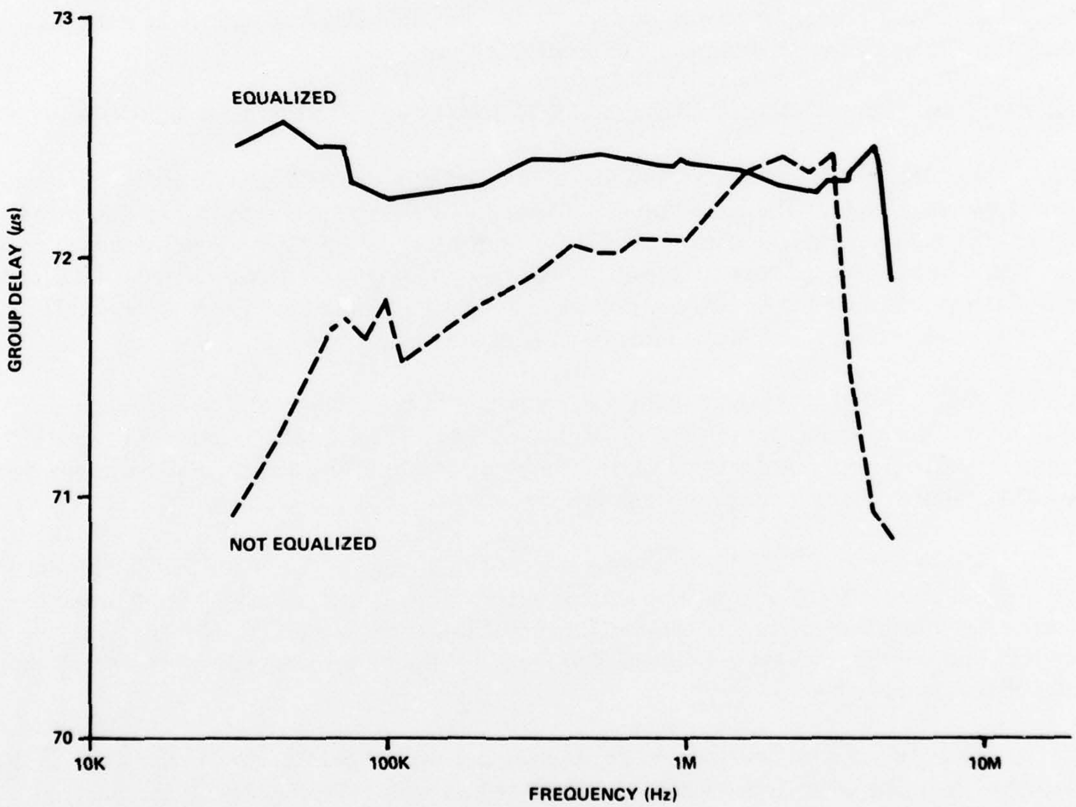


Figure 12. Group delay vs frequency.

The unequalized SD cable output signal, as shown in figure 13, represents a closed eye pattern and is an indication of the amount of distortion introduced by the cable. Here, it is seen that a threshold detector cannot make a "one"-"zero" decision and that it is impossible to re-digitize the incoming data.

The equalizer output eye pattern, as shown in figure 13, is representative of an open pattern and indicates the ease with which one can make the needed "one" or "zero" decision. All that is needed is to set a threshold detector at the center of the eye, where the detection probability is maximum.

SIGNAL-TO-NOISE RATIO (SNR)

A design goal of a 20-dB SNR was chosen because a digital signal can easily be recovered at this level. As shown in figure 10, the cable and equalizer attenuate the data signal about 80 dB so that the equalizer output is about 0.6-millivolt (mv) pk. It is the SNR of this signal that is critical, because if it is too low the digital data cannot be recovered.

Since the level of the noise was well below our ability to measure it with the test equipment available, the following speculation can be made. Since the 0.6-mv signal was easily filtered, amplified, digitized, and decoded with acceptable bit error rate, the SNR at the equalizer output had to be greater than 20 dB. This indicates that very little noise was added to the signal by the cable and equalizer.

DETAILS OF THE COMMAND AND CONTROL (C^2) INTERFERENCE DEMONSTRATION

The ability to receive 6.3-Mbps digital data in the presence of a command and control signal was investigated. The test setup is shown in figure 6. Here it is seen that an AM modulated low frequency signal is transmitted in the opposite direction to the high frequency digital data. The signal separators are shown as high pass and low pass filters in parallel. The low pass filter passes the C^2 data while appearing as a high impedance path to the C^2 data. The filter characteristics of each signal separator are shown in figure 14.

A 10-V pk-pk AM modulated C^2 signal was introduced while simultaneously transmitting 6.3-Mbps digital data in the opposite direction. The carrier frequency of the AM signal was varied from 100 Hz to 100 kHz. The bit error rate of the digital data was monitored while the AM carrier was swept through this range.

The results of this test are shown in figure 15. "Good data" implies that the bit error rate (BER) did not increase from that found in the telemetry section, which implies that there is no interference. "Errors" imply that the BER started to increase, and "no sync" implies that the data was interfered with too much for the bit error rate detector to lock on and count errors.

Figure 15 shows that there is no interference up to 10 kHz, then errors start to increase, then disappear from 13 kHz to 16 kHz, where sync is finally lost. This can be explained if the curves for the low pass and high pass sections are added together. It is seen that the attenuation of the summation of both sections decreases between 10 kHz and 13 kHz, allowing interference to couple through (figure 14). The summation curve then

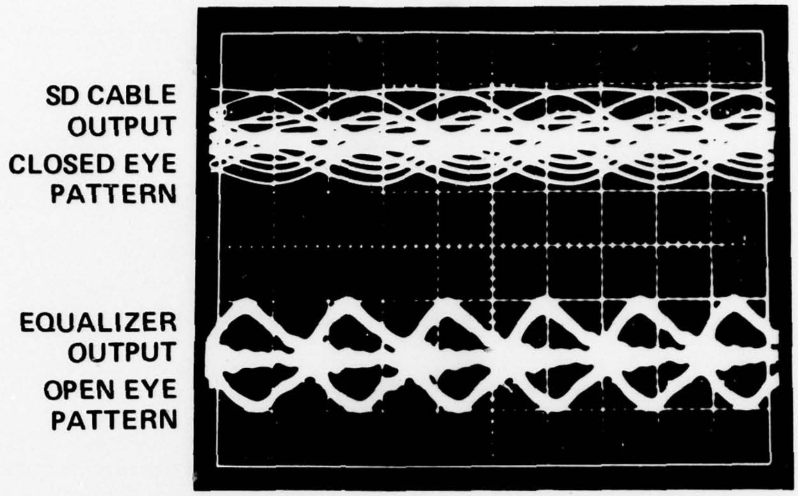


Figure 13. Eye patterns.

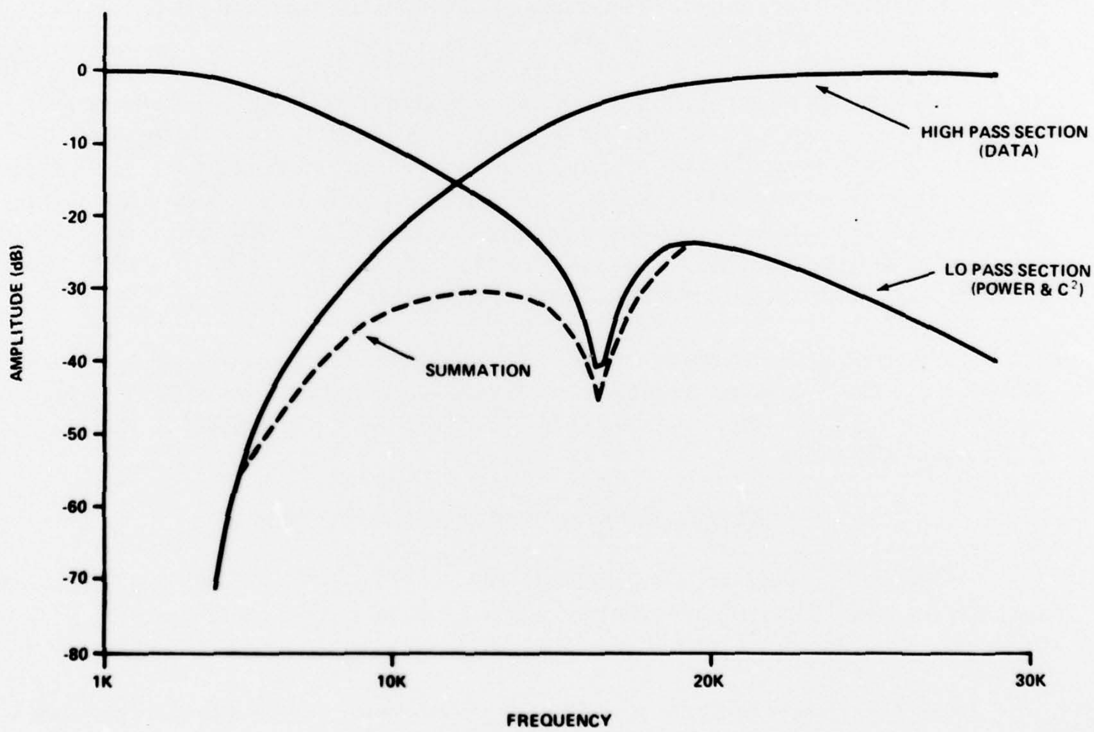
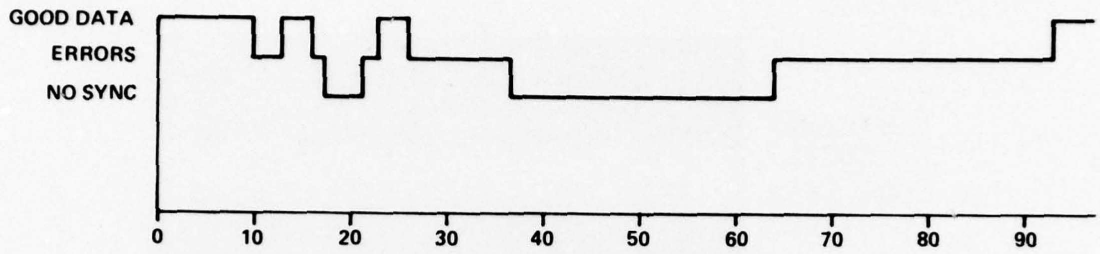


Figure 14. Signal separator filter characteristics.



% MODULATION AND MODULATING FREQUENCY DOES NOT HAVE ANY EFFECT ON INTERFERENCE

Figure 15. C^2 interference.

increases in attenuation between 13 kHz and 16 kHz, shutting off the interference, and then decreases above 16 kHz, causing a loss of sync. The good data at around 25 kHz, the regain of sync after 60 kHz, and good data after 90 kHz can be explained by the continued roll-off of the signal separators beyond the design limits of the low pass filter.

In addition, it was noted that the percent of modulation and the modulating frequency had no effect on the interference. Even with the signal separator's rather slow filter roll-off characteristics, a 10 kHz modulated C^2 signal can be passed with no interference to the digital data. This data carrier frequency can probably be increased by improving the roll-off of the low pass filter, increasing the low frequency cut-off of the high pass filter, and inserting a C^2 channel between 10 kHz and 20 kHz.

The signal separator characteristics were designed for a C^2 signal, AM-modulated on the 60-Hz power. Later, it was decided that there was probably room for the C^2 signal between the 60-Hz power and the low frequency components of the digital signal. If the C^2 signal could be fit in between these two, the C^2 data rate could be increased considerably. However, the contract for the equalizers and signal separators was let before this was decided, and thus the low pass section of the signal separator was designed for 60 Hz, and the low end of the high pass had a low frequency cut-off point of 20 kHz.

In view of the encouraging results of the interference test, the C^2 channel will be shifted to at least 10 kHz. An additional test, to determine the maximum low frequency cut-off of the high pass filter, will have to be conducted in order to specify the final design of the signal separators.

CONCLUSIONS AND RECOMMENDATIONS

This year's analysis and testing clearly indicate the feasibility of the WESTBED concept. On the basis of the telemetry results, it appears possible to disperse repeaters at 20-nmi intervals.

The next logical steps are to (a) design, install, and exercise a prototype service lead assembly; (b) conduct a power analysis to fully characterize the power subsystem; and (c) design and implement a telemetry test with full system power to determine the maximum permissible length between repeaters.

APPENDIX A

PRELIMINARY MECHANICAL DESIGN ANALYSIS

INTRODUCTION

A very preliminary analysis of mechanical loads has been conducted to estimate the following WESTBED design parameters:

1. Line loads to be seen during service lead deployment and recovery;

2. The minimum reasonable service lead length;

3. Station keeping requirements imposed upon the service craft in order to avoid undue loads on the service leads; and

4. The size, length and required flotation characteristics of the service lead recovery line.

Only static loads have been included in this analysis; dynamic loads have not been considered.

SERVICE LEAD RECOVERY PARAMETERS

Given:

Cable Type: SD
$w = 0.317$ lb/ft in water
Breaking strength = 19,500 lb
Water depth: 15,000 ft

Find:

Maximum service lead loading, minimum service lead length and the station keeping requirements for the surface craft.

Assumptions:

1. The cable acts as a catenary with no vertical load present in the cable at its point of tangency with the bottom.

2. The system will remain static.

3. The maximum cable stress will occur at the surface.

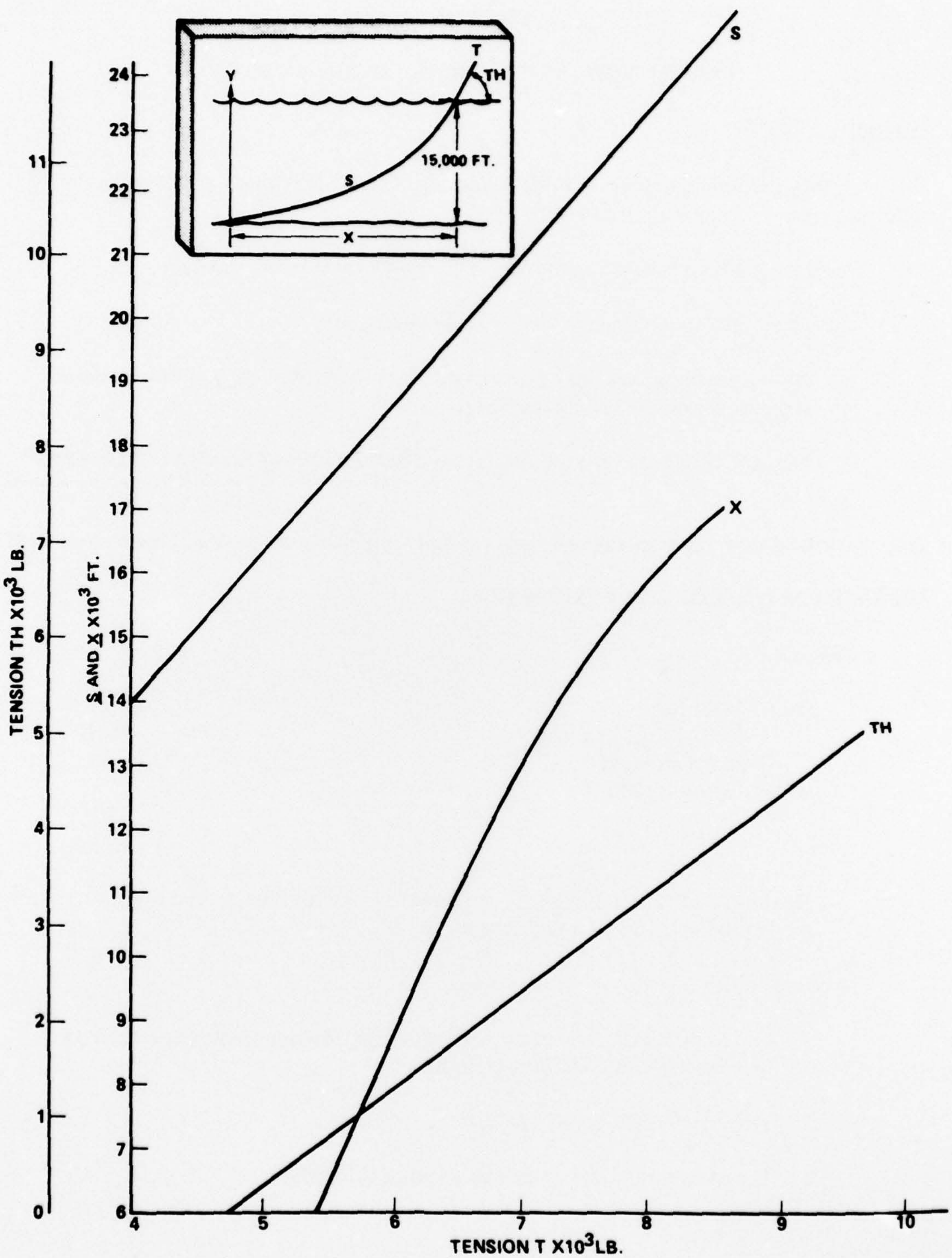


Figure A-1. Service lead recovery parametric relationships.

For the configuration shown in Figure A-1:

$$S = \text{Cable Length} = 2Y(T/W) - Y^2$$

$$X = \left(\frac{T}{W} - Y\right) \text{Cosh}^{-1} \left(\frac{T/W}{T/W - Y}\right)$$

$$T_H = T - WY$$

These relationships have been solved for values of T from T = 5,000 lb to T = 8,000 lb. The results are also presented in Figure A-1. From these curves, a cable tension at the surface of 5,600 lb was selected. This value, although rather arbitrary, provides a reasonable compromise between cable length (it has to be at least 15,000 ft long), reasonable cable static loads (a safety factor > 3), reasonable horizontal displacement for ship maneuvering and minimal horizontal loads. Thus from Figure A-2:

T = 5,600 lb
S = 17,460 ft
X = 6,870 ft

A station keeping capability was selected for the service craft by requiring that the boat would remain within the bounds of X = 2500 ft x X = 6,800 ft (i.e., the surface craft should be able to remain within approximately 0.5 mile from a specified point). This will limit the maximum tension and minimize the amount of cable needed for the service lead.

SERVICE LEAD RECOVERY ASSEMBLY

Given:

1. The recovery line must lift the full suspended weight of the service lead (5,600 lb) plus the weight of the service lead termination clump when the clump is near the surface.

2. The termination clump must be large enough to prevent dragging of the service lead due to ocean currents acting on the recovery line when the recovery line is deployed to the surface.

3. The current structure at the 15,000 ft site is assumed to be:
   3 knots at depths from 0 - 1,000 ft
   1 knot at depths from 1,000 ft to 4,500 ft
   0.2 knots at depths from 4,500 ft to 15,000 ft

4. The flotation unit attached to the rising end of the recovery line must provide adequate buoyancy to bring the line to the surface for the assumed current distribution.

Find:

1. Recovery line size (length, diameter and construction).
2. Buoyancy required to bring the recovery line end to the surface.
3. The weight required at the bottom end of the recovery line to prevent it from dragging the service lead when the recovery line is deployed vertically (i.e., before the service ship retrieves the recovery line).

Solution:

The service lead/recovery line assembly concept is shown in the bottom deployed position in figures 3 and A-2. Figure A-3 depicts the situation after the recovery line is deployed to the surface. Analysis of the loads, line lengths and flotation characteristics was performed utilizing a NOSC-Hawaii computer program developed for this purpose. Several iterations were made to minimize the required line size, length, anchor weight (W_1) and flotation requirement. The solution arrived at is by no means optimum but it should be in the ball park and is useful for general system sizing and as indication of concept feasibility. Results of the analysis are:

Recovery Line Length: 21,500 ft

Recovery Line Description: Stepped line diameter (a) 9,500 ft of 1 1/8 "diameter power braid (Samson Rope) extending from the service lead termination anchor (W_1); and (b) 12,000 ft of 3/8 "diameter KEVLAR line from the end of the 1 1/8 "line to the flotation unit.

Recovery Float Specifications:
Buoyancy 1,500 lb
CdA 5 ft^2

Recovery Float Anchor (W_2): 2,000 lb

The stepped sizing of the recovery line was selected to help reduce the amount of flotation needed and the size of the anchor (W_1). The external factor controlling these parameters, aside from providing adequate strength, is the current. The configuration arrived at provides a small cross section in the near surface region along with adequate cable strength (12,000 lb breaking) to recover the system to the point where the larger line surfaces. The larger line is sized to support the full load seen when the service lead and anchor (W_1) are near the surface.

Line sizing was derived as follows:

Load required to support the service lead at the surface:	5,600 lb
Weight of anchor (W_1):	1,200 lb
Total load:	6,800 lb

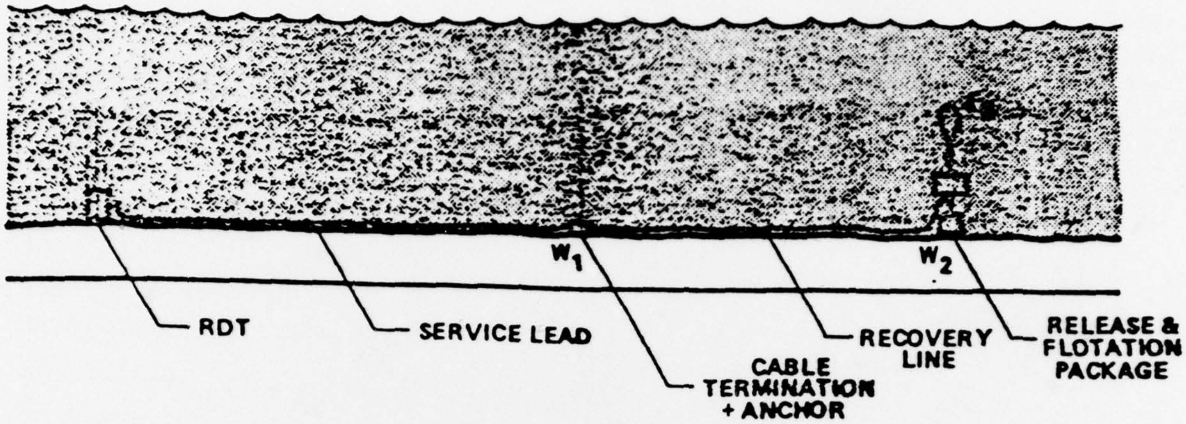


Figure A-2. Service lead and recovery line assembly arrangement installed on the ocean floor.

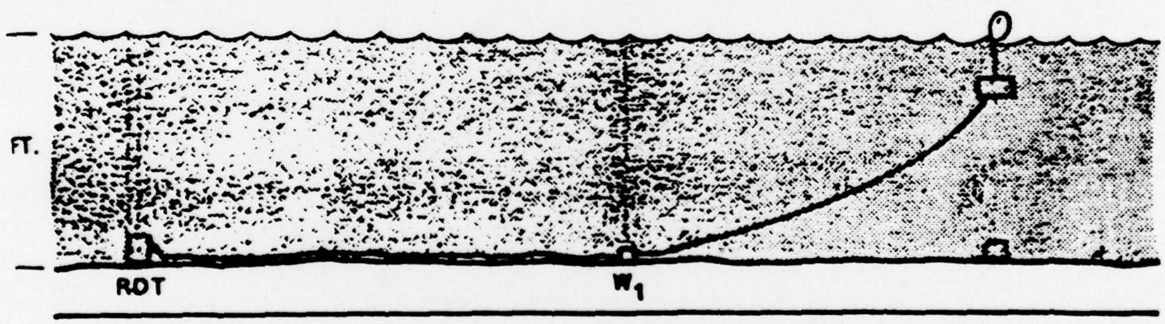


Figure A-3. Service lead and recovery line assembly arrangement after recovery float has surfaced.

Using a 5:1 safety factor, the line breaking strength should then be:

$$L_B = \frac{6,800}{0.2} = 34,000 \text{ lb}$$

This strength will be provided by a 1 1/8 "diameter Samson Power Braid line. The coordinates and parameters in table A-1 describe the physical configuration and loads seen by the above cable system when deployed in the water column.

Table A-1. Recovery line geometry.

No. of Segments	X	Z	
Payload	0.	0.	Cable Angle = 4.8° from vertical
50.	850.	1783.	
100.	2047.	3385.	
150.	3379.	4876.	
200.	4771.	6312.	
250.	6197.	7714.	
300.	7657.	9081.	
350.	9151.	10410.	
400.	10680.	11700.	
450.	12243.	12948.	
500.	13841.	14151.	
537.	15045.	15011.	Length = 21,480 ft
Anchor	Horizontal Force		Cable Tension = 1205 lbs
	988.		Cable Angle = 55.1° from vertical

The segments are each 40 ft long. Thus, the coordinates indicate the position of the cable in 2000 ft increments from the surface to the ocean floor. X and Z are 0 at the surface float. It must be stated again that this is a very simplistic analysis and that a thorough dynamic analysis must be performed as a portion of the final design.

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