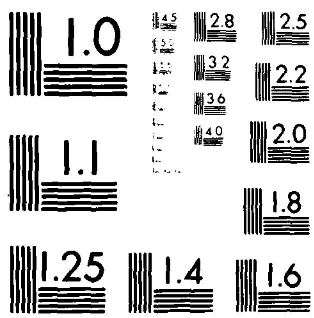
AD-A109 480 EFFECTS TECHNOLOGY INC SANTA BARBARA CA F/G 17/2
FIBER OPTIC CODEC LINK (FOCOL). VOLUME 1.(U)
JAN 81 W NAUMANN, E LILES, R D HOGG DNA001-79-C-0021
UNCLASSIFIED ETI-CR81-865-VOL-1 DNA-5747F-1 NL

1 OF 1
AD
A109480

END
DATE
FILMED
2-82
DTIC



MICROCOPY RESOLUTION TEST CHART
NATIONAL BUREAU OF STANDARDS 1963-A

ADA109430

DNA 5747F-1

FIBER OPTIC CODEC LINK (FOCOL)

Volume 1—Final Report (Technical)

(12)

LEVEL II

Walter Naumann
Elizabeth Liles
R. Douglas Hogg
Effects Technology, Incorporated
5383 Hollister Avenue
Santa Barbara, California 93111

26 January 1981

Final Report for Period 1 November 1978—26 January 1981

CONTRACT No. DNA 001-79-C-0021

APPROVED FOR PUBLIC RELEASE;
DISTRIBUTION UNLIMITED.

THIS WORK SPONSORED BY THE DEFENSE NUCLEAR AGENCY
UNDER RDT&E RMSS CODE B345079462 J11AAXAX01310 H2590D.

Prepared for
Director
DEFENSE NUCLEAR AGENCY
Washington, D. C. 20305

405842

82 01 08 027

DNA PRINTING PLANT

UNCLASSIFIED

SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER DNA 5747F-1	2. GOVT ACCESSION NO. AD-A100 480	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) FIBER OPTIC CODEC LINK (FOCOL) Volume 1—Final Report (Technical)		5. TYPE OF REPORT & PERIOD COVERED Final Report for Period 1 Nov 78—26 Jan 81
		6. PERFORMING ORG. REPORT NUMBER CR81-865
7. AUTHOR(s) Walter Naumann Elizabeth Liles R. Douglas Ho		8. CONTRACT OR GRANT NUMBER(s) DNA 001-79-C-0021
9. PERFORMING ORGANIZATION NAME AND ADDRESS Effects Technology, Incorporated 5383 Hollister Avenue Santa Barbara, California 93111		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS Subtask J11AAXAX013-10
11. CONTROLLING OFFICE NAME AND ADDRESS Director Defense Nuclear Agency Washington, D.C. 20305		12. REPORT DATE 26 January 1981
		13. NUMBER OF PAGES 66
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS (of this report) UNCLASSIFIED
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

16. DISTRIBUTION STATEMENT (of this Report)

Approved for public release, distribution unlimited.

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

This work sponsored by the Defense Nuclear Agency under RDT&E RMSS Code B345079462 J11AAXAX01310 H2590D.

19. KEY WORDS (Continue on reverse side if necessary and identify by block number)

Data Link	Digital Electronics
Fiber Optic	Field Test
Data Transmission	Underground Test
Coder-Decoder	High Explosive Test
Codec	Nuclear Weapon Effects Test

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The fiber optic codec link was designed to meet the majority of data transmission requirements for both Underground Nuclear Weapon Effects Tests and High Explosive Tests at a substantial cost saving over current transmission methods including other multiplexing systems. The link is capable of transmitting a maximum of 92 channels of data over a fiber optic cable up to two kilometers in length. The bandwidth of the input data is switch selectable as 5kHz, 10kHz, or 20kHz. Fewer channels are available at higher bandwidths as lower bandwidth channels are paralleled

(continued)

to achieve higher bandwidth channels. Greater dynamic range is provided by the use of companding analog to digital converters which feature higher resolution for small signals.

Volume 1 of the final report includes the technical discussion of the link program.

Volume 2 of the final report is the manual for the link which provides a detailed description of the link and operationg instructions.

TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

1.0 INTRODUCTION

The objective of this contract was to design, assemble and evaluate a field test compatible fiber optic data link.

The Fiber Optic Codec Data Link (FOCOL) resulting from the program is optimized to DNA's needs in underground test (UGT) and high explosives (HE) tests. No one system can fill all needs, but this link was designed to handle almost all HE test and much UGT test data and provide a substantial cost saving even over other multiplexing systems. It is a continuous system and so is not limited by record time, memory size or critical timing. Its companding[(1)] feature provides good resolution for small signals minimizing the need for two channels at different sensitivities. Additional options for digital recording, redundant recording or local storage could be added in exchange for higher per channel costs.

The program was divided into five main tasks. They are listed below and are discussed in the main body of this report.

I. System Definition.
II. System Specification.
III. Hardward Evaluation.
IV. Prototype Link Assembly and Evaluation.
V. Fabrication of a Second Prototype Link.

All of these tasks were successfully completed by Effects Technology, Incorporated (ETI). The FOCOL hardware was delivered April 1981 with Serial No. 001 going to Bendix Field Engineering, Las Vegas and Serial No. 002 going to the Air Force Weapons Lab (NTED) Albuquerque, New Mexico.

(1) The companding transfer function is approximately logarithmic allowing greater resolution for small signals.

2.0 SYSTEM DEFINITION

The purpose of this task was first to identify the requirements for a field compatible data link and then to research and compare present technology in terms of these desired requirements to generate a system definition.

2.1 SYSTEM REQUIREMENTS

The following is a list of the general system requirements for a field compatible link based on both the prior field test experience of ETI personnel and discussions with Defense Nuclear Agency (DNA) personnel.

NUMBER OF CHANNELS

The contract Scope of Work Statement defines the system capability to be targeted at about 100 channels.

SYSTEM BANDWIDTH

Based on results from past high explosive (HE) and underground tests (UGT) (e.g. Diablo Hawk and Miser Bluff, both in 1978) the bandwidth of the system was chosen to be 20 kilohertz (kHz). Half of the channels of one HE test were below 6 kHz and 80 to 90 percent (%) were below 20 kHz.(1) In the other HE tests all data obtained were below 20 kHz.(2) Bandwidth requirements for UGT vary from below 5 kHz to as much as hundreds of megahertz (MHz); however, a substantial number of measurements require bandwidths below 20 kHz.

ENVIRONMENTAL

In defining the environmental requirements for a data link, both the HE and UGT test environments were considered. These requirements are generally intended only for the transmitter portion of the link since the receiver can be placed in a more controlled environment.

TEMPERATURE

The HE environment is typically a desert area and as such determines the temperature extremes that the link must withstand. The temperatures typically vary from -20°F to about 120°F, depending on the time of day and year.

HUMIDITY

While the HE environment determines the temperature requirement, the UGT environment dictates the humidity requirements. This requirement is based on the fact that the humidity in the tunnel is usually 80 to 90%.

MOISTURE

This is not a problem in the UGT environment but can become a problem in the HE environment due to occasional cloud bursts. It was decided that instead of weather proofing the transmitter section of the link, a cover would be required to house such instrumentation and protect it from moisture.

VIBRATION

The HE environment determines vibration requirements since the data link must be able to withstand the ground shock. This demands that the design be ruggedized to prevent loosening of connectors, components and circuit boards.

ELECTROMAGNETIC NOISE

The UGT environment is significantly more severe than the HE environment in the area of electromagnetic pulse (EMP) induced transients. The presence of EMP requires that protection circuitry be provided to eliminate transient noise from interferring with data transmission.

NUCLEAR RADIATION

Again, the UGT environment defines the environment. The transmitter, which is housed in an alcove, must be able to survive 1 rad(si) of nuclear radiation.(3) The cable interconnecting the transmitter and receiver must also be able to withstand this dose of radiation as a portion of it's length will be located in the alcove area.

INPUT VERSATILITY

Since the purpose of the link is to transmit many channels of data from a variety of different measuring sensors, the link should be designed with a generally acceptable input requirement. It was decided that a high level input requirement to the link would be the most versatile since different sensors require different signal conditioning circuitry.

OUTPUT COMPATIBILITY

The requirement for the output format of the data link was to provide analog output for each channel. This applies for both HE and UGT test environments.

COST EFFECTIVENESS

One major requirement which the data link must fulfill is that of cost effectiveness. The link was to be designed in such a way as to maximize system performance and reliability and to minimize cost.

2.2 SYSTEM CHARACTERISTICS

With the above requirements in mind, a detailed technology review was prepared by ETI personnel. A summary of this review can be found in Appendix A. This review provides information concerning components that were considered in the design of the data link both in terms of their present features and what could be expected in the future (within five years). One of the design decisions to be made was whether the link should use analog or digital transmission. Included in Appendix B is a comparison between analog and digital transmission methods. Another decision to be made was whether fiber optics should replace electrical cables as the transmission medium. A cost comparison between the use of fiber optics and electrical cables was made and is included in Appendix C.

Appendix D provides a charted comparison of components and transmission methods as they relate to the system requirements. This provides a reference for determining the most cost effective method of data transmission.

All of the above mentioned material was presented to Messers. R.C. Webb (HQ,DNA) and R. Bonn (FC,DNA) along with a discussion of alternate approaches to the data link design. The conclusions drawn from this meeting were that of the two link designs (analog and digital) the digital design would be built and it would have the following characteristics:

2.2.1 Multiplexed Transmission

In general, multiplexing of data saves money because the bandwidth of cables increases faster than their cost. The limit is determined by the number of channels of data to be transmitted. Examples of multiplexing many channels may be found in telephone applications. Multiplexing of from 20 to 92 channels, depending on bandwidth, onto one cable was chosen as compatible with test needs and with CODEC (coder-decoder) circuit and fiber optic capabilities.

2.2.2 Digital

Analog to digital conversion before data transmission was selected for several reasons. First, in most cases data are digitized eventually so the decision was not to add digital conversion but to perform it at an earlier time. Digital multiplexing avoids the initial expenses and the time consuming calibrations and set up required by analog multiplexers. Another advantage is the relative immunity of digital signals to noise and amplitude fluctuations during transmission.

2.2.3 Real Time Transmission

Real time data transmission was chosen for the following reasons. Recording system or link failures are not likely to occur at the instant of the shot since they are not in the shock environment until after the data is transmitted. The alternative is local data storage via memories. One disadvantage is that they are subjected to high schock levels which are difficult to dty run. Another disadvantage is that for data of the bandwidths considered local memory is not cost effective. Thus, real time data transmission provides a continuous transmission which is relatively "transparent" to the user. It is treated much as a conventional cable.

2.2.4 Fiber Optic Data Transmission

Based on the information presented in Appendix C, the reasons for choosing fiber optics are the following:

1.) Cost Benefits

When compared with electrical cables (both RG 333 and TSP) the total cost, including cable and installation, was less for fiber optics. Table 1 in Appendix C compares fiber optics to electrical cables without multiplexing. The result of comparing cables with the same bandwidth capability is that fiber optics is a factor of four less expensive than electrical cables. The primary reason for this is the small size of fiber cable which leads to lower installation costs. Table 2 in Appendix C compares fiber optics to electrical cables when multiplexing is included. In this case fiber optics is less expensive than twisted shielded pair (TSP) by a factor of two to three. The cost benefit over other electrical cables (RG 333 and RG 213) is not as great. However, it must be remembered that fiber optics is an ermerging technology and costs are dropping rapidly for both cables and electrical components. Conversely, coaxial cables are a mature technology and their costs are continually increasing.

2.) Bandwidth

The bandwidth capability of fiber optic cables (400 MHz) is much greater than the best of the electrical cables (100 MHz). This becomes important when considering the transmission of 400 MHz data which is obtained in EMP experiments. Bandwidth also becomes an important factor when considering the amount of data that can be multiplexed on one cable.

3.) Noise Immunity

One of the big advantages over electrical cables is noise immunity. Electrical noise pick up and ground problems are important detrimental factors for electrical cables. However, through the use of fiber optic cables these problems are eliminated.

REFERENCE

1. Personal communication with Noel Gontick, Defense Nuclear Agency, Field Command,

2. MISERS BLUFF results symposium, 27 to 29 March, 1979, Defense Nuclear Agency.

3. Personal communication with Larry Scott, Jaycor, P.O. Box 85154, San Diego, Ca. 92138

3.0 SYSTEM SPECIFICATION

Based upon the system definition developed in Task I, a system design was produced. A decision was made in a meeting with Messrs. R.C. Webb (HQ,DNA) and R. Bonn(FC,DNA) to base the design of the digital link on CODEC microcircuits. A black diagram of the basic system design is shown in Figures 1 and 2. Figure 1 presents the transmitter and Figure 2 the receiver. As Figure 1 shows, the analog input signal is first sent through an input protection circuit and then filtered before being digitized by the CODEC mircocircuit. The input protection circuit provides protection from electromagnetic noise sources such as EMP by limiting the voltage of the input signal to a safe level for downstream circuitry. The low pass filter is essential for eliminating unwanted high frequency (aliasing) signals. The bandwidth of each channel of the system was chosen at a break point in cost versus bandwidth which meets the requirements of most high explosive test data and much nuclear weapons effects test data.

The system uses CODEC (code-decoder) microcircuits which have been developed for use in the telephone industry. They are low in cost and have been designed for ease in multiplexing. These devices are analog to digital converters with a companding transfer function, which results in an over 12 bit resolution at small signals with an 8 bit word. The specifications for the link are given in Table I. The sampling rate for one channel is 16 kHz and four channels can be switched together to obtain two 32 kHz or one 64 kHz sampling rate channels. The corresponding bandwidths are 5 kHz to 20 kHz. A review of the data from a typical High Explosive test, Misers Bluff, indicated that 5 kHz was adequate for most of the data and none, including air shock interaction data, was observed which could not be accommodated by the 20 kHz capability of [illegible] In nuclear weapon effects tests, most impulse and [illegible] be accommodated by the 20 kHz capability of this multi- [illegible] slow for stress and device diagnostic measurements. [illegible], the data link provides a switch selectable bandwidth. [illegible], 10 kHz and 20 kHz. However, due to the maximum [illegible] CODECs, fewer channels are available at higher [illegible] shows the correspondence between bandwidth and [illegible]. Various combinations of channels and bandwidths can [illegible].

[illegible] has a total capability of transmitting 92 channels of 5 kHz [illegible] data. These channels are divided into four groups for multi- plexing convenience. Each group has its own data bus onto which is multi- plexed all 23 channels of that group. The data rate for this bus is 3.07 MBPS. This time division multiplexing is accomplished by a sync generator which provides a conversion initiation signal to each of the 23 CODECs in a group. Further multiplexing is achieved by the group multi- plexer. This section receives the four group data buses and multi- plexes them onto one data bus by clocking the data at four times the data rate for one group bus. This 12.28 MBPS signal is then encoded into a Manchester (Biphase-L) code which combines data and clock information. A frame sync is added at this time for demultiplexing purposes. The encoded signal is delivered to the fiber optic transmitter consisting of a light emitting diode (LED) and a driver. Due to the relatively short distances required by the data link, an LED can be used instead of the more trouble- some laser diode. The fiber optic cable encloses a 200 μm diameter graded index fiber having much greater bandwidth capability than that required by the 12.28 Mbs encoded data stream. Optical power levels at the receiver are sufficient to enable use of a PIN diode rather than an avalanche photodiode. The optical receiver converts the optical signal back to an electrical one. The frame sync code is detected and used for main- taining proper timing.

The recovered 12.28 MBPS data stream is then decoded to separate clock and data. The data stream is then demultiplexed into the four 3.07 MBPS group data buses. The group data buses are fed to the appropriate CODEC microcircuits for digital to analog conversion. The sync generator controls the timing for this operation and accomplishes the task of demultiplexing the 23 channels in each group. The resultant analog signals are then filtered before being made available for recording. The link has an overall system gain of one and an analog signal range of ±3 volts.

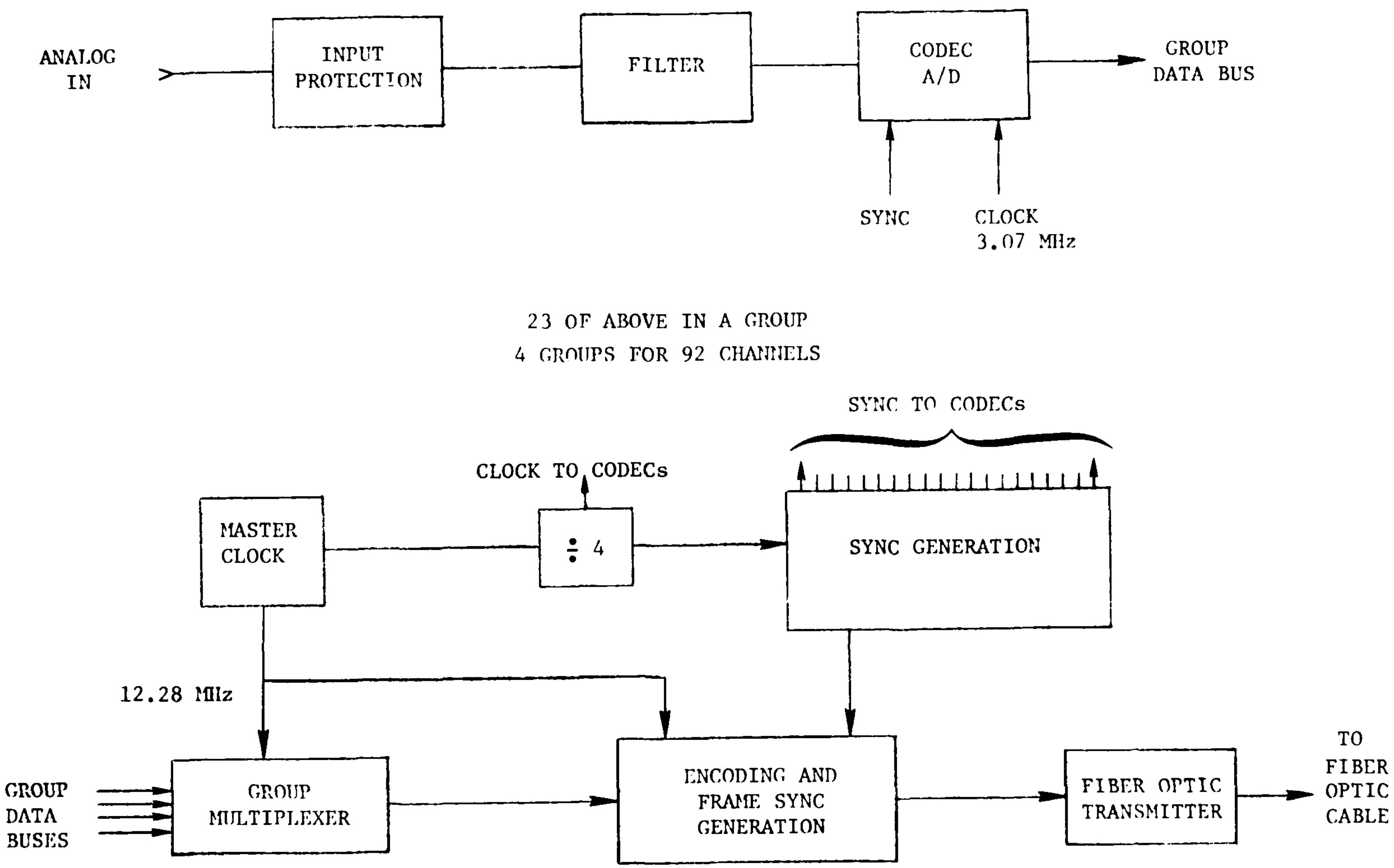


Figure 1. Coder and transmitter

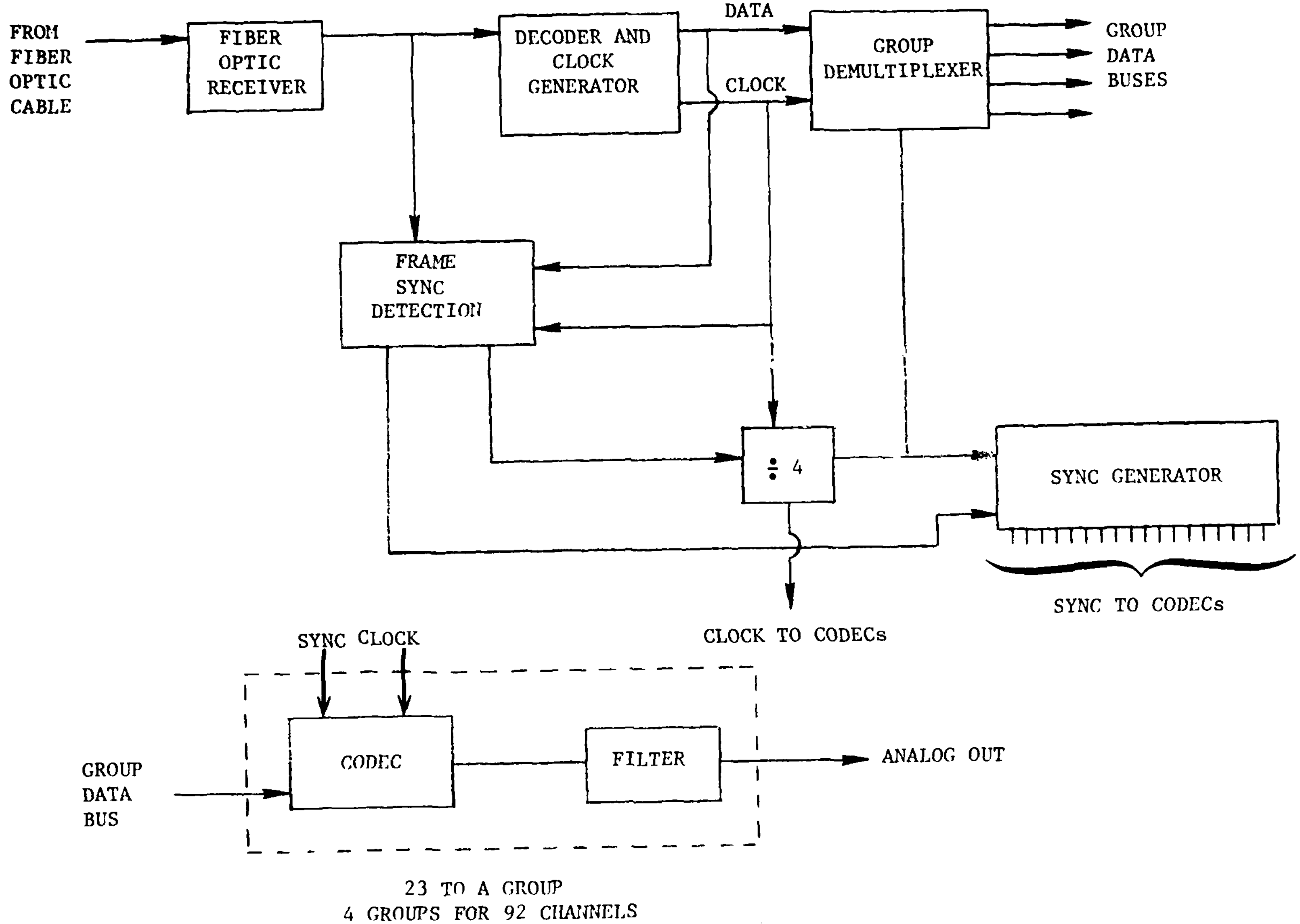


Figure 2. Receiver and decoder

Table I

SYSTEM SPECIFICATIONS

GENERAL

Number of Channels	92 to 20
Sampling Rate	16 KHz to 64 KHz
Tradeoff of Channels versus Sampling Rate	4 channels at a time can be switched together to give 2 channels at 32 KHz or 1 channel at 64 KHz
Bandwidth	D.C. to 0.3 times the sampling rate for 6 dB attenuation
Resolution	8 bit companding analog to digital (0.25% resolution near zero)
Data Transmission Rate	12.28 Mbps decodable to 4 each 3.07 Mbps
Fiber Type	Graded index
Electrical to Optical Transducer	Light emitting diode (LED)
Optical to Electrical Transducer	PIN diode
Coding	Manchester (Biphase-L): 12.28 Mbps NRZ-L: 3.07 Mbps

ELECTRICAL

Power	105 to 125 VAC, 60 Hz, 1.1 amp transmitter 1.0 amp receiver
Digital Levels	TTL
Connectors	BNC
Input Impedance, Analog	10K ohms
Input Impedance, Digital	50 ohms
Output Impedance, Analog	300 ohms
Output Impedance, Digital	50 ohms
Sampling Rate - f_o	16 KHz, 32 KHz or 64 KHz

ELECTRICAL (Continued

*Frequency Response	
(D.C. to 0.3 f_o)	+0, -6db
(D.C. to 0.1 f_o)	+0, -10%
(D.C. to 0.03 f_o)	+0, -2%
Resolution	8 bit digital, μ255 law companding[1]
Small Signals	± 0.025% of full scale or ± 0.74 mVolt
Large Signals	± 1.6% of full scale or ± 47 mVolt
Signals from 1% of Full Scale, to Full Scale	<± 5% of signal
*Noise (D.C. to 0.3 f)	(Quantizing Noise) + (<0.5 mV RMS)
*Noise (D.C. to 1MHz)	(Quantizing Noise) + (<5 mV RMS)
Linearity	Less than ± quantizing step size
Zero Accuracy	0 ± 5 mV
Voltage Gain	1 ± 1% plus quantizing noise
Maximum Signal Voltage	+2.8 / -3.0 volts
Input Signal Limiter	± 6 volts
*Pulse Response	Ringing <±10% at ≈0.3 f Damping time constant <100 μsec
Overload Recovery	To 1% of full scale within 10 μsec after a 100 volt, 10 μsec overload
*Antialiasing Filter	>18 db attenuation at $f_o/2$

*These specifications can be improved or modified with different input and/or output filters.

---

(1)Siliconix Telecommunication Data Book, November 1979.

OPTICAL

Connectors	Amphenol 906
Fiber Type Recommended	Siecor 122 63 μm core diameter 0.21 numerical aperture 6 db/km attenuation
Gain Margin; Typical (Depends on the transmitter and receiver installed and on other factors)	15 db (compared to a 10m link)

PHYSICAL DIMENSIONS

19 inch rack width

12.5 inch height

22 inch depth overall, Transmitter

18.5 inch depth overall, Receiver

21.5 inch depth behind rack mount, Transmitter

17 inch depth behind rack mount, Receiver

60 pounds weight, Transmitter

55 pounds weight, Receiver

ENVIRONMENTAL

Transmitter, 0 to 55°C

Receiver, 15 to 30°C

Table II

BANDWIDTH/CHANNEL TRADEOFF

Bandwidth	Channels
5 KHz	92
10 KHz	44
20 KHz	20

4.0 HARDWARE EVALUATION

During the design stages of the data link several hardware components were evaluated. Evaluation of these components took the form of both comparison of specification literature and, when possible, actual laboratory testing. The types of components that were evaluated fell into five categories:

1.) CODEC microcircuits
2.) Filters
3.) Fiber optic transmitters
4.) Fiber optic receivers
5.) Fiber optic connectors

The results of the evaluations are presented in following sections.

4.1 CODEC MICROCIRCUITS

Since one of the major design goals was to minimize costs, CODEC microcircuits were investigated. CODEC is an acronym for coder-decoder and these circuits were developed for use in the communications industry. Their advantages in addition to low cost include companding A/D (analog to digital) and D/A (digital to analog) converters plus on-chip multiplexing circuitry. These devices are made by several manufacturers and all were available at the time of the investigation. After careful comparison, the CODEC circuits were made by Siloconix for the following reasons.

1.) The encoding and decoding sections of the circuitry were placed on separate ciips. This best fits the needs of the data link since only encoding is performed at the transmitter and only decoding is performed at the receiver. This leads to lower chip costs since the circuits containing both the encoding and decoding sections are more expensive. Since fewer total circuits are involved power requirements are also somewhat lower.

2.) The Siliconix circuits can be operated at a 3 Mpbs clock rate instead of the nominal 1.54 Mbps used by all the others. This results in a 16 hKz sampling rate per channel and thus provides a higher bandwidth capability.

3.) The decoder can decode up to four encoded channels. This means that a 65 kHz sampling rate can be accommodated with a single decoder. This leads to a signal bandwidth capability of 20 kHz.

4.) The circuitry is CMOS which means low power dissipation.

Of these reasons, numbers two and three were the deciding factor since none of the other chips allowed that mode of operation. Although a large fraction of the data require less than a few kilohertz response, it was felt important to offer increased bandwidth capability for these circumstances where it is necessary.

4.2 FILTERS

For any sampled system, anti-aliasing filters are required. In the present system, where three bandwidth ranges are provided, a large number of filters are required. More specifically, seven filters were required on each coder circuit board in the transmitter. This means that the filters must be physically small in order to fit on the circuit boards. There were two choices of four pole filters available in a small size. The preferred filter type is a linear phase filter which has the advantage of allowing little time delay distortion. Their disadvantage is that they have a very slow roll off with increasing frequency. Unfortunately, good phase response and high roll off rate are conflicting requirements. In order to have the required rejection at the sampling frequency, the 3 db bandwidth would have to be about 1/6 of the sample rate or less instead of 1/3.

In addition, the possibility of using switched capacitor transversal filters was investigated. These devices are new and offer both very good phase response and fast roll off. They are effectively 65 pole filters whose cutoff frequency is set by an external clock. They can be switched to a different cutoff frequency by changing the frequency of the external clock. This means that only one filter per channel would be required instead of seven. At the time that the link design was finalized these devices were not available in production quantities and thus not considered.

Instead of the above type filters, a filter made by K. R. Electronics was chosen. The characteristics of this filter are that it has a non-linear phase response and a small (∿10% overshoot). The roll off characteristic is 39 db per octave which allows more bandwidth to be used.

4.3 FIBER OPTIC TRANSMITTER

The fiberoptic transmitter consists of an LED and a driving circuit. At the time that the design was finalized there were no acceptable transmitter units available which included both the driver and the LED. The driver for the LED is basically a transistor with a current limiting resistor. A unit made by Fibercom was chosen because of its TTL compatible input.

Three types of LED's were tested in the laboratory, a pigtailed type, and lensed type and one other type. The Laser Diode Labs type IRE 160 FB had a fiber optic "pigtail" bonded to the package to couple out more light. The Spectronics SPX 3188-004 contained a lens bonded to the LED chip for the same purpose. The Meret MDL 4777 SKPL transmitter LED was bare but contained an integral driver circuit.

During testing it was determined that the maximum current for the Laser Diode LED, consistant with long LED life, was 50 mA average (100 mA peak). The optical power coupled into a fiber was 100 μW but only 5-8 μW was coupled to a 62 μm fiber core. The lensed Spectronics LED coupled 15 μW and the Meret only 1.5 μW into the same fiber core.

The lensed Spectronics LED was selected for use in the link.

4.4 FIBER OPTIC RECEIVER

The fiber optic receiver consists of a PIN photodiode, an amplifier, and a current to voltage converter. The receiver requirements for the data link are:

a) Sensitivity $\lesssim .5\ \mu W$
b) Bandwidth < 15Mbps RZ, 30 Mbps NRZ
c) Digital output, TTL compatible

Three units were evaluated, one made by Maxlight (Model 6000), one by Meret (MDL 4777SKPL) and one by Spectronics (SPX-4141-503). The Max light receiver sensitivity was 0.5 μW. The Meret receiver sensitivity was 1.5 μW and the Spectronics was 0.25 μW.

While the Maxlight receiver has been used in the first prototype, it can no longer be purchased. The receiver made by Spectronics is a more recent design and has not been fully tested at this time but it is being considered for the second prototype.

4.5 FIBER OPTIC CONNECTORS

At evaluation time there were two choices of connectors for small (62 μ) fibers, one made by Amphenol and one by Deutsch. The latter were more expensive at the time and required a liquid lens. Although the Deutsch connector has not been fully evaluated, use of the liquid was felt to be a disadvantage in a field test environment particularly for HE tests in desert areas where dust is a problem. The Amphenol connectors are modified SMA connectors and are somewhat more difficult to install since they require polishing for good light transmission. One advantage is their use on a large number of commercial LED's and photodetectors. The Amphenol 906 connector was selected.

Progress is being made on making fiber optic connectors easier to install and less expensive. Deutsch has come out with a better connector which can be installed with a hand tool. These and others should be evaluated in the future.

5.0 PROTOTYPE LINK ASSEMBLY AND EVALUATION

A prototype fiber optic data link was assembled and evaluated at ETI. A manual was written to describe the link as well as provide operating information. A copy of the manual including a full set of circuit schematics is provided in this section. A number of tests were conducted to determine additional information on the operational characteristics of the data link. These tests included electrical, optical and environmental measurements. The electrical measurements included frequency response, noise, linearity, zero accuracy, system gain, pulse response, overload recovery and attenuation characteristics of the input filter. The optical power gain margin was measured to determine the operating range of the fiber optic receiver. Several environmental tests were made including low level vibration and operating temperature range. The results of all these evaluation tests are listed in the system specification section of the manual.

APPENDIX A

TECHNOLOGY REVIEW

TECHNOLOGY REVIEW

COMPONENT	NOW (COMMERCIALLY AVAILABLE)	FUTURE (WITHIN 5 YEARS)
LED	Outputs to several mW. Response to about 200 MHz. Lifetimes to 10^6 hours.	Response to GHz range. Lifetimes about the same. Attempts to have narrower spectral width. Improved fiber coupling schemes.
LASER	Outputs to many mW. Response to greater than 1 GHz. Lifetimes of 10^4-10^5 hours. Wavelengths 0.8-0.9 microns.	More power. Response to several GHz. Possible lifetimes of 10^6-10^7 hours. Wavelengths to 1.3 microns.
MODULATORS	Commercial electro-optical and acousto-optical to about 500 MHz and 50 MHz respectively. Extinction ratios to 1000:1.	Higher frequencies and more convenient drive electronics. Broader wavelength range.

TECHNOLOGY REVIEW

COMPONENT	NOW (COMMERCIALLY AVAILABLE)	FUTURE (WITHIN 5 YEARS)
LED and Laser Drivers	Digital: DC to 100 Mbs. Custom fabrication to 1 gigabit/sec	Production digital units to 1 gigabit/sec.
	Analog: DC to 500 MHz. (Wideband microstrip devices with transistor final stage).	Analog modules depend on mostly military development as the tele-communications industry is tending to go digital.
Photodiode Preamplifiers	Transimpedance amplifiers to about 200 MHz. Microstrip devices to about 1 GHz. For digital use, comparators to several hundred megabit/sec.	Analog devices to several GHz. Not much change in noise figures. Digital devices to the gigabit/sec range.

TECHNOLOGY REVIEW

COMPONENT	NOW (COMMERCIALLY AVAILABLE)	FUTURE (LESS THAN 5 YEARS)
Fibers	No standard size or material yet. Typical products are 63 micron core, 4 db/km, 1 GHz-km graded index and 200 micron core, 5-10 db/km 25 MHz-km step index.	Single mode fiber-bandwidth to many GHz. Improved radiation resistance by selective doping. Better coatings for improved environmental resistance.
Cables	Ruggedized cable available for both direct burial or overhead use. Armored on special order. Suitable for pulling through 1 mile long pipe now.	Price drop as ruggedized cable volume increases. Improved gas block characteristics for environmental seal.

TECHNOLOGY REVIEW

COMPONENT	NOW (COMMERCIALLY AVAILABLE)	FUTURE (LESS THAN 5 YEARS)
Splitters and Combiners	Star couplers and a few directional couplers. Excess loss of 3-6 db. Some wavelength separators.	Fiber couplers of the canstar type with excess losses of less than 1 db.
Integrated Optical Circuits	None commercially	Crossbar switches, multiplexers. Potential for high speed. Bragg cells for multiplexing also.

TECHNOLOGY REVIEW

COMPONENTS	NOW (COMMERCIALLY AVAILABLE)	FUTURE (LESS THAN 5 YEARS)
Pin Photodiodes	Bandwidths to about 500 MHz. Response .6 A/Watt. NEP around 10^{-15} - 10^{-13} Watts/$\sqrt{Hz}$ Good for $\lambda < 1$ micron.	Devices for 1.3 micron range. Higher speeds from different compounds.
Avalanche Photodiodes (APD)	Bandwidth to about 1 GHz. Response about 60A/Watt. NEP around 10^{-14} - 10^{-13} Watts/$\sqrt{HZ}$	New compounds with response to several GHz. New devices for 1.3 micron range.

TECHNOLOGY REVIEW

COMPONENT	NOW (COMMERCIALLY AVAILABLE)	FUTURE (LESS THAN 5YEARS)
Connectors	No standard. Devices range from plastic (AMP) to modified coax (Amphenol) to multicable ruggedized (ITT). Losses from 3-4 db with simpler ones to claimed .5 db with expensive devices. Prices from a few dollars to $500.	Easier to use standard connectors. Losses consistently less than 1 db. More field ruggedized units. Somewhat simpler procedures for connections.
Splicers	Several types-epoxy and heat shrink, fiber fusers. Losses to less than 1 db. Fusers give inconsistent results with different types of fibers.	Faster, field suitable units for fusion and epoxy. Cost should come down.

TECHNOLOGY REVIEW

COMPONENT	NOW (COMMERCIALLY AVAILABLE)	FUTURE (LESS THAN 5 YEARS)
Memories	65536 bit chips are just becoming available. Smaller chips with access times less than 25 nsec now. Non-volatile memories are more expensive but available. Shift registers for temporary storage are available and inexpensive.	Density, speed and number of bits per cent will continue to increase rapidly. The one million bit chip is expected between 1981 and 1984. 20 of these could store 2000 channels of data, 1000 words per channel, 10 bits per word. (All the Diablo Hawk Data Channels).
Microprocessors	Eight bit 4 MHz devices are standard. 16 bit devices are just coming out. Bit slice machines with cycle times to less than 100 nsec.	Continued increase in word size, speed and flexibility. 16 bit 10-20 MHz devices along with 32 bit machines within 5 years.

TECHNOLOGY REVIEW

COMPONENT	NOW (COMMERCIALLY AVAILABLE)	FUTURE (LESS THAN 5 YEARS)
CODECs	Sample times now to 20 KHz direct, multiplexed to about 80 KHz. Several types with varying features and power.	Pressure is towards low power, low cost and more channels per chip. On board filters to be included to lower parts count.
Analog Memories	Now available with short term (msec to sec) storage and up to 1000 bits per chip Bandwidth to about 20 MHz.	Increasing number of bits per chip. Hold times should improve some. Bandwidth changes uncertain.
Analog Integrated Oscillators and Amplifiers	Broadband modular units to approximately 2 GHz. Narrower band devices to 10 GHz Filters available for portions of these ranges Surface Acoustic Wave (SAW).	Increased high frequency capability and lower cost. SAW devices should show much improvement.

TECHNOLOGY REVIEW

COMPONENT	NOW (COMMERCIALLY AVAILABLE)	FUTURE (LESS THAN 5 YEARS)
A/D Converters	Speeds to 33 nsec (30 megawords/sec) at 8 bit resolution. To about 1 μsec at 12 bits.	Straightforward techniques may go to several hundred megawords/sec at 8 bits. Electro-optical methods may go to several gigawords/sec. New electronic circuit to about 10 gigawords/sec at 5 bits.
Digital Multiplexing	20–50 megabits/sec with standard TTL logic. (Data sample rate of .5 μsec X number of channels). ECL devices to a few hundred megabits/sec.	ECL devices in the GHz range with lowered power consumption. Some MOS techniques are capable of perhaps .5 GHz at a few mW.

APPENDIX B

ANALOG/DIGITAL TRADEOFFS

ANALOG/DIGITAL

SYSTEM TRADEOFFS

FACTOR	ANALOG	DIGITAL
Link Bandwidth	About 500 MHz practical now. Linearity problems make multiplexing difficult.	About 200 Mbs now. Less efficient with bandwidth . Digital storage can ease link requirements considerably.
Error Rate (Crosstalk/SNR)	Depends on modulation method. Laser modulation is not very good.	Very good. Data can be sent with error codes and multiple transmissions can be used.
Channel Capacity	Limited by bandwidth in real time.	Limited by bit rate. With local storage, limited by time available.
Cost	Multiplexers and demultiplexers are more expensive and require more maintenance.	Digital devices are getting cheaper as development continues.
Reliability	Requires integrity of entire system.	Local storage backup will prevent data loss due to link failure.

ANALOG/DIGITAL

SYSTEM TRADEOFFS

FACTOR	ANALOG	DIGITAL
Expansion	Easy to add channels in a FDM system as faster links become available.	Expansion requires more of a system redesign to accommodate faster devices.
Channel	A direct analog link can use the entire link bandwidth. VCO's use about one fourth.	Limited by A/D converters to about 10 MHz. Future devices to several GHz.

ANALOG/DIGITAL

SYSTEM TRADEOFFS

FACTOR	*ANALOG*	*DIGITAL*
Recording Methods	Low freq. (Less than about 2 MHz) recorders. Higher frequencies, oscilloscopes or Tektronix 7912.	Storage can be done on mag tape, disks or other media if processor used. Otherwise digital tapes or reconversion to analog and use of same recorders as for analog data.
Maintenance	Requires extensive stock of replacement items or a well equipped repair facility.	Replacements done from small set of replacement boards. Can be done by low level personnel.

APPENDIX C

FIBER OPTICS COST TRADEOFFS

COST COMPARISON

FIBER OPTICS VS. ELECTRICAL CABLES IN UGT

The purpose of this appendix is to demonstrate the cost savings when using fiber optic cables in place of electrical cables in nuclear underground tests (UGT). The analysis is based on current proven technology. The result is a greater advantage than existed only a year ago and is due to price reductions and improved components.

A number of costs contribute to the total for a data transmission system. These are cable, cable installation, cable termination, optical transmitter and receivers, and multiplexers. All costs shown in this appendix and throughout this document are 19.80 dollars.

Cable

Table 1 shows the comparison of three types of electrical cable and two fiber optic cables. The first electrical cable is 7/8 inch (2.2 cm) diameter "foam flex" coaxial calbe RG 333, which is the highest bandwidth cable (100 MHz) in general use in UGT. RG 213 is a lower bandwidth coaxial cable of about 1 cm diameter. Twisted shielded pair (TSP) is a balanced line with a 50 kHz bandwidth which is the lowest bandwidth signal line in general use and is about 0.5 cm in diameter. A TSP cable with 20 signal lines is used.

The Fiber Optic cable selected is the Siecor type 021 cable containing 10 fibers or lines. It is 0.8 cm in diameter and is armored for handling protection. Each fiber has less than 6 db/km attenuation and a 400 MHz bandwidth for a 1 km length. Several other fiber optic tables have similar characteristics. A lower bandwidth fiber optic table is also considered. A bandwidth of only 100 MHz is considered for direct comparison with RG 333 and to minimize the cost of the optical transmitter and receiver. Each line actually has a bandwidth of 200 MHz. The two fiber optic cables are the same size. Costs of the cables are given in line 3 of Table 1.

Cable Installation

In Table 1, the "quantity of lines for equal installation cost" is the quantity which can be installed in one "down hole" from the mesa to the tunnel. A cost of $700,000 is used for the total DNA cost to install these cables from the mesa to the experimenters' alcove. This cost is based on information obtained from Mr. R. Shirkey, the DNA Chief of Engineering, FCTC, Field Command Test Construction at the Nevada Test Site. This cost is equal to the cost of a new cable plant installed for the EMP pipe on Diablo Hawk. The cost is a little low since only labor is included and not miscellaneous materials. In addition, this analysis assumes 100 RG 333 cables or their equivalent where in the Diablo Hawk EMP group only 66 cables were installed, some being smaller than RG 333. Higher costs, however, would only further favor fiber optic cables.

Cable Termination

The next cost in the table is for terminating the cables. NTS estimates are that about 6 ends of RG 333 can have connectors attached by an electrician in a day and that a day of labor is about $300 including overhead. Since the cable is installed in three sections, 6 ends must have connectors attached so $300 per cable is estimated. Fiber optics are small but when stripped to the bare fiber are fragile so the same cost as RG 333 is used. $500 for connectors is added for a total of $800 for fiber optic termination. The cost for electrical cable termination is included in line 7.

Optical Transmitters and Receivers

In the case of the fiber optic links, electrical to optical transmitters and optical to electrical receivers must be included. $2,500 is a reasonable estimate per line for the 400 MHz link. For the 100 MHz link much simpler components and circuits result in a $500 cost.

Total Cost

The total cost per line in the table is the sum of the costs for the above components. In order to compare costs on an equal basis, the cost for a 400 MHz data rate is tabulated for each cable type. The cost is also tabulated for a 20 kHz data rate. These rates correspond to one fast fiber optic and one TSP line, respectively.

For high frequency, non-multiplexed data, the conclusion in line 12 is that fast fiber optic links are 7 times less expensive than RG 333, the nearest electrical competitor. The primary reasons are the fiber optic large bandwidth and small size (low installation cost).

Multiplexing

Lines of different bandwidths were compared by using groups of cables with equal total bandwidth. While this comparison is generally valid, it must be qualified for special cases. Obtaining fast data with many slow cables is not practical. 400 MHz data (as obtained in EMP experiments) cannot be sent on coaxial cables but can on fiber optics. If fiber optics are unavailable, expensive down hole recording of these data is necessary. Slow data can, however, be sent on fast lines efficiently using multiplexing. This favors fast lines.

It is difficult to convert data above 10 MHz from analog to digital form and multiplexing data of this bandwidth requires extra design effort, so making use of the 400 MHz bandwidth of the fiber optic link for slow data will require some added costs. These disadvantages may compensate to some degree for the advantages of fast links stated in the preceding paragraph.

To avoid these uncertainties the following comparison is made. The slow fiber optic link has the same bandwidth so is directly comparable to the electrical RG 333 and shows a factor of 4 lower cost which is independent of multiplexing.

Table 2 shows the effects of adding multiplexer costs. All costs are per 50 kHz data channel. The cost on line 3 for the first level of multiplexing dominates the analysis. This is because of individual filters and other components required for each channel. Costs for higher levels of multiplexing are spread over numerous channels and so become less significant. Costs for cables are also small compared to first level multiplexing costs, however cost advantages are shown for high bandwidths and fiber optics up to the narrow band fiber optic link.

A factor of 2 to 3 cost advantage is shown in Table 2, line 6 for multiplexing fast cables rather than use of TSP cable. An additional disadvantage of TSP is its low noise rejection properties for which it is difficult to assign a cost.

OTHER CONSIDERATIONS

In all the cost figures, it should be remembered that fiber optics is an emerging technology and prices are dropping rapidly for both cables and electrical components. For instance the price of optical fibers has dropped by a factor of two in the last year.

Coaxial cables, on the other hand, are a mature technology and their costs are continually increasing.

The issue of local digital storage of data has been avoided to save cable costs. This is because this technology applies to either electrical or optical lines and can reduce, but not eliminate, the cost of either. The risks of lost digital memories due to alcove collapse or other reasons are always present underground, so transmission of data before this can occur is advisable.

Another often quoted advantage should be repeated at this time. Electrical noise pick up and ground problems in the cable are eliminated using fiber optics. An effort is being made by DNA to arrive at a comprehensive grounding and shielding plan which would be simplified by extensive use of fiber optic links.

While the effects of radiation on fibers are not fully understood, the radiation levels are insignificant (< 1 rad) in the alcoves and other areas proposed for these links.

Other work is needed in the area of fiber termination. At present, this requires additional personnel training, but equipment and procedures are improving.

An important point is the successful field demonstrations of fiber optic links in UGT by LASL and others. Both 500 MHz fast links for reaction history monitoring, and slow 4 MHz links have been fielded successfully, and as a result of these tests the J8 group at LASL intends to transition to all data transmission using fiber optics. This, and routine use by telephone companies and others, indicates that it is not a matter of deciding if fiber optics is ready but rather, deciding how DNA can best make the transition.

SUMMARY

When considered on a cost per unit bandwidth basis, higher bandwidth and fiber optic cables have a distinct advantage. The greatest advantage is for multiplexed low frequency data on fiber optic cables which is why the FODL (fiber optic data link) was built for this area. Most of the advantage is retained when using multiplexing and electrical cables, while a smaller but real advantage results from using fiber optics on non-multiplexed high frequency data.

Table C-1 Fiber Optic Cost Comparison For UGT

FACTOR \ LINE TYPE	FIBER OPTIC		ELECTRICAL		
	WIDE BAND	NARROW BAND	RG 333	RG 213	TSP
1. Bandwidth	400 MHz	100 MHz	100 MHz	10 MHz	50 kHz
2. Number of Lines for 400 MHz Rate	1	4	4	40	8,000
3. Cost of Cable Per Line	$2,100	$1,100	$2,200	$700	$135
4. Quantity of Lines Per Cable	10	10	1	1	20
5. Cost, 1 km of Cable (3) x (4)	$21,000	$11,000	$2,200	$700	$2,700
6. Quantity of Lines for Equal $700,000 Installation Cost (see Test)	7,000	7,000	100	400	2,000
7. Installation Cost Per Line ($700K : (6))	$100	$100	$7,000	$1,750	$350
8. Cost of Termination Per Line	$800	$800	-Included in Item 7-		
9. Cost of Transmitter & Receiver Per Line	$2,500	$500	0	0	0
10. Total Cost Per Line (3) + (7) + (8) + (9)	$5,500	$2,500	$9,200	$2,450	$490
11. Total Cost for 400 MHz (2) + (10)	$5,500	$10,000	$37,000	$98,000	$3,900,000
12. Total Cost for 50 kHz (11) : 8,000	$0.70	$1.20	$4.60	$12.00	$490
13. Cost Factor ((11) : 5,500)	1	1.8	6.7	18	700

TABLE C-2

COST COMPARISON INCLUDING MULTIPLEXING COSTS, PER 50 kHz DATA CHANNEL

LINE TYPE / FACTOR	Fiber Optic		Electrical		
	WIDE BAND	NARROW BAND	RG 333	RG 213	TSP
1. From Line 12 in Table 1, Cost for a 50 kHz Data Channel	$0.70	$1.20	$4.60	$12	$490
2. Bandwidth of one Line	400 MHz	100 MHz	100 MHz	10 MHz	50 kHz
3. Multiplexer 50 kHz to 10 MHz	$200	200	200	200	----
4. Multiplexer 10 MHz to 100 MHz	$2	2	2	----	----
5. Multiplexer 100 MHz to 400 MHz	$3	----	----	----	----
6. Total Cost per 50 kHz Data Channel	$205	203	207	212	490

(1) + (3) + (4) + (5)

APPENDIX D

COMPARISON OF COMPONENTS AND TRANSMISSION METHODS

FIBER OPTIC LINKS

LINK BANDWIDTH	DEVICES			
	LED-PIN	LED-APD	LASER-PIN	LASER-APD
10 MHz	X	X	X	X
100 MHz	X	X	X	X
500 MHz			X	X
1 GHz				X

LINK ALTERNATIVES

	FIBER OPTICS	LASER	COAX	MICROWAVE	MM WAVE	TSP
Bandwidth	1 GHz	1 GHz	10-100 MHz	1 GHz	Several CHz	10 KHz
1 KM Cost	$7K/500 MHz	5K	4K	About 10K	20K-40K	400
Relative Strength	3 (All or Nothing)	1 (Alignment?)	2	5 (Dents)	5 (Dents)	4
Source and Detector Reliability (Hours)	LED 10^6 Laser 10^4-10^6 PD 10^6	Laser 10^3-10^6	NA	Tube 10^2-10^4 Solid State 10^5-10^6	?	NA

LINK SELECTION GUIDE

CHANNEL BANDWIDTH	DEVICES					
	ANALOG	ANALOG FDM	FLASH A/D	HIGH SPEED A/D	A/D	CODEC
< 10 KHz	X	X	X	X	X	X
< 30 KHz	X	X	X	X	X	(X)
< 100 KHz	X	X	X	X	X	
< 1 MHz	X	X	X	X		
< 10 MHz	X	X	X			
> 10 MHz	X		(1980)			

CABLE SELECTION

CABLE BANDWIDTH	GRADED INDEX			STEP INDEX	
	5 MICRON	63 MICRON	125 MICRON	200 MICRON	600 MICRON
10 MHz	X	X	X	X	X
25 MHz	X	X	X	X	
100 MHz	X	X			
500 MHz	X	X			
1 GHz	?	X			
> 1 GHz	?				

COMPONENT	COST/CHANNEL
CODEC	$100 Plus Share of Multiplexer and Link
A/D	$200-300 Plus Share of Multiplexer and Link
High Speed A/D	$250-350 Plus Share of Multiplexer and Link
Flash A/D	$1000 Plus Link (Or Share if Local Storage)
Analog	
10 KHz	Share of Multiplexer and Link or TSP
10 MHz	Share of Multiplexer and Link
>50 MHz	Link Cost Plus Storage Device

DISTRIBUTION LIST

DEPARTMENT OF DEFENSE

Assistant Secretary of Defense
Comm, Cmd, Cont & Intell
ATTN: Principal DASD (C3I), H. Van Trees

Assistant to the Secretary of Defense
Atomic Energy
ATTN: Executive Asst

Defense Advanced Rsch Proj Agcy
ATTN: STO, C. Thomas
ATTN: R. Kahn
ATTN: H. Winsor

Defense Communications Agcy
ATTN: Code 670, R. Lipp
ATTN: Code C661, T. Trenkle

Defense Communications Engineer Ctr
ATTN: R200
ATTN: Code R311

Defense Intelligence Agcy
ATTN: DB-4C2, C. Wiehle

Defense Nuclear Agcy
ATTN: RAEV
ATTN: RAEV, G. Baker
ATTN: SPTD, T. Kennedy
ATTN: STRA
ATTN: SPTD
ATTN: STNA
ATTN: STSP
ATTN: RAEV, W. Mohr
ATTN: RAAE
3 cy ATTN: SPSS
4 cy ATTN: TITL
4 cy ATTN: SPTD, R. Webb

Defense Technical Info Ctr
12 cy ATTN: DD

Field Command
Defense Nuclear Agcy
ATTN: FCT
ATTN: FCP
ATTN: FCTC
ATTN: FCTT, W. Summa
ATTN: FCTT
ATTN: FCTMOF
2 cy ATTN: FCTO
2 cy ATTN: FCTMEI

Field Command
Defense Nuclear Agcy
Livermore Br
ATTN: FCPRL

Field Command
Defense Nuclear Agcy
Los Alamos Br
ATTN: FCPRA

Under Secretary of Defense for Rsch & Engrg
ATTN: R. Ruffine

DEPARTMENT OF THE ARMY

BMD Advanced Technology Ctr
Department of the Army
ATTN: ATC-O, F. Hoke
ATTN: ATC-T, M. Capps

BMD Systems Cmd
Department of the Army
ATTN: BMDSC-HLE, R. Webb
ATTN: BMDSC-AOL, A. Duman
ATTN: BMDSC-HLA, T. Perdue
ATTN: BMDSC-HW, R. Dekalb
ATTN: BMDSC, E. Williams

Chief of Engineers
Department of the Army
ATTN: DAEN-MCE-D
ATTN: DAEN-RDL

Deputy Chief of Staff for Rsch Dev & Acq
Department of the Army
2 cy ATTN: DAMA-CSS

Electronics Tech & Devices Lab
US Army Electronics R&D Cmd
ATTN: DELET-R, S. Kronenberg

Harry Diamond Labs
Department of the Army
ATTN: DELHD-N-EM, C. Share
ATTN: DELHD-N-P
ATTN: 00100, Commander/Tech Dir/TSO
ATTN: DELHD-N-EM
ATTN: DELHD-N-RBC, J. Klebers
ATTN: DELHD-N-RBC, T. Conway
ATTN: DELHD-N-RBC, R. Gilbert

US Army Chemical Sch
ATTN: ATZN-CM-CS

US Army Comm-Elec Engrg Instal Agcy
ATTN: Tech Lib
ATTN: L. Stanley

US Army Communications Cmd
ATTN: Tech Ref Div
ATTN: CC-OPS-WR, R. Nelson

US Army Communications R&D Cmd
ATTN: DRDCO-COM RM, I. Kullback
ATTN: DRDCO-COM RM, A. Mondrick
ATTN: DRDCO-COM RM, S. Divita
ATTN: DRDCO-COM RM, L. Dorkin
ATTN: DRDCO-COM RM, R. Christain

US Army Concepts Analysis Agcy
ATTN: CSSA-ADL

DEPARTMENT OF THE NAVY

Naval Electronic Systems Cmd
ATTN: PME 117-211, B. Kruger
ATTN: Code 3101, F. Deckelman

DEPARTMENT OF THE NAVY (Continued)

Naval Postgraduate Sch
ATTN: Code 1424, Lib

Naval Research Lab
ATTN: Code 6570, R. Ginther
ATTN: Code 5503, J. McCallum
ATTN: Code 7904, B. Collins
ATTN: Code 5584, R. Allen
ATTN: Code 7909, D. Garrett
ATTN: Code 5584, E. Friebele
ATTN: Code 7904, B. Evans
ATTN: Code 6500, T. Giallorenzi
ATTN: Code 7909, D. Griscom
ATTN: Code 7904, L. Abella
ATTN: COMSAT, Dr. Revese
ATTN: Code 5584, B. Evans
ATTN: Code 2627
ATTN: Code 5584, G. Sigel

Naval Surface Wpns Ctr
ATTN: Code R14, I. Blatstein
ATTN: Code F31
ATTN: C. Holton
ATTN: Code R15, G. Hammond

Naval Surface Wpns Ctr
ATTN: R. Hudson
ATTN: DF-24, H. Lewis
ATTN: Tech Lib & Info Svcs Br

Office of Naval Rsch
ATTN: Code 474, N. Perrone

Strategic Systems Proj Ofc
Department of the Navy
ATTN: NSP-43
ATTN: SP272, H. Nakayama

Naval Coastal Systems Lab
ATTN: H. Larrimore

DEPARTMENT OF THE AIR FORCE

Air Force Institute of Technology
ATTN: Lib

Air Force Systems Cmd
ATTN: Tech Lib
ATTN: DLW

Air Force Weapons Lab
Air Force Systems Command
ATTN: DYC, E. Taylor
ATTN: DEX, J. Renick
ATTN: NTE, M. Plamondon
ATTN: NT, D. Payton
ATTN: DYV
ATTN: DYC, J. Emmes
ATTN: SUL
ATTN: NTYC, Mullis

Air Force Wright Aeronautical Lab
ATTN: AAD-3, K. Trumble
ATTN: AAD-3, D. Zann

Air University Lib
Department of the Air Force
ATTN: AUL-LSE

DEPARTMENT OF THE AIR FORCE (Continued)

Deputy Chief of Staff
Rsch, Dev, & Acq
Department of the Air Force
ATTN: AFRDQI

Rome Air Dev Ctr
Air Force Systems Command
ATTN: ESR, A. Yang
2 cy ATTN: ESR, J. Wall

OTHER GOVERNMENT AGENCIES

Central Intel Agcy
ATTN: OSWR/NED

Institute for Telecommunications Sciences
ATTN: J. Hull

DEPARTMENT OF ENERGY CONTRACTORS

EG&G, Inc
ATTN: R. Robichaud

Lawrence Livermore Natl Lab
ATTN: Tech Info Dept Lib

Los Alamos Natl Lab
ATTN: R. Thorn
ATTN: E. Hodson
ATTN: H. Agnew
ATTN: C. Keller
ATTN: MS 670, J. Hopkins
ATTN: MS 364
ATTN: J. McQueen
ATTN: J. Johnson
ATTN: P. Whalen
ATTN: MS/410, P. Lyons
ATTN: B. Killian

Sandia Natl Labs
Livermore Lab
ATTN: Lib & Scty Class Div

Sandia Natl Lab
ATTN: H. Miller
ATTN: M. Landry
ATTN: C. Barnes
ATTN: J. Kennedy
ATTN: A. Chaban
ATTN: R. Heckman
ATTN: K. Mitchel
ATTN: L. Vortman
ATTN: 3141
ATTN: Org 2330, E. Barsis
ATTN: C. Broyles
ATTN: E. Eernisse
ATTN: J. Plimpton

DEPARTMENT OF DEFENSE CONTRACTORS

Aerospace Corp
ATTN: Tech Info Svc

Applied Rsch Associates, Inc
ATTN: J. Bratton

Applied Rsch Associates, Inc
ATTN: S. Blouin

DEPARTMENT OF DEFENSE CONTRACTORS (Continued)

Applied Theory, Inc
2 cy ATTN: J. Trulio

University of Arizona
ATTN: J. Burke

AVCO Rsch & Systems Grp
ATTN: Lib A830

BDM Corp
ATTN: T. Neighbors
ATTN: Corp Lib

Bell Tel Labs
ATTN: J. Fleming

University of California at Los Angeles
ATTN: J. Mackenzie

California Rsch & Technology, Inc
ATTN: S. Schuster
ATTN: K. Kreyenhagen
ATTN: Lib

California Rsch & Technology, Inc
ATTN: D. Orphal

University of California
ATTN: J. Mackenzie

Calspan Corp
ATTN: Lib

Catholic University of America
ATTN: J. Clark

Charles Stark Draper Lab, Inc
ATTN: Tech Lib

Consolidated Controls Corp
ATTN: R. Sherburne

University of Denver
ATTN: J. Wisotski

Develco, Inc
ATTN: D. Ray
ATTN: L. Rorden

Effects Technology, Inc
ATTN: R. Parisse
ATTN: E. Bick
4 cy ATTN: R. Hogg
4 cy ATTN: E. Lyles
4 cy ATTN: W. Naumann

EG&G Wash Analytical Svcs Ctr, Inc
ATTN: Lib

EG&G/Kirtland
ATTN: S. Ornell

EG&G, Idaho, Inc
ATTN: WCB-W2, M. Stanley
ATTN: CF 689, C. Lai

DEPARTMENT OF DEFENSE CONTRACTORS (Continued)

EG&G, Inc
ATTN: T. Davies
ATTN: R. Lynn
ATTN: M. Nelson

EG&G, Inc
ATTN: P. Zavaharo
ATTN: G. Hughes

Electromech Sys of New Mexico, Inc
ATTN: R. Shunk

Galileo Electro-Optics Corp
ATTN: L. Owen
ATTN: J. Makuch

General Dynamic Corps
ATTN: K. Wilson

General Electric Co
ATTN: J. Whitten

H-Tech Labs, Inc
ATTN: B. Hartenbaum

Honeywell, Inc
ATTN: J. Ready

Horizons Technology, Inc
ATTN: R. Kruger

IIT Research Institute
ATTN: M. Johnson
ATTN: A. Tulus
ATTN: Doc Lib

Information Gatekeepers, Inc
2 cy ATTN: P. Polishuk

International Comm & Energy
ATTN: S. Elion

JAYCOR
ATTN: H. Hardwick

JAYCOR
ATTN: H. Linnerud

JAYCOR
ATTN: S. Brucker

JAYCOR
ATTN: R. Poll

Kaman Sciences Corp
ATTN: F. Rich
ATTN: Lib

Kaman Tempo
ATTN: J. Shoutens
ATTN: DASIAC

Massachusetts Inst of Technology
ATTN: W. Brace

DEPARTMENT OF DEFENSE CONTRACTORS (Continued)

Mission Research Corp-San Diego
ATTN: B. Passenheim
ATTN: V. Van Lint

Mitre Corp
ATTN: Tech Rept Ctr
ATTN: B. Metcalf
ATTN: J. Quarato

Pacific-Sierra Rsch Corp
ATTN: H. Brode

Physics Applications, Inc
ATTN: C. Vincent

Physics International Co
ATTN: Tech Lib
ATTN: E. Moore
ATTN: F. Sauer

Polytechnic Institute of New York
ATTN: A. Oliner

R & D Associates
ATTN: J. Lewis
ATTN: W. Graham
ATTN: Tech Info Ctr
ATTN: D. Shrinivasa
ATTN: R. Port
ATTN: C. Rogers
ATTN: A. Field
ATTN: P. Haas

Rand Corp
ATTN: A. Laupa

University of Rutgers
ATTN: H. Smyth

Science Applications, Inc
ATTN: R. Miller
ATTN: J. Dishon

Science Applications, Inc
ATTN: Tech Lib

Science Applications, Inc
ATTN: Tech Lib
ATTN: W. Mendes

Science Applications, Inc
ATTN: Tech Lib

DEPARTMENT OF DEFENSE CONTRACTORS (Continued)

Science Applications, Inc
ATTN: W. Chadsey
ATTN: B. Chambers III
ATTN: W. Layson

Science Applications, Inc
ATTN: K. Sites

Southeastern Institute of Technology
ATTN: R. Watson

Southwest Research Institute
ATTN: A. Wenzel
ATTN: W. Baker

Spectronics, Inc
ATTN: L. Stewart

Sperry Univac
ATTN: U2-T20, W. Davis

SRI International
ATTN: B. Gasten/P. De Carli
ATTN: D. Keough

Sylvania Systems Grp
ATTN: J. Waldron

Systems, Science & Software, Inc
ATTN: Lib

Texas A & M University Sys
ATTN: J. Handin

Theodore B. Belytschko
ATTN: T. Belytschko

TRW Defense & Space Sys Grp
ATTN: Tech Info Ctr

Valtec Corp
ATTN: W. Trout
ATTN: I. Aggarwal

University of Michigan
ATTN: V. Weston

OTHER

Brookhaven Natl Lab
ATTN: P. Levy

FILMED

2-8