Transmission Experiments over the All-Optical Network

by

Andrew Ugarov

Submitted to the Department of Electrical Engineering and Computer Science
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Abstract

This thesis describes various applications of an All-Optical Network (AON) testbed, constructed by an ARPA sponsored Consortium consisting of AT&T, DEC, and MIT. The applications focused on simultaneous video and audio transmissions for video distribution (e.g., instructional seminars and two way video conferancing). Two video sources were investigated: HDTV and MPEG NTSC video in ATM/SONET format. In addition, a number of demonstrations were used to illustrate and test the reliability of the links on the AON. Finally, a 155-MHz-compatible 1300-nm laser transmitter was developed.

Thesis Supervisor: Erich P. Ippen
Title: Elihu Thomson Professor of Electrical Engineering

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Chapter 1

The All-Optical Network (AON) Testbed

An All-Optical Network (AON) Consortium, made up of AT&T Bell Laboratories, Digital Equipment Corporation, and Massachusetts Institute of Technology, sponsored by the Advanced Research Projects Agency (ARPA) was formed in 1993 to develop the technologies for future high-speed high-capacity optical networks. The goals of the AON Consortium are to research and exploit the properties of fiber optics for advanced broadband communication. To achieve this goal, an extensive test-bed has been planned and a significant part of it has been already incorporated since January, 1994 [6].

The AON network is an optical WDM (Wavelength Division Multiplexing) system. It is also all optical in that optical signals are not converted to electronic signals within the network. The network hierarchy consists of local, metropolitan, and wide area nodes. Electronic access is provided through optical terminals that support multiple users and services. Advanced modern components such as a 1.5μm distributed Bragg reflector lasers, wavelength routers, and broadband frequency converters are used in the network to perform routing and broadcast connections. In addition, a control network, implemented at a wavelength of 1.3 μm, is used for network control and datagram service. This chapter outlines the architecture of the testbed and describes its services.

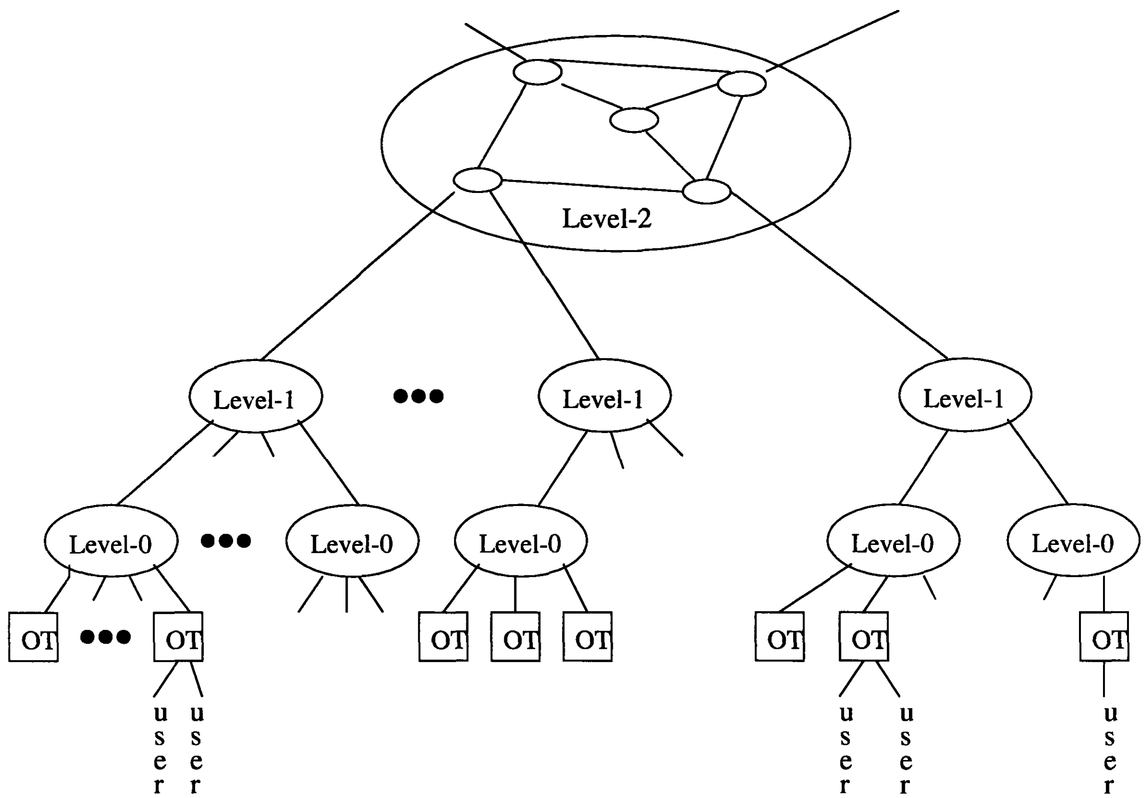

Figure 1-1: AON hierarchy

1.1 AON Architecture

The three-level hierarchy of the AON is shown in Fig. 1-1 [6]. Level-0 is a high performance local area network. Optical Terminals (OT's) are connected to Level-0 through a fiber pair. Level-1 is a metropolitan area network connected to Level-0 using wavelength routing. Finally, Level-2 is a wide area network used to interconnect Level-1s. At present, there are four Level-0's: one at DEC, two at MIT Lincoln Labs, and one at MIT Campus. There is also one Level-1 at MIT Lincoln Labs.

Optical Terminals are attached via an Access Point (AP) to the AON through a Level-0 network. Level-1's principal function is to interconnect Level-0's and provide access to Level-2. A wavelength router, is used in Level-1's operations. Each Level-0 which is connected to the Level-1 is assigned one input and one output port of the wavelength router. When the signals arrive at a Level-1, they are amplified and then passed to an output port which is a function only of the input channel frequency.

Thus, the choice of the output port is made at the time of transmission. In the Level-1 broadcast mode, the signals are routed to one of the output ports assigned a broadcast star. The channels which are used for broadcast depend on the particular configuration of the star.

1.2 AON Services

This section describes the various services that are provided by the AON.

An important concept of a WDM network is wavelength routing. This property is essential to the AON. It means that the path of the input signal through the network is determined by the wavelength and origin of the signal, the states of the network switches, and wavelength changers. Wavelength routing provides a transparent light path between optical terminals. A light path is a path the optical signal takes from a source to a single destination.

A and B services, which are discussed below, are transparent. This indicates that their channels may be used to transmit with any data and modulation format as long as the power levels and bandwidth specifications are within the network's limits. Below, the A, B, as well as the C Service are described in the context of the current testbed.

1.2.1 A Service

The A-Service is a transparent physical circuit-switched service which connects OT's with a clear light path. The A-Service allows point-to-point, point-to-multipoint, and multipoint-to-multipoint simplex and duplex connections [5]. Currently, the test-bed A-service cards use On/Off keying at 1.244 Gbps and 2.488 Gbps. Users request a wavelength using the C-Service. When the request is granted, the source tunes its transmitter to the assigned channel and the receivers tune their fiber Fabry-Perot filters (FFP) to the same channel [6].

Although the A-Service does not require a fast tuning laser, since a single frequency is used throughout the transmission, an AT&T fast switching Distributed

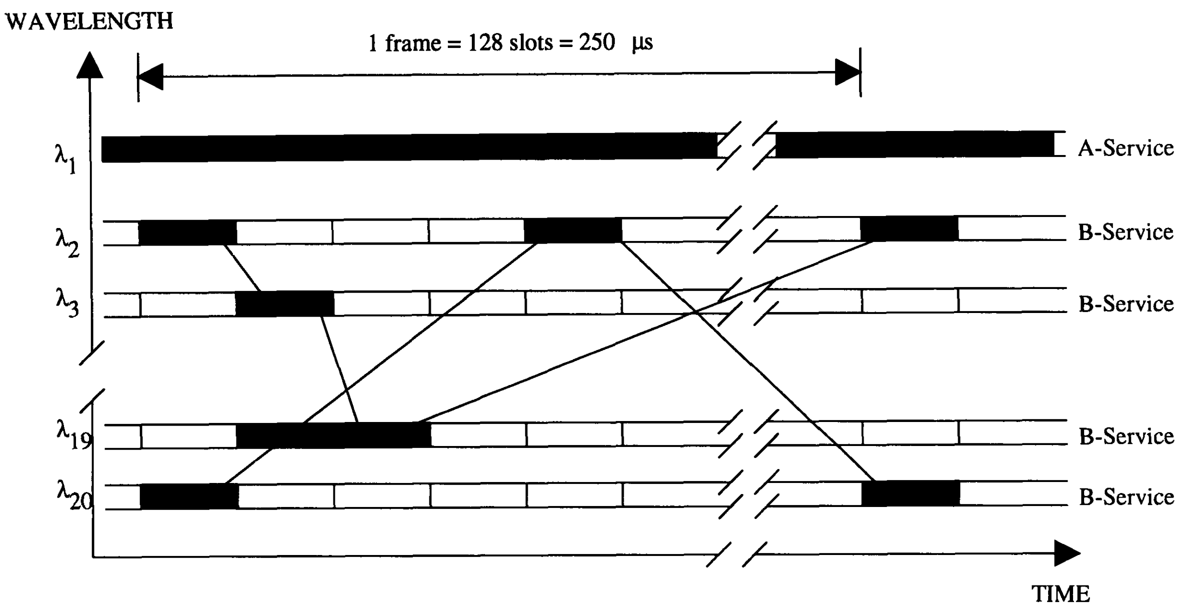

Figure 1-2: AON A and B Channels

Bragg Reflection (DBR) laser is implemented to provide commonality with the B-Service hardware. This same laser is also used in the B-Service. A Mach-Zehnder modulator and a commercial differential driver are used for amplitude shift keying (ASK) modulation in the A-Service transmitter.

The A-Service receiver does not require a fast switching capability. As a result, tunable Fiber Fabry-Perot (FFP) filters are used to select a channel that is to be received. This can be done using a variety of tuning algorithms which determine which channels are active.

1.2.2 B Service

The B-Service is a simultaneous WDM and TDM (Time Division Multiplexing) circuit-switched service useful for lower bandwidth applications. This service allows multiple users to share network resources to achieve simultaneous independent optically-routed connections of different data rates and formats. The B-Service also allows point-to-point, point-to-multipoint, and multipoint-to-multipoint simplex and duplex connections.

The B-service uses the same transmitter as the A-Service and utilizes On/Off keying modulation at 1.244 Gbps rate. Fig. 1-3 illustrates the differences between the A and B-Services. The B-Service shares the same 20 optical frequencies spaced 50 GHz apart as the A-Service. In addition, each wavelength is time slotted with a 250 μs frames divided into 128. Each user can request from 1 to 128 slots per frame depending on the application. As a result, the transmitter hops between different wavelengths of transmission to provide proper time division multiplexing between the various inputs [6].

Since the FFP filters used in the A-Service are not fast enough for the B-Service tuning, heterodyne detection is used with a tunable oscillator to implement a rapidly tunable optical receiver. The B-Service receiver must rapidly select one of 20 channels of optical data. As a result, the receiver hops from channel to channel according to a schedule contained in the OT controller.

1.2.3 C Service

The C Service is the signalling channel of the AON. It is used for control of network operations, administration, telemetry, and resource scheduling [5]. This service is implemented as an analog, amplitude modulated system at 1310 nm. Messages are carried by broadcast Ethernet between the OT's and the Level-0 hub.

1.2.4 Complex Services

The A, B, and C Services are the basic services provided to the OT's by the AON. More complex services are provided through these basic services. These depend on the nature of the OT's. Several different OT's are expected to be added to the AON in the future. An OT could be simply a workstation or a video server, but it could also be a complicated piece of networking equipment such as a SONET Add Drop Multiplexer, an ATM switch, or a gateway to other networks.

Chapter 2

High-Definition Television

One aspect of this thesis was the investigation of transmission of High-Definition Television (HDTV) over the AON. The high bandwidth provided by the AON is capable of supporting the high bandwidth of HDTV. This application would have been particularly interesting since existing electronic network technologies cannot support HDTV signals without compression and subsequent loss of quality. Although in the end no equipment was developed and no components were purchased, several interesting lessons were learned.

HDTV provides the spectator with approximately six times the spatial resolution of the present National Television System Committee (NTSC) format images. Several various standards of HDTV are currently used, but the recent formation of the Grand Alliance, an organization which joins all the major players in the field of HDTV, created standardization for the main format for HDTV. One format is 720 lines per frame and 1280 active samples per line. The other format uses 1080 lines per frame and 1920 active samples per line. Both of these variations offer far more resolution then the NTSC standard of 481 samples per line with 44 lines in vertical intervals [4].

Currently, HDTV signals must be sent over the standard NTSC 6 MHz channels. Thus, the HDTV sequences must be compressed to fit the standard. This is, of course, a cause of information and clarity loss. The A-Service of the AON could be used to send uncompressed HDTV signals. A rate of about 2.5 Gbps could provide adequate transmission at a frame rate of 60 Hz.

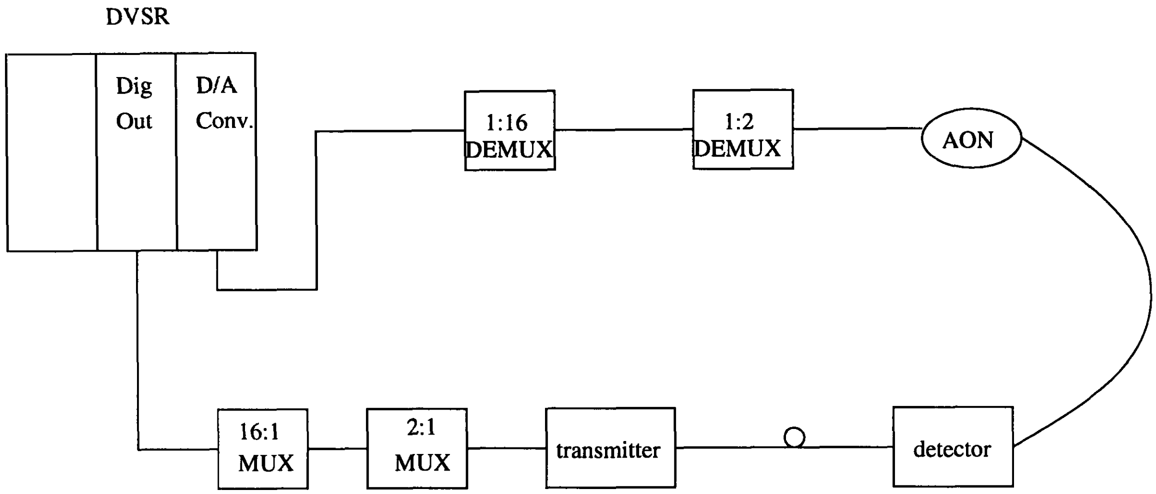

Figure 2-1: HDTV transmission setup

2.1 Setup

The proposed setup for the transmission of HDTV sequences over the AON is illustrated in Fig. 2-1. A key component of the setup is the Digital Video Silicon Recorder (DVSR), an image sequence system produced by Videotechnik und Elektronik (VTE) Digitalvideo. The DVSR located, in the HDTV laboratory, at MIT, consists of A/D converter, memory, and a D/A converter. In short, the VTE stores the analog video signal in memory in digital form. Then, this signal can be displayed by going through a D/A converter at the output.

It was proposed to place the D/A converter part of the DVSR at a location remote from the digital output of the DVSR. In this way, the AON could be used to transport the digital HDTV sequence. To understand the need for all the other components in the system, a brief overview is provided.

2.2 Image Sequence System

The DVSR image sequence system is a video system designed for the capture, storage, and display of video sequences and could be used to transmit digital HDTV sequences over the AON. The DVSR takes an HDTV sequence, digitizes it (with A/D Converter), and stores it in a large RAM. On the other end of the DVSR, the

Video Digital Analog output processor H (VDAH) outputs a digital signal which is then converted to analog in the Video Digital Analog processor J (VDAJ). The VDAJ in turn outputs the analog signal onto the screen. The VDAH and VDAJ comprise the so called AVOP81 High Speed Analog Video Output Processor [14].

The proposal was to place the VDAH at MIT and the VDAJ at the other end of the AON and transmit the digital signal coming out of the VDAH. The output from the VDAH is in 3 Red Green Blue (RGB) channels, each of which is 8 bits wide. In addition, there is a synchronization signal which consists of 2 bits and an additional control bit. Thus, the VDAH has a 27 bit parallel output.

To transmit the information over the AON, the output must be put in serial form. It was proposed to transmit the data on the A service of the AON, which can support rates of up 2.488 Gbps and perhaps a little higher. Thus, the frequency of the serial form can be about 2.5 Gbps. The sampling frequency of the output can be calculated as the product of the number of lines per frame, the total number of pixels per line, and the frame rate. Since the HDTV screen used at MIT is $1024 * 1280$ pixels and the frame rate can be adjusted to 60 Hz, the sampling frequency is calculated to be 78.6 Mpixels/sec. As the output from the VDAH is 27 bit wide, there would be a need to use a 32 bit wide multiplexer. This would amount to a serial rate of 2.52 Gbps, a rate that could probably be supported on the A service of the AON.

Unfortunately, there do not exist any 32 bit wide chips operating at these fast rates on the market. As a result, it was decided to use two 16:1 multiplexers at half the rate and then use a 2:1 multiplexer for the two parallel outputs. A similar solution can be used on the receiver end: first, the serial data coming out of the AON will be demultiplexed into two parallel outputs by a 1:2 demultiplexer and then these two output will be fed into 1:16 bit demultiplexer to recover the original transmitted sequence.

2.3 16:1 MUX/DEMUX

Several different manufacturers of multiplexers were contacted to determine which components would be most suitable. Vitesse Semiconductors and Hewlett Packard (HP) were the two manufacturers who manufacture chips fast enough for this application. Unfortunately, neither the Vitesse chips nor the HP chips come with an evaluation board. There are two smaller manufacturers who build custom boards using the HP G-Link chip. This last option was the most suitable for this project, which was not meant to be a long term experiment in circuit design.

One particular problem with the HP G-Link chip is that it adds two extra error-correction bits for every 8 bits of data. As a result, the information rate is 20% less then the data rate. This posed major problems as the current A-service of the AON cannot support higher rates then 2.5 Gbps, and for the transmission of full uncompressed HDTV, one would need an information rate of 2.5 Gbps and an even higher data rate with the use of the HP G-Link chip. Therefore, for the G-Link to be used, there will be a need to adjust the raster parameters of the VTE to reduce the sampling frequency. After investigating this matter, it seems that raster parameters must be adjusted by the manufacturers of the VTE.

Lincoln Laboratory has recently mentioned that they possess a few custom made boards that use the Vitesse 16:1 MUX/DEMUX chip. Since the Vitesse chip does not add the extra error correction bits, this option might be feasible.

2.4 2:1 MUX/DEMUX

Because there were no 32 bit wide multiplexers and demultiplexers available, it was necessary to use a 2:1 MUX/DEMUX pair to complement the 16:1 MUX/DEMUX chip set. A timing diagram of the necessary function is illustrated in Fig. 2-2. When the clock is low, the output takes the value of one of the sequences, and when the clock is high, the output takes the value of the other sequence. Both SONY and NTT were found to produce a chip that would operate at high enough speeds, but

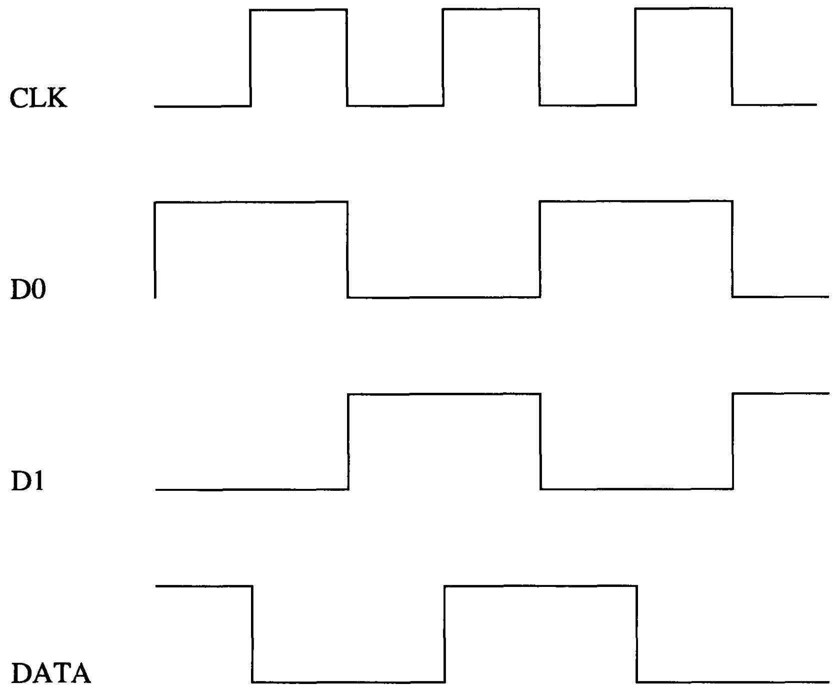

Figure 2-2: 2:1 MUX timing diagram

this issue needed to be investigated further.

It was decided for practical and functional purposes to custom design the 1:2 demultiplexer on the receiver end. The design is illustrated in Fig. 2-3. Basically, the incoming data is distributed to two parallel outputs. The output of one of the channels is updated when the clock triggers the flip-flop. Since the clocks provided to the two flip-flops are opposite each other, the two outputs will be updated on opposite cycles but with the same frequency (half the original clock frequency). Thus, the input will be split into two outputs. The timing diagram of Fig. 2-4 illustrates this point.

To construct a custom 1:2 demultiplexer, there was a need to purchase two simple chips: one which would have contain the two flip-flops and one which would have included the inverter.

2.5 Short Optical Link

Once the data coming out of the VTE has been properly serialized, there is a need to transmit the signal from the HDTV Laboratory in Building 36 to the OT in Building

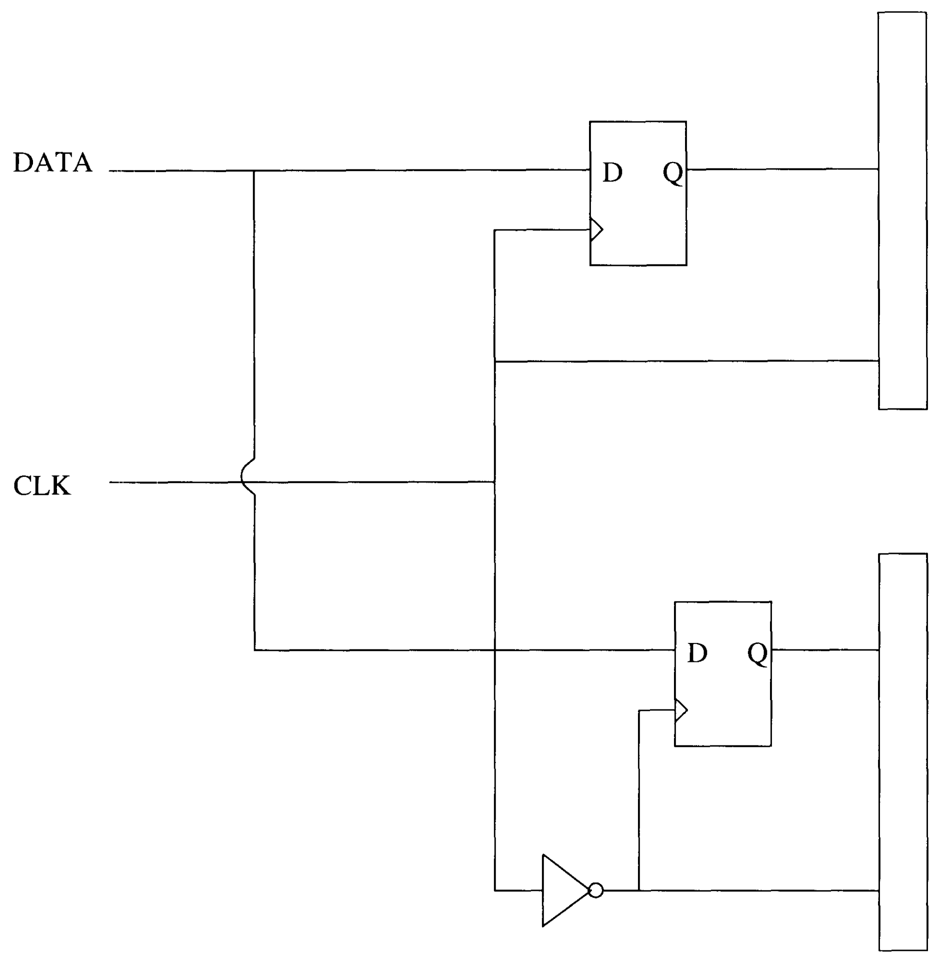

Figure 2-3: 1:2 DEMUX design

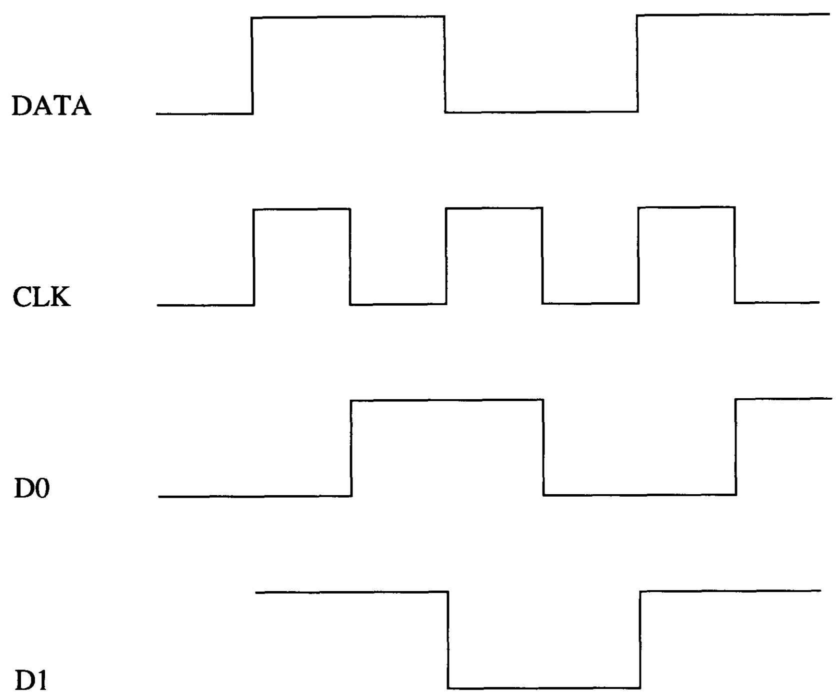

Figure 2-4: 1:2 DEMUX timing diagram

35. There is a need to send the data via an optical fiber due to the high loss of the electrical connection.

2.6 Summary

Although this was an exciting project, it was of high risk for the scope of this thesis. One main difficulty is in using a 2:1 demultiplexer with commercial boards. If there is a single error in transmission, then it would be difficult to determine which bit was dropped and the entire output might be skewed. In addition to the concern with error recovery, there was still the issue that the rate of the A-Service might not suffice for uncompressed HDTV. Changing the raster parameters of the VTE also seemed very difficult. Overall, it was decided that solving the issues involved would require too much effort and funding for what was supposed to be a quick demonstration of AON's capabilities. This part of the thesis was terminated.

Chapter 3

The EMMI Multimedia Interface

The AT&T multimedia interface product called the EMMI^{TM} was used in most transmission experiments conducted in this thesis. The EMMI can be viewed as a video and audio coder-decoder (codec). It is one of the few available codecs which incorporate Asynchronous Transfer Mode/Synchronous Optical Network (ATM/SONET) technology. The EMMI is externally attached to a computer and can be controlled through it. This chapter outlines the major functions of the EMMI and describes some modifications that are needed to make the EMMI more useful for AON transmission.

Fig. 3-1 is the EMMI's interface diagram. The EMMI provides a duplex link: it simultaneously transmits and receives standard NTSC video, CD-quality stereo audio, and data information [2]. Through the software, the user can select one of three

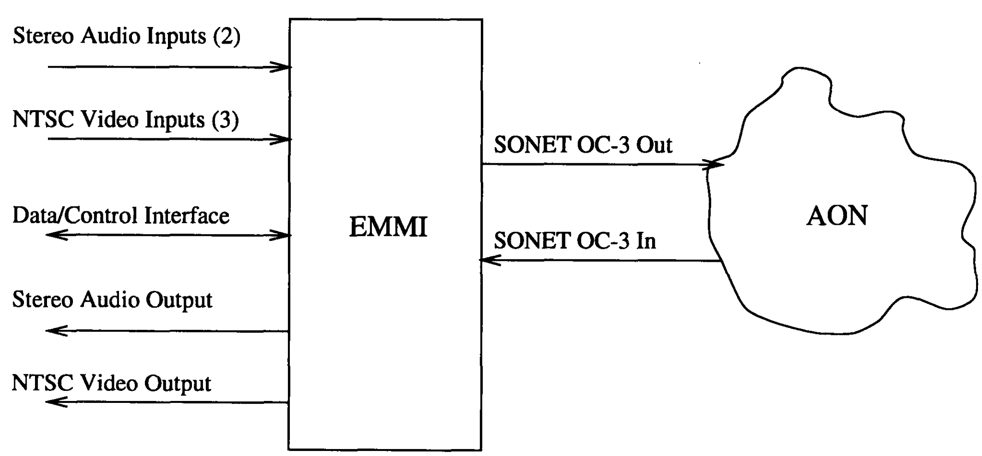

Figure 3-1: EMMI Interface Diagram

	input		output
output type	min	max	min
laser	-31dB	-14dB	-11dB
LED	-31dB	-14dB	-16.8dB

Table 3.1: EMMI optical connection range level

possible video inputs and one of two audio inputs. The video signal is compressed through the motion Joint Photographic Experts Group (JPEG) algorithm before transmission (the extent of compression is user selectable), and the audio signal is sampled at the rate of 44.1 kHz to provide a CD quality signal. The EMMI is connected to a workstation via a standard SCSI II cable. In addition, the EMMI has an NTSC video and an audio output.

On the optical side, information is transmitted using the SONET OC-3c standard (155.52 MHz). The optical output of the EMMI can be configured to be a Light Emitting Diode (LED) transmitter (to be used for transmission over short distances) or an Intermediate Reach Laser Transmitter (to provide a more powerful output). Table 3.1 provides the outputs and acceptable input ranges for the optical connections of the EMMI.

3.1 EMMI and the B-Service

It would be ideal to use the EMMI with the B-Service as opposed to the A-Service. In the A-Service, the EMMI transmission would be taking up an entire channel, whereas in the B-Service, the EMMI can be supported using about 20 of the 128 time slots available on a single channel. Unfortunately, the EMMI hardware poses one particular difficulty with this vision.

The SONET Interface Card (SIC) is used as a connection between the OC-3 input (generated by the EMMI) and a BSDI interface card which provides an interface to the AON. The BSDI card is used to provide timing and control critical to the B-Service [6]. This scheme is depicted in Fig. 3-2. The SIC includes an 8 kbyte First-In-First-

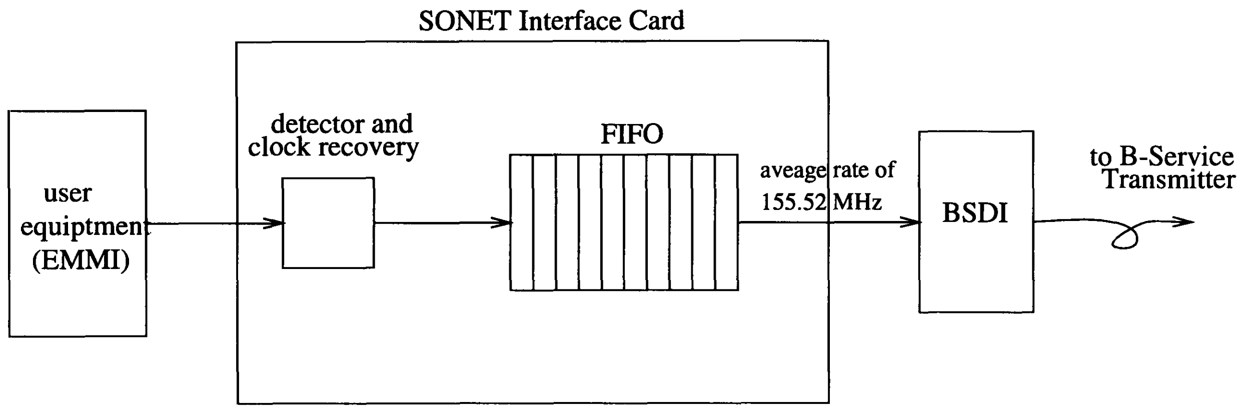

Figure 3-2: SONET Interace

Out (FIFO) buffer. The output from the FIFO buffer is transmitted to the BSDI card at bursts of roughly 1.24 GHz, but the average rate, which is controlled by the master oscillator, is the SONET OC-3 rate. The rate of the input into the FIFO must be equal to or less than this average rate because otherwise the buffer would overflow. In fact, a very slight difference in rates can result in frequent buffer overflows.

To force the FIFO input to have the same rate as the output, it is necessary to somehow provide information about the output rate to the input internally within the EMMI. The technology of the EMMI did not provide this loop back timing. Initially, the Clock and Data Recovery Unit (CDRU) were not connected to the crystal oscillator. The crystal oscillator generates a SONET OC-3 rate by itself. The problem with this configuration is that this rate might vary slightly from the rate of input and thus will cause the FIFO buffer to overflow.

3.2 EMMI Modifications

Dan Castagnozzi, at MIT Lincoln Lab, has been working to make modifications to the EMMI's. One solution was to use a Surface Acoustical Wave (SAW) filter in the CDRU. In this case, the CDRU would be able to drive the crystal oscillator with the rate of the input to the EMMI. This modification is illustrated in Fig. 3-3. There was one problem that was created as a result of this arragement. If there was no input into the EMMI, then no clock was provided for the output and the EMMI crashed.

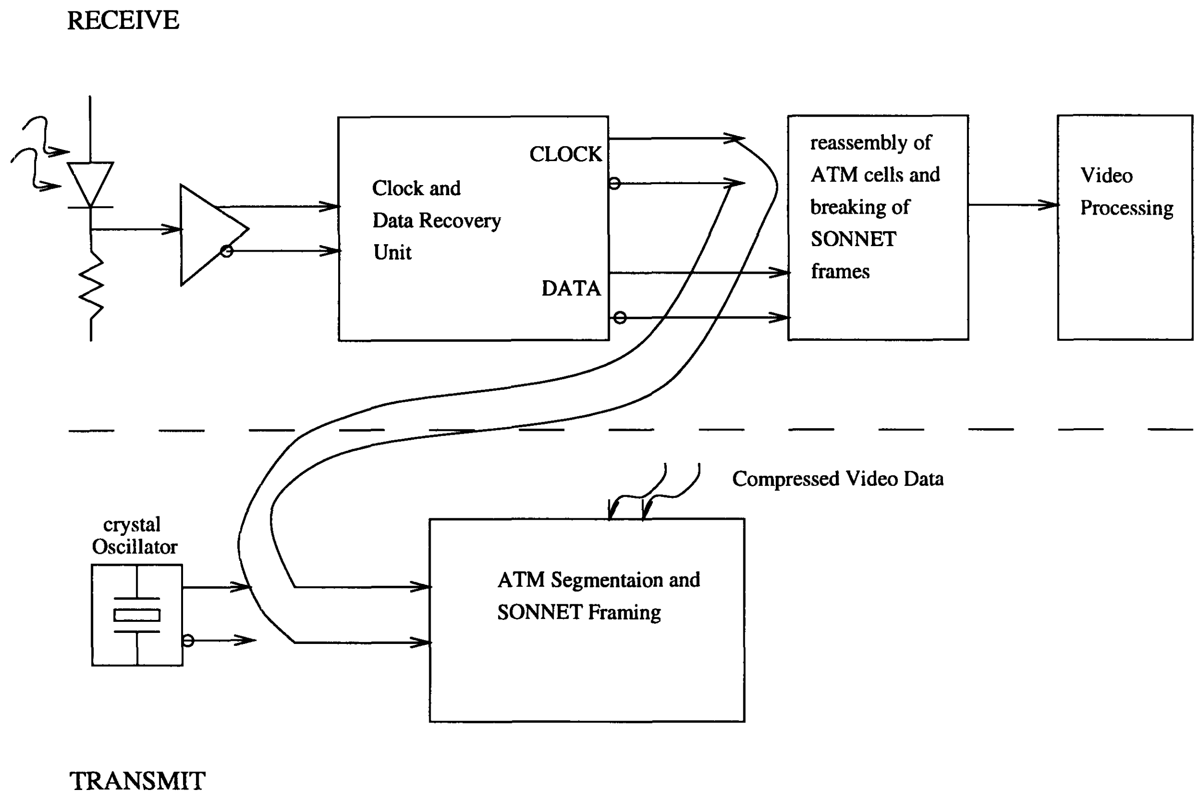

Figure 3-3: EMMI Modification

Clearly, this problem made transmission on the EMMI highly unreliable.

As a result, it was decided to try to implement a new solution. It was necessary to find a chip that would contain both a crystal oscillator on it as well as a phase locked loop (PLL) for clock recovery of the input. In this way, if there was an input then the PLL could be used to drive the oscillator, and if there was no input, then the oscillator would be able to provide its own SONET OC-3 rate. This modification to the EMMI is still in process, and as of the moment of writing, it is only feasible to use the A-Service for reliable transmission using the EMMI on the AON.

3.3 Active Terminator

One significant inconvenience with the EMMI is that it requires a computer to start its operation. At the time when proper selections have been made using the software, the computer can be disconnected from the EMMI. Of course, without it, it is impossible to change the settings, such as compression levels and volume levels. Also, if there is a power outage, there is a need to use the computer again to recommence operation. Fortunately, AT&T is planning to make active terminators in the near future that would have a configuration file programmed into them and would allow restarting the EMMI without the use of a computer. Appendix A includes the configuration file that was sent to AT&T to be used in an active terminator. It is the same configuration file that is automatically saved by the EMMI when a transmission link is established between two connections and all the settings are properly adjusted. In the more distant future, there are plans to allow a computer on one end to control an EMMI on the other side of the link without a computer. Such advances are not yet available at the time of writing.

Chapter 4

Video Conferencing

One very obvious and logical application of the AON is to high quality video. One can imagine that with the wide bandwidth that is provided by the AON, services such as video and audio conferencing can be supplemented with more impressive features. For instance, a simultaneous computer connection can be established where users in different sights can have access to the same files and programs. Another option is for a speaker at one sight to send transparencies and pictures to the other sight. In short, many options exist for advanced video conferancing.

Unfortunately, the major obstacle to such visionary video conferencing on the AON is the lack of software which can provide such services with fiber optic connections. This chapter, therefore, focuses on the software that was available with the AT&T EMMI.

Aside from the issue of software availability, there are other important factors that need to be taken into consideration with video conferencing applications. This chapter discusses in detail the issue of acceptable audio quality and some of the currently available technology on the market. Finally, the chapter concludes with a discussion of the practicle possibilities for video conferencing over the AON.

4.1 EMMI's Video Conferencing Application

The Video Conferencing application of the EMMI provides a graphical user interface that can control the EMMI from a local computer. The EMMI is able to communicate with other EMMI's using Transport Control Protocol/ Internet Protocol (TCP/IP). In order to run the application, it is necessary to create a file containing the proper IP addresses and a file containing all the ATM network Virtual Path Identification/ Permanent Virtual Channels (VPI/VCI) addresses. Sample files are appended in Appendix B. These files are essential to provide a proper connection between all the EMMI's in the network. In this case, the software was tested with only two EMMI's.

The application itself provides basic video conferencing between two users. It is possible to establish a connection by calling another location and obtaining permission from it. At that point, an audio, video, and data link is established. Through the data link, it is possible to use a "whiteboard", which allows two users to draw and to paste pictures simultaneously on the screen. Unfortunately, because of the early stages of development of the software, the program crashed when both users were using the whiteboard extensively at the same time. Clearly, this bug must be fixed by the manufacturers in the future.

4.2 Audio Quality

Sound quality is dependent on a very large number of variables. In fact, it is quite difficult to quantify all the variables and specify what exactly is suitable sound quality. This thesis did not focus on extensive research on room acoustics and sound theory. The following discussions, therefore, are somewhat qualitative and simply offer some insight as to what factors can improve audio quality in video conferencing. The focus here will be on room acoustics and on the audio system itself.

4.2.1 Room Acoustics

The two major factors in room acoustics are decay time and background noise level.

Decay time can be defined as the time it takes for the sound which hits the microphone directly (it arrives there after hitting other obstacles in the room including the walls) to decay and not be noticable. One source defines an acceptable decay time to be .75 seconds [9]. Clearly, decay time will be lower in room with good absorbing materials, such as thick carpet and heavy drapes, than a room with reflective materials, such as marble and tile. Decay time is also a function of size and shape of the room. Typically, a large room with high reflecting ceilings will have a very large decay time.

In addition to decay time, the background noise level in the room is also an important factor for audio quality. Typical background noise that is encountered in real situations is noise from fans in computers and other electronic equiptment, noise from air vents, flourescent light noise, etc. There exist standardized Noise Criteria (NC) curves to determine the background noise level of a room. Rooms used for video conferencing need to have an NC rating of 35 or less, which is very low noise [9].

4.2.2 Audio System

The three most important factors that determine how well an audio system is able to function are talker-to-microphone distance, the number of microphones used, and the microphone pickup pattern [9]. Clearly, the further the speaker is from the microphone the more noise and less signal will be received by the microphone. On the other hand, if there are several microphones which are receiving information simultaneously, in order to accommodate for the distance between microphone to several speakers, there would be a dramatic increase in the noise that the system would pick up. Finally, the microphone pickup pattern will be important in determining from what direction the microphone will pick up sound. All these factors are important to consider when designing an appropriate audio system.

A common problem with a two way communication system is the problem of audio feedback. Fig. 4-1 illustrates this particular phenomenon. Feedback occurs if the microphone on one end of the system picks up sound from the loudspeaker that transmits sound from the other end. If there is significant feedback on both ends of the transmission system, then the acoustic quality becomes inadequate. Feedback prob-

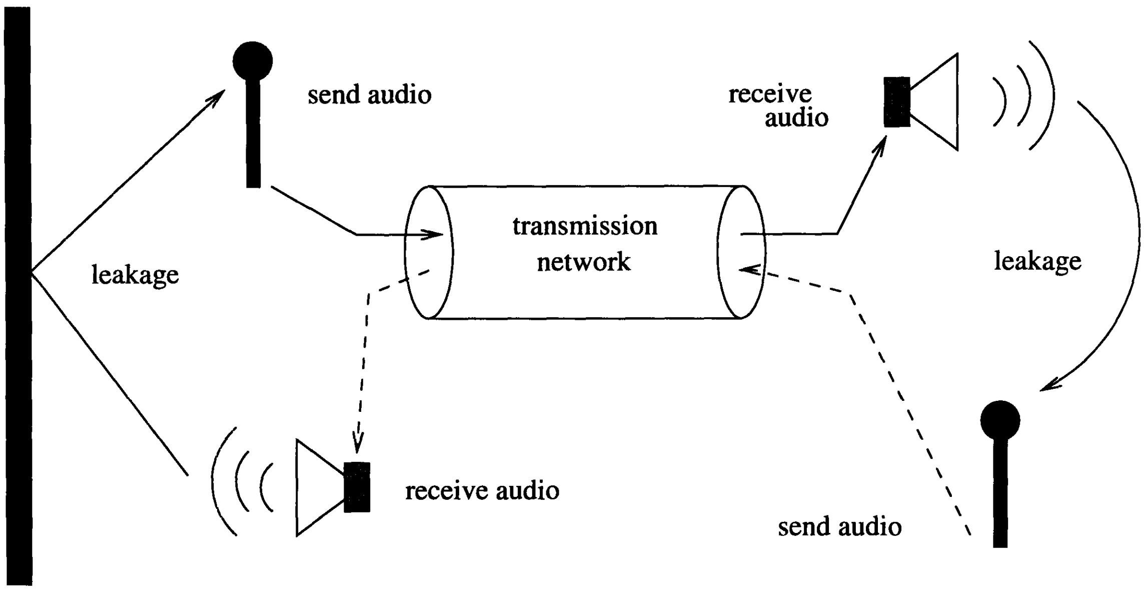

Figure 4-1: The Feedback Effect

lems can be alleviated by proper positioning of directional microphones, adjustment of volume, and by the use of the commercially available "echo cancellers".

4.3 Audio System Implementations

An effort was made to explore various possibilities for audio systems at justifiable cost. A number of echo cancellers and directional microphones was explored. Below, is a discussion of the equiptment that was used and tested and its effectiveness.

4.3.1 Echo Cancellers

Echo cancellers are devices which are designed to reduce the feedback effect often encountered in video conference systems. The principle with which an echo canceller operates is fairly simple. The echo canceller device, which in most cases is just a simple box the size of a video cassette recorder, tries to identify the impulse response of a room by projecting white noise in the room environment. Then, when the real conversation takes place, the device is able to subtract the echo from the total voice signal by using the previously found impulse response function.

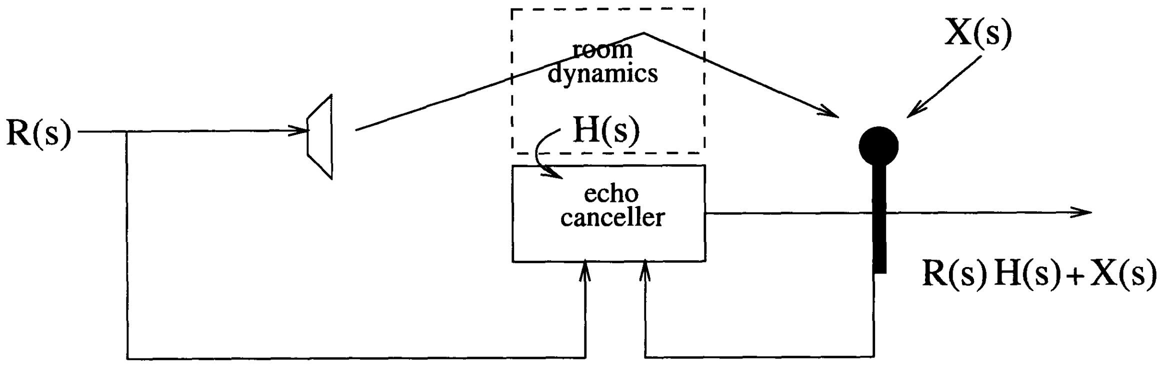

Figure 4-2: Echo-canceller block diagram

This is illustrated more clearly by Fig. 4-2. Let $X(s)$ be the input of a speaker on one side of the network and $Y(s)$ be the output. Let $R(s)$ be input of the speaker on the other side. Finally, let $H(s)$ be the transfer function associated with the room acoustics. This is the transfer function that can be measured by the echo cancellor when it produces white noise in the training phase. For white noise, $R(s) = 1$ and the output is simply

$$Y(s) = R(s)H(s) + X(s) = 1 * H(s) + 0 = H(s)$$

When there is regular conversation, with no echo cancellation, the output is

$$Y(s) = R(s)H(s) + X(s)$$

But, since, there is echo cancellation, the device knows the input from the other side, $R(s)$ and from the previously determined $H(s)$, it can cancel the echo, $R(s)H(s)$. The output, then, simply becomes $X(s)$.

Unfortunately, there are a few problems with the use of echo cancellors. For one, it is very difficult for the device to learn precisely the transfer function of the room. Also, people and objects move in the room environment. This changes the dynamics of the system and the transfer function becomes slightly different. One solution to this problem is echo cancellors which constantly adjust to the ongoing changes in the room, but this might be somewhat inaccurate.

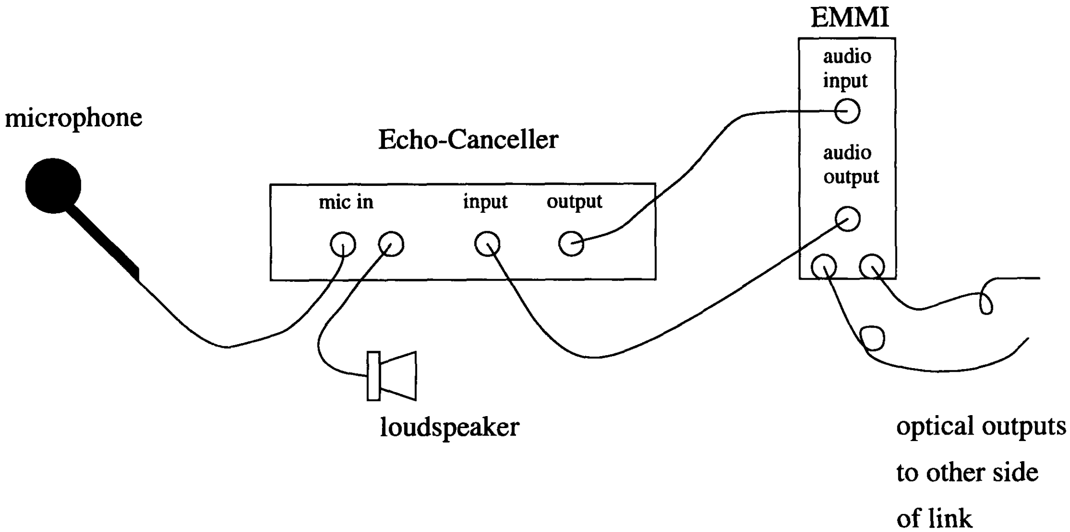

Figure 4-3: Setup for echo-canceller testing. One side of link

The general setup that was used with the echo cancellers is illustrated in Fig. 4-3. A microphone was connected in each room to an echo canceller device. This device was, in turn, connected to an EMMI with two audio links: input and output. The EMMI's in both rooms were connected together with standard multi-mode fiber with ST connectors.

Two different echo cancellers were tested in the same environment: the Gentner GT700 and the Coherent Voicecrafter 3000. It was found that the Coherent Voicecrafter was a simpler machine to use from an operating point of view since it did not have the many adjustment pots found on the Gentner GT700. These pots were provided to adjust the levels of the signals transmitted to and received from the other side of the link. The Coherent device provided automatic adjustment of these levels.

An alternative setup was tried in the testing process. Instead of using two echo cancellers, only one was used. This prevents a long decay of the feedback, which is eliminated on one side of the link. Thus, on one side of the link, a microphone was simply connected to the EMMI audio input bypassing the echo-canceller. This was conducted in the same conditions as the previous experiments. Both the Coherent and the Gentner products were tested.

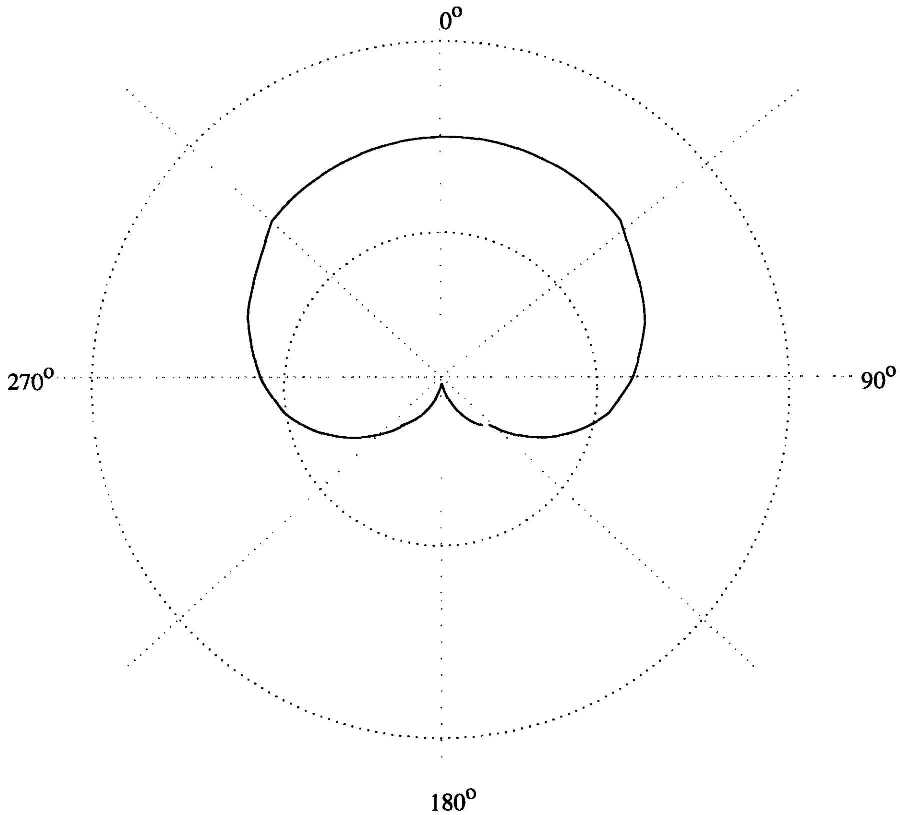

Figure 4-4: Polar Pattern of a Unidirectional Microphone

4.3.2 Unidirectional Microphones

It was decided to also examine an option that did not utilize the echo-cancelling devices for comparison purposes. Two different types of microphones were used. First, a simple cam-corder microphone was used. In this case, the feedback in the audio was quite apparent, and, as a result, it was necessary to limit the audio transmission to a one way link. The second type of microphone that was used was a directional microphone. Fig. 4-4 illustrates a typical polar pattern for the microphone. It can be seen that this kind of microphone does not pick up any sound from one direction. Therefore, the loudspeaker was placed in that area to minimize the feedback effect. And, when compared to the regular microphone, the unidirectional microphone displayed limited feedback effect.

4.3.3 Analysis of Results and Future Plans

In all cases in which echo-cancellers were used, (2 echo-cancellers, 1 echo-canceller, Gentner, and Coherent products) the result was fairly similar. There was an occasional howling noise produced from improper adjustments of the devices. The overall echo-cancellation quality of the Coherent product was somewhat better then the Gentner device, and as expected, the quality of two echo-cancellors was better then that obtained with one. Unfortunately, the total audio quality was not impressive. It was necessary to keep the volume at a low level to prevent howling sounds from the devices. The quality of the audio was surprisingly good when the simple unidirectional microphones were used with a power amplifier and was not much worse then the audio quality obtained with echo-cancellers.

One factor that could have contributed to the poor performance of the echo cancellers was the fact that the rooms that were used in the testing were far from ideal. One of the rooms was very large and not a conference room at all. In addition, there were various objects that could have added a significant amount of echo. Also, the two rooms were very close to each other and there was some noticable cross-talk that could be heard between the two locations.

Despite the far from ideal conditions of the two rooms, it was decided that the cost associated with echo cancellers (roughly $1000) did not justify their purchase for the current needs. As previously described, the unidirectional microphones with a simple power amplifier were quite satisfactory and produced very little noticeable feedback.

As a result, two mixing boards (with amplifiers) were purchased from Radio Shack: MX-1000 6-Channel Microphone Mixer. In addition, four unidirectional microphones were purchased: Two Pressure Zone Microphone (PZM) from Radio Shack and two surface-mounted unidirectional condenser microphones (model 819) from Shure Brothers Inc.

This equipment is sufficient for the current needs of the laboratory, but in the future, when there is a desire to implement high quality audio/video conferencing, there will be a need to rely on more sophisticated equipment such as "echo cancellers".

At present, the equipment purchased is stored at MIT Lincoln Laboratories, and in the near future there is potential for its use. There are a few options for video conferencing possibilities. These possibilities are examined in the final chapter of the thesis.

Chapter 5

Seminar Transmission

In recent months there has been great interest to provide the services of the AON for the scheduled transmission of seminars between MIT and Lincoln Labs. This would allow the transmission of various programs from Lincoln Labs to MIT and vice versa, as well as a bi-directional service for such seminars. In short, an effort was made to institutionalize the service of the AON to transmit regularly scheduled programs. This chapter summarizes the various links that were established for the transmission of a number of seminars and programs. The problems that were encountered and their solutions are described as well. Once again, the AT&T EMMI was widely used in these applications. For reasons described earlier in Chapter 3, the current EMMI's could not be used reliably with the B-Service. Therefore, all the work summarized in this chapter used the A-Service of the AON.

5.1 The MIT-Lincoln Laboratory Link

The AON laboratory in MIT is located on the fourth floor of Building 35. It contains a Level-0 and an optical terminal and is capable of providing A-Service and B-Service transmission on the AON. In order to use this laboratory, there was a need to connect it with a location at MIT from where seminars and conferences could be televised. A decision was made to connect the Building 35 laboratory with the office of MIT Cable Television (MIT CATV) in Building 9 with a pair of multi-mode fibers.

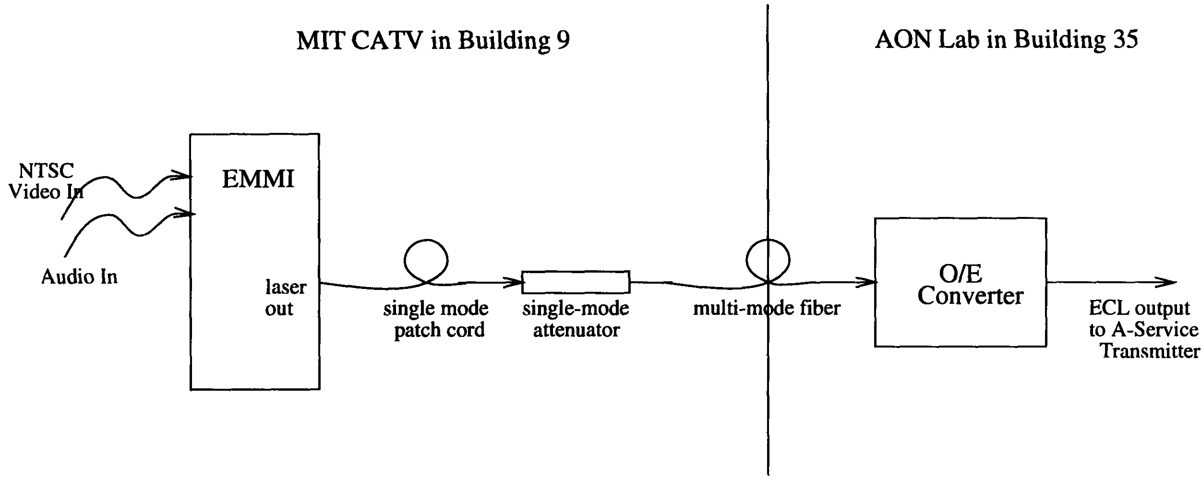

Figure 5-1: Setup used for OQE Seminars

One clear advantage is that this connection provided a opportunity to transmit MIT CATV services over the AON. Another advantage is that there would be no need to provide a direct fiber link to every room that would be used for programs to be transmitted. The drawback is that the AT&T EMMI had to be placed at the MIT CATV location in order to transmit over the fiber to the Building 35 lab and that only rooms connect to MIT CATV via a coaxial cable could be used for transmission. This introduces great limitations to the amount of experimentation that can be conducted on the link between MIT and Lincoln Lab and adds an additional burden to the MIT CATV personnel. These facts should not pose problems in the future as there is a desire to provide a permanent link between MIT and Lincoln Labs.

5.1.1 OQE Seminars

The Optics and Quantum Electronics Group at MIT sponsors a weekly seminar on Wednesday mornings at 11am-12pm in the Grier Room B, 34-401B. This seminar provides an ideal setting for experimental transmission from MIT to Lincoln Laboratory over the AON. Fig. 5-1 illustrates the setup that was used for the seminar transmission. This setup is explained in detail below.

One particular difficulty that was encountered in seminar transmission from MIT to Lincoln Labs is the issue of attenuation. Table 3.1 illustrates the acceptable output

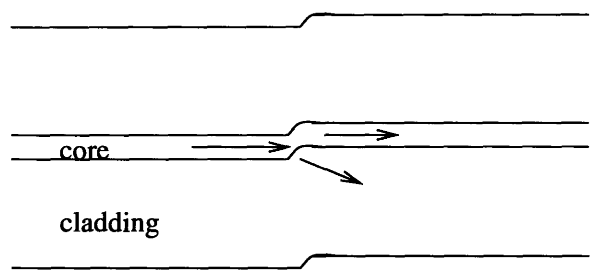

Figure 5-2: Offset Waveguide Attenuators

and input ranges for the two different types of EMMI's: LED output and laser output [1]. Since, at the time of writing, only the EMMI's with the laser outputs were available for use (the other two EMMI's were being modified), there was a need to use attenuators since the short distance of the fiber between MIT CATV and the AON Laboratory did not provide enough attenuation to meet the input requirements.

Unfortunately, the only attenuators possessed by the laboratory at the time of experimentation were single mode attenuators. Fig. 5-2 illustrates the operation of attenuators. Most of the attenuators that are used in the laboratory are offset (displaced) waveguide attenuators. If a single mode attenuator is used with a single mode fiber, no problem is caused. A portion of the power is dissipated through the cladding and a portion of the power is retained in the core of the fiber.

Unfortunately, if a single mode fiber is used in conjunction with a multi-mode fiber difficulties arise. The issue is the same when a single-mode fiber is placed after a multi-mode fiber. The major difficulty is that the core of a single-mode fiber is much smaller than the core of a multi-mode fiber (5 μm as opposed to 50 μm in diameter). Fig. 5-3 illustrates the differences in coupling from multi-mode fiber to single-mode fiber and vice versa. In coupling from a single-mode fiber to a multi-mode fiber, the single mode is coupled to many modes. On the other hand, a single-mode fiber which is placed after a multi-mode fiber will receive only a very small portion of the power (perhaps as little at 1%). There is an additional difficulty. There is great instability in the multi-mode pattern impinging upon the single-mode fiber at the end of the multi-mode fiber. As a result, there is great variation in the power that is transmitted through to the multi-mode fiber.

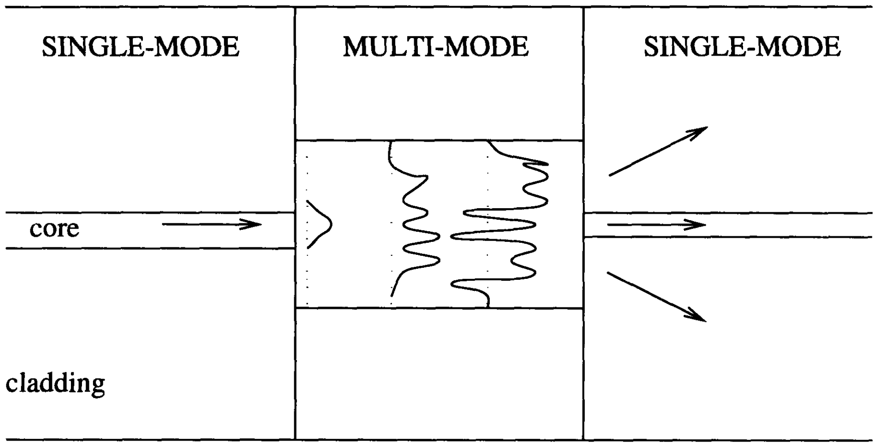

Figure 5-3: single-mode and multi-mode fiber coupling

From the above explanation, it is clear that there is a need to use a single-mode fiber in conjunction with a single-mode attenuator. Thus, to remedy the situation, single mode patch cords were used to connect the EMMI to the attenuator. At that point, it was possible to connect the multi-mode fiber.

Another important point that must be mentioned is the fact that a single-mode fiber can be connected effectively only to a laser output EMMI. This is because the output of an LED is too divergent and cannot be focused enough to couple enough power into the narrow diameter of a single-mode core. Since at the time of writing only laser EMMI's were available, this was not an issue in this case, but attention to this fact must be taken in the future.

In short, a single-mode 20dB attenuator was used (with a single-mode patch cord) in the link between Building 9 and Building 35. In the Building 35 AON Lab, the attenuated optical signal was transformed to an electrical ECL level signal using an Optical to Electrical (O/E) Converter previously fabricated by Dan Castagnozzi of Lincoln Laboratory. This ECL level signal was fed into the A-Service transmitter of the AON.

5.1.2 Vice President Albert Gore's Speech

To accommodate MIT CATV and to make more practical use of the EMMI's, it was decided to provide Lincoln Laboratory's EMMI's to MIT CATV for the trans-

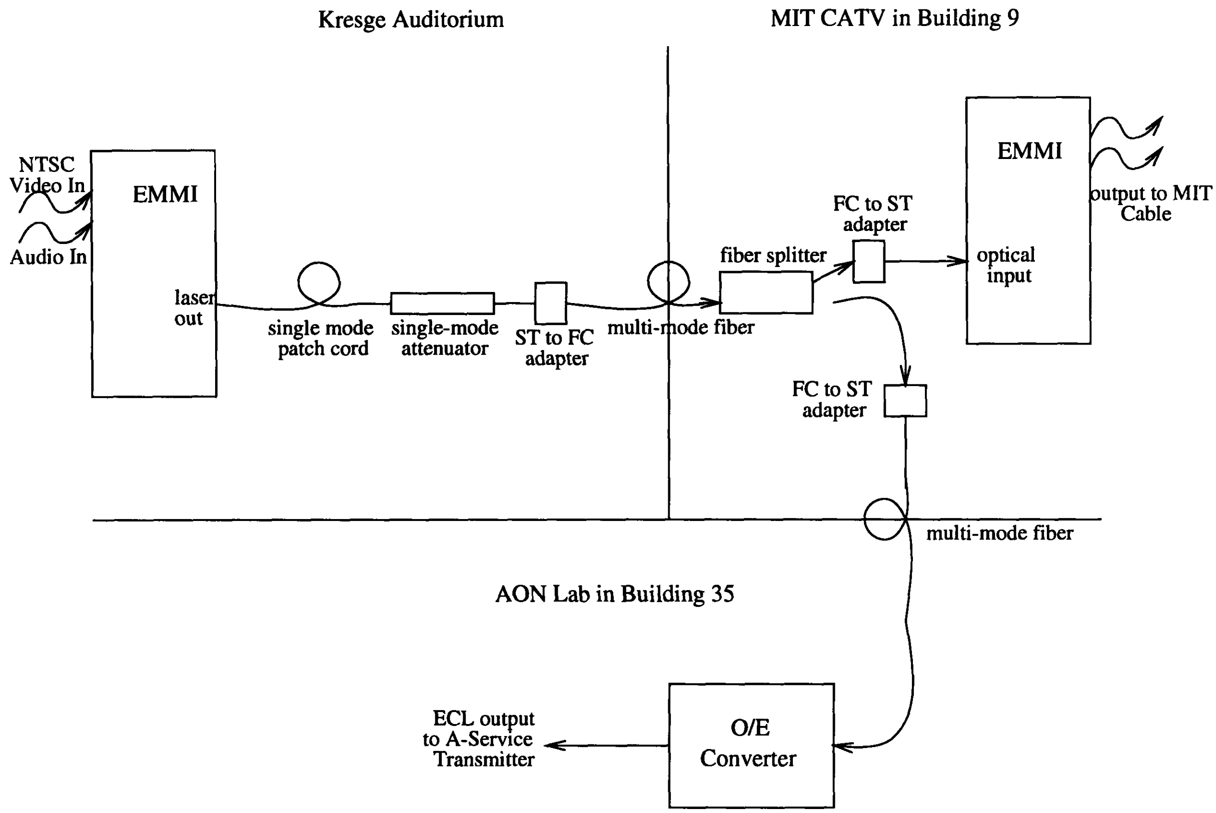

Figure 5-4: Setup used for Vice President Gore's Speech

mission of Vice President Gore's lecture to an Environmental Journalists Conference conducted at MIT.

Fig. 5-4 illustrates the setup that was used for Vice President Gore's lecture. A laser EMMI was set up at Kresge Auditorium, the site of the lecture. This laser transmitted to MIT CATV in Building 9 through an existing fiber connection. After a 20dB attenuator was added to the link, a splitter was connected to split the input into two. One output was used for Cable Transmission, the other was transmitted to the AON Lab in Building 35. The addition of a splitter introduced a minor loss in the output signal of 4dB. Fortunately, this loss was insignificant and did not affect the performance of the link. The transmitted lecture was successfully recorded on a VCR at Group 67 of MIT Lincoln Laboratory.

A minor difficulty in this transmission was the difference in optical connectors. Two types of connectors were used. The EMMI's and the link between the AON Lab and MIT CATV use the ST type connector, while the fibers between Kresge

Auditorium and MIT CATV use the FC type connector. This issue was resolved by using several adapters.

5.2 The Lincoln Laboratory-MIT Link

As opposed to relatively flawless transmission from MIT to Lincoln Labs, there were a number of difficulties encountered in the other direction. A number of demonstrations were conducted to verify the quality of video in the transmission from Lincoln Labs to MIT. In addition to several attempts at bi-directional video links, the monthly Thursday Night Seminar sponsored by the Laser and Electro-Optics Society (LEOS) at Lincoln Labs was transmitted. As a result, it was observed there there were occasional errors on the link. In order to use the AON on regular basis for scheduled programs, it was necessary to make the link error free. This section describes the various corrections that were made to fix the link. It was not until only recently that the problem was correctly fixed by Mark Stevens of Lincoln Labs.

5.2.1 Modulation Bias

An On/Off keyed Modulator is used in the A-Service Transmitter to output an optical signal to the AON. It is driven by an ECL level electrical input signal. The modulator is, in fact, a differentially driven Mach-Zehnder Interferometer. As a result, it has a sinusoidal transfer function. These issues are illustrated in Fig. 5-5.

For proper output level, it is necessary to have V_π and the bias voltage properly adjusted. V_π signifies the voltage required to turn the modulator from full off to full on. It is, therefore, the required swing in voltage between the optical transmitter peak and the optical transmitter minimum. The bias, on the other hand, is the point halfway between the voltage of 0 and V_π. It is necessary to adjust the bias to be at the correct setting so that an input minimum will result in an optical on, and an input maximum will result in an optical off. The A-Service Transmitter board includes a pot for this bias adjustment.

It was thought that improper bias was the cause of bit errors. Unfortunately,

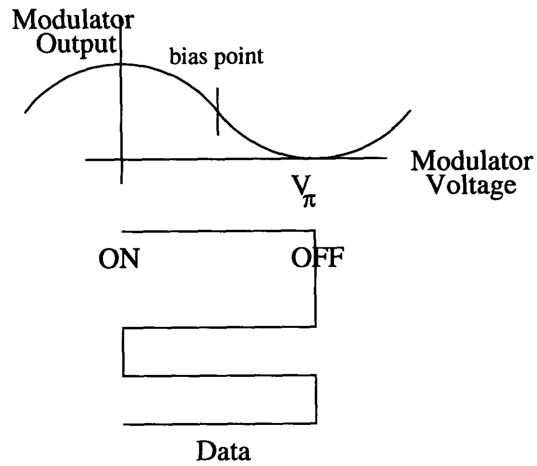

Figure 5-5: On/Off keyed Modulation

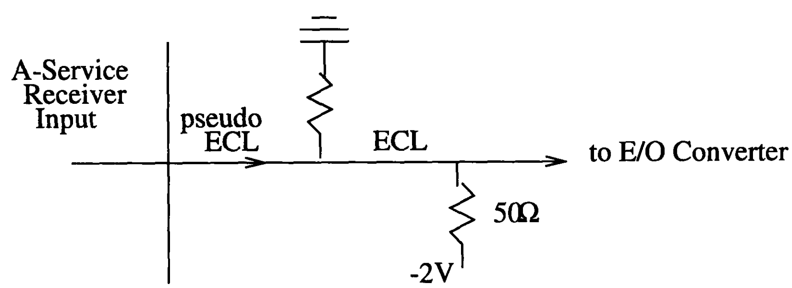

Figure 5-6: Connections to A-Service Receiver

adjustment of the pot did not improve significantly the error rate.

5.2.2 ECL Level Output Resistor

Fig. 5-8 illustrates the connection to the A-Service receiver board. The output of the A-Service Receiver board is at a pseudo-ECL level electrical signal. It is clear that this output needs to be adjusted to an ECL level signal to comply with the E/O converter that bridges the board to the EMMI. Also, by ECL convention, which is further discussed in the following chapter, the ECL signal must be terminated with a 50Ω resistor to -2V. All these details are shown in the figure.

A possible reason for the errors was thought to be the value of the resistor. If the value of the resistor was not correct, then the signal would not be at an ECL level. Changing the value of the resistor might have solved that problem but, unfortunately, did not eliminate the errors in the transmission.

5.2.3 Bias Capacitors in the A-Service Transmitter

It turns out that the errors were created for reasons other then the ones described above. The reasons were due to an incorrect value of some of the internal capacitors on the A-Service Transmitter board. As mentioned previously, the A-Service was designed for rates of 1.2 GHz and 2.4 GHz, whereas transmissions with the EMMI were at the rate of 155 MHz. Thus, it was necessary to use larger bias capacitors.

Chapter 6

The Connection to DEC

Recently there has been an effort made to utilize the AON for transmissions to and from the Littleton, MA location of Digital Equipment Corporation (DEC). A number of successful demonstrations showed the capability of the AON to transmit to and from DEC.

Since the AON is used mainly for experimental purposes, it has been suggested that it would be desirable to maintain a permanent transmission link out of the AON band. It so happens that there are two additional single-mode fibers between Lincoln Laboratory and DEC. It is, therefore, quite straightforward to utilize this dedicated link for transmissions using the AT&T EMMI's.

This chapter describes the setup envisioned for this dedicated link between Lincoln Lab and DEC. For reasons described below, it was necessary to fabricate a new circuit that will be used as a simple repeater with a laser output. The technology of the circuit is described in this chapter as well.

6.1 Setup

It is currently possible to utilize two laser EMMI's for the dedicated link between Lincoln Labs and DEC. Unfortunately, it is necessary to locate the EMMI's at the sight of the lecture to be transmitted, which is normally away from the AON laboratory. Since the auditorium with the EMMI is usually connected to the AON laboratory

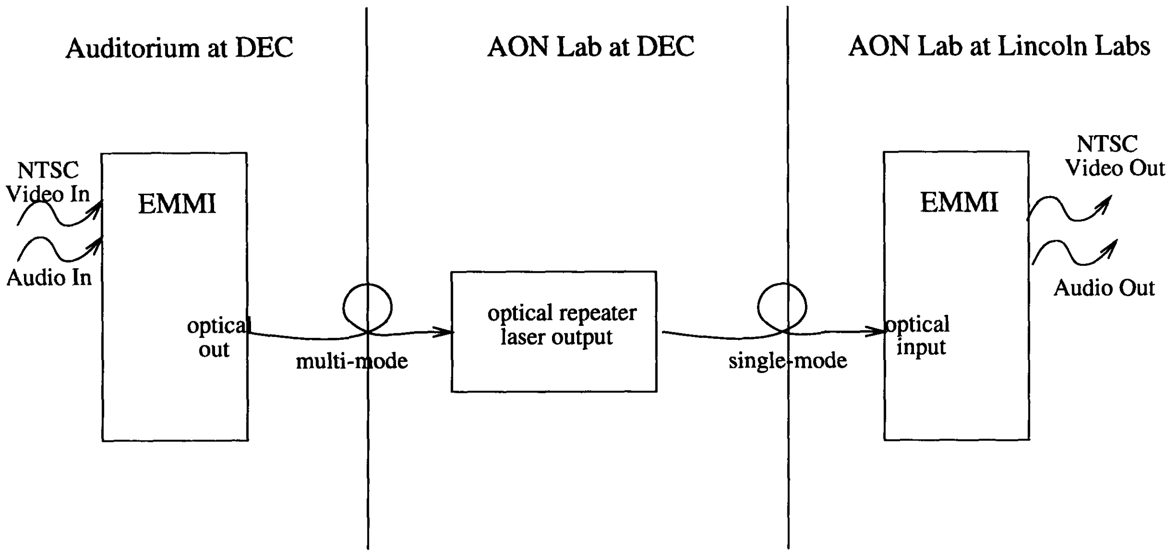

Figure 6-1: Setup for Dedicated Link

via a pair of multi-mode fibers, a repeater will need to be placed at the lab that will take the optical multi-mode fiber input and retransmit it into the pair of dedicated single-mode fibers. Because of the lower cost and its simplicity, it was decided to utilize a 1300nm laser for this application. The setup described is illustrated in Fig. 6-1.

6.2 Emitter Coupled Logic (ECL) Technology

ECL technology is the fastest logic circuit family. Its high speed is achieved by operating all transistors out of saturation and by maintaining small voltage swings. [11]. The following is a brief discussions of the conventions of ECL technology which was used in designing the circuit of the repeater.

A typical ECL gate output has emitter followers at its outputs. From basic circuit analysis, it is evident that for the transistor to be in its operational state, it is necessary to have the base voltage to be more than 0.6 volts greater then the emitter voltage of the transistor. It is also important to have a higher collector voltage than base voltage. If V_{CC} is set to ground, the base voltage is determined by the internal circuitry of the ECL gate to be between 0 and -0.8 volts. As a result, a logical choice

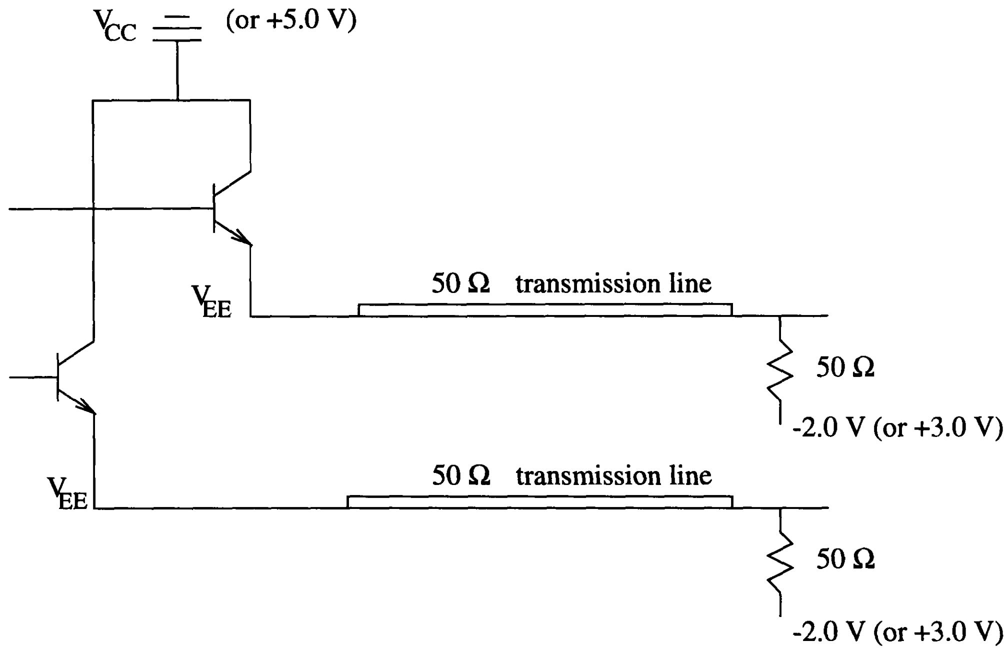

Figure 6-2: ECL Conventions

for V_{EE} is -2.0 volts. alternatively, V_{CC} can be set to +5.0 volts. In that case, the base voltage will be between 5.0 and 4.2 volts, and a logical choice for V_{EE} becomes +3.0 volts. This convention is called PECL: Positive ECL.

There is another issue with ECL logic. In most cases of high-speed logic circuits, the output circuit drives a transmission line. It is necessary to terminate the transmission line with a matched load (in most cases a 50Ω resistor) to eliminate "ringing" that could corrupt the logic signals. The points described above are current ECL conventions and are illustrated in Fig. 6-2.

An ECL output normally appears in a differential pair. As a result, the same current appears across both of the resistors. Thus, the -2 volt (or +3 volt) termination can be converted to a ground. This AC ground is possible if an additional circuit is added to draw the same current out of the transistor. A similar dc current can be drawn if the emitter is pulled down to a 5 volt source (or ground) with a 300Ω resistor. This provides an alternative termination for ECL output, as shown in Fig. 6-3.

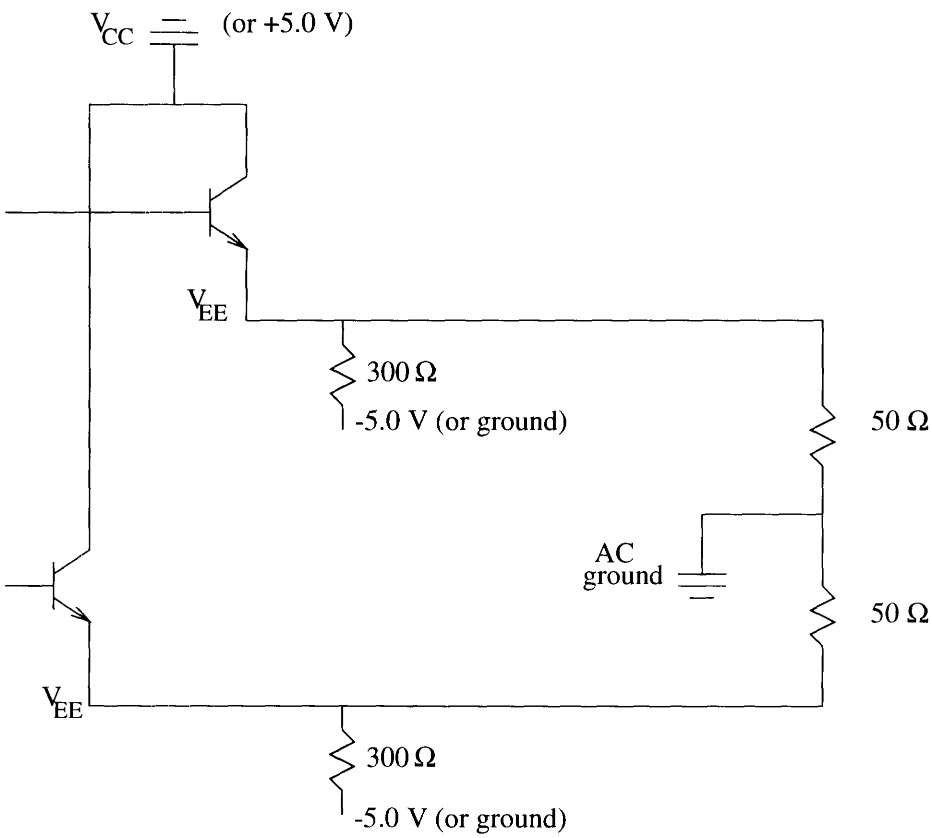

Figure 6-3: Alternative ECL Termination

6.3 Circuit Design

Fig. 6-4 illustrates the design of the circuit of the optical receiver and a laser transmitter. The circuit is capable of accepting an optical input. Its only function is to retransmit the same signal with a 1300 nm wavelength laser.

The data is ECL level and is terminated by the technique described in the previous section. An alternative would be to create a Thevenin equivalent circuit to match the 50Ω resistor termination to ground, but this would involve more complicated circuitry. Small bypass capacitors are located close to the pins to eliminate spikes in power. The large capacitor is added for long transients.

The two chips used are the OCP SRC-03 SONET Receiver Module with Clock Recovery and the OCP STX Transmitter Module. The receiver has a ST receptacle and the transmitter has a FC connector at the end of a pigtailed fiber. The receiver module with clock recovery is pin compatible with a module that does not contain clock recovery. A disadvantage of using the clock recovery is that only SONET OC-3 rate can be used for transmission. On the other hand, it is advantageous to use clock recovery to eliminate any jitter in the signal. After the clock is recovered it is used to resample the data.

6.4 Conclusions and Further Recommendations

This thesis examined various possibilities of permanent transmission along the AON. A good relation with MIT CATV has been established, and a dedicated link between Lincoln Laboratory and DEC has been created to bypass the AON all together. Despite these advances, there remain a large number of issues to be examined in the future.

Perhaps the most attractive feature that the AON could provide for seminar transmission is the ability to provide bi-directional links. This would greatly increase the audience participation and be clearly a distinct advantage. If seminar transmission along the AON will continue to be done through MIT CATV, there will be a need

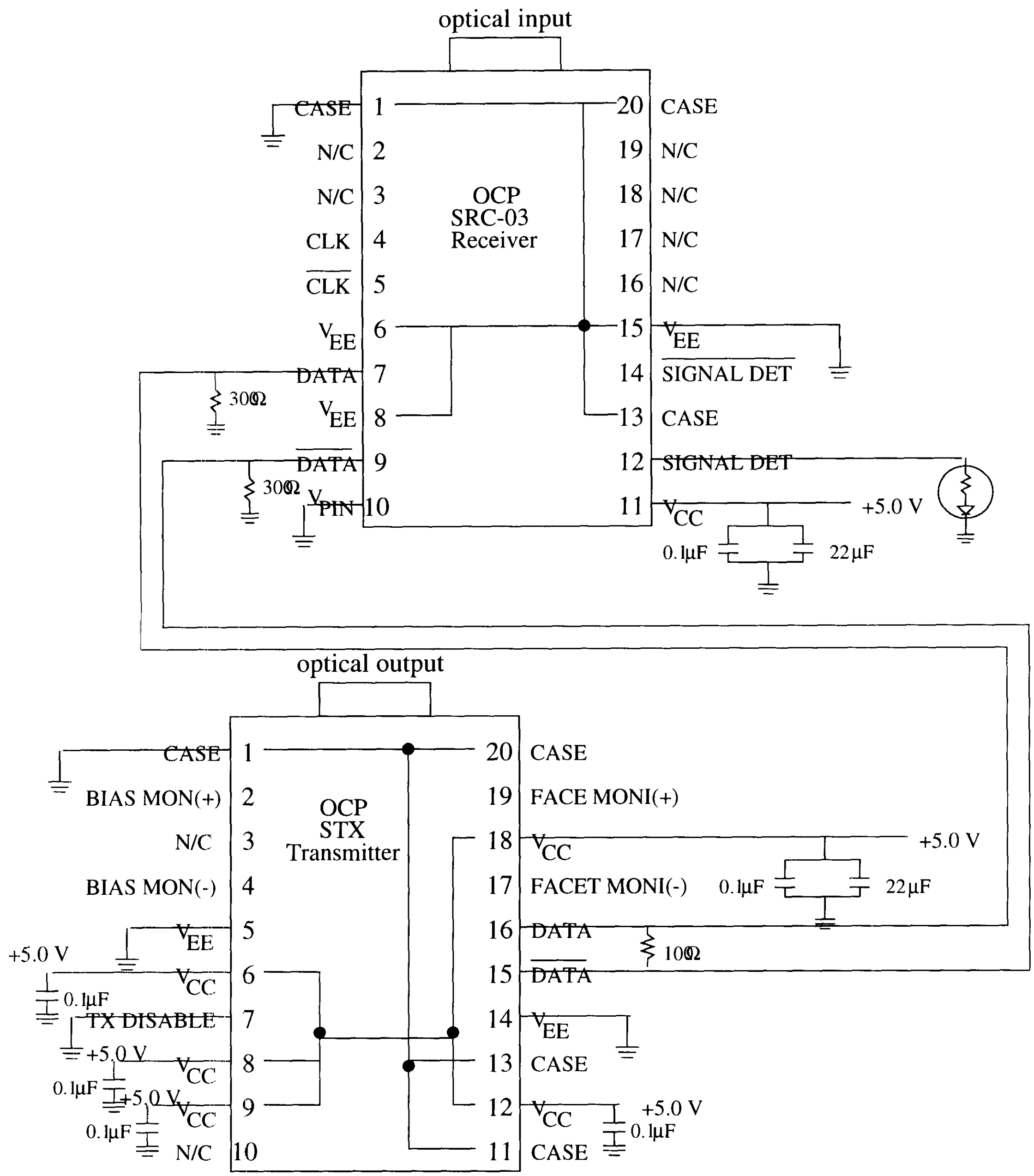

Figure 6-4: Receiver and Transmitter Circuit: Top View

to have direct involvement from CATV in this effort. In addition, there are only a limited number of rooms in MIT which have CATV links for two directions. Of course, there is also the issue that if seminars are to be transmitted via bi-directional links, there will be a need to purchase dedicated equipment, such as echo-cancellers to provide for adequate audio conferencing. The microphones in possession currently will not be adequate for large seminars and conferences.

To provide scheduled reliable transmission of various programs to AON sights would require eventually bypassing the AON altogether, as in the DEC case. This is because the AON is an experimental network and is constantly undergoing changes and adjustments. Since there are no extra fibers between MIT and Lincoln Labs, there would be a need to transmit in the nearband of the AON (just outside the 1550 nm range) to still make use of the Erbium Doped Fiber Amplifier (EDFA) of the AON. This issue needs more investigation at this point.

Appendix A

EMMI Configuration File

```
[VCS]
Contacts=c:/emmi_v12/contacts
VideoCommand=c:/vbfs200/winappl/fs200win.exe
AtmMapfile=c:/windows/atmmap
MainWinPosition=8,11,176,45
WhiteBoardWinPosition=136,96,459,320
CaptureWinPosition=296,0,108,45
CallWinPosition=296,107,239,191
EmmiControlPosition=0,0,392,234
WbToolsWinPosition=8,29,108,166
[Identity]
FirstName=Mr_Wallace
LastName=The_Man
Address=tcp:host=wallace,port=9000
[EMMI]
Device=EMMI$
VideoSource=Source1
AudioSource=Source1
VideoLoopback=Off
```

```
AudioTransmitMute=Off
AudioReceiveMute=Off
VideoTransmitBlanking=Off
VideoReceiveBlanking=Off
VideoTransmitQFactor=88
VideoReceiveQFactor=88
VolumeReceiveLeft=15
VolumeReceiveRight=15
VolumeTransmitLeft1=7
VolumeTransmitRight1=7
VolumeTransmitLeft2=7
VolumeTransmitRight2=7
```

Appendix B

Video Conferencing Files

ATMMAP File:

```
[ATMMAP]
 Source=wallace
 Destination=gromit
 Service=EmmiVideo
 TransmitVPI=0
 TransmitVCI=32
 ReceiveVPI=0
 ReceiveVCI=32
[ATMMAP]
 Source=wallace
 Destination=gromit
 Service=EmmiAudio
 TransmitVPI=0
 TransmitVCI=33
 ReceiveVPI=0
 ReceiveVCI=33
[ATMMAP]
```

```
 Source=wallace
 Destination=gromit
 Service=Data
 TransmitVPI=0
 TransmitVCI=34
 Interleave=3
[ATMMAP]
 Source=gromit
 Destination=wallace
 Service=EmmiVideo
 TransmitVPI=0
 TransmitVCI=36
 ReceiveVPI=0
 ReceiveVCI=36
[ATMMAP]
 Source=gromit
 Destination=wallace
 Service=EmmiAudio
 TransmitVPI=0
 TransmitVCI=37
 ReceiveVPI=0
 ReceiveVCI=37
[ATMMAP]
 Source=grommit
 Destination=wallace
 Service=Data
 TransmitVPI=0
 TransmitVCI=38
 Interleave=3
```

****

HOSTS File:

```
127.0.0.1       localhost
155.34.60.61    wallace
155.34.60.60    gromit
```

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