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Design and implementation of a fiber optic token-ring local area network

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Monterey, California

THESIS

DESIGN AND IMPLEMENTATION OF A FIBER OPTIC TOKEN-RING LOCAL AREA NETWORK

by

Gary Bibeau

December 1991

Thesis Advisor: John P. Powers

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This thesis describes the design and implementation of a fiber optic token-ring local area network (LAN). This design features fiber optic channels between stations on the network without the use of a wiring concentrator. The initial LAN electrical signal operating at 4 Mbps was provided by a LAN adapter card based on the TMS380 chipset developed for twisted pair copper wire. Since the physical characteristics of fiber and wire vary, use of this adapter necessitated that the design be able to deceive system initialization diagnostics and continuity checks designed for a wire system. Successful LAN communications over the fiber optic channels are described.

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DESIGN AND IMPLEMENTATION OF A FIBER OPTIC TOKEN-RING LOCAL AREA NETWORK

by

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Captain, United States Marine Corps
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Submitted in partial fulfillment of the
requirements for the degree of

MASTER OF SCIENCE IN ELECTRICAL ENGINEERING

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December 1991

ABSTRACT

This thesis describes the design and implementation of a fiber optic token-ring local area network (LAN). This design features fiber optic channels between stations on the network without the use of a wiring concentrator. The initial LAN electrical signal operating at 4 Mbps was provided by a LAN adapter card based on the TMS380 chipset developed for twisted pair copper wire. Since the physical characteristics of fiber and wire vary, use of this adapter necessitated that the design be able to deceiver system Successful LAN communications over the fiber optic channels are described.

C.1

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I. INTRODUCTION

A. GENERAL

Fiber optics are fast becoming ubiquitous in everyday communications. Because of fiber's light weight and smaller size, many long-haul communication companies are using it to replace existing coax cables. Local area networks (LANs) using fiber are also being developed that will utilize these and other advantages.

One example of a LAN application is the Fiber Distributed Data Interface (FDDI) which will operate as a high performance token-ring LAN with data rates up to 100 Mbps, over distances up to 200 km, serving up to 1000 stations [Ref. 1:p. 166]. The FDDI net may also serve as a backbone connection for wire LANs. FDDI is designed to conform with the IEEE standard 802.5 for Token Ring operation.

1. Advantages of Fiber Optics

Information-carrying capacity increases with the bandwidth of the transmission medium and with the frequency of the carrier. Engineering technology for coax cables has basically peaked but fiber optics are only beginning to be exploited. Optical fiber has a potential useful range of 1 THz (100,000 GHz), but currently achievable data rates are much lower. Under laboratory conditions 20 Gbps has been achieved over 68 km. This was done by multiplexing 10 lasers at different wavelengths, operating at 2 Gbps each, onto a single fiber. [Ref. 2:p. 28] So the growth potential for this medium in enormous.

Another advantage of fiber is that it is a dielectric and therefore has no electro-magnetic (EM) conduction or induction. This means that fiber optics can run beside high voltage lines with no detrimental effect. It also means that fiber is not affected by power line surges or EM interference from machinery or other wires. Therefore, it can be especially useful in harsh factory environments. [Ref. 1:p. 67]

A further advantage of fiber is that it cannot short or cause sparks, so it can run near or through hazardous areas such as fuel tanks. It is also not susceptible to cross-talk or radio interference. All these properties combine to produce lower data error rates.

Perhaps the largest benefit to military applications is that a fiber optic LAN has very high security. It does not radiate, so electro-magnetic emanations cannot be picked up by unauthorized users. Also, it is virtually impossible to tap undetected because any attachment to the cable will produce a loss in power. [Ref. 1:p. 166] Therefore, the military could maintain a relatively secure computer network without the expense and related problems of information encrypting and decrypting.

B. THESIS OBJECTIVES

The Optical Electronics Laboratory at the Naval Postgraduate School is conducting a continued effort to develop a practical and functional, completely fiber, Local Area Network. Initial research was conducted by LT M. Anderson [Ref. 3] to develop a fiber optic interface module, capable of converting a typical LAN electrical signal to an optical signal.

The object of this thesis was to build on that research to design and construct a token-ring local area network that consists of a fiber-optic channel between two computers. This network should be able to utilize commercially available token-ring system boards and be able to successfully send and receive messages without error.

Follow-on research to this thesis is planned to develop a star-configured token-ring that will provide greater reliability and will facilitate insertion and de-insertion of multiple computers to the net.

C. THESIS ORGANIZATION

Chapter II provides basic background information on local area networks and the Open Systems Interconnection (OSI) model with emphasis on operation of token ring systems and protocols. It also describes operation of the TMS-380 chipset, the basic LAN component within the computer.

Chapter III describes the existing network components and presents specifications used in design. Chapter IV deals with detailed hardware design, construction and operation of the network along with performance parameters when implemented into the LAN. Chapter V follows with conclusions and recommendations.

II. TOKEN RING NETWORKS

A. LANS AND THE OSI MODEL

Local Area Networks (LANs) are generally defined to contain computer and communication elements geographically contained within 10 kilometers and usually using a shared transmission media. [Ref. 5:p. 2] The OSI model is a conceptual network structure. Networks are partitioned into a series of layers to reduce their design complexity. The OSI model is partitioned into seven layers. The bottom four layers define the network and how it functions, and the top three layers define how the network is used. [Ref. 6:p. 1-2]

Figure 2-1 shows the relationship of the seven layers to one another. Note that the actual path taken by communication between two products starts at the top, then down through the seven layers of the sender, across the physical layer, and up through the receiver's seven layers. The key idea is that, although actual data transmission is vertical, each layer can be programmed as though it were horizontal. [Ref. 1:p. 20]

This thesis mainly covers the two lowest layers, the Physical layer and Data Link layer. The Physical layer defines the mechanical and electrical connection. The Data Link layer defines the way that data is formatted for transmission and how access to the network is controlled. [Ref. 6:p. 1-2]

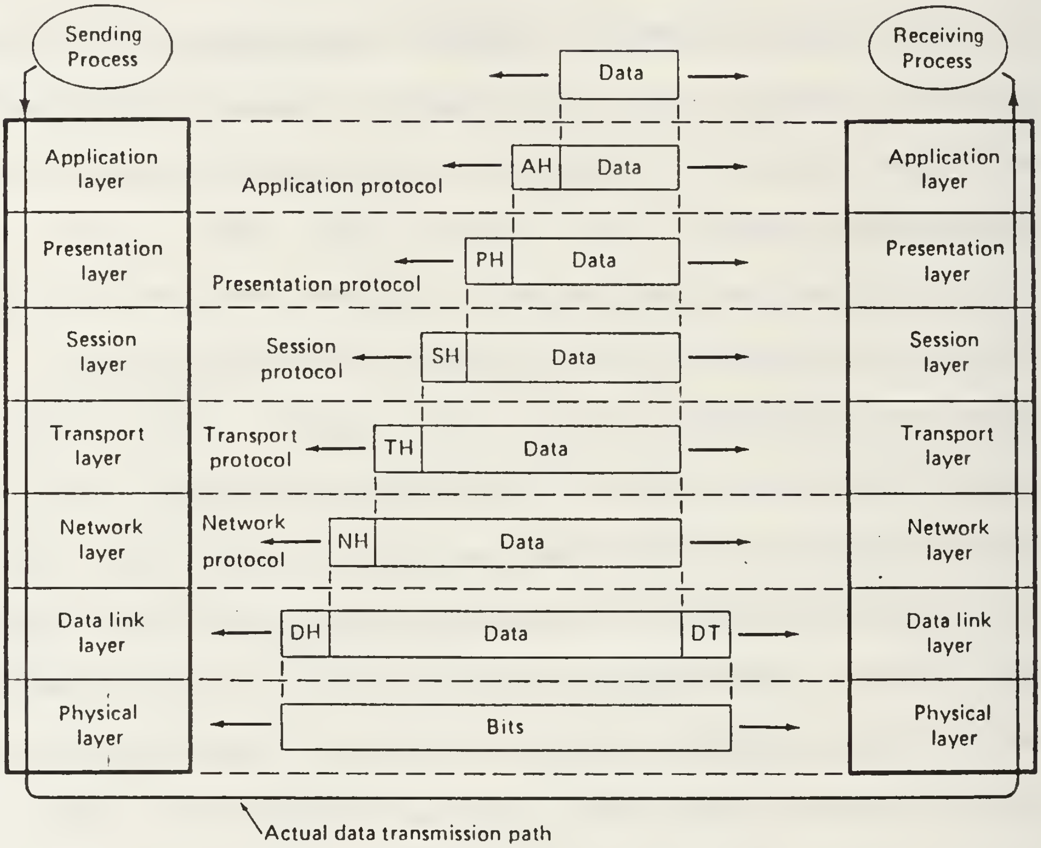


Figure 2-1. The OSI Seven-Layer Network Model [from Ref. 1:p. 20]

1. IEEE Standards.

The Institute of Electrical and Electronic Engineers (IEEE) has developed a set of local area network standards and protocols for the Physical and Data Link layers. The Data Link layer has been subdivided into two layers, the Medium

Access Control (MAC) sublayer and the Logical Link Control (LLC) sublayer.

The IEEE standard 802.5 defines the MAC and physical sublayers for a star-configured topology with a token passing access method. Figure 2-2 shows the IEEE standards that apply to the bottom two layers of the OSI model. Note that the 802.5 standard mainly deals with the physical layer, but also applies to the data link layers. The IEEE standards 802.3 and 802.4 deal with other access methods that are not of concern to this project. The 802.2 standard describes the Logical Link Control (LLC) protocol used in the upper part of the data link layer. The 802.1 standard gives an introduction to the set of standards and defines the interface primitives.

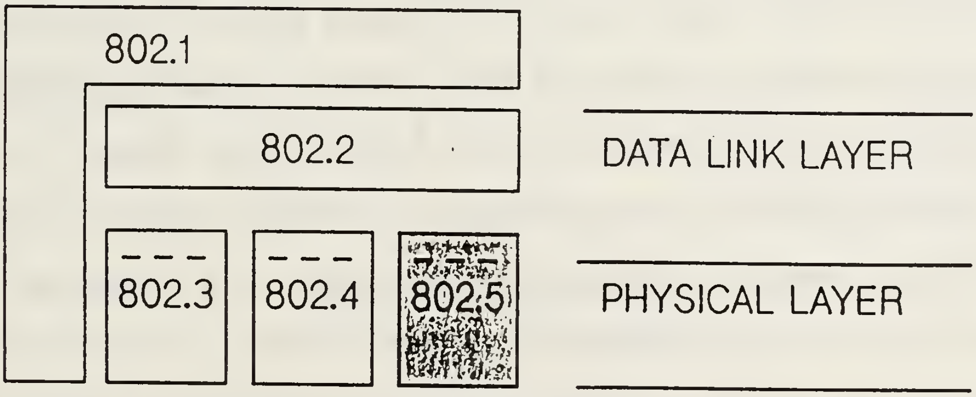


Figure 2-2. Applicable IEEE standards to the Bottom Layers of the OSI Model [from Ref. 4:p. i]

B. TOKEN RING LAN

A ring is not really a broadcast medium but a collection of individual point-to-point links that happen to form a circle. A token is a special bit pattern that circulates around the ring. There is only one token and a station must "capture" it to transmit. This prevents collisions of two or more stations attempting to utilize the channel simultaneously. Figure 2-3 shows the format of the token. A token is 24 bits (3 bytes) in length, and consists of starting delimiter (SDEL), access control (AC) and ending delimiter (EDEL) fields. Each field is one byte in length. The starting and ending delimiters are used to provide synchronization to the adapter and also to define the beginning and end of the information in the AC field. Six bits of the AC field are used to define priority access of stations on the ring, one bit is used by the ring monitor as a monitor count bit and the last bit is a token indicator used to differentiate between a free token and a frame.

Upon capture of the token, a station changes the token status to busy by changing the indicator bit in the AC field. The station then transmits a data frame. The data frame consists of the token with extra fields appended to it. These extra fields provide address data (Destination Address, Source Address), error control (Frame Check Sequence), frame type (Frame Control) and the information being transmitted (Information Field). A Frame Status byte is also attached to

TOKEN FORMAT

Starting Delimiter	Access Control	Ending Delimiter
1 Byte	1 Byte	1 Byte

Figure 2-3. Format of Token for Token-Ring
[from Ref. 6:p. 1-5]

the end of the token. By setting a designated bit indicating that the message was received, this field will indicate the results of the frame's circulation around the ring to the station that originated the frame. Figure 2-4 shows the format for the data frame.

Starting Delimeter	Access Control	Frame Control	Destination Address	Source Address	Information Field	Frame Check Sequence	Ending Delimiter	Frame Status
(1 byte)	(1 byte)	(1 byte)	(6 bytes)	(6 bytes)		(4 bytes)	(1 byte)	(1 byte)

Figure 2-4. Format of Data Frame for Token-Ring
[from Ref. 6:p. 1-5]

A frame is transferred sequentially, bit by bit, from one active station to the next. Each station receives the frame from its upstream neighbor and reads the address. If the frame is addressed to a different station, the frame is retransmitted to the station's downstream neighbor. When the frame reaches its destination address, the data is copied and receipt is acknowledged by setting the frame copied bit in the frame status field of the data frame. The entire frame is repeated around the ring back to the transmitting station which will remove (drain) the frame from the ring, check for errors and regenerate a new token. A token-holding timer controls the maximum period of time that a station can occupy the medium before passing the token. [Ref. 7:p. 24]

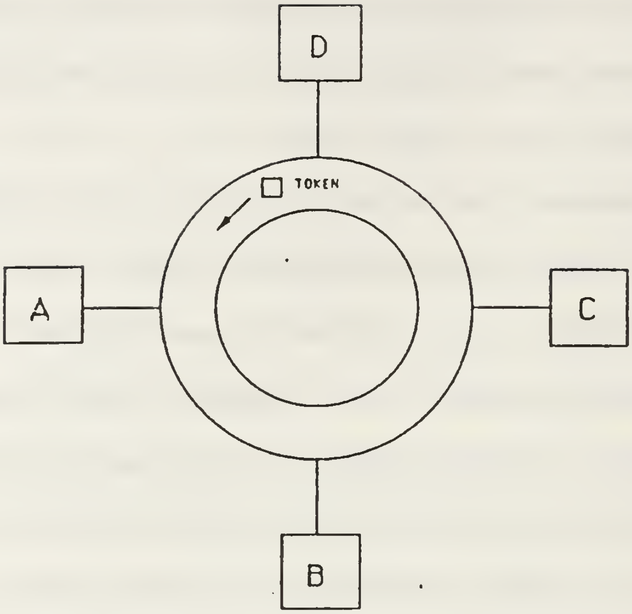
The token passing sequence is shown in Figure 2-5(a-f). When no station has data to transmit, the token circulates freely (Figure 2-5a). When a station has a message to send to another (Station A to Station C, for example), station A will seize the token and transmit a data frame (Figure 2-5b). Station B receives the frame and checks the address. Since the address does not correspond to that station, Station B repeats the frame (Figure 2-5c). This continues until the data frame reaches Station C which recognizes the address, copies the frame and acknowledges receipt and then repeats the data (Figure 2-5d). Any intermediate stations on the return trip of the data frame will also read the address and then repeat the data (Figure 2-5e). When the transmitting station, Station A, receives the repeated data frame, it checks the frame for errors and for the frame copied bit and then releases the token (Figure 2-5f).

The ring must designate a monitor station that oversees the ring. Every station has the capability to become the monitor. If the designated monitor station goes off-line a contention protocol ensures that another station is elected monitor quickly. [Ref. 1:p. 159]

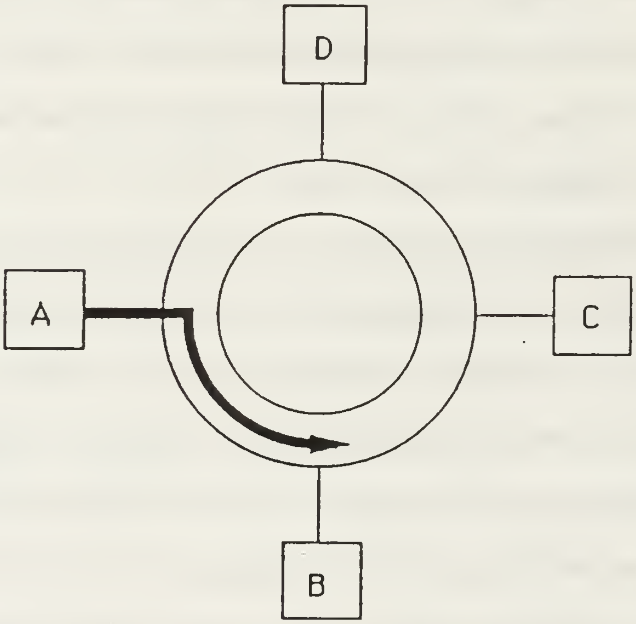
Among the monitor's responsibilities are seeing that the token is not lost, taking action when the ring breaks, cleaning up the ring when garbled frames appear, and watching out for orphaned frames. An orphan frame occurs when a station transmits a short frame in its entirety onto a long ring and then crashes or is powered down before the frame can be drained. If nothing is done to remove the orphan frame, the frame could circulate forever.

To check for lost tokens, the monitor has a timer that is set to the longest possible tokenless interval, which would be equal to each station transmitting for the full token holding time. If this timer goes off, the monitor drains the ring of all frames and issues a new token.

When a garbled frame appears, the monitor can detect it by its invalid format or checksum. The monitor then opens the ring to drain the frames, issuing a new token when the ring has cleared up. Finally, the monitor detects orphan frames by setting the monitor bit in the Access Control byte whenever the frame passes through. If an incoming frame to the monitor has this bit set, something is wrong since the frame has passed the monitor twice without being drained. The ring monitor will then drain the frame. [Ref. 1:p. 160]

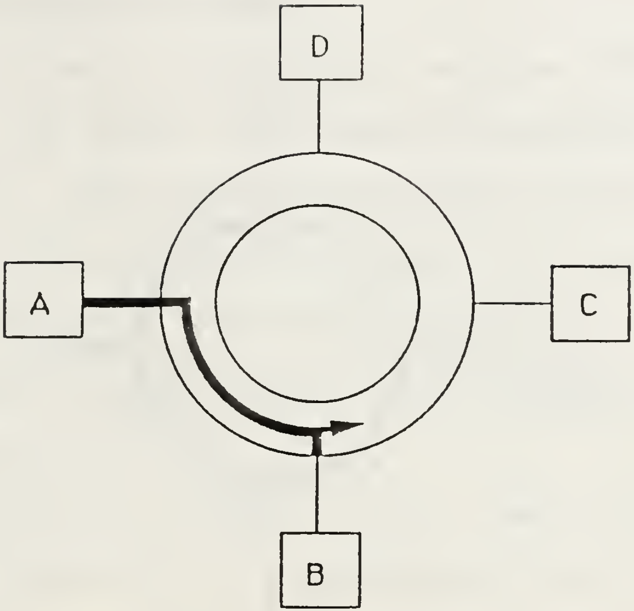


(a) Circulating token, any station can transmit upon receiving the token

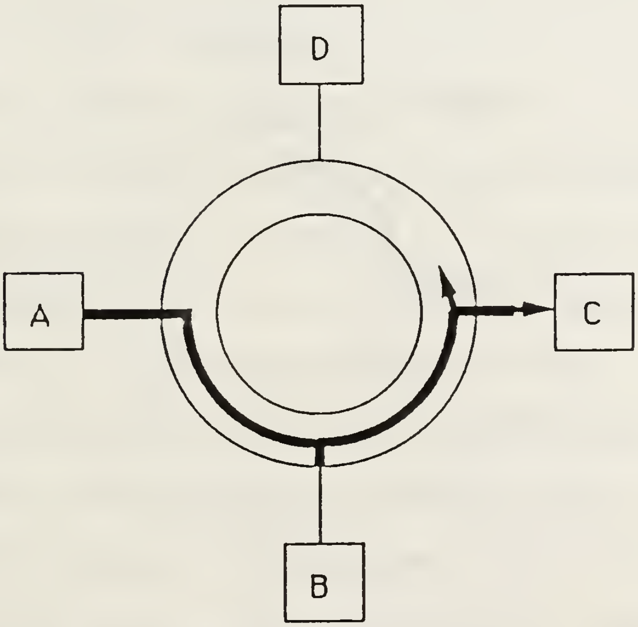


(b) Station A seizes token, transmits frame of data addressed to station C

Figure 2-5. Transmission Sequence Using Token-Ring [from Ref. 3:p. 10]

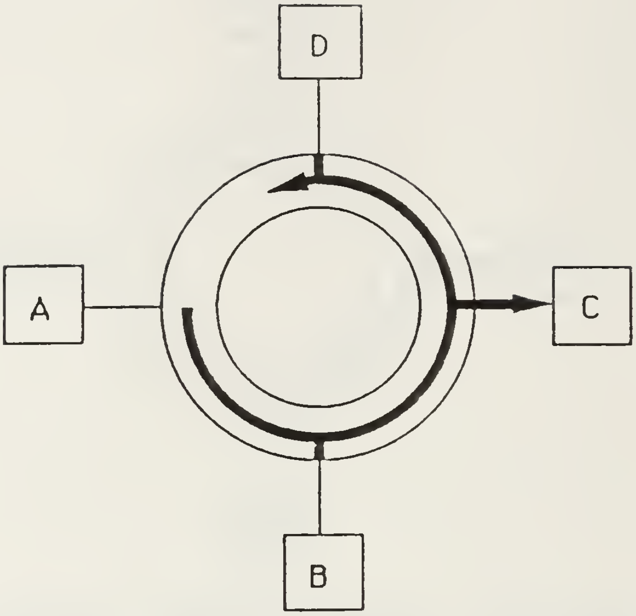


(c) Station B receives frame, checks address, and repeats frame

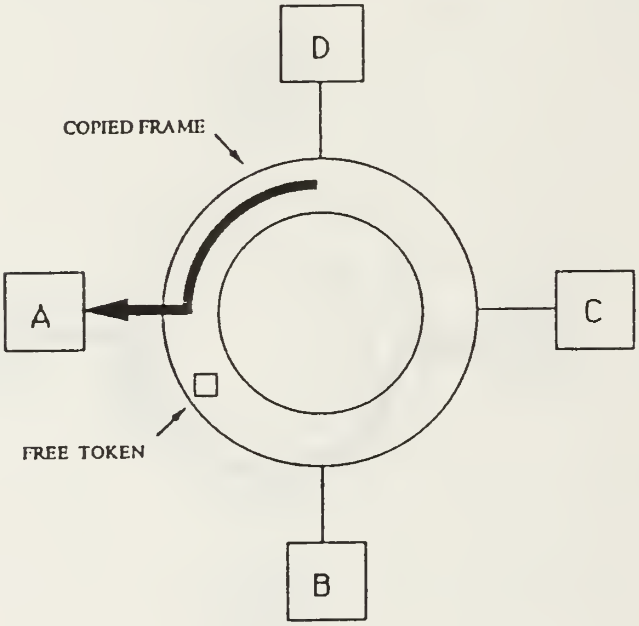


(d) Station C receives frame, recognizes address, acknowledges receipt and repeats data

Figure 2-5 cont.



(e) Station D repeats frame



(f) Station A receives acknowledgement and repeated data, transmits free token (only), the cycle repeats

Figure 2-5 cont.

C. TMS380 LAN ADAPTER CHIPSET

This thesis used a National Cash Register (NCR) token ring system. The NCR system uses Texas Instruments TMS380 LAN Adapter Chipset. The TMS380 uses a token passing technology compatible with the IEEE 802.5 standard. The chipset provides a 4 Mbps data rate. Network reliability is enhanced by dedicated error checker circuits, on-chip diagnostic and error monitoring software.

The architecture of the chipset uses five integrated circuits (see Figure 2-6). A high-speed Direct Memory Access (DMA) host-system bus interface combines with a 16-bit CPU with on-chip buffer RAM, a protocol handler with on-chip ROM for software and a pair of chips for interfacing to the physical media. [Ref. 6:p. 1-1]

1. TMS38030 System Interface (SIF).

The SIF provides up to 40 Mbps of data to the host system via DMA bus master transfers. It has a 24-bit address reach into the host system and a "scatter write-gather read" DMA feature that allows discontiguous memory blocks to be transferred and received via linked lists. [Ref. 6:p. 1-8]

2. TMS38010 Communications Processor (CP)

The CP contains a dedicated 16-bit CPU with 2.75K bytes of on-chip RAM. It executes the adapter software contained within the TMS38020. Figure 2-7 shows the flow of data between the host system, the LAN adapter chipset and the

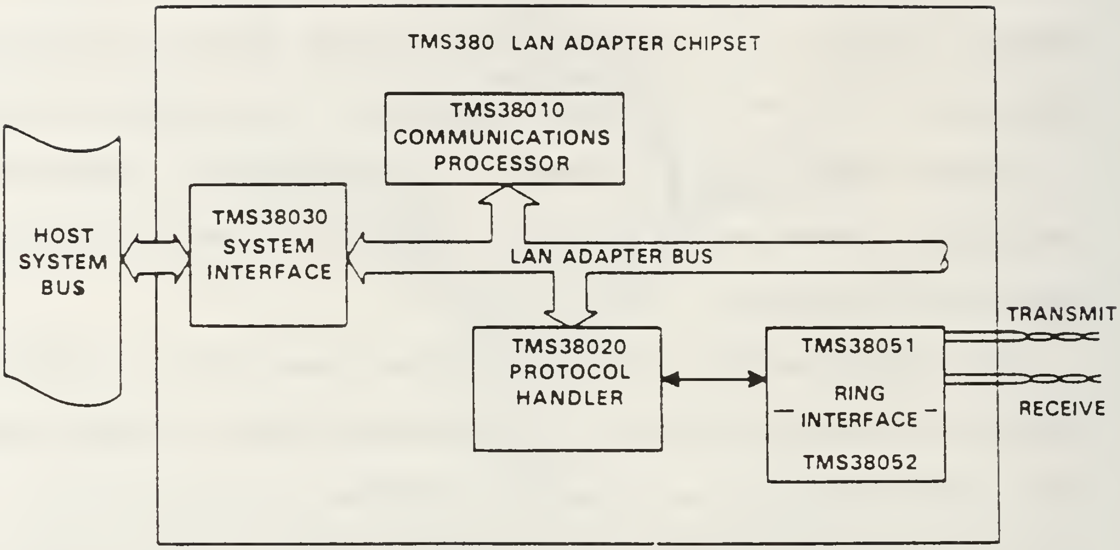


Figure 2-6. Architecture of TMS 380 LAN Adapter Chipset [from Ref. 6:p. 1-7]

ring. The CP executes instructions received from the ring through the protocol handler and manipulates data within the memory of the host system through the system interface.

3. TMS 38020 Protocol Handler (PH)

The PH chip performs hardware-based protocol functions for a 4 Mbps token ring LAN compatible with the IEEE 802.5 standard. An on-chip ROM contains 16K bytes of adapter software executed by the CP (see Figure 2-7). This software supports reliable ring operation, LAN management services, and diagnostic coverage of the adapter chipset. The PH implements

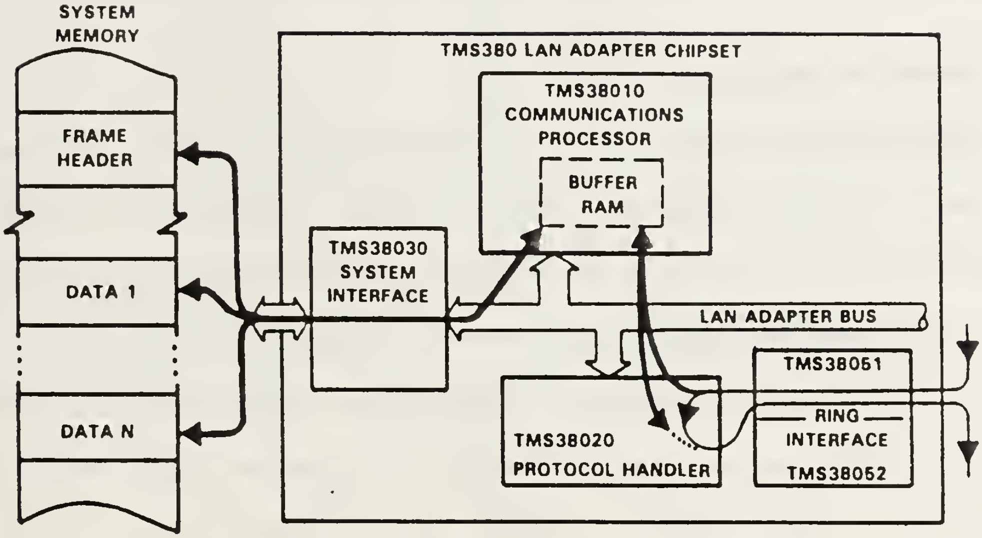


Figure 2-7. Data path within the LAN Adapter Chipset [from Ref. 6:p. 11]

the Differential Manchester encoding and decoding used in this ring.

Four DMA channels are used for frame transfers, two for transmit and two for receive. Data integrity is verified by cyclic redundancy checks (CRC) and detection of Differential Manchester code violations. [Ref. 6:p. 1-8]

4. TMS38051/2 Ring Interface (RI)

These two chips provide the ring interface controller and the ring interface transceiver. They contain both digital and analog circuitry to allow connection to the LAN through separate receive and transmit channels.

Most importantly, the RI provides a phantom drive signal to a wiring concentrator, a loop-back path for diagnostic testing and error detection of wire faults. The function of these elements is described in the next section.

D. NETWORK RELIABILITY

The problem with token ring networks is that, if the cable between stations breaks, the ring dies. To prevent this, most networks use a wire hub so that the network operates logically as a ring but physically resembles a star. That is, the data flow is from point-to-point around the ring, but all stations are connected by cable to a center point so that the network outwardly looks like a star (see Figure 2-8). In this configuration, if the cable to an individual station breaks, the station and its cable can be removed from the ring at the hub with no detrimental effect to the network. The NCR token ring system uses this architecture.

Because reliability is so essential to the integrity of the ring, the TMS380 chipset performs a set of diagnostics to test the functioning of the adapter card before allowing the insertion process to begin. The Communications Processor first conducts a self-test of the circuitry on the Protocol Handler and the Ring Interface (see Figure 2-9).

Physical insertion of the station into the ring is performed by the Phantom Drive signal provided by the ring interface. The Phantom Drive is a DC bias voltage impressed onto the transmit signal. It is called a "Phantom" drive signal because the DC level is transparent to the station's

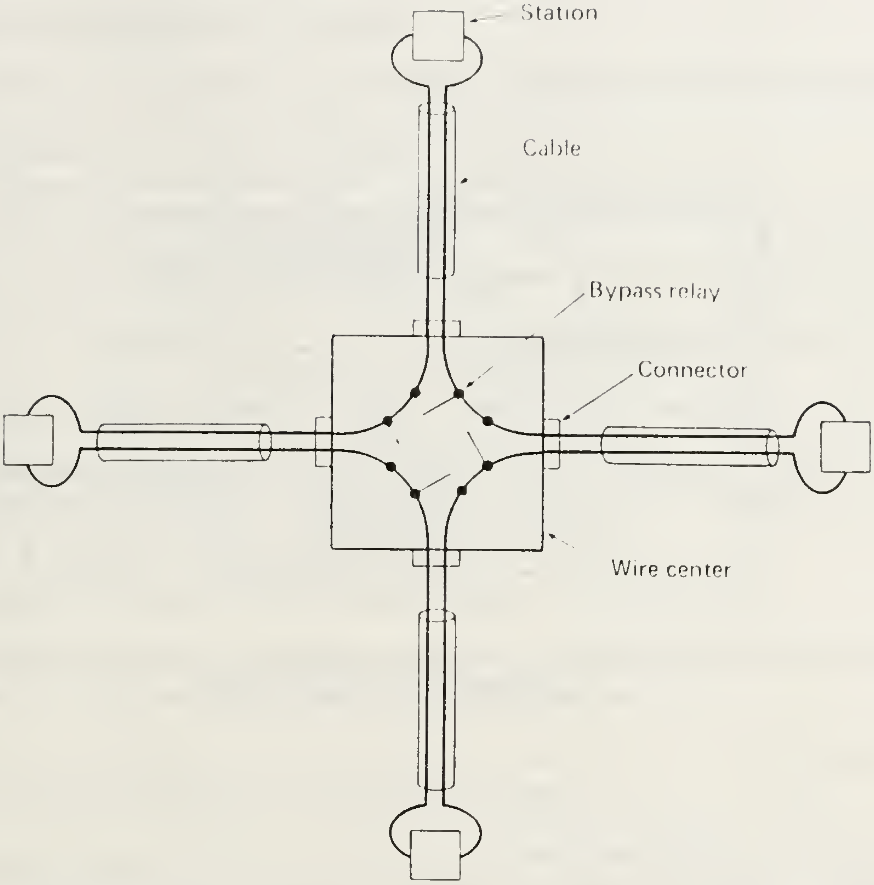


Figure 2-8. A Star-Configured Ring
[from Ref. 1:p. 156]

transmitted data. The Phantom Drive triggers the control relays in the wiring concentrator that insert the station serially into the ring. These relays open the closed path within the cable and attach the cable to the ring, directing the signal through the new station (see the right side of Figure 2-10). Loss or absence of the Phantom Drive results in the station being bypassed or removed from the ring (as seen in the left side of Figure 2-10).

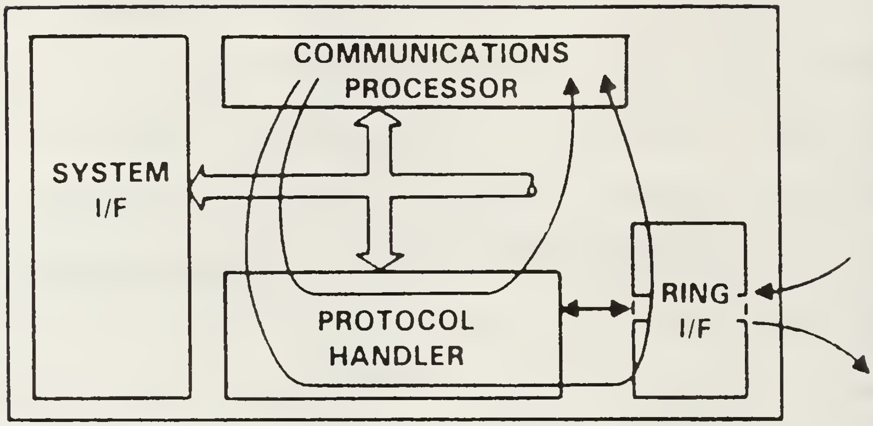


Figure 2-9. Adapter Card Function Check
[from Ref. 6:p.1-9]

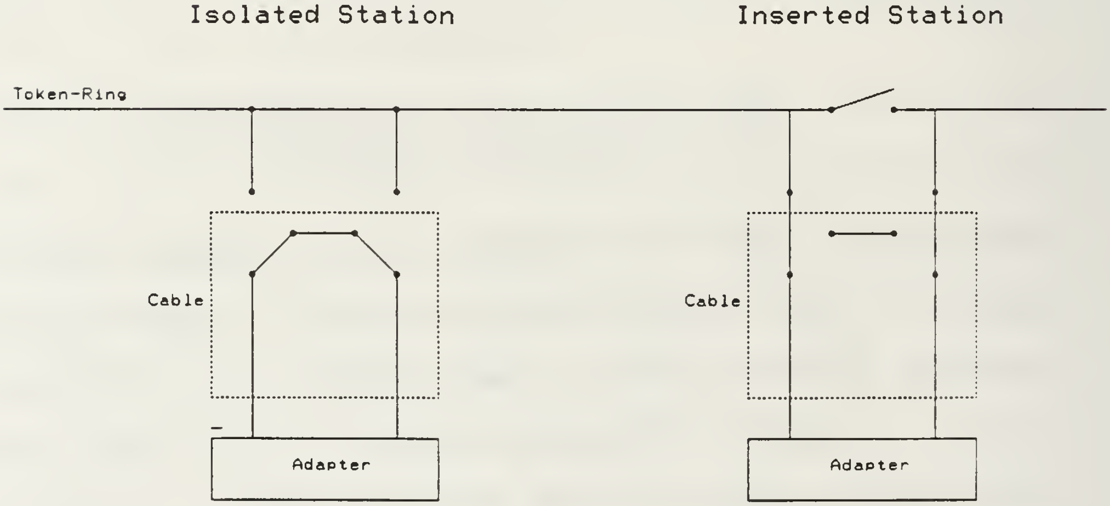


Figure 2-10. Insertion Relays

E. Station Insertion Process

The station insertion process consists of five phases.

1. Phase 0 - Cable check

The purpose of the cable check is to verify the integrity of the cable connecting the adapter to the hub, as well as the transmitter and the receiver. To perform the check, the following events are performed sequentially:

- A path is opened from the CP, through the ring interface chip, down the cable and back (no Phantom Drive current yet) [see Figure 2-11].
- A token is fired into the cable.
- When the token is successfully recovered, a test data frame is transmitted around the cable.
- When the transmitted frame is received, it is checked for code violations and CRC errors.
- If the frame is not received within 40 milliseconds, the adapter will try to transmit a second time. After two unsuccessful attempts the test will fail, and the station will not be inserted into the ring.
- When all tests are completed successfully, the insertion process exits to Phase 1. If any test failed, the insertion process will be aborted and the error message "Network Adapter Hardware Error" will appear.

2. Phase 1 - Physical Insertion

This phase of the insertion process inserts the station into the ring and then verifies that an active monitor is present on the ring and, if not, enters the monitor contention mode.

The first step is for the station to be added to the ring by activating the Phantom Drive circuit. The wiring

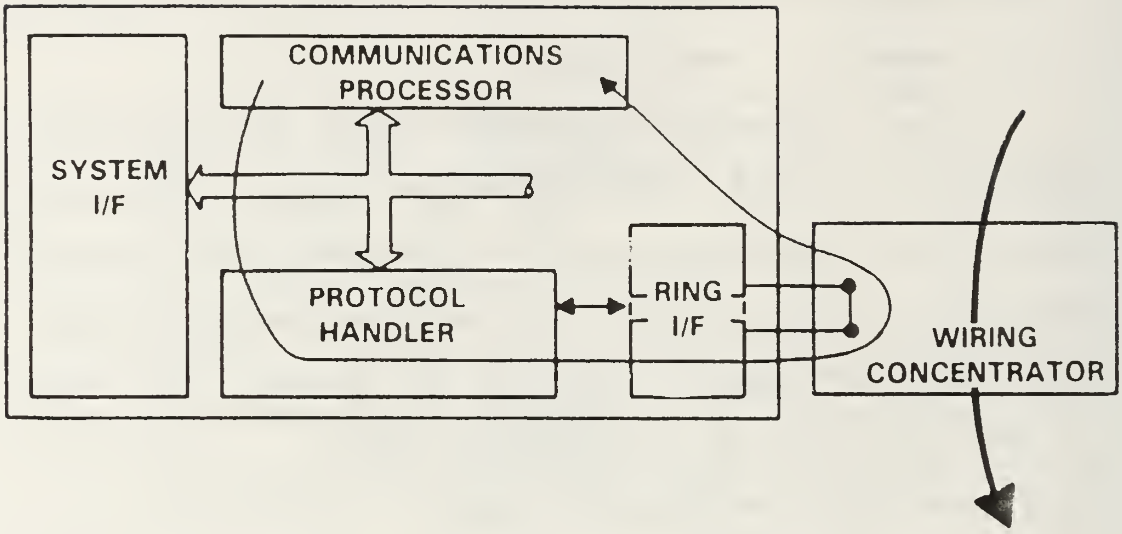


Figure 2-11. Path of Data for Cable Check
[from Ref. 6:p 1-9]

concentrator physically inserts the adapter into the ring by using the Phantom current to activate a relay. The station waits for an indication of an active monitor's presence as a result of receiving one of the following frames:

1. An active monitor present (AMP) MAC frame.
2. A standby monitor present (SMP) MAC frame.
3. A ring purge MAC frame.

If none of these frames are received within 18 seconds, the adapter starts the monitor contention process. If contention is tried and no monitor is established, insertion is terminated and an error message is posted. If successful, the insertion process exits to phase 2.

3. Phase 2 - Address Verification

This test is to verify that the adapter has a unique ring station address for the ring.

- The adapter transmits a series of data frames addressed to itself.
- It verifies its address by receiving two frames with no indication of a duplicate address.
- The station will deinsert when two frames are received indicating that there is a station on the ring with the same address. Otherwise, the insertion process exits to phase 3.

4. Phase 3 - Participation in Ring Poll

This process ensures that the adapter acquires the upstream neighbor's address (UNA) and also allows the nearest downstream adapter to acquire this adapter's address.

- The ring poll process is initiated and continues at seven second intervals to allow an ordered list of stations to be maintained by the ring monitor.
- The process exits to phase 4 when the initial ring poll is complete.

5. Phase 4 - Request Initialization

The function of this phase is to provide a mechanism for obtaining additional operational parameters that will replace the defaults set at the start of the insertion process. To obtain these parameters, the adapter sends a request for initialization around the ring. If a Ring Monitor is present, it will return the existing ring parameters to the requesting station. If no monitor is present, the requesting station will become the monitor and define the operating parameters for the ring. Once this phase is complete, the station becomes an operational part of the token ring network.

III. DESIGN REQUIREMENTS

A. SYSTEM CONFIGURATION

The first objective of the thesis work was to implement the Token Ring local area network using normal wire media. Figure 3-1 shows the system block diagram. The system configuration used the following components:

- Two IBM XT clone PC's.
- A Wiring Concentrator (also known as a Multiple Access Unit [MAU]).
- Two token ring adapter cables.

An NCR token ring LAN adapter card was installed into each computer. These cards were obtained commercially and are based on the TMS380 chipset.

The token ring adapter cables are shielded differential pair wires. There is a transmit (+) and transmit (-) pair, and a receive (+) and receive (-) pair. Use of the differential pair was designed to limit adverse capacitance and inductance effects. Because the current is equal in magnitude but opposite in direction, these effects will cancel. The cable has a male 9-pin subminiature D connector on one end that attaches directly to the LAN adapter card in the PC. Only 4 of the 9 pins are utilized to connect the two differential pairs. The other end of the cable is a Medium

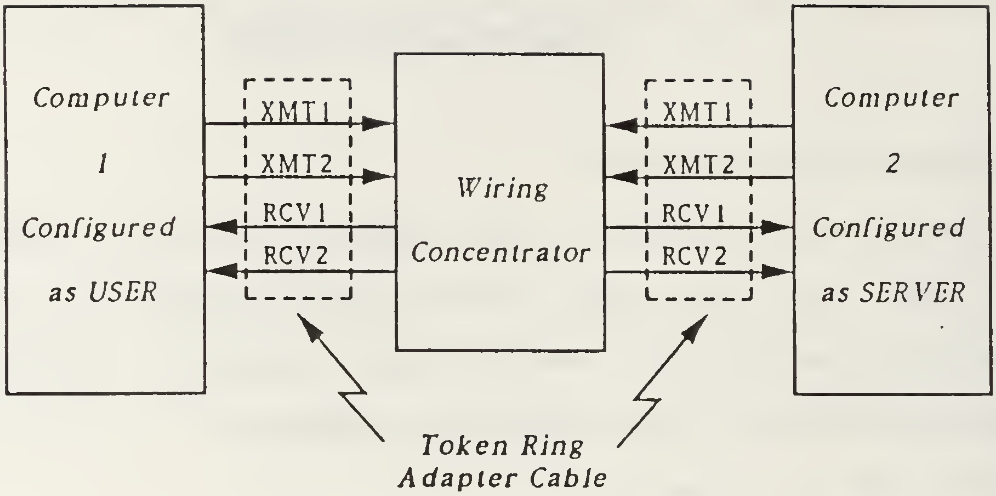


Figure 3-1. Block Diagram of a Token-Ring Network [from Ref. 3:p. 16]

Interface Connector that plugs into the wiring concentrator.

The concentrator (MAU) is a series of electrical relays that are activated by the Phantom Drive to serially insert individual stations into the ring (see Figure 3-2). When there is no Phantom Drive, the station is not inserted into the ring (see right part of Figure 3-2). When the Phantom Drive is present, relays within the wiring concentrator are opened to allow the station access to the ring (see left part of Figure 3-2). The MAU is a passive device. It requires no external power (other than that provided by the adapter cables).

It should be noted that the wire network will not function without the wiring concentrator. It is not possible to have just a two-computer network that is connected only by a cable from computer to computer. This is due to the initial diagnostic routines used by the LAN adapter card and the path of the Phantom Drive,as described in the next section.

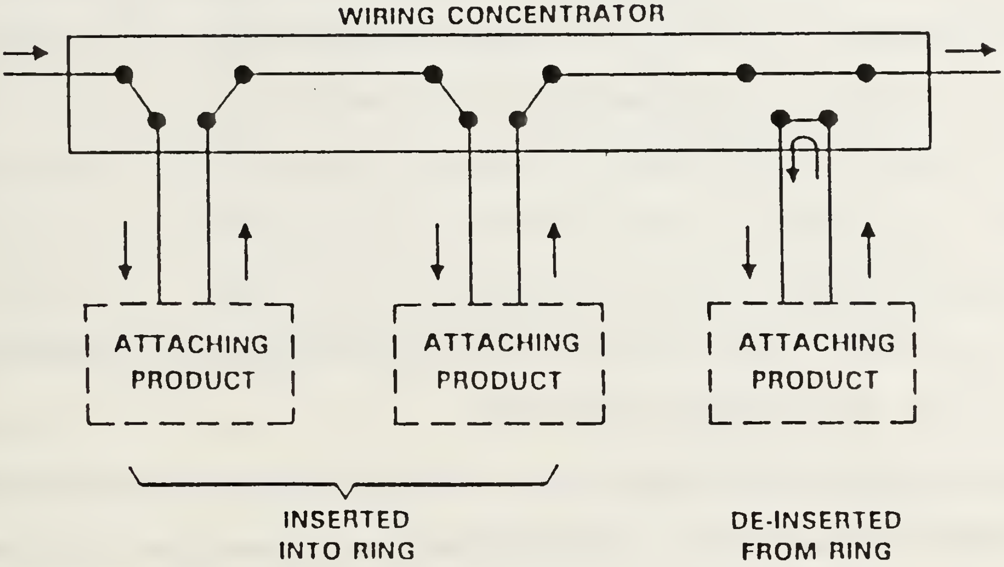


Figure 3-2. Block Diagram of Wiring Concentrator [from Ref. 6:p. 1-4]

B. ERROR DIAGNOSTICS

As part of the bring-up diagnostics, described in Chapter II, the adapter circulates a token through the cable before allowing the station to be inserted into the ring. When the computers are directly connected, with no MAU in between, there is no closed loop path for the token to follow during diagnostics (see Figure 3-3). This causes the network boot process to fail. This was an especially important consideration when trying to by-pass the MAU to create a total fiber system, as discussed in subsequent chapters.

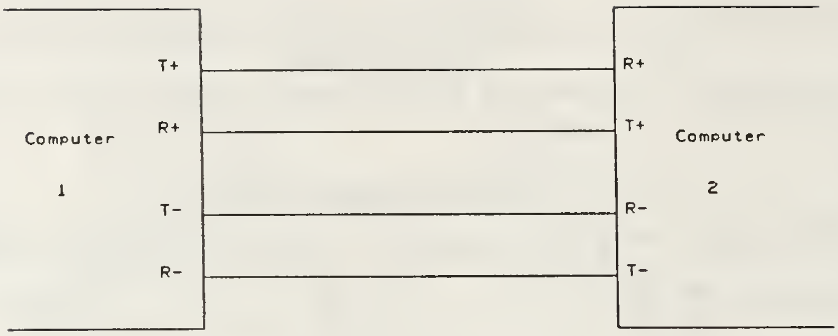


Figure 3-3. Direct Wire Attachment of Computers

1. Wire Fault Condition

The Phantom Drive is integrated into the TMS 38052 on the adapter board. In addition to controlling the insertion into the ring, this DC signal is used to monitor the adapter cable for an open or short circuit condition.

The Phantom Drive circuit is activated upon assertion low of *NSRT[1] on the 38052 chip (see Figure 3-4). When *NSRT is asserted, a DC voltage is placed on the PHOUTA and PHOUTB pins (#19 and #18). The resultant DC current travels through the transmit pair (pins B and O in Figure 3-4) to the MAU where it activates the relay that inserts the station into the ring. The current is then returned to ground through the inductor (L1) at the adapter via the receive pair (see pins G

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[1] * indicates an active low signal

and R on the right side of Figure 3-4). Figure 3-5 shows the path that the Phantom Drive current follows. [Ref. 6:p. 4-127]

A wire fault condition is detected by monitoring the current being supplied through the PHOUTA and PHOUTB pins. In the event that an abnormally high or low current, as specified in the data sheet in Table 3-1, is detected on either pin, the *WFLT output is asserted low and the station is removed from the ring by discontinuing the Phantom Drive. [Ref. 6:p. 4-128] The wire fault logic will recognize a load condition greater than 9.9 kΩ to ground as an open circuit fault. Between 9.9 kΩ and 5.5 kΩ the status of the load cannot be determined. The adapter may interpret either a fault or an operational condition. The desired load condition is between 5.5 kΩ and 2.9 kΩ, where the adapter will recognize the load as within operational parameters. Less than 2.9 kΩ but greater than 100 ohms to ground is again an indeterminate condition. Below 100 ohms is recognized as a short circuit and a definite fault condition. [Ref. 6:p. A-110] So, as shown by Figure 3-6, normal operation with the *WFLT held high is best achieved when PHOUTA and PHOUTB see loads less than 5.5 kΩ but greater than 2.9 kΩ.

The energy detect circuit can distinguish between potentially valid data at the input and a quiet condition (no data). When the ring interface receives a signal, the *REDY line (pin 13, Figure 3-4) is asserted low if a minimum signal energy is detected on the input pair and the input signal is

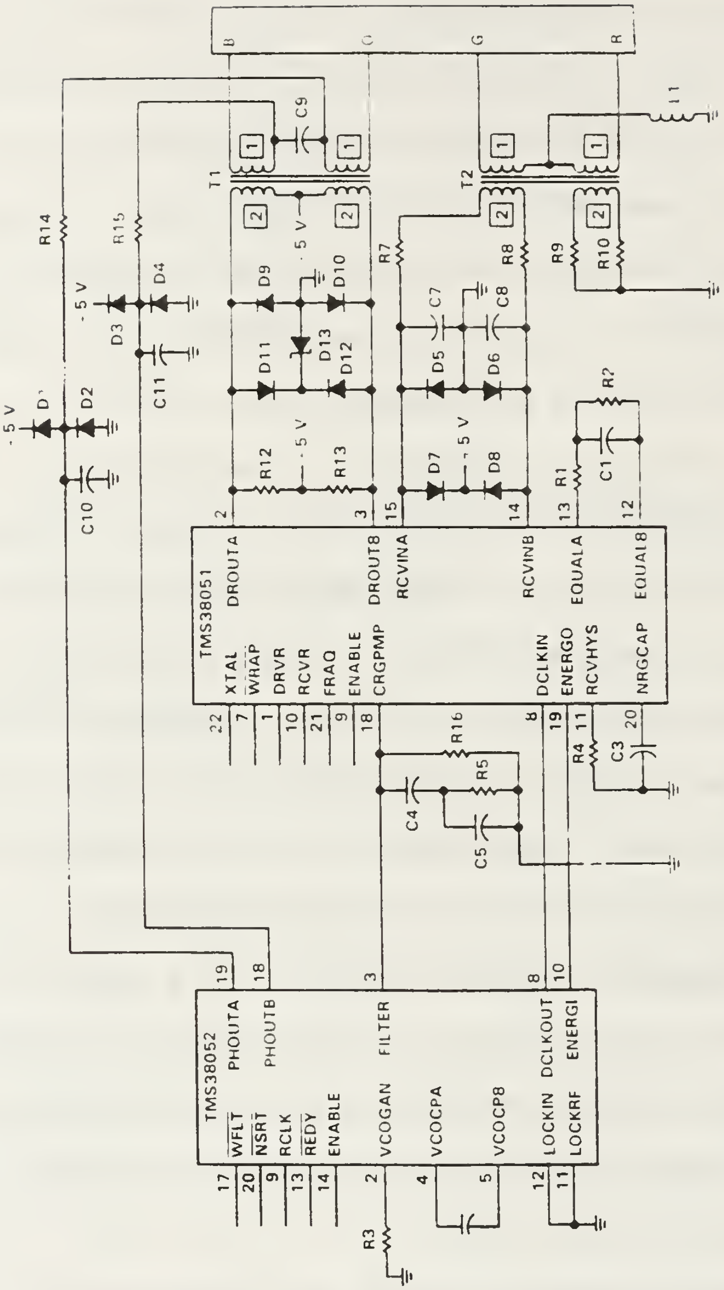


Figure 3-4. Schematic of TMS 380 LAN Adapter Card [from Ref. 6:p. A-100]

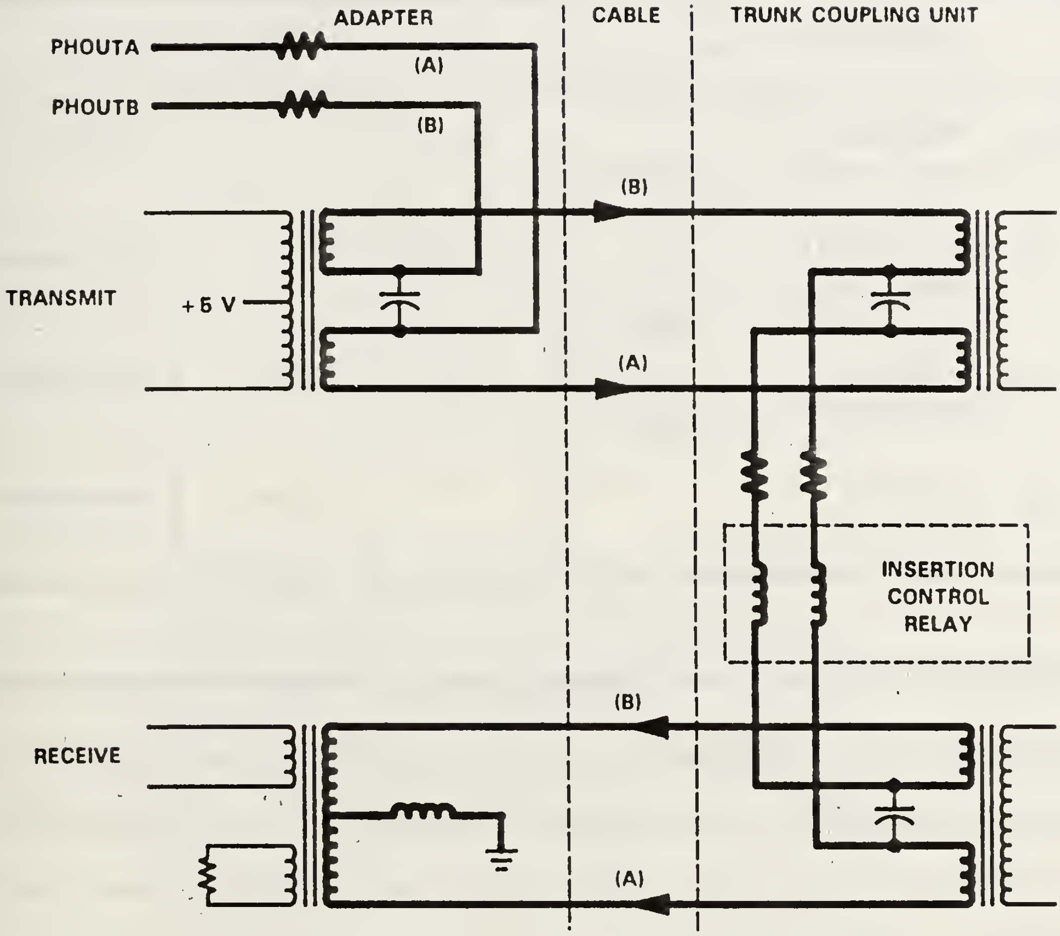


Figure 3-5. Path of Phantom Drive Current
[from Ref. 6:p. 4-127]

locked in by the Phase Locked Loop (PLL). [Ref. 6:p. 4-121]

C. TOKEN RING SIGNAL

The network uses Differential Manchester coding as called for in IEEE standard 802.5. In this scheme, a signal transition always occurs in the center of the bit time. A

TABLE 3-1
PARAMETER LIMITS OF PHANTOM DRIVER FOR SUCCESSFUL OPERATION
[from Ref. 6:p. A-100]

Parameter		MIN	MAX	Unit
V_{OH} High-Level Output Voltage	Measured at PHOUTA & PHOUTB	4.1		volts
I_{OS} Short Circuit Output Current		3.8		milli-amps
I_{OH} High-Level Output Current		-4.0	-20	micro-amps
I_{OL} Low-Level Output Current			-100	micro-amps

"zero" bit is indicated by a transition at the start of the interval (see top waveforms of Figure 3-7). A "one" bit has no transition at the start of the interval (see bottom waveforms of Figure 3-7).

Differential Manchester is polarity independent, so it does not matter if the transition is up or down. The signal transitions are symmetric about zero, thus providing an average zero volt DC level. Violations of the coding rules may be easily detected to facilitate error detection and provide for synchronization of bit streams. [Ref. 6:p. 3-6] Figure 3-8 shows the signal on both wires of the receive

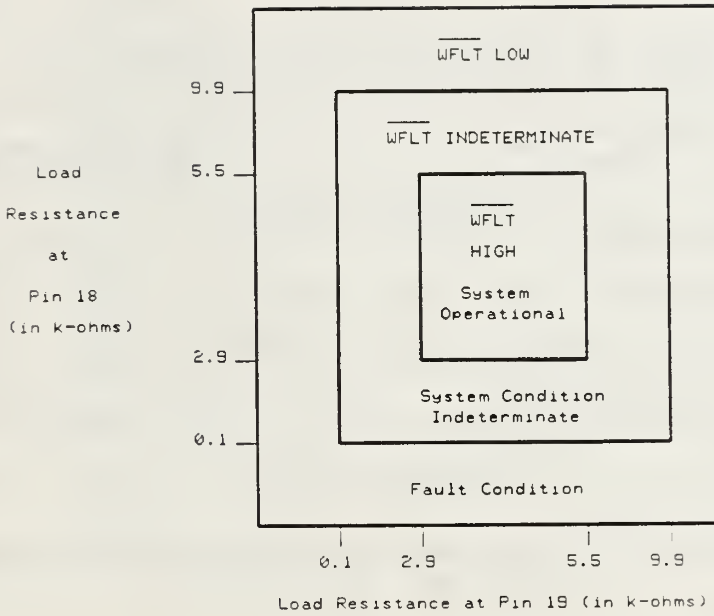


Figure 3-6. Wire Fault Load Conditions
[from Ref. 6:p. A-100]

differential pair taken at pins G and R of Figure 3-4. Because of the mid-bit transition Differential Manchester coding requires twice the bandwidth of the signaling rate.

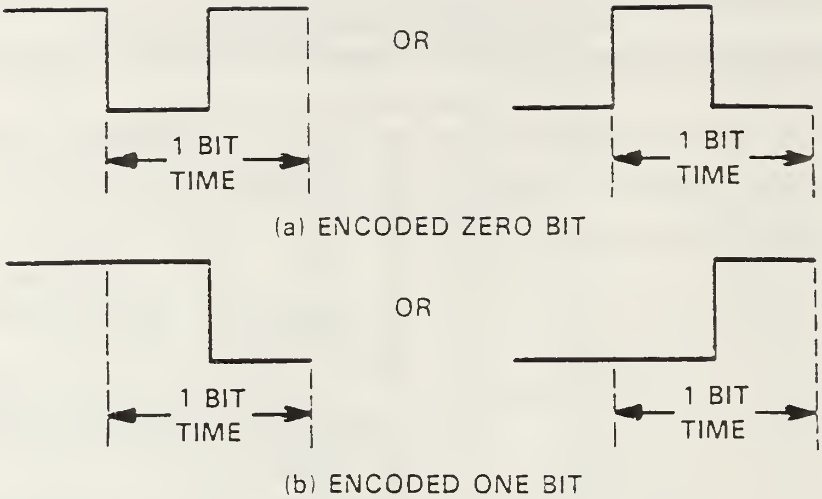


Figure 3-7. Differential Manchester Encoding
[from Ref. 6:p. 3-6]

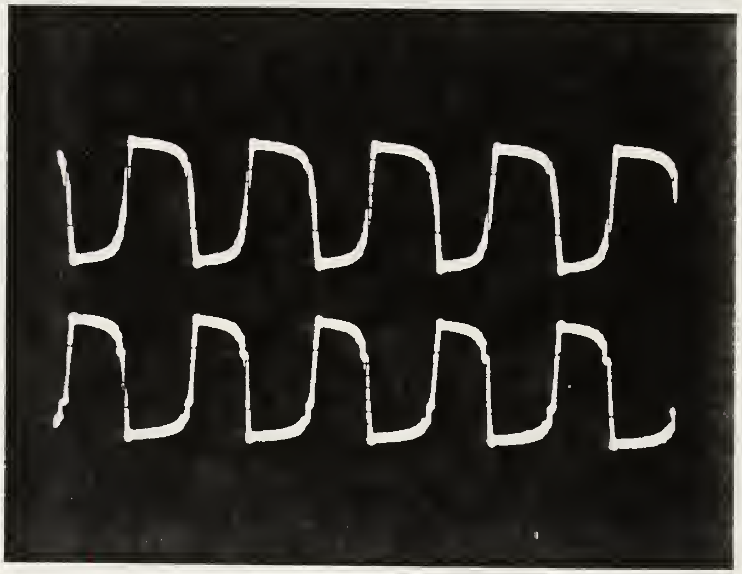


Figure 3-8. Signal Carried by Differential Pair

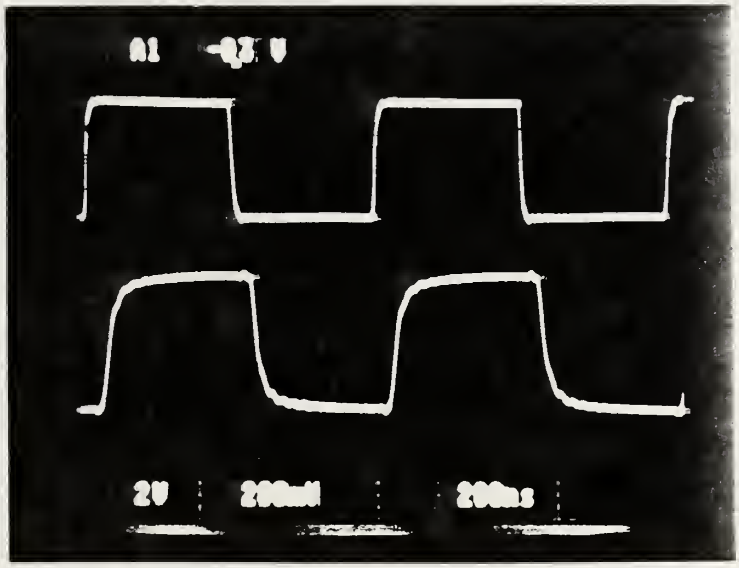
IV. DESIGN DESCRIPTION AND EVALUATION

A. DESIGN APPROACH

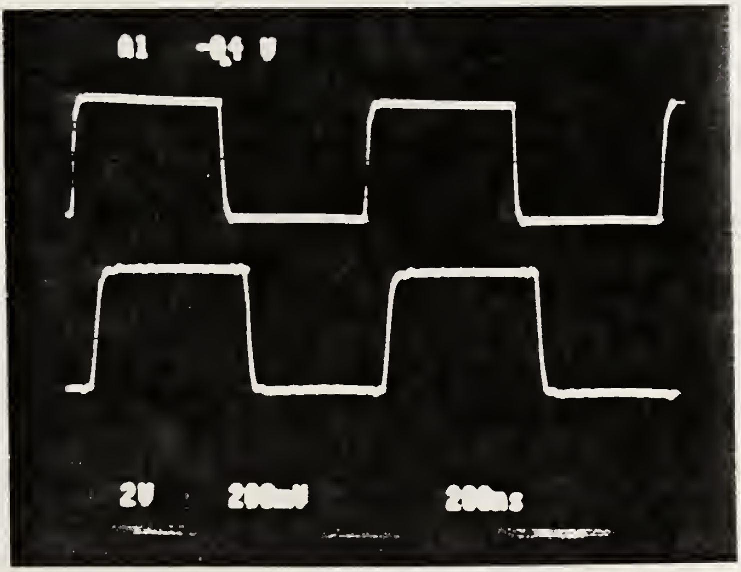
The first step to the circuit design was to select components that would best fit the necessary parameters required by the LAN and the IEEE standard. The operational amplifier used was the Elantec 2020C as employed in previous research by Anderson. [Ref. 3] This op-amp was chosen because of the need for fast settling time and a wide bandwidth. [Ref. 3:p. 24] The IEEE standard requires that the LAN signal transit between the 10% and 90% voltage levels in less than 25 nsec. The EL 2020C satisfies this requirement. [Ref. 7:p. 1-83]

The fiber optic receiver and transmitter used were chosen based on the data rate. The LAN operates at 4 Mbps but the use of Differential Manchester coding requires a bandwidth of 8 Mbps. The Hewlett-Packard components selected are improved versions of the one used by Anderson [Ref. 3], due to their high speed and low cost. The HFBR-1414 fiber optic transmitter contains an 820 nm GaAlAs LED emitter. It uses the improved AT&T ST bayonet-style connector and a double-lens optical system that provides high coupling efficiency, which allows the emitter to be driven at lower current levels. This results in lower power consumption in the LED and increased reliability of the transmitter. [Ref. 8:p. 3] The HFBR-1414 can handle data rates up to 35 Mbaud which is more than adequate.

The HFBR-2414 fiber optic receiver is designed to operate with the 1414 transmitter. It uses the same double-lens system with ST connector. The 2414 receives an optical signal and converts it to an analog voltage. The output is a buffered emitter-follower. The superiority of the new LED package using ST-type connectors and improved internal circuitry of the 2414 versus the old screw-type connector and package of the 2404 is evident in Figure 4-1. The top wave in each photo is a 1 MHz square wave generated by a pulse generator and the bottom wave is taken at the output of the receiver circuit (pins G and R of Figure 3-4). Note that the new receiver yields a much sharper rise and fall, creating a better reproduction of the square wave. Also, because the signal amplitude from the 2414 receiver is much larger than from a simple PIN photodiode, it is less susceptible to EMI, especially at high data rates. [Ref. 8:p. 9] The frequency response of the 2414 receiver is typically from DC to 25 MHz. Although it is an analog receiver, it is easily compatible with a digital system. HP also makes a digital receiver, HFBR-2412, but it is limited to a 5 Mbaud data rate and therefore was inadequate for the required network data rate of 8 Mbaud.



(a) Top - 1 MHz input square wave
Bottom - Output of HBFR-2404



(b) Top - 1 MHz input square wave
Bottom - Output of HBFR-2414

Figure 4-1. Comparison of HFBR-2404 to HFBR-2414

The attenuation (dB/km) of the selected fiber, in conjunction with the amount of optical power coupled into it, determines the achievable link length. the parameters that most significantly affect the optical power coupled to the fiber are fiber core diameter and numerical aperture (NA). In general, as fiber core diameter is increased or, as the NA is increased, the optical power increases. In this case, since the transmitter is tailored to the fiber, the optical power levels off at a diameter of about 250 μm or at an NA of around 0.34. [Ref. 8:p. 11]

Fiber losses for a Local Area Network are usually not significant because of the relatively short distances between stations. The fiber used was a 62.5 μm core diameter cable, 3 meters in length, with ST connectors provided by HP with the transmitter/receiver test kit.

1. Design Objectives

a. The first objective was to use these components to recreate an improved version of the fiber interface circuit developed in previous research by Anderson [Ref. 3]. The second was to implement that circuit on the differential pair of receive wires between the MAU and the LAN adapter, and make any changes or improvements as necessary.

b. The next objective was to operate the LAN with the receive-side fiber link installed and to observe and evaluate the impact of fiber on the LAN adapter diagnostics and fault detection.

c. The final objective was to use the knowledge gained in the prior parts to design a complete fiber LAN that would circumvent the need for a wire-type Multiple Access Unit (MAU).

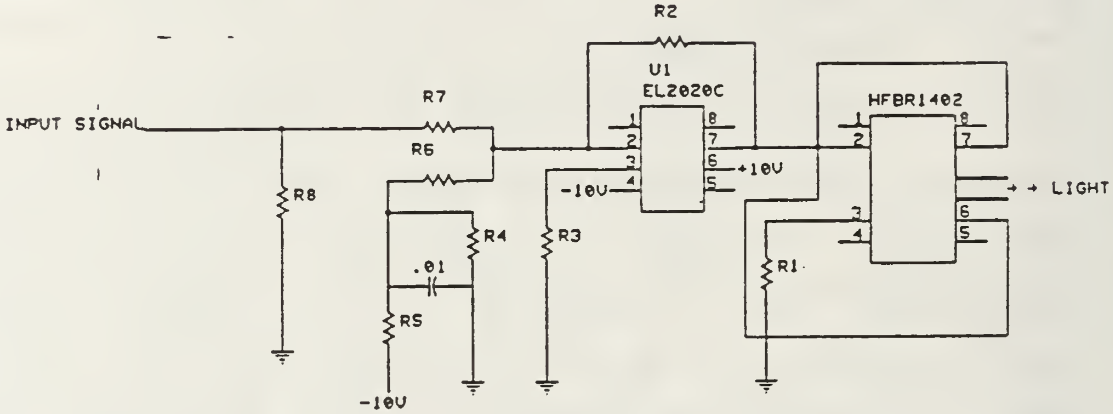
B. SYSTEM DESIGN

1. Previous Design

Figure 4-2 (a-b) shows the schematic of the LAN interface module designed by Anderson [Ref. 3]. This circuit is capable of taking incoming data from the receive differential pair, converting it to an optical signal, transmitting along a fiber and recovering the original data. The reproduced wave is not as square as the incoming wave, especially as the frequency increases, but it does not need to be since Differential Manchester signalling only senses the transition between low and high. However, this module may only be inserted after the network is booted up and running since the diagnostics would fail at boot up if the interface modules were present.

2. Token-Ring System Initialization

System initialization was attempted with the fiber module inserted into just one receive line (see Figure 4-3). Each time system start-up was attempted, an error message stating "Network Adapter Hardware Error" appeared. This was due to the fact that the circuit on the fiber line induced a delay in one signal (see Figure 4-4). Because of this delay, the receiver phase-locked-loop (PLL) was unable to lock onto the signal and an exception error was generated.

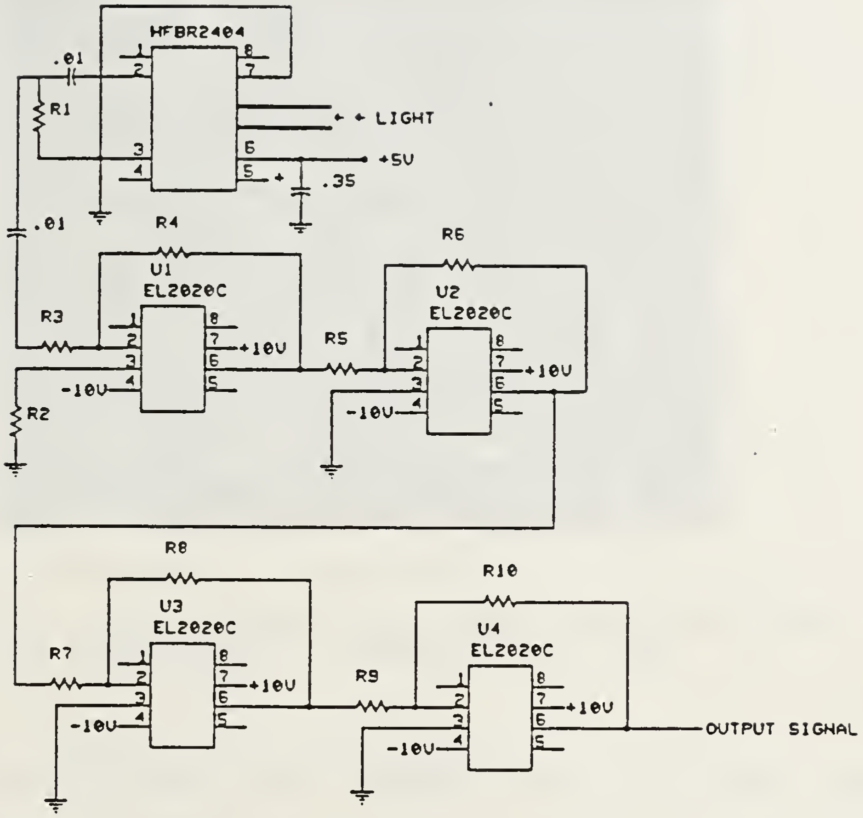


NOTE 1: All op-amp power supplies are capacitively coupled to ground by 4.7uF tantalum capacitors.

NOTE 2: All capacitor values are in microfarads.

R1 = 15	R5 = 1K
R2 = 1K	R6 = 1K
R3 = 330	R7 = 1K
R4 = 430	R8 = 2K

Figure 4-2(a). Previously Designed Transmitter Circuit [from Ref. 3]



NOTE 1: All op-amp power supplies are capacitively coupled to ground by 4.7uF tantalum capacitors.
NOTE 2: All capacitor values are in microfarads.

R1 = 510	R6 = 1K
R2 = 330	R7 = 430
R3 = 330	R8 = 680
R4 = 680	R9 = 750
R5 = 100	R10 = 750

Figure 4.2(b). Previously Designed Receiver Circuit [from Ref. 3]

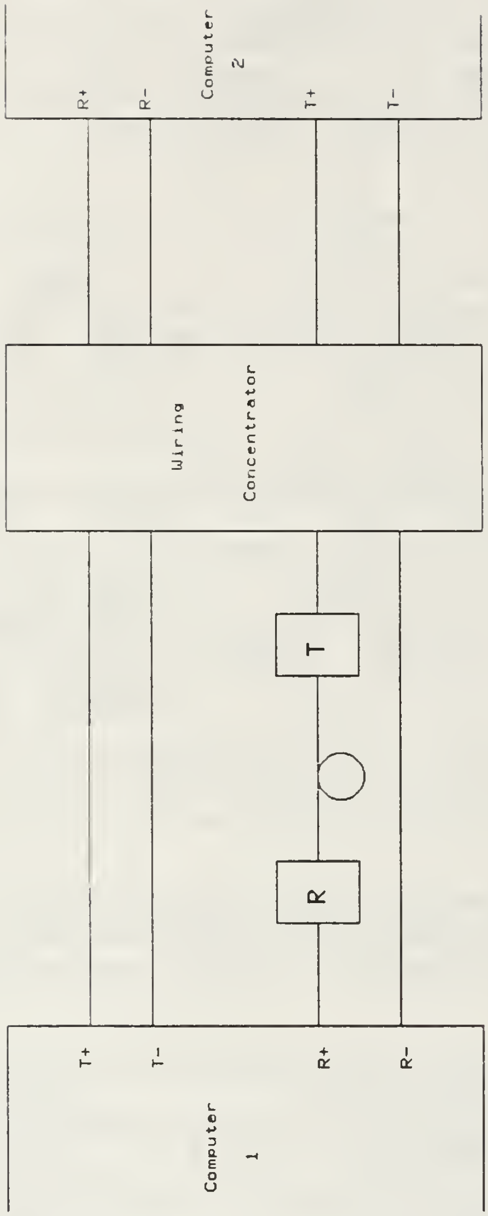


Figure 4-3. Block Diagram of Circuit One Receive Line

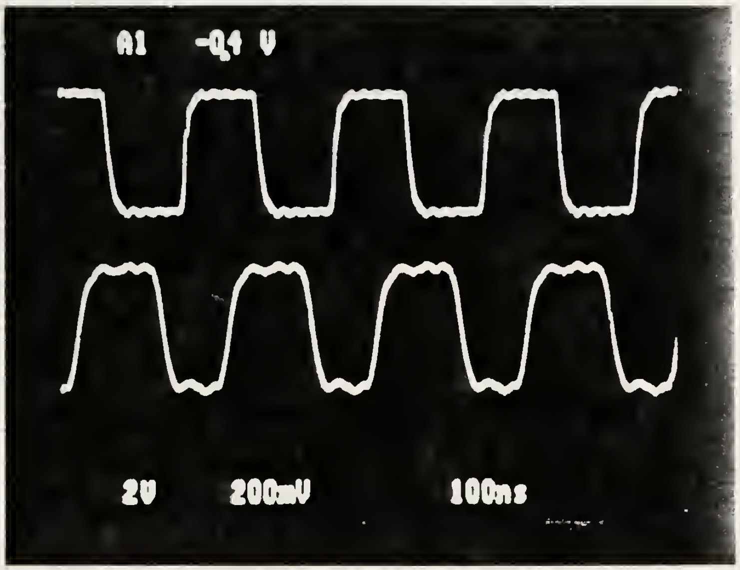


Figure 4-4. Input Square Wave (top) vs Output Wave of Fiber Circuit (bottom) at 4 MHz

The network was then booted with the fiber module installed in both receive lines (see Figure 4-5). The token ring adapter system would boot but would not operate. Each computer on the net would seem to initialize, no exceptions or error messages would be generated and the main network menu would appear, but messages could not be sent. When a message was transmitted, it would not be received and the adapter would output an error message stating "Addressee Not Found". The same message would appear on both the computer with the fiber module inserted and the computer attached to the MAU directly by wire. It was observed, however, that, if one of the receive lines was grounded between the transmitter and the R^{+}_{out} pin of the wiring concentrator (see Figure 4-5) while the network was being booted, then a message could be received and sent. This would happen whether the receive line stayed grounded or was released.

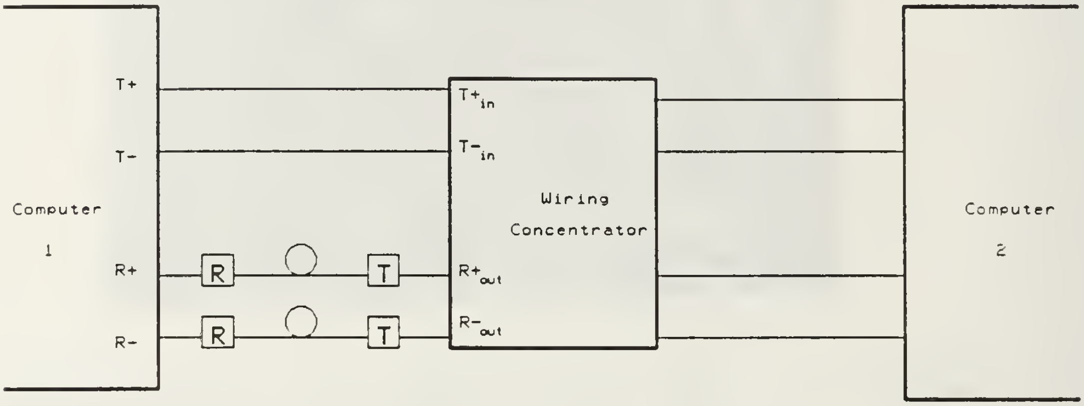


Figure 4-5. Block Diagram of Circuit Inserted on Both Receive Lines

To understand this situation, it is necessary to refer back to the ring insertion process described in Chapter II and the wire fault detection in Chapter III. Figure 3-5 showed that the phantom drive requires a closed path from the transmit circuitry to ground on the receive circuit. The ends of the interface connection are electrically isolated with a fiber circuit. The current stops at the transmit side and then is regenerated on the receive side. It was necessary to give the transmit current a momentary path from R^{+}_{out} to ground during the boot process for the address verification ring poll process to work and for the network to boot properly. Otherwise, the network will boot, but the addresses of the other stations will not be acquired, thus generating the "Addressee Not Found" error message. The next design objective was to redesign the fiber system to operate without the concentrator and to incorporate features which would allow the adapter to pass the address verification check.

3. Transmitter Design

The first modification was to change the values of the resistors used by the initial summing op-amp (see Figure 4-6). As described in Chapter III, the pins that impress the phantom drive voltage, PHOUTA and PHOUTB, onto the transmit pair also monitor the load resistance to detect an open or short circuit. When the op-amp in the transmitter circuit is powered, the inverting input (pin 2) is at virtual ground. Therefore, the load resistance appearing at the PHOUTA and PHOUTB pins is equivalent to whatever the value of the input resistor, R1, to the op-amp is. A 4.3 kΩ resistor was used to be within the limits specified by Figure 3-6.

The basic transmitter circuit used a voltage divider to provide a dc bias to the input signal. The data signal from the adapter card is bipolar, alternating between approximately +2 and -2 volts. However, light is unipolar; it has only a positive value or zero. In order to recover the entire input waveform, it was necessary to shift the signal by 3 volts dc so that it would alternate from approximately +1 to +5 volts. Since the op-amp also inverts the signal, a -3 volt

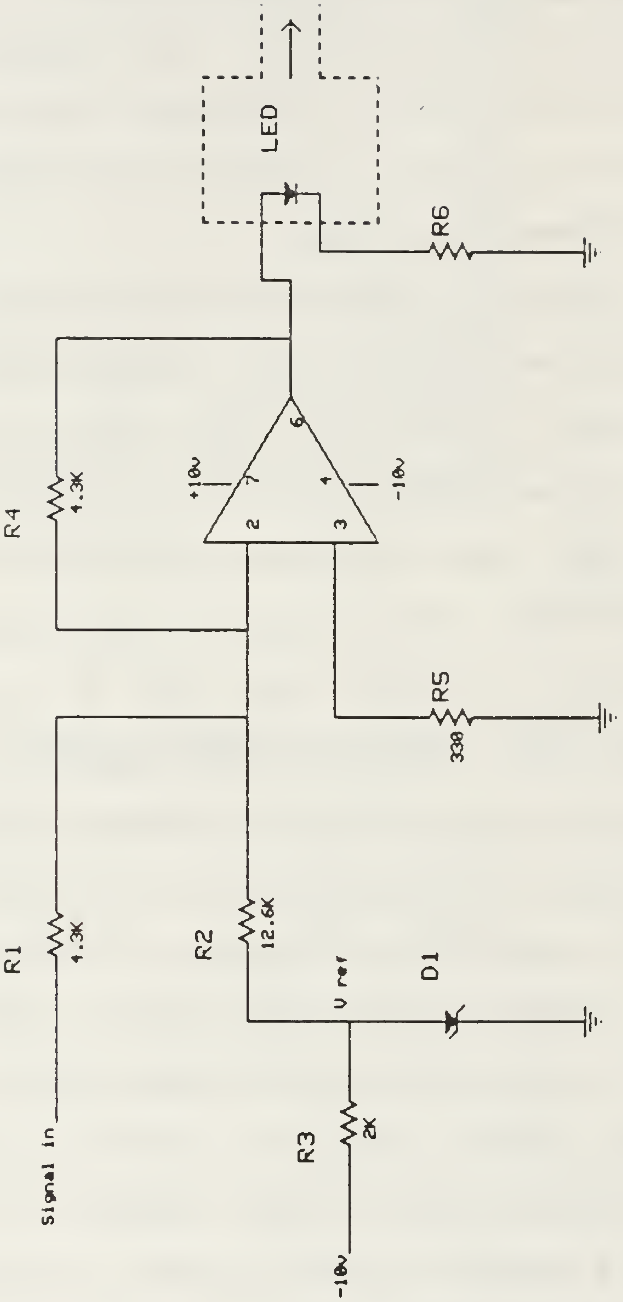


Figure 4-6. Schematic of Transmitter Circuit

bias was used on the second input of the op-amp summer so that the inverted output would have a +3 volt bias. To obtain a more consistent voltage level, a 3-volt Zener diode was used in place of the voltage divider. This 3 volt shift was necessary only for the transmit circuit on the receive side where phantom drive voltage was not present. When the 5-volt phantom drive was present, a different level of shifting was required (as discussed next).

When the circuit was placed on the transmit lines, the phantom drive already provided the signal with a five volt bias. However, when this positive voltage level is inverted by the op-amp summer, the signal then alternates between -7 volts and -3 volts. As previously mentioned, the LED transmitter is unipolar and a negative voltage will not activate the device; hence, it was necessary to change the weighting of the input lines to the op-amp summer. The original circuit used an equal weight for each input line. By changing R2 in Figure 4-3 to a value of 12.6 kΩ, it was possible to achieve a DC level of +3 volts at the output without adjusting the input voltage.

Adjusting the resistor R6 (see Figure 4-6) on the cathode side of the LED controls the current through the diode and, thereby, the intensity of the generated light. This, in turn, controls the current generated by the receiver. So, adjusting R6 to the proper value ensured that the receiver current remained within acceptable levels specified on the data sheet (Table 3-1). When the 2404 transmitter is used, the value of R6 was 52 ohms to obtain an output wave with amplitude identical to the input wave. When the 2414 transmitter was used, R6 was increased to 190 ohms to maintain the same output amplitude. This reduction in required drive current indicated improved electrical-to-optical efficiency. Another option would be to leave R6 at 52 ohms and then to decrease the amplification of the receiver circuit. This would perhaps be a better design because it would decrease distortion of the wave introduced by large amounts of amplification.

4. Receiver Design

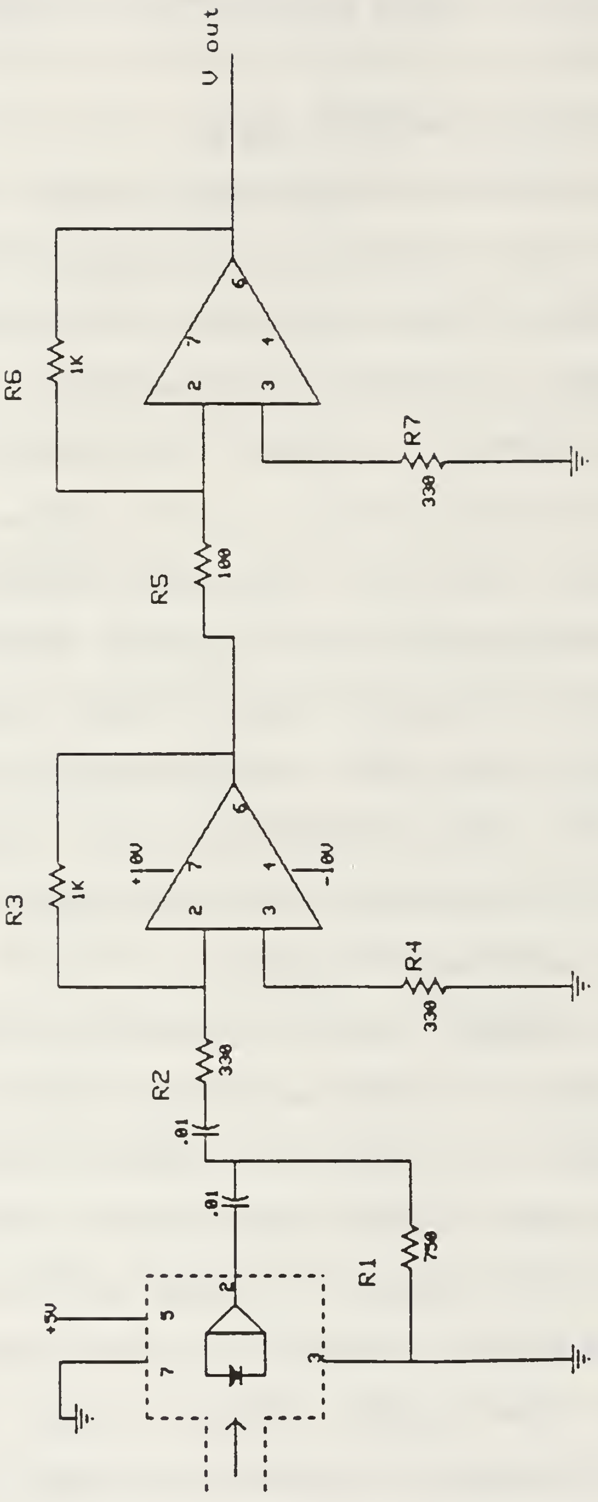
The original design used four op-amps after the optical detector to amplify the signal in stages and then invert it to its original form. This was done to prevent overshoot, ringing and oscillations. [Ref. 3:p. 28] By experimentation, it was found that two op-amps could reproduce an output wave similar to the input (see Figure 4-7). Accordingly, values were adjusted to correspond with greater amplification by the first stage. Figure 4-8 (a-d) shows the performance of each of the four channels. An 8 MHz square wave (shown on top) was input to simulate the data signal. The bottom wave of each figure shows the output of the fiber circuit (see Figure 4.8). Each channel shows that the reproduced wave is similar to the input in both amplitude and period. There is a loss of the high-frequency ripple shown on the input wave due to the response time limitations of the op-amp used.

5. Total Fiber Network Design

Having achieved duplication of the input signals in each channel, the next step was to proceed to the design of an all-fiber network. The first problem to overcome was to allow the LAN adapter to perform its diagnostic routines with no wiring concentrator in the net. The initial approach taken was to make external changes to the adapter card. On the Protocol Handler, TMS 38020, the *WFLT pin was wired high and the *REDY pin was wired low. It was assumed that, if the *WFLT pin was continually high, no fault could be indicated. If the *REDY pin was wired low, it was hoped that the signal energy would be indicated as sufficient. But this apparently violated the chip diagnostic routine because the system would not boot when configured this way.

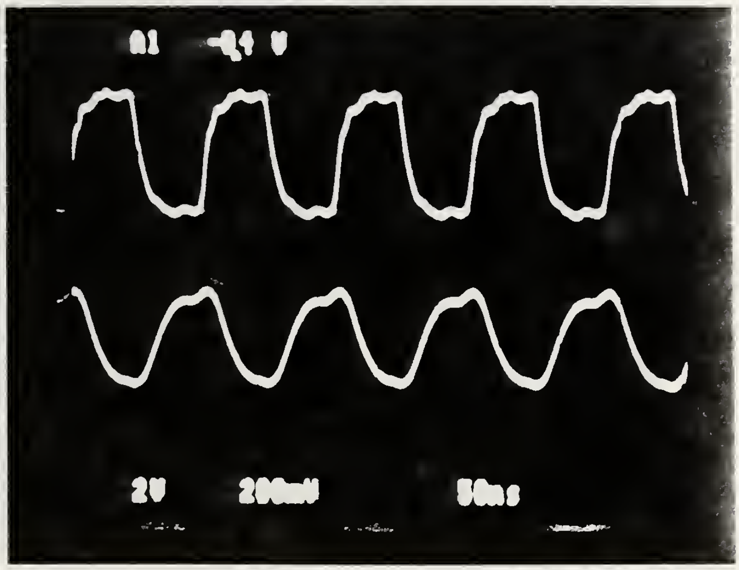
The simplest solution proved the most expedient. Since all computers on the net cannot and do not access the net at the same time, one station must be first. Therefore, we considered what the net looks like to the first computer that boots up and accesses a regular wire token-ring LAN.

As described in Chapter II, after internal diagnostics on the card, the adapter fires a token into the cable connecting the station to the MAU. When the token is sent and recovered, it indicates the cable is intact. The system then

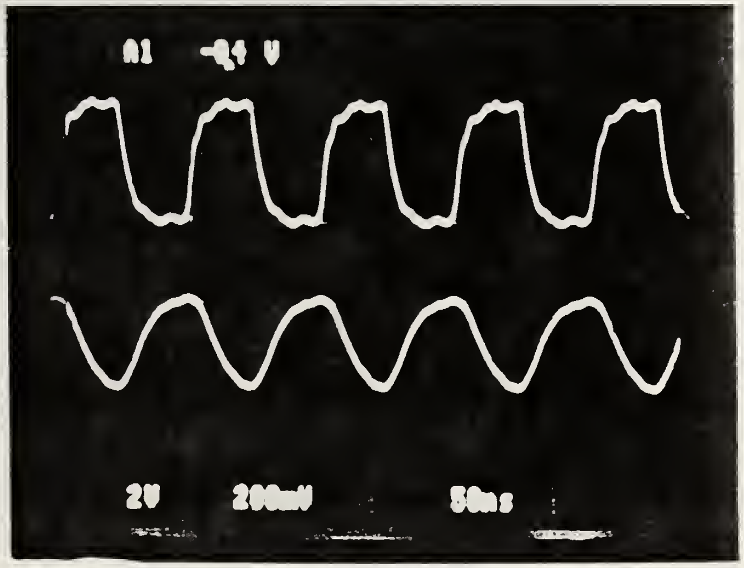


Note 1: All capacitor values are in micro-farads

Figure 4-7. Schematic of Receiver Circuit

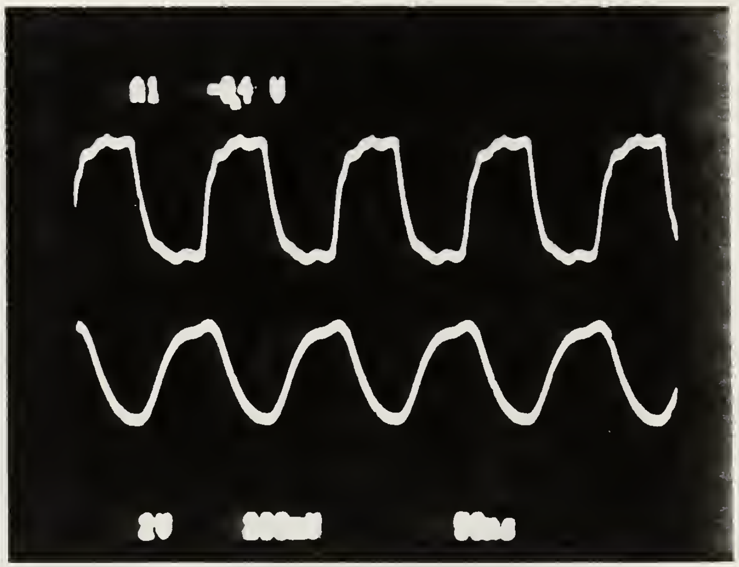


(a) Channel 1

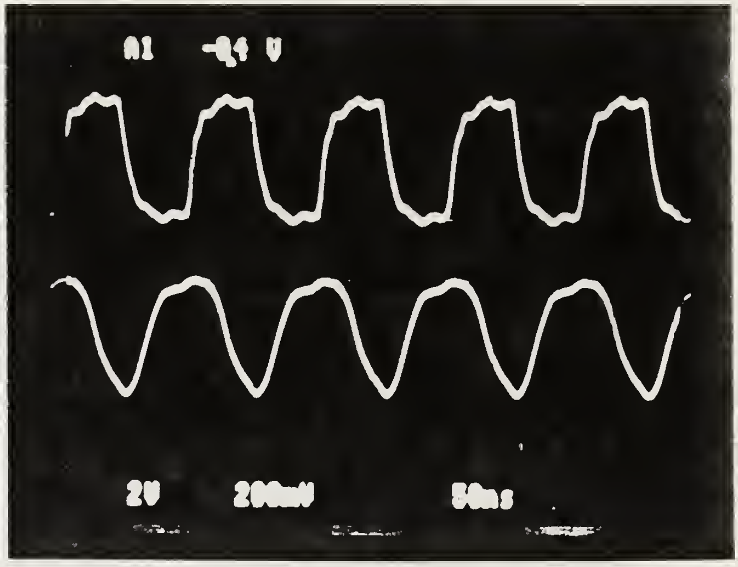


(b) Channel 2

Figure 4-8. Performance of Fiber-Optic Channels



(c) Channel 3



(d) Channel 4

Figure 4-8 cont.

activates the phantom drive and the station is inserted into the ring. The station then circulates a token around the ring. However, if the station is the first one on the ring, the token just circulates around the ring and back to the same station. So, in effect, for the first computer on the net, the cable check and ring continuity check is just a lengthening of a closed path.

Therefore, to pass the error diagnostics and ring insertion process, all that is needed is a closed path with the proper resistance. This can be accomplished by placing a 4.3 kΩ resistor between the transmit (+) and the receive (+) pins of the adapter (see Figure 4-9) and another between the transmit (-) and the receive (-) pins. As long as the fiber circuit is not powered, the portion of the transmit line that extends past the resistor simply appears as an unconnected, open-circuit wire. Then, after the other stations are booted, the fiber circuit is powered up, which offers a path around the ring, and the stations enter the monitor contention process to establish the ring monitor (as discussed in Chapter II). The system will then be able to operate properly and be able to send and receive messages.

The only remaining problem was to incorporate a switch that would allow power to be supplied to the fiber circuit after the network boot process was complete. This was accomplished by a simple RC timing circuit (see Figure 4-10). The 102 μF capacitor used the 5 volt phantom drive to charge.

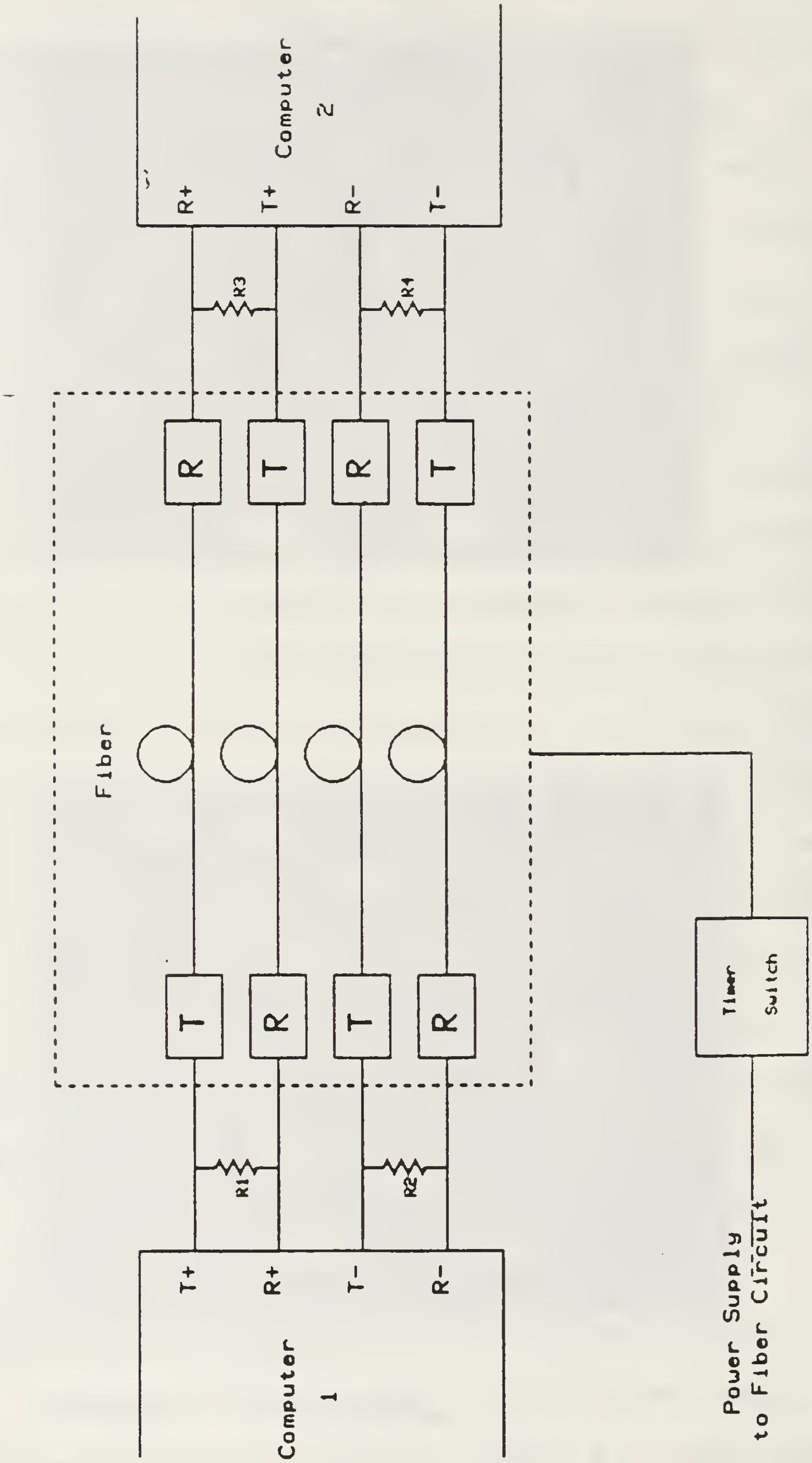


Figure 4-9. Block Diagram of All-Fiber Network

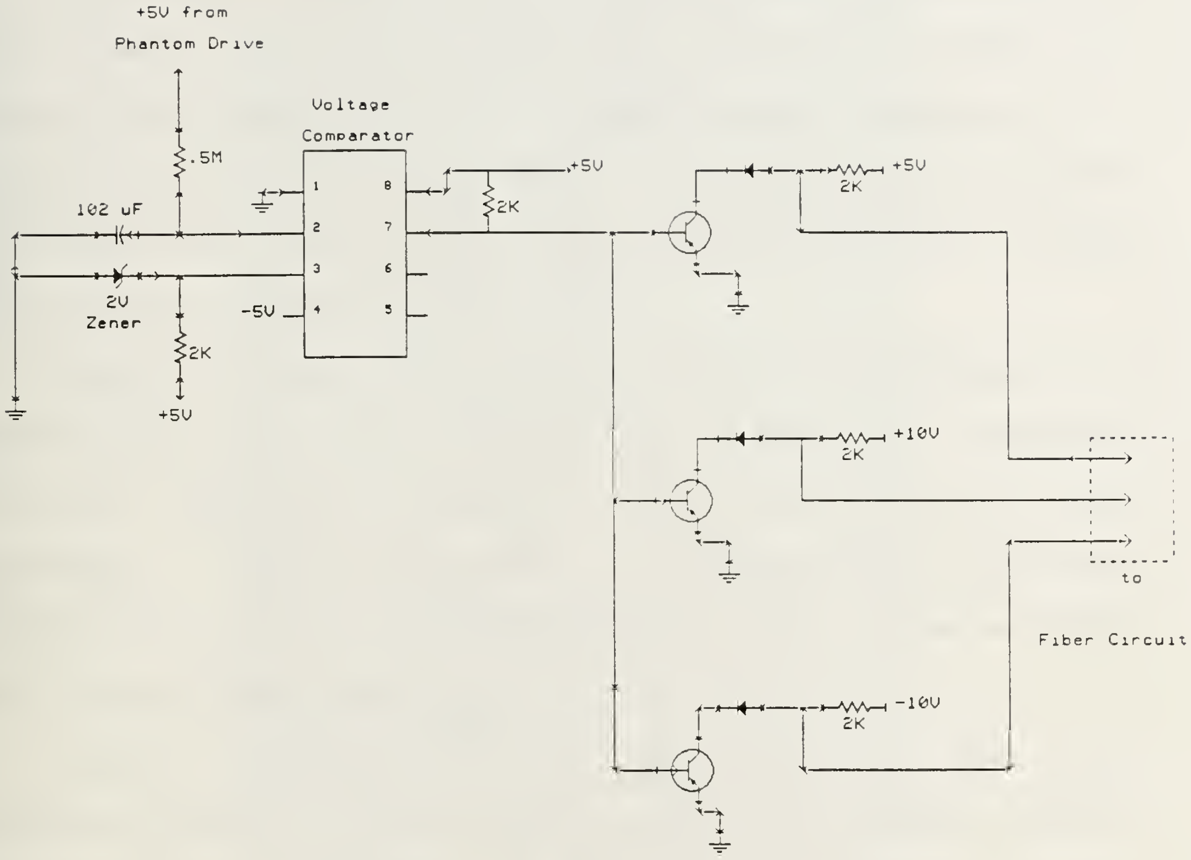


Figure 4-10. Schematic Diagram of Power Switch

The time constant of the RC circuit, made up of the 102 μF capacitor and the 0.5 MΩ resistor, was set so that the voltage comparator could not assert a signal until the full boot process was completed (see Figure 4-11). In our circuit this time was about 60 seconds. Once the signal from the comparator is asserted, the PNP transistors are disabled and power is supplied to the circuit.

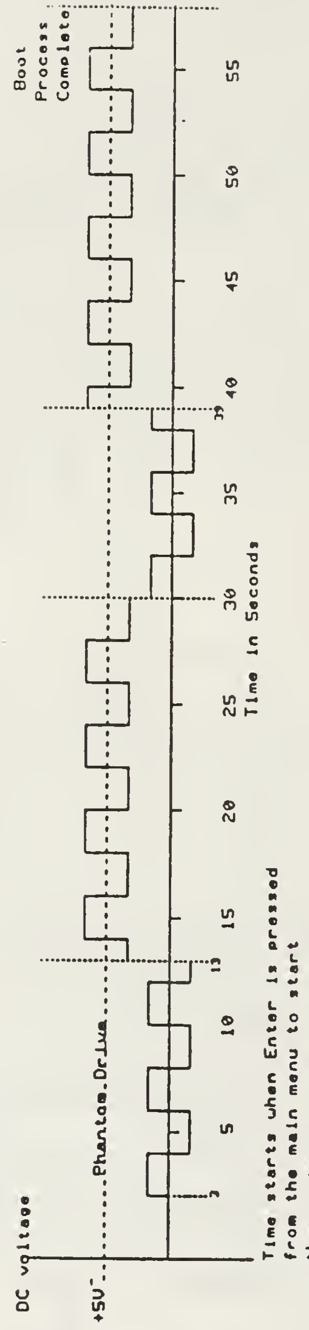


Figure 4-11. Network Timing Diagram

C. DESIGN EVALUATION

The design described in this chapter met the objective of this thesis which was to design and construct a token-ring local area network between two computers that consists of all fiber-optic channels. When the circuit was assembled as shown in Figure 4-9, each computer in the network was able to send and receive messages without error.

Figure 4-12 shows the signal waveforms when standard wire cabling was used. The left waveform in the figure shows the transmit differential pair with the 5-volt phantom drive impressed. The right waveform of the same figure shows the differential pair of the receive lines. The center waveform is a ground level reference.

Figure 4-13 shows the same signals sent over the fiber channel network. The waveforms on the fiber channel show the same type of distortion as shown in Figures 4-8 (a-d). Although the waves are not as square as the wire channel signals, error-free messages were still sent because of the use of Differential Manchester signalling (recall from Chapter III that Differential Manchester signalling only needs to sense the transition between low and high).

The fiber network design is no longer a star-configured ring as described in Chapter II; it is now both a physical and logical ring. Therefore, reliability is degraded. If a break occurs in one of the fiber cables, the entire ring will be out

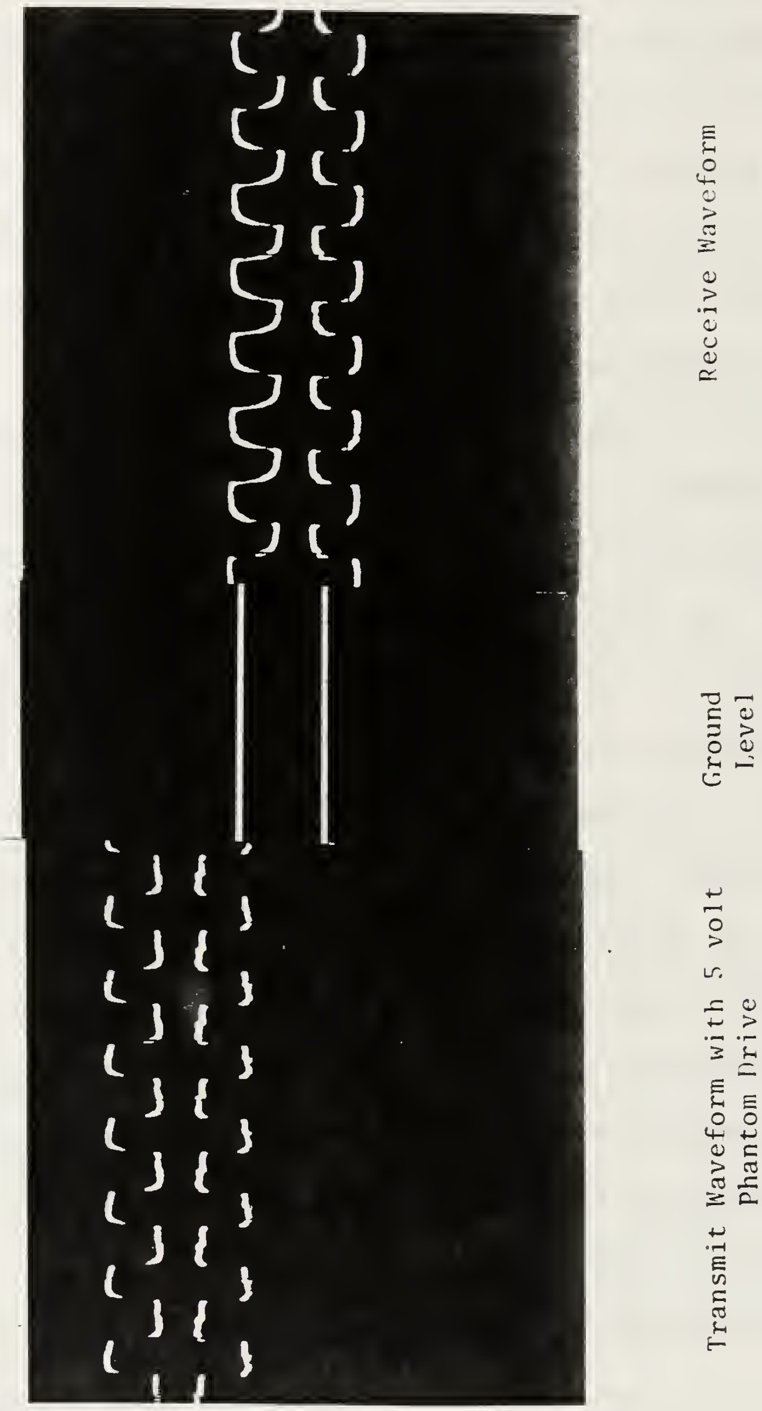


Figure 4-12. Signal Waveforms of Standard Wire Network

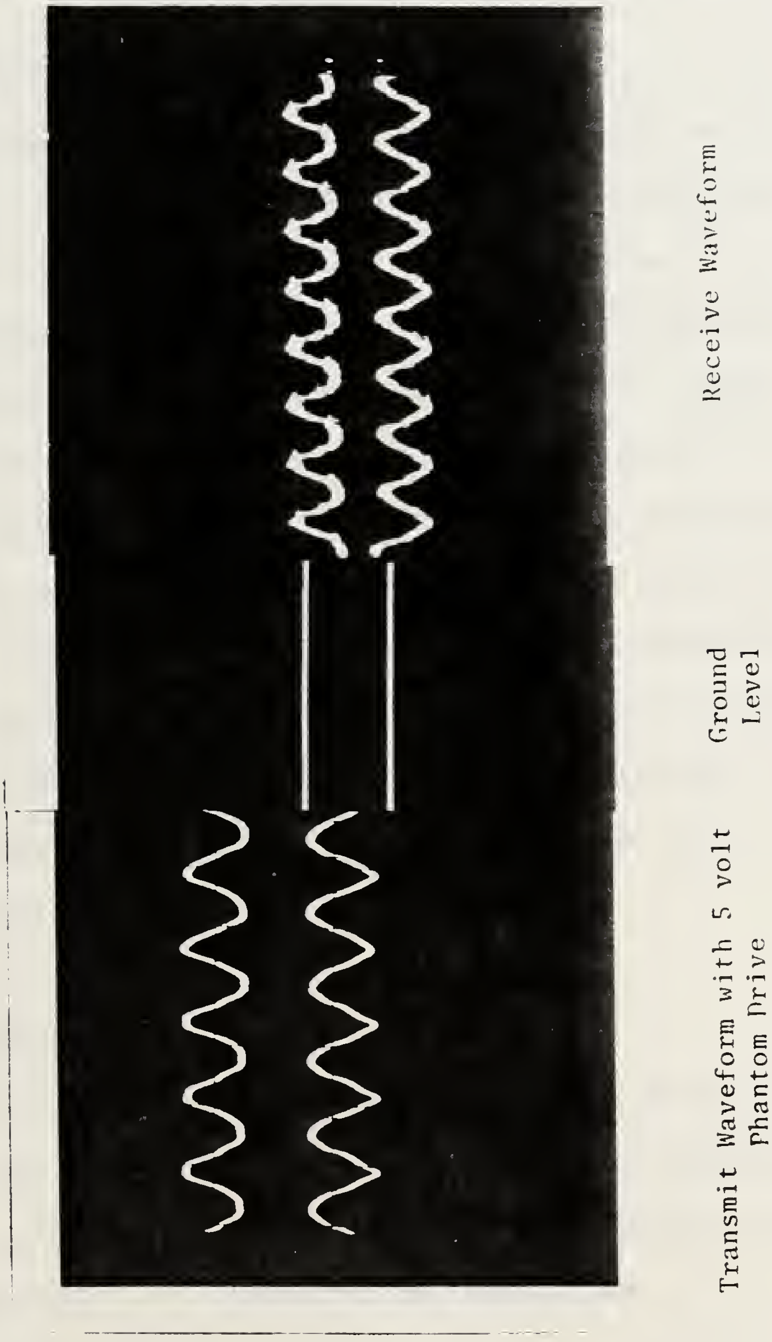


Figure 4-13. Signal Waveforms of Fiber-Optic Network

of service.

V. CONCLUSIONS AND RECOMMENDATIONS

A. CONCLUSIONS

This thesis accomplished the design goal of producing a fiber-topic token-ring local area network. The circuitry was relatively simple; the primary limiting factor in this design was the token-ring adapter card. The TMS380 token-ring system was designed to operate using standard wire cables. All of the initialization diagnostics and fault-detection checks are directed toward a wire system. The use of fiber drastically changed the physical characteristics of the ring; there was no longer a complete closed electrical path. Therefore, design considerations had to be directed to subvert or disable the fault detection devices that were no longer applicable. Future fiber-optic LAN projects will also have to consider this in their design.

B. RECOMMENDATIONS

Follow-on research could be done to modify the transmitter and receiver to multiplex the signal off the differential pair onto a single fiber instead of two. Techniques to monitor the fiber continuity also need to be developed.

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